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RECENT WORK AND RESULTS OF THE RADIONUCLIDE METROLOGY LABORATORY FROM IFIN-HH*

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Abstract. This paper refers at the Radionuclide Metrology Laboratory (RML) work accomplished since the last scientific event "2008 Workshop of the Decay Data Evaluation Project" (DDEP-2008), consisting in training sessions for the nuclear decay data evaluators, Bucharest (Romania), during the period 12–14 May, 2008, when the main author presented the activities of the RML from IFIN-HH.

Key words: radionuclide metrology, absolute methods of standardization, international comparisons.

1. INTRODUCTION

As a contributing laboratory within the international project Decay Data Evaluation Project (DDEP), the RML presented the overview paper "*Main Research Area and International Activities of the Radionuclide Metrology Laboratory from IFIN-HH*" at the DDEP 2008 workshop [1]. This presentation refers at the work accomplished since the scientific event "2008 Workshop of the Decay Data Evaluation Project" (DDEP-2008).

Official Status of the Laboratory. The Radionuclide Metrology Laboratory (RML**)** was created in early sixties.

On international scale, IFIN-HH is a designated participant in International Committee of Weights and Measures-Mutual Recognition Agreement (CIPM-MRA) in the field of ionizing radiations, member of the CIPM-Consultative Committee for Ionizing Radiation, Section II – Radionuclide Measurement [CIPM-CCRI (II)]; it is also an associated member of the European Association of Metrology Institutes-EURAMET, Technical Committee for Ionizing Radiations (IR-TC).

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On the national level it is recognized as a primary standard laboratory and recently obtained the Attestation as the owner of the National Standard of the becquerel (Bq) unit for the physical quantity activity (of a radionuclide), according to the Order of the General Director of the Romanian Bureau for Legal Metrology (BRML) no. 103/ 08.04.2013, Annex 1.

Infrastructure, equipment, personnel:

– *Infrastructure.* Situated in the Radioisotopes and Radiation Metrology Department (DRMR) building, RML disposes of 6 rooms for: preparation of sources, balances, measurement rooms and of the radon standard.

– *Basic equipment.* Installations for absolute (direct) standardization: (i) Two 4πPC-γ coincidence systems provided with gas flow proportional counters and NaI(Tl) crystals; (ii) Two variants of LSC-TDCR system, based on 3 PMTs and respectively 6 CPMs; (iii) A photon-photon coincidence system with two thin NaI(Tl) crystals.

System for ^{222}Rn production, circulation, recovery in liquid scintillator and as gas in glass recipients, and its standardization.

Installations for relative (indirect) standardization: (i) two large area, multiwire window and windowless proportional counters; (ii) X and gamma-ray spectrometry system with Si(Li) and high efficiency HPGe; during 2012 the Si(Li) system was completed with a dedicated system for spectra analysis; (iii) the system containing an ionization chamber CENTRONIC IG12/20A, operated with a Keithley E6517A Electrometer.

Under construction: the Radon chamber for the calibration of radon measurement equipment.

– *Personnel.* The staff members are: 4 PhDs, a PhD person partially employed, a young PhD, student and one Technician. A number of 3 PhD theses of RML personnel, treating subjects from our activities, were successfully presented at the Bucharest University.

2. MAIN RESEARCH AREAS

2.1. ABSOLUTE STANDARDIZATION

An overview paper, containing the most significant contributions of the RML in the development of methods for absolute standardization of radionuclides was presented at the Second European Nuclear Physics Conference (EuNPC 2012) [2]. This paper presents the most recent contributions in the field.

2.1.1. Most recent work regarding the use of the 4πPC-γ method

It refers at radionuclides of interest for nuclear energy, metrology, medicine, environment.

– *The radionuclide* ^{124}Sb*, a beta-gamma emitter with complex decay scheme,* was standardized for the first time in the laboratory, within the project EURAMET 907 [3]. The special problem with this radionuclide was with the preparation of solid sources, due to the volatility of antimony. On the beta channel the whole spectrum and on the gamma channel the energy of 602.72 keV were counted, and the extrapolation procedure was applied. Our laboratory can be identified as number 6 in the paper by B. Chauvenet *et al.* [3].

– *New positron emitting radionuclides:* ^{64}Cu – *EURAMET project 1085 and* ^{68}Ga, ^{18}F, ^{124}I – *National Project: PN-II-ID-PCE-2011-3-0070* "Absolute standardization and study of the decay parameters of the positron emitters for PET systems. Metrological traceability assurance" [4].

