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Results of the intermediate checks on the working standards used for routine calibrations of ionizing radiation dosimeters in a ^{60}Co gamma ray beam - experience from over a year of calibration laboratory activity

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Laboratory accredited by the Polish Centre for Accreditation, accreditation No. AP 155*

* an actual scope of accreditation No. AP 155 is available on the PCA website: www.pca.gov.pl

Introduction

Every calibration laboratory accredited for the conformity with the norm ISO/IEC 17025 has to fulfil its requirements. One of these requirements concerns the **monitoring of the validity of results**.

The Polish Secondary Standard Dosimetry Laboratory (**SSDL**) has been accredited by the Polish Centre of Accreditation for the conformity with the norm ISO/IEC 17025 [1, 2] since May 28, 2014. One of the accredited activities (according to the Scope of Accreditation No. AP 155) is **calibration of ionizing radiation dosimeters in a ^{60}Co gamma ray beam in terms of dose absorbed to water**.

The Polish SSDL calibrates the ionizing radiation dosimeters (referred to further in the text as "**customer dosimeters**") in the above-mentioned field from all the radiotherapy centres in Poland.

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Introduction

At the Polish SSDL, it was decided that **monitoring of the validity of the calibration results will include, among others, periodic intermediate checks on the working standards used for the calibration of the customer dosimeters**. According to the norm, these checks shall be carried out according to a procedure defined by the accredited laboratory.

The aim of this study is to present **the results of the intermediate checks on the working standard used for routine calibrations of customer dosimeters in a ^{60}Co gamma ray beam in terms of absorbed dose to water**.

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Material

The material of this study were the results of 45 intermediate checks on the **one working standard**, used routinely at the Polish SSDL **in the period from December 2021 to March 2023**.

The analysed working standard was an electrometer KEITHLEY type 6517A, serial number: 0760205 (manufacturer: Keithley Instruments) with ionization chamber type 2571, serial number: 2458 (manufacturer: Nuclear Enterprises Technology).

According to the recommendations of the IAEA Technical Reports series no. 469 (section 6.2.1), this working standard:

- is used routinely at the Polish SSDL for calibrations of customer dosimeters;
- is calibrated against **the secondary standard*** which is **not used** in routine calibrations of customer dosimeters.

* **KEITHLEY electrometer type 6517A, serial number: 0815930 (manufacturer: Keithley Instruments) with ionization chamber type: 2571, serial number: 2885 (manufacturer: Nuclear Enterprises Technology). This standard is calibrated regularly by Central Office of Measures in Warsaw, acting as National Metrology Institute in Poland.**

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Methods

Part 1: Method of the intermediate checks

The intermediate checks were carried out according to a procedure defined by the Polish SSDL, i.e. **on the same day the working standard was used for the calibration of the customer dosimeter** in the **^{60}Co gamma ray beam of the Theratron 780E unit, from Theratronics**.

Each intermediate check consisted of a comparison of:

- the mean value of the absorbed dose to water: $\boldsymbol{D}_{\mathbf{mean}}$ (based on 10 measurements of the charge M_i, in calibration conditions, as presented by the IAEA technical Reports 398 and 469)

and

- the value of the dose absorbed to water calculated according to the radioactive decay of the ^{60}Co source: $\boldsymbol{D}_{\mathbf{calc,\,x}}$ with a half-life of 1925.5 days.

Calibration set at the Polish SSDL in a ^{60}Co gamma ray beam of the Theratron 780E unit

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Part 1: Method of the intermediate checks

