

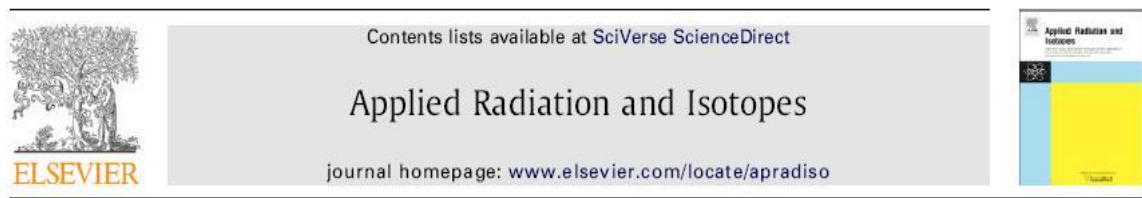
**LISTA DE PUBLICATII A PROIECTULUI: PN-II-ID-PCE-2011-3-0070,
Ctr. 23/05.10.2011. Etalonarea absoluta si studiul datelor de dezintegrare ale emitatorilor
de pozitroni folositi in sisteme PET. Asigurarea trasabilitatii metrologice.**

**Director de proiect,
Dr. Maria Sahagia**

(i) Lucrari publicate

- 1. M. Sahagia, A. Luca, A. Antohe, C. Ivan.** *Standardization of ^{64}Cu and ^{68}Ga by the $4\pi(\text{PC})\beta\text{-}\gamma$ coincidence method and calibration of the ionization chamber.* Applied Radiations and Isotopes, 70, 9(2012)2025-2030

Applied Radiation and Isotopes 70 (2012) 2025–2030



**Standardization of ^{64}Cu and ^{68}Ga by the $4\pi(\text{PC})\beta\text{-}\gamma$ coincidence method
and calibration of the ionization chamber**

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ARTICLE INFO

Available online 3 March 2012

Keywords:

PET radionuclides ^{64}Cu

^{68}Ga

Efficiency extrapolation

Ionization chamber calibration

ABSTRACT

The paper treats the application of the $4\pi(\text{PC})\beta\text{-}\gamma$ coincidence method for the standardization of the radionuclides ^{64}Cu and ^{68}Ga . The general coincidence equations are written. Two types of extrapolation were described and used in measurement: the positron-annihilation coincidence, and the counting of all emitted radiations; both methods are compared with respect to results, advantages and drawbacks. The impurities' content correction was applied. The standardized solutions were used to calibrate the ionization chamber CENTRONIC IG12/20A and to determine the gamma-rays emission intensities.

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2. M.-M.Bé, P.Cassette, M.-N. Amiot, M.C.Lépy, C.Bobin, K.Kossert, O.J.Nahle, O.Ott, C.Wanke, P.Dryak, G.Ratel, **M. Sahagia, A. Luca, A. Antohe**, L.Johansson, J.Keightley, A.Pearce.*Standardization, decay data measurements and evaluation of ^{64}Cu* . Applied Radiations and Isotopes, 70, 9(2012)1894-189

Applied Radiation and Isotopes 70 (2012) 1894–1899



Contents lists available at SciVerse ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso



Standardization, decay data measurements and evaluation of ^{64}Cu

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ARTICLE INFO

Available online 28 February 2012

Keywords:

^{64}Cu standardization

^{64}Cu decay scheme

Half-life

γ -Ray intensities

x-Ray intensities

ABSTRACT

The purposes of this study were to create national activity standards of ^{64}Cu , to make possible the definition of an international key comparison reference value and to determine the decay data in order to improve the decay scheme. Four laboratories measured the activity of a ^{64}Cu solution; these results were compared through the International Reference System. Moreover, the laboratories carried out new measurements of the photon emission intensities and of the half-life. A new decay scheme was derived from these new values and the previously published ones.

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3. A. Luca, M. Sahagia, A. Antohe. *Measurements of ^{64}Cu and ^{68}Ga half-lives and gamma-ray emission intensities*. Applied Radiation and Isotopes, 70, 9(2012)1876-1880

Applied Radiation and Isotopes 70 (2012) 1876–1880



Contents lists available at SciVerse ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso



Measurements of ^{64}Cu and ^{68}Ga half-lives and γ -ray emission intensities

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ARTICLE INFO

Available online 25 February 2012

Keywords:

^{64}Cu

^{68}Ga

Half-life

Gamma-ray emission intensities

Gamma-ray spectrometry

Well-type ionization chamber

ABSTRACT

The ^{64}Cu and ^{68}Ga half-lives and γ -ray intensities were measured at IFIN-HH. The determination of absolute photon emission intensities was based on absolute activity standardizations carried out in this laboratory using the $4\pi\text{PC}-\gamma$ coincidence method. The half-lives were measured with a well-type ionization chamber. The photon emission intensities (relative and absolute values) were measured with a calibrated high-resolution γ -ray spectrometer. The results obtained and their uncertainties are discussed and compared with values of other authors.

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4. M. Sahagia, A. Antohe, A. Luca, A. C. Wätjen, C. Ivan, „The Support Offered by the Romanian Primary Activity Standard Laboratory to the Nuclear Medicine Field”, [abstractnumber.doc2353248](#), Congress IRPA13, Glasgow, 2012, Proc., published in Rom. J.Phys.vol.58,nos.1-2(2013)106-116

NUCLEAR MEDICINE

THE SUPPORT OFFERED BY THE ROMANIAN PRIMARY ACTIVITY STANDARD LABORATORY TO THE NUCLEAR MEDICINE FIELD*

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Received May 23, 2012

The paper presents the involvement of the Radionuclide Metrology Laboratory from IFIN-HH, Romania, in the assurance of the correct measurement of radiopharmaceuticals activity in nuclear medicine. Development and international validation of primary standards, development of secondary standards and direct support offered to the domain, consisting from calibration services and organization of comparisons/proficiency tests, are presented. Analysis of the results obtained in the calibration of several types of radionuclide calibrators during a six years period is done. It includes the following actions: check of the measurement uncertainty, recalibration when necessary, control of the calibrators' behavior in time. A comparison between calibration check and the results of the participation of the staff at proficiency tests is done.

Key words: radiopharmaceutical, primary activity standard, International System of Units (SI), radionuclide calibrator, metrology services.

* Paper presented at the 13th International Congress of the International Radiation Protection Association, IRPA13, Glasgow, Scotland, 13-18 May 2012.

Rom. Journ. Phys., Vol. 58, Nos. 1–2, P. 106–116, Bucharest, 2013

5. M. Sahagia^{*}, R. Ioan, A. Luca, A. Antohe, C. Ivan, B. Neacsu, C. Ghioca. *Standardization of ^{18}F and its use for the Romanian PET metrological traceability chain assurance* published in Applied Radiation and Isotopes, 87(2014)14-18

Applied Radiation and Isotopes 87 (2014) 14–18



Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso



Standardization of ^{18}F and its use for the Romanian PET metrological traceability chain assurance



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HIGHLIGHTS

- Presents establishment of the ^{18}F FDG Romanian PET traceability chain.
- Shows work at IFIN-HH and at the users' site.
- An ^{18}F solution was standardized by the $4\pi\beta(\text{PC})-\gamma$ coincidence method.
- Includes measurement of half-life for detection of positron emitting impurities.
- CENTRONIC IG12/20A ionization chamber and radionuclide calibrators calibrated.

ARTICLE INFO

Available online 27 November 2013

Keywords:

^{18}F

$4\pi\beta(\text{PC})-\gamma$ coincidence method

Gamma-ray spectrometry

Half life

Ionization chamber

Radionuclide calibrator

ABSTRACT

This paper presents the work performed at IFIN-HH and at the users' sites, aimed to establish the ^{18}F FDG Romanian PET traceability chain. It summarizes the operations: (i) Absolute standardization of a ^{18}F solution, by the $4\pi\beta(\text{PC})-\gamma$ coincidence method; (ii) Control of gamma-ray impurity content and measurement of the activity by gamma ray spectrometry; (iii) Measurement of the half life, for detection of some short/long life positron emitter impurities; (iv) Calibration of the CENTRONIC IG12/20A ionization chamber; (v) Calibration of commercial radionuclide calibrators.

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6. 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.* Published in Applied Radiation and Isotopes 87(2014)410-413

Applied Radiation and Isotopes 87 (2014) 410–413



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Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso



Standardization of Tc-99 by two methods and participation at the CCRI(II)-K2. Tc-99 comparison



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HIGHLIGHTS

- Standardization of Tc-99 by two methods: TDCR and $4\pi(\text{PC})\beta\text{-}\gamma$ efficiency tracing.
- Combined uncertainty of the final result is lower with the TDCR method.
- Both methods give results in rather good agreement within the stated uncertainties.
- Using both methods gives a more robust result for the activity of Tc-99.
- New code version TDCR-07c of LNHB provides TDCR results in better agreement with the CCRI(II)-K2.Tc-99 comparison.

