Radioprotection, vol. **46**, n° 6 (2011) S681–S685

DOI: 10.1051/radiopro/20116737s

Survey of the impact of enhanced natural radioactivity on human and natural environments: The example based on PORANO project

B. Michalik[1], M. Wysocka[1] and A. Liland[2]

[1]*Central Mining Institute (GIG), Poland*
e-mail: b.michalik@gig.eu
[2]*Norwegian Radiation Protection Authority (NRPA), Norway*

Abstract. Technologically enhanced naturally occurring radioactive materials (TENORM) touch many aspects of our life. Alterations of the natural composition of rocks during mining and processing may results in an increment of radiation risk to not only humans but wild plants and animals. Each particular type of TENORM determines a unique scenario of exposure. The "PORANO" project is focused on three aspects related to this theme:

- methods of monitoring of TENORM occurrence,
- methods of applying radiation risk assessment,
- regulation improvement.

All above aspects of are considered - occupational, public and environmental risk. Also, the effect of associated pollutants interaction are taken into account. The mining industry, as a source of contamination for vast land areas, will be subject to major environmental investigations. The well scientifically justified assessment of TENORM impact on workers and the environment is the most important effect of the project. Developed measurement procedures, sampling strategies, risk assessment and mitigation methods will create a base for the improvement of national environmental monitoring. In the future all developed methods will be applied for assessment of natural background at sites for emerging Polish NPP as well as locations in the vicinity of radioactive waste repositories.

1. THE CHALLENGE

The overwhelming majority of present-day radioecological investigations are connected to the study of artificial radionuclides. Far less attention has been paid to radiation risk for people and the environment from exposure to enhanced ionizing radiation originating from naturally occurring radioactive materials. After thorough studies it was acknowledged that technologically enhanced natural occurring radioactive materials (TENORM) are present very frequently in our environment with an exposure as important as the one from manmade radionuclides. Enhanced natural radioactivity touches a lot of aspects of our common life, from occupational risk to public exposure where large amounts of bulk waste are located near to populated areas [1]. Each case of TENORM in the environment usually reflects an exposure scenario differing from the ones caused by artificial radionuclides [2]. In light of shortage of well-founded information about TENORM waste had been dumped in the one's neighborhood the public comprehension of this fact is a plentiful source of very serious effects far more detrimental and painful than the direct exposure to radiation. Therefore, the principle of keeping the radiation exposure as low as reasonably achievable (ALARA), economic and social factors taking into account, is particularly challenging for cases of enhanced naturally occurring radioactivity since the occurrence is at the same time natural and possibly hazardous.

Usually the TENORM-type waste materials can amount to hundreds of thousands of cube meters. Often the material has been dumped directly into the environment and is often mixed with other pollutants such as heavy metals or hydrocarbons. The waste thus falls under different regulations (for contaminants and radiation) at the same time, but these regulations have not been harmonized to cope with mixed contaminants. European regulations are usually very detailed for different dangerous substances, while the EC Directive 96/29/EURATOM2 seems as if enclosing not so many details as necessary. The result is that the problems of TENORM are not well regulated at the moment with reference to human being and occupational hazard as well as environment. The awareness of this problem is often lacking in non-nuclear industry so many companies do not perform radioactivity measurements as long as no precise regulation exists. In spite of the number of reports issued recently describing effects of TENORM in industry and the environment, this kind of risk assessment and regulation is not addressed at an appropriate level.

2. THE RESPONSE

The importance of radiation risk caused by natural radioactivity was first underlined in the EC Directive 96/29EURATOM which sets forth basic safety standards against the danger arising from ionizing radiation. Since this directive came into effect, a lot of research on this theme has been undertaken. However, the use of anthropogenic radioactivity standards often ignored the natural causes of radioactivity or assessed them on a case by case basis resulting in a substantial underestimation of the risk from those other sources of radiation.

To prepare a coherent system of rules and recommendation designated for the monitoring and control of risks related to the presence of natural radioactivity, it is necessary to start with a clear problem formulation and define appropriate risk scenarios. Based on the inventory of radionuclides at a specific site and knowledge about radionuclide migration in the environment, the possible effects of radiation on man and biota can be assessed. Based on the assessments, an improved regulatory system can be established to protect man and the environment from harmful effects of enhanced natural radiation.

The challenge has been taken by consortium consisting of Central Mining Institute (GIG), Central Laboratory of Radiation Protection (CLOR) from Poland and Institute for Energy Technology (IFE), Norwegian Radiation Protection Authority (NRPA) from Norway in frame of the "PORANO" project. The project is focused on three aspects:

- methods for monitoring TENORM
- methods for risk assessment for biota and humans
- recommendations and improvement of regulations.

