COMPARISON OF EXTRAPOLATION CHAMBER MEASUREMENTS OF THE ABSORBED DOSE RATE IN BETA RADIATION

C. Lecante*, I.Uryaev #, N. Villevalde #, E.Rumyantseva # , B. Chauvenet*

VNIIM-D.I.Mendeleyev Institute for Metrology, Saint-Petersburg
* BNM-LNHB, CEA, Saclay

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Abstract : The Russian (VNIIM) and French (BNM-LNHB) national primary laboratories organized in 1997 a bi-lateral comparison in beta dosimetry. This comparison of national standards, EUROMET.RI(I)-S2.B2, was carried out through a transfer ionization chamber manufactured by the VNIIM. The calibration factors of this chamber were determined by both laboratories in terms of absorbed dose rate at 7 mg.cm^{-2} of tissue depth, for the beta radiation fields of ^{90}Sr-^{90}Y, ^{204}Tl and ^{147}Pm.

INTRODUCTION

In 1997, a comparison of National Primary Standards for realizing the unit of the absorbed dose rate to tissue for beta radiation was carried out between Mendeleyev Institute for Metrology (VNIIM, St.Petersburg, Russia) and BNM-LNHB (CEA, Saclay, France) for the beta radiation of ^{90}Sr-^{90}Y, ^{204}Tl and ^{147}Pm.

The VNIIM Primary Beta Ray Standard is a set with an extrapolation chamber constructed at the VNIIM. The distance between the plate beta ray source and chamber may be changed from contact to 80 mm.

The BNM-LNHB Primary Beta Ray Standard is a set with an extrapolation chamber manufactured by the PTW. The reference distances source-chamber are 200 mm for ^{147}Pm and 300 mm for ^{90}Sr-^{90}Y and ^{204}Tl.

The comparison was performed using a constant volume parallel-plate ionization chamber Type PK2-01 n°2 designed and constructed at the VNIIM as a secondary standard. The calibration factors of this chamber were determined by both laboratories for the beta radiation fields of ^{90}Sr+^{90}Y, ^{204}Tl and ^{147}Pm radionuclide sources specified in ISO 6980 and at 7 mg.cm^{-2} of soft tissue depth.

EXPERIMENTAL ARRANGEMENTS

Irradiation conditions for the comparison

The beta radiation reference fields of BNM-LNHB [1] and VNIIM were used as radiation fields for the comparison. The main characteristics of the sources and of irradiation conditions are presented in table 1.

Table 1. Main characteristics of the sources and irradiation conditions

	BNM-LNHB			VNIIM		
Radionuclide	^{90}Sr-^{90}Y	^{204}Tl	^{147}Pm	^{90}Sr-^{90}Y	^{204}Tl	^{147}Pm
Nominal activity GBq	1.69 01/04/97	0.06 01/04/97	2.75 01/04/97	8 01/04/97	2 01/04/97	0.7 01/04/97
Active diameter (mm)	42	42	42	50	40	50
Material and Window thickness (mg cm^{-2})	Ag 50	Ag 20	Ag 5	Steel 0.1 mm	Al 0.2 mm	Titanium dioxide 1 μm
Calibration distance (mm)	300	300	200	80	80	80

All irradiations were performed without filters.

Transfer ionization chamber (PK2-01 n°2)

The PK2-01 n°2 transfer chamber used for the comparison was manufactured by the D.I. Mendeleyev Institute for Metrology. It is a parallel-plate ionization chamber with a thin entrance window and a guard ring surrounding the collection electrode. The polarizing voltage was to 100 V (both polarities).

The main characteristics of the PK2-01 n°2 chamber are presented in table 2.

Table 2. Characteristics of the PK2-01 n°2 chamber

Entrance window material	Graphited polyethylene terephtalate
Equivalent tissue depth, d_{win} (mm)	0.0553
Collector material	PMMA
Thickness (mm) of collector material	20
Area of collecting electrode (cm²)	6.9887 ± 0.0004
Width of the groove (mm)	0.3
Guard ring width (mm)	40
Potential gradient (V)	100
Distance between electrodes (mm)	2

Ionization current measuring systems

To measure the very low currents (of the order of 10 fA) originating from the chamber, the BNM-LNHB used an integrating current measuring system, a Keithley 642 electrometer in the capacitor feed-back mode. The ionization currents were all normalised to the air temperature 293.15 K and air pressure 101.325 kPa.

At the VNIIM, the charge Q collected by the transfer chamber was measured using the voltmeter-electrometer Type B7-57 made in the Republic of Belarus. The measured ionization current was normalized to the air temperature 293.15 K and air pressure 101.325 kPa.