For the simple decay scheme radionuclide ^{18}F (96.86% positron emission), the coincidence of positrons with annihilation rays method was applied: on the beta channel the whole spectrum for pulses with amplitudes higher than 1 keV and in the gamma channel the 511 keV annihilation quanta were counted. The efficiency extrapolation method was used, varying the efficiency. The source activity was derived by extrapolation to 100% beta efficiency [5].

By difference of ^{18}F, the other radionuclides are electron capture and positron emission decaying, with more complex decay scheme. In the case of ^{64}Cu and ^{68}Ga, both classical method (a), selective detection of positrons and annihilation quanta and counting of their coincidences, and a more complex one (b), consisting from the detection of all the emitted radiations and counting coincidences: positrons-annihilation quanta and X-ray, Auger electrons (X,A) – gamma rays, were applied [6]. In the case of method (b), the measurements were done by setting a discrimination level of ≤ 1 keV and with the source uncovered; on the gamma-ray channel, both annihilation and gamma-rays were registered. Both methods were applied and compared, the agreement being satisfactory. The final result was calculated as the arithmetic mean of both methods' results.

The radionuclide ^{124}I has a very complex decay scheme and the variant (a) cannot be applied, as the high energy X,A radiations overlap the positron spectrum; only method (b) can be applied. On the beta channel, the whole impulse spectrum was measured and on the gamma channel four energy windows were used: counting only 511 keV annihilation quanta; counting the quanta with energies > 1510 keV, following exclusively electron capture events; combinations of annihilation and other higher energy gamma rays. The processing of the experimental data is under way [7].

– *Standardization of* ^{177}Lu *and* ^{186}Re, important radionuclides used for targeted radiotherapy, was done within the frame of the Joint Research & Development Project (JRDP) IFA-CEA C2-05/01.03.2012, "Creation of national standards for some emerging pharmaceutical radionuclides to ensure the radioprotection of patients and medical staffs", IFIN-HH/LMR (Romania) – CEA/LIST/LNHB (France). Both, ^{177}Lu and ^{186}Re, belong to the category of strong beta, week gamma-ray emitters, with a triangular decay scheme. The extrapolation method was applied, taking into account the special type of extrapolation, when a limited interval of linearity can be used and a higher extrapolation slope occurs, [8, 9].

2.1.2. Recent standardizations by the liquid scintillation counting

The most recent standardization by the liquid scintillation counting refers at the pure beta emitters, ^{3}H and ^{99}Tc. Both measurements were performed in two key comparisons: CCRI(II)-K2.H-3 and CCRI(II)-K2.Tc-99.

(i) *The beta pure radionuclide* ^{3}H has a low endpoint beta energy, 18.56 keV, and its standardization needs a maximum attention. The variant of the Triple to Double Coincidence Ratio of the Liquid Scintillation Counting (LSC-TDCR), implemented in our laboratory with the help of the LNHB, Dr. Philippe Cassette, was used. In these measurements both TDCR-LS counters were used: the classical one, based on three photomultipliers (PMTs), taken as reference, and our new built system containing six channel photomultipliers (CPMs) and a new optical chamber with a new design [10]. A total number of six vials, from glass and plastic, containing Ultimagold LLT scintillator were prepared and measured.

The measurements with the classical counter implied the adjustment of the HV = 2.2 kV, appropriate values of the threshold values, of 50, 90, 110 mV respectively on the individual PMTs and a Birks constant value k_B = 0.011 cm MeV^{-1}.

The new CPMs system was operated at a HV = 3 kV, with an unique threshold set at 240 mV. A different value of the Birks constant, k_B = = 0.019 cm MeV^{-1}, was used. These measurements revealed the following conclusions: when using 3 CPMs, an activity value less by 3.5% than in the classical PMT system; when using six CPMs, the efficiency was substantially improved and the activities were respectively different by –0.4% and +0.7% for two sources.

Construction of a compact and portable LSC-TDCR is very important in applications for on site, measurement of ^{3}H activity. Such a prototype, based on CPMs, with a new design of optical chamber and enhanced electronics, based on the Field Programmable Gate Array (FPGA) technology, was constructed at PTB, Germany [11]. The reported difference from the classical system is –1.74% for ^{3}H, in agreement with our results. Following these efforts of miniaturization of the TDCR-LSCs, the commercial Hidex 300 SL normal and "Metro" versions, produced by Hidex Oy, Finland, is an option for on site ^{3}H activity measurement.

