NORM in the petroleum and geothermal industries: evolution of the French radioprotection legislation

Stéphane Lafortune, Jean-Claude Pinte

NORM in the petroleum and geothermal industries: evolution of the French radioprotection legislation

LAFORTUNE, Stéphane; PINTE, Jean-Claude
Institut National de l'Environnement Industriel et des Risques / French National Institute for Industrial Environment and Risks (INERIS)
Parc Technologique ALATA – BP 2
60 550 Verneuil-en-Halatte
FRANCE
e-mail: stephane.lafortune@ineris.fr
phone: +33 (0)3 44 55 67 91

Abstract

Fluids produced from oil or gasfields and aquifers are naturally radioactive due to the presence of potassium-40 and isotopes from decay chains of uranium-238 and thorium-232 in these reservoirs. Thus, natural radionuclides can be carried away towards surface when petroleum or geothermal reservoirs are drilled and produced. These radionuclides can precipitate in deposits forming in process equipment, which can then be unusually radioactive, expose workers to hazardous materials and create waste disposal problems. Workers can also be exposed to high concentrations of radon. Due to their natural origin, these accumulations of radionuclides in equipment are called Naturally Occurring Radioactive Materials (NORM). They are also known as TENORM, because they are "technologically enhanced".

In closed systems, exposition to gamma radiations penetrating equipment to the external surface can be reduced by restricting and controlling access to appropriate areas. But personnel may come into direct contact with NORM during maintenance and cleaning operations, when opening equipment and vessels.

In France, hygiene and safety rules concerning the protection of workers in the petroleum and geothermal industries are formulated in a specific regulation related to extraction and mining. Presently, both petroleum and geothermal industries are not included in the list of activities which have to follow radiation protection measures concerning exposition to NORM. French authorities are currently planning to update the list by including these two activities. There is a real need to realize a state-of-the art of the exposition level of workers and to standardize the dose limits with those given by the French Labour and Public Health Codes.

This paper will present the origin of NORM and radon contamination in the petroleum and geothermal industries and discuss the French legislation evolution for the radiation protection of personnel working in these two industries.

What are NORM and where do they come from?

NORM (acronym for Naturally Occurring Radioactive Materials) refer to materials containing radionuclides (or radioactive materials) from **natural sources** (Californian DHS 1996).

NORM can be found in underground oil and gas reservoirs or aquifers. They are present in rocks as uranium-238 (^{238}U), thorium-232 (^{232}Th), potassium-40 (^{40}K) and their radioactive progeny.

Whereas potassium-40 has only two stable daughter isotopes: calcium-40 (^{40}Ca) and argon-40 (^{40}Ar), uranium-238 and thorium-232 have longer decay chains before reaching final stable isotopes: lead-206 (^{206}Pb) and lead-208 (^{208}Pb) respectively. The main decay chains of uranium-238 and thorium-232 are shown on the figure below (see fig. 1).