ARTICLE INFO

Available online 12 November 2013

Keywords:

CCRI(II)-K2.Tc-99 comparison

LSC-TDCR

$4\pi(\text{PC})\beta\text{-}\gamma$ efficiency tracer method

ABSTRACT

The work accomplished within the participation at the 2012 key comparison of Tc-99 is presented. The solution was standardized for the first time in IFIN-HH by two methods: LSC-TDCR and $4\pi(\text{PC})\beta\text{-}\gamma$ efficiency tracer. The methods are described and the results are compared. For the LSC-TDCR method, the program TDCR07c, written and provided by P. Cassette, was used for processing the measurement data. The results are 2.1% higher than when applying the TDCR06b program; the higher value, calculated with the software TDCR07c, was used for reporting the final result in the comparison. The tracer used for the $4\pi(\text{PC})\beta\text{-}\gamma$ efficiency tracer method was a standard ^{60}Co solution. The sources were prepared from the mixture $^{60}\text{Co} + ^{99}\text{Tc}$ solution and a general extrapolation curve, type: $N_{\beta\text{Tc-99}}/(M)_{\text{Tc-99}} = f[1 - \epsilon_{\text{Co-60}}]$, was drawn. This value was not used for the final result of the comparison. The difference between the values of activity concentration obtained by the two methods was within the limit of the combined standard uncertainty of the difference of these two results.

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7. M. Sahagia**, A. Luca, R. Ioan, A. Antohe, C. Ivan, B. Neacșu. *Metrological traceability assurance in production and use of radiopharmaceuticals for pet imaging and targeted radiotherapy*. Published in Rom. Journ. Phys., Vol. 59, Nos. 1-2, P. 119-130, Bucharest, 2014.

METROLOGICAL TRACEABILITY ASSURANCE IN PRODUCTION
AND USE OF RADIOPHARMACEUTICALS FOR PET IMAGING
AND TARGETED RADIOTHERAPY *

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*) Paper presented at the TRACE Workshop on Development of New Radiotracers for PET Imaging
and Targeted Radiotherapy, 03-05 April 2013, Magurele, Romania

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Received April 11, 2013

The paper presents the implication of the Radionuclide Metrology Laboratory (RML) from IFIN-HH in solving the problems connected with the quality assurance of radiopharmaceuticals in production and use, by assuring the metrological traceability in the control of the radiometrological parameters: measurement of activity and radioactive concentration, radionuclide purity as well as measurement of the decay scheme parameters. The following problems are treated: (i) Absolute standardization of PET radionuclides: ^{64}Cu and ^{68}Ga and study of their decay scheme parameters; absolute standardization of radionuclides used in targeted - molecular radiotherapy (MRT): ^{153}Sm , ^{177}Lu , $^{186,188}\text{Re}$ and ^{89}Sr ; calibration of the secondary standard ionization chamber and of some commercial radionuclide calibrators. (ii) Radionuclide purity analysis and its influence on the activity calculation. The aspects presented are an overview of published papers.

Key words: radionuclide metrology, absolute standardization, positron emitters, strong beta-weak gamma emitters

Rom. Journ. Phys., Vol. 59, Nos. 1-2, P. 119-130, Bucharest, 2014

8. IRPA - FS

Fourth European IRPA Congress. Radiation Protection Culture – A global challenge, June 23-27, 2014

Geneva, Switzerland, www.irpa2014europe.com

Abstract book Updated version 02.07.2014

Recenzata in publicatia

Radiation Protection Dosimetry (2015), Vol. 164, No. 1–2, pp. 179–180

doi:10.1093/rpd/ncv288

FOURTH EUROPEAN IRPA CONGRESS

23–27 June, 2014 – Geneva, Switzerland

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Lucrare publicata integral in Abstract book, pag. 279 - 282

IRPA 2014

PS5-4: MEASUREMENTS & DOSIMETRY

PS5-4/36 - Measurement of positron emitting radionuclides' activity and their use for the calibration of the PET calibrators.

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Romania

The paper presents the work deployed for the establishment of the metrological traceability chain for the calibrators used for the measurement of positron emission radionuclide based radiopharmaceuticals.

It refers to the following aspects:

- Absolute standardization of PET radionuclides: ^{18}F , ^{64}Cu , ^{68}Ga , ^{124}I , by the $4\pi\beta(\text{PC}) - \gamma$ coincidence method, using the detection of all emitted radiations and the efficiency extrapolation method.

- Calibration of the CENTRONIC IG12/20A ionization chamber for various types of recipients, to be used for the measurement of the radiopharmaceutical solution and establishment of the IFIN-HH secondary standard for PET radionuclides.

- Calibration of various types of PET radionuclide calibrators used in the radiopharmaceutical and nuclear medicine units.

Key words: positron emitting radionuclides, absolute standardization, traceability chain, radionuclide calibrators



Measurement of ^{124}I



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HIGHLIGHTS

- Absolute standardization of ^{124}I solution by the $4\pi\beta(\text{PC})$ - γ coincidence method.
- Calibration of the CENTRONIC IG12/20A ionization chamber.
- γ -ray spectrometry activity measurement and determination of impurities.
- Comparison of the results of the three methods.

ARTICLE INFO

Article history:
Received 4 March 2015
Accepted 3 December 2015
Available online 4 December 2015

Keywords:
 ^{124}I standardization
 $4\pi\beta(\text{PC})$ - γ coincidence method
ionization chamber
 γ -ray spectrometry

ABSTRACT

The paper describes the measurements performed at IFIN-HH regarding the creation of a Romanian ^{124}I standard, consisting of: absolute standardization of the solution by the application of the $4\pi\beta(\text{PC})$ - γ coincidence method; Calibration of the CENTRONIC IG12/20A ionization chamber with a standardised solution and comparison with a calculated efficiency; γ -ray spectrometry activity measurement and determination of the impurity levels; Comparison of the results of the three methods.

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Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradisoExperimental determination of some nuclear decay data in the decays of ^{177}Lu , ^{186}Re and ^{124}I 

Aurelian Luca*, Maria Sahagia, Mihail-Razvan Ioan, Andrei Antohe, Beatris Luminita Savu

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HIGHLIGHTS

- ^{177}Lu , ^{186}Re and ^{124}I studies are necessary for nuclear medicine applications.
- Accurate nuclear decay data needed for these nuclides were measured.
- Half-life values were determined using a $4\pi\gamma$ ionization chamber.
- Photon emission intensities were measured by gamma-ray spectrometry.
- These new results will be used for future nuclear decay data evaluations.

ARTICLE INFO

Article history:

Received 24 March 2015

Accepted 24 November 2015

Available online 2 December 2015

Keywords:

Photon emission intensity

Gamma-ray spectrometry

Half-life

 ^{177}Lu ^{186}Re and ^{124}I

ABSTRACT

A detailed experimental study of the radionuclides ^{177}Lu , ^{186}Re and ^{124}I was conducted at IFIN-HH, Radionuclide Metrology Laboratory. Absolute photon emission intensities in the decays of these radionuclides were measured by high-resolution gamma-ray spectrometry. Half-life measurements using a well-type ionization chamber were also performed. These new experimental results will be useful for the future updates of the existing nuclear decay data evaluations, offering reliable and accurate data for the users.

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11. M.Sahagia, A.Luca, A.Antohe, M-R.Ioan, C.Ioan. *Recent work and results of the radionuclide metrology laboratory from IFIN-HH.Rom. Rep. in Phys.* 68 No.1,(2016)177-190

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

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Received July 17, 2014

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.

