Report to the 18th Meeting of the CCRI(I), May 2007 Recent Activities in Measurement Standards and Dosimetry at METAS, 2005-2007

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1. Introduction

The Thermometry and Ionising Radiation Section continues to maintain and develop the Swiss standards of absorbed dose to water and air kerma and to provide calibration and verification services for therapy level dosimeters. Considerable staff changes have occurred since the previous meeting of the CCRI(I) in 2005. The former head of section, Dr Manfred Sassowsky, left METAS on 30 April 2005. This position was taken over by Dr Damian Twerenbold on 1 June 2005. Dr Harald Quintel left METAS in 2005 and Dr Sándor Vörös became a scientific collaborator on a permanent position the same year. Solange Gagnebin started to work on her PhD thesis at METAS on 1 May 2006.

2. Facilities

2.1 Microtron Accelerator

METAS maintains a M22 microtron electron accelerator with two beam lines.

One beam line is equipped with a conventional treatment head producing therapeutic photon and electron beams. Nine photon beam qualities in the range from $TPR_{20,10}$ = 0.639 to $TPR_{20,10}$ = 0.802 (4 MV to 21 MV) with dose rates from about 0.5 Gy/min to 4 Gy/min are regularly used for measurements with the primary standard sealed water calorimeter. Some other additional beam qualities are occasionally used for research purposes. Ten electron beam qualities in the range from R_{50} = 1.75 gcm^{-2} to R_{50} = 8.54 gcm^{-2} (5.3 MeV to 22.4 MeV) with dose rates from about 1 Gy/min to 4 Gy/min are regularly used for measurements with the primary standard chemical dosimeter. All beam qualities are also used for verification or calibration of reference dosimeters.

The second beam line produces a narrow electron beam in the energy range from 5.3 MeV to 22.4 MeV with beam pulse currents from 100 µA to 50 mA. This beam line is mainly used for research experiments and for establishing the total absorption experiment using Fricke solution.

In 2005/2006 the accelerator system was upgraded and the existing computer control system was replaced by a modern Siemens Simatic S7-400 SPS control system. Specifications and control procedures were developed by METAS, the system itself was realized and installed by an external company. In parallel the existing analog field servo of the treatment head was replaced by a digital one (developed by METAS) which in turn is controlled by the new SPS system.

The existing modulator which becomes more and more unstable should be replaced by two new solid sate modulators. The replacement is planned in the fall of 2007. This will also allow an extension of the energy range down to about 2.5 MeV and a variable pulse length from 1.5 to 4 µs. It should improve the stability of the accelerator system considerably.

2.2 ^{60}Co treatment unit

A commercially available irradiation unit of type General Electric Alcyon II is used to produce the ^{60}Co beam. In December 2004 the source was exchanged and the radiation field was characterized before and after changing the source by means of a set of transfer ionisation chambers of types NE2611A, NE2561 and NE2571. The new source has an activity of about 165 TBq (01.05.2007) resulting in a dose rate of about 0.84 Gy/min at an SCD of 1 m at a depth of 5 gcm^{-2} in water. The treatment unit is mainly used for the realization and dissemination of the quantity absorbed dose to water.

2.3 160 kV X-ray Generator

A Pantak HF160c X-ray generator equipped with an X-ray tube of type Comet MXR-160 04-1.5 is used to produce therapeutic X-ray fields from 10 to 100 kV. Standard radiation qualities in the range from T10 to T100 (according to DIN 6817) are used for realization and dissemination of the quantities absorbed dose to water and air kerma. The 3D remotely controlled table used to support and locate the standards and reference dosimeters in the radiation fields was recently upgraded.

3. Calibration and Verification Services

The current range of radiation dosimetry calibration and verification services provided by METAS is summarised in table 1, at the end of this report.
The reference dosimetry systems used in the Swiss treatment centres to determine the applied dose to a patient must be regularly verified by an authorized authority. METAS is the corresponding authority for high-energy photon (including ^{60}Co) and high-energy electron beams as well as for low-energy X-rays in the range from 10 to 100 kV.
Reference dosimetry at the Swiss treatment centres is performed in terms of absorbed dose to water. The applied procedures for this dosimetry are described in the recommendations No 8, 9 and 10 published by the Swiss Society of Radiobiology and Medical Physics (SSRMP). The verifications provided by METAS comply with these recommendations.