For this a multistage, sequential risk assessment has been developed and then applied. The main obstacle necessary to overcome was that methods to determine the:

- inventory of contaminants at selected sites,
- contaminants' migration and availability in the environment

are independent of the end point of the assessment, whether human or non-human. For risk assessment, on the contrary, different methods must be applied for humans and for biota. The majority of the available data concerning radiation from TENORM is limited to information about mass or volume activity concentration of particular radionuclides. For human exposure (occupational or to the public) these data are sufficient to evaluate the radiation risk using standard derived dose conversion factors based on international recommendations. This was undertaken in the project for selected sites. By contrast, from the point of view of non-human biota risk assessment such an approach is not applicable. The reason is that there are no pre-determined dose conversion factors from monitoring data to exposure of non-human living organisms. With the lack of such conversion factors, there are currently neither limits nor constraints that can be applied in regulations for protection of the environment. So, the project also aims at:

- assessing the biota exposure from internal and external radiation,
- calculating effective doses to different living organisms,
- assess the radiation effects on biota (at individual or population level).

The ERICA approach can deliver robust, good quality information about biota exposure to be used in risk assessments. The other applied approach to non-human biota risk assessment is to score biological effects in standard indicator species. Plant systems seem especially well suited for environmental monitoring. Plant bioassays provide meaningful parameters to assess the toxicity of complex mixtures like industrial wastes even without knowledge of its chemical composition. In contrast to the specific nature of assessments on exposure, studies of biological effects integrate the impacts of all the harmful agents, including synergistic and antagonistic effects. This approach is particularly useful for assessing unknown contaminants, complex mixtures, or hazardous wastes. Thus, a correct estimation of the environment pollution risk needs to be derived from biological tests and pollutant chemical control in ecosystem compartments. Both need to be carried out simultaneously. Hence, the simultaneous use of chemical and biological control methods allows an identification of the relationships between the pollutant concentrations and the biological effects that they cause. In turn, such relationships may allow identifying the contribution of each specific pollutant to the overall biological effect observed. The knowledge generated makes it possible to limit the action of unfavorable factors on biota and to predict the further ecological alterations in regions submitted to intensive industrial impact. It is so important in case of TENORM since they usually contain mixed pollutants. Interaction of contaminants with biota firstly takes place at the cellular level making cellular responses. It is not only the first manifestation of harmful effects, but also can be a suitable tool for an early detection of pollution. Therefore, just genetic test systems seem to be most effective and efficient for an early and reliable displaying of the alterations in the ecosystems resulting from the human industrial activity. Knowing direct effects on biota one can bind those and draw a conclusion about acceptable dose or concentration. So those, beside the use of ERICA approach to the risk assessment a trial of application of genotoxicity tests is taken on. The researches are carried out at selected TENORM sites in Poland and Norway.

3. SITES OF CONCERN

For the example investigation three different sites, affected by different TENORM industry, have been chosen. The wide variety of present at these sites conditions has covered almost all possible typical cases of TENORM occurrence.

3.1 Area affected by iron and niobium ore mining and processing

The Fen complex, including the Søve mines, is located approximately 120 km southwest of Oslo in the county of Telemark. From the 1650's and up to 1927 the Søve mines were used for the mining of iron ore and in 1920 the carbonatite mineral Søvite was discovered in the area. This igneous carbonatite mineral contains elevated levels of niobium, uranium, thorium and rare earths. In the period 1951–1965 Ministry of Industry and Mining started production of ferro-niobium at the Søve mines. During the production process uranium and thorium were concentrated in the slag that was dumped just outside the building where ferro-niobium was produced. Today the slag (600–1000 tonnes) is mixed with other materials and is partially covered. The present volume of the waste deposit is probably between 1500 and 2000 m3 (Dahlgren 2005). In addition the areas around the mine are contaminated with niobium concentrate mixed with local soil.

3.2 Phosphogypsum waste dump

The phosphogypsum waste dump in Wislinka was created in 1969 on land previously used to excavate clay. Depository is located approximately 12 kilometers east from Gdansk the Pomeranian voivodeship capital (north Poland) in the near vicinity of agricultural land and the small village Wislinka. One estimates, that up to the end of 2009, when the depository was closed, about 16 mln tons of phosphogypsum have been stored up on an area of 26 ha (basis surface). With a height of approximately 40 m and the white color of storage material, it differed from the flat and flora rich area and evoked fear for the members of the public who live near the site.

