FINAL REPORT

COOMET.RI(II)-S2.Eu-152 (319/RU/04)

COMPARISON MEASUREMENTS OF RADIONUCLIDE VOLUME SOURCES (Eu-152)

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Abstract

Measurements of the Eu-152 specific activity in artificial volume sample of water density were performed in nine laboratories with the HPGe spectrometry technique. Analysis of the gamma radiation absorption in the sample material confirmed the Compton scattering as the main mechanism of interaction of photons with energy between 300 – 600 keV and 779 -1408 keV in the most important for environmental monitoring substances (food, water, biological materials, soils). A list of CMCs supported by the comparison is suggested.

1. Introduction

In some of COOMET countries spectrometers and radiometers for environmental measurements are calibrated against volume solid granulated radionuclide sources – imitators of the natural objects. Creation of proper services in the list of Calibration and Measurement Capabilities (CMCs) is an actual task for national Metrology Institutes (NMIs). One of the conditions of the CMCs recognition in the MRA CIPM framework is their supporting by a measurement comparison. This comparison is intended to evaluate the uncertainty estimate of radionuclide activity measurements in the volume sources declared by the participants.

2. Pilot laboratory and Participants

The information about the pilot laboratory and participants in the comparison is resumed in Table 1 and Table 2, respectively.

Table 1 Pilot laboratory

Pilot laboratory	All Russian Research Institute for Physical-Technical and Radio-Technical Measurements (VNIIFTRI) (RUSSIA)
Contact person	Sergey Korostin, VNIIFTRI Address: 141570 MENDELEEVO Moscow region RUSSIA Phone: +7 495 535-93-05 Fax: +7 496 466-25-76 e-mail: ir@vniiftri.ru

Table 2 Participants

№	NMI	Address for sending the sample	Acronym	Amount of the material (cm^3) in the sample [1]	Contact person
1	All-Russian Scientific Research Institute of Physical, Technical and Radio Measurements [2]	141570, Moscow Region, Mendeleevo RUSSIA	VNIIFTRI	1000	Sergey Antropov ir@vniiftri.ru Phone: + 7 495535-08-13 Fax: +7 495 535-93-05
2	Belarusian State Institute of Metrology	93, Starovilensky trakt 220053, Minsk,, BELARUS	BelGIM	1100	Valeriy Milevsky ion@belgim.belpak.minsk.by Phone: +375 17 2336504 Fax: +375 17 2880938
3	Bulgarian Institute of Metrology - National Centre of Metrology	"G.M.Dimitrov" blvd. 52 "b" 1040 Sofia BULGARIA	BIM - NCM	550	Violeta Andonova v.andonova@bim.government.bg Phone:+359 68 603 348 Fax: :+359 2 9702 735
4	Center of Isotopes-Radionuclide Metrology Department	Centro de Isotopos AP 3415, San Jose De Las Lajas Habana CUBA	CENTIS-DMR	500	Tulio Hernandez atulio@centis.edu.cu phone: 537 579563, 537 579524 Fax: (53 7) 8669821
5	Physikalisch-Technische Bundesanstalt	Fachbereich 6.1 Bundesallee 100 38116 Braunschweig GERMANY	PTB	500	Dirk Arnold dirk.arnold@ptb.de phone: +49-531-592-6120 Fax: +49-531-592-6109
6	Ministry of the Environment Radiation and Noise Division	Str. Knafei Nesharim 5, POB 34033, Jerusalem 95464, ISRAEL	ISR-MoE	1000	Victor Steiner victors@sviva.gov.il Phone. 972-3-6420822 Fax. 972-3-6426268
7	Latvian National Metrology Centre Ltd. Radiation Metrology and Testing Centre (RMTC)	31 Miera str. LV-2169, Salaspils, LATVIA	RMTC	1000	Antons Lapenas alap@latnet.lv Phone +371-7901210 Fax +371-7901210
8	Slovak Institute of Metrology	63, Karloveská 84255, Bratislava, SLOVAKIA	SMU	500	Anton Svec svec@smu.gov.sk Phone +421 2 60294655 Fax +421 2 602670
9	National Scientific Centre "Imstitute of Metrology"	42, Mironositskaya str. 61002 Kharkiv, UKRAINE	NSC «IM»	550	Vladimir Evseev ev@metrology.kharkov.ua Phone (057) 704-98-93 Fax (057) 700-34-47

[1] In accordance with the data given in the Form of Participant..
[2] Pilot-laboratory

3. Comparison Material

3.1 General description

The granulated material will be used as the comparison material. The characteristics of the material are the next:

- main radionuclide - Eu-152;
- the material is synthetic resin based granules with Fe impurity 14,5 %
- shapes of grains ~ cubic like with side ~ 2.5-3.5 mm ;
- poured density ~ 0.98 g/cm;
- specific activity ~ 10 Bq/g;
- the highest temperature for drying of the material is 80 ^{0}C
- packing of the sample - polyethylene bag having marked label.

3.2 Homogeneity

The pilot-laboratory made the control of the samples homogeneity with a beta radiometer. The control technique was made by measurements of count rates for 5 specimens taken from each sample. The volume parameter of the homogeneity control (volume of taken specimens) was determined by the radiometer's vessel dimension (ø7cm, depth 0.5 cm, V= 19 cm^3). A Sr/Y-90 reference source was measured for the spectrometer energy calibration control. The range of the energy window was adjusted from 104 to 7000 keV. The registered average number of impulses was 4800. Relative standard deviations were calculated for each sample (5 measurements) and were found less then 1 %.