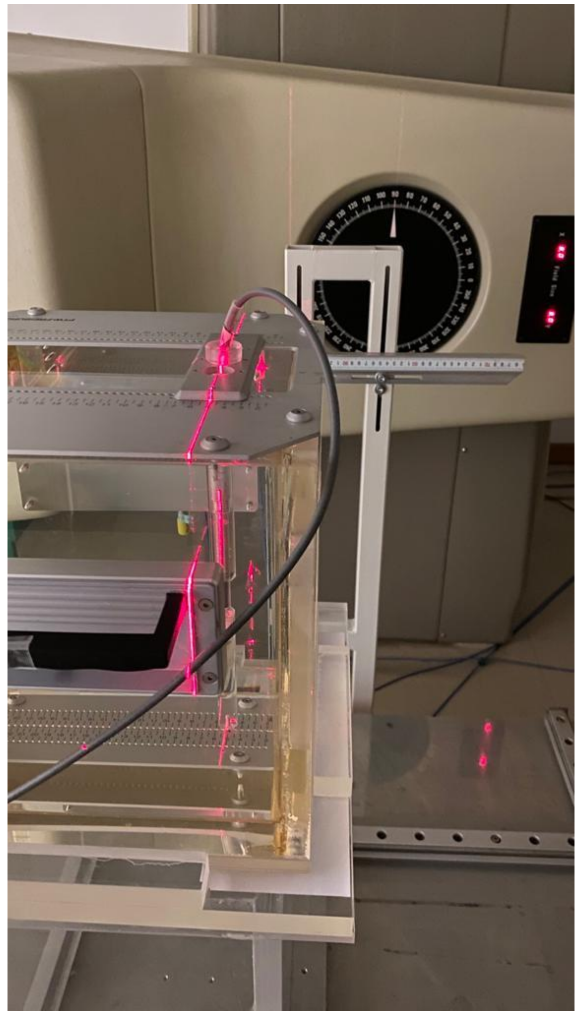
The ionization chamber of the working standard was placed in the dedicated holder (PTW 4333/ U13) **in a water phantom** (PTW-Freiburg, type 4322) in such a way that the reference point of the chamber is at a depth of 5.0 g/cm^2, at a 100.0 cm distance from the radiation source, in a field size of 10.0 cm x 10.0 cm at the plane of the chamber's reference point.

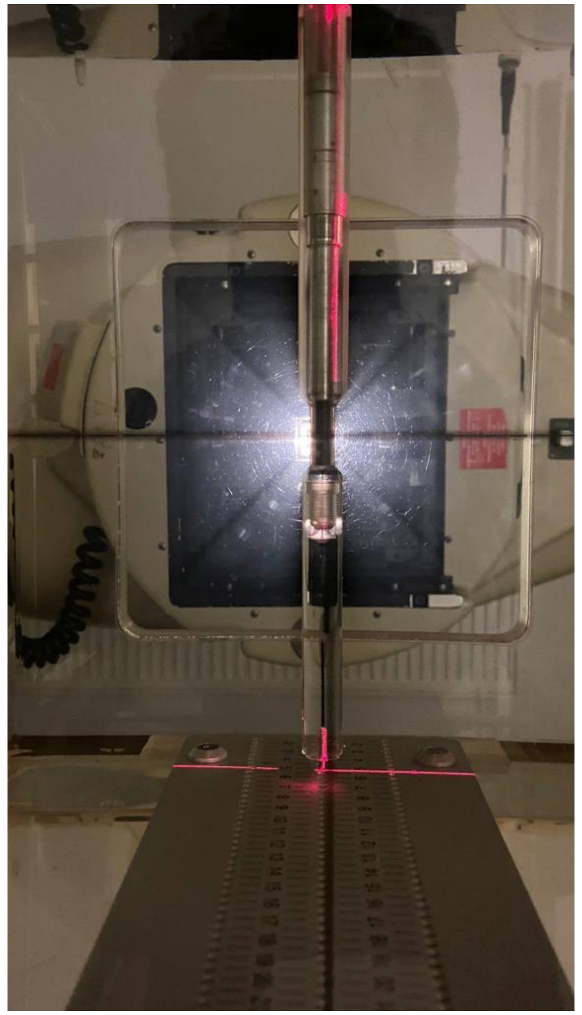
During the charge measurements:

- the water temperature in the phantom;
- the air pressure

were measured with calibrated instruments, i.e.:

- a digital thermometer from Elmetron, type PT-401, serial number 0418/09;
- a digital barometer from VAISALA, type PTB330, serial number E4230001.





Calibration set at the Polish SSDL in a ^{60}Co gamma ray beam of the Theratron 780E unit

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Methods

Part 1: Method of the intermediate checks

At the Polish SSDL, Δ parameter was adopted as the measured of the intermediate check result:

$$\Delta = \frac{|D_{\text{mean}} - D_{\text{cal, x}}|}{D_{\text{mean}}} \cdot 100 \quad [\%]$$

where:

$$D_{\text{mean}} = \left(\frac{\sum_{i=1}^{n} M_i}{n}\right) \cdot N_{D,\text{w}} \cdot k_{Tp} \quad (*)$$

where:

M_i [nC] – the charge measured with the ionization chamber of the working standard in the i successive measurement;

$n = 10$ – number of successive measurements of the charge (M_i) in a given measurement series;

