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Progress report on radiation dosimetry standards, facilities and related topics at VSL, 2007 – 2009

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1. Introduction

The following sections present brief summaries on activities related to standards, facilities and calibration services at VSL over the period 2007 –2009 with respect to radiation Dosimetry. Research activities at VSL have been focused on absorbed dose to water for medium x-rays, low energy photon dosimetry and for 3D dosimetry in complex phantoms and very small radiotherapy beams, used in IMRT and radio surgery. At the first of March 2009 NMi Van Swinden Laboratory changed into VSL, Dutch Metrology Institute.

2. Accommodation and facilities

The accommodation and facilities at VSL did not change in the period 2007 – 2009. To be able to perform test measurements for proton dosimetry, the proton beam at KVI (Kernfysisch Versneller Instituut), the accelerator institute of the University of Groningen was used.

3. Air kerma standard and facilities

3.1 Re-evaluation of wall and non-uniformity correction factors for ^{173}Cs

The primary standard for air kerma for ^{137}Cs photon beams in the Netherlands is a cylindrical Bragg-Gray cavity, having an air volume of 2.5 cm^3. To re-evaluate the correction factor for the influence of the graphite chamber wall, measurements were performed using wall thicknesses of 3, 4, 5 and 6 mm. At every wall thickness the measurements were performed with the cylindrical chamber radial, axial and oblique positioned to de beam axis. For the same wall thicknesses and orientation of the cylindrical chamber Monte-Carlo calculations were performed to estimate the influence of the graphite walls for the 2.5 cm^3 Bragg-Gray cavity. The calculated Kerma-rate in air was, within the uncertainties, the same for all combinations of orientation and wall thicknesses. Applying the new found value for the wall correction value resulted in a decrease of the kerma rate of the ^{137}Cs photon beam at VSL by a factor of 0.9961. The uncertainty for determination of the air kerma rate of a ^{137}Cs source is 0.80% (coverage factor k = 2).

3.2. EUROMET comparisons

EUROMET 545: *Intercomparison of NMI air kerma standards for ISO 4037 narrow spectrum series radiation qualities.* The project has been finished and a project report has been written. It was distributed among the participants of the project in October 2007. In 2008 it was published in *Metrologia*: *Comparison of national air kerma standards for ISO 4037 narrow spectrum series in the range 30 kV to 300 kV*, L. Buermann, M. O'Brien, D. Butler, I. Csete, F. Gabris, A. Hakanen, J.-H. Lee, M. Palmer, N. Saito and W. de Vries, *Metrologia, 2008,* ***45****, Tech. Suppl., 06013*
EUROMET 738: *Intercomparison of the personal dose equivalent for photon radiation.* In this comparison a transfer ionization chamber has to be measured in terms of $H_p(10)$ in five different radiation qualities under specified radiation incidence conditions. The measurements were performed in February/March 2007. A final report is being made.

EUROMET project 813: *Comparison of air kerma and absorbed dose to water measurements of Co-6o radiation in radiotherapy.* Measurements for this project have been completed in March 2007. The final report of this project has been distributed among the participants of the project in February 2009.

4. Absorbed Dose standards

4.1 Absorbed dose standards based on a water calorimeter

VSL is operating a water calorimeter as a primary standard for high-energy photon radiation. In 2008 VSL has developed a water calorimeter for medium-energy x-rays. The calorimeters are transportable and can be used for absorbed dose measurements on different sites.
At the end of 2008 preliminary measurements have been performed in the experimental proton facility of KVI (Kernfysisch Versneller Instituut) in Groningen, The Netherlands. Currently a follow-up of these measurements is being prepared.
At present VSL is investigating the feasibility of water calorimetry for small field dosimetry Initially this study makes use of the VSL ^{60}Co-source. If the study proves that water calorimetry in small beams is feasible, it will be extended to clinical photon beams.