(ii) Lucrari prezentate la Conferinte internationale/workshopuri

- Conference ICRM 2013: 19-th International Conference on Radionuclide Metrology and its Applications, ICRM 2013, Antwerp, Belgium, 17 – 21 June 2013, hosted by the European Commission – Joint Research Centre. Institute for Reference Materials and Measurements (IRMM).
<http://irmm.jrc.ec.europa.eu/icrm2013>

1. M. Sahagia*, R. Ioan, A. Luca, A. Antohe, C. Ivan, B. Neacsu, C.Ghioca. *Standardization of ^{18}F and its use for the Romanian PET metrological traceability chain assurance*” Poster P#005. Paper published in Applied Radiations and Isotopes

Standardization of ^{18}F and its use for the Romanian PET metrological traceability chain assurance

M. Sahagia*, R. Ioan, A. Luca, A. Antohe, C. Ivan, B. Neacsu, C. Ghioca
IFIN-HH, Monrol srl - Romania

- Establishment of the ^{18}F - Romanian PET traceability chain.
- Standardization of ^{18}F by the $4\pi\beta(\text{PC})$ - γ coincidence and by γ -ray spectrometry.
- Control of impurities and measurement of the half-life.
- Calibration of the CENTRONIC chamber and of commercial calibrators

Poster #005



Maria Sahagia



Session: Radionuclide metrology in life sciences

2. 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.* Poster P#004. Paper published in Applied Radiations and Isotopes

Standardization of Tc-99 by two methods and participation at the CCRI(II)-K2 Tc-99 comparison

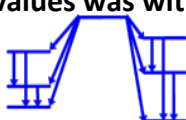
M. Sahagia*, A. Antohe, R. Ioan, A. Luca C. Ivan
IFIN-HH - Romania

- Participation at the 2012 key comparison of Tc-99 using LSC-TDCR and $4\pi(\text{PC})\beta$ - γ tracer
- LSC-TDCR method: program TDCR07c, copyright of P. Cassette; value used for reporting the result
- $4\pi(\text{PC})\beta$ - γ efficiency tracer method: tracer - standard ^{60}Co solution; value not used for reporting the result.
- Difference between the two determined values was within the limit of uncertainty

Poster #004



Aurelian Luca



Session: Intercomparisons

- **TRACE 2013 - Development of New Radiotracers for PET Imaging and Targeted Radiotherapy, IFIN-HH, Workshop, 3 – 5 April 2013 .**
- 1. **M. Sahagia, A.Luca, R.Ioan, A.Antohe, C.Ivan, B. Neacsu.** *Metrological traceability assurance in production and use of radiopharmaceuticals for PET imaging and targeted radiotherapy.* Oral presentation. Paper published in Romanian Journal of Physics



Metrological traceability assurance in production and use of radiopharmaceuticals for PET imaging and targeted radiotherapy

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 ROMANIA

TRACE **Workshop on Development of New Radiotracers for PET Imaging and Targeted Radiotherapy**
03-05 April 2013, Magurele Romania

- **Fourth European IRPA Congress, Radiation protection Culture – a global challenge, Geneva, Switzerland, June 23-27, 2014**
- 1. **M. Sahagia, M-R. Ioan, A. Antohe, A. Luca, C. Ivan.** *Measurement of positron emitting radionuclides' activity and their use for the calibration of the PET calibrators,* a fost prezentata ca poster

Measurement of positron emitting radionuclides' activity and their use for the calibration of the PET calibrators.

M. Sahagiu*, R. Ioan, A. Antohe, A. Luca, C. Ivan

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Introduction

The PETCT diagnosis procedures use radiopharmaceuticals based on the radionuclides decaying by positron emission. Their quality is defined by (i) chemical compound, (ii) radiometrical and physico-chemical characteristics, *European Pharmacopoeia*, 8th edition 2014-2016, determined by precise measurement of their activity. The Romanian Radiometric Metrology Laboratory (RML) is established within the IFIN-HH, Magurele - Bucharest, as a primary national standard. IFIN-HH is a designated institute in the field of ionizing radiations in the relation with the International Committee of Weights and Measures - Mutual Recognition Arrangement (CIPM - MRA). It assures the entire metrological traceability chain for all the radiopharmaceuticals in Romania. At this moment, practically the problem of the most used SPECT ^{123}I and $^{99\text{m}}\text{Tc}$ was solved. For ^{123}I we participated at the BIPM RI(II)-K1.1-131 key comparison G. Rati, C. Michotte, M. Sahagiu, T. S. Park, P. Dryak, J. Sechorova, F. Maringer and M. Kreuziger. *Metrologia Technical Supplement*, 45, 06007 (2008) and for $^{99\text{m}}\text{Tc}$ we participated at the key comparison SI-T1 in 2013. C. Michotte, M. Sahagiu, M. R. Ioan, A. Antohe, A. Luca BIPM RI(II)-K4.70-99m Report, 2014. We calibrate currently all the radionuclide calibrators belonging to the Romanian hospitals. M. Sahagiu, A. Antohe, A. Luca, A.C. Wajngen, C. Ivan, *Rev. J. Phys.* 58, 1-2 (2013) 106-116. The introduction of the PET radionuclides required us to standardize them absolutely and to assure the national traceability chain. The obtained results, some of them already published and others in the deployment, regarding a list of four PET radionuclides, ^{18}F , ^{68}Ga , ^{124}I , is presented in the paper

Absolute standardization of the radionuclides

The absolute standardization of these radionuclides was done by the $4\pi\beta(\text{PC})\gamma$ coincidence method, using an installation composed from two detection blocks - proportional counter (PC) and scintillation detector, NaI(Tl), with the electronic chains and a coincidence selector. A set of several solid sources, prepared gravimetrically from the solution, were measured, the activity and activity concentration were determined. The general coincidence equations, connecting the counting rates, N_β , N_γ , N_α , activity N_0 , decay scheme parameters a_i , and detection efficiencies ϵ_i , are

$$N_\beta = N_0 \sum_{r=1}^n a_r \epsilon_r \beta_r + (1 - \epsilon_r \beta_r) \epsilon_{\beta\gamma} \gamma; N_\gamma = N_0 \sum_{r=1}^n a_r \epsilon_r \gamma_r$$

$$N_c = N_0 \sum_{r=1}^n a_r \epsilon_r \beta_r \epsilon_{\gamma\gamma} + (1 - \epsilon_r \beta_r) \epsilon_{\beta\gamma} \epsilon_{\gamma\gamma}$$

When the variation of efficiency extrapolation is applied, the equations are written in an equivalent form, where K and $(1-K)$ are the extrapolation slopes

$$N_\beta = N_0 [1 - K(1 - \epsilon_r \beta_r)]$$

$$N_\gamma = N_0 [1 - K(1 - \epsilon_r \gamma_r)]$$

$$K = \frac{\sum a_r \epsilon_r \beta_r (1 - \epsilon_{\beta\gamma} \epsilon_{\gamma\gamma})}{\sum a_r \epsilon_r \beta_r (1 - \epsilon_{\beta\gamma} \epsilon_{\gamma\gamma})}$$

E.L. Grigorescu, M. Sahagiu, A. Razdolescu, C. Ivan. *Nucl. Instrum. and Methods Phys. Res. A* 369(1996) 414-420.

The above mentioned radionuclides are either almost pure positron emitters, such as ^{18}F (96.86% positron decay), or mixtures of beta and electron capture decays. ^{68}Ga (88.86% positrons), ^{68}Zn (56% beta plus/minus) and ^{124}I (22.7% positrons). M.-M. Ba et al. *Monographie BIPM-5. Table of Radionuclides*, Ed. Bureau International des Poids et Mesures, Pavillon de Breteuil, F-92310 Sevre, France, ISBN 92-922-2206-3, J. Katakura, Z.D. Wu. *Nuclear Data Sheets* 109, 7 (2008) 1655-1677. For higher the atomic numbers the weight of positron decays diminishes and $4\pi\beta(\text{PC})\gamma$ coincidence method in standardization must be adapted accordingly.

The extrapolation variant of the coincidence method was applied, adapted to the characteristics of the decay scheme. In the case of ^{18}F , only positrons on the beta channel, and annihilation quanta (511 keV) on the gamma channel, were counted. M. Sahagiu, R. Ioan, A. Luca, A. Antohe, C. Ivan, B. Neacsiu, C. Ghinea. *Appl. Radiat. Isot.* 87 (2014) 14-18. The radionuclide purity level was determined by the precise measurement of the half life and its comparison with the reference value. In the case of radionuclides ^{68}Ga and ^{124}I , both variants were applied: positron-annihilation quanta coincidence and counting of all emitted radiations on both detection channels. The radionuclide purity was determined in two different modes, for ^{68}Ga , the high resolution gamma-ray spectrometry was used for the impurities ^{68}Zn , ^{68}Ge , ^{68}Ga , the suspected impurity was ^{68}Ga father radionuclide, resulting also in ^{68}Ga . It was measured by the coincidence method. M. Sahagiu, A. Luca, A. Antohe, C. Ivan. *Appl. Radiat. Isotopes* 70, 9 (2012) 2026-2030. The results allowed us to determine their main decay scheme characteristics in good agreement with other participants within the EURAMET project 1085. A. Luca, M. Sahagiu, A. Antohe. *Appl. Radiat. Isotopes* 70(2012)1876-1880. M.-M. Ba, F. Cassano, M.C. Lopy, M.-N. Amet, K. Kowari, O.J. Ndiye, O. Ott, C. Wank, P. Dryak, G. Rati, M. Sahagiu, A. Luca, A. Antohe, L. Johansson, J. Keightley, A. Pearce. *Appl. Radiat. Isotopes* 70(2012)1894-1899

^{124}I is a relatively new positron emitter in use and takes the advantage of replacing the SPET ^{123}I (^{124}I) radiopharmaceuticals with a PET variant in the diagnosis of the Alzheimer disease, due to its longer half life, as compared with ^{123}I , ^{124}I allows deeper investigations of the biochemical processes. K.W. Chang, C.C. Chen, S.Y. Lee, L.H. Shen, H.E. Wang. *Appl. Radiat. Isot.* 67(2009)1397-1400. Only two papers were published up to now D.H. Woods, S.A. Woods, M.J. Woods, J.L. Wakepeace, C.A. Downey, D. Smith, A. Munster, S.E. M. Lucas, H. Sharma. *Appl. Radiat. Isot.* 43, 4 (1993) 581-585; S.M. Qaim, T. Bisinger, K. Hergers, D. Nayak, H.H. Coenen. *Radiation. Acta* 35 (2007) 67-73. An analysis on positron emitters' standardization status was done in B.E. Zimmerman. *Appl. Radiat. Isot.* 76(2013)31-37. In our work, under deployment, we propose to use of the $4\pi\beta(\text{PC})\gamma$ coincidence method with the counting of all positrons, Auger electrons and x-rays, in the flow proportional counter, working at the atmospheric pressure and the setting of several counting windows on the gamma channel. The final results will be presented in the paper: M. Sahagiu, R. Ioan, A. Luca, A. Antohe, C. Ivan. *Standardization of ^{124}I by the $4\pi\beta(\text{PC})\gamma$ coincidence method and study of the decay scheme parameters*. Internal report IFIN-HH, 2014.

