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Istituto Superiore di Sanità
Rome, May 15-17, 2024

ABSTRACT BOOK

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The European NORM Association (ENA) gathers the main European radioprotection expertise in the field of NORM (Naturally Occurring Radioactive Materials). The widespread presence of NORMs in many industrial sectors causes radiation protection problems complex to solve and difficult to standardize. The workshop is aimed to provide a space to compare techniques and solutions for radiation protection problems, to illustrate and compare the regulatory approaches of different EU countries, and to give room to emerging issues or topics. One session host the European ALARA Network Workshop (EAN), focused on the Optimization application in the NORM field. The choice of the ISS as venue for the ENA's Third European Conference is particularly significant, because during a Conference about NORM, held at the ISS in June 2017, first actions were taken to give life to the ENA. The Conference is co-organized by ISS-National Center for Radiation Protection and Computational Physics, ENA and the Italian Radiation Protection Association (AIRP).

Key words: NORM, natural radioactivity, radiation protection

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La European NORM Association (ENA) riunisce le principali competenze europee in materia di radioprotezione nel campo dei NORM (Naturally Occurring Radioactive Materials). La presenza diffusa dei NORM in molti settori industriali causa problemi di radioprotezione complessi da risolvere e difficili da standardizzare. Il workshop intende fornire uno spazio per confrontare tecniche e soluzioni per problemi di radioprotezione, per illustrare e confrontare gli approcci normativi dei diversi Paesi dell'UE e per dare spazio a questioni o argomenti emergenti. Una sessione ospita il workshop della European ALARA Network (EAN), incentrato sull'applicazione dell'ottimizzazione nel campo NORM. La scelta dell'ISS come sede del ENA's Third European Workshop è particolarmente significativa, perché durante una Conferenza sui NORM, tenutasi all'ISS nel giugno 2017, sono state intraprese le prime azioni per dare vita all'ENA. La Conferenza è co-organizzata dall'ISS-Centro Nazionale di Radioprotezione e Fisica Computazionale, dall'ENA e dall'Associazione Italiana di Radioprotezione (AIRP).

Parole chiave: NORM, radioattività naturale, radioprotezione

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President of ENA

Francesco Mancini
President of AIRP

Francesco Bochicchio
Head of National Center for Radiation Protection and Computational Physics, National Institute of Health

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Cristina Nuccetelli
National Center for Radiation Protection and Computational Physics, National Institute of Health

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Session I

Circular economy/reuse & recycling of NORM residues

Chairs

Cristina Nuccetelli, Stéphane Pepin

ISEMIR-N PLATFORM AND INTERCOMPARISON EXERCISE ON NORM ANALYSIS (PRELIMINARY RESULTS) INVITED SPEAKER

Halil Burcin Okyar, Jizeng Ma, Miroslav Pinak
International Atomic Energy Agency

The IAEA is the one of the leading international organisations in establishing and maintaining the information exchange platforms, such as Information System on Occupational Exposure in Medicine, Industry and Research (ISEMIR), which is a tool to improve implementation of optimization of occupational radiation protection for interventional cardiology facilities (ISEMIR-IC) and for non-destructive testing companies carrying out industrial radiograph (ISEMIR-IR).

With the experience gained from the operation of ISEMIR modules, UMEX and others and demand from Member States to strengthen their capabilities for the realistic assessment of radiological impacts of NORM, a new web-based module (so-called ISEMIR-N) has been developed to improve the optimization of occupational radiation protection in different industrial processes involving Naturally Occurring Radioactive Material (NORM) through regular collection and maintenance of data on occupational exposure. The ISEMIR-N covers all NORM industrial processes and offers a model for dose assessment, but not in character of a dose registry and aims to enhance the worker protection through strengthening and harmonizing the radiation protection programmes for different NORM involving industrial operations and processes. Design has been completed by March 2019 and IT development has been initiated by June 2021. The initial design characteristics were evaluated with an IAEA Technical Meeting that was organized in November 2021 attended by 69 official participants from 41 Member States. The ISEMIR-N platform is in use with 54 users from 51 organisations.

The ISEMIR-N with its conceptual background, organizational characteristics, technical content and interfaces will be described.

The IAEA has also a programme focusing specifically on occupational radiation protection, which promotes an internationally harmonized approach to the issue and develops safety standards and guidelines to reduce radiation exposure at the workplace. It also helps Member States in applying these standards and guidelines in practice. Within this programmatic framework and with the support of IAEA Regional Technical Cooperation Project RER/9/155, the Joint IAEA-EEAE (Greek Atomic Energy Commission) Regional Intercomparison Exercise on Radioanalytical Characterization of NORM Samples was organized. The aim of this exercise was to assess the capabilities of the Member States in the region to satisfactorily implement appropriate radioanalytical techniques (i.e., gamma spectrometry, alpha spectrometry, liquid scintillation counting) for the radiological characterization of NORM in line with the IAEA Safety Standards, particularly GSG-7.

The preliminary results of the intercomparison exercise will be introduced and discussed.

CRITICAL RAW MATERIALS: EUROPEAN PERSPECTIVES AND SOLUTIONS INCLUDING ENVIRONMENTAL IMPACT

Rob Wiegers (a), Stéphane Pepin (b), Govert de With (c)
(a) IBR Consult BV, The Netherlands
(b) ENA, European NORM Association
(c) NRG, Nuclear Research and Consultancy Group, The Netherlands

In Europe is since 2008 an ever growing awareness on the dependency the EU has on all kind of materials necessary for a modern economy. In order to reduce this dependency, the EU set up a list of so-called critical materials mainly existing of Li and REE's. Furthermore, policies have been developed to decrease this dependence such as the recent European Critical Material Act of March 2023. They promote new policies and developments such as recycling of these materials as well as the development of an EU based mining industry for these types of materials. One of the options is to look into current waste streams to assess whether they consist of relevant amounts of interesting materials. The Act requires Member States to step up efforts to recover critical raw materials from waste products and mining waste. In our presentation we will go into a number of relevant waste streams as well as potential technologies by which the generally low concentrations of Li, REE's or other critical materials can be economically feasible retrieved. The potential and environmental constraints of landfill mining will also be discussed. Moreover, also the environmental impact will be discussed as well as management options for the remainder of the separation step.

BRIDGING BARRIERS TO ENABLE RECYCLING OF PHOSPHOGYPSUM IN ALTERNATIVE CEMENTITIOUS BINDERS

Wouter Schroeyers (a), Linde Pollet (a,b), Nazanin Love (a), Katrijn Gijbels (a), Robbe Geysmans (c), Tanja Perko (c), Mikael Hult (b), Robert Malina (a), Sonja Schreurs (a)
(a) Hasselt University, CMK, NuTeC, Nuclear Technology, Faculty of Engineering Technology & Environmental Economics, Faculty of Business Economics, Belgium
(b) JRC-Geel, Belgium
(c) SCK-CEN, Belgium

The recycling of Phosphogypsum (PG) in construction materials represents a multidisciplinary challenge where technical, radiological, chemical and stakeholder perception related barriers need to be overcome. From the 215 million-ton PG that is produced annually only 60-80 million ton is being recycled. In this context it is important to make a distinction between the recycling of the -often well controlled product- PG that is produced directly from industrial processes and the very heterogeneous PG that is present in landfills.

For the replacement of gypsum in different cementitious binders and concrete types, PG can be considered. Remaining traces of phosphoric acid, fluorides, metals, naturally occurring radionuclides, rare earth elements or organic substances in PG can however influence the mechanical properties of cementitious binders (e.g. delay in setting time, reduction in workability or strength), require additional measures for handling by construction workers or result in a negative environmental impact.

The current study takes a closer look at the different barriers that limit/inhibit the recycling of PG in alternative cementitious binders and concretes such as ettringite and alkali activated binders and concretes using these binders. The research needs and steps to overcome these barriers are discussed. The focus of the study is on recycling of PG in cementitious binders and concretes considering legislative (e.g. Euratom Basic Safety Standards (EU-BSS)), technical (focusing on mechanical properties), safety and environmental requirements (radiological and leaching properties) and considering the input from socio-economic research on stakeholder perception and acceptance. The study aims to contribute to the construction of a strategic research road map identifying multidisciplinary research gaps regarding the use of naturally occurring radioactive materials in new cementitious binders and concretes.

Support for this work was provided by the King Baudouin foundation project 2020-E2141050-E001 and the Horizon 2020 Euratom research and training programme under grant [agreement No 900009, RadoNORM project].

AN APPROACH TO NORM TREATMENT BASED ON SOLUTIONS DEVELOPED FOR INDUSTRIAL WASTE

Boguslaw Michalik (a), Hubert Makuła (b), Zbigniew Bzowski (b)
(a) Silesian Centre for Environmental Radioactivity, Poland
(b) Department of Environmental Monitoring, Central Mining Institute, Poland

Materials, residues, or waste currently considered as NORM were not emerged suddenly and in overwhelming majority have existed since a relevant industry was set into operation. Therefore, they already are subject to regulation and treatment developed for non-radioactive waste. Content of radionuclides is only an additional property recently raised to be considered in terms of radiation protection. In such situation an assumption could be that NORM management and treatment system may be established on existing regulations set by European directives on waste and on waste from extractive industry, unless NORM are classified as radioactive waste. If the applicable clearance level in NORM is exceeded any already applied/permissible option of treatment, considered as waste recovery or disposal operations, including preparation prior to recovery or disposal must be individually verified against dose limits. If dose limits are exceeded a treatment option of concern shall be subject to authority control in terms of radiation protection, including justification and optimization or not allowed to be used in a certain case.

Already developed complete system of waste management cover 15 well defined disposal options as well as 13 ones for recovery. These possible options of treatment had been defined before the problem of natural radioactivity was raised therefore, hence when used towards NORM their effectiveness against radioactivity must be checked. However, considering NORM as usually having more common with conventional, industrial waste than with radioactive ones no significant obstacles are expected. Brief analysis of disposal and recovery options included in waste directive was caried out in terms of radiation protection and environment radioactivity, when necessary, was done resulting in positive recommendation to be used for NORM.

Using of already developed complete system of waste management assures mutual interaction with many other regulations dealing with e.g. environment, Occupational Health and Safety (OHS), classification and management of dangerous substances, labour law. As well as possible interactions with another pollutants/stressor are automatically included.

This approach is one option considered for the development of clearly found scientific and practical rationales for improving regulatory approaches of NORM treatment and management, which are one of the most important outcomes of WP 5 Mitigation of RadoNorm project.

LESSONS LEARNED FROM THE START HOUSES: A CASE STUDY IN UTILIZING NORM RESIDUES IN THE CIRCULAR ECONOMY

Katerina Navrátilová Rovenská, Ivana Ženatá, Ivana Fojtíková
SURO, Státní Ústav Radiační Ochrany, Czech Republic

Following the Velvet Revolution, there was a pressing need to address the health risks associated with houses constructed from clinker concrete panels with high 226Ra content (1 - 4 Bq/g of 226Ra in clinker) from late 50ties till 1986 in the former Czechoslovakia (so called START houses). Exposure of inhabitants to radiation consisted not only from external radiation with gamma dose rates up to 2μGy/h but also from inhalation of radon progenies (equivalent radon concentration up to 500 Bq/m3). Thanks to the register of clinker panels customers, most of the buildings were identified and measured. Various strategies aimed at reducing of exposure of inhabitants have been tested. Forced over pressurizing ventilation was found as the most efficient measure against radon originating from building material; the identification of optimized measure reducing the external radiation was less successful.

Most of the activities were carried out in the 90s, at that time there was also a high awareness of the issue. In recent years, the situation changed. Many of START houses were inherited or sold, measurement results have been lost or forgotten. In addition, massive energy-saving campaigns began, which resulted in many START houses being thermally retrofitted.

The evolution of the START house story offers valuable insights and lessons for current efforts in the utilization of Naturally Occurring Radioactive Materials (NORM) residues in the circular economy. It underscores the importance of comprehensive risk assessment repurposing NORM residues.

CONCRETE MADE WITH NORM-CONTAINED BY-PRODUCTS: STAKEHOLDERS' PERCEPTION IN THREE EUROPEAN COUNTRIES

Nazanin Love (a,b), Robbe Geysmans (b), Sara Leroi-Werelds (a), Nadja Železnik (c), Ivana Fojtíková (d), Tanja Perko (b,e), Wouter Schroeyers (a), Robert Malina (a)
(a) Hasselt University, Belgium
(b) SCK-CEN, Belgium
(c) EIMV, Slovenia
(d) National Radiation Protection Institute, Czech Republic
(e) University of Antwerp, Belgium

This exploratory comparative study aims to understand the perspectives of both the industry and end-users regarding the usage of alternative cementitious binders made with NORM-contained by-products. As the third-largest CO_2-emitting industry, the cement sector poses significant environmental challenges. The incorporation of secondary raw materials in cementitious binders not only holds the potential to reduce CO_2 emissions but also contributes to a circular economy by repurposing industrial by-products. Due to the limited application of certain NORM-contained industrial by-products, they have accumulated in landfills, posing potential environmental and health hazards. While there has been significant development in the technical aspects of using these materials in alternative cementitious binders, little attention, to date, has been given to the social and marketing aspects. This transdisciplinary study brings novel insights into these overlooked dimensions.

We opted for a qualitative research methodology as it is an effective method when little is known about the topic. It also helps to understand the complex situations and generate hypotheses to be tested in a larger scale quantitative study. In total, we conducted 66 interviews across three European countries with two distinct stakeholder groups: the industry, comprising concrete-producing companies, associated organisations, federations, and construction companies; and end-users, which includes individuals engaged in building or renovating their homes. The selected countries, Belgium, Slovenia, and the Czech Republic, were chosen based on location, population size, and prior usage of hazardous materials in the building sector. Each interview, lasting approximately one hour, provided valuable insights.

Thematic and comparative analysis of the data unveiled three main themes of their concerns: health, long-term durability, and financial concerns. Major differences among the countries were identified, particularly in relation to health concerns. Within the health theme, three sub-themes emerged: the role of certification, similar past experiences, and non-residential application of the new type of cement. The findings provide a comprehensive understanding of how various factors influence each concern among stakeholders. For example, despite the importance of certification, a lower level of trust towards authorities among both stakeholders in Slovenia led to higher health concerns. Due to higher health concerns, only the non-residential usage of the new type of cement was accepted by end-users and the industry in Slovenia, as well as the industry in the Czech Republic. This study provides insights into the barriers and facilitators influencing the acceptance of NORM-contained materials, which is particularly useful for policymaking and communication strategies.