3.3 Area affected by radium bearing waters from coal mining industry

The phenomenon of the radioactivity of saline waters from coal mines in Poland was discovered in the 1960's. The analysis of the radium isotopes in inflows showed, that the input of ^{226}Ra was of about 725 MBq per day, while the corresponding value for ^{228}Ra was roughly 700 MBq per day [3, 4]. In spite of the spontaneous process of precipitation and then sedimentation in underground galleries certain proportion of radium is released daily to the surface along with the other mine effluents. This results in a significant increase of radium concentration in the environment surrounding collieries [5]. To control salt discharge into inland waters and allow suspended material, carried by underground brines, to settle, settling ponds were employed in coal mines. Besides artificial ones, some natural lakes or fishing ponds were adapted for this purpose. In these ponds, under advantageous circumstances radium isotopes can co-precipitate with barium and concentrate in bottom sediments. Sediments with concentration of both radium isotopes together exceeding 200 Bq/kg were found inside 25 exploited settling ponds. The total capacity of all these ponds reaches 5 millions cubic meters [6].

For the exemplary assessment of environmental risk two former-natural fishing ponds that had been adapted as a settling pond were chosen. Both ponds had been exploited for over 20 years. During this period more than 240 000 m^3 and 113000 m^{3}of suspended material was deposited in the ponds respectively. The average radium isotopes (^{226}Ra + ^{228}Ra) activity concentration in these sediments is slightly above 1000 Bq/kg in the first pond and 6500 Bq/kg in the second. The maximum observed of radium activity concentration in the sediment reaches 15000 Bq/kg and 67 500 Bq/kg, respectively, and exceeds 160 000 Bq/kg in scales encrusting in the vicinity of the former discharge point of waters into the second pond. The pond sediments formed as results of radium and barium precipitation or adsorption on particles of suspended matter followed by sedimentation. Therefore these sediments have no significant uranium and thorium content. Also, the age of sediments is too short to get secular equilibrium between radium and its long-lived progeny, so the activity concentration of ^{210}Pb and ^{210}Po are negligible too. From the radiation protection point of view, radium is the most prominent radionuclide among the potential contaminants of concern, so the investigation focused on the behaviour of radium isotopes ^{226}Ra and ^{228}Ra.

4. CONCLUSION

All results gathered during the project realization, scientific as well as practical and economic will be used for the improvement of regulations dealing with the TENORM industry in both countries. Based on achieved results the possibility of remediation of different areas affected by TENORM is planned to be analyzed in the project. Contrary to the technical method of land reclamation a possibility of application of phytotechnologies is taken into account. Especially in the preliminary stage of remediation, the stabilization of radioactive pollutants seems to the most effective based on results of ground to biota transfer factors and bio-mass production.

The last but not least, activity in frame of the project is also aimed at capability of the developed monitoring methods for current radiation background at the sites for further Polish NPP as well as in cases of contamination caused for artificial radioactivity on example of low activity waste repository in Różane, Poland.

Acknowledgements

Project is pursued by consortium consisting of Central Mining Institute (GIG), Central Laboratory of Radiation Protection (CLOR) from Poland and Institute for Energy Technology (IFE), Norwegian Radiation Protection Authority (NRPA) from Norway. Project is supported by a grant from Norway through the Norwegian Financial Mechanism (project No. PNRF-192-AI-1/07 project acronym: “PORANO”).

References

[1] Baxter M.S. (1996): Technologically enhanced radioactivity: An overview. Journal of Environmental Radioactivity Vol. 32, issues 1–2, s. 3–17.

[2] Martin A. et al. (1997): Materials containing natural radionuclides in enhanced concentrations, Directorate-General Environment, Nuclear Safety and Civil Protection, contract No B4-3070/95/00387/MAR/C3 Final report No EUR 17625 EN.

[3] Chałupnik S., Wysocka M., Mielnikow A., Michalik B., Skowronek J. (2005): Radium balance in discharge waters from coal mines in Upper Silesia region. Naturally Occurring Radioactive Materials NORM IV. IAEA-TECDOC-1472, IAEA October 2005, s. 314–320.

[4] Chałupnik S., Wysocka M. (2009): Changes of radium concentration in discharge waters from coal mines in Poland as a result of mitigation. Radioprotection Vol. 44, No. 5, s. 813–820.

[5] Chałupnik S., Michalik B., Wysocka M., Skubacz K., Mielnikow A. (2001): Contamination of settling ponds and rivers as a result of discharge of radium-bearing waters from Polish coal mines. Journal of Environmental Radioactivity 54, s. 85–98.

[6] Michalik B. (2002): Inwentaryzacja i badania osadników wód dołowych przeznaczonych do likwidacji w aspekcie zagrożenia naturalnymi izotopami promieniotwórczymi /The inventory and investigation of settling ponds in mines designrted for closing inbthe context on natura radioactivity/ (in Polish). Dokumentacja pracy statutowej GIG. Katowice, GIG.

[7] Karsten L., Michalik B., Wiegand J. (2007): Availability of radium isotopes and heavy metals from scales and tailings of Polish hard coal mining. Journal of Environmental Radioactivity 94, s. 137–150.