(ii) *Standardization* of ^{99}Tc*,* radionuclide of interest in Nuclear Energy. It is a pure beta emitter with moderate end point energy, 293.8 keV, second forbidden transition, with a form factor $\lambda_2 = (0.54 \pm 0.02)$. A preliminary comparison, regarding the processing of a set of measurement data of the NIST, USA, was organized. The results were situated in two distinct groups, one consistent with the CRV and CIEMAT/NIST(CEN) method and another, including our result, with a 2% lower value; we had used the program TDCR06b, offered by Dr. P. Cassette [12]. In this new comparison, CCRI(II)-K2.Tc-99, having as pilot laboratory NPL, UK, we applied two parallel methods: LSC-TDCR and 4πPC-γ tracing method, using a ^{60}Co standard solution as tracer [13]. In the case of the liquid scintillation method, we prepared 3 plastic and 3 glass vials and used both Hionic Fluor and Ultimagold LLT scintillators. The influence of vial material, scintillator, long term stability and value of k_B were followed; k_B was chosen as $k_B = 0.012$ cm MeV^{-1}. The last version of program, TDCR07c, offered also by Dr. Cassette, taking into account the non symmetry of photomultipliers, was applied. For the reporting of the result we evaluated a combined uncertainty, u_c = 0.40%. In the case of the tracer method, when applying the extrapolation procedure for a number of 6 sources, prepared from mixed solution, we obtained a linear extrapolation graph and a value of activity by 0.69% less then in the case of TDCR-LSC; due to the higher value u_c = 0.98% this measurement was reported only as a supplementary one.

2.2. PRIMARY RADON STANDARD: RADON GENERATION AND STANDARDIZATION – NATIONAL PROJECT 71–102, 2007–2010

In applying the Liquid Scintillation (LS) method for the absolute standardization of ^{222}Rn, two type of problems occur: the correction for the decay of ^{214}Po during the dead time of the counter and construction of a system for ^{222}Rn generation from a ^{226}Ra source, its circulation, quantitative recovery, aimed at the construction of a metrological traceability chain from primary to secondary standards, as the LS method is a destructive one.

The absolute standardization of the ^{222}Rn, in equilibrium with its short life daughters, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, by using the liquid scintillation counting (LSC) had been performed at LNHB by a Franco-Romanian team, Cassette *et al.* [14].

2.2.1. LSC measurements and correction for the decay of ^{214}Po

The basic equations for activity calculation, considering a 100% detection efficiency in LS for alpha and high energy beta rays of the entire short life decay chain, are [14]:

$$R = R_0\left[1-0.0008576\tau\left(1+\tfrac{\tau}{2}(\rho-\lambda)\right)\right];\ R_0 = 5.0242 \cdot A_{\mathrm{Rn222}}. \quad (1)$$

R and R_0 are counting rates, A_{Rn222} is the activity of radon, ρ is true counting rate in absence of any dead time, τ is the base dead time of the counter and λ is the decay constant of ^{214}Po (Monographie BIPM-5, 2008).

2.2.2. Construction of primary radon system at IFIN-HH

First step was the construction of a glass ^{222}Rn system, and development of the absolute standardization method by LSC, solving the problem of ^{214}Po decay correction [15].

The second step was the construction of the metal system, provided with all the gauges for the control of radon generation, circulation and recovery, in order to assure the realization of the metrological traceability chain from primary to secondary standards.

2.2.3. Realization of the metrological traceability chain

The principle of traceability chain, as presented in [16], is based on: (i) transfer of radon from a gas vial to a LS ampoule and controlled recovery of the remaining gas; (ii) combination of the primary (absolute) standardization of the LS ampoule with the secondary (relative) measurements by gamma-ray spectrometry and ionization chamber.

Tables 1 and 2 present the results obtained in the calibration of the HPGe spectrometer and of the CENTRONIC IG12/20A ionization chamber, for gas and LS dissolved radon, 20 ml filled ampoules and vials.

Table 1

Efficiency of the HPGe spectrometer

Recipient /type	Energy keV	$\varepsilon_{radon} \times 10^4$, [s^{-1} $Bq^{-1}{}_{radon}$] Transfer from LSC
ampoule /gas	352 ^{214}Pb	1.160 ± 0.014
	609 ^{214}Bi	0.960 ± 0.013
vial /gas	352 ^{214}Pb	1.152 ± 0.018
	609 ^{214}Bi	0.937 ± 0.015
ampoule/LS	352 ^{214}Pb	0.989 ± 0.010
	609 ^{214}Bi	0.800 ± 0.009

Table 2

Calibration factor of the ionisation chamber

Recipient/ type	*K*, pA/MBq of ^{222}Rn
ampoule/gas	53.00 ± 0.63 transfer from LSC
vial/ gas	51.91 ± 0.02 transfer from LSC
ampoule /LS	50.45 ± 0.15 absolute measurement

2.2.4. Study of detection efficiency in LS

This study quantified the influence of detection of radon chain radiations in LS, the amount of radon non dissolved in LS, collection of light in photocathode. It was done with two types of comparative measurements: (i) ampoules containing various quantities of LS (ii) ampoules measured with the two LS counters of RML, [17].