Calibration of the secondary standard, ionization chamber

The RML disposes of a CENTRONIC IG12/20A ionization chamber, which serves as basis for the transmission of the activity unit value to the commercial radionuclide calibrators. The calibration factor F of the chamber, expressed as pA/MBq of solution, was determined experimentally using recipients with standard solutions. An evaluation of the chamber efficiency, ϵ_0 , expressed also in units pA/MBq, was done based on data obtained for other radionuclides, verified in international comparisons. M. Sahagiu, A.C. Wajngen, A. Luca, C. Ivan. *Appl. Radiat. Isot.* 68(2010) 1268-1269, according to Schrader. *Ionization chambers*. *Metrologia* 44(2007) S53-S56.



Radionuclide/ Vial volume	E_0 (pA/MBq)	F (pA/MBq)	$(E_0 - F)/F$ (%)
^{18}F / 5 ml	32.67 ± 1.06 (k=1)	32.80 ± 0.33 (k=1)	- 0.40
^{68}Ga / 5 ml	6.25 ± 0.21 (k=1)	6.302 ± 0.099 (k=1)	- 0.83
^{68}Zn / 5 ml	32.06 ± 1.02 (k=1)	31.81 ± 0.29 (k=1)	+ 0.79
^{124}I / 5 ml	32.65 ± 1.33 (k=1)	Not yet determined	-

The uncertainty budget of the F values

(i) standard solution activity uncertainty: 0.86% for ^{18}F , 1.60% for ^{68}Ga and 0.68% for ^{68}Zn .

(ii) maximum static uncertainty u_s , 0.5%, background and stability: 0.1%.

(iii) decay correction 0.1 - 0.3%.

(iv) weighing of solutions: 0.1%.

The uncertainty budget of E_0

(i) individual activity uncertainties of radionuclides used for calibration.

(ii) uncertainty of the fitted parameters of the calibration curve.

(iii) decay scheme parameters.

(iv) dependence of the annihilation quanta on the place of positron annihilation.

In the case of ^{124}I the evaluation was more difficult, due to the big number of emitted gamma-rays, many of them with energies higher than the energy of ^{60}Co 1250 keV, the maximum energy for which we disposed of experimental data.

Calibration of commercial radionuclide calibrators

Several types of commercial radionuclide calibrators, belonging to the IFIN-HH, Radiosotope and Radiation Metrology Department, to other radiopharmaceutical producers, or to nuclear medicine units, were calibrated using the solutions standardized with the calibrated ionization chamber, whose activities were taken as reference values. The producer's dial setting, for the respective radionuclides, except ^{68}Ga , were used. The measured values were compared with the reference ones



Radionuclide/ Solution volume	Deviation of the measured activity from reference value, %				
	ATOMLAB 500 BIODEX	CAPINTEC 15R	CURIE MENTOR 4	VEENSTRA VDC - 405	Solution provider's certification
^{18}F 0.5 ml (2012)	+ 1.7	+ 8.3	-	-	-
^{18}F 0.5 ml (2013)	+ 2.8	+ 4.5	- 7.6	+ 3.3	-
^{18}F 5 ml (2013)	- 0.6	+ 3.5	- 8.8	-	-
^{68}Ga 5 ml (2012)*	- 6.6	-	-	-	-
^{124}I 1.3 ml (2013)**	-	+ 0.56	-	- 8.3	- 0.26

*Dial setting of ^{18}F ;

**Theoretical calculation of efficiency

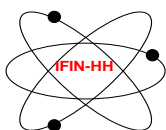
Conclusions

- A number of four PET radionuclides were standardized absolutely by the $4\pi\beta(\text{PC})\gamma$ coincidence method; the positron-annihilation and all emitted radiations coincidences were counted; the obtained uncertainties are satisfactory.
- The secondary standard, CENTRONIC IG 12/20A was calibrated experimentally with standard solutions and theoretical efficiencies were calculated; the agreement between the two rows of values is very good.
- Several types of medical commercial radionuclide calibrators were calibrated with standard solutions, finding deviations less than 10% from the reference values.

Acknowledgements. This work was supported by a grant of the Romanian National Authority for Scientific Research, CNCS - UEFISCDI, project number PN-II-ID-PCE-2011-3-0070

- **5th Workshop of the Decay Data Evaluation Project (DDEP-2014), October 6-8, 2014 - Bucharest-Magurele, Romania.**

1. Lucrarea **M. Sahagia, A.Luca, A. Antohe, M-R. Ioan, C.Ivan.** *Recent work and results of the radionuclide metrology laboratory from IFIN-HH*, a fost prezentata ca Lectie Invitata la workshop si a inclus si principalele rezultate obtinute in proiect. **Ea a fost acceptata pentru publicare la revista Romanian Reports in Physics, Articles in press, Nov.2015**



**5th Workshop of the Decay Data Evaluation Project
(DDEP-2014)
October 6-8, 2014 - Bucharest-Magurele, Romania**

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

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- Conference ICRM2015 „20-th International Conference on Radionuclide Metrology and its Applications”, ICRM2015, Vienna, Austria, 8-11 June, 2015, hosted by the Technical University Vienna, www.tuwien.ac.at

1. M. Sahagia*, M-R. Ioan, A. Antohe, A. Luca „Measurement of ^{124}I ,”

Measurement of ^{124}I

M. Sahagia, M-R. Ioan, A. Antohe, A. Luca, C. Ivan. IFIN-HH



Creation of a Romanian ^{124}I standard.

- Absolute standardization of the solution by the $4\pi\beta(\text{PC})-\gamma$ coincidence method;
- Calibration of the CENTRONIC IG12/20A ionization chamber and comparison with a calculated efficiency;
- γ -ray spectrometry activity measurement and determination of the impurity level;
- Comparison of the results of the three methods.

Poster # 013



Maria Sahagia



Session. Radionuclide Metrology Techniques

2. A. Luca*, M. Sahagia, M.-R. Ioan, A. Antohe, B. L. Neacsu „*Experimental determination of some nuclear decay data in the decays of ^{177}Lu , ^{186}Re and ^{124}I* ”,

Experimental determination of some nuclear decay data in the decays of ^{177}Lu , ^{186}Re and ^{124}I



A. Luca, M. Sahagia, M.-R. Ioan, A. Antohe, B.L. Neacsu,
Horia Hulubei National Institute for R&D in Physics and Nuclear
Engineering, Romania

- ^{177}Lu , ^{186}Re and ^{124}I studies are necessary for nuclear medicine applications.
- Accurate needed nuclear decay data for these nuclides were measured.
- Half-life values were determined by using a well-type ionization chamber.
- Photon emission intensities were measured by gamma-ray spectrometry.
- These new results will be used for future nuclear decay data evaluations.