FROM MINING WASTE TO VALUABLE RESOURCE: THE APPROACH OF THE RESEARCH FUND FOR COAL AND STEEL PROJECT MINRESCUE FOR A CIRCULAR ECONOMY APPROACH TO COAL MINE WASTE GEOMATERIALS

Liberato Ferrara
Department of Civil and Environmental Engineering, Politecnico of Milan, Italy

The problem of Coal Mining Waste Geomaterials (CMWGs) is particularly important as the volume of disposed waste is enormous. CMWGs are chemically heterogenous, prone to particle breakage by compaction, rapid degradation by wetting-drying cycles, and susceptible to liquefaction when loosely deposited. Furthermore, spontaneous combustion and leaching of acidic water to the surrounding environment are among the environmental challenges they present. Coal extraction is still ongoing, for example in 2019, the total coal production in Europe, North America and Asia Pacific amounted to 577.4 Million tonnes (Mt), 701.5 Mt, and 5911.8 Mt respectively. This ongoing production adds more CMWGs to the amount already in storage facilities (>10,700 Mt by some estimates, and imposes additional costs on producers and extra burdens on the environment. Given the concerning state of the global climate, the environmental impacts of coal extraction and production activities are rapidly becoming a focus for researchers in civil engineering.

Given the context outlined above, the recently concluded RFCS project MINRESCUE (GA 899518) has worked to develop innovative concepts for managing, recycling and upcycling waste geomaterials generated by coal mining activities across Europe. The core objective of the project is to create and validate strategies to upgrade CMWGs as constituents in sustainable construction materials and products. The considered strategies are based on the engineering functionality assigned to the improved waste material, the service life of the construction product and its application, the pertinent use scenarios. The considered strategies are tailored as a function of the physical, chemical/mineralogical and mechanical properties of the available CMWGs. The project will provide ready-to-use tools that will be used to promote sustainable and durable reuse of CMWGs for the production of building components.

RADIOACTIVITY REDUCTION FOR NORM PHOSPHOGYPSUM BYPRODUCT OF PHOSPHATE FERTILIZER INDUSTRY

Meriem Essakhraoui (a,c), Maria Assunta Navarra (a), Nils Haneklaus (b), Hamid Mazouz (b), Aziz Boukhair (c), Fouad Bentis (c)
(a) Sapienza University of Rome, Italy
(b) University Mohamed 6 Polytecnic, Morocco
(c) University Chouaib Doukkali, Faculty of Sciences, Morocco

The phosphate fertilizer industry generates more than 250 million metric tons of phosphogypsum annually worldwide that present a significant challenge due to its large volume and environmental and potential environmental risks associated with storing the material. The management adopted by most of fertilizer producer is storage or release to the sea. Only relatively small quantities of PG are presently recycled for use in agriculture or construction since the material is considered NORM.

Phosphogypsum that originated from sedimentary rock contains radioactive elements such as radium-226. This radioactivity limits the use of phosphogypsum to large volume application specially in construction and agriculture.

The objective of this work is to propose a new process to purify phosphogypsum with the goal of reducing the radioactivity. The results show that the proposed purification process leads to a potential reduction of radioactivity in the final phosphogypsum product.

Session II

Regulatory approach

Chairs

Rosabianca Trevisi, Burcin Okyar

OVERVIEW OF HERCA ACTIVITIES ON NORM AND BUILDING MATERIALS INVITED SPEAKER

Heloisa Fonseca (a), Peter Görst (b)
(a) Environmental Planning and Protection Division, Emergency and Radiation Protection Department, Portugal
(b) Authority for Nuclear Safety and Radiation Protection, The Netherlands

HERCA is a network of competent authorities with decision capacity, focussing on exchange and discussion on significant issues of Radiological Protection. The main objective of this voluntary association is to identify common significant radiation protection issues and propose harmonisation and/or practical solutions towards a common approach for these issues, whenever possible. HERCA functions through task forces, a network and working groups dedicated to specific areas, one of these is the Working Group on Natural Radiation (WG NAT). This group focuses on the practical implementation of the European Basic Safety Standards Directive (EU BSSD) provisions related to Radon, Naturally Occurring Radioactive Materials (NORM), and Building Materials. WG NAT action plan includes several actions on the topics of NORM and Building Materials. Some of these actions are: National approaches to NORM waste/residue management, Graded approach to regulation of NORM related industries, Commodities containing NORM, Operational quantities to facilitate the measurement of surface contamination, and Overview of the implementation of EU BSSD Article 75-2 regarding the indicative list of materials of concern set out in Annex XIII. Over the years, several initiatives have been established to address these actions, such as the development of guidance, workshops, and technical discussion groups. In a more recent development, the WG NAT has prepared and circulated a questionnaire on NORM and Building Materials to enhance comprehension of how member countries implement the EU BSSD and deal with these challenges. Responses from 18 countries were analysed and presented at WG NAT spring meeting in Vienna. The insights gained from this survey will help to shape the group's new action plan and will ultimately contribute to more effective management of NORM and Building Materials throughout Europe.

MANAGING NORM RESIDUES: APPLICATION OF A FRAMEWORK TO SUPPORT THE DECISION-MAKING PROCESS

Natalie R.E.N. Impens (a), Catrinel Turcanu (a), Edouard Rodolphe Jean Vialou (b), Horst Monken-Fernandes (c)
(a) SCK-CEN, National Nuclear Research Centre, Belgium
(b) CBMM, Brazil
(c) IAEA, International Atomic Energy Agency

The main goal of IAEA ENVIRONET (Network of Environmental Remediation and NORM management) is to promote the adoption of good practices in environmental management. Within the scope of ENVIRONET, IAEA established the MAESTRI project (MAnagEment SysTems SuppoRting envIronmental Remediation Projects). This project developed an integrative framework for the sustainable environmental management of contaminated sites, from a holistic perspective. Specifically, the framework draws on social-multi criteria evaluation as a decision-aid paradigm, and on sustainability assessment as an overarching framework for evaluating environmental remediation options, taking into account the plurality of social, economic and environmental dimensions and values to be considered. This framework can be applied for any specific case study, as well as for broader discussions on the implementation of sustainability and circularity principles.

In this contribution, the step by step decision-aid methodology established within the MAESTRI project has been applied as a structured approach to the integrated management of a hypothetical contaminated NORM site, characterized by hosting large amounts of NORM residues.

The paper presents the decision-aid steps applied to a set of four scenarios, including "Managing the disposed residue on-site", "NORM treatment with removal of radionuclides to enable safe reuse of the bulk", "NORM treatment with extraction of radionuclides, separation of (other) precious elements and optimisation of the valorisation of all fractions", and "Exporting the NORM residue to another country for recycling and valorisation purposes". The results of this decision-making exercise will be presented, including a comprehensive stakeholder mapping and some tools to support the decision-making process. In this exercise the three pillars of sustainability (social, environmental, economic) have a central role.

Based on these results, practical and operational needs are defined in terms of policy, technology, economy, regulations and stakeholder engagement in line with the principles of the circular economy.

GAMMA RADIATION EMITTED BY BUILDING MATERIALS - TOWARDS A REGULATORY FRAMEWORK IN FRANCE

Anne Cordelle (a), Hélène Caplin (a), Anne Mathieu (a), Pierrick Jaunet (b), Anne Jegouzo (b)
(a) IRSN, France
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The subject of the presentation is the state of reflection and discussion in France regarding the implementation of regulatory provisions related to the external exposure of people in a building, due to gamma radiation emitted by NORM in the materials and products of construction used.

The control system provided for in French regulations is built on two levels: the first level, as set out in Directive 2013/59/Euratom, is based on the calculation of an I index for each of the materials used. The formula for this index is based on the activity concentration values measured for Ra226, Th232 and K40 in the material; a second level of control is planned if the I index is greater than 1, but the modalities have yet to be defined - they are the subject of the work presented.

The authors propose the following approach.

A first step would be to apply the calculation method developed by CEN (the European Committee for Standardization), which is the subject of standard NF EN 17637 published in 2022. This method uses formulas and charts to assess a dose to ensure that the reference level inside the building is respected.

If the first step does not guarantee compliance with the reference level, a final step would allow a more realistic dose calculation (e.g. using a Monte Carlo calculation code) to demonstrate compliance with the reference level inside the building.

The state of reflection and discussion will be detailed during the presentation, with a focus on some themes, with the particular aim of ensuring that the practices envisaged are consistent with those in other European countries:

The real radiation protection issues associated with the use of these materials.

The calculation configuration(s) selected to implement the CEN approach, and the idea of developing a numerical tool to guide the person in charge of the assessment.

Finally, the responsibility for carrying out these calculations (by the material producer/supplier or by the builder?).

ELIMINATION OF NORM-WASTE IN SWITZERLAND: A NEW NATIONAL DIRECTIVE

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Switzerland is not confronted with large scale industrial activities producing NORM-waste. However, such waste, mainly in limited amount, is common. The Federal Office of Public Health (FOPH), the regulatory authority for radiation protection in Switzerland, convened a working group to draft and implement a new directive precising elimination pathways and procedures for the elimination or recycling of NORM above clearance values. The working group included representatives of FOPH, of surveillance authorities for industry and NPP's (Suva and ENSI), of the federal office of environment OFEV, cantonal authorities as well as landfill owners.

NORM-waste is all waste containing NORM above the clearance level for NORM. The Radiological Protection Ordinance RPO defines this level, based on the EU-BSS, at 1 Bq/g for radionuclides of the U-238 and Th-232 decay chains and 10 Bq/g for K-40. Waste under this value is not considered NORM and can be dealt with as conventional waste. Possible elimination pathways for NORM-waste are not defined by the ordinance and therefore not restricted but a dose limit for members of the public is set at 0.3 mSv/year. NORM-waste elimination or recycling pathways must therefore comply with the conventional waste regulation plus get approval from FOPH regarding the respect of the 0.3 mSv/year limit.

Such a procedure must be coordinated between the different state actors to allow for a smooth implementation. The new directive explicit the collaboration between the several involved actors and authorities and defines the procedures applicable. It describes the possible elimination pathways (landfilling, incineration, valorisation, export), sets decision criteria and explains the underlying reasons.

Such a directive does not have a binding legal value but sets a standard for the activity and facilitate processes for all actors. A significant added value is the stakeholder involvement in the elaboration of the directive, thus facilitating greatly its acceptance and spreading to relevant parties.

The presentation will highlight the different elimination pathways and models underlying the dose calculations. Further, procedures waste owners must follow in order to get approval of the involved authorities will be exemplified and a few case studies will be presented.

SHOULD TRADE UNIONS BE CONCERNED ABOUT NORM?

Stéphane Pepin
ENA, European NORM Association; CSC Services Publics, Belgium

Exposure to NORM is one of the many hazards workers may be affected to in workplaces dealing with NORM. Often, in the development and implementation of NORM regulations, safety authorities involve as main stakeholders the operators of industries involving NORM, radiation protection experts and sometimes Health and Safety advisors. Rather seldom, the stakeholders engagement process will involve directly the affected workers or their trade unions. Raising awareness among the workers themselves and empowering them may however significantly contribute to an improvement of occupational radiation protection. The presentation will describe how trade unions may play a role in this process - especially regarding an integrated approach of the different hazards on the workplace.

The International Labour Organisation (ILO) acknowledges the role of social dialogue in the development and implementation of Occupational Safety&Health (OSH) policies: the Occupational Safety and Health Convention, 1981 (No. 155) requires that the most representative organizations of employers and workers be consulted on the formulation, implementation and periodical review of a coherent national policy on OSH.

Social dialogue as a tool to promote health and safety at work, was also adopted in 2022 in an opinion by the European Economic and Social Committee (EESC). Various European directives, such as Directive 89/391/EEC (so-called occupational safety and health "Framework Directive"), set out minimum requirements and fundamental principles, such as the principle of prevention and risk assessment, as well as the responsibilities of employers and employees. The presentation will review some of the main European and international directives and conventions regarding occupational Health&Safety. It will describe how workers organisations may play a role in enhancing occupational radiation protection in industries dealing with NORM taking into account an integrated approach of the various occupational hazards.

DOES ENA NEED A STRATEGIC RESEARCH AGENDA? INITIATIVE FOR A DEDICATED SRA ON THE RESEARCH NEEDS IN NORM

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(d) SCK·CEN, Belgian Nuclear Research Centre, Belgium

This presentation will emphasize the importance of a strategic approach towards research within the European Norm association. We'll delve into ENA research needs, identify initial research gaps, and determine whether to establish a dedicated European Norm Association Strategic Research Agenda or better integrate NORM research needs into existing strategic agendas of allied associations in radiation protection.

Over the past decade, there has been significant consolidation of radiation protection research in Europe through the collaboration of six research platforms. These platforms, gathered under the MEENAS umbrella (https://www.meenas.eu/), comprised of research centers, university groups, and funding bodies across EU Member States, focus on specialized areas like societal aspects (SHARE), health risks (MELODI), radioecology (ALLIANCE), radiological emergencies (NERIS), dosimetry (EURADOS) and medical radiation applications (EURAMED). All those platforms have their own strategic research agendas and consider NORM within their own specialized area. However, as a result NORM research needs are scattered across those agendas.

Although, research is being conducted in the field of NORM, we believe these needs are not fully covered in any single SRA and require input from the ENA to address them comprehensively and guide the needs for future research. For example, research gaps include NORM's role in supporting circular economy, sustainable approach in NORM, its implications from potential new energy sources on the environment and human health, and gaps in understanding the social, economic, and cultural aspects of NORM management.

The presentation will identify the needs for NORM research emphasizing key gaps in existing SRAs. A way forward to gather input from the ENA community on their research needs will be discussed as well as the need for a dedicated SRA on NORM or integration of ENA’s research needs into existing SRAs. A full discussion with ENA members - as part of the presentation - on the next steps is envisaged.

Session III

European Alara Network-EAN Session

Chairs

Cristina Nuccetelli, Julie Morgan

OPTIMIZATION OF PROTECTION, THE CORNERSTONE OF RADIATION PROTECTION A VIEW ON THE NORM INDUSTRIES

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The application of the optimization principle is the cornerstone of radiation protection and the European ALARA Network (EAN) strives in its activities to promote the exchange and dissemination of practical optimization for all exposure situations. The application of the optimization principle has shown its benefits in radiation protection and in the holistic approach to protection in planned exposure situations.

The optimization approach, based on a forward looking risk-aware attitude, supports safety and safety culture as a whole. The structured approach inherent to the ALARA process provides transparency to the stakeholders on the implemented protection measures and the acceptable risk level. This leads to a balanced judgement on the risks and the benefits allowing an optimal use of the resources. Optimization provided the cornerstone of protection and radiation protection.

NORM and radon (at workplace or in other circumstances) are seen as an existing exposure situations (from sources that already exist when decisions to control them are made). However in the Euratom Directive, radon and NORM exposures of workers are to be managed “as planned exposure situations” and are governed by elements in national regulations. In practice, in both approaches the decision to control and the level of control translate in the application of the justification and the optimization of the protection, transparent and integrated with the protection from other hazards present, as will be developed in the presentation.

Applying the ALARA (optimization) procedure leads to a radiation protection that is optimized in an integrated and graded approach for the protection of workers, the public, and the environment, where radiation protections complements the protection strategy already in place or planned to manage other hazards.

OVERVIEW OF THE UK REGULATIONS ON NORM AND EXAMPLES OF APPLICATION

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Management of NORM in the UK is subject to regulation to control the radiation doses received by persons working with the material and by members of the public exposed due to disposal of NORM waste. The basis for the regulations, exemptions for trivial exposure scenarios and required control measures to ensure doses are kept as low as reasonably practicable (ALARP) are described, illustrated by examples of current and historical situations where NORM is present.

