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Original

Calibration factor fluctuation for radiological protection instruments used in Nuclear Medicine Departments — experience from CLOR

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Abstract

BACKGROUND: The calibration of the dosimetric instruments is a basis of safety of the people working with the ionization radiation. The necessity of calibration is especially important in the institutions where the open radioactive sources are used. The paper presents the abilities of CLOR's radiological protection instruments calibration facility and the important conclusions from calibrations results for group of instruments used in Nuclear Medicine Department in Poland.
MATERIALS AND METHODS: The results for five types of instruments dedicated for dose rate as well as for contamination measurements were presented. Analyzes were based on the results presented at calibration certificated of chosen instruments.
RESULTS: It has been shown that the calibration factor might fluctuate by 50% in period of one year for particular instrument as well as for more than 100% for two instruments of the same type.
CONCLUSIONS: The presented results prove the importance of the calibration process and it is evidence that the calibration process of the radiation protection instruments should be performed periodically for the test of dose rate measurements as well as for contamination measurements abilities.

KEY words: calibration factor, nuclear medicine, radiological protection instruments

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Introduction

Nuclear Medicine Departments (NMD) are one of the most vulnerable for radioactive contaminations laboratories due to the presence of open, liquid form radioactive sources. The activity unit of sources vary from tens GBq up to few of MBq. Basically in NMD the active instruments might be divided into two groups. The first one includes instruments for radiological protection purpose and the second one consist of instruments used for estimation of the activity of the administrated sources. This paper is focused on the first group of instruments employed for workers safety ensuring.

The adequate radiological instrument is a priority. Basing on the International Atomic Energy Agency (IAEA) safety Standard for NMD [1] controlled and supervised areas established in NMD should be periodically monitored using survey meters and contamination monitors. The instruments employed in NMD should fulfill two main requirements: they should be able to measure the specific kind of radiation present in particular Department and must be calibrated periodically for confirmation of their proper work.

According to the Polish Atomic Law [2] the radiological instruments must be calibrated only by the Laboratories holding the quality system approved by The Polish Centre for Accreditation. The quality system must include the validated calibration procedures that give the certainty of proper calibration process. The calibration of particular instruments dedicated to dose rate measurement must be performed at least once per year. An exception are instruments with their own certificated check source which should be calibrated at least once per two years [3]. Polish law does not specify the frequency of calibration for contamination monitors but basing on the experience with the reliability of that kind of instruments it is recommended to calibrate at least once a year.

The Laboratory for Radiological and Radon Instruments Calibration (LWPDiR) of the Central Laboratory for Radiological Protection (CLOR) in Warsaw holds the accreditation certificate number AP057 since 2002. In framework of the Laboratory four validated procedures are used. Two of them concern a calibration of dose rate

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meters using isotopic gamma sources and RTG. Whereas the third one relates to contamination monitors calibrations using alpha and beta radiation emitters. The last procedure is dedicated to radon instruments calibration. For each calibration process the adequate Calibration Certificate is provided. The Certificate includes the basic information about instrument, results with uncertainty, tables, plots and the instruction for results application.

This paper presents the procedures established in accredited Laboratory for calibration of dose rate and contamination meters used in Nuclear Medicine Departments. Review of the dosimetric devices used in Polish NMD was performed. Basing on the results of calibration the changes of the properties for commonly used in NMD instruments, visualized by calibration factor fluctuation in time was presented.

Material and methods

According to the Polish Standard PN-EN ISO/IEC 17025 [4] methods used in the Laboratory must be validated to improve their suitability for intentional usage. The basic way of validation was participation at comparisons hosted by the National Metrology Institute or other approved organization. Additionally for validation purposes the following techniques are suggested: using reference standards materials during calibration, comparison of results obtained with other methods, periodical assessment of influencing factors and uncertainty assessment.

LWPDiR Calibration facility specification

In the framework of LWPDiR six calibration stands are in operate: Gamma, RTG, Contamination, Neutron, Beta Secondary Standard 2 (BSS2) and Radon. Four of them are covered by the quality system fulfilling the 17025 Standard requirements. For calibration of instruments used in NMD purpose only Gamma, RTG and Contamination stands are involved.