Poster 039



Mihail-Razvan Ioan



Session: Nuclear Decay Data

Conference ICRM2017 „21-st International Conference on Radionuclide Metrology and its Applications”, ICRM2017, Buenos Aires, Argentina, 15-19 May, 2017

Titlu Rezumat. ” Standardisation of ^{67}Cu and calibration of the ionization chamber. Impurities and decay scheme problems”, autori: M. Sahagia*, A. Luca, M-R. Ioan, A. Antohe, C.Ivan

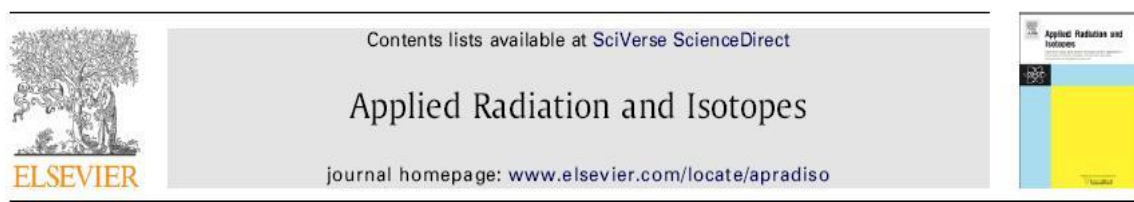
**PUBLICATION LIST OF THE PROJECT: PN-II-ID-PCE-2011-3-0070,
Ctr. 23/05.10.2011. Absolute standardization and study of the decay data of the positron
emitters used for PET systems. Assurance of the metrological traceability.**

**Project leader,
Dr. Maria Sahagia**

(i) Published papers

- 1. M. Sahagia, A. Luca, A. Antohe, C. Ivan.** *Standardization of ^{64}Cu and ^{68}Ga by the $4\pi(\text{PC})\beta\text{-}\gamma$ coincidence method and calibration of the ionization chamber.* Applied Radiations and Isotopes, 70, 9(2012)2025-2030

Applied Radiation and Isotopes 70 (2012) 2025–2030



**Standardization of ^{64}Cu and ^{68}Ga by the $4\pi(\text{PC})\beta\text{-}\gamma$ coincidence method
and calibration of the ionization chamber**

M. Sahagia*, A. Luca, A. Antohe, C. Ivan

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ARTICLE INFO

Available online 3 March 2012

Keywords:

PET radionuclides ^{64}Cu

^{68}Ga

Efficiency extrapolation

Ionization chamber calibration

ABSTRACT

The paper treats the application of the $4\pi(\text{PC})\beta\text{-}\gamma$ coincidence method for the standardization of the radionuclides ^{64}Cu and ^{68}Ga . The general coincidence equations are written. Two types of extrapolation were described and used in measurement: the positron-annihilation coincidence, and the counting of all emitted radiations; both methods are compared with respect to results, advantages and drawbacks. The impurities' content correction was applied. The standardized solutions were used to calibrate the ionization chamber CENTRONIC IG12/20A and to determine the gamma-rays emission intensities.

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2. M.-M.Bé, P.Cassette, M.-N. Amiot, M.C.Lépy, C.Bobin, K.Kossert, O.J.Nahle, O.Ott, C.Wanke, P.Dryak, G.Ratel, **M. Sahagia, A. Luca, A. Antohe**, L.Johansson, J.Keightley, A.Pearce.*Standardization, decay data measurements and evaluation of ^{64}Cu* . Applied Radiations and Isotopes, 70, 9(2012)1894-1899

Applied Radiation and Isotopes 70 (2012) 1894–1899



Standardization, decay data measurements and evaluation of ^{64}Cu

M.-M. Bé^{a,*}, P. Cassette^a, M.C. Lépy^a, M.-N. Amiot^a, K. Kossert^b, O.J. Nähle^b, O. Ott^b, C. Wanke^b, P. Dryak^c, G. Ratel^d, M. Sahagia^e, A. Luca^e, A. Antohe^e, L. Johansson^f, J. Keightley^f, A. Pearce^f

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ARTICLE INFO

Available online 28 February 2012

Keywords:

^{64}Cu standardization

^{64}Cu decay scheme

Half-life

γ -Ray intensities

x-Ray intensities

ABSTRACT

The purposes of this study were to create national activity standards of ^{64}Cu , to make possible the definition of an international key comparison reference value and to determine the decay data in order to improve the decay scheme. Four laboratories measured the activity of a ^{64}Cu solution; these results were compared through the International Reference System. Moreover, the laboratories carried out new measurements of the photon emission intensities and of the half-life. A new decay scheme was derived from these new values and the previously published ones.

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3. A. Luca, M. Sahagia, A. Antohe. *Measurements of ^{64}Cu and ^{68}Ga half-lives and gamma-ray emission intensities*. Applied Radiation and Isotopes, 70, 9(2012)1876-1880

Applied Radiation and Isotopes 70 (2012) 1876–1880



Contents lists available at SciVerse ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso



Measurements of ^{64}Cu and ^{68}Ga half-lives and γ -ray emission intensities

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ARTICLE INFO

Available online 25 February 2012

Keywords:

^{64}Cu

^{68}Ga

Half-life

Gamma-ray emission intensities

Gamma-ray spectrometry

Well-type ionization chamber

ABSTRACT

The ^{64}Cu and ^{68}Ga half-lives and γ -ray intensities were measured at IFIN-HH. The determination of absolute photon emission intensities was based on absolute activity standardizations carried out in this laboratory using the $4\pi\text{PC}-\gamma$ coincidence method. The half-lives were measured with a well-type ionization chamber. The photon emission intensities (relative and absolute values) were measured with a calibrated high-resolution γ -ray spectrometer. The results obtained and their uncertainties are discussed and compared with values of other authors.

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4. M. Sahagia, A. Antohe, A. Luca, A. C. Wätjen, C. Ivan „, The Support Offered by the Romanian Primary Activity Standard Laboratory to the Nuclear Medicine Field”, [abstractnumber.doc2353248](#), Congress IRPA13, Glasgow, 2012, Proc., published in Rom. J.Phys.vol.58,nos.1-2(2013)106-116

NUCLEAR MEDICINE

**THE SUPPORT OFFERED BY THE ROMANIAN PRIMARY ACTIVITY
STANDARD LABORATORY TO THE NUCLEAR MEDICINE FIELD***

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Received May 23, 2012

The paper presents the involvement of the Radionuclide Metrology Laboratory from IFIN-HH, Romania, in the assurance of the correct measurement of radiopharmaceuticals activity in nuclear medicine. Development and international validation of primary standards, development of secondary standards and direct support offered to the domain, consisting from calibration services and organization of comparisons/proficiency tests, are presented. Analysis of the results obtained in the calibration of several types of radionuclide calibrators during a six years period is done. It includes the following actions: check of the measurement uncertainty, recalibration when necessary, control of the calibrators' behavior in time. A comparison between calibration check and the results of the participation of the staff at proficiency tests is done.

Key words: radiopharmaceutical, primary activity standard, International System of Units (SI), radionuclide calibrator, metrology services.

* Paper presented at the 13th International Congress of the International Radiation Protection Association, IRPA13, Glasgow, Scotland, 13-18 May 2012.

Rom. Journ. Phys., Vol. 58, Nos. 1–2, P. 106–116, Bucharest, 2013

5. M. Sahagia^{*}, R. Ioan, A. Luca, A. Antohe, C. Ivan, B. Neacsu, C. Ghioca. *Standardization of ^{18}F and its use for the Romanian PET metrological traceability chain assurance* published in Applied Radiation and Isotopes, 87(2014)14-18

Applied Radiation and Isotopes 87 (2014) 14–18



Standardization of ^{18}F and its use for the Romanian PET metrological traceability chain assurance



M. Sahagia^{a,*}, R. Ioan^a, A. Luca^a, A. Antohe^a, C. Ivan^a, B. Neacsu^a, C. Ghioca^b

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HIGHLIGHTS

- Presents establishment of the ^{18}F FDG Romanian PET traceability chain.
- Shows work at IFIN-HH and at the users' site.
- An ^{18}F solution was standardized by the $4\pi\beta(\text{PC})-\gamma$ coincidence method.
- Includes measurement of half-life for detection of positron emitting impurities.
- CENTRONIC IG12/20A ionization chamber and radionuclide calibrators calibrated.

ARTICLE INFO

Available online 27 November 2013

Keywords:

^{18}F

$4\pi\beta(\text{PC})-\gamma$ coincidence method

Gamma-ray spectrometry

Half life

Ionization chamber

Radionuclide calibrator

ABSTRACT

This paper presents the work performed at IFIN-HH and at the users' sites, aimed to establish the ^{18}F FDG Romanian PET traceability chain. It summarizes the operations: (i) Absolute standardization of a ^{18}F solution, by the $4\pi\beta(\text{PC})-\gamma$ coincidence method; (ii) Control of gamma-ray impurity content and measurement of the activity by gamma ray spectrometry; (iii) Measurement of the half life, for detection of some short/long life positron emitter impurities; (iv) Calibration of the CENTRONIC IG12/20A ionization chamber; (v) Calibration of commercial radionuclide calibrators.

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6. 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.* Published in Applied Radiation and Isotopes 87(2014)410-413

Applied Radiation and Isotopes 87 (2014) 410–413



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journal homepage: www.elsevier.com/locate/apradiso



Standardization of Tc-99 by two methods and participation at the CCRI(II)-K2. Tc-99 comparison



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HIGHLIGHTS

- Standardization of Tc-99 by two methods: TDCR and $4\pi(\text{PC})\beta\text{-}\gamma$ efficiency tracing.
- Combined uncertainty of the final result is lower with the TDCR method.
- Both methods give results in rather good agreement within the stated uncertainties.
- Using both methods gives a more robust result for the activity of Tc-99.
- New code version TDCR-07c of LNHB provides TDCR results in better agreement with the CCRI(II)-K2.Tc-99 comparison.

