Progress Report on Radiation Dosimetry at the VNIIM

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This is an overview of radiation dosimetry activities at D. I. Mendeleyev Institute for Metrology (VNIIM) from May 2011 to February 2013 for the meeting of Section I (x- and gamma rays, charged particles) of Consultative Committee for Ionizing Radiation (CCRI), March 26–28, 2013.

In the VNIIM laboratory for x-ray, gamma, bremsstrahlung and beta radiation dosimetry there are 8 members (4 scientists, 3 engineers and 1 technician).

National primary standards development

The primary standard for x-rays and gamma radiation air kerma

In 2011 the VNIIM x-rays and gamma radiation air kerma primary standard has passed the procedure which is called "the Restatement of the Standard". This is an internal procedure conducted by Federal Agency on Technical Regulating and Metrology of Russia. The aim is to bring to correspondence all of the standard documentation with its latest modifications.

The history of the standard started in 1938 when the primary standard of x-rays and gamma radiation exposure and exposure rate was developed at the VNIIM; two times (in 1969 and in 1982) the standard was upgraded. In 2007 a long period of improvement of the standard started. A lot of modern devices were purchased and forced into application within the standard, essential calculations and measurements were done. In 2009–2012 the VNIIM renewed the results of an ordinary cycle of key comparisons with the standard.

The most important changes in the standard structure are described below.

In 2008 graphite-walled cylindrical cavity ionization chamber ND1005 was purchased and adopted as the VNIIM air kerma primary standard for gamma radiation. The correction factors for wall effects and for axial non-uniformity were calculated for this chamber using the CAVRZnrc code (the NRC, Canada) and taking into account calculated spectra of the VNIIM Co-60 and Cs-137 sources. ND1005 chamber characteristics were approved by the results of comparison with the BIPM on air kerma for Co-60 and Cs-137 gamma radiation (BIPM.RI(I)-K1 and K5) held in November 2009.

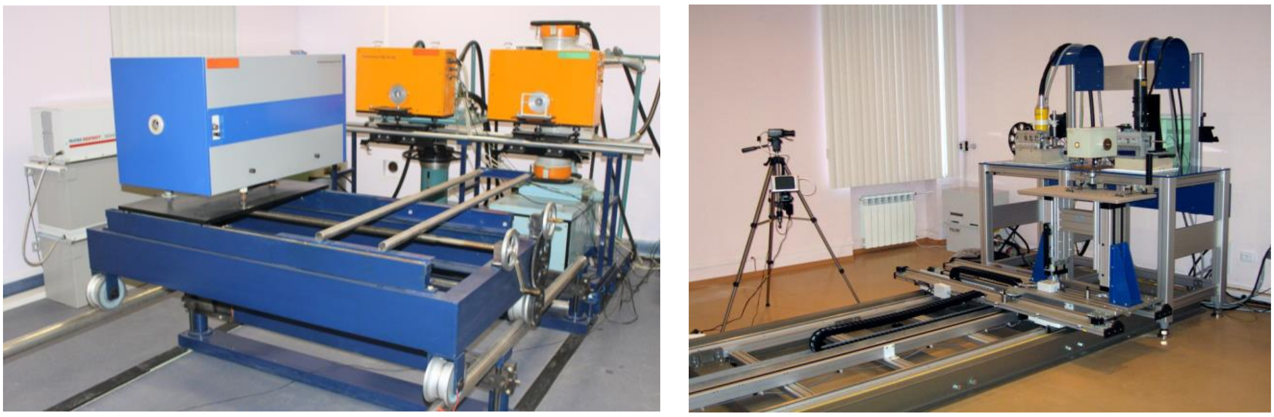
The VNIIM primary standard ionization chamber for medium-energy x-rays IK 70-300 (Figure 1, a) correction factors were re-evaluated for different radiation qualities. Corresponding calculations were done using the egs_fac code (the NRC, Canada). New correction factors of IK 70-300 chamber were applied for the first time in the comparison with the BIPM for medium-energy x-rays air kerma (BIPM.RI(I)-K3) in October, 2010.

Low-energy x-ray primary standard installation was re-equipped (Figure 1, b). New facilities include: two x-ray units comprising x-ray tubes with tungsten and molybdenum anodes; two beam formers for the x-ray tubes with automatic shutter closing and filters setting; calibration bench with ruler and laser alignment system; ORTEC HPGe planar detector for spectra measurements; system for electrical measurements and environmental monitoring (two Keithley electrometers, Keithley humidity probe, precise thermometer and barometer).

New set of low-energy x-ray radiation qualities was established, including therapeutic, diagnostic, radiation protection, CCRI and mammography.

The correction factors for primary standard chambers were calculated using the egs_fac code. The characteristics of improved low-energy x-rays air kerma primary standard were confirmed by the results of the comparison with the BIPM (BIPM.RI(I)-K2) carried out in

November and December 2011. The VNIIM also took part in mammography radiation air kerma key comparison with the BIPM (BIPM.RI(I)-K7) in November 2012.