Novel methods of reusing NORM waste as an alternative to disposal, challenges faced by waste producers and disposal methods are also discussed.

The author is a qualified expert in radiation protection and radioactive waste management and has worked at the UKHSA for over 30 years. The Radiation Chemical and Environmental Hazards Directorate of the UK Health Security Agency is the UK authority on radiation protection, with input into the regulatory framework, assessment of the environmental impact of disposal of radioactive waste and commercial advisory services for radiation protection and radioactive waste management amongst its functions.

CIRCULAR ECONOMY IN THE LAST QUARTER OF XX CENTURY: A PARADIGMATIC EXAMPLE IN A NORM INDUSTRY OF SOUTH-WEST OF SPAIN

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The term "circular economy" invading our NORM documents in the XXI century, looking for recycling and valorization of the residues generated along the production process of NORM industries, can find since the last quarter of the XX century a paradigmatic example in a NORM factory located in the South-West of Spain and devoted to the production of titanium dioxide pigments by the sulphate process.

The production process was originally forced to be changed in this factory due to restrictions and limitations imposed to the disposal of the residues, finishing in a process where most of the residues are recycled generating by-products that have a well defined and clear market. These recycled by-products constitute nowadays an important fraction of the total income of the factory.

In this presentation, the "old" and "new" production processes will be presented in detail, and all the residues and by-products generated as well as the raw materials will be characterized radiometrically, remarking the different markets found for the valorized by-products and their negligible radiological impact.

Other pioneering attempt of residue valorization in the last quarter of the XX century, also in South-West of Spain in a NORM industry devoted to the production of phosphoric acid, will be additionally presented and commented.

ENHANCING RADIATION PROTECTION PRACTICES: OPTIMIZATION PRACTICES FOR NORM INDUSTRIES AND LEGACY SITES IN GREECE

Constantinos Potiriadis
EEAE, Greek Atomic Energy Commission, Greece

This study investigates the optimization of radiation protection measures within Naturally Occurring Radioactive Materials (NORM) industries and sites operating in Greece. These industries encompass diverse sectors such as the production of phosphoric acid, aluminum production, and electricity generation from coal.

Drawing upon insights from regulatory framework, industry practices, and scientific research, this paper offers a comprehensive analysis of optimization techniques tailored to the Greek context. Key considerations include the characterization of NORM sources, assessment of exposure pathways, and the implementation of dose monitoring protocols. By optimizing radiation protection practices, NORM industries and sites in Greece can enhance operational safety, minimize radiation exposure risks, and ensure compliance with regulatory requirements.

NORM SAMPLE CHARACTERIZATION: CHALLENGES FOR IN SITU GAMMA MEASUREMENTS

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The characterization of NORM materials is a crucial step in the residues management process. Sampling small amounts of material for laboratory analysis is not always a viable option due to the large amount of residues and the possible inhomogeneities, which makes difficult to assure the representativity of the samples.

In situ gamma measurements represent an alternative approach for NORM characterization, since they can provide results referred to the material as a whole, avoiding the manipulation of contaminated material and potentially reducing time and resources. This technique includes different sources of uncertainty, which should be carefully considered, especially when the activity concentration is close to the clearance levels. In particular, the efficiency calibration of these measurements is usually based on modelling software and, therefore, the more accurate the geometric model provided is, the more reliable the results are. As a consequence, the Total Measurements Uncertainty (TMU) is usually dominated by lack of precise knowledge about the distribution of activity and density within the material.

A realistic evaluation of the TMU is crucial to determine if a method is suitable for NORM characterization in terms of sensitivity, with respect to the clearance levels.

In this study, the performance of a low-resolution gamma spectrometer (Mirion SPIR-Ace NaI detector) and a portable HPGe detector (Mirion Falcon) was evaluated for in field NORM characterization; whenever possible, the results were compared with laboratory analyses on representative samples. The in situ results are based on experimental spectra acquired with different geometries (big bag, drum, concrete retube waste container “Casagrande”). The measurement efficiency was calculated via ISOCS Canberra modelling software for different activity distribution models, such as uniform distribution and single point source. A sensitivity analysis on factors affecting the uncertainty was performed. The distribution models which maximize and minimize the efficiency were included in the TMU estimation.

On the basis of this analysis, the advantages and limitations of different methods for in situ gamma measurements are examined; reliability of in situ measurements are also compared with laboratory measurements of representative samples.

A GRADED APPROACH TO CHARACTERIZE THE EXPOSURE CRITICAL SCENARIOS IN INDUSTRIES INVOLVING NORM

Ilaria Peroni (a), Silvia Bucci (a), Elena Caldognetto (b), Giuseppe La Verde (c), Federica Leonardi (d), Cristina Nuccetelli (e), Gabriele Pratesi (a), Mariagabriella Pugliese (c), Rosabianca Trevisi (d), Raffaella Ugolini (b), Gennaro Venoso (e), Flavio Trotti (b)
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(e) National Center for Radiation Protection and Computational Physics, National Institute of Health, Italy

With the implementation of the European Council Directive 59/2013/Euratom (2013EU-BSS) into the legislation of the EU Member States, the application field of the radiation protection system is extended to industrial sectors that have not been included so far.

As part of a research project aimed at providing stakeholders with useful tools to meet their legal obligations for the radiation protection of workers and the public, a general methodology for the characterization of exposure scenarios relevant to industries using NORM has been developed. The methodology adopts the graded approach already recommended by ICRP in the publications N.103 and N.142 and endorsed by the 2013 EU BSS.

This methodology, consisting of two phases with four consecutive steps each, provides a general procedure that can be adapted to a specific industrial sector and/or scenario.

The first phase aims to identify and characterize the most critical exposure scenarios and the radiological content of NORMs involved in the different stages of the industrial processes.

In the second phase, the relevant exposure scenarios are used to assess the dose to workers and the public.

Existing and well-proven calculation codes have been used for dose assessment and dedicated user-friendly software has also been developed.

A number of schemes are presented as operational tools of the methodology, in order to facilitate and coordinate an effective series of actions finalized to exempt or not a NORM involving industry.

HANDLING OF CONTAMINATED COMMODITIES IN AUSTRIA & CURRENT DEVELOPMENTS

Susan Friedreich, Franz Kabrt, Claudia Landstetter, Christian Katzlberger
AGES, Austrian Agency for Health and Food Safety, Austria

Up to now, import and trade of contaminated commodities in Austria were surveyed based on screening studies and event-related controls. Since 2023, the department for radiation protection of AGES started a regular monitoring of consumer products and contaminated commodities. On behalf of the authority, the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, we furthermore implemented a database of consumer products and contaminated commodities which is continuously updated every three to six months, primarily based on web research, but also taking random samples in local trade or following official reports and other hints, e.g. portal monitor alarms.

As part of the monitoring, random measurements of already known and new or newly named contaminated commodities are carried out. The focus is on products where activity concentration or dose reference level were exceeded in previous measurements of equivalent products or where reference levels are likely to be exceeded.

A prominent and still highly relevant example are leggings with tourmaline worked into the material. The random samples ordered and measured in our laboratory with gamma spectroscopy result in activity concentrations up to 4 Bq/g Th-232 for most products of this type. Another important example are products sold on numerous websites as test objects for Geiger counters, e.g. radium dials or autunite rock samples which have activity concentrations of Ra-226 up to several Becquerel per gram.

Further, thorium welding electrodes from certain producers still need to be considered due to activity concentrations resulting under conservative conditions in an effective dose of more than 20µSv per year, which is twice the reference level for consumer products.

Currently, the possibilities of cooperation with the Austrian customs are being explored to establish a regular exchange of information to support our monitoring activities. Ideally, the collaboration will result in a targeted control of products which have already been measured in our laboratory, as for the leggings, to consequently stop them from being imported. This is particularly important since it is frequently impossible to track back the products to the actual producers.

A first draft of protection strategies for contaminated commodities in Austria has been completed. For this purpose, the strategies for managing contaminated areas according to the Council Directive 2013/59/EURATOM have been adapted. The standardized procedures shall ensure an effective course of action starting from suspicious cases through the investigation to the resulting actions.

RESEARCH QUESTIONS ON NORM EMERGING FROM THE RADONORM PROJECT

Laureline Février (a), Laura Urso (b), Gennaro Venoso (c), Jelena Popic-Mrdakovic (d), Virginie Chapon (e), Thuro Arnold (f), Susanne Sachs (f), the whole RadoNorm WP2 Team for NORM

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One of the aims of the Work Package 2 "Exposure" of the European project RadoNorm (2020-2025) is to develop methodologies and tools applicable at European level to identify and quantify exposure of population and environment due to Naturally Occurring Radioactive Material (NORM). In particular, focus is on adapting and optimizing current approaches for identification and evaluation of exposure in light of international and national requirements for handling NORM more compelling than in the past and based on new available scientific evidence. The project is in an advanced stage of progress and several results have been obtained. However, these also let emerge research questions, which may be worth addressing in the future. For example, a methodology to establish a NORM inventory has been developed and applied to gather systematic information on NORM from European countries. Information gained, abundant for naturally occurring radionuclides (NOR), indicated that additional and more systematic information on amounts and handling approaches of other contaminants is needed. This as a basis for the establishment of a more efficient optimized and integrated approach for evaluating NORM involving situations. Impact of most recent ICRP dose coefficients for intake of radionuclides by workers and for external radiation has been analyzed for several generic NORM scenarios. Moreover, with the aim to help stakeholders for a practicable implementation of the radiation protection requirements, screening values (defined in terms of activity concentration corresponding to annual effective dose of 1 mSv/year) have been derived for NORM residues disposable in conventional landfills, and for the reuse of NORM sludge as fertilizer in agriculture. For obtaining these screening values, however, generic consideration of groundwater pathway proved difficult and a systematic analysis of types of landfills and typical hydrological characteristics of these landfills at EU level (i.e. a kind of mapping) would be necessary to use water flow and solute transport models with optimized and less conservative parameters. In addition, for the groundwater pathway, in order to better define the sorption of NOR to soil, e.g. via the Kd parameter, sorption/desorption properties of uranium, radium and polonium have been investigated experimentally or via geochemical models (e.g. smart-Kd approach). To improve the predictive capability of these models, gaps for thermodynamic NOR data have to be filled, especially for radium and polonium. In addition, NOR interactions with organic matter and quantification of the microbial influence on NOR migration in soil are needed to better predict the radionuclide mobility over space and time, which is needed for realistic dose calculations and evaluation of remediation activities.

Session IV

Young professionals

Chairs

Christian Kunze, Lonneke Van Bochove

USE-STAGE LIFE CYCLE IMPACT ASSESSMENT FOR NORM IN A ROOM MADE OF BAUXITE RESIDUE (BR) CONTAINING NOVEL BUILDING MATERIALS

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The construction sector is a major contributor to climate change with ~8-9% of total anthropogenic CO2 emissions due to cement production. Projected over the next 50-100 years, the limited supplementary cementitious material (SCM) availability and increase in urbanisation are driving the cement industry to find alternative sustainable SCMs. As a promising candidate to replace clinker by ≥30 wt%, Bauxite Residue (BR), a by-product of the alumina industry's Bayer process which involves Naturally Occurring Radioactive Materials (NORM), is assessed in this study. The objective is to consider a potential burden shifting in the life cycle of novel BR-based SCM-containing concrete materials due to natural ionising radiation impacts. Two treatment technologies converting BR into effective SCMs are investigated: co-calcination developed at VITO NV and vitrification by the KU Leuven. The co-calcination samples are from the Mytilineos Aluminium of Greece plant in Agios Nikolaos, Greece, while the vitrification samples are from the Alum S.A. alumina refinery in Tulcea, Romania. These treatment processes further enhance the radioactivity levels. This study focuses on the ionising radiation dose received at the use stage of building materials, omitting an evaluation of manufacturing processes. The worst-case scenario for the exposure of the human body to NORM in a living space was designed with a first- or upper-floor room made only of the novel concrete materials on the walls, floor and ceiling, without any windows, with the dose point in the center. As the basis of comparison, the functional unit (FU) was selected as a 1 m3 concrete structure involving treated BR-based SCM by 3.6 wt%, with 25 MPa compressive strength. Material-specific radioactivity concentrations and masses form the inventory database. Two dose assessment models calculating exposures due to external gamma and radon gas with progeny were run within the LCA-NORM framework for each BR treatment technology. For gamma exposure modelling, the approach in EN standard 17637, including effective dose conversion coefficients (DCCs) in Table 2 of the standard, was used. Per FU, exposure to gamma rays is 0.0011 mSv/y for co-calcination and 0.0015 mSv/y for vitrification. The radon exposure was modelled by following the UNSCEAR approach and corresponding DCCs. Per FU, radon exposures are 0.05 mSv/y for co-calcination, 0.02 mSv/y, for vitrification. To demonstrate the overall exposure, the combined use-stage dose (gamma and radon) received by one person living in the room for a year is 0.60 mSv/y for the co-calcination case and 0.24 mSv/y for the vitrification case. The current results indicate that at the use stage of the concrete life cycle, the studied materials do not exceed the EU Basic Safety Standards Directive threshold values for maximum allowable doses (1 mSv/y for gamma, 10 mSv/y for radon). These observations are valid specifically for the processes and raw materials of the aforementioned alumina refineries. Future work may address the manufacturing stage to complete the assessment throughout the product life cycle.

This research was performed within the ReActiv project and received funding from the EU Horizon 2020 Programme (H2020/2014-2020) under grant agreement n° 958208.

NORM VALORIZATION USING OIL SHALE ASH AND BASALT-BORON FIBER IN CONCRETE – AN ENVIRONMENTAL LIFE CYCLE ASSESSMENT

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(d) Institute of Mechanics, Riga Technical University, Latvia

Supplementary cementitious materials in concrete limit the environmental impacts associated with clinker production. Oil Shale Ash (OSA), a residue from NORM-involving oil shale combustion, has found use as such a material for achieving a circular economy. Due to the slight negative effect of OSA on strength, basalt-boron fiber (BBF) is added in this work to enhance the mechanical properties and, in addition, the neutron-shielding capabilities. The environmental impacts and potential benefits of these novel concretes, potentially suitable for radioactive waste management among other applications, are determined in this study.

A Life Cycle Assessment (LCA) model was constructed to represent the whole production process of a set of novel concrete mix designs with varying compositions. The environmental impacts in a choice of categories, including global warming potential (GWP), freshwater ecotoxicity potential and ozone depletion potential, were determined for all mixes. After analysis, the mixes were compared to each other and to the conventional concretes in use today. Results showed a significant reduction in environmental impacts from the replacement of cement by OSA. Representatively, for most cases, it was shown that each 1% of cement replaced by OSA in the concrete reduced the total GWP by over 0.7%. On the other hand, the inclusion of BBF represents a noticeable fraction (up to 17%) of the total impact of the concrete mixes, suggesting that BBF is used only where its properties are vital. In total, the novel mixes could show outstanding reductions in GWP (kg CO2-eq) per kilogram of concrete compared to conventional alternatives of similar characteristics. No radiological concerns are seen.

