

REPORT TO THE CCRI SECTION I ON THE ACTIVITY CARRIED OUT AT ENEA-INMRI ON PHOTON AND CHARGED PARTICLE DOSIMETRY IN THE PERIOD 2009 – 2011

M.P. Toni, M. Pinto, A.S. Guerra, M. Pimpinella, M. Bovi, S. Loreti

Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti

ENEA, C. R. Casaccia

Mailbox 2400, 00100 AD Roma (Italy)

1. INTRODUCTION

The present report is a summary of the 2009-2011 activities carried out (or ongoing) at the ENEA-INMRI in the field of interest of CCRI Section I, i.e. photon and charged-particle dosimetry. The main characteristics of the national standards maintained in Italy at the ENEA-INMRI in the field of radiation dosimetry are reported in Table I.

Table I. National standards maintained at ENEA-INMRI in the field of photon and charged particle dosimetry

Quantity	Standard	Radiation Quality	Measurement Range / Gy s ⁻¹
Air-Kerma	-Free-air ion chamber	10-50 kV X-ray	1 10 ⁻⁶ - 7 10 ⁻³
	-Free-air ion chamber	60-300 kV X-ray	7 10 ⁻⁷ - 3 10 ⁻⁴
	-Cavity ion chamber	⁶⁰ Co gamma-ray	2 10 ⁻⁴ - 7 10 ⁻³
	-Calibrated ion chamber	¹³⁷ Cs gamma-ray	2 10 ⁻⁶ - 3 10 ⁻⁴
	-Calibrated ion chamber	¹⁹² Ir gamma-ray	≅ 3 10 ⁻³
Absorbed Dose to water (external beams)	-Graphite calorimeter	⁶⁰ Co gamma-ray	2 10 ⁻³ - 2 10 ⁻²
	-Calibrated chemical dosimeter		8 10 ⁻³ - 3 10 ⁻¹
Absorbed Dose to tissue-equivalent materials	-Extrapolation ion chamber	¹⁴⁷ Pm, ⁸⁵ Kr and ⁹⁰ Sr/ ⁹⁰ Y beta particles	3 10 ⁻⁷ - 5 10 ⁻⁴

2. NATIONAL STANDARDS DEVELOPMENT

In the following, some relevant characteristics and the new activities with standards in table 1 –after the latest CCRI(I) meeting (2009)– are described.

2.1 Air- kerma standards

The air-kerma standards at ENEA-INMRI are:

- a parallel-plate free-air chamber for low energy x-rays, ;
- a cylindrical and telescopic free-air chamber (Attix-type) for medium energy x-rays;
- a group of cylindrical cavity ionization chambers for ⁶⁰Co gamma rays, with different geometries.

The following secondary standards are also available:

- a 30 cm³ ionization chamber (plastic walled) for air-kerma measurements with ¹³⁷Cs gamma rays calibrated by means of a linear interpolation procedure based on the chamber response for the ⁶⁰Co gamma rays and a 250 keV mean energy x-rays. In the next future, this standard will be replaced by a new ion chamber directly calibrated against the BIPM primary standard for ¹³⁷Cs gamma rays.
- a 1000 cm³ ionization chamber (plastic walled) for air-kerma measurements with ¹⁹²Ir gamma rays. This standard is currently calibrated by means of an interpolation procedure based on the response curve as a function of energy, for several medium-energy x-ray qualities and ⁶⁰Co gamma rays.

2.2 Absorbed dose to water standards (external beams)

The absorbed-dose to water standard operating at ENEA-INMRI is based on a graphite calorimeter and an ionometric transfer system (thick-walled graphite ionization chamber) for ⁶⁰Co gamma-ray absorbed dose to water.