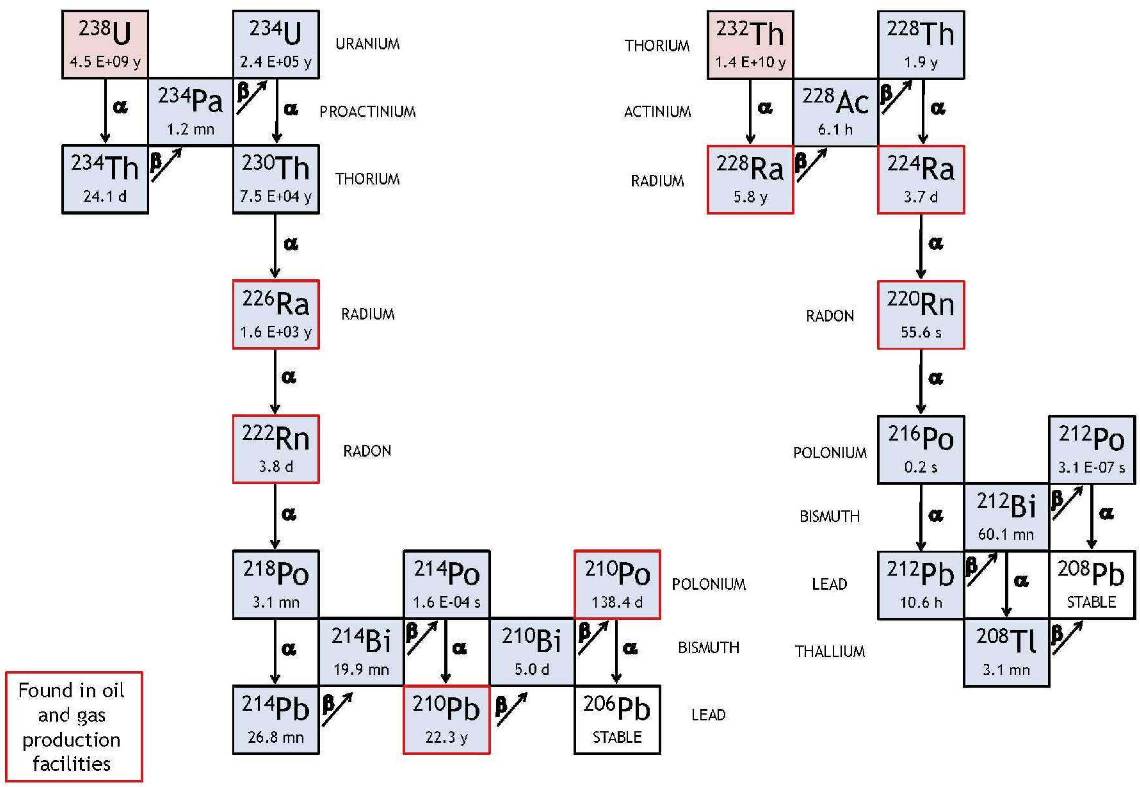

Fig. 1. Decay chains of uranium-238 (left-hand) and thorium-232 (right-hand). Half-life times are given in years, days, hours, minutes or seconds. Mother isotopes are shown by a red background, daughter radioactive isotopes by a blue background and daughter stable isotopes by a white background. Red frames show the main radionuclides present in NORM and found in oil and gas production facilities.

If the less soluble isotopes, such as uranium and thorium, remain bound to the rock matrix, soluble and gaseous elements produced by radioactive decays can accumulate in fluid phases and migrate out of the reservoir (Paschoa 2009).

Thus, NORM can be found in different phases. As for radon (Rn), they can be in gaseous phase. They can also be dissolved in fluids (oil, water) and reprecipitate as carbonates and sulphates of calcium, barium and strontium... if there is any change in temperature or pressure conditions of the fluid phase.

NORM in the petroleum and geothermal industries

A technologically enhanced occurrence

In oil and gas fields or in the geothermal industry, NORM may occur as radioactive materials that have been concentrated through production processes. Thus, some people also call them TENORM because they are "technologically enhanced". Concentration processes are different and depend on the nature of the radionuclide.

Depending its solubility and its ability to precipitate as a mineral phase, a radionuclide can (1) stay trapped in the rock matrix within the reservoir, (2) precipitate along the pipes of the industrial installations, (3) be present in residues or (4) in produced fluids (oil, gas, water) (Gray 1993; SNIFFER 2005).

During extraction processes, produced fluids are submitted to temperature and pressure changes: equilibrium with reservoir conditions is no more ensured and deposits can precipitate onto the internal surface of pipes or as particulates which will be accumulated in residues and sludges. These deposits can contain radionuclides and be considered as NORM (Betts and Wright 2004).

Considering the half-life times of the different radionuclides from uranium-238 and thorium-232 decay chains, radium (^{224}Ra, ^{226}Ra and ^{228}Ra), radon (^{220}Rn and ^{222}Rn), lead-210 and polonium-210 are the main radionuclides that could be found in oilfield, gasfield and geothermal facilities.

Fig. 2 draws the list of possible NORM occurrences in these industrial facilities.