Conventional concrete was compared with novel alternatives that can provide cheaper, more environmentally friendly, and otherwise optimal solutions. It was seen that the mixes involving OSA and BBF could be used beneficially in many applications as greener alternatives. Different fibers suitable for concrete materials were compared using an environmental LCA approach.

This research was funded by the Baltic Research Programme Project No. EEA-RESEARCH-165 "Innovation in concrete design for hazardous waste management applications" under the EEA Grant of Iceland, Liechtenstein, and Norway Project Contract No. EEZ/BPP/VIAA/2021/6.

OVERVIEW OF DECOMMISSIONING OF A NORM LEGACY SITE FROM DCP PRODUCTION. CHALLENGES AND LESSONS LEARNED

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The manufacturing of Dicalcium Phosphate (DCP), which is used as an animal feed additive, produces large amounts of NORM known as fluorite sludge. DCP precipitates following phosphoric acid synthesis via the interaction of F-rich phosphorite with HCl. During this reaction, fluorite (CaF_2) precipitates, reaching up to 40-50 wt% in the final sludge. Additionally, fluorite sludge contains significant concentrations of Rare Earth Elements (REE). The legacy site at El Hondón (Cartagena, South Spain) contains more than 0.5 Mt of the fluorite sludge. Its restoration plans have already been approved by the Spanish competent authorities in radiological matters and are pending for execution based on further authorizations. One critical issue in the restoration project has been to ensure the geochemical and hydrogeological stability of residues, preventing radionuclide mobility. In this study, an overview of the decommissioning project of El Hondón site has been performed with focus on the disposal of the radionuclides, and their low mobility.

Fluorite precipitation during DCP production triggers radionuclide separation from the phosphoric acid since it fixes significant activities of 210Po, 226Ra, 230Th, 238U and 210Pb. The final activity of the fluorite sludge is of few $Bq \cdot g^{-1}$. According to numerical calculations, the mobility of these radionuclides in the site and their potential impact on the environment is not relevant due to the permeability of the residues, chemical stability of host mineral under the given pH-Eh-salinity conditions and the sorption of the radionuclides on the minerals occurring in the site, such as iron oxides or hydroxides.

In addition to the intrinsic stability of the residue, a cover layer and technosoils are being designed to reduce radon emission and for further revegetation of the site. These consist of layers of materials like foundry slag, fly ash from biomass plants, glass remains, clay, bricks, construction waste, organic material, and compost.

On the other hand, a limited area of the site was covered by Ra-rich sediments combined with pipeline scales, likely belonging to DCP process factory. These residues were characterized by much higher activity concentration, mainly 226Ra and significantly higher external dose than the rest of the site. Therefore, an additional restoration project has been undertaken to properly manage the most active part of the site with the focus on its rapid final disposal. These residues have been adequately characterized, analyzed and finally disposed in the facility for low and intermediate level radioactive waste located at El Cabril.

NORM IN GEOTHERMAL INSTALLATIONS: IDENTIFICATION OF RADIOLOGICAL RISKS, THEIR PERCEPTION AND COMMUNICATION

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Geothermal energy is a renewable energy source that uses Earth's natural heat to provide globally electrical or thermal energy. Geothermally heated water is brought to the surface in places where heat reservoirs are situated at a reachable depth, containing minerals and impurities. Depending on the properties of the installation, various substances accumulate in specific places of the installation, causing the build-up of scales and sludges. This leads to increasing concentrations of, for example, naturally occurring radionuclides (NORs), heavy metals, and/or rare earth elements. In addition, the UNSCEAR report from 2016 mentions that the public dose per unit of electricity produced by the geothermal industry is the highest amongst the different technologies evaluated. However, this conclusion was based on very limited amounts of data available, this calls for further investigations to generate more data and understanding of radiation risks in geothermal industry.

A multi-disciplinary approach was adapted to assess the radiological risk and perception linked to the geothermal industry. A technical study was set in place to characterize residues (sludges and filters) generated during operation of a geothermal installation in The Netherlands. This allows assessing the radiological risk when handling these materials during the operation and maintenance of the installation. This was executed through radiological (alpha-particle and gamma-ray spectrometry) and non-radiological characterization (ICP and XRF). Results show concentrations of the different radionuclides under exemption limits. Keeping in mind that this is a case study and these results cannot be extrapolated. A social science study researched how radiological risks are perceived and communicated. For this, media content analysis, interviews, and a workshop were conducted. The study found that information on radiological risk in the public discourse is limited reported on. Stakeholders reveal different kinds of risks present during the operation of a geothermal installation. The radiation risk was mainly perceived to emerge during the maintenance of the plant and during waste management.

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 900009 and runs under the Collaborative Doctoral Partnership between JRC and UHasselt agreement number 35342.

RADON AND ITS PROGENY MIGRATION IN A NATURAL GAS EXTRACTION AND TREATMENT FACILITY: IN-SITU CHARACTERIZATION OF PB-210-CASE STUDY

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In the Oil&gas facilities, radon and its progeny can be found in the gas and in films on the inside of the gas treatment/handling equipment. The radon appears to concentrate preferentially in the natural gas output of the plant. Pb-210 and Po-210 that accumulate in films are especially problematic because they are more difficult to be measured on the inside of piping and equipment due to the lack of a strong gamma decay. Generally in order to measure for Pb-210 and Po-210, it is necessary to open the piping or valves.

This paper presents a real-world case study focusing on in-situ characterization measurements and analysis conducted at a natural gas extraction and treatment facility and on the results that measurement methodology can achieve. In situ gamma spectrometry analyses detected significant levels of Pb-214 and Bi-214, attributed to the passage of compressed gas containing Rn-222. Bypassing the filter resulted in a rapid decrease in Rn-222 progeny concentrations, reaching near-zero levels after approximately 2 hours, preventing any contamination meter from detecting potential issues during a plant shutdown. Since the filter accumulates solid Pb-214 and Bi-214, it is reasonable to assume the accumulation of Pb-210 and Po-210 as well.

Measurements conducted on the exhaust filter confirmed this hypothesis. By removing the filters from their cylindrical containers and performing multiple measurements along the filter's length using a portable HPGe detector, the distribution of Pb-210 contamination along the filter was delineated. The results indicated levels exceeding general clearance levels outlined in RP122 Part 2 and included in the Council Directive 2013/59 EURATOM.

This case study highlights the importance of comprehensive in-situ characterization and the challenges associated with detecting and managing radioactive contamination in gas processing facilities, particularly when dealing with Pb-210 and Po-210.

Moreover, the study has enabled the development of a characterization strategy for plant components aimed at managing the potential removal of residues or maintenance activities that may involve them. Given the nature of the matrices and contamination distribution in this type of residue, sampling and quantitative analyses performed in laboratory are often not feasible. Therefore, Non-Destructive Assay (NDA) measurements are proposed as a viable alternative when it is necessary to determine the radiological status of a component within the scope of radiation protection. Furthermore, these measures would allow for a reduction in the quantity of residues destined for disposal by identifying hotspots in components contaminated with Pb-210 and Po-210. If these were entirely disposed of in a landfill, it would result in a significant increase in costs.

ACTIVE MEASUREMENT OF RADON AND THORON INDOORS AND IN MATERIALS WITH HIGH RESOLUTION ALPHA SPECTROMETRY

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Active radon and thoron measurement systems based on the electrostatic collection of the ionized descendants of the two isotopes and on alpha spectrometry are the most effective. They allow you to monitor both gases through the analysis of alpha spectra with high energy resolution and therefore follow the variations in radon and thoron concentrations with optimal temporal resolution. Devices based on this mechanism allow both to measure and/or monitor the activity concentration of radon and thoron in air and to determine the rate of exhalation and/or emanation from NORM materials. The results of several such systems that have been built, tested and calibrated in our Radon and Thoron Reference Chamber to derive efficiency and versatility for different purposes will be presented and discussed.

STUDY AND CHARACTERIZATION OF ZEOLITES FOR THE REMOVAL OF ARTIFICIAL RADIONUCLIDES IN WASTEWATER SAMPLES FROM NUCLEAR POWER PLANTS POSTER

Fabrizio Ambrosino (a), Giuseppe Della Peruta (a), Francesco Pisciotta (b), Carlo Gravino (c), Giuseppe La Verde (a), Gaetano Gagliardo (a), Nicola Gargiulo (c), Domenico Caputo (c), & Mariagabriella Pugliese (a).
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Being the most important inorganic adsorbents and cation exchangers, zeolites have also been proposed and successfully used for the decontamination of artificial radionuclides-containing wastewaters. In this work, water solutions from the processes of cooling and storing the irradiated fuel elements of the former nuclear power plant of Garigliano (Italy) are considered. Samples of the wastewater are characterized radiologically by performing γ-spectrometry using HpGe detector: 137Cs and 60Co are main sources. Perusing within literature in terms of selectivity and efficiency of zeolites in the removal of radionuclides, LTA-type zeolites, beside FAU-type zeolite and some natural zeolitic terms, are expected to be the best solution for the decontamination of water containing 137Cs and 60Co. This work falls within the decommissioning of the above cited facility and aims to provide an alternative solution for correctly managing the problem of radioactive wastewaters. In-batch experiments - by using simulated solution containing Cs e Co not radioactive isotopes and two synthetic zeolites (4A and 13X) together with one natural term (philipsite-rich tuff) - have been performed to obtain the kinetic characterization of the exchange process. By inductively coupled plasma spectrometry (ICP) the Cs and Co concentrations have been monitored over time. The results demonstrate the high efficancy of zeolite 13X having almost 100% of adsorption of both elements, in a relatively short time in the order of 10-20 minutes. The results obtained will be used for the design and setup of an in-situ pre-pilot plant to carry out tests with contaminated water stored at the former Garigliano nuclear power plant. Once the method of radionuclides removal from wastewater by zeolites has been standardized, it can be extended to all the similar nuclear industrial realities. Zeolite 13X presents a promising alternative for decommissioning radioactive wastewater, reducing volumes from thousands of cubic meters to approximately one cubic meter of radionuclide-bearing zeolite waste.

CASE STUDY: ASSESSMENT OF ANNUAL EFFECTIVE DOSE TO THE POPULATION RESULTING FROM THE DISPOSAL OF NORM RESIDUES EXCEEDING THE CLEARANCE LEVELS AND OPTIMIZATION OF THE MEASUREMENTS REQUIREMENTS POSTER

Gianluca Ciocari, Edoardo Bencivenga, Lenardo Baldassarre, Gianluca Simone
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This paper introduces a real-world case study involving the evaluation of the annual effective dose to the population from the disposal of Naturally Occurring Radioactive Materials (NORM) residues exceeding both general and specific clearance levels outlined in RP122 Part2 and included in the Council Directive 2013/59 EURATOM. The disposal site receives various types of NORM residues generated by the titanium dioxide industry and has been operational since 1972, with disposal activities expected to continue until around 2035. The calculation model takes into account scenarios and formulas outlined in RP 122 Part 2 for the disposal scenario, incorporating realistic assumptions wherever possible and referencing the dose received by the population once the disposal site is fully closed. For this purpose, the historical framework of the landfill was reconstructed through a retrospective analysis.

Through a more accurate parametrization of exposure scenarios and a customized calculation model, it has become possible to safely dispose of NORM residues exceeding the specific clearance levels outlined in RP122 Part 2 for the disposal scenario but remaining below the dose criterion for members of the general public of 300 μSv/year. In this real-world case, improbable contributions from external irradiation and direct inhalation or ingestion of landfill dust have been excluded.

The study has enabled the definition of analytical requirements to demonstrate the absence of NORM contamination in groundwater and vegetables, ensuring compliance with the annual effective dose. In fact, the calculation model has allowed for the establishment of performance requirements for the sampling plan, identifying the matrices that have the most significant impact on dose calculation and defining the Minimum Detectable Activity Concentrations (MDAs) to be achieved for these matrices. Specifically, for the disposal scenario, the dose to the representative individual of the population is governed by the activity concentration in groundwater, which is used for irrigating cultivated fields and contributes to the so-called secondary ingestion dose.

In matrices where the activity concentration is very low, lower than the minimum detectable concentration used in dose calculation, it becomes necessary to assume the concentration of activity of the radionuclide of interest to be equal to the MDA. However, this can lead to an overestimation of the annual effective dose in some cases, which may be deemed undesirable.

RADIOLOGICAL SAMPLING AND MEASUREMENT CAMPAIGN TO IMPROVE RADIOLOGICAL MONITORING OF THE TERRITORY OF KOSOVO POSTER

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As part of the bilateral cooperation financed by the Belgian Federal Public Service Economy, IRE Lab has been working since 2013 in partnership with the Kosovo Agency for Radiation Protection and Nuclear Safety (KARPNS). This collaboration involves organizing sampling and measurement campaigns on samples collected on Kosovo's territory.

To assess the NORM problem on the territory of Kosovo, A sampling plan is drawn up each year by the KARPNS with the support of the IRE. This plan takes into account areas of increased risk and the results of previous years. Collected water and soil samples are sent annually to the IRE Lab laboratory for analysis. For water, the parameters and limits monitored are those defined in the EU Council Directive 2013/51/Euratom. Soils are analyzed at least with the following NORM vectors: K-40, Pb-210, Ra-226, Ra-228, Th-228 and U-238.

Samples are prepared and stored in accordance with current ISO standards. The following analysis techniques are used: Proportional counting for gross alpha and beta measurements, liquid scintillation for tritium and Ra-226 measurements, ICP-MS for K-40 and uranium measurements, and high-resolution gamma spectrometry for soil analysis. All these techniques are accredited ISO 17025.

For 2022 and 2023, 47 samples (43 water and 4 soil) collected in Kosovo were analyzed at IRE Lab's Radioactivity Measurement Laboratory. The results of the analyses carried out on these water and soil samples are generally compliant, but values higher than the control thresholds defined in Euratom directive 2013/51 were observed on several water samples. Additional analyses were therefore carried out on these samples. The results obtained confirm that the value observed is due to the presence of natural radioisotopes and that they are lower than the derived concentrations defined in the directive. None of the samples taken in 2022 and 2023 therefore present a radiological risk.

MANAGEMENT OF INDUSTRIAL SITUATIONS WITH RESIDUAL CONTAMINATION OF CS-137 FROM CHERNOBYL ACCIDENT POSTER

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After almost 40 years from Chernobyl accident in 1986, artificial radionuclides released can still be found in environmental matrix such as soil, wood and food. The most common radionuclide is Cesium-137: a release was estimated in about 85 PBq after the accident, with depositions mainly in the areas close to the nuclear power plant. The diffusion of the radioactive cloud in the following days led to a distribution of contaminants on the other European countries.

In Italy a surface contamination of about 300 km2 was estimated, with a variability of 37-185 kBq/m2. The most exposed areas were those in the northern part of the country.