DESCRIPTION OF THE PRIMARY STANDARDS OF ABSORBED DOSE RATE TO TISSUE

The standards used by both laboratories to establish their references of absorbed dose rate to tissue in beta radiation fields are extrapolation chambers. These chambers are parallel plate ionization chambers of circular cross-section with a variable air gap. These instruments permit the extrapolation to zero air cavity thickness of the measurement results and thus to obtain the Bragg-Gray conditions.

The absorbed dose rate to tissue-equivalent materials, determined under the Bragg-Gray conditions [2], is obtained by the relation

$$\overset{\circ}{D}_t(d_{win}) = \bar{S}_{t,air}\,.\frac{W}{e}.\frac{1}{\rho_0}.\frac{1}{a}.K'.\left[\frac{d(KI)}{dl}\right]_{BGC}$$

where

d_{win}	is the equivalent tissue depth,
$\bar{S}_{t,air}$	is the ratio of the average mass collision stopping powers for tissue and air,
W	is the mean value of the energy expended in air per ion pair formed,
e	is the charge of electron
ρ_0	is the density of air in the collecting volume in reference conditions,
a	is the effective area of the extrapolation chamber collecting electrode,
K	is the product of the extrapolation chamber correction factors which are dependent on cavity depth,
K'	is the product of the extrapolation chamber correction factors which are independent of cavity depth,
I	is the current measured and corrected for climatic influences on the air of the cavity (pressure, temperature, relative humidity), background noise, the effects of polarity and recombination, the attenuation of β radiation in the air between the source and the entrance window, radioactive decay,
$[d(KI)/dl]_{\mathrm{BGC}}$	is the slope obtained under Bragg-Gray conditions, of the ionization current vs cavity depth, l, equal to the value of the experimental slope extrapolated to zero thickness.

The main characteristics of the extrapolation chambers are summarised in table 3.

Table 3. Main characteristics of the extrapolation chambers

	BNM-LNHB	VNIIM[3]
Entrance window materials and associated masses per unit area (mg.cm^{-2})	Graphited Hostaphan 2.61	Aluminised mylar 0.508 + polyethylene terephthalate 6.5
Equivalent tissue depth, d_{win} (mm)	0.024$^{(a)}$	0.065$^{(b)}$
Collector material	PMMA	PMMA
Collector thickness (mm)	31	30
Area of collecting electrode (cm^2)	7.16 ± 0.06	7.082 ± 0.002
Width of the groove (mm)	0.2	0.2
Guard ring width (mm)	15	40
Potential gradient (V/mm)	10	100
Distance between electrodes (mm)	0.25 to 2.0	0.3 to 0.7
Distance to the beta source (mm)	200(^{147}Pm) to 300(^{204}Tl, ^{90}Sr-^{90}Y)	0 to 80

(a) To obtain the reference depth (7mg.cm^{-2}) of tissue, an additional absorber (36 µm) of mylar is positionned in front of the window.

(b) To increase d_{win} to tissue depth 0.07 mm, a special correction has been made.

The physical constants and correction factors for the determination of absorbed dose rates are summarised in table 4.

Table 4. Physical constants and correction factors with associated expanded uncertainties (*k* = 2)

	BNM-LNHB[2]			VNIIM		
	^{90}Sr-^{90}Y	^{204}Tl	^{147}Pm	^{90}Sr-^{90}Y	^{204}Tl	^{147}Pm
$\bar{S}_{t,air}$	1.110 ± 0.015	1.121 ± 0.015	1.124 ± 0.015	1.117 ± 0.015	1.120 ± 0.015	1.140 ± 0.015
W/e (J C^{-1}) for dry air	33.97 ± 0.06	33.97 ± 0.06	33.97 ± 0.06	33.97 ± 0.002	33.97 ± 0.002	33.97 ± 0.002
ρ_0 (kg m^{-3})	1.20470[4] ± 1.10^{-5}	1.20470[4] ± 1.10^{-5}	1.20470[4] ± 1.10^{-5}	1.293(a) ± 1.10^{-4}	1.293(a) ± 1.10^{-4}	1.293(a) ± 1.10^{-4}
$T_{1/2}$ (year)	28.15[5] ± 0.2	3.79[5] ± 0.04	2.6234[5] ± 0.0008	29.12 [6]	3.78 [6]	2.623 [6]
Correction factors for : -divergence of the beam k_{div}	1.0067(b) ± 0.001	1.0067(b) ± 0.001	1.0100(b) ± 0.001	1.008_7(c) ± 0.001	1.008_7(c) ± 0.001	1.008_7(c) ± 0.001
-attenuation of beta particles in the collecting volume k_{ac}	1.0000 ± 0.0001	1.0000 ± 0.0001	1.0000 ± 0.0001	1.0000 ± 0.0001	1.0000 ± 0.0001	1.0000 ± 0.0001
-perturbation of beta radiation by the chamber side walls k_{pl}	0.986(c) ± 0.001	1.000(c) ± 0.001	1.004(c) ± 0.001	0.998(c) ± 0.001	0.999(c) ± 0.001	1.001_3(c) ± 0.001
-electrostatic attraction of the entrance window k_{el}	1.000 ± 0.001	1.000 ± 0.001	1.000 ± 0.001	1.000 ± 0.001	1.000 ± 0.001	1.000 ± 0.001
-bremsstrahlung from the beta source k_{br}	0.998 ± 0.001	0.994 ± 0.002	0.999 ± 0.002	1.000	1.000	1.000
-difference between the material of entrance window and tissue k_{w}	1.026 ± 0.012	1.008 ± 0.02	0.415 ± 0.006	0.997 ± 0.001	0.997 ± 0.001	0.997 ± 0.001
-difference in backscatter between the material of chamber and tissue k_{rd}	1.010 ± 0.003	1.010 ± 0.003	1.000 ± 0.002	1.010 ± 0.003	1.010 ± 0.003	1.010 ± 0.003