Conclusions of the experiment:

(i) The classical 3PMTs system measurement. $\varepsilon_\beta = 1$ in all cases; ε_{geom} values rise with the degree of LS filling of the ampoules.

(ii) The 6CPMs system measurement. $\varepsilon_\beta < 1$ in all cases and depends on the collection of the light on the photocathodes, which is different for the three ampoules.

Conclusion from the entire project. The system allows to obtain recipients with radon as gas or dissolved in liquid scintillator, having the activity certified; these recipients follow to be used for the calibration of the radon chamber, under construction at RML, and to participate at international comparisons.

2.3. RELATIVE MEASUREMENTS

2.3.1. Gamma-ray spectrometry

The HPGe system was calibrated for ^{222}Rn decay chain as presented at section 2.2.3.

The implementation of the Monte Carlo program in the system and calculation of the efficiency for various metallurgical samples within the Joint Research Project (JRP) EURAMET, EMRP, IND04-Metrometal, WP3, was finalized by its validation through the comparison with various other Monte Carlo programs.

The system was also used for the determination of the emission intensities of gamma-rays of ^{124}Sb , ^{64}Cu and ^{68}Ga [18], ^{177}Lu and ^{186}Re.

It was also used for characterization of the radioactive content in various furnace slag matrices, to be used for preparation of ^{226}Ra standards [19], IND 04 MetroMetal.

The measurements of radioactive content of various contaminated matrices, to be used as reference materials, were performed within the frame of several supplementary comparisons and interlaboratory comparisons (ILCs), organized within the IND04-MetroMetal.

2.3.2. Ionization chamber CENTRONIC IG12/20A

A list of 18 radionuclides was reported in the paper [20]. Recently it was completed with the calibration for ^{18}F [5], ^{64}Cu and ^{68}Ga [6], ^{177}Lu [9] ,^{186}Re, and ^{222}Rn chain, Section 2.2.3.

2.4. PARTICIPATION AT NUCLEAR DECAY DATA PROJECTS

The activities were deployed within the frame of international projects like:

– Evaluation of nuclear decay data (IAEA CRP F42006, DDEP) for ^{234}Th, ^{228}Ra, ^{211}Bi, ^{211}Po and ^{113}Sn [21, 22].

– Decay data evaluations (IAEA CRP F41029, 2012–2015): ^{52}Fe, ^{52,52m}Mn, ^{230}U and ^{226}Th (work in progress).

– Measurement of photon emission intensities according to Section 2.3.1.

2.5. NEW NATIONAL PROJECT ON RADON MEASUREMENT

Realization of a Radon Chamber – Calibration Stand for the Equipment Used in the Measurement of Radon and Daughter Products Concentration in Air. CARSTEAM, Contract no. 141/2012 (2012–2016): IFIN-HH, University of Bucharest – Faculty of Physics, ICSI – Rm. Valcea.

The realization of the project is a logical continuation of the finalized primary radon standard project, which was concluded by two propositions of application:

– to distribute certified radon standards to the end users;
– to construct a radon chamber at IFIN-HH, in order to assure calibration services for them.

The radon chamber was designed to meet the requirements of the ICE standard 61577 – "Radiation protection instrumentation – Radon and radon decay product measuring instruments".

It has a useful volume of 1 m^3 and will be fed with radon either as radon gas standards (static regime), or directly connected to the ^{226}Ra source (dynamic regime). The design is finalized and the construction of mechanical components started; other components were purchased.

3. INTERNATIONAL AFFILIATION AND INTERNATIONAL ACTIVITIES

3.1. AFFILIATIONS

IFIN-HH is a member of the International Committee for Radionuclide Metrology (ICRM), presenting regularly papers at the biennial Conferences; it is a member of the CIPM-CCRI(II), presenting reports and updated lists of papers. It is also an active member of DDEP, organizing workshops as: 2008, 2009, 2013 and 2014 and participating with papers at other workshops. IFIN-HH is an associated member of EURAMET; RML presents annual reports to the Technical Committees: TC-IR and to the TC-Q, together with the IFIN-HH Dosimetry Laboratory.