In this work two examples of contaminated materials found in different situations are reported: 1) ashes from combustion of contaminated wood with pretty high concentration of Cs-137 and natural radionuclides such as Pb-210 and K-40 and 2) a relatively new case in the dismantling of industrial plants rooftops, where contamination due to the resuspension of Cs-137 after the fall-out and accumulation during rains was found. It is not uncommon for people or workers to be unaware of the presence of this potential radiological risk due to manipulation and internal contamination, also caused by the lack of appropriate personal protective equipment.

The results of high resolution gamma spectrometry analysis performed on the contaminated materials are reported. Afterwards radiological impact on workers employed in the plants where contamination was found is estimated, focusing on the specific industrial cycle and recycling solutions.

A possible way to dose reduction is presented in compliance with the ALARA principle.

Finally different methods of contaminated materials (and wastes) management are examined, such as disposal or reuse, with relative radiological impact.

Poster session

Poster Presentation

Chairs

Elisa Van Hassel, Mauro Magnoni

A GEOLOGICAL APPROACH AS A SUPPORT FOR THE ITALIAN NATIONAL ACTION PLAN AGAINST RADON RISK

Margherita Arpaia (a), Mauro Bonasera (b), Roberta Carta (b), Rossella Maria Gafà (b), Lucio Martarelli (b), Federico Massimi (a), Patrizio Petricca (b), Diego Pieruccioni (b), Mauro Roma (b), Valerio Vitale (b)
(a) Ministry for Environment and Energetical Safety, Italy
(b) ISPRA, Geological Survey of Italy, Italy

The Italian Ministry for Environment and Energetical Safety and the National Institute for Environmental Protection and Research (ISPRA) signed an agreement on the prevention and reduction of geogenic risk from radon exposure. Accordingly, geological indicators related to high radon indoor concentrations have been defined and associated to data about territory and population. Geological approaches applied in Italy and at international level for reduction of long-term radon exposure risks have been taken into consideration.

The starting geological data are from the Lithological Map of Italy 1:100,000 scale, published by ISPRA at the web geoportal of the Geological Survey of Italy. The lithologies defined in the map have been linked to three potential radiogenic emissivity classes (high, intermediate, low). The association between lithotypes and emissivity classes was carried out by a qualitative and univocal process. A following step was the carrying out of a territorial study by a GIS analysis using overlay and spatial query tools. This approach allowed to calculate the percentage of the territory of each Italian municipality featured by rocks having a high level of radiogenic emissivity.

These first products have constituted an annex document to the Italian National Action Plan against radon risk.

A recent stage of activity regarded the proposal of a national/regional scale model based on statistical methods concerning Machine Learning (ML) algorithms. ML criteria have been applied to a dataset including various selected geographical and geological control parameters (features) that allowed the calibration of a predictive model of a target variable, namely the areas with different degree of radon indoor emissivity. The best fitting model was selected after a model comparison metric process also considering the selection of different subgroups of feature and the optimization of the involved model parameters (hyperparameter tuning). The selected best model might then be implemented for the realization of potential radon emissivity maps, both at national and regional scale, that may be useful for the selection of the priority areas of intervention for contrasting radon risk. Furthermore, the same model may be as well finalized to predict the radon emissivity in any area of the Italian territory where the control parameter values are opportunely known.

The main products of the agreement will be accessible at an under development ministerial website dedicated to the Italian National Action Plan against radon risk.

ENVIRONMENTAL CS-137 ACCUMULATION IN ROOF-COVERING TEXTILE: CHARACTERIZATION OF THE CONTAMINATION AND DISPOSAL PROPOSAL

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ARPA FVG, Environmental Protection Agengy of Friuli Venezia Giulia, Italy

During a routine roof maintenance, a contractor substitutes an old textile material used as protection for the underlying plastic cover. The material triggers an alarm of the radiation detection system of the disposal facility. Further investigations, carried out by a radiation protection expert, show the presence of high concentration of Cs-137. After some months, the situation occurs again: same contractor and disposal facility but different location of the worksite. The unusual events are reported to the Environmental Protection Agency of Friuli Venezia Giulia (ARPA FVG), which performs an inspection both at the disposal facility and at the worksite of the contractor, taking samples of the material and performing measurements.

The investigation takes into account the possible origins of the contamination considering either human activities or accidents related to industries in the area. The absence of such situations shift our focus to a natural origin of the Cesium.

Considering the ground deposition in our area, the fall-out maps of the nuclear accidents and the samplings in the worksite surroundings, we can affirm, with good confidence, the natural origin of the contamination.

In this work, we present the results of our measurements and the total activity estimate, focusing on Cs-137 and Pb-210. As a final consideration, we discuss a proposal for the disposal of the textile material according to the Italian law D.Lgs. 101/2020 - article 204.

NATURAL RADIONUCLIDES IN SEWAGE SLUDGE OF URBAN WASTEWATER

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In the perspective of a transition towards circular economy processes, sewage sludge is increasingly taking the characteristics of a resource and less and less those of a waste. It is therefore important to know the characteristics of these materials in detail to ensure and optimise their exploitation through circular economy processes.

It is well known that natural radionuclides are ubiquitous as they are found in different compartments of the biosphere, such as rocks, soil, seas, fresh water, atmosphere, etc... They are naturally more concentrated in some raw materials; there are also production processes that use materials with NORM and may result in non-negligible concentrations of some radionuclides in products, by-products or waste. However, studies on the presence of natural radionuclides in sewage sludge worldwide are scarce.

In 2012 started a continuous monitoring programme of sewage sludge produced from ETRA SpA, an integrated water management company working in the Provinces of Padova, Treviso and Vicenza. Under a convention between CNR-ICMATE and ETRA, which was set up with the main objective of monitoring the presence of artificial radionuclides of medical origin potentially present in sewage sludge, the activity concentrations of the main natural gamma-emitting radionuclides could also be determined.

The database presented in this paper consists of approximately 300 long-term gamma-spectrometry counting measurements of dewatered sewage sludge samples from 15 purification plants (Asiago, Bassano, Battaglia Terme, Cadoneghe, Camposampiero, Carmignano, Cervarese, Cittadella, Limena, Mestrino, Onara, Rubano, Selvazzano, Vigonza, Villafranca Padovana) that are periodically monitored from ICMATE-CNR.

In this paper, the study of natural gamma-emitting radionuclides is presented with a focus on the determination of the components of the natural decay chains of 238U and 232Th, of 7Be and 40K. The main natural radionuclides determined by high-resolution hyperpure germanium gamma spectrometry are: 7Be, 40K, 210Pb, 212Pb, 214Bi, 214Bi, 228Ac, 234Th. On the contrary, the study of the artificial radionuclides 137Cs and 131I, which are most frequently found in wastewater, was carried out in a previous work.

ANALYSES OF SLAG AND ASH SAMPLES PERFORMED BETWEEN 2019 AND 2023, WITH A FOCUS ON RADIOACTIVE EQUILIBRIUM IN NATURAL DECAY CHAINS

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The products of coal combustion (ash, slag and cinder) are commonly used as raw materials for the production of building materials; however, on their own, they are classified as materials released from a workplace with the possibility of increased radiation from a natural source of radiation (NORM). The national regulatory body (State Office for Nuclear Safety) issued a recommendation for measuring and evaluating the content of radionuclides in building materials in the Czech Republic, with the purpose of measuring and limiting the content of selected natural radionuclides. This particular recommendation considers ashes and slags to be materials with an intact radioactive equilibrium in the natural decay chains.

The evaluation of building materials, as per the State Office recommendation, is based on the determination of the mass activities of 40K, ^{226}Ra and 228Th, and the calculation of the Activity Concentration Index. Thanks to the assumption of an intact radioactive equilibrium, ^{226}Ra does not have to be assessed via the activities of radon daughters – its mass activity can be determined directly from the 186 keV peak, with ^{226}Ra making up 57.5 % of the total peak area. This approach simplifies the determination of ^{226}Ra, since the sample containers do not have to be hermetically sealed.

On their own, slags and ashes are assessed as radioactive substances released from a NORM workplace, and a more detailed analysis is required. In this case, radioactive equilibrium in the decay chain cannot be assumed. From 2019 to 2023, the National Radiation Protection Institute analysed over 120 slag and ash samples by the means of gamma spectrometry. The mass activity of ^{226}Ra was determined using several approaches, mainly from the daughter products of radon decay, and using ^{238}U.

These results were used to verify the assumption of intact radioactive equilibrium in coal combustion products. Thanks to the longer measurement times for NORM samples, the results are burdened with lower uncertainty, and more detailed information about the natural radionuclides content can be gained thanks to the achieved detection sensitivity. The obtained results make it feasible to evaluate the potential disturbance in the radioactive equilibrium, and other dependencies in both natural decay chains, as well as, for example, the effect of the sample sealing carried out before the measurement.

IMPLEMENTATION OF DOSE CALCULATION METHODS FOR NORM BY-PRODUCTS IN BUILDING MATERIALS IN CIRCULAR ECONOMY FRAMEWORK

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Risk assessment of exposure to indoor natural radioactivity plays an increasingly important role in human protection and one of the main sources is building materials. On the other hand, production processes, including those building material related, are also involved in the economic transition by evaluating the use of by-products from other industrial sectors in compliance with environmental sustainability. This work not only evaluates the radiation protection from building materials but also takes on the challenge of adopting the circular economy principles. The two main goals were: 1) radiometric characterization and calculation of Index I of pozzolan from Altavilla Irpina (Avellino) in Italy, used as a natural igneous additive for concrete, performed by gamma spectroscopy; 2) comparison between different methodologies for calculating the annual effective dose of building materials (CEN/TR 17113:2017, the RESRAD-BUILD software, and an experimental method already adopted in literature). The same approach was extended to a potential reuse of fly ash – a NORM by-product of coal combustion in thermal power plants – to produce concrete. The study aligns with the circular economy principles which involve the extension of the life cycle of materials by reducing the need for natural resources, suggesting a possible positive compromise between radioprotection and preservation of environmental heritage.

The radiometric results obtained through gamma spectrometry for pozzolan from Altavilla Irpina do not raise specific radiological concerns, as this exhibits a radiological content significantly lower than that of other pozzolans.

For the annual effective Dose (D) calculation, four concrete configurations with different percentages of pozzolan or fly ash were evaluated.

The D values were calculated by the three different methods implementing RESRAD-BUILD with the most recent Dose Conversion Factor (DCF) from ICRP 144/2020. Finally, the results were compared with each other to identify the most conservative method.

While not fully compliant with the dose limitation principle, these preliminary results represent a compromise between radioprotection and the conservation of future natural resource management.

FROM WASTE TO RESOURCE: RECYCLING POTENTIAL OF SCALE RESIDUES FROM GEOENERGY

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High concentrations of some naturally occurring radionuclides are often recorded in residues from the geothermal, oil and gas industry. The radionuclides are incorporated into mineral deposits (scales) that form during deep fluid production due to the change in thermodynamic conditions. The main radionuclides are Ra-226, Ra-228 and Pb-210. Depending on the chemical processes leading to scaling, $CaCO_3$, $BaSO_4$, SiO_2 and Pb-containing minerals are the dominating phases. Currently these residues are disposed of although the scales commonly contain valuable metals. With the current thirst for critical raw materials it is crucial to develop new methods to recycle the residue. Circular economy leads to both economic and ecological benefits. This study explores the potential for reusing the scales from geogenic sources.

At the geothermal in-situ research laboratory Groß Schönebeck (NE Germany) production of highly saline (265 g/L TDS) geothermal fluid led to the precipitation of various minerals (scaling) in the well and above ground facilities. The scale residues were recovered from bailer and filter samples. Their main mineralogical constituents are Sr-rich barite, laurionite, native copper, magnetite, and calcite. Radionuclide activities were measured via gamma- and alpha-spectrometry and range from 1 to 134 Bq/g for Ra-226, 0.5 to 93 Bq/g for Pb-210 and 0.5 to 60 Bq/g for Ra-228. The scales contain substantial amounts of economically viable elements, such as Cu, Ba (in barite), As and Zn (detected via ICP-MS and XRF). Rare Earth Element (REE) and lithium content of 0.3 ppm and 200 ppm, respectively, were measured in the geothermal fluids.

The scales will be analysed for REE content, together with other critical elements, to identify the value of the residues. Autoradiography and microprobe/SEM-EDX analyses will be performed to determine the location of single elements and radionuclides. The evaluation will lead to a first assessment of the usability of the scales and essentially to a proposal for further research on recycling of the residues under consideration of radiological safety.

ASSESSMENT OF EXPOSURE TO RADON IN THE UNDERGROUND TOURIST ROUTE OF THE HISTORIC SILVER MINE - BASED ON TWO YEARS OF RESEARCH

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(b) Historic Silver Mine-Tarnowskie Góry, Poland

Radon and its decay products, characterized by a short half-life, pose a serious threat to human health. The problem of radon hazards at underground workplaces (especially in mines) has been studied for years. Research on this topic is also being conducted in Poland. Besides active mines, in recent years, the popularity of underground tourist routes has increased, in Poland currently there are about 200 of them. Conditions present there let one study exposure to radon not disturbed by a technological process going on.

The hazard associated with the presence of radon isotopes in the air is usually considered separately and not together with the hazard caused by other naturally occurring radionuclides. Separate reference levels and dose limits are established for radon hazards, and the effective dose from radon is often not included in the assessment of total dose to workers in NORM involving industries. In the Basic Safety Standards Directive (Council Directive 2013/59/Euratom), as well as in IAEA (International Atomic Energy Agency) SAFETY STANDARDS SERIES No. GSG-7, there are certain requirements to include radon hazard in the assessment of total occupational exposure in NORM involving industries, but not this has been intelligibly highlighted.

This paper presents the results of two years of research conducted in the Historic Silver Mine in Tarnowskie Góry. The authors made efforts to carry out two-year measurements of Radon Activity Concentration (RAC) in 3-month periods at 30 measurement points in the mine. Based on the collected data, effective doses for mine workers were calculated. The Potential Alpha Energy Concentrations (PAEC) of short-lived radon decay products were also measured, based on which effective doses were again determined. In the next step, the values calculated in two ways (based on PAEC measurement and based on RAC) were compared. It has been shown that radon and its progeny can cause a significant increase in the effective dose in workplaces, even in the absence of liquid or solid NORM, and the assessment of radiation exposure based solely on the measurement of radon activity concentration does not reflect the actual exposure. Based on the results obtained, it is concluded that radon is an important factor that should be taken into account when assessing exposure sources in the case of NORM.

