Progress Report on Radiation Dosimetry at the VNIIM

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Introduction

This is a short overview of the D. I. Mendeleyev Institute for Metrology (VNIIM) activities in the field of photon, electron and beta dosimetry for the last 2 years.

The information in the sections is summarized under the topics of research and development in the VNIIM: national primary standards improvement, measuring instrumentation calibration and verification, type approval, product certification for radiation safety and regulations development. The results of international cooperation and the list of publications and talks are also included.

National primary standards development

X-rays and gamma-radiation air kerma primary standard

Gamma-radiation

The primary standard for gamma-radiation air kerma of the VNIIM is a set of two cylindrical graphite cavity ionization chambers identified as C1 and C30. The volumes are 1.040 cm^3 and 30.02 cm^3 respectively, the graphite density is 1.634 g/cm^3.

The last key comparison between the standards of air kerma of the VNIIM and the BIPM took place in 1997. At that time the VNIIM cavity ionization chambers' correction factors had been determined experimentally. In 2007 following the recommendations of the CCRI and keeping in mind the experience of world's advanced standard laboratories, the correction factors for the VNIIM primary standard cavity chambers C1 and C30 for wall effects (k_{wall}) and for axial non-uniformity (k_{an}) were calculated using Monte-Carlo methods.

At the first step the spectra calculation with the MCC-3D program was made for Co-60 and Cs-137 sources. The MCC-3D program is developed by Saint-Petersburg Polytechnic Institute for three dimensional modeling for ionizing radiation transfer and registration. Using this program it is possible to simulate the collimator, source, type of radiation and to generate beam interactions with the materials in the specified conditions. The spectra achieved for 10^9 primary photons are presented in Figure 1.

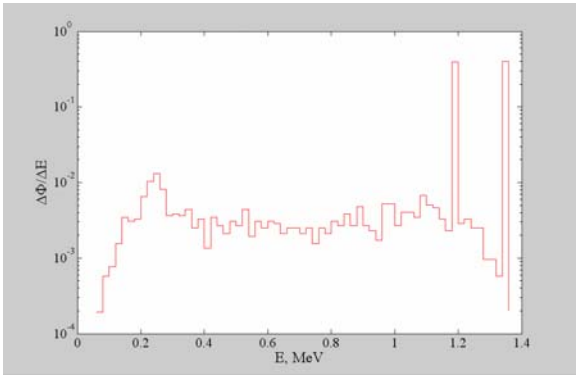
The Co-60 spectrum for the VNIIM collimator in the field of diameter 20 cm at 1 m from the source has a scatter contribution of 21 %. The Co-60 spectrum for "Luch-1" collimator in the field 10 × 10 cm at 1 m from the source has a scatter contribution of 30 %. The Cs-137 spectrum for the VNIIM collimator in the field of 11 × 11 cm at 80 cm from the source has a scatter contribution of 30 %.

At the next step the wall and axial non-uniformity correction factors were determined using the CAVRZnrc code of the EGSnrc system developed by the NRC, Canada. The calculation comprised 10^9 primary photons so as to achieve a numerical statistical uncertainty (Type A) of 0.03 % for the calculated dose deposited in the cavity. Simulations were carried out for two different source geometries – a parallel beam and a point source.

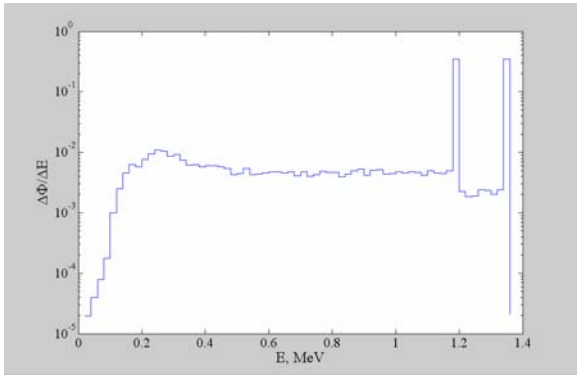
The results of the correction factors calculation are presented in Table 1.