3.3 Stability

The pilot-laboratory measured each sample in Marinelli geometry with a NaI(Tl) 63x63 spectrometer every month since August 2006. The sample count rate was registered in the 70-1200 keV energy window. All measurements were normalized to the first one, the August point. There was not any trend in the registered count rates and the deviations from the first measurement represented an uncertainty contribution to the Eu-152 activity concentration in the comparison material of 0.8 %.

3.4 Samples delivery to the participants

The comparison samples were prepared by the pilot-laboratory and then they were sent to the address given in the Participant's Form previously filled by each participant laboratory. Amount of the material in the samples was defined in accordance with information given in that Form.

The Eu-152 activity in each sample was less than the minimal permissible value for transportation of radioactive materials (in accordance with the Russian rules). Therefore the samples were sent by usual post mail.

The samples were kept in the participant laboratories after the comparison.

3.5 Measurement conditions

There were not any special conditions for the Eu-152 activity concentration determination in the comparison sample. The participants could use any measurement technique.

4. Reports of results

The data were reported in accordance with the agreed reporting form (see Appendix). The summary of the reported results is given in Table 3.

5. Data evaluation

5.1 General description.

The main idea of the data evaluation is determination of the deviation of the participants' results from the well-defined value of the material specific activity (supplementary comparison defined value SCDV). The SCDV should be traceable to a primary laboratory.

5.2 SCDV determination

Because of density of measured material almost equal to the water one, the Pilot laboratory determined SCDV by means of direct comparison of the material activity with a prepared in the same measurement geometry Eu-152 reference solution. The reference solution was calibrated with a Eu-152 point source calibrated by VNIIM. The stages of the SCDV determination are described below and schematic represented in Fig.2.

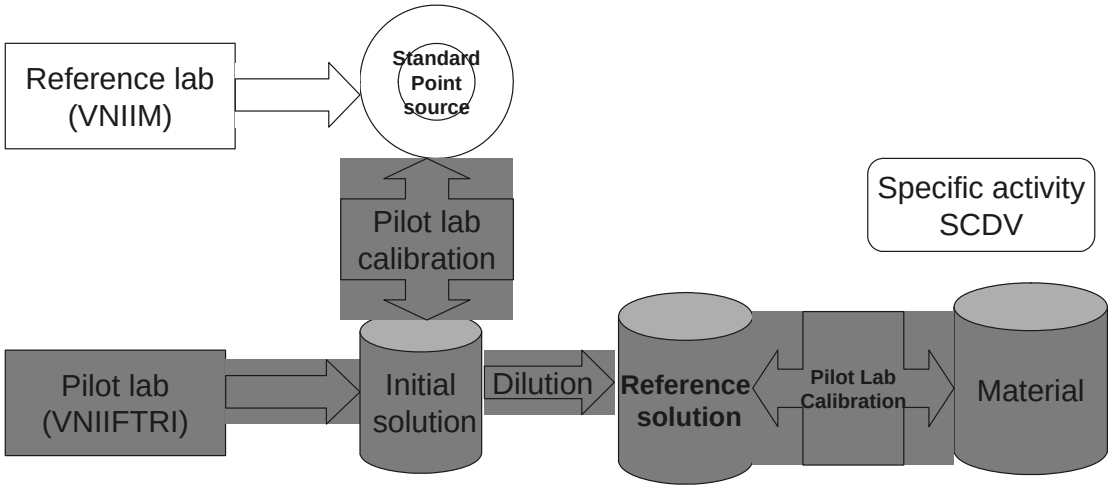

Fig. 1 SCDV determination

Table 3. Reported results

NMI	Specific activity, Bq/g	U, Bq/g k=2	U, % k=2	Date	Traceability	Calibration method	Geometry of measurements	Measurement technique	Software
SMU	8,643	0,360	4,2%	06.04.2006	CMI	sources	Marinelli	calibrated spectrometer	Genie-2000 (CANBERRA)
SSDL MAVA	8,34	0,260	3,1%	01.01.2006	PTB	sources	Marinelli	calibrated spectrometer	Genie-2000 (CANBERRA)
MoE-ISR	8,444	0,456	5,4%	02.05.2006	NIST (via DKD)	Ra226 volume source	Marinelli	calibrated spectrometer	Genie-2000 (CANBERRA)
PTB	8,71	0,270	3,1%	01.05.2006	PTB	solutions	100 ml cylinder	calibrated spectrometer	Interwinner version 4.1 (CANBERRA)
CENTIS-DMR	8,3	0,8	9,6%	11.08.2006	OMH	IAEA MRC S-2 (Lake sediment) spiked with Eu152	165 ml cylinder	calibrated spectrometer	SILENA EMCAPLUS (SILENA)
BIM-NCM	8,4	1,005	12,0%	31.05.2006	CMI	sources	Marinelli	calibrated spectrometer	GENIE PC (CANBERRA)
NSC IM	8,34	0,34	4,2%	21.04.2006	VNIIM	Natural radionuclides mixture volume source	Marinelli	calibrated spectrometer	AkWin (AtomKomplex Prylad)
BelGIM	8,46	0,35	4,0%	01.06.2006	VNIIM	solution	Marinelli	direct comparison	Gamma-Vision v. 5.1 (EG&G ORTEC)
VNIIFTRI	7.94	0,240	3,2%	01.06.2006	VNIIM	source	Marinelli	calibrated spectrometer	Progress (Amplituda)