VALORISATION OF NORM RESIDUES AND TAILINGS IN LINE WITH THE PRINCIPLES OF CIRCULAR ECONOMY: OPPORTUNITIES AND CHALLENGES PROPOSED BY THE IAEA ENVIRONET WORKING GROUP #5

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The successful IAEA NORM in Industry Conference, (NORM 2020), sparked a rich discussion about the need to consider multi-criteria perspectives for engaging NORM-related industries to the potential within a Circular Economy framework for innovative approaches for valorising high-volume residues and tailings certain of these industries generate. Since then, a dedicated working group, WG5, has been established within the IAEA Environet (Network of Environmental Remediation and NORM management) programme, using a holistic approach. WG5 is tasked with developing a report entitled: Valorisation of NORM residues and tailings in line with Circular Economy principles. Overall, six working groups are working together under Environet to create a comprehensive platform for delivering on the promise of preserving value in, or enhancing value from, NORM residues and tailings. The WG5 report, to be published in the IAEA Nuclear Energy Series, summarises what the holistic approach is and how it can be used by industry, policymakers and regulators, and academia to partner for a successful circular economic transition for NORM-related industries. In the time the report has been in development, major policy changes and related legislation have been introduced in many countries worldwide to promote the circular economy transition, especially for energy, and to develop new markets in secondary raw materials, promote the de-commodisation of the economy and propose financing mechanisms that can support this. This has added momentum and focus to the purpose of the report, especially in respect of practical advice, success stories and case studies demonstrating how valorisation can be achieved and how the necessary capabilities for delivering value can be developed and deployed. WG5 is composed of public and private sector experts with backgrounds in policy and strategy, safety, regulation, industry, consultancy and research. The NORM valorisation focus is aligned to particular UN Sustainable Development Goals, such as clean affordable energy and responsible production and consumption. The Report offers examples of how innovative value chains from NORM residues and tailings are being created, and through careful stakeholder engagement throughout, winning and retaining their trust and confidence, offering opportunities to (also) remediate areas affected by past NORM related activities. It provides tools and case studies for quality assurance and safety assessment to address public and consumer concerns and identifies challenges with respect to policy and

regulation brought with this new policy-driven approach. The document will present a practical decision tree for assessing whether, how and under what conditions a NORM related material can be used and commercialised. This decision-tree is designed from a radiological point of view, but always within an all-hazards frame in which radiological risk may in reality be the least significant of the safety concerns regarding secondary resource valorisation.

HOW CAN RADONORM CONTRIBUTE TO IMPROVING NORM REGULATION

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RadoNorm aims to reduce scientific, technical and societal uncertainties in the assessment of risks from low-dose ionizing radiation with a special focus on radon and Naturally Occurring Radioactive Material (NORM). Within the five scientific work packages (Exposure, Dosimetry, Effects and Risks, Mitigation, and Societal Aspects), much work has been accomplished in understanding and mitigating risks from NORM.

At the very beginning of RadoNorm, the NORM e-survey was carried out, which helped to create an inventory of NORM-involving sites across Europe. Through this, a methodology for identification and classification was created and implemented, and a list of NORM-involving industries in Europe has been identified. This new methodology would ideally help countries in developing classification systems for various NORM-involving processes.

Moreover, operational values could be elucidated for sludge resulting from water treatment facilities to be used as fertilizer, which frequently contains NORM residues. This consequently enables a graded-approach to push for increased reuse of NORM-containing sludge and at the same time ensure compliance with the radiation protection requirements, encouraging circular economy. Circular economy in the building industry has also been investigated in terms of the use of industrial by-products, containing NORM, as alternative building materials. Here, the industry has shown concern with respect to availability of these materials, financial factors, technical performance, sustainability, customer demand and certification.

Mining legacy sites pose a potential problem for NORM-exposure. Research has shed light on mechanisms involved in transfer of NORM in the environment, which also shows promise for remediation strategies and biorecovery of precious metals such as uranium from these legacy sites.

In the geothermal industry, risk perception from industry professionals was investigated. It was found out that the risk perception of NORM exposure though the pumped underground water is minimal by these professionals, which continues to make it an attractive energy solution. The industry however continues to implement strategies for risk management and there is room for improvement.

TEMPORAL UNCERTAINTY AS A KEY PARAMETER FOR METROLOGICAL SUPPORT OF INDOOR RADON MEASUREMENTS

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The EU-BSS mandates that the annual average radon level in buildings should not exceed 300 Bq/m^3, aligning with recommendations from WHO, ICRP, and IAEA. However, both the European measurement protocol, as defined by ISO 11665-8, and the recently updated US standards ANSI/AARST lack stringent metrological support for reliable conformity assessment. Additionally, testing protocols in the US (short-term tests for 2–7 days) differ notably from those in European Union countries (long-term tests for at least 2 months). The challenge of implementing a unified and metrologically sound protocol for indoor radon testing arises from two primary factors:

Neglect by national radon regulators of fundamental ISO/IEC concepts like 'measurement uncertainty' and 'conformity assessment', which have been globally adopted in measurement standardization with the backing of the Joint Committee for Guides in Metrology.

Misalignment in prioritizing indoor radon regulation and research planning in Europe, evidenced by: concentrating efforts on detailing Radon Priority Areas (RPA) through geological data collection instead of conducting large-scale indoor radon tests. Accumulating indoor test results not only identifies buildings with high radon levels but also enhances RPA zone accuracy, like in the US.

Significant underestimation of the role of temporary (key) uncertainty of indoor radon in decision-making, traditionally substituted by surrogate parameters such as the Seasonal Correction Factor (SCF) and Coefficient Of Variation (COV).

The results from the recently concluded European metrological project “MetroRADON” (Metrology for Radon Monitoring, metroradon.eu), and the planned outputs of the current European project “RadoNorm” (Managing Risk from Radon and NORM, radonorm.eu), do not offer strict metrological support for indoor radon measurements.

Our proposed rational criterion for conformity assessment of a room with a norm takes into account both the temporal and instrumental uncertainties, enabling the utilization of both short- and long-term measurements while ensuring specified reliability in decision making (typically no less than 95%). Also, the presentation explores mathematical algorithms for determining both temporal and instrumental uncertainties.

NORMA: A PROJECT ON RADIOPROTECTION FROM NORM BY-PRODUCTS REUSE IN THE FRAMEWORK OF CIRCULAR ECONOMY

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The goal of "NORMA" project, is the drafting and implementation of standardized procedures so that the stakeholders of radiation protection in NORM involving industries can more easily fulfill the obligations established by current legislation. On the other hand, the project aims to adopt the circular economy paradigm to evaluate the potential reuse of this kind of industries' by-products while ensuring the safety of workers and population in terms of annual effective dose.

NORMA is a pool of interdisciplinary skills. It is promoted by Università degli Studi di Napoli Federico II, Istituto Superiore di Sanità (ISS), Regional Environmental Protection Agencies (ARPA) of Tuscany, Veneto and Lombardy, and Politecnico di Milano, with the financial support of INAIL.

This work describes in detail the structure and organization of the project, fitted in a constantly evolving regulatory context. NORMA project has a duration of 24 months and is structured in two phases, each of which involves the carrying out of specific activities and the achievement of specific objectives, according to the graded approach methodology. Phase I concerns the definition of the criteria for representative sampling of liquid and gaseous residues and effluents. Added to this are: radiometric characterization measurements of the identified matrices and feasibility studies of the reuse of NORM residues as raw-secondary materials in other industrial sectors. Phase II is characterized by practical-experimental activities and the development of calculation methods for estimating the dose for workers and the population.

A PROTOCOL TO CHARACTERISE NORM MATRICES AND EXPOSURE SCENARIOS IN GEOTHERMAL ENERGY PRODUCTION

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According to the Italian legislation on radiological protection, geothermal energy production plants are one of the industrial sectors identified and controlled as NORM involving practices.

Starting from a collection of radiological information about Italian geothermal plants, the general graded methodological approach, recently developed to characterize the exposure scenarios in NORM involving practices, was applied to the geothermal energy production sector. In general, the tiered methodological approach consists of two phasis, each consisting of four steps.

The application of the methodology to geothermal plants allows to analyse the process, identify the solid (such as scales, filtering materials, etc.) and non-solid NORM matrices of interest (such as the geothermal fluid), relevant radionuclides, appropriate analytical methods and scenarios for dose assessment for workers and members of the public, taking into account national Exemption/Clerance Levels established both as in terms of activity concentrations and in terms of effective dose.

Several schemes are presented as useful tools to support employer and radiation protection professionals in the application of a tailored graded approach to the geothermal industrial sector.

REUSE OF SEWAGE SLUDGE CONTAINING NORM AS AGRICULTURAL FERTILIZER: RADIOLOGICAL DOSE ASSESSMENT FOR WORKERS AND MEMBERS OF THE PUBLIC

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With a view of supporting circular economy, increased reuse in agriculture of sludge produced by Groundwater Filtration Facilities (GFF) and by Wastewater Treatment Plants (WWTP) receiving sewage from NORM involving industries is expected. Therefore, within the European project RadoNorm, a study was carried out to evaluate the annual effective dose of agricultural workers and population living near agricultural fields where sludges containing NORM are spread.

Both for GFF and WWTP sludge exposure scenarios are developed considering the annual sludge spreading and the annual application of sludge over many years, thus accounting for accumulation of radionuclides in arable lands. Exposure scenarios have been modelled using dose coefficients for external and internal exposure pathways taken from the most recent ICRP publications in a generic and conservative way by means of RESRAD (ONSITE) software.

For GFF, a generic methodology to assess doses and to obtain screening values (Operational Levels - OLs) was developed considering a unit activity concentration of NOR in sludge. OLs (in terms of $kBq \cdot kg^{-1}$) can be used as screening tools by an authority/operator, even non-experts in the field of radiation protection, to verify if dose criterion of 1 mSv per year is complied with. For WWTP, to develop screening values related to the total discharged annual activity by relevant NORM involving industries two main aspects have been considered: the size of the waterworks in terms of Population Equivalent (PE) and the distribution of radionuclides between solid and liquid phase in the sludge.

In this presentation, main results of the modelling exercises and considerations about the possible use of this methodology to support decision makers will be discussed.

APPLICATION OF INTDOSKIT TOOL FOR PARAMETER ANALYSIS OF DOSE COEFFICIENTS FOR INGESTION OF URANIUM AT WORKPLACES

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The International Commission on Radiological Protection (ICRP) publishes dose coefficients for internal emitters incorporated into the body in its series of publications for Occupational Intakes of Radionuclides (OIR). These ICRP reference values are calculated using the parameters of a reference man as well as chosen radiation and tissue weighting factors and intended to be primarily used for purposes of regulatory control and hence not subject to uncertainty. However, it should be noted that uncertainties exist in their derivation and applications and ought to be studied in order to ensure their reliability when applied as protection quantities in radiation protection. This study describes a comprehensive probabilistic uncertainty analysis of doses for the ingestion of U-238 by workers using the ICRP Human Alimentary Tract Model (HATM) and systemic model for uranium. Probability distributions were assigned to HATM and systemic model parameters based on uncertainties from published literature. The uncertainties in the HATM were restricted to particle transport rates while those for the systemic model of uranium where restricted to transfer rates having the greatest impact on the biokinetics of uranium in the systemic organs and tissues. INTDOSKIT, an in-house software tool developed by the authors using the R statistical programming language and RStudio as the Integrated Development Environment (IDE) was used to model the biokinetics and dosimetry of U-238 using parameters of a reference man and the model was successfully validated using data from ICRP OIR dataviewer software. For uncertainty analysis, Monte Carlo simulation were done by INTDOSKIT using the random sampling technique with 60000 runs that sampled parameters from the chosen probability distributions and a dose distribution output. A statistical summary was performed on the generated dose distribution. Additional Monte Carlo simulations were also performed to investigate the influence of individual parameters on the calculated dose distributions. The results of the global uncertainty analysis showed that the effective dose coefficient is well described by a lognormal distribution with a geometric mean of 3.2E-08 Sv/Bq and a geometric standard deviation of 2.0 while results of the sensitivity analysis showed that it is the uncertainty on the fraction of uranium absorbed from the alimentary tract to blood (f1) that is responsible for the largest single contribution to the uncertainties in the effective dose coefficient. These results were consistent with those obtained by other authors who performed similar studies. This study demonstrates the robustness of INTDOSKIT as a reliable tool for performing internal dose calculations as well as uncertainty and sensitivity analysis on the calculated doses.

DEVELOPMENT OF A PROCESS FOR REMOVAL OF NATURAL RADIONUCLIDES AND OTHER POLLUTANTS IN ACID WATERS FROM PHOSPHOGYPSUM STACKS

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In Huelva city (Spain), there are several Phosphogypsum (PG) piles over the salt marshes of the Tinto River covering about 1000 ha. These deposits contain acidic waters (pH<2) with very high levels of natural radionuclides and other pollutants, which could be released into their surroundings. The natural radionuclides concentrations in these leachates, especially U isotopes, ^{210}Pb and ^{210}Po are 4-5 orders of magnitude higher than the found ones in unperturbed freshwaters. Furthermore, the concentrations of heavy metals, metalloids (As, Cd, Cr, Cu, Ni, Pb, Zn) and some anions (F^-, PO_4^{3-} and SO_4^{2-}) are also significantly higher. In this work, a cleaning process based on the neutralization of these acidic leachates was carried out by using different alkaline chemical reagents, such us $Ca(OH)_2$, $CaCO_3$, NaOH, Na_2CO_3, $Mg(OH)_2$, $MgCO_3$).

It was proved that the neutralization treatment of PG Leachates (PGL) using $Ca(OH)_2$ is a good option for their cleaning since a high removal efficiency of contaminants was obtained. After applying the process, a clean liquid was obtained which could be discharged into the environment after filtration, with an extremely low potential environmental risk.

Along the alkaline treatment of PGL, solid wastes are generated with different chemical and mineralogical compositions depending on the pH reached and the reagent used. The main finding during $Ca(OH)_2$ treatment was that the fluorine is removed from dissolution as fluorite (CaF_2) at pH around 3, precipitating with some gypsum ($CaSO_4\ 2H_2O$). Nevertheless, calcium phosphate dominates the precipitated phase during the alkaline treatment up to pH around 12, where monetite ($CaHPO_4$) and brushite ($Ca(PO_3OH)\cdot 2H_2O$) are the prevailing species formed at neutral pH range and fluorapatite ($Ca_5(PO_4)_3F$) in more basic conditions.

The formation of these solid wastes leads to think about the possibility of designing a treatment to recover the fluoride and phosphate contents. This can contribute to the circular economy and improve the environmental conditions of the surroundings of the PG stacks, avoiding the discharge of these compounds. However, the presence of pollutants such as metals, metalloids and radionuclides, especially As, Cd, Cr, Mn, Zn, As and ^{238},^{234}U, is significant, due to the high concentrations found in the solids formed. In fact, their concentrations are greater than those found in the phosphate rock (mainly composed of fluorapatite mineral).

Considering that the annual generation of PGL in Huelva could be about $3\cdot10^5$ m^3, their treatment with $Ca(OH)_2$ would produce around $2\cdot10^4$ t of fluorapatite, which should not be ignored. However, further research must be conducted to reduce the pollutants in the solid, especially for the uranium content, whose recovery would pose about 8 t per year.

URANIUM, RADIUM, LEAD AND POLONIUM LEVELS IN THE AREA OF THE PHOSPHOGYPSUM BASIN IN SOUTH ITALY - "EX LIQUICHIMICA" AREA

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The characterization of NORM/TENORM materials must be performed using different nuclear techniques, able to show the complete scheme of the equilibrium of the radionuclides in the different natural chains. The characterization must be done in order to be able to determine the levels of radionuclides present in them, in order to verify the clearance levels for the correct management of the material, of the area management in which they are located and determine any breakage of the natural chains to identify NORM/TENORM pollution phenomena in the environment where these materials are stored. All this is particularly important in order to organize the remediation of polluted sites.

