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EDUCATION AND TRAINING TRADITION AT IFIN-HH IN RADON MEASUREMENT AND EVALUATION OF RADIOLOGICAL IMPACT*

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Abstract. This paper presents the work carried out in *Horia Hulubei* National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH) for the measurement of indoor and outdoor ^{222}Rn concentration as a historical development and as present situation, focused on the assurance of its metrological chain, from primary standardization, up to in field measurement. These activities are in tight connection with the activity of education and training for staff involved in exposure to naturally occurring radioactive materials (NORMs), especially radon, and for those involved in the measurement of radon concentrations in field. Two types of training actions will be presented: the courses organized for people working in uranium industry and public health and the course prepared and presented within the ANNETTE EU Project, Horizon 2020 Research and Innovation Programme.

Key words: Radon measurement, ^{222}Rn standard system, Radon chamber, Indoor and outdoor radon, education and training, ANNETTE, EU project.

1. INTRODUCTION

The measurement of naturally occurring radioactive materials (NORMs) has a very long tradition in IFIN-HH, starting with the pioneering work of Ana Daniş and coworkers, who introduced the passive method based on CR-39 solid state nuclear track detectors (SSNTDs), encapsulated in special monitoring devices, for the measurement of indoor radon concentration. The system was manually operated and its working principle, as well as its first calibration, are described in the paper [1]. Three types of calibration sources were used: a ^{222}Rn, a ^{226}Ra + ^{222}Rn, and a sealed ^{226}Ra source [2]. The calibrated system was used for the monitoring of the indoor radon in Bucharest and surrounding area, as reported in the paper [3]. A further

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progress in the development of the system in IFIN-HH was the introduction of a commercial automatic, Radosys Equipment provided with CR-39 detector chips in RSKS type chambers, with etching in NaOH in the Radobath RSB4 unit [4] by Angela Vasilescu, such as described in the paper [5]. At the present time, the equipment is in operation at the Department for Life and Environment Physics (DFVM), the SALMROM laboratory, designated as a notified testing laboratory by Romanian Regulatory Body (CNCAN), certificate LI 1653/2018. The system was verified by participation in interlaboratory comparisons (ILCs), both in an international exercise [4] and with the similar system established in the Babes Bolyai University by Constantin Cosma [6], validated also in an international exercise [7]. The SALMROM laboratory disposes also of a portable system for the measurement of the atmospheric radon and thoron in air, water and soil, type PYLON. The content of radon (^{222}Rn) and thoron (^{220}Ra) daughters' and anthropogenic radionuclides outdoor, within IFIN-HH area, is continuously surveyed by the Laboratory of Personal Dosimetry and Environment (LDPM), as presented in the paper [8], by Ana Stochioiu *et al.*, CNCAN designated laboratory, certificate LI 2151/2018. The prescriptions of the national standard: STAS 12457-86 are also followed. The same Department disposes of two units of monitors type "AlphaGUARD", which also separately monitors atmospheric pressure, temperature and relative humidity. They are used for advanced studies regarding the influence of radon on gamma-ray rate in atmosphere, Anca Melintescu *et al.* [9], and for the measurement of environmental radioactivity, Romul Mărgineanu [10].

2. ASSURANCE OF THE METROLOGICAL TRACEABILITY CHAIN FOR ^{222}Rn IN IFIN-HH

All equipment(s) for in field measurement of radon concentration, belonging to IFIN-HH laboratories, as well as to other interested Romanian units, were originally calibrated by their producers; they need recalibration after a working period of several years. The operation can be performed by the producers or other foreign metrology laboratories, or in our Radionuclide Metrology Laboratory (LMR) of IFIN-HH. This is the reason why the real, Romanian metrological traceability chain for the measurement of ^{222}Rn activity, was established based on a system for absolute (primary) standardization, implemented in the LMR. The system was conceived such as to assure the entire chain: (i) A primary standard, (ii) A set of two secondary standards, (iii) A tertiary standard, at present time under development.