5.3 Reference solution preparation technique

a. An initial solution of Eu $(NO_3)_2$ in 0,1 N HNO_3 was prepared (specific activity Q_{is} ~ 164 kBq/g);
b. The reference solution was obtained by dilution of 0.0955 g aliquot of the initial solution in 1 l of water.
c. An aliquot of the initial solution was used for preparing of the two reference point sources (0.0117g and 0.05888 g aliquot weights);
d. The reference solution was prepared in the Marinelli beaker identical to the comparison's material container;
e. One day before the reference solution preparing, the Marinelli beaker was filled with a carrier solution: 0,1 N HNO_3 containing 20-30 mg/l of Eu $(NO_3)_2$.
f. After 24 hours the carrier solution was replaced by 1 l weighted ^{152}Eu reference solution

5.4 Measurements

The reference point sources were compared with the standard point source calibrated by VNIIM (expanded uncertainty 1% k=2) using a NaI(Tl) 63x63 spectrometer. The count rate was measured in 70-1200 keV energy window.

The equation for the material specific activity calculation (SCDV):

$$Q_{SCDV} = \frac{n_m - n_{bg}}{n_{ref} - n_{bg}} \frac{n_{ss} - n_{bg}}{n_{rs} - n_{bg}} \frac{m_i}{m_m m_{rs}} A_{ss}, \quad (1)$$

where n_m – count rate from the Marinelli beaker filled with the comparison material; n_{ref} - count rate from the Marinelli beaker filled with the reference solution; n_{ss} - count rate from the standard point source; n_{rs} - count rate from the reference point source; n_{bg} – background count rate measured with pure non-radioactive resin sample put in the Marinelli beaker manufactured together with the working one in one set;; m_i – weight of the initial solution aliquot in the reference solution; m_m - weight of the comparison material in the Marinelli breaker; m_{rs} - weight of the initial solution aliquots (0,01170 g and 0,01123 g) used for preparing of the two reference point sources, A_{ss} – activity of the standard point source calibrated by VNIIM (18.8 kBq for the reference date U_{SS} - 1.1 % for k=2).

All parameters in Eq.1 were measured 10 times and the type A uncertainties were determined in the conventional way.

The value of the specific activity of the material (SCDV) was found equal to 8.55 Bq/g (for the reference date 01.01.06) and the respective expanded uncertainty U_{SCDV} = 0,28 Bq/g (k=2).

The uncertainty budget is given in the Table 4.

Table 4. SCDV uncertainty

Standard uncertainty, Bq/g Contribution due to	A	B
Statistics Activity calibration Mass Inhomogenety Stability	0.075	 0,043 0.004 0.09 0.06
Combined uncertainty (Quadratic summation)	0.075	0.12
Total combined standard uncertainty	0.14	
Expanded uncertainty k=2	0.28	
Level of confidence	0.95	

5.5 Data evaluation

The participant results shall comply with the next criteria, in the case of confirming the declared uncertainties [1]:

$$\widetilde{E}_n = \frac{|Q_i - Q_{SCDV}|}{2\sqrt{u^2(Q_i) + u^2(Q_{SCDV}) - 2\,\mathrm{cov}(Q_i, Q_{SCDV})}} < 1 \qquad (2)$$

Where Q_i – specific activity measured by the *i*-th participant, $u(Q_i)$ – standard uncertainty of the measured activity by the *i*-th participant, $u(Q_{SCDV})$ - standard uncertainty of the SCDV.

All participant data were recalculated to the reference date 01.01.06. The used Eu-152 half-life value was equal to 13.522 years [2]

The only source of covariance is the dissemination the Bq unit from VNIIM (which defined the SCDV) to participants. Three NMIs have traceability to VNIIM: VNIIFTRI, BelGIM, NSC IM. Only BelGIM and VNIIFTRI used for calibration Eu-152 sources or solutions. NSC IM utilized for calibration a volume source of natural radionuclides. VNIIFTRI used for calibration a point source and uncertainty due to calibration was 0.17 Bq/g. BelGIM used a calibrated solution and declared an uncertainty due to calibration equal to 0.08 Bq/g. Therefore,

$$\mathrm{cov}(Q_{SCDV}, Q_{VNIIFTRI}) = 0.17 * 0.074 = 0.012 \text{ and } \mathrm{cov}(Q_{SCDV}, Q_{BelGIM}) = 0.08 * 0.074 = 0.006$$

The list of the $\widetilde{E}_i$ values are given in the Table 5. Results of the comparison are given in the Fig.2.

Table 5 Results of the comparison.