Verifications provided by METAS in the period from 01.05.2005 to 30.04.2007:

- High-energy photons (including ^{60}Co): 28 (total 66 beams, incl 18 ^{60}Co)
- High-energy electrons 9 (total 47 beams)
- Low energy X-rays 13 (total 61 beams)

The number of verifications per year is slowly increasing in all energy ranges. This is due to the increasing number of treatment centres. Recently opened centres even install low energy X-rays generators for treatment purposes and other existing centres resume the treatments in this energy range.

The SSRMP is organizing a yearly TLD comparison among its members. In the frame of this comparison METAS acts as a reference laboratory, irradiating a number of TLDs in its ^{60}Co beam as well as in the accelerator beams under reference conditions.

4. Dissemination of the Quantity Absorbed Dose to Water for International Customers

In 2006 six secondary standard dosimetry systems from the Austrian standards laboratory BEV (2 systems with 2 Roos chambers, 2 sytems with NACP02 chambers and 2 systems with

PTW 30012 chambers, each system with an UNIDOS10001 electrometer) were calibrated against the METAS primary standards.

The four plane parallel chambers were calibrated in six electron beams each and the 2 thimble chambers in five photon beams (including ^{60}Co).

5. Absorbed Dose Standards

The absorbed dose primary standards operated at METAS cover the full range of the current range of radiation dosimetry calibration and verification services provided by METAS according to table 1.

5.1 Photon Beam Dosimetry Standards

The internal transfer standards, a number of ionisation chambers of types NE2561/2611A and NE2571A, are regularly calibrated against the sealed water calorimeter in the entire energy range. The calorimeter itself was upgraded in 2006: The water tank was replaced by a new one with a Polystyrene entrance window with a thickness of 2.58 mm. A new support of the vessel and the ionisation chambers was built in. This new support improves the alignment of the vessel and the chambers.

Work is also underway to replace the single AC bridge with 2 thermistors in opposite arms by 2 independent AC bridges, each equipped with a single themistor and a separate lock-in amplifier.

The regularly calibrated thermistors have been proven to be stable within 0.1 % over a period of more than five years, irrespective of the accumulated dose. No changes in the calibration parameters due to an accumulated dose of more than 3000 Gray could be observed.

5.2 Electron Beam Dosimetry Standards

The primary standard is a chemical dosimeter which is based on the total absorption of an electron beam in Fricke solution at a given well known energy. The thus calibrated Fricke solution is used to regularly calibrate plane parallel chambers of type NACP02 which in turn are used for the conservation and dissemination of the quantity absorbed dose to water.
The total absorption experiment was repeated in 2007. The new results are in agreement with the results obtained in 1999/2000 to within 0.2 %.

The pulse dose dependence of the radiation yield of Fricke solution containing 1 mmol/L NaCl was experimentally determined in the pulse dose range from 0.05 Gy/pulse to 600 Gy/pulse. The analysis of the experimental results is still ongoing.

The internal transfer chambers are always calibrated against the Fricke solution just prior to using them for the yearly verifications.

5.3 Low Energy X-Rays Standards

METAS maintains five secondary standard chambers (3 of type PTW 23342 and 2 of type PTW 23344) that are used to verificate customer dosimetry systems in the range from 10 kV to 100 kV. The standard qualities used are T10 to T100 according to DIN6817.

In 2006 these five chambers were calibrated in terms of absorbed dose to water at the PTB against their primary standard. The calibration at the PTB is repeated every two years. Prior to a verification of a customer dosimeter the stability of the secondary standards is checked at T30 using the METAS 50 kV free air chamber (FAC).

6. Air Kerma Standards

Since the reference dosimetry procedures at the Swiss treatment centres are all based on absorbed dose to water measurements it has been decided to suspend developments of primary standards for air kerma and to use secondary standards in cases where a calibration in terms of air kerma is required which is not covered by the 50 kV free air chamber.

6.1 ^{60}Co Standards

METAS maintains two secondary standard chambers (1 of type NE2611A, 1 of type NE2571A). In 2006 these chambers were recalibrated by the BIPM. The new calibration coefficients agree within 0.3 % with the coefficients obtained in the previous calibration at BIPM in 1997.