(i) The primary standard is based on a system for generation of ^{222}Rn from a solid ^{226}Ra flow through source, type PYLON 1025 RN, its circulation and quantitative recovery in receptacles under a controlled pressure and temperature regime, realized within the PNCDI II Project, Code SEPRAD. Figure 1 represents the system.

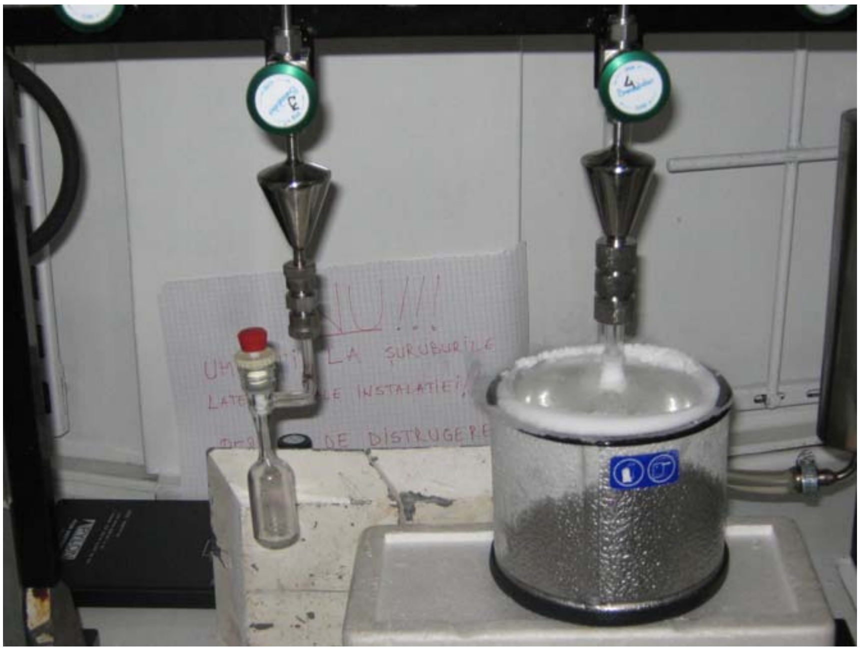

Fig. 1 – ^{222}Rn standard system.

The measurement of ^{222}Rn activity is based on the liquid scintillation counting (LSC); the works accomplished both in the Laboratoire National Henri Becquerel (LNHB) – France by a common French – Romanian team and in IFIN-HH (using the system mentioned above), are described in the papers [11, 12].

(ii) The set of secondary standards consists from an ionization chamber and a gamma-ray spectrometer, calibrated using primary standardized receptacles with radon, both prepared as radon gas vials, or ampoules containing radon dissolved/ adsorbed in liquid scintillator (LS).

The transfer of activity unit to the secondary standards is accomplished *via* a combination of primary and secondary measurements, as described in the paper [13]. The whole system was validated in an international comparison exercise CCRI(II)-K2. ^{222}Rn, organized by the International Committee for Weights and Measures – CIPM-CCRI(II) – Radionuclide Measurements, with 5 primary standard participating laboratories, as described in [14]. The relative difference between the IFIN-HH result and the estimation of the pilot laboratory, LNHB-France, computed at the same reference time, was only 0.77 %, confirming the reliability of our reported activity. At present time, the system is used to prepare receptacles with standard radon as gas or in LS, with activity certified with a combined standard uncertainty less than 2% (coverage factor, k = 1).

(iii) The tertiary standard, consists from a radon chamber. It is under development and will be used for the calibration of the equipment for in field measurements [15]. It was designed in IFIN-HH, and the main part of the physical construction was performed in collaboration with colleagues from ICSI Rm. Vâlcea; a Monte Carlo program for calculation of the radon progeny concentration inside the chamber volume was elaborated in Bucharest University [16]. All these works were accomplished within a National Project PNCDI II, code CARSTEAM.