NMI	u_c, % k=1	Data for the reference date 01.01.06	Deviation from SCDV	$\widetilde{E}_i$
SMU	2.1	8.756	2.4%	0,445
SSDL MAVA	1.6	8.340	-2.4%	0,557
MoE-ISR	3.2	8.584	0.4%	0,060
PTB	1.5	8.852	3.6%	0,770
CENTIS-DMR	4.8	8.553	0.1%	0,002
BIM-NCM	6.0	8.573	0.3%	0,020
NSC IM	2.1	8.466	-1.0%	0,191
BelGIM	2.0	8.634	1.0%	0,198
VNIIFTRI	1.6	8.497	-0.6%	0,170

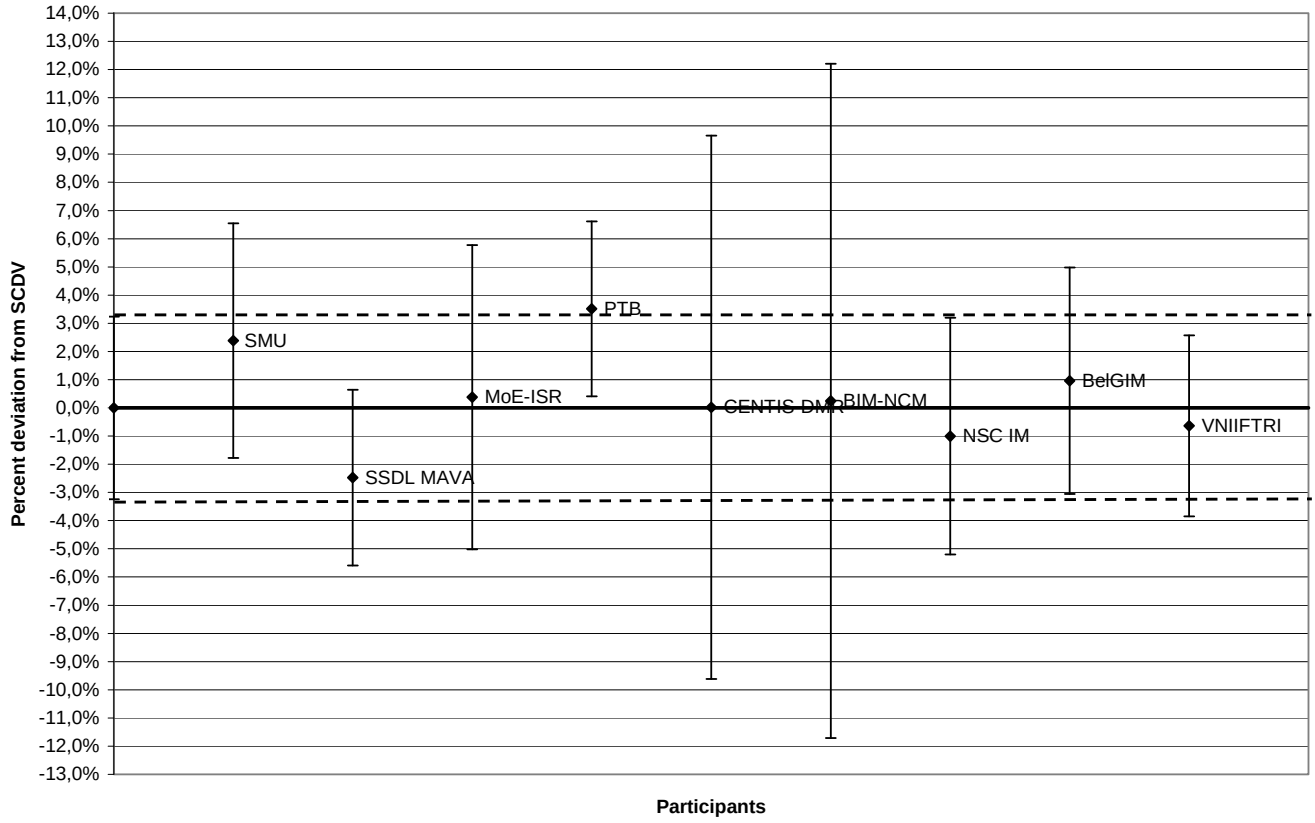

Fig.2 Results of the comparison. Dotted lines identify the limits for the SCDV expanded uncertainty (k=2).

6. Discussion of the results.

6.1 Physics of the Eu-152 gamma quanta in the different types of mediums

The resin used as the matrix (absorption medium) of the transfer standard has the chemical formula $\left(C_{39}H_{52}O_7\right)_{0,855}Fe_{0,145}$. In Fig. 3, the dependence of the photoelectric cross section to Compton scattering cross section ratio versus photon energy is calculated for the resin using the E.Storm and H.I.Israel reference data [2], is presented. It is confirmed that in the resin medium

$(C_{39}H_{52}O_7)_{0,855}Fe_{0,145}$ the main mechanism of interaction for the photon absorption is the Compton scattering at photon energies in the ranges 300 – 600 keV and 779 -1408 keV. Therefore, the Compton scattering defines the photon absorption to all hydrocarbon and hydroxide mediums specified in the "Classification of services for RI CMCs" [3]: water, foods, biological materials and flora.

In order to appreciate the main mechanism of the gamma photon absorption in a soil a similar calculation was performed for SiO_2 (Fig.4). In this case, the photoelectric cross section to Compton scattering cross section ratio is less than 1% at photon energies higher than 300 keV.