A transfer standard system based on ferrous sulphate and dichromate dosimeters is also currently operating for calibration in the industrial-level irradiation range. The ferrous sulphate solution is used in the dose rate range from 30 Gy/h to 1 kGy/h. The potassium-silver dichromate solution is used in the dose rate range from 1 kGy/h to 10 kGy/h. The ferrous sulphate solution is firstly calibrated against the primary standard of absorbed dose to water in the reference ⁶⁰Co gamma beam with a dose rate of about 30 Gy/h, then used to calibrate the dichromate dosimeters in a pool-type ⁶⁰Co irradiation plant at a dose rate of about 1 kGy/h. The combined relative standard uncertainty on the absorbed dose to water rate at the reference point in the pool-type irradiation facility is 1.7%. The transfer standard has been recently validated participating in the CCRI(I)-S2 supplementary comparison of standards for absorbed dose to water for ⁶⁰Co gamma radiation at radiation-processing dose levels (see annex1, ref. 24).

3. NEW STANDARDS UNDER DEVELOPMENT

The main characteristics of the new standards under development –and not yet commissioned as national standards– at the ENEA-INMRI in the field of radiation dosimetry are reported in Table II.

3.1 Absorbed dose to water standards (external beams)

A new absorbed dose to water standard based on a water calorimeter was constructed at the ENEA-INMRI some years ago. Some preliminary tests have been conducted on this standard, but they have not yet been completed due to shortage of dedicated personnel. The recruitment of a new researcher is planned by the end of the year to complete this research project.

Table II. New standards under development at ENEA-INMRI in the field of photon and charged particle dosimetry

Quantity	Standard	Radiation Quality	Measurement Range / Gy s ⁻¹
Absorbed Dose to water (external beams)	-Water calorimeter	⁶⁰ Co gamma-ray	2 10 ⁻³ - 2 10 ⁻²
Absorbed Dose to water (brachytherapy)	-Large angle and variable volume ion chamber	¹²⁵ I gamma-ray	≤ 5 10 ⁻⁵
	-Well-shaped graphite calorimeter	¹⁹² Ir gamma-ray	≤ 6 10 ⁻²

3.2 Absorbed dose to water standards (brachytherapy)

In 2008 the ENEA-INMRI became a partner of the EU joint research project “Brachytherapy”¹ and within its framework it started to develop two new absorbed dose to water standards for low dose rate (LDR) and high dose rate (HDR) brachytherapy (BT) sources, respectively. The development of these two standards is at its final stage and preliminary tests gave satisfactory results.

3.2.a Low dose rate Brachytherapy Standard

The LDR BT standard is designed to determine the absorbed dose to water due to ¹²⁵I LDR sealed BT sources. Monte Carlo simulations were first launched to optimize the basic design of the standard, using both codes PENELOPE and EGSnrc. The homogeneity of the electric field inside the ionization chamber was investigated using calculations based on the 3D boundary element method (BEM).

The standard consists in a large-angle, variable volume ionization chamber. A Monte Carlo-based conversion procedure allows to determine the absorbed dose to water at 1 cm ($D_{w,1\text{ cm}}$) from the BT sources. The calculation procedure relies on the method described by T Schneider et al.². All Monte Carlo based correction and conversion factors were calculated using both PENELOPE and EGSnrc++ codes.

The final estimation of the overall uncertainty associated to the $D_{w,1\text{ cm}}$ measurement is in progress. An accurate preliminary estimate puts the combined standard uncertainty value between 2.5 % and 3.0 %, largely depending on the choice of the measuring volumes. Further measurements and calculations are in progress to lower the uncertainty towards a value between 2.0 % and 3.0 %.

The characteristics of the new standard and preliminary results will be published shortly.

¹ “Increasing cancer treatment efficacy using 3D Brachytherapy” is a project funded with the Grant Agreement No. 217257 between the EC and EURAMET under the Seventh Framework Programme. The coordination of the “Brachytherapy” project has been entrusted to the ENEA-INMRI and coordinated by Dr Maria Pia Toni

² T Schneider, *A method to determine the water kerma in a phantom for x-rays with energies up to 40 keV*, Metrologia 46 (2009) 95–100.

Some relevant characteristics of the standard are already reported in annex 1, ref.7, 10,11,13,25.