6.2 Low Energy X-rays Standards

On request METAS offers calibrations in terms of air kerma at therapy level in the range from 10 kV to 100 kV. The standard qualities used are T10 to T100 according to DIN 6817. These qualities are established using the FAC (T10 to T50) or using the secondary standards traceable to PTB (T70 and T100). Prior to a calibration or verification of a customer dosimeter the stability of the secondary standards is checked at T30 using the FAC.

7. Comparisons and EUROMET Projects

7.1 EUROMET Project 605

METAS acts as coordinator of the Project 605 “Beam Quality Specification of High-Energy Photon Beams”.
The specification of the quality of a high-energy photon beam has been subject of several studies due to its relevance in radiation dosimetry. However, no beam quality specifier has been found that satisfies all the requirements of being unique for the entire range of photon energies used in radiotherapy and for all types of accelerators used in hospitals and standard laboratories, as well as being easy to measure. The aim of the project is to investigate the characteristics of the existing and widely used beam quality specifiers in more detail in order to determine the optimal beam quality specifier.
A set of four cylindrical ionisation chambers belonging to METAS (2 of type NE2571A, 1 of NE2561 and one of NE2611A) were calibrated in terms of absorbed dose to water in the ^{60}Co beams and in several high-energy X-ray beams at participating laboratories (ENEA, LNHB, METAS, NPL, NRC and PTB). Beam quality measurements were performed in the accelerator beams in order to compare the efficacy of $TPR_{20,10}$ and $\%dd(10)_x$ as beam quality specifiers. In total 28 accelerator beams were measured. The measurements were completed in 2006 and the analysis of the data is still ongoing. The final report is scheduled for June 2007.

7.2 EUROMET Project 813

METAS participated in the EUROMET project 813 “Comparison of air kerma and absorbed dose to water measurements of ^{60}Co radiation in radiotherapy” with OMH acting as pilot laboratory. In January 2007 four ionisation chambers from OMH were calibrated in the ^{60}Co beam in terms of air kerma and absorbed dose to water against the Swiss standards.

7.3 ARPANSA-METAS Bilateral Comparison

The analysis of the recent bilateral comparison of air kerma and absorbed to water in ^{60}Co radiation has been completed. The results indicate an agreement within 0.34 % (absorbed to water) and 0.48 % (air kerma) between the laboratories. The paper will be submitted for publication shortly.

7.4 METAS-NPL High-Energy Electron Beam Comparison

A comparison of absorbed dose to water primary standards in high-energy electron beam radiation was started recently. Irradiations of four plane-parallel ionisation chambers of type NACP02 (2 from METAS, 2 from NPL) in the energy range from 4 MeV to 22 MeV have been carried out at METAS and at NPL. The experimental work is already completed and the analysis of the data is expected to be finished by June 2007. It is planned to submit the paper for publication in 2007.

8. Monte Carlo Simulations

A Monte Carlo simulation project was started in the fall of 2003. Results have been obtained for several types of investigations, among which the following ones may be cited:

- Total absorption experiment in a Fricke solution: the energy losses due to escaping Bremsstrahlung photons, backscattering and absorption in the surrounding material have been calculated.
- Material corrections for the secondary to primary standard comparison: small bags and ampoules of Fricke solution are used for measurement in parallel with secondary standard ionization chambers, and small corrections for the presence of materials other than water are calculated by Monte Carlo using a full description of the treatment head.
- Beam quality specifiers: a detailed simulation of the treatment head was performed in order to calculate $TPR_{20,10}$ and %dd(10) for all photon beam qualities commonly used at METAS, as well as R_{50} for the electron beams.

9. Proton Beam Dosimetry

Cancer therapy with proton beams has become increasingly important and is a well established method. In the framework of the ProScan project at the Paul Scherrer Institute (PSI), the spot-scanning technique is being characterized for subsequent application in hospitals. In a joint project between METAS and PSI a modified version of the existing high-energy photon sealed water calorimeter which is in operation since 1999 is being tested for suitability as a primary standard for scanned proton radiation.

In a first step a feasibility study has been conducted to investigate the linear energy transfer dependence of the heat defect and the influence of the time and space structure of the scanned proton beam on the homogeneity and stability of the temperature field in the water calorimeter. Simulations were validated against experimental data (taken in photon beams) of the existing calorimeter used in photon beams.