The laboratory covers two calibration halls. Hall 1 (H1) with dimension 8 m × 6 m and Hall 2 (H2) 11 m × 7 m and a separate room for Radon (R) calibration chamber. In H1 Gamma and Contamination stands were placed, whereas H2 includes RTG, Neutron and BSS2 calibration stands. In all rooms the air conditioning systems were installed to allow performing the calibration procedures in required environmental conditions.

The main element of RTG stand is X-ray tube with a set of special filters compatible with requirements of the International Standard ISO-4037 series [5–8].

The set is adjusted for narrow (N series) X-ray beam production. Spectra are characterized by high voltage used for their production, by mean energy of photons and first and second half value layer (1HVL and 2HVL). The dose rate is manipulated by distance between RTG tube focus and reference point of measurement (FMPD — Focus Measurement Point Distance) and additionally by current applied to the cathode. The values characterizing beams quality and measurement capabilities were presented in Table 1. The FMPD may be varied within 0.5 m to 8.1 m. The reference point of measurement is designated by laser positioning system.

The Gamma calibration bench is equipped with the irradiator type OB85/3 with tree radioactive sources: ^{137}Cs, ^{60}Co and ^{241}Am. The calibrated instruments are mounted into the trolley outfitted with lasers based positioning system. The distance between center of radioactive source to reference point of measurements may vary from 0.68 m to 6 m and it can be controlled with precision of 1 mm. In addition a dose rate is controlled by applying leads absorbers at shape of disks with 1.85 cm, 2.25 cm and 7.5 cm in thickness. The Gamma stand is fully automatic and the control is realized from safety area in the control room. The characterization of gamma sources presents Table 2.

For reference values of X-ray, gamma dose rate a UNIDOS electrometer with PTW ionization chambers was involved. The reference values of surface emission for contamination calibration sources were obtained basing on sources Certificates. To prevent of influence of radioactive decay of the isotopic sources (taking into account the half life time) the references values are reassessed for each three months for gamma sources. In case of surface sources,

Table 1. Characterization of narrow (N) X-ray beams used in LWPDiR

Beam	U [kV]	[keV]	1 HVL [mm Cu]	2 HVL [mm Cu]	Range of air kerma rate [μGy·h^{-1}]
N-40	38.6	33	0.088	0.087	3.6 ÷ 12600
N-60	61.0	48	0.23	0.26	29.4 ÷ 96000
N-80	80.0	65	0.60	0.63	12.0 ÷ 43800
N-100	98.5	83	1.08	1.20	4.2 ÷ 16200
N-120	118.0	100	1.68	1.82	4.2 ÷ 16500
N-150	145.4	118	2.35	2.53	25.8 ÷ 112500
N-200	193.0	164	4.07	4.14	8.4 ÷ 31800
N-250	240.8	208	5.36	5.39	6.6 ÷ 25200
N-300	281.7	250	6.39	6.45	3.0 ÷ 13200

Table 2. Characterization of gamma sources used in LWPDiR

Source	Gamma radiation energy [MeV]	Half life time [years]	Range of air kerma rate [μGy·h^{-1}]
^{137}Cs	0.662	30.07	0.2 ÷ 60000
^{60}Co	1.250	5.27	0.2 ÷ 6000
^{241}Am	0.059	432.2	15.0 ÷ 20

Table 3. Characterization of surface sources used in LWPDiR

Source	Maximum energy of particles [MeV]	Half life time [years]	Surface emission [$cm^{-2}s^{-1}$]
^{14}C	0.156	5730	2.39
^{36}Cl	0.709	$3.01 \cdot 10^5$	4.05
$^{90}Sr\backslash^{90}Y$	2.274	28.79	8.27
^{241}Am	5.484	432.2	3.64

they are recalibrated one per 10 years at manufacturing lab. In addition, for surface sources (mainly for $^{90}Sr\backslash^{90}Y$), the reference values of surface emission is recalculated for date of the particular calibration.