4.2 Absorbed dose standard for low-energy photon

In the last years the use of low energy photon sources became more relevant in radiotherapy. An example is the use of ^{125}I seeds in case of prostate cancer. At VSL a feasibility study has been started in 2007 to investigate the possibility of determining the absorbed dose to water for low energy, low dose rate sources. Some source and phantom geometries have been simulated with MC code PENELOPE. A coaxial extrapolation chamber was designed and constructed. The current measurements (in the order of femto-amperes) and the related energy deposition are compared with the results of the MC-calculations.

4.3 Three-Dimensional Dosimetry

Developments in radiotherapy are progressing fast. Treatment techniques such as Intensity Modulated Radiation Therapy (IMRT), TomoTherapy and radiosurgery considerably improve the treatment of cancer patients. Because of the increase in complexity of the dose delivery for these techniques, absolute dosimetry in a single point is more difficult and additional knowledge of the dose distribution in a 3D volume is necessary. In 2007 a study on the feasibility of a 3D dosimetry system as verification service of radiotherapy treatment planning and delivery for complex treatment techniques has been started. The scientific literature has been investigated on available and suited 3D dosimeters and anthropomorphic phantoms.
Based on this feasibility study, radiochromic film was selected as suited dosimeter. In 2008 the readout system for the radiochromic film, a flatbed scanner, was characterized with respect to polarization, position dependent variation in scanner sensitivity. Also the dose response curve was determined and a correction method for position dependent variation in film sensitivity was developed which decreased the uncertainty contribution due this variation with 50%. The method of film dosimetry was validated for homogeneous fields. End of 2008 a simple (i.e. homogeneous) anthropomorphic phantom was designed and constructed.

In 2009, the first measurements for inhomogeneous fields were performed. The measurements were validated with Monte Carlo simulations. Both methods the calculations and the simulations are traceable to the VSL primary standard.

3.1 Absorbed dose standard for HDR sources

Within the framework of EMRP – JRP06 a water calorimeter for HDR sources is being developed. The source self-heat was modelled and determined. A method to reduce the temperature rate due to source self-heat was developed. The design for the new high purity cell was made, and construction of it is underway. June 2009 the first measurements will be performed.

5. Key comparisons

An indirect comparison of the standards for the quantity absorbed dose to water was carried out between the VSL and the BIPM in September 2005. The comparison was based on the calibration coefficients determined for three NE2611A type ionization chambers under reference conditions in the ^{60}Co beams of both institutes. The comparison result, reported as a ratio of the VSL and the BIPM evaluations, is 0.9926 with a relative standard uncertainty of 4.9×10^{-3}. This result replaces the previous indirect comparison result obtained in 2000 for the ongoing BIPM.RI(I)-K4 comparison. The opportunity was also taken to undertake a pilot study using the VSL water calorimeter at the BIPM.

6. k_Q measurements in high-energy photon beams

The VSL primary standard for absorbed dose to water in high-energy photon beams, the water calorimeter, has been used to determine k_Q factors of 4 types of in total 24 cylindrical ionization chambers in clinical photon beams from 6 MV to 25 MV. The results obtained from these measurements have been used in NCS report 18, Code of Practice for the Absolute Dose Determination in High energy Photon and Electron Beams, together with other experimentally determined k_Q factors.

7. Publications (March 2007 – May 2009)

NMi report nr: VSL-ESL-IO-2007/3, Wall correction factors for a cylindrical cavity chamber and ^{137}Cs radiation using Monte-Carlo methods.
NCS, Nederlandse Commissie voor Stralingsdosimetrie, Report 18: Code of Practice for the Absolute Dose Determination in High energy Photon and Electron Beams, NCS Report 18, January 2008
De Prez L.A. and De Pooter J.A., The new NMi orthovolt x-ray absorbed dose to water primary standard based on water calorimetry, Phys. Med. Biol. 53 (2008) 3531 – 3542
Burn D T and De Prez L A, Key comparison BIPM.RI(I)-K3 of the air-kerma standards of the VSL, Netherlands and the BIPM in medium-energy x-rays, Metrologia, 2009, 46, Tech. Supp., 06004
BIPM and VSL, Comparison of the standards for absorbed dose to water of the VSL and the BIPM for ^{60}Co gamma rays, Draft B.