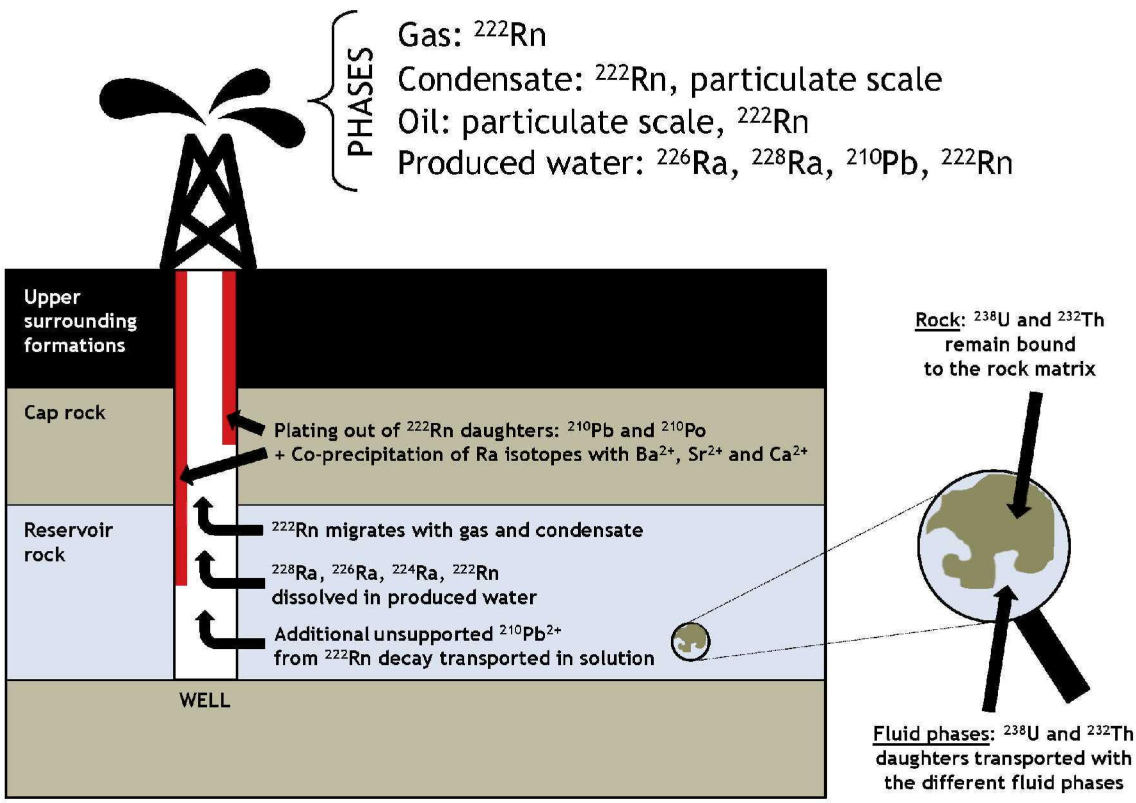

Fig. 2. Schematic cross section of an oil/gas reservoir or an aquifer with migration pathways and phases of the main radionuclides which can induce occurrences of NORM accumulations in petroleum and geothermal industrial facilities.

Risks induced to workers

The enhanced levels of radionuclides in industrial facilities can potentially raise a problem to operating and cleaning personnel. The radioactive decay of radionuclides from chains of uranium-238 and thorium-232 takes place by emission of either alpha or beta particles and by the emission of gamma rays. Exposition to these ionising radiations can cause damage to the body tissues.

Whereas alpha particles are stopped after a penetration of about 50 micrometers in a human tissue, and beta particles go no further than 1 centimeter, gamma rays are highly penetrating. One must be aware that even if they do not penetrate far the human body, alpha particles are particularly hazardous when they are inhaled or ingested, because the energy released by the radioactive decay is expended over a very short distance (Reed et al. 1991).

Personnel working near closed systems where NORM accumulations occur could then be exposed to gamma rays. For personnel working near open systems or opening closed systems for cleaning operations, the risk of direct contact with radioactive materials by inhalation of gaseous NORM and ingestion of solid NORM is real (Gray 1993; Reed et al. 1991; Takhautdinov et al. 1996).