3.2. PARTICIPATION IN INTERNATIONAL COMPARISONS

The RML participated at many key and supplementary comparisons, as part of: (i) validation of its equipment and methods; (ii) support for recognition of the declared Calibration and Measurement Capability files (CMCs); (iii) its participation in international projects.

3.2.1. Recent key comparisons

BIPM,RI(II)-K1.Co-57, 2008. The extrapolation coincidence method was used. The results are published in [23].

BIPM.RI(II)-K1.Cs-137, 2009. The efficiency tracer method, using ^{134}Cs standard solution and calibration of the ionization chamber methods were used. The result is published in [24].

CCRI(II)-K2.H-3, 2009. The measurements were described at Section 2.1.2 and in [11]. The combined standard uncertainty, u_c, reported for the comparison was 0.88%.

CCRI(II)-K2.Lu-177, 2009, pilot laboratory NIST, USA, and *BIPM RI(II)-K1.Lu-177*, 2013. Our first result was 3% higher than the Comparison reference value; the new measurements are described in [9] and an ampoule was sent to the BIPM-SIR; the preliminary IFIN-HH result is in good agreement with the SIR arithmetic mean.

CCRI(II)-K2.Tc-99, 2012, described at Section 2.1.2. and in [13], pilot laboratory, NPL. The results are under analysis at BIPM.

BIPM.RI(II)-K4Tc-99m [TI], 2013. This comparison was done at IFIN-HH, RML with the participation of Dr. Carine Michotte from BIPM; the measurements were done by two methods: 4πPC-γ coincidence [25] and ionization chamber. The comparison report was published [26].

3.2.2. Supplementary comparisons

CCRI(II)-S6.Co-57, 2008. Supplementary comparison of a ^{57}Co solution, part of the IAEA CRP No. E2.10.05. The results are published in [27]

EUROMET project 907, 2008. ^{124}Sb activity measurement and determination of photon emission intensities. Details were presented in Section 2.1.1 and [3]. RML result agrees with the comparison mean.

CCRI(II)-S7, 2009. Evaluation and reporting of uncertainty budget in the application of the 4πPC-γ coincidence method for standardization of a ^{60}Co solution, BIPM – NPL, IRA-METAS.

CCRI(II)-S8, 2010–2011. "Comparison on ^{40}K, ^{137}Cs and ^{90}Sr activity content in dried bilberry material", organizer the JRC-IRMM, Belgium. We determined ^{40}K and ^{137}Cs concentration, using the gamma-ray spectrometry.

CCRI(II)-S9, 2011–2012. "Supplementary comparison on ^{137}Cs and ^{40}K activity concentrations in KRISS rice powder reference". The measurements were performed by gamma-ray spectrometry and results are still under analysis at KRISS.

CCRI(II)-S10.LASCE, 2012–2013. “Large area sources comparison exercise”. The windowless large area proportional counter type DEXTRAY AB710 $(250 \times 400 \times 30)$ mm^3, offered by LNHB. A set of 4 sources: ^{241}Am (alpha); ^{14}C, ^{147}Pm, $^{90}(Sr+Y)$ (beta) were measured directly in the plateau region, with a 0.5 keV discrimination threshold. The emission rates in 2πsr geometry and the uniformity for one source were reported. The results were used to calibrate the window large area counter. The important finding was that the previous determined efficiencies of the counter, ε, in s^{-1}/(part/s in 2πsr), were in good agreement with those new determined values.

Interlaboratory Comparisons (ILCs) within the EURAMET-EMRP IND04-MetroMetal, 2013–2014, regarded metallurgical samples, as follows: 2 cast steel contaminated with ^{60}Co; 4 slag samples with ^{60}Co, ^{137}Cs and ^{226}Ra; 1 fume dust with ^{137}Cs and a small activity of ^{60}Co. The samples were prepared by PTB, Germany and CIEMAT, Spain and the comparisons were organized by the JRC-IRMM, Belgium.

3.3. PARTICIPATION AT INTERNATIONAL PROJECTS

3.3.1. EURAMET-EMRP, under article A169

JRP ENG08. Joint Research Project (JRP) – Contract: Metrology for new generation nuclear power plants. Metrofission, Coordinator, NPL-UK, 2010–2013. RML participated in WP8, organizing a Workshop in June 2013, during the ICRM2013 Conference, Antwerp, Belgium. One member of RML was awarded 6 months EURAMET Mobility Grant (EMR) at ENEA, Italy.