At the present time, the chamber, with a useful volume of 1 cubic meter, is perfectly isolated and monitored as temperature, tightness and pressure. The filling with a certified concentration of radon inside its volume for the calibration of the equipment follows to be assured in two manners: with a standard radon gas vial in a static regime, or directly connected to a flow through ^{226}Ra source, with a certified emission rate of radon. The software for computer controlled operation of the radon chamber was recently implemented and tested. Before entering in normal exploitation, the chamber will be validated by international comparisons, planned within our participation at the EURAMET-EMPIR joint research project (JRP) *Metrology for radon monitoring* (16ENV10 MetroRADON), http://metroradon.eu/. Three comparison tests are planned: the absolute standardization of a low activity concentration of a radon sample, in the range (100–300) Bq/m^3; absolute standardization of a thoron (^{220}Rn) sample; validation of the traceability, performance and precision of the radon chamber for activity concentrations in the range from 300 Bq/m^3 to 10,000 Bq/m^3, by participating to an exercise. This exercise will consist in successive calibrations of the same commercial radon monitor, type AlphaGUARD, belonging to the organizer of the comparison, to be sent successively to the participating laboratories.

3. EDUCATION AND TRAINING ACTIVITIES CARRIED OUT BY IFIN-HH

Our specialist staff involvement in the education and training (E&T) of persons exposed to NORM, at work and at home, has a long tradition in IFIN-HH. The Center for Training and Specialization in Nuclear Field (CPSDN) organized such a specialization course regarding radon, especially devoted to the people working in the uranium industry: exploration, mining and processing for production of fuel for the nuclear plant. The lecturer for all these courses, over a long period, as normally should be, was Ana Daniş, the pioneer of radon measurement in IFIN-HH (see Section 1) [17]. She retired in 2004 and a new lecturer and a new requirement of course content were necessary, mainly detailing the aspects of evaluation of its radiological risk. This course was conceived such as to respond the requirements of the new comer people in uranium industry, but also to those of people involved in environment and public health measurements. For this task, a person involved in radon measurement in IFIN-HH was asked to elaborate this course, starting with the 2004 year. It contained information about NORM materials, their content in environment, their physical-nuclear and dosimetric parameters and the requirements of the CNCAN norm: Radiological Safety Norms on the Operational Radiation Protection in Mining and Processing of the Uranium and Thorium Ores (Normele de securitate radiologică privind radioprotecţia operaţională în mineritul şi prelucrarea minereurilor de uraniu şi toriu), Norm CNCAN/MNR-01/2002, which was in agreement with the requirements of the *Fundamental Norm for Radiological Safety* (NSR 01, CNCAN order 14/2000). The courses were upgraded in order to be compliant with the new international and national normalisation documents, as they were published. The courses were delivered both in IFIN-HH and on the locations of the interrested people, at Feldioara uranium processing plant and at Crucea uranium mine, belonging to the National Uranium Company. Once these activities were stopped, the interest in these courses lowered. Parallel courses, entitled *Assessment of the radiological impact on the population and the environment generated by exploitation and preparation of uranium and thorium ores* were delivered by Mihai Popescu from CPSDN.

The knowledge and a part of this course content were available and an opportunity to valorize our experience was possible once the ENEN (European Nuclear Education Network) launched a new education and training (E&T) project entitled ANNETTE *(Advanced Networking for Nuclear Education and Training and Transfer of Expertise)* EU project, Grant Agreement no. 661910, 2016–2020, Horizon 2020. IFIN-HH, represented by the CPSDN, was included as a participant in the project, within the list of 25 universities and research institutes from EU countries, participating at this joint effort of education and training (E&T) and vocational education and training (VET). The whole project includes 8 working packages (WP), IFIN-HH being a participant in the WP2: "Design and implementation of coordinated E&T and VET efforts in nuclear areas". Two types of CPD Master Courses were engaged, within the generic subject *Radiation protection and international framework*, credited with 4 ECTS (European Credits): (i) "Principles of Radiation Protection and International Framework. Regulatory Control", delivered as a e-learning course and (ii) "Radon and its radiological impact", presented in this paper.