ARTICLE INFO

Available online 12 November 2013

Keywords:

CCRI(II)-K2.Tc-99 comparison

LSC-TDCR

$4\pi(\text{PC})\beta\text{-}\gamma$ efficiency tracer method

ABSTRACT

The work accomplished within the participation at the 2012 key comparison of Tc-99 is presented. The solution was standardized for the first time in IFIN-HH by two methods: LSC-TDCR and $4\pi(\text{PC})\beta\text{-}\gamma$ efficiency tracer. The methods are described and the results are compared. For the LSC-TDCR method, the program TDCR07c, written and provided by P. Cassette, was used for processing the measurement data. The results are 2.1% higher than when applying the TDCR06b program; the higher value, calculated with the software TDCR07c, was used for reporting the final result in the comparison. The tracer used for the $4\pi(\text{PC})\beta\text{-}\gamma$ efficiency tracer method was a standard ^{60}Co solution. The sources were prepared from the mixture $^{60}\text{Co} + ^{99}\text{Tc}$ solution and a general extrapolation curve, type: $N_{\beta\text{Tc-99}}/(M)_{\text{Tc-99}} = f[1 - \epsilon_{\text{Co-60}}]$, was drawn. This value was not used for the final result of the comparison. The difference between the values of activity concentration obtained by the two methods was within the limit of the combined standard uncertainty of the difference of these two results.

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7. M. Sahagia, A. Luca, R. Ioan, A. Antohe, C. Ivan, B. Neacșu.** *Metrological traceability assurance in production and use of radiopharmaceuticals for pet imaging and targeted radiotherapy.* Published in Rom. Journ. Phys., Vol. 59, Nos. 1-2, P. 119-130, Bucharest, 2014.

**METROLOGICAL TRACEABILITY ASSURANCE IN PRODUCTION
AND USE OF RADIOPHARMACEUTICALS FOR PET IMAGING
AND TARGETED RADIOTHERAPY ***

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*) Paper presented at the TRACE Workshop on Development of New Radiotracers for PET Imaging
and Targeted Radiotherapy, 03-05 April 2013, Magurele, Romania

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Received April 11, 2013

The paper presents the implication of the Radionuclide Metrology Laboratory (RML) from IFIN-HH in solving the problems connected with the quality assurance of radiopharmaceuticals in production and use, by assuring the metrological traceability in the control of the radiometrological parameters: measurement of activity and radioactive concentration, radionuclide purity as well as measurement of the decay scheme parameters. The following problems are treated: (i) Absolute standardization of PET radionuclides: ^{64}Cu and ^{68}Ga and study of their decay scheme parameters; absolute standardization of radionuclides used in targeted - molecular radiotherapy (MRT): ^{153}Sm , ^{177}Lu , $^{186,188}\text{Re}$ and ^{89}Sr ; calibration of the secondary standard ionization chamber and of some commercial radionuclide calibrators. (ii) Radionuclide purity analysis and its influence on the activity calculation. The aspects presented are an overview of published papers.

Key words: radionuclide metrology, absolute standardization, positron emitters, strong beta-weak gamma emitters

Rom. Journ. Phys., Vol. 59, Nos. 1-2, P. 119-130, Bucharest, 2014

8. IRPA - FS

Fourth European IRPA Congress. Radiation Protection Culture – A global challenge, June 23-27, 2014

Geneva, Switzerland, www.irpa2014europe.com

Abstract book Updated version 02.07.2014

Introduced in:

Radiation Protection Dosimetry (2015), Vol. 164, No. 1–2, pp. 179–180

doi:10.1093/rpd/ncv288

FOURTH EUROPEAN IRPA CONGRESS

23–27 June, 2014 – Geneva, Switzerland

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Full text of the paper published in Abstract book, pps. 279 - 282

IRPA 2014

PS5-4: MEASUREMENTS & DOSIMETRY

PS5-4/36 - Measurement of positron emitting radionuclides' activity and their use for the calibration of the PET calibrators.

M. Sahagia, R. Ioan, A. Antohe, A. Luca, C. Ivan

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and Nuclear Engineering, IFIN-HH, Bucharest. 30

Reactorului str., Magurele, Ilfov County, code 077125,

Romania

The paper presents the work deployed for the establishment of the metrological traceability chain for the calibrators used for the measurement of positron emission radionuclide based radiopharmaceuticals.

It refers to the following aspects:

- Absolute standardization of PET radionuclides: ^{18}F , ^{64}Cu , ^{68}Ga , ^{124}I , by the $4\pi\beta(\text{PC}) - \gamma$ coincidence method, using the detection of all emitted radiations and the efficiency extrapolation method.
- Calibration of the CENTRONIC IG12/20A ionization chamber for various types of recipients, to be used for the measurement of the radiopharmaceutical solution and establishment of the IFIN-HH secondary standard for PET radionuclides.
- Calibration of various types of PET radionuclide

calibrators used in the radiopharmaceutical and nuclear medicine units.

Key words: positron emitting radionuclides, absolute standardization, traceability chain, radionuclide calibrators

9. M. Sahagia*, M-R. Ioan, A. Antohe, A. Luca „Measurement of ^{124}I ” Appl. Radiat Isot 109(2016)349-353

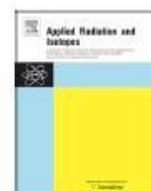
Applied Radiation and Isotopes 109 (2016) 349–353



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journal homepage: www.elsevier.com/locate/apradiso



Measurement of ^{124}I



M. Sahagia*, M-R. Ioan, A. Antohe, A. Luca, C. Ivan

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HIGHLIGHTS

- Absolute standardization of ^{124}I solution by the $4\pi\beta(\text{PC})$ - γ coincidence method.
- Calibration of the CENTRONIC IG12/20A ionization chamber.
- γ -ray spectrometry activity measurement and determination of impurities.
- Comparison of the results of the three methods.

ARTICLE INFO

Article history:

Received 4 March 2015

Accepted 3 December 2015

Available online 4 December 2015

Keywords:

^{124}I standardization

$4\pi\beta(\text{PC})$ - γ coincidence method

Ionization chamber

γ -ray spectrometry

ABSTRACT

The paper describes the measurements performed at IFIN-HH regarding the creation of a Romanian ^{124}I standard, consisting of: absolute standardization of the solution by the application of the $4\pi\beta(\text{PC})$ - γ coincidence method; Calibration of the CENTRONIC IG12/20A ionization chamber with a standardised solution and comparison with a calculated efficiency; γ -ray spectrometry activity measurement and determination of the impurity levels; Comparison of the results of the three methods.

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10- A. Luca*, M. Sahagia, M.-R. Ioan, A. Antohe, B. L. Neacsu „Experimental determination of some nuclear decay data in the decays of ^{177}Lu , ^{186}Re and ^{124}I ” Appl.Radiat.Isot. 109(2016)146-150

Applied Radiation and Isotopes 109 (2016) 146–150



Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso



Experimental determination of some nuclear decay data in the decays of ^{177}Lu , ^{186}Re and ^{124}I



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HIGHLIGHTS

- ^{177}Lu , ^{186}Re and ^{124}I studies are necessary for nuclear medicine applications.
- Accurate nuclear decay data needed for these nuclides were measured.
- Half-life values were determined using a $4\pi\gamma$ ionization chamber.
- Photon emission intensities were measured by gamma-ray spectrometry.
- These new results will be used for future nuclear decay data evaluations.

ARTICLE INFO

Article history:

Received 24 March 2015

Accepted 24 November 2015

Available online 2 December 2015

Keywords:

Photon emission intensity

Gamma-ray spectrometry

Half-life

^{177}Lu

^{186}Re and ^{124}I

ABSTRACT

A detailed experimental study of the radionuclides ^{177}Lu , ^{186}Re and ^{124}I was conducted at IFIN-HH, Radionuclide Metrology Laboratory. Absolute photon emission intensities in the decays of these radionuclides were measured by high-resolution gamma-ray spectrometry. Half-life measurements using a well-type ionization chamber were also performed. These new experimental results will be useful for the future updates of the existing nuclear decay data evaluations, offering reliable and accurate data for the users.

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11. M.Sahagia, A.Luca, A.Antohe, M-R.Ioan, C.Ioan. *Recent work and results of the radionuclide metrology laboratory from IFIN-HH*. Rom. Rep. in Phys. 68 No.1,(2016)177-190

Romanian Reports in Physics, Vol. 68, No. 1, P. 177–190, 2016

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

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Received July 17, 2014

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.