As a small discrepancy (0.11 %) had been identified previously between the two standard chambers, the opportunity was taken to check the volume of the larger chamber C30. The airspace between the components of applied potential electrode was checked and the air volume between the collecting electrode and the stem was reevaluated. The new volume value for C30 is

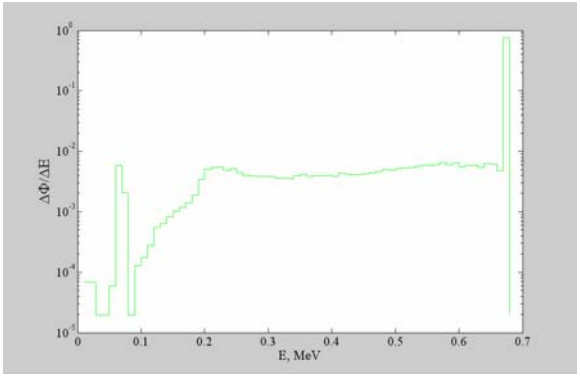
30.02 cm^3, an increase of 0.54 % (previous value of 29.86 cm^3) and has the same uncertainty evaluation, 0.10 %. This results in an overall change for the C30 standard, including the new correction factors, of 0.86 %. The difference between the C1 and C30 standards has now reduced to 0.09 %.



The Co-60 spectrum for the VNIIM collimator



The Co-60 spectrum for "Luch-1" collimator



The Cs-137 spectrum for the VNIIM collimator

Fig. 1

Table 1

Correction factors/ Chamber	Co-60 beam (VNIIM collimator)			Co-60 beam ("Luch-1" collimator)		Cs-137 beam (VNIIM collimator)	
	C1	C30	ND1005	C1	ND1005	C1	ND1005
k_{wall}	1.0189	1.0286	1.0203	1.0193	1.0206	1.0257	1.0271
k_{an}	1.0004	1.0006	1.0007	0.9998	1.0008	1.0002	1.0000

Consequently, the air-kerma calibration coefficient for the transfer chamber used in the 1997 key comparison with the BIPM is 49.36 Gy/μC (uncertainty 0.42 %), which is an increase of 0.96 % over the previous value of 48.89 Gy/μC.

The VNIIM result of the BIPM.RI(I)-K1 key comparison for Co-60 has been re-evaluated as 1.0062 (uncertainty 0.26) from 1 November 2007 (taking into account the new evaluation of the BIPM primary standard).

X-rays

The VNIIM primary standard for low-energy and medium-energy X-rays are free-air ionization chambers IK 10-60 and IK 50-400. To develop the low-energy X-ray primary standard and to improve the medium X-ray primary standard the correction factors for free-air ionization chambers calculation should be done. The calculation is planned to be realized by the key comparison with the BIPM in 2010.

Re-equipment

To improve the primary standard for gamma-radiation air kerma in 2008 the VNIIM purchased the graphite cavity ionization chamber ND1005 (with the certificate for dimensions, volume and electrical characteristics from the MKEH). The volume is 1.020 cm^3, the graphite density is 1.73 g/cm^3. The correction factors for wall effects and for axial non-uniformity calculations were done for this chamber (see Table 1). Additional calculations were done to clarify that the discrepancy between the correction factors for ND1005 and C1 chambers (of almost the same dimensions) is due to the difference in graphite density.

In 2007 the VNIIM began the low-energy X-ray primary standard re-equipment. It is planned to produce the therapeutic radiation qualities, ISO4037 qualities for the radiation protection facilities calibration, IEC61267 qualities for the diagnostic apparatus control units calibration. Mammography radiation qualities are also planned to be included into the low-energy X-ray primary standard.

Besides free-air ionization chamber IK 10-60 it is planned to use IK 5-20 and 10-100 as the primary standard chambers for low-energy X-rays.

Last year the VNIIM acquired the X-ray unit MG103/4.5 YXLON International with the x-ray tube Y/TU/160-B02 (W-anode). The mammography X-ray unit ISOVOLT 3003 with the X-ray tube FA 100/3 (Mo-anode) type PW 2185/00 will be supplied by the end of spring, 2009.