For calibration of contamination meters four surface sources are used. The contamination calibration stand is equipped with three beta emitters: ^{14}C, ^{36}Cl and $^{90}Sr/^{90}Y$ and one alpha emitter: ^{241}Am. All sources have the same dimension 150 mm × 100 mm and are realized as a metal plates with uniformly distributed radioactive material. According to the International Standard 6980-1 [9], the reference values are obtained in surface emission [$cm^{-2}s^{-1}$]. Characterization of the contamination sources including their surface emission and maximum energy of particles was presented in Table 3.

Process of calibration

Independently from calibration range the calibration process includes all activities from delivering the instrument to issuing of the calibration Certificate and sending device back to the Customer. For each calibrated device the unique case number is assigned and the same number hold the final calibration Certificate. If the instrument has any malfunction the Customer is informed and the adequate unserviceability report is issued. The calibration is performed according to the adequate accredited instruction depending on calibration range declared by the Customer.

Analyzed instruments

The group of analyzed units is presented in Table 4. The CLOR experience shows that the most commonly used instruments in Polish NMD are RKP 1–2 surveys.

The RKP 1–2 is a multipurpose analog device based on the set of three Geiger-Miller (G-M) detectors capable to measure Gamma/X-ray/Contamination (β). Although the RKP 1–2 is a construction of the 80s. According to the technical specification the RKP 1–2 instruments are able to measure with 25% accuracy. Two another multipurpose instruments used at NMD which calibrations results were presented at the paper were EKO-C and RK-100 surveys. The EKOC is a digital instrument based on Pancake type G-M detector and is dedicated for Gamma/Xray/Contamination (β) measurements. The measurements uncertainty declared by the manufacturer for EKO-C instrument is at the level of 20%.

At the last few years an increased number of RK-100 instruments used in NMD was observed. The instrument was dedicated for Gamma/X-ray/Contamination (α, β) measurements, depending on the configuration. For α and β radiation measurements, the probe with special set of filters was dedicated. According to the technical specification, the device is dedicated for Gamma/X measurements at the range from 0.1 μSv to 10 Sv.

Table 4. The list of the analyzed instruments used at NMD dedicated for gamma (G), X-ray (X) and contamination (C) measurements

Device type (probe)	Measuring capabilities	No. of analyzed device
RKP-1-2	G/X/C	4
EKO-C	G/X/C	2
CONTAMAT	C	1
RK-100 (Rk100)	G/X/C	1
RUST-3 (SGB-1P)	C	2

Results

The calibration results were noted from calibration certificates. Results were obtained from calibration certificates provided during two or three consequently years that analyzed instruments were tested.

Calibrations for dose rate measurements

The fluctuation of calibration factors (CF) for analyzed RKP 1–2 instruments were presented on Figures 1A–D. The variation of the CF for particular RKP 1–2 instrument reaches almost 50% in period of one year (Figure 1A). As one can see the response of the instrument can change by constant value for all measuring range (Figure 1C) or can be quite stable for part of the measuring range and changing only on the ends of the range (Figure 1A). The observed trends and overlapping values of CF in the following years prove the repeatability of the calibration method.

Figure 2 presents the results of calibrations performed for particular RK-100 instrument at three following years for gamma radiation measurements. It was shown that the use of RK100 needs a special attention at the range below 10 $\mu Sv \times h^{-1}$. The fluctuation of the CF on that range reaches 35% in period of three years.

Third multipurpose instrument dedicated for Gamma/X-ray/Contamination (β) measurements analyzed was EKO-C. The instrument is also commonly used at other branches specially in the industry. Figure 3 shows the results of particular EKO-C calibration using gamma radiation. As one can see the values of CF at the following two years are characterized by the almost stable difference depending on the measuring range. The highest fluctuation are observed at the lowest measuring range and it reaches 60%. The differences decreased at the highest measuring range where the difference between the CF assessed in 2014 and 2015 was at the level of 10%.