The density of electrons is important for Compton absorption correction. There is the rule Z=2M for the chemical elements up to Z=57 (M is the atomic mass). Therefore, simple weighing defines poured electron density and Compton absorption correction can be made as the mass absorption one

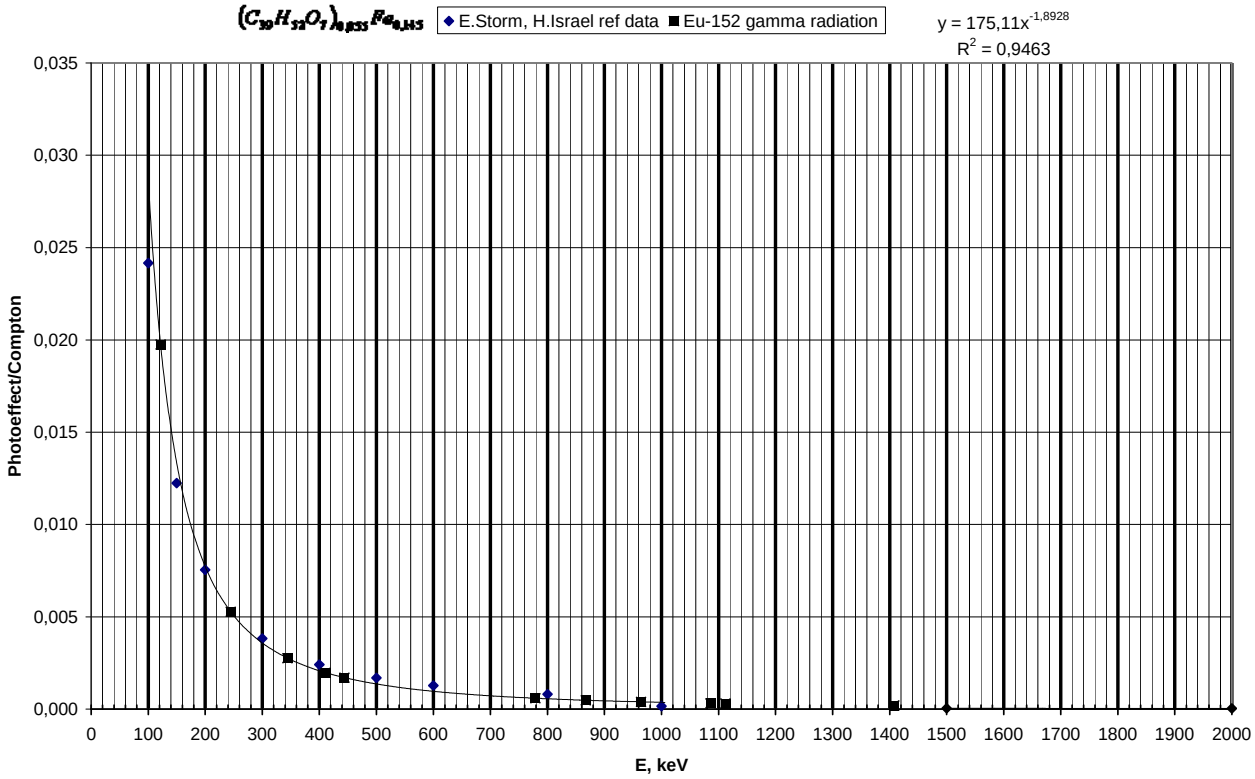

Fig.3 Dependence of the photoelectric cross section to Compton scattering cross section ratio versus photon energy for the resin $(C_{39}H_{52}O_7)_{0,855}Fe_{0,145}$