(iii) Papers presented at international Conferences/Workshops

- Conference ICRM 2013: 19-th International Conference on Radionuclide Metrology and its Applications, ICRM 2013, Antwerp, Belgium, 17 – 21 June 2013, hosted by the European Commission – Joint Research Centre. Institute for Reference Materials and Measurements (IRMM).
<http://irmm.jrc.ec.europa.eu/icrm2013>

1. M. Sahagia*, R. Ioan, A. Luca, A. Antohe, C. Ivan, B. Neacsu, C.Ghioca. *Standardization of ^{18}F and its use for the Romanian PET metrological traceability chain assurance* Poster P#005. Paper published in Applied Radiations and Isotopes

Standardization of ^{18}F and its use for the Romanian PET metrological traceability chain assurance

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- Establishment of the ^{18}F - Romanian PET traceability chain.
- Standardization of ^{18}F by the $4\pi\beta(\text{PC})-\gamma$ coincidence and by γ -ray spectrometry.
- Control of impurities and measurement of the half-life.
- Calibration of the CENTRONIC chamber and of commercial calibrators

Poster #005



Maria Sahagia



Session: Radionuclide metrology in life sciences

2. 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.* Poster P#004. Paper published in Applied Radiations and Isotopes

Standardization of Tc-99 by two methods and participation at the CCRI(II)-K2 Tc-99 comparison

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IFIN-HH - Romania

- Participation at the 2012 key comparison of Tc-99 using LSC-TDCR and $4\pi(\text{PC})\beta\text{-}\gamma$ tracer
- LSC-TDCR method: program TDCR07c, copyright of P. Cassette; value used for reporting the result
- $4\pi(\text{PC})\beta\text{-}\gamma$ efficiency tracer method: tracer - standard ^{60}Co solution; value not used for reporting the result.
- Difference between the two determined values was within the limit of uncertainty

Poster #004



Aurelian Luca



ICRM 2013

Session: Intercomparisons

- TRACE 2013 - Development of New Radiotracers for PET Imaging and Targeted Radiotherapy, IFIN-HH, Workshop, 3 – 5 April 2013 .
- 2. M. Sahagia, A.Luca, R.Ioan, A.Antohe, C.Ivan, B. Neacsu. *Metrological traceability assurance in production and use of radiopharmaceuticals for PET imaging and targeted radiotherapy*. Oral presentation. Paper published in Romanian Journal of Physics



Metrological traceability assurance in production and use of radiopharmaceuticals for PET imaging and targeted radiotherapy

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ROMANIA

TRACE

Workshop on Development of New Radiotracers for PET Imaging and Targeted
Radiotherapy
03-05 April 2013, Magurele Romania

- **Fourth European IRPA Congress, *Radiation protection Culture – a global challenge*, Geneva, Switzerland, June 23-27, 2014**
- 2. **M. Sahagia, M-R. Ioan, A. Antohe, A. Luca, C. Ivan.** *Measurement of positron emitting radionuclides' activity and their use for the calibration of the PET calibrators*, was presented as poster.

**Measurement of positron emitting radionuclides' activity and their use for
 the calibration of the PET calibrators.**

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Introduction

The PETCT diagnosis procedures use radiopharmaceuticals based on the radionuclides decaying by positron emission. Their quality is defined by (i) chemical compound, (ii) radiometrical and physico-chemical characteristics, *European Pharmacopoeia*, 8th edition 2014-2016, determined by precise measurement of their activity. The Romanian Radiometric Metrology Laboratory (RML) is established within the IFIN-HH, Magurele - Bucharest, as a primary national standard. IFIN-HH is a designated institute in the field of ionizing radiations in the relation with the International Committee of Weights and Measures - Mutual Recognition Arrangement (CIPM - MRA). It assures the entire metrological traceability chain for all the radiopharmaceuticals in Romania. At this moment, practically the problem of the most used SPECT ¹²³I and ¹¹¹In, was solved. For ¹²³I we participated at the BIPM RI(II)-K1.1-131 key comparison G. Ridel, C. Michotte, M. Sahagie, T. S. Park, P. Dryak, J. Sochorova, F. Maringer and M. Kreuziger. *Metrologia Technical Supplement*, 45, 06007 (2008) and for ¹¹¹In we participated at the key comparison SI-T1 in 2013. C. Michotte, M. Sahagie, M. R. Ioan, A. Antohe, A. Luca BIPM RI(II)-K4.70-99m Report, 2014. We calibrate currently all the radionuclide calibrators belonging to the Romanian hospitals. M. Sahagie, A. Antohe, A. Luca, A.C. Wägen, C. Ivan, *Rev. J. Phys.* 58, 1-2 (2013) 106-116. The introduction of the PET radionuclides required us to standardize them absolutely and to assure the national traceability chain. The obtained results, some of them already published and others in the deployment, regarding a list of four PET radionuclides, ¹⁸F, ⁶⁸Ga, ¹²⁴I, is presented in the paper.

Absolute standardization of the radionuclides

The absolute standardization of these radionuclides was done by the 4πβ(βC)γ coincidence method, using an installation composed from two detection blocks - proportional counter (PC) and scintillation detector, NaI(Tl), with the electronic chains and a coincidence selector. A set of several solid sources, prepared gravimetrically from the solution, were measured; the activity and activity concentration were determined. The general coincidence equations, connecting the counting rates, N_β , N_γ , N_c , activity N_0 , decay scheme parameters a_α , and detection efficiencies ϵ , are:

$$\begin{aligned}
 N_\beta &= N_0 \sum_{r=1}^n a_r f_{\beta r} + (1 - \sum_{r=1}^n a_r f_{\beta r}) f_{\beta\gamma} I_\gamma; N_\gamma = N_0 \sum_{r=1}^n a_r f_{\gamma r} \\
 N_c &= N_0 \sum_{r=1}^n a_r f_{\beta r} f_{\gamma r} + (1 - \sum_{r=1}^n a_r f_{\beta r}) f_{\beta\gamma} f_{\gamma r}
 \end{aligned}$$

When the variant of efficiency extrapolation is applied, the equations are written in an equivalent form, where K and $(1-K)$ are the extrapolation slopes

$$\begin{aligned}
 N_\beta &= N_0 [1 - K(1 - N_c/N_\gamma)] \\
 N_\gamma &= N_0 [1 + (1-K) N_c/N_\gamma] \\
 K &= \frac{\sum a_r f_{\beta r} [1 - (f_{\beta\gamma} + \epsilon_{\beta\gamma})/(1 + a)]}{\sum a_r f_{\beta r} (1 - \epsilon_{\beta\gamma})} \cdot \frac{1 - \sum a_r f_{\gamma r}}{\sum a_r f_{\gamma r}}
 \end{aligned}$$

E.L. Grigorescu, M. Sahagie, A. Razdolescu, C. Ivan. *Nucl. Instrum. and Methods Phys. Res. A* 369(1996) 414-420.

The above mentioned radionuclides are either almost pure positron emitters, such as ¹⁸F (96.86% positron decay), or mixtures of beta and electron capture decays. ⁶⁸Ga (88.86% positrons), ⁶⁴Cu (56% beta plus/minus) and ¹²⁴I (22.7% positrons). M.-M. Ba et al. *Monographie BIPM-5. Table of Radionuclides, Ed. Bureau International des Poids et Mesures, Pavillon de Breteuil, F-92310 Sevre, France, ISBN 92-922-2206-3, J. Katakura, Z.D. Wu. Nuclear Data Sheets* 109, 7 (2008) 1655-1677. For higher the atomic numbers the weight of positron decays diminishes and 4πβ(βC)γ coincidence method in standardization must be adapted accordingly.

The extrapolation variant of the coincidence method was applied, adapted to the characteristics of the decay scheme. In the case of ¹⁸F, only positrons on the beta channel, and annihilation quanta (511 keV) on the gamma channel, were counted. M. Sahagie, R. Ioan, A. Luca, A. Antohe, C. Ivan, B. Neacsu, C. Ghinea. *Appl. Radiat. Isot.* 87 (2014) 14-18. The radionuclide purity level was determined by the precise measurement of the half life and its comparison with the reference value. In the case of radionuclides ⁶⁸Ga and ¹²⁴I, both variants were applied: positron-annihilation quanta coincidence and counting of all emitted radiations on both detection channels. The radionuclide purity was determined in two different modes, for ⁶⁸Ga, the high resolution gamma-ray spectrometry was used for the impurities ⁶⁷Co, ⁶⁶Co, ⁶⁴Cu, for ¹²⁴I, the suspected impurity was ¹²³I. M. Sahagie, R. Ioan, A. Antohe, C. Ivan. *Appl. Radiat. Isotopes* 70, 9 (2012) 2026-2030. The results allowed us to determine their main decay scheme characteristics in good agreement with other participants within the EURAMET project 1085. A. Luca, M. Sahagie, A. Antohe, *Appl. Radiat. Isotopes* 70(2012)1876-1880. M.-M. Ba, F. Cassano, M.C. Lapp, M.-N. Amet, K. Kossert, O.J. Nohle, C. Ott, C. Wank, P. Dryak, G. Ridel, M. Sahagie, A. Luca, A. Antohe, L. Johansson, J. Keightley, A. Pearce. *Appl. Radiat. Isotopes* 70(2012)1894-1899.