(a) T_0 = 273.15 K

(b) for chamber depth = 2 mm and source-entrance window distance = 200 mm (^{147}Pm) to 300 mm (^{204}Tl, ^{90}Sr-^{90}Y) ; U = 20 V

(c) for chamber depth = 0.7 mm and source-entrance window distance = 80 mm ; U = 30 V

In both laboratories, the slope of extrapolated values was determined according to linear fitting.

RESULTS OF THE COMPARISON

The calibration factor of the transfer chamber N_a (Gy/C) is defined for each participant as the quotient of their respective standard value of absorbed dose rate to tissue at depth 7 mg cm^{-2} by the ionization current I_n measured with the PK2-01 n°2 transfer chamber and corrected for climatic influences on the air of the cavity, background noise, polarity and recombination effects, attenuation of the β radiation in the air between the source and the entrance window, and radioactive decay. The results given by both laboratories are presented in table 5 with their expanded uncertainties (*k* = 2).

Table 5 Results of the comparison with associated expanded uncertainties (k = 2)

	BNM-LNHB[(a)]			VNIIM		
	^{90}Sr-^{90}Y	^{204}Tl	^{147}Pm	^{90}Sr-^{90}Y	^{204}Tl	^{147}Pm
$\overset{\circ}{D}_t$ (0.07) (Gy s^{-1})	1.253 10^{-4} [7] ± 3.0 10^{-6}	2.020 10^{-6} [8] ± 5.9 10^{-8}	5.420 10^{-6} [9] ± 1.4 10^{-7}	1.029 10^{-3} ± 2.1 10^{-5}	8.382 10^{-5} ± 1.7 10^{-6}	4.366 10^{-5} ± 8.7 10^{-7}
I_n (A)	5.4847 10^{-12} ± 6 10^{-16}	8.6746 10^{-14} ± 1 10^{-16}	3.1623 10^{-13} ± 2 10^{-16}	4.4934 10^{-11} ± 6 10^{-14}	3.5974 10^{-12} ± 5 10^{-15}	2.347 10^{-12} ± 7 10^{-15}
N_a (Gy C^{-1})	2.28 10^7 ± 6 10^5	2.33 10^7 ± 7 10^5	1.71 10^7 ± 5 10^5	2.29 10^7 ± 5 10^5	2.33 10^7 ± 5 10^5	1.86 10^7 ± 4 10^5

(a) Reference date : 1/4/97

The discrepancies between the two laboratories are given in table 6, where ΔN_a is the difference $N_{a(BNM\text{-}LNHB)}$ minus $N_{a(VNIIM)}$.

Table 6 Relative difference between the results of the two laboratories

	^{90}Sr-^{90}Y	^{204}Tl	^{147}Pm
$\Delta N_a/N_a$ (%)	-0.44	0	-8.8

The results are in agreement for ^{90}Sr-^{90}Y and ^{204}Tl but for ^{147}Pm, the difference is significant. Additional measurements showed that this difference could be explained by the conditions of irradiation which were different in the two laboratories. Indeed, the BNM-LNHB standard and calibration distances follow the recommendations of the standard ISO 6980 [1] whereas the VNIIM reference points are only at 80 mm from the source. The beta radiation emitted by ^{147}Pm being low in energy (62 keV mean energy), the thickness of air crossed by this radiation can influence significantly the energy spectrum received by the detector. For the same reason, the use of sources of different characteristics (material, window thickness) can generate a difference on the results.