NORM issues have been well studied in different states of the USA or in countries as Canada, Norway, United Kingdom and by other oil-producing countries. Several studies have been performed and have permitted to detect equipments where NORM accumulations can preferentially occur (see fig. 3 and 4) (Gray 1993).

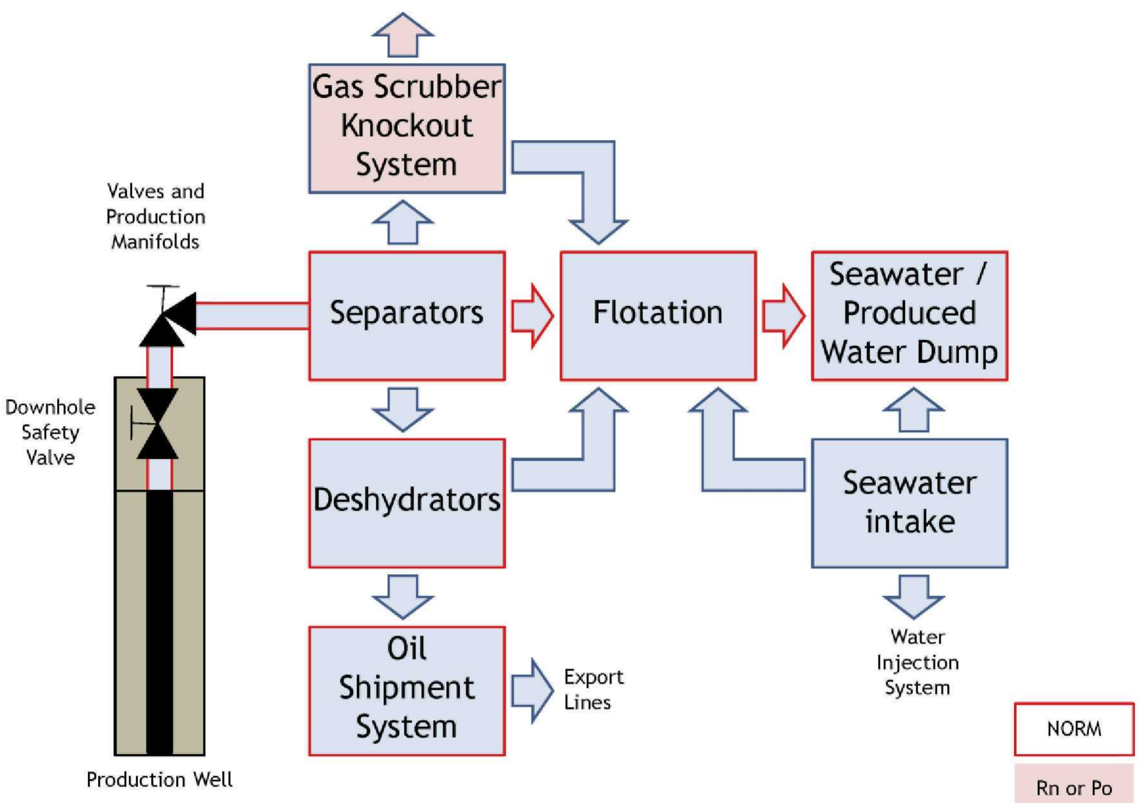

Fig. 3. Simplified design of an offshore oil production unit. Equipments where NORM accumulations are mainly found are shown by red frames. Equipments where radon or polonium are mainly found are shown by a red background (Reed et al. 1991).