$N_{D,\text{w}}$ [cGy/ nC] – the calibration coefficient value of the working standard, given in its actual calibration certificate;

k_{Tp} – factor to correct the response of an ionization chamber of working standard for the effect of the difference that may exist between the reference temperature ($T_{\text{ref [°C]}} = 20$ °C or $T_{\text{ref [K]}} = 293.15$ K) and pressure ($p_{\text{ref}} = 1013$ hPa) specified by the calibration laboratory and the temperature ($T_{[°C]}$ [°C] or $T_{[K]}$ [K]) and pressure (p [hPa]) of the chamber in the user facility under different environmental conditions, determined by the following formula:

$$k_{Tp} = \frac{p_{\text{ref}}}{p} \cdot \frac{T_{[K]}}{T_{\text{ref [K]}}} = \frac{p_{\text{ref}}}{p} \cdot \frac{273.15 + T_{[°C]}}{273.15 + T_{\text{ref [°C]}}}$$

$$D_{\text{cal, x}} = D_{\text{cal, 0}} \cdot e^{-\frac{x \ln 2}{1925.2}}$$

where:

$D_{\text{cal, 0}}$ [cGy] – the value of the absorbed dose to water, in cGy, calculated according to Eq. (*) with the use of the secondary standard for calibration of the working standard on day “0”;

x – number of days since day „0” to the day of the intermediate check.

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Methods

Part 1: Method of the intermediate checks

At the Polish SSDL, it was decided that the result of the intermediate check is acceptable when the following relation is met:

$$\Delta < k \cdot u_{\mathrm{p,\,r}}\,(D_{\mathrm{mean}})$$

where:

***k* = 2 – coverage factor of the combined uncertainty of the measurement of the D_{mean} value with an expanded probability of around 95 %;**

$$u_{\mathrm{p,\,r}}\,(D_{\mathrm{mean}}) = \frac{u(D_{\mathrm{mean}})}{D_{\mathrm{mean}}} \cdot 100 \;\; [\%]$$

In order to evaluate the $u_{\mathrm{p,\,r}}\,(D_{\mathrm{mean}})$ values, two following methods may be used:

a) **method #1** („mild”), in which all the components of the combined uncertainty are taken into account;

b) **method #2** („sharp”), in which all the components of the combined uncertainty are taken into account except the component linked with the calibration coefficient (as a component of the uncertainty which does not change in the two year cycle of the intermediate checks, since the calibration coefficient of the working standard and its uncertainty are established every two years).

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Methods

Part 2: Acceptance criteria of the intermediate checks results

Method #1:

Following the uncertainty propagation rule according to the IAEA recommendations, the percentage relative value of the combined uncertainty of the measurement of the D_{mean}, $\boldsymbol{u_{p,\,r}(D_{mean})}$, was calculated using the formula:

$$u_{p,\,r}\,(D_{mean}) = \sqrt{\left(\frac{u(M_{mean})\cdot 100}{M_{mean}}\right)^2 + \left(\frac{u(N_{D,\,w})\cdot 100}{N_{D,\,w}}\right)^2 + \left(\frac{u(k_{Tp})\cdot 100}{k_{Tp}}\right)^2 + \left(\frac{u(k_{other})\cdot 100}{k_{other}}\right)^2} \quad [\%]$$

$u(M_{mean})$ [nC] – type A standard uncertainty of the measurement of M_{mean}, according to the following formula:

$$u(M_{mean}) = \sqrt{\frac{1}{n\cdot(n-1)}\cdot\sum_{i=1}^{n}(M_i - M_{mean})^2}$$

$n = 10$ – number of successive measurements of the charge (M_i) in a given measurement series;
M_{mean} [nC] – arithmetic mean value of 10 measurements of charge (M_i)

$u(N_{D,\,w})$ [cGy/nC] – type B standard uncertainty of the determination of the calibration coefficient for absorbed dose to water: $N_{D,\,w}$ (for $k = 1$) **determined on the basis of the actual calibration certificate of the working standard**

Validity of calibration coefficient	Calibration coefficient: $N_{D,\,w}$ [cGy/nC]	Expanded uncertainty, $k = 2$ $U(N_{D,\,w})$ [cGy/nC]	Relative standard uncertainty, $k = 1$ $\frac{u(N_{D,w})\cdot 100}{N_{D,w}}$ [%]
from November 25, 2020 to November 16, 2022	4.526	0.050	0.55
from November 17, 2022 until now	4.527	0.050	0.55

Note:
At the Polish SSDL, the working standard is calibrated every two years against the secondary standard.