In the site of national interest of Tito Scalo (South Italy), "ex Liquichimica" Area, following specific samplings, characterizations were carried out for the determination of Uranium, ^{226}Ra, ^{210}Pb and ^{210}Po as well as the gamma emitters with various analytical techniques and through specific radiochemical procedures.

The above determinations were performed on various matrices, including surface and groundwater, soils, silt-sediments and plants, for a total of 257 soil samples, 47 groundwater samples, 8 surface water samples, 8 silt-sediment and 10 plant samples. The analyzes were conducted using radiochemical procedures accredited according to the UNI EN ISO 17025 standard, specific for the determination of U, Ra, Pb and Po in phosphogypsum.

The analytical techniques used are complex and involve multiple steps for the treatment of the sample and the sequential separation of the radionuclides for their determination: in particular, the above procedure involves the use of liquid scintillation, alpha and gamma spectrometry after radiochemical treatment of the starting matrix.

This work shows in detail the IAEA/AQ/34 procedure and the analytical data for each group of analyzed matrices of the phosphogypsum basin of the "ex Liquichimica" area of Tito Scalo.

ZIRCON AND ZIRCONIA INDUSTRY: RADIOLOGICAL CHARACTERIZATION OF THE REFRACTORY PRODUCTION IN ITALY

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Zircon sands are widely used in industrial processes, as they provide specific physical properties to a variety of products. Refractory manufacture can use zircon sands (and derivatives) as raw material; tiles and ceramic industry also use these sands (eventually grinded to flour), typically in the enamel production. All zircon sand contains radionuclides of natural origin, primarily those in the U-238 and Th-232 decay series, with activity concentrations significantly higher than those in normal rocks and soil. For this reason, processing of zircon sands (and derivatives) is a working activity included in the Italian regulatory system as Planned Exposure Situations, that needs to be addressed as of radiological concern for the known radiological significance for workers and members of the public.

Starting from the general methodology, developed in the frame of the research project INAIL-BRIC 2019 ID30, for applying the graded approach in NORM involving industries, a tailored graded methodology for zircon and zirconia industry was developed and hereby reported.

The application of the general methodology to the refractory production has included an in-depth analysis of production processes with the support of the involved stakeholders. Raw materials, residues and effluents have been experimentally analyzed by gamma and alpha spectrometry and liquid scintillation counting. Finally, exposure scenarios for worker and members of the public have been identified and effective annual doses evaluated.

The results obtained for the refractory production will be presented.

TRANSPORT OF NORM MATERIALS: DOSE ASSESSMENTS FOR WORKERS CONSIDERING REALISTIC SCENARIOS

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According to the international regulations on the transport of radioactive material (IAEA SSR-6 and SSG-26, 2018) exemption levels of NORM materials, in terms of activity concentration, are generally higher than the General Clearance Levels set out in the European Basic Safety Standards (EU-BSS) for the practices involving NOR materials. It follows that a load not classified as 'radioactive' under IAEA regulations may not be exempt in terms of activity concentration by the European regulations and requires a dose assessment.

In the European Union, the transport scenario described in the Radiation Protection 122-Part II (RP 122-II) guidelines is generally used for this kind of dose evaluations. However, since RP 122-II was published more than 20 years ago, pre-dating the current EU-BSS, the evaluations done according to this document have been updated in the framework of the European RadoNorm project and of the Italian "NORMA" project.

Following the recent ICRP Publications, dose coefficients for intake and external irradiation per unit of activity concentration have been recalculated. For external irradiation, these evaluations were performed both for the "driving" and the "loading/unloading" phase of the transport scenario, in contrast to the RP 122-II, which reports only one dose coefficient for both phases.

Moreover, a sensitivity analysis by varying parameters of the transport scenario, such as density and size of the load, have been performed. This analysis will allow more realistic dose assessments, overcoming the cautious assumptions of the RP 122-II in the selection of some parameter values.

All these evaluations will help the authors to improve a web-form screening tool (dose calculator) designed to assess doses to workers in selected scenarios, including a specific new one related to transport. The web-form screening tool will be available on the Italian Physical Agents Portal (PAF) website, with the aim of supporting stakeholders in their legal obligations under Italian radiation protection legislation.

DECOMMISSIONING CHALLENGES AND SAFETY MEASURES IN THE NORM INDUSTRY

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TiO_2 pigment manufacturing and phosphate industry (phosphoric acid production) are the most significant NORM (Naturally Occurring Radioactive Material) sectors in Korea. In 2016, a TiO_2 facility terminated its operations due to financial issues and completed Decommissioning and Dismantling (D&D), including site clean-up. In 2018, as a legacy site, a silica manufacturing company that had been in operation for about 40 years disposed of decommissioned installations to relocate the plant. Recently, a crippled phosphoric acid production facility in the fertilizer industry was dismantled.

During the D&D process of such facilities or installations, various types of NORM residues (such as scales inside pipes, filters, rubber linings on the inner walls of tanks, etc.) are generated in large quantities, and these are typically identified through Radiation Portal Monitors (RPMs) for recyclable scrap metal.

In legislation, there are no safety guidelines established for the D&D of NORM facility. However, if a registered handler intends to treat, dispose of or recycle NORM residues, they must notify to the national authority and comply with safety measures as prescribed by law.

This presentation introduces cases studies of decommissioning experiences and safety measures in the NORM industries.

Session V

Radon and NORM

Chairs

Boguslaw Michalik, Federica Leonardi

THE NEW NATIONAL NORM DATABASE INVITED SPEAKER

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With the transposition of Council Directive 59/2013/Euratom (EU-BSS), the Italian competent regulatory authority for nuclear safety and radiation protection (ISIN), in the framework of the national database of environmental radioactivity, called SINRAD, is implementing a section dedicated to NORM, where data and information about the radiological content in raw materials, residues and effluents of industrial sectors relating to Naturally Occurring Radioactive Material (NORM) are collected.

Dosimetry services, commissioned by the operator of NORM plants, will upload the measurement results on this new section of the national Database (DB).

Background information to define the new DB section comes from scientific literature, national project outcomes and technical relations transmitted by NORM plants operators to national competent authority (ISIN). From a preliminary data analysis, the most represented industrial sectors are oil and gas production, ground water filtration facilities, zircon and zirconium industry, processing of phosphate and potassium ores, cement and geothermal energy production.

The main goals of the NORM section of SINRAD are to get an updated national inventory of NORM industries, to obtain an overview of the radiological content in the different matrices, to provide guidance for establishing strategies and priorities in supervisory activities and to identify useful hints for a regulatory review.

In this work a description of the new NORM section of SINRAD will be presented.

MEASUREMENT OF THE THORON EXHALATION RATE FROM NORM SAMPLES – A ROUND ROBIN STUDY

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Thoron exposure from building materials has been a topic of considerable research; nevertheless, measurement of thoron exhalation from building materials is still subject of continued investigation. While international harmonized standards for radon from building materials such as e.g. ISO-11665-9 (ISO, 2016) already exist, measurement protocols for determining the thoron exhalation rate from building materials are at present still based on internal procedures developed by the laboratories itself. For this reason an inter-laboratory comparison on the thoron exhalation rate of two NORM samples is performed with eight participating laboratories. The laboratories use different testing principles, such as different sample preparation, test setup and detection equipment.

The laboratory measurements are analyzed using the statistical methods of ISO-13528 (ISO, 2022) for proficiency testing in interlaboratory comparisons. The results demonstrate a relative standard uncertainty of around 20% in the assigned value. The findings highlight three areas for improvement of the measurement robustness. These are: i. traceable thoron standards for detector calibration, ii. robust protocols for measurement and sample treatment and iii. implications of material characteristics and its effect on thoron exhalation. The work will present the findings from the inter-laboratory comparison and will critically review the test procedures used by the laboratories.

EVALUATING THE CONTRIBUTION OF BUILDING MANUFACTS TO THE INDOOR RADON CONCENTRATION

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Council Directive 2013/51/Euratom requires to consider any source of radon including the building materials. Assessing the radon activity that exhales from building structures is crucial to identify the best strategies to prevent radon from entering a building or reducing its concentration in the inhabited spaces. According to the current state of knowledge and technology, the radon surface exhalation rate from building structures may be estimated through i) the modelling of the radon transport inside the structure, ii) the theoretical correlation with the radon exhalation rate measured on a sample of the same building material, or iii) the direct measurement performed on the manufact.

Among the three approaches, only the third one is suitable to consider the influences of the environmental parameters and the installation conditions, i.e., the width and geometry of the slab, how units are laid in and bound together, the presence of binding elements and covering layers. A study has been conducted to investigate the possible correlation existing between the radon exhalation rate measured in closed containers on a building material sample and the actual radon exhalation rate from a building manufact (a wall) made of the same material. The radon exhalation rate measurements on the wall have been performed through an experimental apparatus developed at the Italian National Institute of Health.

The design and objectives of the study are presented as well as the preliminary results obtained with some high-exhaling building materials. These results include the comparison between the radon exhalation rate obtained from the material sample and the exhalation rate measured directly on two walls having different sizes. The influence of the superficial treatment on the resulting radon exhalation rate is discussed as well.

RADON AND LONG LIVED DECAY PRODUCTS IN LNG

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While producing Natural Gas (NG), some amount of Radon-222 (further on Radon) is brought to the earth surface. According to UNSCEAR reports, the activity concentration of Radon in NG varies in different host rocks from 10 -6.000 Bq m^{-3}. Due to the decay of Radon, there is an ingrowth of the associated decay products. Due to its relative long half-life, for questions dealing with Naturally Occurring Radioactivity (NOR), Lead-210 is the most interesting radionuclide. It is common to find Lead-210 bearing residues (also known as black powder) during pigging of gas pipelines.

In the ever changing energy market there is a need for flexible use of resources. The possibility of transport of Natural Gas over greater distance without using pipelines is found in Liquified Natural Gas (LNG). LNG carriers take a few days to months to travel from the port of loading to the destination. By many in the industry it was assumed that due to the longer travel time there is no radon present in the LNG by the time it is transferred at final destination. Therefor it is assumed that no NOR is present in the installations receiving and processing the LNG back to NG.

The investigation of recent findings of NOR in LNG regasification units provide a clear view on what happens with Radon and Lead-210 from the production of natural gas, the liquification to LNG, the transport of LNG to the regasification.

The LNG sector operates internationally, this means that the LNG carriers and floating storage and regasification units need to obey not only national nuclear rules in the countries of the producer but also that of the receiver, as well as transport and maritime regulation. These rules tend to differ a lot. This increases the demand for uniformity in regulations.

This contribution will address the knowledge as well as the lack of knowledge of the fate of Radon and Lead-210 in LNG and the challenges that come with it considering the international character of the industry.

Session VI

NORM in the industry and the integrated approach of radioactive and non-radioactive contaminants

Chairs

Rob Wiegers, Gennaro Venoso

INTEGRATED APPROACH IN REGULATION AND MANAGEMENT OF EXPOSURE SITUATIONS CONTAINING NORM AND OTHER (NON-RADIOACTIVE) TYPE HAZARDS INVITED SPEAKER

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There are exposure sites worldwide, both planned and existing ones, which commonly contain Naturally Occurring Radioactive Materials (NORM), i.e., elevated levels of ^{238}U, 232Th and their progeny, as well 40K, together with other, non-radioactive types of hazards (e.g., heavy metals, asbestos, rare earth elements, physical hazards etc). Examples to be mentioned are various legacy or decommissioning sites, certain active NORM involving industries, waste management at disposal sites. International and national regulatory requirements commonly consider radioactive and non-radioactive hazard separately, what may result in different regulatory, operational and management activities focused on each type of hazard independently.

During recent decades, interest has been raised for development of an integrated approach for the protection of workers, public and the environment that consider NORM and non-radioactive hazards together, in a joint inclusive manner, allowing optimization of management and control, aiming to minimize the unnecessary industry burden, while ensuring complete radiation and occupational health and safety protection.

Such an integrated approach needs to consider existing legislative requirements, to define the objectives of the work (depending on specific case/exposure situation), site investigation and impact assessment, consider the measures to be applied, evaluate associated uncertainties and constraints, and consider the roles of stakeholders (in some cases).

In the present work, the most important features (benefits, constraints, current status) of such an integrated approach for control and management of NORM and other hazards are presented and discussed on examples of different case characteristics (industry involving NORM, NORM affected legacy sites, waste management of NORM waste). In addition, an overview of ongoing related research within the RadoNorm project work will be provided.

NORM SURVEYS IN O&G DECOMMISSIONING PROJECTS

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Petroleum production is most often connected with the co-production of NORM in the form of radioactive precipitates on the inner surfaces of the production systems and NORM bearing sediments collected in tanks and drains.

Even though the NORM repeatedly is removed during revision stops throughout the production phase, significant amounts of NORM may remain in the production systems after end of production. Even though NORM may be present in both oil and condensate/gas production systems, the main quantities of NORM on a petroleum installation are connected to the production of oil.

The fate of disused installations vary from dismantlement and consequent reuse/disposal of all materials to re-installation and further production at a new location. The latter is especially relevant for floating installations like FPSOs and TLPs. In any case, the "NORM" status for the installation must be obtained and preferably quantified to assess the costs and options related to NORM de-contamination and waste handling.

By itself, the NORM survey is a purely practical exercise aboard the disused installation, where the challenge is to obtain the necessary data to fulfill the survey objectives. The objectives may differ between surveys but will in addition to identification and quantification of NORM often also include concrete recommendations regarding e.g. project specific de-contamination methods, NORM waste disposal and regulatory and trans-boundary issues.

The NORM survey is preferably conducted by radiologically skilled and experienced personnel with at least a basic knowledge of petroleum production systems.

The presentation covers the typical issues relevant for a petroleum installation NORM survey:

- NORM survey objectives,
- pre-survey considerations,
- relevant NORM waste forms,
- survey parameters,
- NORM measurements,
- typical NORM contaminated system parts,
- NORM quantity estimation,
- regulatory and trans-boundary issues,

and includes practical examples from relevant NORM surveys.