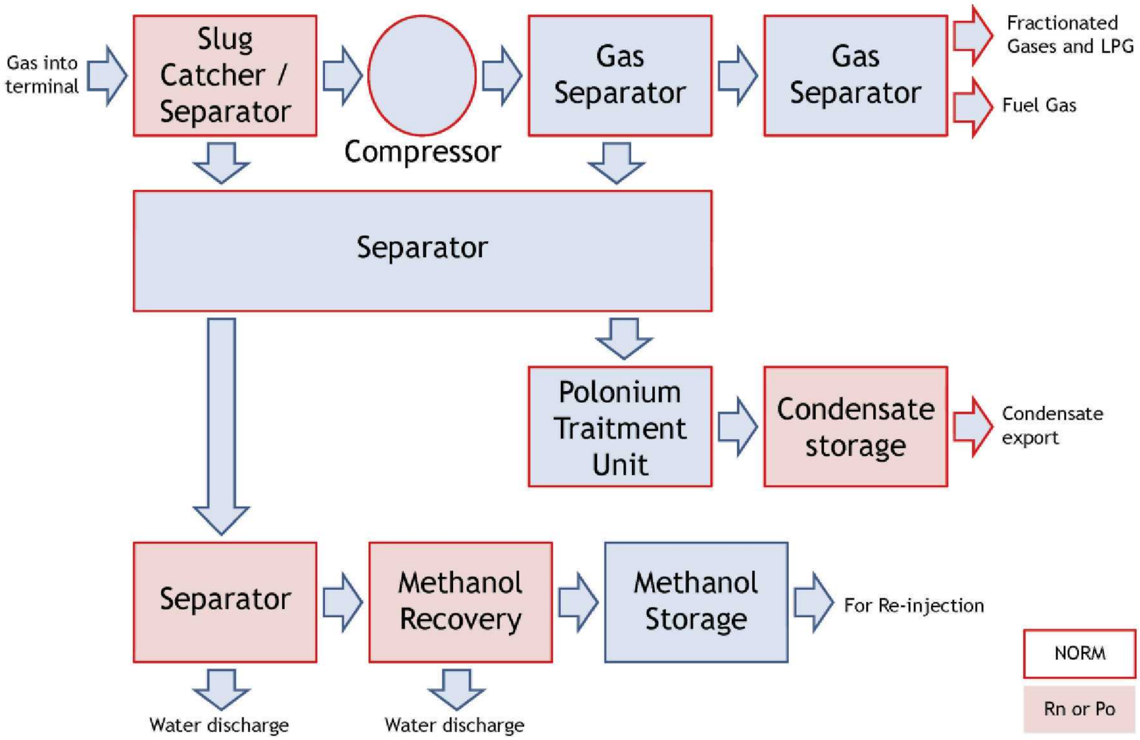

Fig. 4. Simplified design of an onshore gas terminal. Equipments where NORM accumulations are mainly found are shown by red frames. Equipments where radon or polonium are mainly found are shown by a red background (Reed et al. 1991).

Taking into account experts' conclusions and experience feedbacks, stakeholders have to define hygiene and safety rules concerning the radiation protection of workers that are appropriate to risks incurred by the personnel of the petroleum and geothermal industries.

French regulation for radiation protection of workers

Dose limits and categories of workers

In France, hygiene and safety rules concerning the protection of workers are formulated in the Labour Code.

But, hygiene and safety rules specific to extractive and mining industries (including petroleum and geothermal industries) are an exception and are formulated in a dedicated regulation called *Règlement Général des Industries Extractives* (RGIE or "French specific regulation related to extractive and mining industries").

Concerning radiation protection aspects, the two legislative texts divide workers in three categories referring the level of exposition that they can encounter: "A category" workers, "B category" workers and other workers who do not belong to one of the two previous categories.

Each category is defined by specific levels of exposition: the classification of a worker in one category depends on the "effective dose" and/or the "equivalent dose" (see glossary for definitions) received by this worker.

Pregnant women and under-18-year-old workers cannot work in environments that expose them to radiation levels which could justify considering them as "A category" workers.

Each category also implies specific constraints for the employers concerning risks prevention in terms of information, formation, medical care of their employees...

Dose limits given by the two texts to define the categories of workers are different. The dose limits defining categories of workers in the French Labour Code are below the values given by RGIE. A standardization is currently under study. The limit values are given in the two tables below (see tables 1 and 2).

Table 1. Dose limits for each category of workers defining by the French Labour Code.