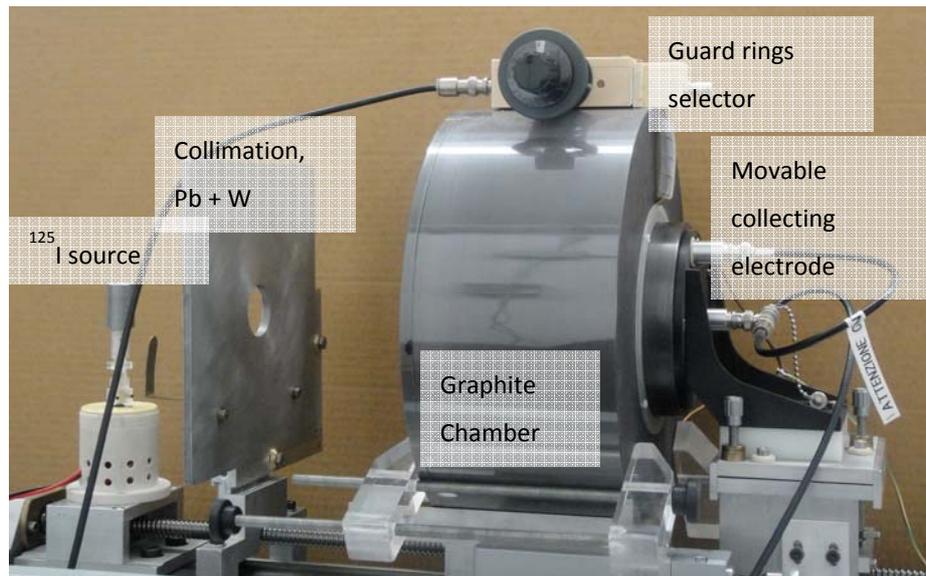


Figure 1. Schematic view of the ENEA-INMRI LDR BT standard.

3.2.b High dose rate brachytherapy Standard

The ENEA-INMRI absorbed dose standard for HDR BT sealed sources (e.g. the ^{192}Ir capsules for remote afterloading) is a three-body (core, jacket and medium) portable graphite calorimeter for absorbed dose to graphite measurements. The calorimeter is designed for measuring the absorbed dose to graphite at 2.5 cm distance from the brachytherapy source. At 2.5 cm distance a good compromise between the need of minimizing the effects of the strong dose gradients near the source and the production of a still acceptable signal is reached. The calorimeter has a cylindrical symmetry with respect to the source position, like the well-type ionization chambers widely used for the characterization of HDR BT sealed sources. To achieve the conditions of full backscattering at the measurement point, the calorimeter is inserted in a larger cylindrical graphite phantom, having diameter and height equal to 20 cm. Using Monte Carlo calculations, the absorbed dose to graphite at 2.5 cm distance from the BT source into absorbed dose to water at 1 cm distance from the source. The correction factors relevant to calorimeter gaps, brachytherapy source geometry, finite size of the core, etc., have been also determined by Monte Carlo simulations.

Monte Carlo calculations by EGSnrc were done to optimize the core dimensions. 3D heat transfer simulations were performed by finite element method, to optimize the gap number, the gap size and the coating of the internal surfaces of the calorimeter. Following, the best arrangement of the heaters necessary for the electrical calibration of the calorimeter in the 3 bodies of the calorimeter was found. The calorimeter can be operated either in the quasi-adiabatic or the quasi-isothermal mode of operation. The core, the jacket and the medium are surrounded by 0.5 mm vacuum gaps to minimize heat loss by conduction. The enclosure to obtain high vacuum (about 10^{-5} mbar) around the core, the jacket and the medium is made of PMMA (Figure 2). The temperature variation in the core and in the

jacket is measured by 0.3 mm diameter NTC microthermistors and a precision DC powered Wheatstone bridge (Figure 3). In the medium, larger size NTC thermistors have been used.