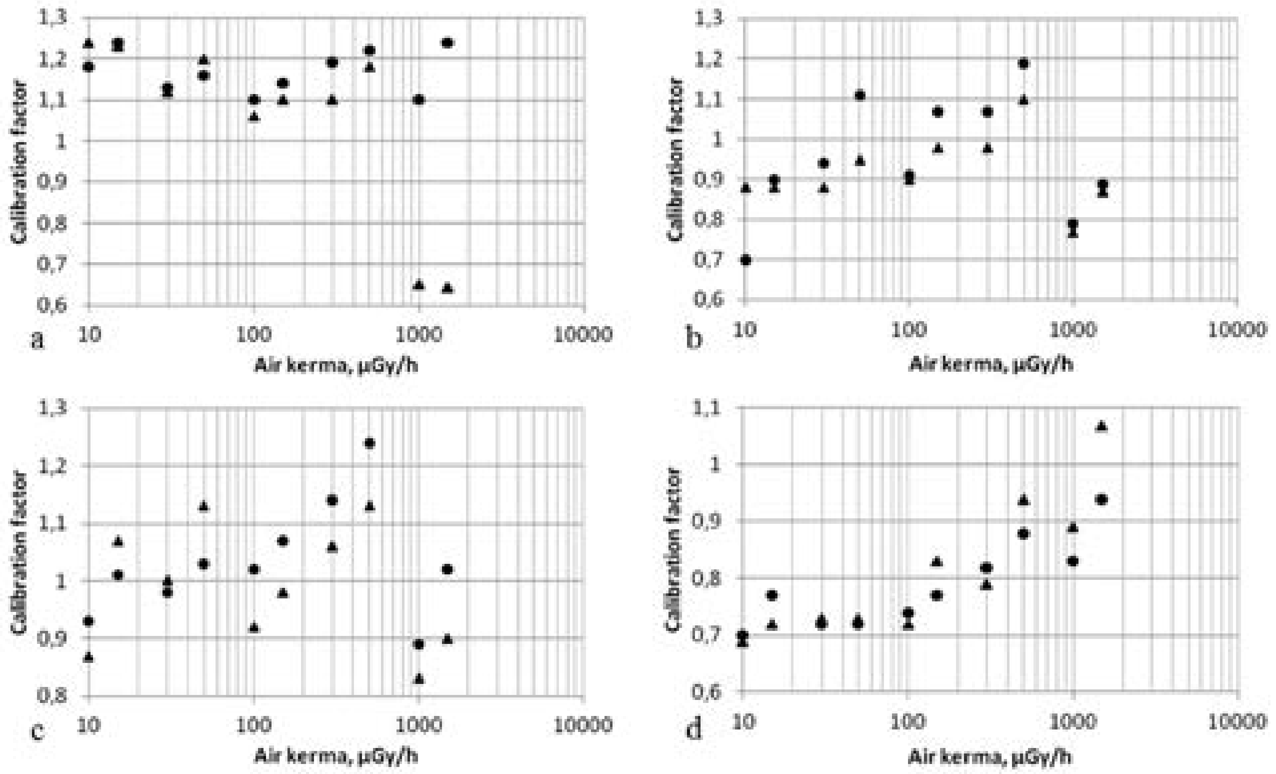

Figure 1. Changes of the CF of particular (**A**–**D**) RKP 1-2 device basing on results in 2014 (▲) and 2015 (•) depending on value of reference air kerma

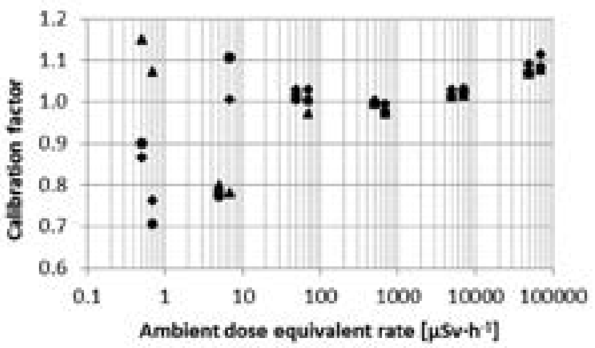

Figure 2. CF changes for particular RK-100 device basing on calibration results from 2013 (•), 2014 (⧫) and 2015 (▲) depending on the value of reference ambient dose equivalent rate