Preparation and delivery of the course. The course was planned to be presented during three full days and was proposed to be delivered face to face, as teaching activities and practical sessions. Before being accepted by ENEN and publicly announced, the course author, developed the Learning Outcomes of the course, presented in Table 1, regarding its content and its expected results of training, such as required by ENEN.

The course was accordingly prepared, in order to address the scope declared in the Table 1 assertions. It was organized as oral teaching [18] and two practical sessions. The oral theoretical lesson was organized in 5 chapters, with detailed subchapters, as shown in Table 2.

Table 1

Learning Outcomes of the Radon and its radiological impact

Course on *"Radon and its radiological impact"*		
Units and LO Statements		
Unit 1 – Radiological characterisation of radon (1 ECT)	**Responsibility / Autonomy** **Autonomously apply radon measurements and characterisation from radiological protection point of view**	
	Skills	**Knowledge**
Analyzes radon origin and its spread in environment, according to UNSCEAR reports in terms of their radiological impact Evaluates radon influence over the precise measurement of low activity samples in order to assure the survey of the environment Applies the specific methods for the measurement of radon activity in order to verify the compliance with established reference levels	• Select and use of the appropriate equipment in the measurement of radon in various media • Use special physical quantities specific to radon measurement • Apply methods and use appropriate equipment for the measurement of radon and progeny concentrations in different places – quality assurance • Apply the correct methods/procedures for measurement of radon activity in various media: in air, in water, in soil, at home and working places • Apply radon background corrections when measuring various low activity samples in different phases of NPP operation	• Describe the uranium-radium-radon and daughters decay chain characteristics • Knowledge and interpretation of UNSCEAR data bases • Describe the specific quantities in radon measurement: activity (SI and non SI units) and energy (Potential Alpha Energy Concentration, Equilibrium factor) • Understand of the methods for subtraction of background influence in low activity samples, applying the principles of the ISO11929/2010 standard
Unit 2 – Regulatory control on exposure to indoor radon in dwellings and workplaces (1 ECTS)	**Responsibility / Autonomy** **Autonomously apply radiation protection against radon in workplaces and at home**	
	Skills	**Knowledge**
Analyzes the European and international documents in terms of radon exposure requirements Applies the national regulatory requirements regarding radon exposure in order to implement of the optimisation process for exposures in existing exposure situations Applies radon specific dosimetric assessments in order to ensure the adequate level of radiation protection in workplaces and at home	• Accomplishment of the international legislation (EC Directive 59/2013) regarding radon, in the light of the ICRP PUBLICATION 115/2010 • Apply the relevant regulations and guidance for the existing exposure situations involving exposure to radon • Calculation of the doses for personnel being irradiated from distance or incorporating radon and daughters, at home and at work places • Calculation of the effective doses due to radon (internal and external) exposure	• Specify the relevant international Documents: EC59/2013, ICRP115/2010, etc. • Describe the regulatory requirements regarding radon exposure in workplaces and at home • Describe the calculation of dose to activity conversion factors to be applied in evaluation of doses due to radon exposure
Assessment criteria = to demonstrate mastery and innovation, advanced skills, required to solve complex and unpredictable problems in a specialised field of "Radon measurement and dose evaluation"	–	–
Recommended assessment methods: Practical and written test, face to face examination, grid test with multiple choices [choosing among different options].	–	–