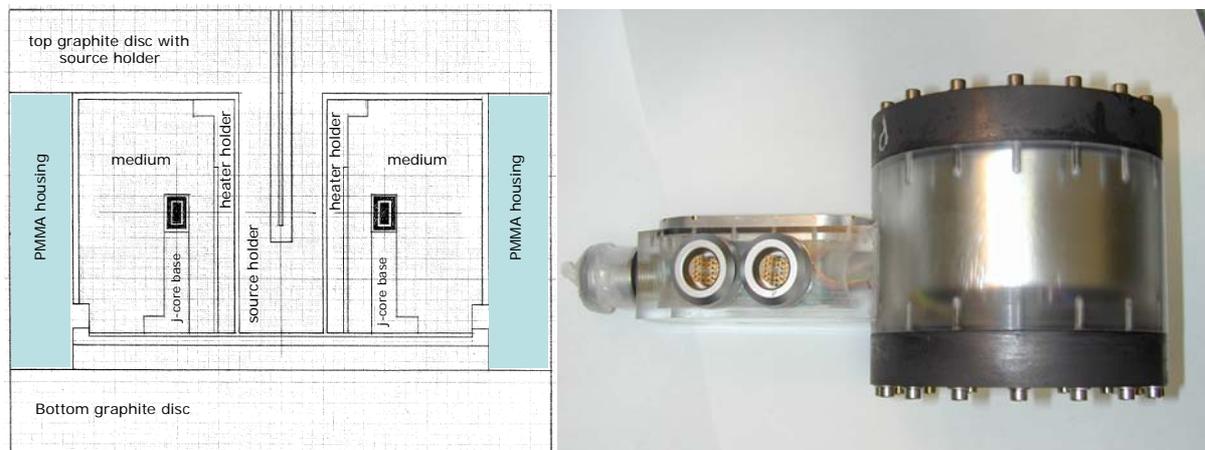


Figure 2. Schematic section and lateral view of the graphite calorimeter. The annular core diameter is 50 mm. The PMMA housing diameter is 130 mm.

The final arrangement is of 2 sensing thermistors in the core, 2 in the jacket, 2 in the medium. Similarly there are 2 heating thermistors in the core, 2 in the jacket, 8 in the medium. The medium is temperature controlled by a PID system acting on a peripheral wire-wound heating resistor. The thermal stability of the medium (hours) is about 10^{-3} K. The short term stability (minutes) is of about 10^{-4} K. A typical 4 min calibration run is showed in Fig. 4.



Figure 3. The electronic equipment for controlling the calorimeter is composed of a switching frame Keithley 7001, 2 precision power supply Keithley 2400. A fast current source Keithley 6220 coupled to a DC nanovoltmeter Keithley 2182A is used for resistance variation measurements (left). The catheter that drives the ^{192}Ir source is inserted in the calorimeter (right).

The development of the graphite calorimeter has been completed. Improvements of the control and data acquisition software are underway. The characteristics of the new standard and preliminary results will be published shortly. Some relevant characteristics of the standard are already reported in annex 1, ref.7, 10,11,13,25.

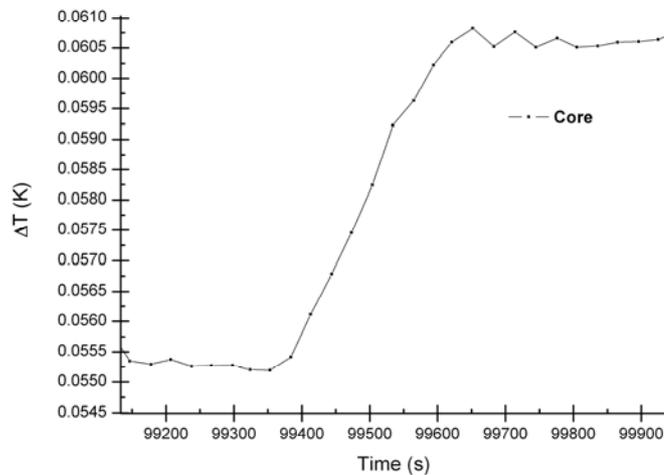


Figure 4. A typical 4 min calibration run, core thermistors.