(a) (b)

Figure 1. The primary standard facilities for x-rays air kerma measurement:
for medium-energy x-rays (a); for low-energy and mammography x-rays (b)

According to changes indicated a certain set of documents was created, a paper describing an upgraded primary standard was issued in *Measurement techniques* journal (translated in English). Metrology characteristics of renewed primary standard for x-rays and gamma radiation air kerma are presented in Table 1.

Table 1. Characteristics of the VNIIM primary standard
for x-rays and gamma radiation air kerma

<table>
<tr><th>Quantity</th><th>Range</th><th>u_{0A}</th><th>u_{0B}</th><th>u_{0C}</th></tr>
<tr><td>Air kerma</td><td>$1\cdot10^{-7}$–20 Gy</td><td rowspan="2">$1.1\cdot10^{-3}$–$1.5\cdot10^{-3}$</td><td rowspan="2">$1.8\cdot10^{-3}$–$3.6\cdot10^{-3}$</td><td rowspan="2">$2.1\cdot10^{-3}$–$3.9\cdot10^{-3}$</td></tr>
<tr><td>Air kerma rate</td><td>$1\cdot10^{-8}$–2 $Gy\cdot s^{-1}$</td></tr>
</table>

In the near future the VNIIM plans to bring the list of dosimetry calibration and measurement capabilities into compliance with the latest changes of the primary standard.

The primary standard for beta radiation absorbed dose in tissue

The main characteristics of the standard are presented in Table 2.

Figure 2. Primary standard extrapolation chamber
for beta radiation absorbed dose in tissue measurement

The view of the primary standard extrapolation chamber is showed in Figure 2.

Table 2. Characteristics of the VNIIM primary standard for beta radiation absorbed dose in tissue

Quantity	Range	u_{0A}	u_{0B}	u_{0C}
Absorbed dose in tissue	$1\cdot10^{-3}$–$1\cdot10^{2}$ Gy	$1.5\cdot10^{-2}$	$1.2\cdot10^{-2}$	$1.9\cdot10^{-2}$
Absorbed dose rate in tissue	$1\cdot10^{-5}$–1 Gy·s^{-1}			

In 2102 new computer program was developed for automatization of measurements with the primary standard extrapolation chamber.

The primary standard for flux, flux density and fluence of electrons, energy flux, energy flux density and energy fluence of electrons and bremsstrahlung radiation for energy up to 50 MeV

The primary standard was developed in 1975 as a part of the system for quality assurance of industrial accelerators. In Russia it is stated by several regulatory documents (GOST 4.477-87, GOST 27632-88) that flux and flux density of charged particles are in the list of main metrology characteristics of industrial accelerators.

The VNIIM has capabilities to measure flux, flux density and fluence of electrons, energy flux, energy flux density and energy fluence of electrons and bremsstrahlung radiation for energy up to 50 MeV and is in need of confirmation of these capabilities.

Metrology characteristics of the primary standard are presented in Table 3. The view of the primary standard thick-walled ionization chamber IKV-6 for energy flux measurements in the field of accelerator BETATRON B 50/50 is presented in Figure 3.

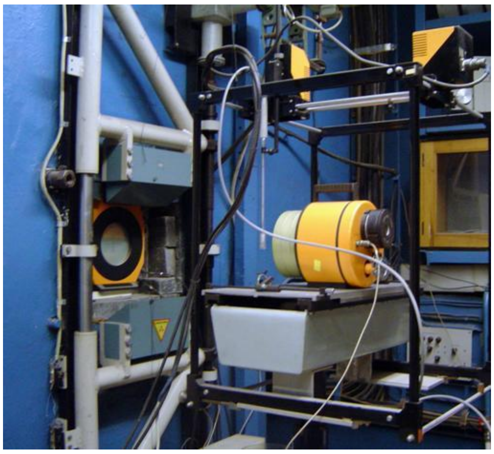


Figure 3. Primary standard thick-walled ionization chamber IKV-6
in the field of accelerator BETATRON B 50/50

Table 3. Characteristics of the primary standard for flux, flux density and fluence of electrons, energy flux, energy flux density and energy fluence of electrons and bremsstrahlung radiation for energy up to 50 MeV

Quantity	Range	u_{0A}	u_{0B}	u_{0C}
Flux of electrons	10^{10}–10^{21} s^{-1}	$5\cdot10^{-3}$	$5\cdot10^{-3}$	$7.1\cdot10^{-3}$
Flux density of electrons	10^{8}–10^{19} cm^{-2}·s^{-1}		$1.1\cdot10^{-2}$	$1.2\cdot10^{-2}$
Fluence of electrons	10^{9}–10^{21} cm^{-2}	$5\cdot10^{-3}$	$1.1\cdot10^{-2}$	$1.2\cdot10^{-2}$
Energy flux	10^{-4}–10^{3} W		$5\cdot10^{-3}$	$7.1\cdot10^{-3}$
Energy flux density	10^{-5}–10^{2} W·cm^{-2}	$5\cdot10^{-3}$	$1.1\cdot10^{-2}$	$1.2\cdot10^{-2}$
Energy fluence	10^{-3}–10^{3} J·cm^{-2}		$1.1\cdot10^{-2}$	$1.2\cdot10^{-2}$