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Part 2: Acceptance criteria of the intermediate checks results

Method #1:

$\frac{u(k_{Tp})\cdot 100}{k_{Tp}}$ [%] – type B relative standard uncertainty of the measurement of k_{Tp}, determined according to the following formula:

$$\frac{u(k_{Tp})\cdot 100}{k_{Tp}} = \sqrt{\left(\frac{u(T_{[K]})\cdot 100}{T_{[K]}}\right)^2 + \left(\frac{u(p)\cdot 100}{p}\right)^2} \quad [\%]$$

$\frac{u(T_{[K]})\cdot 100}{T_{[K]}} = 0.06$ % - type B relative standard uncertainty of the measurement of the water temperature in the phantom: $T_{[K]}$;

$\frac{u(p)\cdot 100}{p} = 0.03$ % - type B relative standard uncertainty of the measurement of air pressure: p

$\frac{u(k_{other})\cdot 100}{k_{other}}$ [%] – type B relative standard uncertainty of the determination of the coefficient k_{other}, determined according to the following formula on the basis of data from **Table**

$$\frac{u(k_{other})}{k_{other}}\cdot 100 = \sqrt{\left(\frac{u(k_{stab.})\cdot 100}{k_{stab.}}\right)^2 + \left(\frac{u(k_{nonlinearity})\cdot 100}{k_{nonlinearity}}\right)^2 + \left(\frac{u(k_{elec.\ acc.})\cdot 100}{k_{elec.\ acc.}}\right)^2 + \left(\frac{u(k_{elec.\ sen.})\cdot 100}{k_{elec.\ sen.}}\right)^2 + \left(\frac{u(k_{phantom\ pos.})\cdot 100}{k_{phantom\ pos.}}\right)^2 + \left(\frac{u(k_{chamber\ pos.})\cdot 100}{k_{chamber\ pos.}}\right)^2} \quad [\%]$$

Components of the uncertainty of k_{other} coefficient	Symbol of quantity	Estimate of the value: x_i	Standard uncertainty: $u(x_i)$	Relative standard uncertainty
Correction factor connected with the long term stability of the working standard	$k_{stab.}$	1.0000	0.0012	0.12 %
Correction factor connected with the nonlinearity of the indications of the working standard	$k_{nonlinearity}$	1.0000	0.0005	0.05 %
Correction factor connected with the long term accuracy of the electrometer of the working standard	$k_{elec.\ acc.}$	1.0000	0.0024	0.24 %
Correction factor connected with the sensitivity fluctuation of the electrometer of the working standard during the measurement session	$k_{elec.\ sen.}$	1.0000	0.001	0.10 %
Correction factor connected with the deviation of the phantom position from the reference position	$k_{phantom\ pos.}$	1.0000	0.0012	0.12 %
Correction factor connected with the deviation of the ionization chamber position from the reference position in the water phantom	$k_{chamber\ pos.}$	1.0000	0.0015	0.15 %

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Methods

Part 2: Acceptance criteria of the intermediate checks results

Method #2:

In order to implement a „sharper" acceptance criterion of the intermediate checks results than in method #1 and to apply the uncertainty propagation rule as in the method #1, **but excluding the uncertainty of the calibration coefficient $u(N_{D,\,w})$** (the largest component of the $u(D_{mean})$), the value of the relative percentage combined uncertainty of the D_{mean} measurement, the $u_{p,\,r}(D_{mean})$, was calculated using the formula:

$$u_{p,\,r}\,(D_{\text{mean}}) = \sqrt{\left(\frac{u\,(M_{\text{mean}})\cdot 100}{M_{\text{mean}}}\right)^2 + \left(\frac{u\,(k_{Tp})\cdot 100}{k_{Tp}}\right)^2 + \left(\frac{u\,(k_{\text{other}})\cdot 100}{k_{\text{other}}}\right)^2} \quad [\%]$$

According to **method #1**, **the relative extended uncertainty of D_{mean} value** was **1.3%**.
According to **method #2**, **the relative extended uncertainty of D_{mean} value** was **0.7%**.
Both these values (i.e. 1.3% and 0.7 %) may be adopted as an acceptance criterion of the Δ parameter.

At the Polish SSDL, value of 0.7 % was adopted as an acceptance criterion of the Δ parameter.