4. INTERNATIONAL COMPARISONS

The international comparisons involving the ENEA-INMRI standards of air-kerma and absorbed dose are those listed below. The current status of the intercomparisons is described in parentheses.

1 - EUROMET 605, "Beam quality specification of high energy photon beams"

(results in course of publication)

2- EUROMET 813 "Measurement of air-kerma and absorbed dose to water due to ^{60}Co gamma radiation"

(results published in 2010).

3- BIPM-ENEA comparison on absorbed-dose-to-water standards for ^{60}Co gamma rays

(results published in 2011).

4- CCRI(I)-S2 "Comparison of standards for absorbed dose to water for ^{60}Co gamma radiation at radiation-processing dose levels"

(results published in 2011).

5- BIPM-ENEA comparison on low energy x-rays

(measurements carried out in January 2011, report due to be published shortly).

6- BIPM-ENEA comparison on medium energy x-rays

(in progress).

7- BIPM-ENEA comparison on mammography x-rays
(in progress).

5. CALIBRATION ACTIVITY

Calibrations of most protection-level and diagnostic dosimeters are traceable to the air kerma standards for low/medium x rays and ^{60}Co gamma rays. Calibrations of therapy-level, and industrial-level dosimeters are traceable to the absorbed-dose-to-water (D_w) standard presently operating only at the ^{60}Co gamma ray quality. Calibrations in terms of D_w at low and medium energy x rays are also available but only with traceability to the air-kerma standards.

5.1 Therapy-level calibration service

a) The therapy-level dosimeters used in the Italian radiotherapy centres are currently calibrated at ENEA-INMRI in terms of absorbed dose to water. Calibrations in terms of air kerma are also performed, however the largest part of the customer requires calibrations in terms of absorbed dose to water.

b) The service for direct calibration of the customer clinical beam (photon and electron beams) by chemical dosimetry has been operational, as in the past. The dosimeters consist of ferrous sulphate solution in sealed glass ampoules (volume of about 1 cm^3) with 0.5 mm wall thickness. A set of reference ferrous sulphate dosimeters (with their holder) is mailed to the customer for irradiation in water phantom. The absorbed dose to water imparted to the dosimeters is evaluated at ENEA-INMRI with a combined relative standard uncertainty of 1.6%. The D_w measurements are traceable to the absorbed-dose-to-water standard for ^{60}Co gamma radiation.

5.2 Protection and diagnostic level calibration service

The dosimeters used in Italy for radiation protection purposes are currently calibrated both at the ENEA-INMRI and at the ACCREDIA secondary standard calibration laboratories. ACCREDIA is the new Italian National Accreditation Body appointed by the State to perform accreditation activity and is recognized at the international level in the framework of the EA and ILAC agreements. At present there are 5 ACCREDIA calibration laboratories operating in Italy. Protection and diagnostic level dosimeter calibrations are made in terms of air-kerma. Protection level dosimeter calibrations are also made in terms of dose-equivalent quantities. The calibration qualities are those recommended by CCRI for standard comparison, ISO 4037 for radiation protection, IEC 1267 for radiodiagnostics and IEC 61223-3-2 for mammography.

5.3 Industrial-level calibration service

A calibration service for high-dose dosimetry is provided by the ENEA-INMRI to industries working on radiation processing of materials for sterilization purposes. Typically, industries ask to irradiate red-perspex dosimeters at certified dose levels in the range between 5 and 50 kGy. The irradiations are made in a pool-type ^{60}Co irradiation plant built at ENEA. The D_w measurements are traceable to the therapy-level absorbed-dose-to-water standard through a transfer standard system based on ferrous sulphate and potassium dichromate transfer dosimeters (see 2.2).

6. DOSIMETRY METHODS FOR RADIOTHERAPY BEAMS

In the period 2009-2011 the ENEA-INMRI research activity related to radiotherapy dosimetry was carried out in the framework of the EURAMET/EC joint research project “External beam cancer therapy”. A summary of the main activity is reported below.