Table 2

1. NATURAL RADIONUCLIDES: CONCENTRATIONS, PROPERTIES 1.1. Natural telluric radioactive series 1.2. Radioactive elements in environment 1.3. Physical, physical-nuclear and chemical properties of the radionuclides 1.4. Radon concentration, determining factors
2. DECAY SCHEMES, EMITTED RADIATIONS. QUANTITIES AND UNITS 2.1. Decay schemes of ^{222}Rn, ^{220}Rn, daughters 2.2. Characteristic quantities of radon, units 2.2.1. Activity 2.2.2. Potential alpha energy 2.2.3. Equilibrium equivalent decay product concentration 2.2.4. Equilibrium factor
3. MEASUREMENT OF RADON AND PROGENY ACTIVITY 3.1. Radon metrology 3.2. In field measurement of radon activity: methods and instruments 3.2.1. Lukas cell 3.2.2. Air filter for the measurement of progeny concentration 3.2.3. Simplified method for determination of daughter's concentration in air by the filter method 3.2.4. Gamma-ray spectrometry method 3.2.5. Methods for continuous monitoring using passive detectors Solid state nuclear track detectors (SSNTDs) Thermoluminescent detectors (TLD) Electrets (E-PERM)
4. DOSIMETRY OF NATURAL RADIONUCLIDES, INCLUDING RADON 4.1. Biological and dosimetric characteristics of the natural elements 4.2. Calculation of effective dose for radon – Dose Conversion Factor (DCF) 4.3. New values of Dose Conversion Factors; Comparison of the dosimetric parameters according to ICRP 65 and ICRP 115, 126 and 137 4.4. Reference values for radon concentrations according to the EU BSS Directive 2013/59/EURATOM 4.5. Conclusions, such as reflected in the EU BSS Directive 2013/59/EURATOM, in agreement with dose calculations
5. INFLUENCE OF RADON ON THE PRECISE MEASUREMENT OF LOW ACTIVITIES OF ENVIRONMENTAL SAMPLES 5.1. Practical situations 5.2. Methods for reducing radon influence 5.3. ISO 11929:2010 standard and radon background

The course was documented on a vast list of references, which are presented at its end, in two distinct lists up to date, consisting in *International Documents* and *Scientific papers & Romanian Norms.* After being finalized, the documents advertising the course were uploaded on the site https://cpsdn.nipne.ro/wp-content/uploads/annette/HH-IFIN_RADON.html and were accessible to the international community, with some details about the content, addressability, structure, date of delivery: 22–24 October 2018, maximum number of participants 6 persons, free of charge. A number of foreign and Romanian persons expressed their interest in following it; due to financial support dysfunctionalities, the final participants were exclusively Romanians, from CNCAN, IFIN-HH and two private companies.

The theoretical lectures were combined with two sessions of practical work in laboratories, divided in groups of three persons each per experiment: *Measurement of ^{222}Rn concentration in environmental samples* in the Department DFVM, SALMROM, responsible persons Marian Romeo Calin and Ileana Radulescu and *Standardization of ^{222}Rn sources* in the Radioisotope and Radiation Metrology Department (DRMR), LMR, responsible persons Aurelian Luca and Andrei Antohe, with the support of Constantin Teodorescu.

Work in SALMROM. The aim of the work was to determine the activity concentrations of radon in soil, water and air, using the portable system Pylon AB-5. The participants at the course were thus familiarized with the measurements system and methods for each type of environment. For each session, measurements for soil, water and air have been performed with the participants, thus values for two different days were obtained.

a) Materials and methods. By the active method, in the SALMROM laboratory, the atmospheric radon concentration measurement was performed with portable Pylon AB-5 system equipped with the CPRD passive scintillation cell detector – ZnS(Ag). The system was used in continuous mode with the calibration factor of 0.0421 ± 4% cpm/(Bq/m^3), 1.558 cpm/(pCi/L) ± 4%. The radon concentrations for predetermined interval were stored in the instrument's memory and transmitted subsequent to a computer. The measurement and calibration of equipment were made in accordance with the procedures of the accredited SALMROM laboratory (SALMROM Quality Manual).

b) Result of training work. The values for radon water measurements varied between (1.30 ± 0.23) Bq/l and (3.50 ± 0.32) Bq/l. For soil measurements the values varied between (650.0 ± 6.2) Bq/m^3 and (1785 ± 10) Bq/m^3. In the case of indoor atmospheric radon measurements values ranged between (40.2 ± 2.0) Bq/m^3 and (144.3 ± 0.23) Bq/m^3. Indoor atmospheric radon measurements are affected by environmental climate conditions, meaning atmospheric pressure, humidity and temperature [19–21].