¹²⁴I is a relatively new positron emitter in use and takes the advantage of replacing the SPET ¹²³I/¹²⁴I radiopharmaceuticals with a PET variant in the diagnosis of the Alzheimer disease, due to its longer half life, as compared with ¹⁸F, ¹¹C, it allows deeper investigations of the biochemical processes. K.W. Chang, C.C. Chen, S.Y. Lee, L.H. Shen, H.E. Wang. *Appl. Radiat. Isot.* 67(2009)1397-1400. Only two papers were published up to now D.H. Woods, S.A. Woods, M.J. Woods, J.L. Wakepeace, C.A. Downey, D. Smith, A. Munster, S.E. M. Lucas, H. Sharma. *Appl. Radiat. Isot.* 43, 4 (1993) 581-585; S.M. Qaim, T. Bisinger, K. Högler, D. Nayak, H.H. Coenen. *Radiochim. Acta* 35 (2007) 67-73. An analysis on new positron emitters' standardization status was done in B.E. Zimmerman. *Appl. Radiat. Isot.* 78(2013)31-37. In our work, under deployment, we propose to use of the 4πβ(βC)γ - y coincidence method with the counting of all positrons, Auger electrons and x-rays, in the flow proportional counter, working at the atmospheric pressure and the setting of several counting windows on the gamma channel. The final results will be presented in the paper: M. Sahagie, R. Ioan, A. Luca, A. Antohe, C. Ivan. *Standardization of ¹²⁴I by the 4πβ(βC)γ - y coincidence method and study of the decay scheme parameters. Internal report IFIN-HH, 2014.*

Calibration of the secondary standard, ionization chamber

The RML disposes of a CENTRONIC IG12/20A ionization chamber, which serves as basis for the transmission of the activity unit value to the commercial radionuclide calibrators. The calibration factor F of the chamber, expressed as pA/MBq of solution, was determined experimentally using recipients with standard solutions. An evaluation of the chamber efficiency, ϵ_0 , expressed also in units pA/MBq, was done based on data obtained for other radionuclides, verified in international comparisons. M. Sahagie, A.C. Wägen, A. Luca, C. Ivan. *Appl. Radiat. Isot.* 68(2010) 1268-1269, according to Schrader. *Ionization chambers. Metrologia* 44(2007) S83-S86.

Radionuclide/ Vial volume	E_0 (pA/MBq)	F (pA/MBq)	$(E_0 - F)/F$ (%)
¹⁸ F / 5 ml	32.67 ± 1.06 (k=1)	32.80 ± 0.33 (k=1)	- 0.40
⁶⁸ Ga / 5 ml	6.25 ± 0.21 (k=1)	6.302 ± 0.099 (k=1)	- 0.83
¹²⁴ I / 5 ml	32.06 ± 1.02 (k=1)	31.81 ± 0.29 (k=1)	+ 0.79
¹²⁴ I / 5 ml	32.65 ± 1.33 (k=1)	Not yet determined	-

The uncertainty budget of the F values
 (i) standard solution activity uncertainty: 0.86% for ¹⁸F, 1.60% for ⁶⁸Ga and 0.68% for ¹²⁴I.
 (ii) maximum static uncertainty u_s : 0.5%, background and stability: 0.1%.
 (iii) decay correction: 0.1 - 0.3%.
 (iv) weighing of solutions: 0.1%.
The uncertainty budget of E_0
 (i) individual activity uncertainties of radionuclides used for calibration.
 (ii) uncertainty of the fitted parameters of the calibration curve.
 (iii) decay scheme parameters.
 (iv) dependence of the annihilation quanta on the place of positron annihilation.
 In the case of ¹²⁴I the evaluation was more difficult, due to the big number of emitted gamma-rays, many of them with energies higher than the energy of ⁶⁰Co 1250 keV, the maximum energy for which we disposed of experimental data.

Calibration of commercial radionuclide calibrators

Several types of commercial radionuclide calibrators, belonging to the IFIN-HH, Radiosotope and Radiation Metrology Department, to other radiopharmaceutical producers, or to nuclear medicine units, were calibrated using the solutions standardized with the calibrated ionization chamber, whose activities were taken as reference values. The producer's dial setting, for the respective radionuclides, except ⁶⁸Ga, were used. The measured values were compared with the reference ones.

Radionuclide/ Solution volume	Deviation of the measured activity from reference value, %				
	ATOMLAB 500 BIODEX	CAPINTEC 15R	CURIE MENTOR 4	VEENSTRA VDC - 405	Solution provider's certification
¹⁸ F/0.5 ml (2012)	+ 1.7	+ 8.3	-	-	-
¹⁸ F/0.5 ml (2013)	+ 2.8	+ 4.5	- 7.6	+ 3.3	-
¹⁸ F/5 ml (2013)	- 0.6	+ 3.5	- 8.8	-	-
⁶⁸ Ga/5 ml (2012)*	- 6.6	-	-	-	-
¹²⁴ I/ 1.3 ml (2013)**	-	+0.56	-	- 8.3	- 0.26

*Dial setting of ¹⁸F;
 **Theoretical calculation of efficiency

Conclusions

- A number of four PET radionuclides were standardized absolutely by the 4πβ(βC)γ - y coincidence method; the positron-annihilation and all emitted radiations coincidences were counted; the obtained uncertainties are satisfactory.
- The secondary standard, CENTRONIC IG 12/20A was calibrated experimentally with standard solutions and theoretical efficiencies were calculated; the agreement between the two rows of values is very good.
- Several types of medical commercial radionuclide calibrators were calibrated with standard solutions, finding deviations less than 10% from the reference values.

Acknowledgements. This work was supported by a grant of the Romanian National Authority for Scientific Research, CNCS - UEFISCDI, project number PN-II-ID-PCE-2011-3-0070

5th Workshop of the Decay Data Evaluation Project (DDEP-2014), October 6-8, 2014 - Bucharest-Magurele, Romania.

- The paper. **M. Sahagia, A.Luca, A. Antohe, M-R. Ioan, C.Ivan.** *Recent work and results of the radionuclide metrology laboratory from IFIN-HH*, was presented as Invited Lecture at the workshop and included the main results obtained within the project. It was accepted for publication in the journal Romanian Reports in Physics, articles in press, November 2015



**5th Workshop of the Decay Data Evaluation Project
(DDEP-2014)
October 6-8, 2014 - Bucharest-Magurele, Romania**

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

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- Conference ICRM2015 „20-th International Conference on Radionuclide Metrology and its Applications”, ICRM2015, Vienna, Austria, 8-11 June, 2015, hosted by the Technical University Vienna, www.tuwien.ac.at

1. M. Sahagia*, M-R. Ioan, A. Antohe, A. Luca „*Measurement of ^{124}I* ,”

Measurement of ^{124}I

M. Sahagia, M.-R. Ioan, A. Antohe, A. Luca, C. Ivan. IFIN-HH



Creation of a Romanian ^{124}I standard.

- Absolute standardization of the solution by the $4\pi\beta(\text{PC})$ - γ coincidence method;
- Calibration of the CENTRONIC IG12/20A ionization chamber and comparison with a calculated efficiency;
- γ -ray spectrometry activity measurement and determination of the impurity level;
- Comparison of the results of the three methods.

Poster # 013



Maria Sahagia



Session. Radionuclide Metrology Techniques

2. A. Luca*, M. Sahagia, M.-R. Ioan, A. Antohe, B. L. Neacsu „Experimental determination of some nuclear decay data in the decays of ^{177}Lu , ^{186}Re and ^{124}I ”,

Experimental determination of some nuclear decay data in the decays of ^{177}Lu , ^{186}Re and ^{124}I



A. Luca, M. Sahagia, M.-R. Ioan, A. Antohe, B.L. Neacsu,
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Engineering, Romania

- ^{177}Lu , ^{186}Re and ^{124}I studies are necessary for nuclear medicine applications.
- Accurate needed nuclear decay data for these nuclides were measured.
- Half-life values were determined by using a well-type ionization chamber.
- Photon emission intensities were measured by gamma-ray spectrometry.
- These new results will be used for future nuclear decay data evaluations.

Poster 039



Mihail-Razvan Ioan



Session: Nuclear Decay Data

Conference ICRM2017 „21-st International Conference on Radionuclide Metrology and its Applications”, ICRM2017, Buenos Aires, Argentina, 15-19 May, 2017

Abstract Title. ” *Standardisation of ^{67}Cu and calibration of the ionization chamber. Impurities and decay scheme problems*”, authors: M. Sahagia*, A. Luca, M-R. Ioan, A. Antohe, C.Ivan