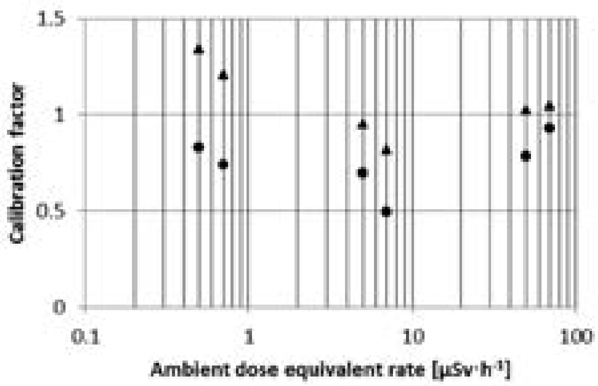

Figure 3. The CF fluctuation for EKO-C instrument at two following years 2014 (•) and 2015 (▲)

Calibration results for surface contamination measurements

Figure 4 shows the CF fluctuation for RK-100 instrument calibrated using ^{90}Sr beta radiation surface source. For the analyzed instrument the maximum deviation of CF was registered between 2014 and 2015 and it was a decrease by 2.7%.

Figure 5 presents CF values for four types of instruments used for beta contamination measurements at NMD. The figure shows the result for the instruments dedicated for contamination measurements (CONTAMAT, RUST-3) as well as for multipurpose instruments (EKO-C, RKP-1-2). As one can see the results for dedicated survey as CONTAMAT are characterized by very good repeatability. The CF for that instrument change maximally for 3.5% at one year period for calibration realized using ^{36}Cl source. As one can see the CF fluctuation depends on particular instrument characteristic as well as on the energy of the particles used during the calibration

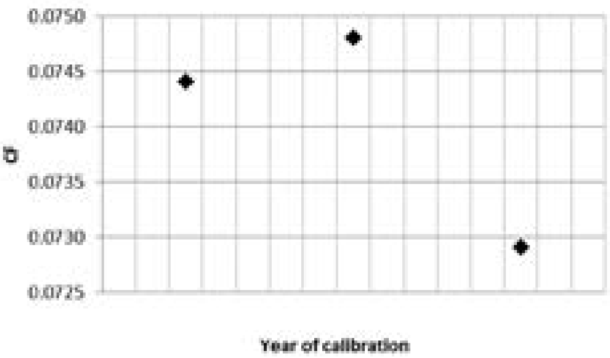

Figure 4. Calibration results for particular RK-100 for contamination measurements using ^{90}Sr surface source performed at three following years

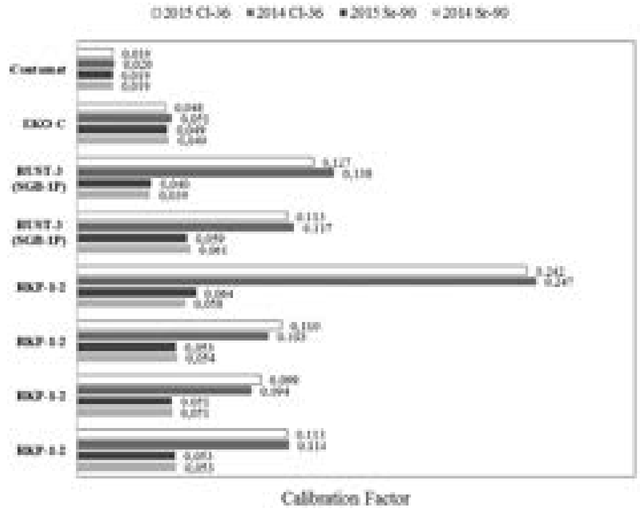

Figure 5. Results of calibration for four types of contamination monitoring instruments performed by two reference sources at two following years

process. For the group of analyzed instruments at almost all cases more repeatable results were obtained for calibration involving higher beta particle energy (^{90}Sr source). In addition as we can observe on RKP-1–2 survey the sensitivity fluctuates from instrument to instrument sufficiently. The effect is observed evidently for lower energy of registered particles, as before.

Conclusions

The presented results show the importance of calibration process of dosimetric instruments. The calibration factor for particular instrument can deviate for more than 50% in period of one year. Taking into account the real measurement situation it could result in underestimating the doses by 50% from the true value. It is evidence that the calibration process of the radiation protection instruments should be performed periodically for the test of dose rate measurements as well as for contamination measurements abilities.

As was shown for RKP-1–2 instruments the CF could fluctuate by more than 100% for the same type of the instruments dedicated for surface contamination monitoring.

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