In the second step a replicate of the existing calorimeter was experimentally tested in the ProScan proton test beam. The first experimental results were obtained in December 2006. Preliminary results indicate the feasibility of water calorimetry in scanned proton beams.

In the third step the replicate of the existing calorimeter will be tested in the ProScan proton beam produced by the PSI gantry 2.

In order to use a sealed water calorimeter as a primary standard for scanned proton beams, the various correction factors will now be systematically investigated.

10. Publications and Reports (2003- April 2007)

P J Allisy-Roberts, D Burns, G. Stucki, *Comparison of the standards for absorbed dose to water of the METAS and the BIPM for* ^{60}*Co gamma radiation*, Rapport BIPM 03/02 (2003)

G Stucki, W Muench and H Quintel, *The METAS absorbed dose to water calibration service for high energy photon and electron beam radiotherapy*, (Proc. Int. Symp., Vienna, 2002) IAEA Vienna (2003) IAEA-CN-96-8, Vol. I, 103-113

G Stucki, W Muench and H Quintel, *The METAS Photon-beam Primary Standard Sealed Water Calorimeter*, Proceedings of a workshop on recent Advances in Absorbed Dose Standards (ARPANSA, Melbourne) http://www.arpansa.gov.au/absdos/proc.htm, 2003

J Medin, C K Ross, G Stucki, N Klassen and J P Seuntjens, *Commissioning of an NRC-Type sealed water calorimeter at META using* ^{60}*Co* γ*-rays*, Physics in Medicine and Biology 49 (2004) 4073-4086

M Sassowsky and E Pedroni, *On the feasibility of water calorimetry with scanned proton radiation*, Physics in Medicine and Biology 50 (2005) 5381-5400

S Gagnebin, D Twerenbold, C Bula, C Hilbes, D Meer, E Pedroni, S Zenklusen, *Measurement of the absorbed dose of scanned protons with a water calorimeter*, PSI Annual Report 2006

Table 1. METAS Calibration Services in Photon and Electron Dosimetry

Calibration or Measurement Service		**Measurand Range [Gy]**		**Measurement Conditions/Independent Variable**		**Expanded Uncertainty k=2**	**Reference Standard used in calibration**	
Quantity	Instrument Type or Method	Minimum value	Maximum value	Parameter	Specifications	Value	Standard	Source of traceability
Absorbed dose to water	Calibration against a secondary standard in a water phantom	1.0E-01	5.0E+01	Photons, high energy	Tissue to phantom ratio (TPR) TPR = 0.634-0.795	1.4	Water calorimeter	METAS
Absorbed dose to water	Calibration against a secondary standard in a water phantom	1.0E-01	1.5E+02	Co-60		1	Water calorimeter	METAS
Absorbed dose to water	Calibration against a secondary standard in a water phantom	1.0E-01	1.5E+02	Electrons, high energy	Half value depth R_{50}=1.75 -8.54 gcm^{-2}	2	Total Absorption in Fricke solution	METAS
Absorbed dose to water	Calibration against a secondary standard in PMMA	5.0E-02	2.0E+01	X-Ray, 10 to 50 kV	Half-value layer (HVL in mm Al) $0.03 \leq HVL \leq 1.0$	3.1	Secondary standard ionisation chamber	PTB
Absorbed dose to water	Calibration against a secondary standard in PMMA	5.0E-02	2.0E+01	X-Ray, 50 to 100 kV	Half-value layer (HVL in mm Al) $1.0 < HVL \leq 4.7$	3.1	Secondary standard ionisation chamber	PTB
Air kerma	Calibration against a secondary standard free in air	1.0E-01	1.5E+02	Co-60		0.9	Secondary standard ionisation chamber	BIPM
Air kerma	Calibration against a primary standard free in air	5.0E-02	5.0E-01	X-Ray, 10 to 50 kV	Half-value layer (HVL in mm Al) $0.03 < HVL \leq 1.0$	1.4	Parallel plate free air ionisation chamber	METAS
Air kerma	Calibration against a secondary standard free in air	5.0E-02	2.0E+01	X-Ray, 50 to 100 kV	Half-value layer (HVL in mm Al) $1.0 < HVL \leq 4.7$	1.9	Secondary standard ionisation chamber	PTB