Work in LMR. The aim of the training was the standardization of a vial with radon gas by the gamma-ray spectrometry method.

a) Materials and methods. The radon primary standard system, Fig. 1 was used, to prepare the radon vial of type presented in Fig. 2a, from the ^{226}Ra source. The entire procedure is described in detail in the paper [13]. The standardization of radon was performed in LMR, RENAR accredited laboratory, LE 013/2017, using the gamma-ray spectrometer, containing a HPGe coaxial GEM semiconductor detector (29 % relative efficiency and the working energy interval (50–3000 keV), associated electronics and operational software ORTEC GammaVision. The system was calibrated in energy, resolution and efficiency using point standard sources, prepared in LMR, traceable to the International System of Units (SI), with a mean uncertainty of 1.7% ($k = 1$). The Operational Procedure PL-LMR-01 prescriptions were followed.

In the case of ^{222}Rn, the calibration was performed using standard radon vials in equilibrium with daughters, according to the description from paper [13], placed at a distance of 42 cm from the detector surface, in orizontal position. The determined efficiencies for this measurement geometry regard the two daughters, as follows: for ^{214}Pb radiation of 352 keV, $\varepsilon = (1.152 \pm 0.018) \times 10^{-4}$ s^{-1}/Bq of ^{222}Rn and for ^{214}Bi radiation of 609 keV, $\varepsilon = (0.937 \pm 0.015) \times 10^{-4}$ s^{-1} /Bq of ^{222}Rn.

b) Result of training work. The effective measurement of the radon source activity was performed together with the participants and the obtained experimental data were processed to calculate the activity and its uncertainty. The measurements were undertaken more than 4 hours after the preparation of the radon source, in order to assure the secular equilibrium between ^{222}Rn and its daughters, ^{214}Pb and ^{214}Bi. The ^{222}Rn activity result obtained was: (175,044 ± 6,652) Bq, on the reference time 23 October 2018, 13:57 local time (RO). The reported uncertainty corresponds to a coverage factor $k = 2$.

Assessment of training results. The recommended assessment method, as presented in Table 1, was: Written test, face to face examination, grid test with multiple choices (choosing among different options). As engaged, the author of theoretical lecture [18] conceived a grid test, containing nine questions, from all chapters; each question had three option responses. All participants were examined by the final written test, with very good exam results. All participants received a Certificate of completion of the training course. The attendees have filled-up a Training Evaluation Questionnaire regarding course progress. The analysis of the responses shows a very good appreciation of the training program.

Participation at the 3rd Progress Meeting of the project. The meeting was organized by ENEN in Brussels, Belgium, on 13–14 December 2018, and analyzed the progress of works and future deployment. The introductory lecture, by Pedro Dieguez – Executive head of ENEN and Walter Ambrosini – Project Director, was entitled: *Reflections on ANNETTE and proposed objectives: where we are, where we should be*. A detailed analysis regarding the accomplishment of all planned actions was done. Analyzing the WP2 objectives accomplishment, the course delivered by IFIN-HH *Radon and its radiological impact* [18], was cited as a successful one. Our offer to repeat it, in case of funding for other participants, was expressed in our report.

4. CONCLUSIONS

A long tradition of measurement of NORM activity exists in IFIN-HH, demonstrated by the realization of the first measurements using the method of solid track detector systems, as well as by introduction of other commercial equipment and their use for the infield measurements. The metrological traceabiliy of ^{222}Rn measurement is assured for the entire chain, starting from the primary standard, based on liquid scintillation measurement, a secondary standard consisting from an ionization chamber and a HPGe spectrometric system and a tertiary system, a radon chamber, under development, destinated for the calibration of the equipment used for infield measurement. The education and training activities in the NORM materials, especially ^{222}Rn and its radiological impact evaluation, were assured both at the national level, by courses delivered for people working in uranium industry, environment measurement and in public health, as well as the international one, *via* the ANNETTE EU Project, Horizon 2020 Research and Innovation Programme.

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