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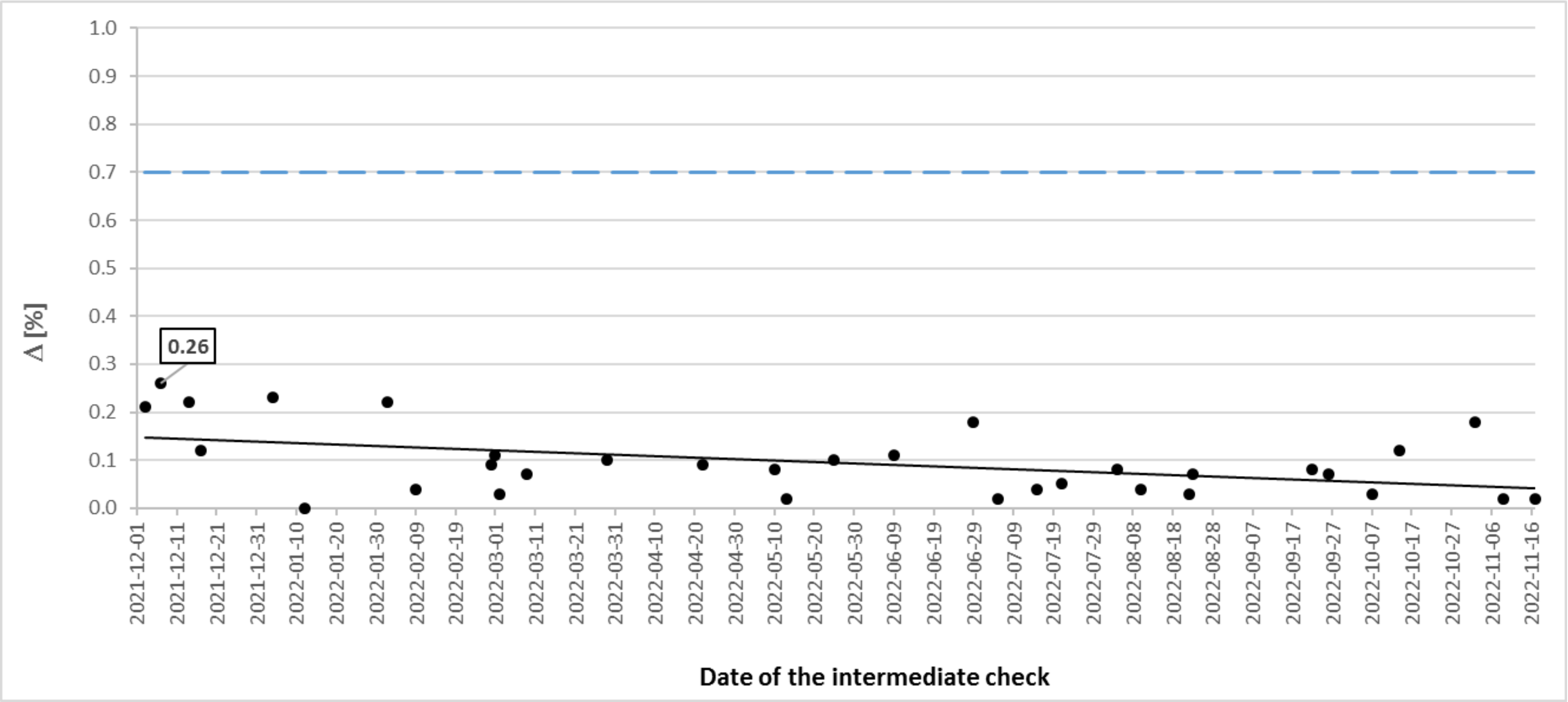
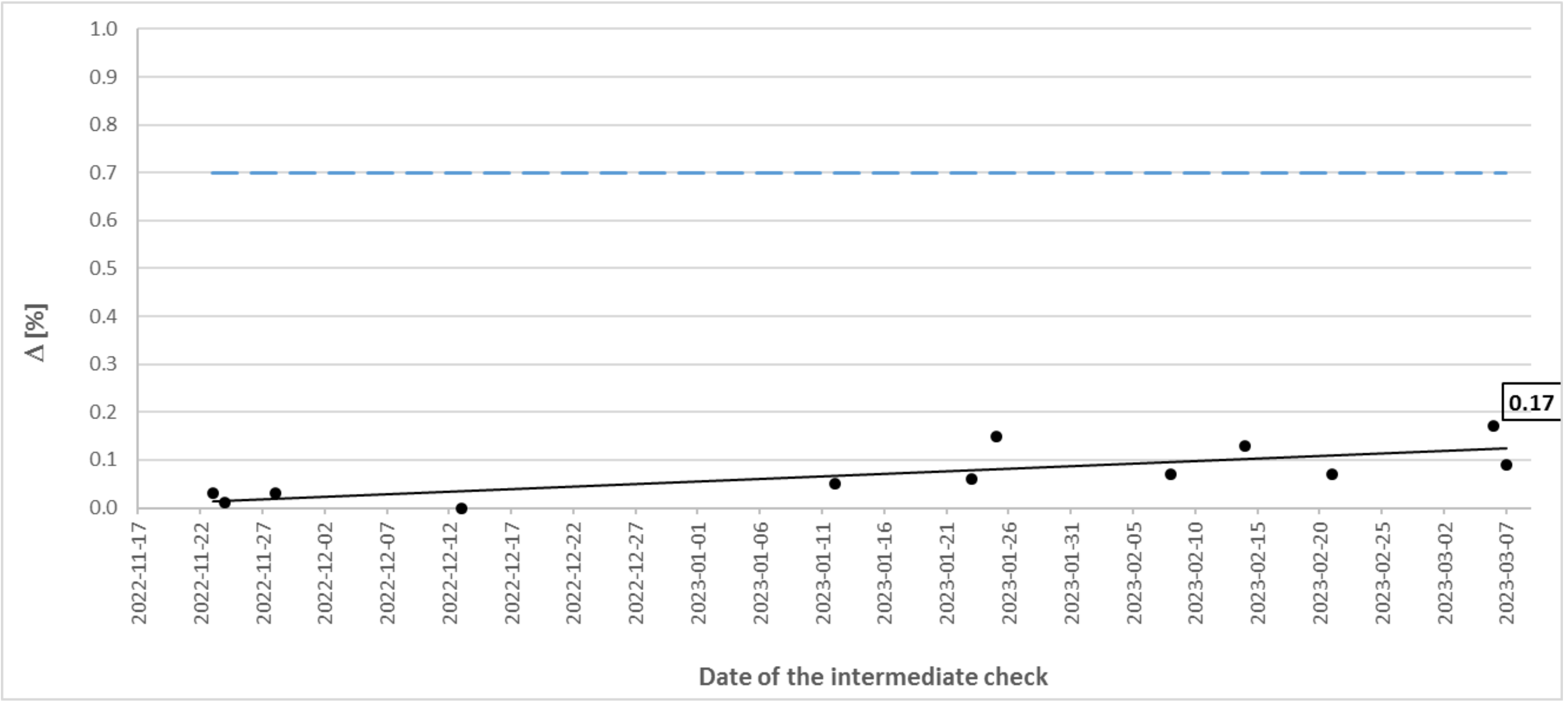
Results