JRP IND04 – Ionizing radiation Metrology for Metallurgical Industry. MetroMetal, Coordinator, CIEMAT – Spain, 2012–2014. RML participates in WP2, WP3 and WP5. All the responsibilities assumed up to now were accomplished, as reported. A young member of RML was awarded a 3 months Early Stage Mobility Grant (ESRMG) at CIEMAT, Spain.

JRP ENV54 – Metrology for Decommissioning Nuclear Facilities. MetroDecom. Coordinator: CMI, Czech Republic, 2014–2017.

3.3.2. IAEA Coordinated Research Projects participation

E.2.10.05 “Harmonization of quality practices for nuclear medicine radioactivity measurements”, Contract no.12921/2004–2008, ROM.

F.4.20.06 “Updated decay data library for actinides”, Contr. 13341/2005–2008, ROM.

F.4.10.29 “Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production”, Contr.17442/2012–2016 ROM, under way.

3.4. BILATERAL COLLABORATION

The collaboration accord with LNHB-France, renewed in 2010, is under operation. The Joint Research & Development Project, IFA-CEA no. C2-05/01.03.2012, is part of this accord.

4. QUALITY SYSTEM OF THE LABORATORY

4.1. CALIBRATION AND MEASUREMENT CAPABILITIES (CMC) AND THE QUALITY SYSTEM

A number of 37 CMCs, including 3 new files and others completed with new key comparisons as technical support, for mono-nuclide solutions, were approved by the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) and published in CIPM-MRA, Annex C, in October 2013.

The Quality System of the IFIN – Ionizing Radiations Metrology Laboratory, according to the EN ISO/IEC 17025:2005, was reported and reconfirmed annually by the EURAMET TC-Q, as a basis for CMCs coverage.

4.2. NATIONAL ACCREDITATION

Designation. The RML is designated as a calibration laboratory for the Romanian units operating in the nuclear field, through the Notification of the National Nuclear Authority (CNCAN); the most recent notification was obtained in 2013.

Accreditation by the national body, RENAR. The laboratory obtained in 2009 the accreditation by the Romanian Accreditation Body (RENAR), according to EN ISO/IEC17025:2005, for two types of operations: Calibration of radioactive sources and Testing-measurement of the low level activities by gamma-ray spectrometry, on the site of the RML.

During 2012–2013 RML extend the accreditation for the calibration of measurement equipment at the users' site and in 2013 obtained a four-years reaccreditation.

5. RADIOACTIVE STANDARDS AND METROLOGY SERVICES

5.1. RADIOACTIVE STANDARDS DELIVERY

RML continued to prepare and deliver standard radioactive sources to various users.

5.2. CALIBRATION SERVICES AND HIGH PRECISION MEASUREMENTS

Standard sources, produced by our laboratory, or imported, were standardized and certified for various users.

A significant work was devoted to the hospitals' and IFIN-HH radioisotope calibrators, which were calibrated with standard solutions of the SPET radionuclides I-131, Tc-99m and the new PET radionuclides Ga-68 and F-18, in order to assure the metrological traceability [28].

New calibration services for measurement equipment, as: HPGe and NaI(Tl) spectrometers, gross alpha and beta activity measurement instruments, liquid scintillation counters, alpha particle spectrometers, were done at the users' site, throughout the country.

5.3. NATIONAL INTERCOMPARISONS, PROFICIENCY TESTS

One proficiency test was organized, on the requirement of the Romanian National Sanitary Veterinary and Food Safety Authority (ANSVSA), serving for the evaluation of the accredited laboratories performing the analysis of the radioactive content of the foodstuff samples. It consisted from the preparation and distribution of volume sources, with a water equivalent matrix, containing a mixture of ^{134}Cs and ^{137}Cs, with a nominal sum activity of 1000 Bq, to be measured by the gamma-ray spectrometry. 13 accredited laboratories of the network took part in the exercise. The test was repeated among the gamma-ray spectrometry accredited/notified laboratories from IFIN-HH, using a source from the set, circulated by the round robin method, [29].

6. CONCLUSIONS

The Radionuclide Metrology Laboratory from IFIN-HH has obtained good results, during the last 5 years period, in the following directions:

- development of the methods for absolute standardization of radionuclides: new positron emitters, new beta-gamma and low energy pure beta emitters;
- realization of the primary radon standard and starting the construction of a radon calibration chamber;
- participation in international projects, like DDEP, EURAMET-EMRP, IAEA-CRPs;
- participation at a significant number of international key and supplementary comparisons;
- widening of the area of metrology services for the national end users, with the calibration of the measurement equipment.