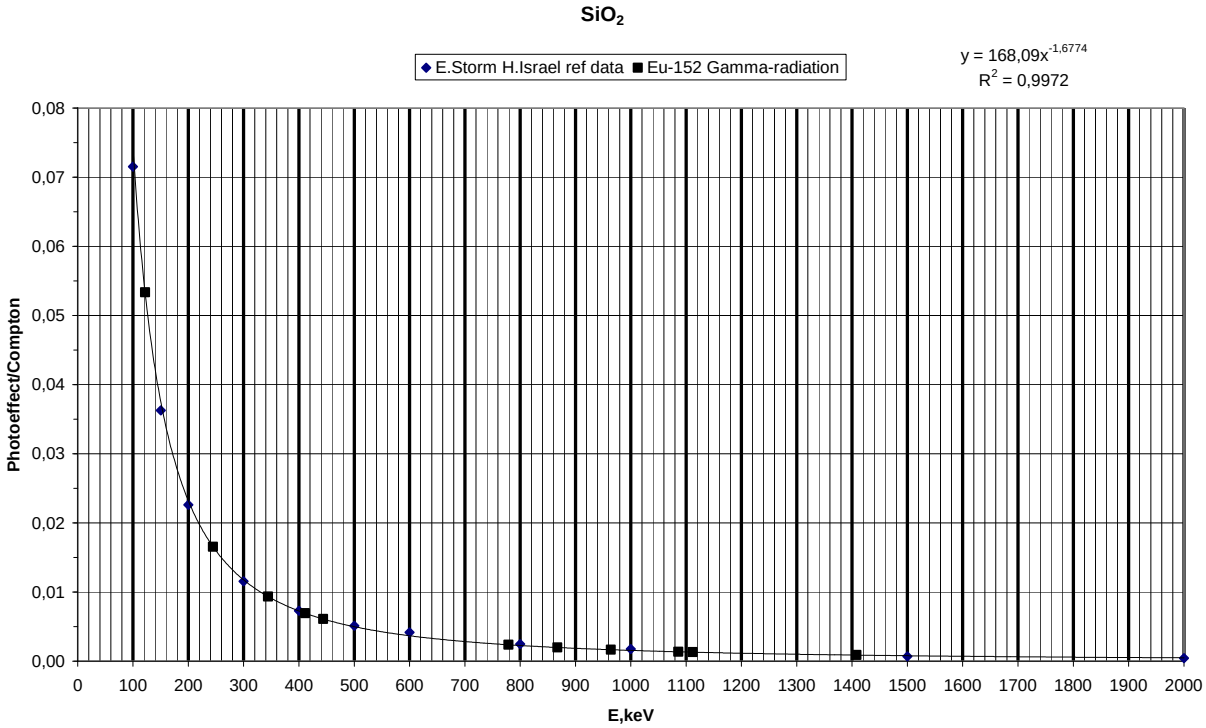

Fig .4 The photoelectric cross sections to Compton scattering cross section ratio versus photon energy for the SiO_2

6.2 CMC supporting

Because of the comparison material has water density, the CMC codified as 2.2.3.1.Eu-152 according [3], can be supported including the description of the measurement geometry employed in this comparison (see Table 3) in the column H of the CMC template.

In accordance with the performed analysis of the gamma radiation absorption, the following CMCs for "reference materials" could also be supported: 2.2.(7…11).1.Eu-152 and 2.2.6.1.Eu-152 with specified matrix (resin with Fe impurity).

In accordance with analyses made in the items 6.1 it could be also suggested that the participants of the comparison can measure specific activity of the radionuclide emitted gamma-quanta in the 250-450 keV and 780 -1400 keV ranges in water, foods, biological materials and flora, as well as in the energy intervals 350-450 keV and 780 -1400 keV in soil.

Then, the proposed set of radionuclide is the next one: natural radionuclide K-40 and nuclear reactor radionuclide I-131. For I-131 radiation (364 keV) the relation of the photo effect cross sections to Compton scattering cross sections for the resin $(C_{39}H_{52}O_7)_{0,855}Fe_{0,145}$ was found equal to 0.25 % and for the SiO_2 - 0.8 %. These uncertainties (non-ideal Compton absorption) should be added to the uncertainty budget. For K-40 radiation (1461keV) the relation of the photo effect cross sections to Compton scattering cross sections for the resin $(C_{39}H_{52}O_7)_{0,855}Fe_{0,145}$ was found equal to 0.02 % and for the SiO_2 - 0.08 %. It is negligible.

Therefore, in accordance with the performed analysis of the gamma radiation absorption, the following CMCs for “reference materials” could also be supported: 2.2.(7…11).1,2. K-40, I-13. The statement “Environmental monitoring sample measurements” could be also introduced in this case into the comments column Q in the CMC column for public viewing.

References

1. COOMET R/GM/19:2008 “Recommendation "Guideline on COOMET supplementary comparison evaluation" - www.coomet.org
2. M.-M. Bé, et. al.Monographie BIPM-5 Table of Radionuclides (Vol. 2 – A = 151 to 242), BIPM 2006 (http://www.bipm.org/utils/common/pdf/monographieRI/Monographie_BIPM-5_Tables_Vol2.pdf)
3. E.Storm, H.I.Israel “Photon cross section from 1 keV to 100 MeV for elements 1 through 100”, Nuclear Data Tables, sec.A7, N.6, 565, N.Y., Acad.Press, 1970

Appendix 1 Uncertainties budgets of the participants.

Slovak Institute of Metrology, Centre for Ionizing Radiations
Slovakia

1. Date of activity measurements April 6, 2006
2. Result of measurement of specific activity 8,643Bq.g^{-1}
3. Uncertainty budget

Standard uncertainty, Bq/g	A	B
Contribution due to		
Efficiency calibration		0,13
Sampling (homogeneity)		0,086
Weighing		0,0004
Peak area measurement	0,075	
Sample attenuation		0,043
Combined uncertainty (Quadratic summation)	0,075	0,16
Total combined standard uncertainty	0,18	
Expanded uncertainty k=2	0,36	
Level of confidence	95 %	

Secondary standard dosimetry laboratory of Metrology and accreditation state agency (Former Latvian National Metrology Centre Ltd. Radiation Metrology and Testing Centre (RMTC)
Latvia

1. Date of activity measurements: April 7 – May 11, 2006
2. Result of measurement of specific activity
   № EU-6 Eu-152 8.34 ± 0.26 Bq/g at January 1, 2006
3. Uncertainty budget

Standard uncertainty, Bq/g	A	B
Contribution due to		
The number of counts uncertainty	0.046	
Efficiency uncertainty		0.13
Combined uncertainty (Quadratic summation)	0.046	0.13
Total combined standard uncertainty	0.14	
Expanded uncertainty k=2	0.26	
Level of confidence	95%	