a)



b)

Values of the Δ parameter as a function of time for one working standard in the period from December 3, 2021 to November 16, 2022 (a) and from November 23, 2022 to March 07, 2023 (b).

Note 1: The dashed line represent an acceptance criterion: Δ = 0.7 %.

Note 2: The number in the text box is the largest value for working standard.

Note 3: The solid line is marked to support the reader, it does not represent the trend fitted to the Δ parameter.

Note 4: On November 17, 2022 there was calibration of the working standard against the secondary standard, new value of $D_{cal,\,0}$ for the intermediate checks on the working standard was obtained.

Since all values of the Δ parameter were below 0.3 %, all results of the intermediate checks on the working standard were more than two times smaller than the acceptance criterion (i.e. 0.7 %).

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Conclusions

The presented results of the intermediate checks indicated that the tested working standard ensured the validity of the calibration coefficients of the customer dosimeters, during the analyzed period of time.

The presented method of carrying out periodic intermediate checks, together with the criterium of their acceptance, is useful in the routine work of a calibration laboratory carrying out calibrations of the ionizing radiation dosimeters in the ^{60}Co radiation beam, in terms of absorbed dose to water.

References

[1] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, General requirements for the competence of testing and calibration laboratories, ISO/IEC 17025:2005, ISO, Geneva (2005)

[2] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, General requirements for the competence of testing and calibration laboratories, ISO/IEC 17025:2017, ISO, Geneva (2017)

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Thank you for your attention.