To investigate the difference found for ^{147}Pm, the BNM-LNHB made additional reference measurements with its own standard extrapolation chamber for a source-detector distance of 8 cm and determined a new calibration factor for the transfer chamber at that distance. To establish the reference value, all correction factors of table 4 were used and considered identical for the two distances. The only change was the correction for the attenuation of air between the source and the detector. This correction was considered as proportional to the source-detector distance. For example for ^{147}Pm, the formula given by Owen [10] for the corresponding factor k_{att} is $k_{att} = 1 + 4(1/k_{TP} - 1)$ in the reference conditions (distance of 20 cm and $P = 101.32$ kPa, $T_0 = 293.15$ K). Here it was assumed that k_{att} could be approximated by $k_{att} = 1 + 4(1/k_{TP} - 1)8/20$. The new results are presented in table 7. Under these conditions, the BNM-LNHB results are now in agreement with the VNIIM results.

Table 7 BNM-LNHB change in results for ^{147}Pm with a source-detector distance of 8 cm (k=2)

	^{147}Pm[(a)]
$\overset{\circ}{D}_t$ (0.07) (Gy s^{-1})	1.0426 10^{-4} ± 5.0 10^{-6}
I_n (A)	5.5772 10^{-12} ± 4 10^{-16}
N_a (Gy C^{-1})	1.87 10^7 ± 9 10^5
$\Delta N_a/N_a$ (%)	0.53

(a) Reference date : 1/4/97

The VNIIM carried out additional reference measurements with their standard extrapolation chamber in the field of a new beta source ^{147}Pm for a source-detector distance of 20 cm and determined a new calibration factor, N_a for the transfer chamber PK2-01 n°2 at that distance. Another beta source ^{147}Pm №014 with activity about 10^{10} Bq was used, as the original source ^{147}Pm №005 had decayed. The correction k_{mass} for the variation in the total air mass between the source and chamber caused by variations in air temperature and pressure was introduced in the measured ionization current. The correction factor was calculated using:

$$k_{mass} = (1 + \alpha h + \beta h^2)^{-1}, \quad [11]$$

where $h = 1 - 1/k_{TP}$;

α, β are empirical constants;

k_{TP} is correction factor for air temperature and pressure.

For the beta source ^{147}Pm and 7mg.cm^{-2} depth to polyethylene terephthalate in front of the chamber entrance window, the values of empirical constants are: $\alpha = 3.0$ and $\beta = 21.5$. The results of the final measurements of the calibration factor, N_a, for the transfer chamber PK2-01 n°2 at the 20 cm source-chamber distance and for beta source ^{147}Pm are summarized in table 8.

Table 8 VNIIM change in results for ^{147}Pm №014
with a source-detector distance of 20 cm (k=2)

	^{147}Pm$^{(a)}$
$\overset{\circ}{D}_t(0.07)$ (Gy s^{-1})	1.105 10^{-5} ± 2.2 10^{-7}
I_n (A)	6.440 10^{-13} ± 1.9 10^{-15}
N_a (Gy C^{-1})	1.72 10^{7} ± 4.0 10^{5}
$\Delta N_a/N_a$ (%)	-0.58

(a) Reference date :27/10/2000

CONCLUSION

The agreement between BNM-LNHB and VNIIM is good for ^{90}Sr-^{90}Y and for ^{204}Tl: the relative difference $\Delta N_a/N_a$ (%) are lower than the standard uncertainties of N_a (≤ 2.2 %).

For ^{147}Pm, we showed that the significant difference between the two laboratories had a link with the different conditions of irradiation in particular with the distance for calibration. Indeed, cross measurements of the two laboratories to the same distances for calibration (to 80 mm for the BNM-LNHB and 200 mm for the VNIIM) reduced the variation from 8.8 % to 0.58 %, and so, taking into account uncertainties on the factor of calibration, we have a good agreement for ^{147}Pm between the two laboratories.

We can thus conclude that, under the same conditions of irradiation, the difference between the BNM-LNHB and the VNIIM for the beta radiation fields of ^{90}Sr-^{90}Y, ^{204}Tl and ^{147}Pm, are lower than or equal to the maximum standard uncertainty on the determination of the calibration factor of 2.2 %.

We can also note the interest of this comparison in enabling the calibration of a transfer chamber, the VNIIM constant volume parallel-plate ionization chamber type PK2-01 n°2 as a secondary standard.

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