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REFERENCES

1. Maria Sahagia, *Main Research Area and International Activities of the Radionuclide Metrology Laboratory from IFIN-HH*, Second workshop for radioactive Decay Data Evaluators, DDEP 2008, Bucharest, Romania, May 12–14, 2008; http://www.nipne.ro/ddep2008/contributions.php.
2. E.L. Grigorescu, M. Sahagia, A.C. Wätjen, C. Ivan, A. Luca, A. Antohe, *Contribution of the Radionuclide Metrology Laboratory to the improvement of the methods for absolute standardization*, Second European Nuclear Physics Conference (EuNPC 2012), Bucharest, Romania, September 17–21, 2012, http://www.nipne.ro/eunpc2012/.
3. B. Chauvenet, M-M. Be, M-N. Amiot, C. Bobin, M-C. Lepy, T. Branger, I. Laniece, A. Luca, M. Sahagia, A.C. Watjen, K. Kossert, O. Ott, O. Nahle, P. Dryak, J. Sochorova, P. Kovar, P. Auerbach, T. Altzizoglou, S. Pomme, G. Sibbens, *et al*., *International exercise on Sb-124 activity measurement*. Appl. Rad. Isotopes. **68**, 1207–1210 (2010).
4. M. Sahagia, R. Ioan, A. Antohe, A. Luca, C. Ivan, *Measurement of positron emitting radionuclides' activity and their use for the calibration of the PET calibrators*, Fourth European IRPA Congress, Geneva, Switzerland, June 23–27, 2014, Extended Abstract, PS5-4 Dosimetry &Measurement/36, pp. 279 282, http://www.irpa2014europe.com.
5. M. Sahagia, R. Ioan, A. Luca, A. Antohe, C. Ivan, B. Neacsu, C. Ghioca, *Standardization of F-18 and its use for the Romanian PET metrological traceability chain assurance,* Appl. Radiat. Isot. **87**, *14–18* (2014).
6. M. Sahagia, A. Luca, A. Antohe, C. Ivan, *Standardization of ^{64}Cu and ^{68}Ga by the 4πβ(PC)-γ coincidence method and calibration of the ionization chamber*, Appl. Radiat. Isot. **70**, *9*, 2025–2030 (2012).
7. M. Sahagia, R. Ioan, A. Luca, A. Antohe, C. Ivan, *Standardization of ^{124}I by the 4πβ(PC) – γ coincidence method and study of the decay scheme parameters*, Internal report IFIN-HH, 2014.
8. M. Sahagia, A.C. Razdolescu, E.L. Grigorescu, A. Luca, C. Ivan, *Precise measurement of the activity of ^{186}Re, ^{188}Re pharmaceuticals*, Appl.Radiat.Isot. **56**, *1–2*, 349–356 (2002).
9. R. Ioan, M. Sahagia, A. Luca, A. Antohe, C. Ivan, *Measurement of ^{177}Lu activity and assurance of the international and national metrological traceability for its use in nuclear medicine*, Fourth European IRPA Congress, Geneva, Switzerland, June 23–27, 2014, Extended Abstract.PS5-1 Dosimetry &Measurement/08, pp. 67–71, http://www.irpa2014europe.com.
10. C. Ivan, A.C. Watjen, Ph. Cassette, M. Sahagia, A. Antohe, E.L. Grigorescu, *Participation in the CCRI(II)-K2.H-3 comparison and study of the new TDCR-LS counter with 6 CPMs*, Appl.Radiat.Isot. **68**, 1543–1545 (2010).
11. O. Nahle, Qi Zhao, C. Wanke, M. Weierganz, K. Kosert, *A portable TDCR system*, Appl. Radiat.Isot. **87**, 249–253 (2014).
12. B.E. Zimmerman, T. Altzitzoglou, D. Rodrigues, R. Broda, P. Cassette, L. Mo, G. Ratel, B. Simpson, W. van Wyngaardt, C. Watjen, *Comparison of triple-to-double coincidence ratio (TDCR) efficiency calculations and uncertainty assessments for ^{99}Tc*, Appl. Radiat. Isot. **68**, 1477–1481 (2010).
13. M. Sahagia, A. Antohe, R. Ioan, A. Luca, C. Ivan, *Standardization of Tc-99 by two methods and participation at the CCRI(II)-K2.Tc-99 comparison*, Appl. Radiat. Isot. **87**, 410–413 (2014).
14. P. Cassette, M. Sahagia, E.L. Grigorescu, M.C. Lepy, J.L. Picolo, *Standardization of ^{222}Rn by LSC and comparison with α- and γ-spectrometry*, Appl. Radiat. Isot. **64**, 1465–1470 (2006).