Electrical and environmental monitoring facilities are purchased as well. The beam former with the automatic shutter closing and the filters setting is designed and tested (see Figure 2).

Fig. 2

The VNIIM plans to finish the low-energy X-ray primary standard re-equipment by 2011 and to take part in the low-energy X-ray air kerma key comparison with the new facilities. The VNIIM is also interested in the mammography radiation air kerma comparison.

For the last two years no essential changes have been made in the **primary standard for beta-radiation absorbed dose in tissue**. The output of day-to-day metrology job performed with this standard, including the comparison results, is described in subsequent sections.

In 2008–2009 the **primary standard for flux, flux density and fluence of electrons, flux energy, flux density energy and energy fluence of electrons and bremsstrahlung radiation for energy up to 50 MeV** was used for the following devices investigations.

The beam quality specifier TPR_{10}^{20} was defined for 4 Russian accelerators SL75-5M and LUR-15M applied in clinics for the radiation treatment. The measurements were held using TM 30010 ionization chamber and UDMC-1k diamond detectors calibrated on the primary standard with water-equivalent phantom. The TPR_{10}^{20} values received are 0.559–0.590 for SL75-5M and 0.632 for LUR-15M respectively. According to these results the recommendations for the manufacturers on the target structure and materials were developed.

The metrological characteristics of Russian diamond detectors of the natural Yakut diamond were examined in the medical accelerators beams with maximum energy of 6 and 15 MeV, absorbed dose rate 0.5–5.0 Gy/min and absorbed dose 1.0–10 Gy.

Russian alanine detectors metrological characteristics investigation in the photon and electron beams of 15 MeV with air kerma rate 1.0–20 Gy/min and air kerma 10 Gy–20 kGy are continued.

International activities

In March, 2008 the VNIIM took part in the EUROMET.RI(I)-K1 comparison of air kerma measurements of Co-60 radiation in radiotherapy (EUROMET Project 813). There is well coincidence between the results of measurements with all of the 4 transfer chambers.

The discrepancy between the results of EUROMET.RI(I)-K1 (2008) and BIPM.R(I)-K1 (1997) comparisons is due to fact that the measurements were held with different facilities, collimators and sources with different air kerma rates. On the other hand the EUROMET.RI(I)-K1 results well match with the results of measurements in COOMET.RI(I)-K1 (2006) performed with the same facilities (taking into account the new BIPM evaluation of air kerma and the VNIIM correction factors changing).

As the validity of the key comparison with the BIPM is running out the gamma-radiation air kerma key comparison is planned to be in November, 2009. The VNIIM plans to replace the primary standard cavity ionization chamber C1 by the new chamber ND1005.

The medium-energy X-ray air kerma key comparison is planned to be held in 2010.

In 2005–2007 the VNIIM participated in EUROMET.RI(I)-S1 supplementary comparison of the absorbed dose rate in tissue for beta radiation (EUROMET Project No. 739). The calibration of the PTB flat ionisation chamber 6.3-Beta-FK007 in terms of the absorbed dose rate in tissue was done.

The results of all the 8 participants are roughly consistent within the scope of the assigned uncertainties. But the results obtained in the standard fields of the VNIIM beta sources are slightly worse than the results of the other participants: for Pm-147 the value for the calibration factor N is higher by 3.8 % compared with the weighted mean value, for Tl-204 – lower by 4.1 % and for Sr-90/Y-90 – higher by 2.8 %. The only explanation for this discrepancy now is that the form of the VNIIM beta sources differs from that conventional for other world metrology institutes: the active area is 12.6–19.6 cm^2, no beam flattening filters are used. Furthermore the measurements with Tl-204 were performed at the distance 20 cm because of the low activity of this source.

In 2009 the VNIIM and the PTB reached agreement to compare the primary standards of the absorbed dose rate in tissue for beta radiation. The standard sources will be calibrated both by the PTB and the VNIIM. For these purposes the VNIIM is going to purchase Kr-85 to replace Tl-204 in the VNIIM set of the standard beta sources.