Sample	Nuclide	Counting	Mass	Activity	Uncertainty			
ID	ID	Date	kg	Bq/kg	CL 68% (k=1)			CL 95% (k=2)
		(dd/mm/yy)			Stat.	Syst.	Total	Total
					%	%	%	%
Eu-5	Eu-152	24/04/06	1.000	8444	0.91	2.5	2.7	5.4

Physikalisch-Technische Bundesanstalt

Germany

1. Date of activity measurements: 2006-05-01
2. Result of measurement of specific activity: **(8.71 ± 0.27) Bq/g** (with k=2 expanded uncertainty)
3. Uncertainty budget

   The uncertainty budget for one emission line of one Eu-152 measurement of one sub-sample is attached at the end. This uncertainty budget was calculated with the commercial software *GUM-workbench*. In total we prepared three sub-samples which were measured with two different gamma-ray spectrometry systems. The above given value is the mean value of the 6 measurement results, taking into account 8 different gamma-ray emission lines (with the highest emission probabilities) for each measurement. Due to the fact that the systematic uncertainties dominates the uncertainty budget and are the same for the six measurement results, the uncertainty of the mean value is not much smaller than for the individual result mentioned in the uncertainty budget.

Quantity	Unit	Definition
m	g	mass of the sample
R	1/s	Mean count rate in the sample spectrum
□	s	Resolution time of the measurement system
t_{diff}	s	Elapsed time from the time the sample was taken to the beginning of the measurement
t_s	s	Live time of the sample spectrum collection
t_r	s	Elapsed real clock time for sample spectrum collection
N_s		Net peak area in the sample spectrum
$p_{□}$		Emission probability of the gamma-ray with energy E
T_{half}	s	Radionuclide half live
□		Full energy peak efficiency
t_b	s	Live time of the background spectrum collection
N_b		Net peak area in the background spectrum
N		Corrected net peak area in the sample
K_1		Correction factor for the nuclide decay from the time the sample was sampled to the start of the measurement
K_2		Correction factor for the nuclide decay during counting period
K_3		Correction factor for a self-attenuation in the measured sample compared with the calibration sample
K_4		Correction factor for pulses loss due to random summing
K_5		Coincidence correction factor for those nuclides decaying through a cascade of successive photon emissions
K_6		Correction factor due to a variation of the sample geometry compared with the calibration sample
a	Bq/g	specific activity in the sample

Uncertainty Budget:

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution	Index
m	87.461000 g	$577 \cdot 10^{-6}$ g	∞	-0.10	$-58 \cdot 10^{-6}$ Bq/g	0.0 %
R	137.156 1/s	0.137 1/s	50	$88 \cdot 10^{-6}$	$12 \cdot 10^{-6}$ Bq/g	0.0 %
τ	$5.00 \cdot 10^{-6}$ s	$1.15 \cdot 10^{-6}$ s	∞	2400	$2.8 \cdot 10^{-3}$ Bq/g	0.0 %
t_{diff}	$1.24416000 \cdot 10^{6}$ s	5.77 s	∞	0.0	0.0 Bq/g	0.0 %
t_s	$172.423400 \cdot 10^{3}$ s	0.289 s	∞	$-51 \cdot 10^{-6}$	$-15 \cdot 10^{-6}$ Bq/g	0.0 %
t_r	$173.020900 \cdot 10^{3}$ s	0.289 s	∞	0.0	0.0 Bq/g	0.0 %
N_s	$1.41506 \cdot 10^{6}$	1200	50	$6.2 \cdot 10^{-6}$	$7.4 \cdot 10^{-3}$ Bq/g	0.3 %
p_γ	0.26580	$1.20 \cdot 10^{-3}$	50	-33	-0.040 Bq/g	7.7 %
T_{half}	$427.100 \cdot 10^{6}$ s	$470 \cdot 10^{3}$ s	50	$-44 \cdot 10^{-12}$	$-21 \cdot 10^{-6}$ Bq/g	0.0 %

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution	Index
ε	0.042920	$279 \cdot 10^{-6}$	50	-200	-0.057 Bq/g	16.0 %
t_b	$615.363400 \cdot 10^3$ s	0.289 s	∞	0.0	0.0 Bq/g	0.0 %
N_b	0.0	0.0	50	0.0	0.0 Bq/g	0.0 %
N	$1.41506 \cdot 10^6$	1200				
K_1	0.99798287	$2.22 \cdot 10^{-6}$				
K_2	0.999859614	$154 \cdot 10^{-9}$				
K_3	1.02700	$5.13 \cdot 10^{-3}$	50	-8.5	-0.044 Bq/g	9.5 %
K_4	0.998629	$316 \cdot 10^{-6}$				
K_5	0.91709	$9.17 \cdot 10^{-3}$	50	-9.6	-0.088 Bq/g	38.0 %
K_6	1.00000	$8.66 \cdot 10^{-3}$	∞	-8.8	-0.076 Bq/g	28.5 %
a	8.76 Bq/g	0.142 Bq/g	270			

Center of Isotopes (CENTIS-DMR)
Cuba.