	Effective dose limit	Equivalent dose limit for the hands, the forearms, the feet and the ankles	Equivalent dose limit for the skin (for a 1 cm^2 surface)	Equivalent dose limit for the crystallnie lens	Articles in the French Labour Code
All workers	≤ 20 mSv per 12-month period	≤ 500 mSv per 12-month period	≤ 500 mSv per 12-month period	≤ 150 mSv per 12-month period	R4451-12 R4451-13
A category workers	> 6 mSv/year	> 150 mSv /year	> 150 mSv /year	> 45 mSv/year	R4453-1 R4453-2
B category workers	> 1 mSv/year	*no value*	> 50 mSv/year	> 15 mSv/year	R4453-3
Population	≤ 1 mSv/year	*no value*	≤ 50 mSv/year	≤ 15 mSv/year	French Public Health Code

Table 2. Dose limits for each category of workers defining by the French specific regulation related to extractive and mining industries (RGIE).

	Effective dose limit	Specific effective dose limit
All workers	≤ 50 mSv per 12-month period ≤ 30 mSv per 3-month period	≤ 12.5 mSv per 3-month period for pregnant women
A category workers	> 15 mSv/year	
B category workers	> 5 mSv/year	≤ 10 mSv/year for pregnant women

Each legislative text defines the list of activities where radiation protection aspects have to be considered by the employers.

French law requires employers from extractive and mining industries to implement measures to prevent their workers from exposure to radiation while (1) mining radioactive substances, (2) when using a radioactive source, or (3) working underground. Petroleum and geothermal industries are possibly concerned by items (2) and (3).

Exposition to NORM

Presently, the French legislation does not regulate the risks of exposition to NORM for workers from petroleum and geothermal industries.

But exposition to NORM is regulated for industries whose hygiene and safety rules are formulated in the French Labour Code. Indeed, the French authorities have drawn for these industries a list of professional activities or classes of professional activities, where exposition to NORM has to be taken into account for the radiation protection of workers (Cazala et al. 2009). The following diagram (see fig. 5) shows the provisions of the French Labour Code for the listed professional activities.