15. M. Sahagia, D. Stanga, A.C. Waetjen, A. Luca, P. Cassette, C. Ivan, A. Antohe, *The Rn-222 standard system established at IFIN-HH, Romania*, Appl. Radiat. Isot. **68**, 1503–1506 (2010).
16. M. Sahagia, A. Luca, A.C. Watjen, A. Antohe, C. Ivan, C. Varlam, I. Faurescu, P. Cassette, *Establishment of the Rn-222 traceability chain with the Romanian Standard System*, Nuclear Instrum. and Meth. in Phys. Res. A **631**, 73–79 (2011).
17. A. Antohe, M. Sahagia, A. Luca, P. Cassette, C. Ivan, *Influence of detection efficiency on the measurement of radon by liquid scintillation counting*. In: P. Cassette (Ed). LSC 2010. *Advances in Liquid Scintillation Spectrometry. Radiocarbon*, Tucson, AZ, pp. 189–197.
18. A. Luca, M. Sahagia, A. Antohe, *Measurement of Cu-64 and Ga-68 half-lives and gamma-rays emission intensities*, Appl. Radiat. Isotopes **70**, *9*, 1876–1880 (2012).
19. M. Sahagia, A. Luca, R.M. Margineanu, N. Navarro Ortega, V. Peyres, B. Perez Lopez, E. Garcia Torano, J.A. Suarez-Navarro, *Determination of the content of natural radionuclides in furnace slag used for the preparation of standard sources*, J.Radioanal.Nucl.Chem. **298**, 2037–2044 (2013).
20. M. Sahagia, A.C. Waetjen, A. Luca, C. Ivan, *IFIN-HH ionization chamber calibration and its validation; electrometric system improvement*, Appl.Radiat.Isotopes **68**,1266–1269 (2010).
21. A. Luca, *Evaluation of Th-234 nuclear decay data*, Appl.Radiat.Isot. **68**, 1591–1594 (2010).
22. A. Luca, M.-C. Lépy, *Measurements of relative photon emission intensities and nuclear decay data evaluation of Sn-113*, Appl. Radiat Isot. **70**, *9*, 1881–1885 (2012).
23. C. Michotte, G. Ratel, S. Courte, R. Fitzgerald, M. Sahagia, *Activity measurements of the radionuclide ^{57}Co for the NIST, USA and the IFIN-HH, Romania in the ongoing comparison BIPM.RI(II)-K1.Co-57*, Metrologia, **49**, Tech. Suppl. 06005 (2012).
24. C. Michotte, G. Ratel, S. Courte, I.A. Kharitonov, A.V. Zanevsky, M. Sahagia, F. van Wyngaardt, M. van Staden, J. Lubbe, B. Simpson, F.J. Maringer, R. Brettner-Messler, *Update of the BIPM comparison BIPM.RI(II)-K1.Cs-137 of activity measurements of the radionuclide 137Cs to include the 2007 results of the VNIIM (Russia), the 2009 result of the IFIN-HH (Romania), the 2010 result of the NMISA (South Africa) and the 2011 result of the BEV (Austria)*, Metrologia **50**, Tech. Suppl. 06014 (2013).
25. M. Sahagia, *Standardization of ^{99m}Tc*, Appl. Radiat. Isot. **64**, 1234–1237 (2006).
26. C. Michotte, M. Sahagia, M. R. Ioan, A. Antohe, A. Luca, *Activity measurements of the radionuclide 99mTc for the IFIN-HH, Romania in the ongoing comparison BIPM.RI(II)-K4.Tc-99m*, Metrologia **51**,Tech. Suppl. 06014 (2014).
27. B.E. Zimmerman, S. Palm, *Results of an international comparison of ^{57}Co*, Appl. Radiat. Isot. **68**, 1217–1220 (2010).
28. M. Sahagia, *12 Chapters on Nuclear Medicine*, Chapter 6 “Role of the Radionuclide Metrology in Nuclear Medicine”, pp. 137–164, December 2011, Publisher InTech, Croatia.
29. M. Sahagia, A. Antohe, A. Luca, C. Ivan, *Results of proficiency tests on the measurement of volume radioactive sources from the mixture ^{134}Cs and ^{137}Cs*, Rom. Rep. Phys. **63**, 1195–1204 (2011).