In 2011–2012 the following investigations were performed using the primary standard. Characteristics of RTE-1 accelerator with scanned electron radiation beam including flux density and energy flux density were determined to create well-known standard field. Energy cutoff of bremsstrahlung radiation in the field of accelerator-defectoscope UEL-6-D (6.0 MeV) was estimated using the results of flux density measurements with conventional graphite phantom and thick-walled ionization chamber IKV-6M (R2). Characteristics of the primary standard calorimetric detector KS-1S were examined in the field of accelerator-sterilizer with maximum energy of 10 MeV, energy flux density 15.0 W·cm^{-2}, flux density of electrons $5.0\cdot10^{13}$ cm^{-2}·s^{-1}, absorbed dose rate in graphite 1.0–40 kGy.

International activities

Comparison of the standards for air kerma of the VNIIM and the BIPM in low-energy x-rays BIPM.RI(I)-K2 was carried out in November and December 2011. Two parallel-plate ionization chambers were used as transfer instruments. Re-evaluated set of the correction factors was used for the VNIIM primary standard chamber IK 10-100. Results of the comparison are presented in Table 4, the stated standard uncertainty for the comparison result is $2.4\cdot10^{-3}$. The results are in agreement with those of the previous comparison of 1998 at the level of 1 part in 10^3, which demonstrates good stability of the standards over this period.

Table 4. Comparison results of the VNIIM and the BIPM primary standards for air kerma in the x-ray range from 10 kV to 50 kV

Radiation quality	10 kV	30 kV	25 kV	50 kVb	50 kVa
$R_{K,\mathrm{VNIIM}}$	0.9968	0.9979	0.9978	0.9987	0.9993

Comparison BIPM.RI(I)-K7 between the mammography x-rays air kerma standards of the VNIIM and the BIPM took place in November 2012. The report of results is under consideration now.

In 2012 the VNIIM among other COOMET members took part in COOMET.RI(I)-S1 comparison of the national standards of air kerma for Cs-137 at protection level conducted by the PTB. In this comparison three TM32002 transfer ionization chambers of the PTB were calibrated against the VNIIM primary standard graphite-walled cylindrical cavity ionization chamber C30 of volume 30.024 cm^3 in the field of the VNIIM Cs-137 source with air kerma rate 3.3 mGy·h^{-1}.

Comparison of the standards for air kerma of the VNIIM and the IAEA in medium-energy x-rays is planned for June, 2013.

Measuring instruments calibration and verification

In 2011–2013 the VNIIM performed calibrations, verifications and comparisons for accredited dosimetry calibration laboratories, atomic power stations, clinics and manufacturers of dosimetry instruments and sources.

Secondary standards calibrations were done for CSM of Moscow region (Mendeleyevo, Moscow region) and Belorussian State Institute of Metrology (BelGIM) (the Republic of Belarus). More than 90 calibrations and verifications of working standards, including dosimetry x-rays, gamma and beta radiation sources were done. More than 1400 calibrations and verifications of measuring instruments for x-rays, gamma and beta radiation were performed.

Measuring instruments testing for type approval

The VNIIM is a state testing center of Russia and is responsible for type approval checkout of imported and home-produced dosimetry devices.

For the last two years 12 Russian and foreign measuring instruments were tested for type approval: universal dosemeters PTW-Unidos E (by PTW-Freiburg, Germany), DAP-meters KermaX Plus C (by IBA Dosimetry, Germany), VacuDAP (by VacuTec Meßtechnik GmbH, Germany); dosemeters for diagnostic radiology Cobia and Piranha (by RTI Electronics AB, Sweden); dosemeters for radiation protection DKG-RM 1603 A, B (by OOO SoftExpert, Russia, Moscow); dosemeters RDS-30 (by Mirion Technologies (RADOS) Oy, Finland); dosimetry system LUXEL+ (by Landauer Inc., the USA); TLD-systems MediSmarts (by ROTEN INDUSTRIES LTD, Israel), AKIDK-401 (by OOO Uralpribor, Russia, Angarsk) and Harshaw 3500 (by Thermo Fisher Scientific Inc., the USA).

Regulations development

According to the changes in the primary standard the VNIIM produced new regulations concerning stages of transfer of air kerma unit to different dosimetry devices from the primary standard "GOST R 8.804-12. State system for ensuring the uniformity of measurements. State verification schedule for means measuring air kerma, air kerma rate, exposure, exposure rate, ambient dose equivalent, directional dose equivalent and personal dose equivalent, ambient dose equivalent, directional dose equivalent and personal dose equivalent rates and energy flux of x-ray and gamma radiation". The regulations will be put in force from January, 1, 2014.

Furthermore for the last two years procedures of measurement, calibration and verification were developed for different types of dosimetry measuring instruments, including DAP-meters, personal x-ray, gamma and beta radiation dosemeters.

Publications and talks

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