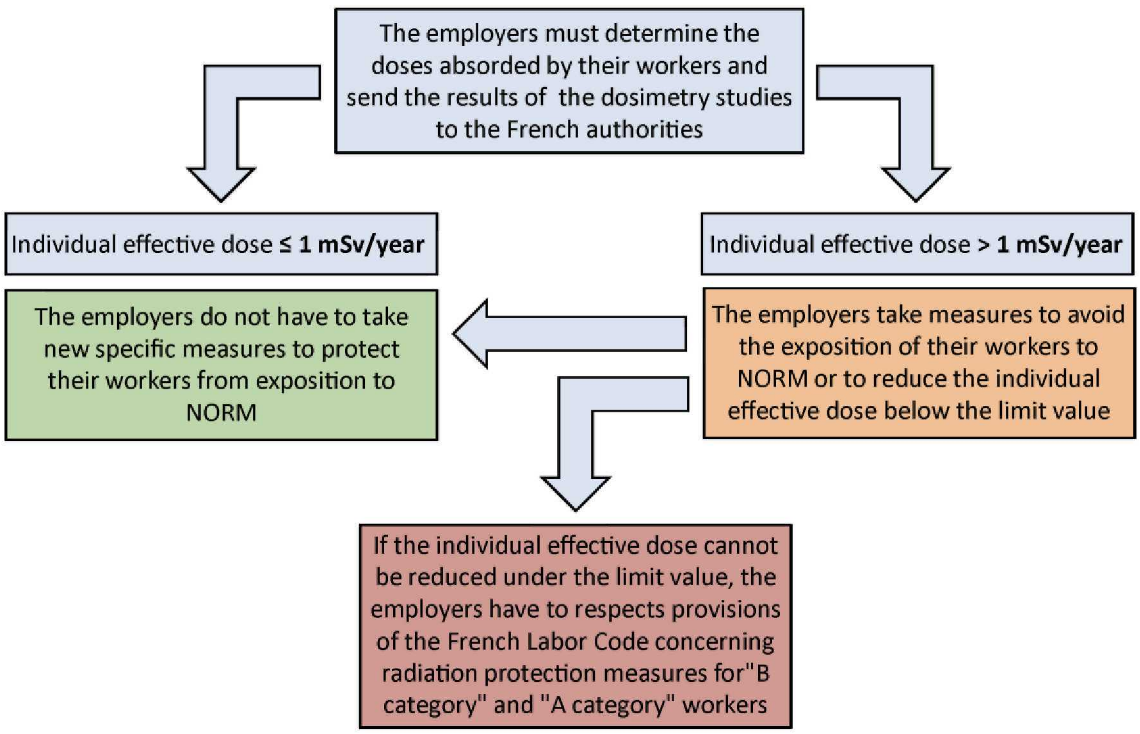

Fig. 5. Measures for the radiation protection of personnel exposed to NORM and working in industries whose hygiene and safety rules are formulated in the French Labour Code.

The principles presented in the previous diagram could be used as a working basis for the updating of the French legislation, in the case where the exposition to NORM for workers from extractive and mining industries would be regulated.

Conclusions

The French law regulates the risks of exposition to NORM (Naturally Occurring Radioactive Materials) for people working in industries whose hygiene and safety rules are formulated in the French Labour Code.

But these risks are not presently taken into account in the French specific regulation related to extractive and mining industries, and more precisely for people working in the petroleum and geothermal industries.

Considering experience and feedback from other countries and from industrial companies, French authorities are currently discussing the updating of the specific regulation related to the protection of workers from extractive and mining industries to consider exposition to NORM. This will mainly concern the petroleum and geothermal industries.

Because a good knowledge of the real exposition to NORM of the French workers in the petroleum and geothermal industries is a fundamental basis for discussions, dosimetry studies will certainly be launched in a next future.

Glossary

Equivalent dose

The equivalent dose takes into account the fact that for the same quantity of energy deposited in an organ or a body by radiation, the biological effects will depend on the nature of the radiation received (alpha/beta particles or gamma rays). It is expressed in sievert (Sv) and is determined by multiplying the absorbed quantity of energy by a weighting factor depending on the nature of the radiation.

Effective dose

The effective dose takes into account the fact that at a same equivalent dose value, biological effects will depend on the irradiated organ. It is expressed in sievert (Sv) and is the product of the equivalent dose with a sensitivity factor depending on the organ which has been irradiated.

References

Betts S. H., Wright N. H. NORM management and disposal -Options, risks, issues and decision making. Proceedings of the SPE Health, safety and environment in oil and gas exploration and production conference. 2004 Mar 29-31; Calgary, Alberta, Canada.

Californian DHS (Department of Health Services). A study of NORM associated with oil and gas production operations in California. 1996.

Cazala C., Loriot G., Pires N., Doursot T., Matouk F., Rannou A., Cessac B., Despres A. NORM industrial plants with potential radiological impact on workers and local population: first lessons from the review of available risk assessment studies in France. Radioprotection 2009; 44 (5): 233-236.

Gray, P. R. NORM contamination in the petroleum industry. Journal of petroleum technology 1993; 45 (1): 12-16.

Paschoa A. S. NORM from the monazite cycle and from the oil and gas industry: problems and tentative solutions. Radioprotection 2009; 44 (5): 957-962.

Reed G., Holland B., McArthur A. Evaluating the real risks of radioactive scale in oil and gas production. Proceedings of the SPE Health, safety and environment in oil and gas exploration and production conference. 1991 Nov 11-14; The Hague, Netherlands. p. 549-558.

SNIFFER. Identification and assessment of alternative disposal options for radioactive oilfield wastes. Summary guidance. Project UKRSR07. 2005.

Takhautdinov Sh. F., Sizov B. A., Diyashev R. N., Zaitsev, V. I., Antonov, G. P., Tatnipineft, A. Influence of radon and decay products on fiel equipment service personnel. Proceedings of the SPE Health, safety and environment in oil and gas exploration and production conference. 1996 Jun 9-12; New Orleans, Louisiana, USA. p. 845-854.

Weblinks

French Labour Code: http://www.legifrance.gouv.fr/

RGIE (French specific regulation related to extractive and mining industries): http://www.industrie.gouv.fr/sdsi/dtss/regl/cdrgie/entree.htm