Measuring instruments calibration and verification

The VNIIM establishes and maintains the standards at the accredited dosimetry calibration laboratories providing the state metrological control via the secondary and working standards calibration, verification and comparisons. For the last two years the secondary standards of X-ray and gamma-radiation air kerma comparisons were held in several centers for standardization and metrology: Mendeleyev CSM (the Moscow Region), URALTEST (Sredneuralsk), TEST-St.-Petersburg (Saint-Petersburg).

The VNIIM also performs the secondary and working standards calibration, verification and comparisons at atomic power stations, clinics and for the manufacturers of the dosimetry instruments and sources, including NIIP (the Moscow Region), SNIIP (Moscow), RNCRHT (the Leningrad Region), and Pyatigorsk plant "Impulse" (Pyatigorsk).

The secondary standards calibration was done for Belarussian State Institute of Metrology (BelGIM) (the Republic of Belarus).

In 2007–2009 more than 90 calibrations and verifications of working standards, including dosimetry souses (Cs-137, Co-60, Ra-226, Am-241, Ni-63, H-3, Sr-90/Y-90, Tl-204, Pm-147) were done. More than 1100 calibrations and verifications of measuring instruments for X-ray, gamma- and beta-radiation were performed, including personal dosimetry control systems with "Harshaw" Model 6600 and KID-08C TLD systems among them which are in operation at the atomic power stations.

Measuring instruments testing for type approval

In January, 2009 the new Law on Measurement Assurance came into operation in Russia. By the Law measuring instruments providing national safety and protection as dosimetry devices (and others connected with ionizing radiation) are still under the state control.

At present there is no agreement for the product certificate recognition between Russia and other countries, including European Community. As a result in Russia there is a rule under which all of the imported devices to be used in the areas of the state control are inspected for the compliance of their characteristics with the values, declared by the manufacturer, and with both Russian and international standard specifications and regulations. In case the results are positive the measuring instrument type will be approved (with the appropriate certificate). This information is included into the State Measurement Assurance Data Collection and the measuring instrument is authorized for application. For the Russian measuring instruments manufacturers the procedure is the same.

The VNIIM is the state dosimetry testing center of Russia. In 2008–2009 19 Russian and foreign measuring instruments were tested for type approval: DAP (dose area product)-meters Kerma-X and Kerma-X-DDP (by IBA Dosimetry, Germany), G64 gamma monitor and intelligent Geiger Mueller detectors GP110i (by Canberra Industries Inc., the USA), FH40G-L10Ω dosimeters (by Thermo Fisher Scientific Inc., the USA), DMC 2000XB personal electronic dosimeters (by Mirion Technologies, the USA), BDMG-300 detectors (by INTRA, Russia) and calibration sets UDG-AT110 (by ATOMTEX, the Republic of Belarus).

Product certification for radiation safety

Certification (including functional testing and radiation protection control) is performed for the devices concerned with radiation but which are not a measuring instrument.

For example, in 2008 certification was made for the customs control X-ray systems including X-ray TV unit WATSON-TV and handheld scanner WATSON, for the X-ray units for structure analysis Module 50 (by FLASH ELECTRONICS, Russia) and for the digital radiography systems Fosfomatic (by TESTRON, Russia).

Regulations development

One of the fields of activity in the VNIIM for the standards maintenance is the procedures development for calibration, verification and beams characteristics measurement. In 2008–2009 procedures for calibration of the X-ray and bremsstrahlung radiation measuring instruments, beta radiation sources were issued. The procedures for the dosimetry measuring instruments verification, including DAP-meters, personal X-ray, gamma and beta radiation dosimeters were developed.

Based on the "Dosimetry in Diagnostic Radiology: An International Code of Practice" (IAEA Technical reports series No. 457, 2007) the procedures for the medical X-ray units characteristics measurements were produced. The procedures for the customs examination accelerators beam parameters control were also developed.

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