NATURAL RADIONUCLIDES AND HEAVY METALS POLLUTION ON SEDIMENTS FROM AN ESTUARY AFFECTED BY BOTH MINING AND INDUSTRIAL ACTIVITIES

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The Huelva estuary is formed by the common mouths of the Odiel and Tinto Rivers, and inside this ecosystem is the biosphere reserve of the Odiel saltmarshes. This ecosystem has been historically affected by Acid Mine Drainage (AMD) and by releases of pollutants from a very large industrial complex, which includes factories of phosphoric acid, TiO_2 pigments, copper production, etc., and a big waste repository containing more than 100 million tons of phosphogypsum (PG) which is a waste generated in the acid phosphoric production. Therefore, this study aims to carry out a comprehensive assessment of the environmental impact existing in sediments from the estuary of Huelva, especially of its main water masses, called Odiel and Tinto channels. For this, it was necessary to previously find a suitable sedimentary background Piedras River in our case, which is a non-impacted system and has similar geochemistry to the problem sedimentary system. The measurement of the gamma emitters belonging to the ^{238}U- and ^{232}Th-series, as well as ^{40}K were carried out by gamma-ray spectrometry using an Extended Range (XtRa) high purity germanium (HPGe) detector, while for alpha emitters, alpha-particle spectrometry was employed using Passivated Implanted Planar Silicon (PIPS) detectors. Prior the measurement of the gamma emitters, only a physical pretreatment od the sample was necessary, while for alpha emitters, a radiochemical method was necessary to applied in order to digest the sample and then, to sequentially extract the Po, Ra, U and Th isotopes. In the case of the measurement of heavy metals and major elements, ICP-MS/OES and XRF, were employed, respectively. To quantify this impact, several pollution indexes such as Enrichment Factor (EF) were used. Most of the analyzed sediment samples are strongly polluted by long-lived natural radionuclides, mainly U isotopes, ^{210}Pb and ^{210}Po with concentrations one order of magnitude higher than unpolluted sediments, mostly due to the releases from the PG piles. The sediments contain mean concentrations that are 5-20 times higher than the background values for heavy metals and metalloids such as Zn, As, Cu or Pb while up to 2 orders of magnitude higher were found for P. The studied sedimentary system is heavily polluted by toxic heavy metals and metalloids according to the U.S. EPA guidelines. The enrichment factors (EF) were extremely high (EF > 50) for As and very severe enrichments ($25 \leq EF < 50$) for P, Cd, Zn, Cu, and Pb. According to the values reached by the indexes, this impact was classified as “serious” pollution for most trace elements, excepting the deepest layers, and “low-moderate” pollution for the ^{238}U-series radionuclides, while no pollution for the ^{232}Th-series and ^{40}K radionuclides was found.

DISPOSAL OF NORM RESIDUES IN LANDFILL: A METHODOLOGY FOR STANDARDIZED ESTIMATES OF COMPLIANCE TO EXEMPTION LEVELS IN TERMS OF EFFECTIVE DOSE FOR INDIVIDUALS OF THE POPULATION

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The Italian legislation on radiological protection establishes the exemption and clearance levels for NORM in terms of activity concentration of main natural radionuclides, as the first threshold for exit from the regulatory system. Half of these levels apply in case of residues to be disposed in landfill. According to the graded approach, it is still possible to be exempted, even if the activity concentration values mentioned above are exceeded, where the exemption level in terms of effective dose is respected, that is respectively 1 mSv/year and 0.3 mSv/ year for workers and for individuals of the population.

It is quite common that residues from NORM industries destined for landfill exceed clearance levels in terms of activity concentration, and radiation protection experts must therefore assess the effective dose to the members of the public to verify compliance with 0.3 mSv/year. To make such estimates it is possible that multiple and not standardized approaches are adopted, also with recourse to sophisticated codes for the dose modelling, such as RESRAD-ONSITE, that require specific training and knowledge.

In this work, indications are given to quantify specific clearance levels for the environmental fate of residues in landfill, for the segments of the natural series of U-238 and Th-232 and for K-40, based on the document Radiation Protection 122 part II (RP122 part II). It is worth noting that in the EC document the dose criterion to the individual of the population, of 0.3 mSv/year, coincides with the exemption level for the general public of the Italian legislation. With respect to the RP 122 part II model, simple modulation factors are proposed (percentage of NORM residues on the total, distance of dwellings from disposal site, etc.) to derive specific clearance levels, less conservative with respect to those reported in the EC document, to take into account local conditions of more limited impact, still compliant with the effective dose of 0.3 mSv/year for the individual of the population. Updated dose coefficients from recent literature are also used.

Session VII

Sampling and characterization

Chairs

Wouter Schroeyers, Christian Di Carlo

MANAGEMENT OF TECHNOLOGICALLY ENHANCED RADIOACTIVE MATERIAL (TENORM) IN THE OIL & GAS COMPANIES ACTIVITIES *INVITED SPEAKER*

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This paper aims to show the best practices that Eni has developed since the early 1990s for the safe management of TENORM matrices, in relation to the operational activities of the plants, waste treatment, disposal and dismantling of installations. As is known, the presence of TENORM in plants can pose a risk of exposure to ionizing radiation for workers, resulting from the introduction of natural radionuclides and external irradiation.

Based on the literature and radiometric monitoring carried out on the plants, it is possible to state that no deterministic effects for workers are possible, attributable to the presence of TENORM in the plants.

The greatest risk derives not so much from external radiation (usually the dose rate detected near the equipment or components contaminated by TENORM, areas frequented by workers, is lower than 0.5 micro Sv/h) but from internal irradiation during maintenance activities.

Following radiometric analysis carried out in recent years has been possible to correlate the concentration of radionuclides present in produced water (Ra-226 or Ra-228) to the TENORM risk. The monitoring carried out also highlighted that the presence of TENORM in components can vary substantially from one plant to another, this depending on physical and chemical parameters such as temperatures, pressure variations, flow geometries, water cut and of course also from the geology properties of the reservoir.

Moreover, frequent maintenance interventions allow the prevention of the formation of scale or sludge in the plant components, reducing in this way the presence of TENORM.

To manage TENORM in Eni production plants, a procedure based essentially on two phases has been developed and adopted:

a preliminary radiometric investigation on site, based on the knowledge of the process, allows the identification of the radiometric anomalies associated with the presence of TENORM in the various components of the plant;

then, collection of samples with a potentially content of natural radionuclide and the characterization of these through gamma spectrometry analysis.

For residues it is necessary to identify the disposal chain, to carry out, adequate dose assessments for representative individuals and for the worker potentially involved.

The contaminated parts of the plant intended for cleaning or disposal activities are stored in areas equipped in a way to avoid potential soil contamination and ensuring also that no accidental release of contaminated material could be happen.

Eni is trying to identify methods for managing TENORM matrices in order to guarantee safe and adequate removal of residues, valorizing, when possible, materials which, once decontaminated, can be reused, or recycled.

RADIOLOGICAL CHARACTERISATION AND PROSPECTIVE DOSE ESTIMATE FOR MINING, STORING AND PROCESSING OF DEEP-SEA MANGANESE NODULES FROM THE CLARION-CLIPPERTON ZONE

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Polymetallic nodules from the deep sea, also known as manganese nodules, are a potentially mineable resource since they contain elevated concentrations of various valuable metals. They also accumulate natural radionuclides to a significant extent, which raises concerns related to radiation safety of workers involved in mining, storage and processing of the nodules. In order to provide a facts-based evaluation of potential exposure scenarios during the industrial exploitation of deep-sea nodules, an extensive radiological characterisation programme has been carried out on bulk and surface samples of nodules from numerous locations within the Clarion-Clipperton Zone in the Pacific. We present specific activities of all dose relevant natural nuclides from the three natural decay chains (U-238, U-235, Th-232), and the radon exhalation rate of water-saturated and dry nodules. The results show elevated specific activities for the nuclides Th-230, Ra- 226, Pb-210, Po-210, Pa-231 and Ac-227, which are in excess of U-238 and U-235, respectively. The radioactive disequilibria are a result of the complex hydrochemical growth mechanisms in the deep sea.

These laboratory results are a sound basis for the estimation of effective doses resulting from the natural occurring radiation of the nodules at different scales of handling. It can be shown that the effective doses potentially incurred by workers on mining and transport vessels, as well as workers in metallurgical processing, may not be trivial. However, with state-of-the-art radiation protection and mitigation measures known from other NORM-affected industries, effective doses can be kept well below the limits for occupational exposure.

UNLOCKING A RADIOLOGICAL PUZZLE: A COMPREHENSIVE APPROACH FOR THE SIMULTANEOUS RADIOCHEMICAL DETERMINATION OF RADIUM, THORIUM, AND URANIUM IN SOLID MATRICES

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The radiological relevance of thorium, uranium and radium in solid matrices such as food, feed, soil and building materials is an aspect of great importance in food safety. These radioactive elements emit ionizing radiation, which can affect both human health and environment. Therefore, proper management and characterization of such materials is crucial to ensure radiological safety. Modern studies contribute to the development of guidelines and regulations for safe management of radioactive materials, ensuring the protection of individuals and the environment from potential harmful effects of radiations. A single method for the simultaneous determination of these three elements and their isotopes has not been established yet.

This study addresses this issue using an alpha spectrometric technique consisting of three main phases: sample chemical digestion, chromatographic separation, and alpha spectrometry analysis. To enhance method's sensitivity, food samples are ashed in quartz crucibles at 700 °C for 48 hours, resulting in the recovery of less than one gram of ash. The solid sample (~ 1g) undergoes alkaline fusion, and the resulting solution is added with 40 mg of Ca and Ba (as chloride salts). The pH of the solution is then lowered to 8 using concentrated HNO_3. The solution is centrifuged, and the precipitate is recovered with 15 mL of 1M $Al(NO_3)_3$ / 3M HNO_3 solution.

The radiochemical separation of U, Th, and Ra applies UTEVA chromatographic resin. The solution is passed through a 2 mL chromatographic column at a flow rate of 1 mL/min, which retains U and Th, allowing Ra and Ba to flow and elute into a clean beaker. This solution is brought to dryness and recovered with concentrated sulfuric acid to form $[Ra]BaSO_4$ precipitate, which in turn is dissolved in 1M HCl - 1M C_2H_5OH solution, in which $RaCl_2$ precipitates and $BaCl_2$ remains in solution. Ra precipitate is dissolved in 200 mL 0.05M HNO_3, in which a 25 mm polyethylene disk impregnated with MnO2 is stirred for 3 hours at 250 rpm on a magnetic stirrer. Though this step, Ra is captured on disk surface within a few µm thickness, so to not degrade the alpha signal. Th is eluted with 15 mL of 5M HCl / 0.05M Oxalic Acid, while U is eluted with 15 mL of 1M HCl. Analytes are finally precipitated with rare earth fluorides on 25 mm polypropylene filters.

The results of the tests performed on IAEA reference materials are summarized in the table below, demonstrating that the method is repeatable and suitable for the determination of the three most important natural alpha-emitting radionuclides in food and feed materials.

CHALLENGES IN CONTROLLING NORM IN BUILDING MATERIALS

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The EU-BSS, apart from setting limits for indoor radon, establishes a reference level of 1 mSv per year for indoor external exposure to gamma rays emitted by the building itself. Additionally, it introduces the Activity Concentration Index (ACI), which determines gamma-ray exposure exceeding typical outdoor levels in buildings made from specific materials. However, a critical review of the EU-BSS reveals several challenges:

a) The traditional measurement strategy focused on detecting contamination with man-made radionuclides creates a certain inertia for the implementation of such rational ISO/IEC concepts as "measurement uncertainty" and "conformity assessment" into NORM regulation practice.

b) There is still no strict metrological support for NORM measurements to assess conformity with the reference ACI at a given reliability of decision-making (at least 95%), considering the main components of ACI uncertainty in both lab and field measurements.

c) Typically, the specific activity of radium-226 is measured in equilibrium with progeny, so test material samples need to be sealed for around a month before ACI measurement, but securely sealing Marinelli beakers proves challenging.

d) While semiconductor gamma-ray spectrometry is prevalent in Europe for its high energy resolution, ACI measurements require heightened detector sensitivity rather than energy resolution since identifying radionuclide composition is not necessary. NaI(Tl) scintillation spectrometry meets this crucial requirement at a lower cost and weight compared to semiconductor spectrometry. Moreover, its maintenance is less cumbersome as it does not rely on liquid nitrogen cooling.

The presentation explores effective strategies in both research and national NORM monitoring to tackle these obstacles.

SELF-ABSORPTION CORRECTION IN GAMMA-SPECTROMETRY ^{210}Pb MEASUREMENTS IN COMPLEX NORM SAMPLES: EXPERIMENTAL AND THEORETICAL APPROACHES

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γ-spectrometry is worldwide recognized as the standard analytical method for the characterization of most NORM matrices containing the radionuclides belonging to the uranium and thorium series. However, in some specific cases, especially when high disequilibrium levels exist between ^{210}Pb and their parents radionuclides, the g-spectrometry measure may become very challenging because of the dramatic self-absorption of the low-energy 46.5 keV ^{210}Pb g emission: the self-absorption correction factor may reach a value of 10 or even more. This is particularly true for high density NORM matrices whose composition is unknown and characterized by the presence of elements with quite high Z number. Matrices with these features are not uncommon in industrial NORM residues and, for that reason, the self-absorption correction must be performed with great care. Actually, a self-absorption correction performed with poor accuracy may result in highly biased activity concentrations estimations, leading to potential severe consequences, namely uncorrected decisions regarding the ultimate fate of the residues.

To tackle this problem, two different methods for the self-absorption correction were tested and compared. The first method, particularly suitable for those matrices whose composition is unknown, is based on the experimental measure of the mass attenuation coefficients of the NORM material, by means of the observation of the absorption of the g-rays emitted by two point sources (^{137}Cs and ^{241}Am). The other method requires the complete knowledge of the composition of the matrix to be tested: if not known, the composition was determined using the SEM-DRX technique (Scanning Electronic Microscopy with X-ray Diffraction). Then, the self-absorption correction factor was calculated by means of the software ANGLE4, a dedicated Monte Carlo software.

The results obtained with these two methods were found in good agreement for a quite wide range (1-10) of values of the self-absorption correction factor.

OPTIMIZATION OF ^{210}Pb GAMMA SPECTROMETRY DETERMINATION IN NORM – A COMPARISON OF THE DIFFERENT SELF-ATTENUATION CORRECTION FACTOR APPROACHES

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NORM management in the Czech Republic is subject to legal regulation; one of the legal requirements is reporting ^{210}Pb content. ^{210}Pb emits low energy photons, which complicates gamma-ray spectrometry determination because the measurement is significantly affected by self-attenuation – therefore, a suitable geometry is necessary, and a proper correction factor must be applied.

In the Gamma Spectrometry Department of the National Radiation Protection Institute, the usual approach to correction factor determination is a calculation performed in EFFTRAN based on the sample composition and density knowledge. However, while treating NORM, the composition of the sample is often unknown and cannot be easily estimated. An alternative method of obtaining self-attenuation correction is performing the transmission method, which is based on a measurement of the mass attenuation coefficient using an external collimated beam of 46.5 keV gamma rays. However, this procedure is lengthy and costs more device time.

To optimize the procedure of ^{210}Pb determination, the NORM typical for the Czech Republic environment were sorted into groups, while taking into account the assumed composition, origin and chemical properties. Then, the mass activity of ^{210}Pb was determined in different ways, combining a high volume geometry, “a thin layer” geometry and the self-attenuation correction factor calculation in EFFTRAN or using the transmission method.

The results from the approaches using the EFFTRAN calculation were compared with the transmission method, to identify for which groups of the typical local NORM the correction factor can be calculated in EFFTRAN using a rough estimation of the composition, and for which groups the experimental transmission measurement is necessary. During the assessment, the used high volume geometries have shown to be unsuitable for the purpose of ^{210}Pb gamma ray spectrometry measurement.

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