1. Date of activity measurements: All the measurements are referred to 11/08/2006.
2. Result of measurement of specific activity: **8,3 Bq/g**
3. Uncertainty budget

Standard uncertainty, Bq/g	
Contribution due to	
Sample gross count, cps (s_{cps}/cps)	0.12
Detector efficiency ($s_\varepsilon/\varepsilon$)	0.2
Decay, d ($s_{decay\ factor}$/decay factor)	0.00004
Summing corrections ($s_{summing\ correction\ factor}$/ summing correction factor)	0.2
Weighing, g (s_{mass}/mass)	0.02
Attenuation correction ($s_{attenuation\ correction\ factor}$/ attenuation correction factor)	0.25
Total combined standard uncertainty	0.4
Expanded uncertainty k=2	0.8
Level of confidence	95 %

Bulgarian Institute of Metrology - National Centre of Metrology (BIM-NCM)
Bulgaria

1. Date of activity measurements: 25.05.2006; 26.05.2006; 29.05.2006; 30.05.2006; 31.05.2006
2. Result of measurement of specific activity: 8,41 Bq/g; 8,38 Bq/g; 8,41 Bq/g; 8,40 Bq/g; 8,40 Bq/g
3. Uncertainty budget

Standard uncertainty, Bq/g	A	B
Contribution due to		
Peak area determination	1,00 %	
Detection efficiency for the given energy		5,46 %
Weight		0,002 %
Homogeneity		1,00 %
Correction for random summing		2,00 %
Combined uncertainty (Quadratic summation)	1,00 %	5,90 %
Total combined standard uncertainty	5,98 %	
Expanded uncertainty k=2	11,96 %	
Level of confidence	≈95%	

National Scientific Centre “Institute of Metrology”
Ukraine

1. Date of activity measurements: 21.04.2006
2. Result of measurement of specific activity: 8.34±0.34 Bq/g
3. Uncertainty budget

Standard uncertainty, Bq/g	A	B
Contribution due to		
count rate	0.025	
efficiency		0.167
mass	0.0017	
density		0.0108
Combined uncertainty (Quadratic summation)	0.0251	0.167
Total combined standard uncertainty	0.169	
Expanded uncertainty k=2	0.338	
Level of confidence	0.95	

Belarusian State Institute of Metrology
Belarus

1. Date of activity measurements – 01-Jun-2006
2. Result of measurement of specific activity – 8,46 Bq/g
3. Uncertainty budget

Standard uncertainty, Bq/g	A	B
Contribution due to		
S_0	0,016	
Ss	0,099	
S_{ss}	0,063	
S_x	0,016	
A_0		0,084599
T		0,020304
m_p		3,38E-05
m_{ss}		0,01692
heterogeneity		0,084599
m_s		2,54E-05
m_c		0,01692
m_x		0,01692
k_V		0,015228
k_d		0
Combined uncertainty (Quadratic summation)	0,014401	0,015817
Total combined standard uncertainty	0,173835	
Expanded uncertainty k=2	0,34767	
Level of confidence	0,95	

4. Measurement technique

Measurements by the gamma-spectrometer with HPG detector. Gamma-spectrometer is using as a comparator.

5. Calibration method and traceability to primary standards

1) Preparing of the solution of the known specific activity A_{ss} from Standard solution which specific activity A_0 is traceable to VNIIM and the measurement of the specific activity of unknown sample by the comparison against the solution in the same geometry (1 l Marinelli)

$$A_{ss} = A_0 \frac{m_s}{m_s + m_c},$$

where m_s – mass of the solution from 1);

m_c – mass of the carrier solution

and specific activity of the sample A_{sx} is

$$A_{sx} = A_{ss} \frac{S_x T_{ss}}{S_{ss} T_x m_x},$$

where S_{ss}, S_x – areas of the full energy peaks for the vessel with the solution and sample;

T_x, T_{ss} – "live" times of the vessel with the sample and solution measurements;

m_x – mass of the sample;

Resulting formalism is

$$A_{sx} = A_0 \frac{m_s m_{ss}}{(m_s + m_c)} \frac{S_x T_{ss}}{S_{ss} T_x m_x} k_V k_d k_{hg},$$

where m_{ss} – mass of 1 l of the prepared solution for the comparison

k_V – correction coefficient for volume of sample in the measurement vessel;

k_d – correction coefficient for the difference in the densities.

In this case $k_V = 1$ and $k_d = 1$. Took into account $m_s < 0{,}001 m_c$, the relative uncertainty is expressed from

$$u_c^2 = u_{A0}^2 + u_{S_{ss}}^2 + u_{S_X}^2 + 2u_T^2 + u_{m_S}^2 + u_{m_{ss}}^2 + u_{m_C}^2 + u_{m_X}^2 + u_{k_V}^2 + u_{k_d}^2 + u_{hg}^2,$$

where u_{hg} – uncertainty for heterogeneity.

Uncertainty due to the recalculation to the report date was negligible.

All Russian Research Institute for Physical-Technical and Radio-Technical Measurements
Russia

Date of activity measurements: 01-06-2006

2. Result of measurement of specific activity 8.496 Bq/g

3. Uncertainty budget

Standard uncertainty, Bq/g	A	B
Contribution due to		
The number of counts uncertainty	0.001	
Efficiency uncertainty		0.14
Combined uncertainty (Quadratic summation)	0.001	0.14
Total combined standard uncertainty	0.14	
Expanded uncertainty k=2	0.27	
Level of confidence	95%	

Used three HpGE spectrometers with different softwares: Progress, ARS and PGAMMA.BI (all manufactured by VNIIFTRI).