6.1. Characterization of a CVD-diamond-detector prototype as transfer standard in radiotherapy photon beams.

A CVD diamond detector prototype fabricated at the laboratories of Rome University “Tor Vergata” (Almaviva et al, 2008, Nucl. Instr. and Meth. A 594 273-277) was tested to establish its suitability as transfer dosimeter in radiotherapy photon beams. The detector is fabricated starting from a commercial High Pressure High Temperature (HPHT) single crystal diamond used as substrate (thickness of about $450\ \mu\text{m}$, section $4\ \text{mm}^2$). Firstly a conductive boron-doped layer is deposited on the HPHT substrate then an intrinsic diamond layer (about $1\ \mu\text{m}$) is grown on the doped surface. Finally an aluminium contact is thermally evaporated on the top of the intrinsic layer. The diamond is encapsulated in a PMMA waterproofing cylindrical housing with external dimensions of 8 mm diameter and 3 cm height. The detector sensitive volume has 2 mm diameter and $1\ \mu\text{m}$ thickness. Due to the p-type/intrinsic/metal structure the device acts as a Schottky-barrier photodiode and can be operated without applying any polarizing voltage.

The signal rise time, the signal reproducibility, the dose and dose rate dependence were investigated in the reference ^{60}Co gamma beam. Several samples were tested, all showing similar characteristics. The detectors showed a fast dynamic response, a linear response with dose and dose rate, a signal repeatability of 0.03% ($k = 1$) and a signal long term reproducibility (months) better than 0.5% ($k = 1$) (Fig.1). Due to the very small sensitive volume the detectors have a low sensitivity (about $0.8\ \text{nC/Gy}$). However, a signal-to-background ratio larger than 10^3 , as recommended in the IAEA TRS 398 protocol, is obtained at typical radiotherapy dose rates (larger than $1\ \text{Gy/min}$).

The energy and field size dependence of the detector response in radiotherapy photon beams was determined by Monte Carlo (MC) simulations. Calculations of k_Q correction factors were performed with the EGS_CHAMBER/EGSnrc MC code. The detector irradiations in a 30 cm x 30 cm x 30 cm cubic water phantom at the reference conditions according to IAEA-398 were simulated for ^{60}Co

beam, 6 MV and 10 MV photon beams. Field sizes from 10 cm x 10 cm to 0.5 cm x 0.5 cm were considered. The detector was modeled with the egs++ geometry package following the real structure of the device. The influence of metal contacts and the effect of the triaxial cable were also evaluated. In the calculations a cutoff energy of 1 keV was used both for electrons and photons. Despite various variance reduction techniques implemented in the code were used the statistical uncertainty on the k_Q factors could not be reduced below 0.4% because the small scoring region (i.e. detector sensitive volume) required very long simulation time. The detector response resulted slightly decreasing with increasing energy: a variation of about 2% was found from ^{60}Co quality to a TPR_{20,10} of 0.74 (10 MV photon beam). The calculations also showed that the detector response is independent of field size, within the MC statistical uncertainty, from 10 cm x 10 cm to 2 cm x 2 cm but quickly increases for smaller field size.

To validate the Monte Carlo calculations D_w measurements by diamond detectors in accelerator beams were compared with D_w measurements by a PTW 30013 reference ionization chamber. Four samples of diamond detectors and the ionization chamber were calibrated against the ENEA-INMRI D_w primary standard in the ^{60}Co reference gamma beam, and used for performing D_w measurements in 6 MV and 10 MV photon beams produced by a Varian DHX clinical accelerator. The D_w values obtained by diamond detectors using the calculated k_Q factors resulted in agreement (within 0.7 %) with those obtained by the reference ionization chamber using the k_Q factor from the IAEA TRS 398 protocol. A further validation of the Monte Carlo calculations was obtained by the experimental determination of k_Q factors for the diamond detectors at PTB. Two diamond detectors were calibrated against the PTB absorbed dose to water standard in the reference ^{60}Co gamma beam and in 6 MV and 10 MV photon beams with field size 10 cm x 10 cm and 3 cm x 3 cm. The experimental and calculated k_Q factors were in agreement within the statistical uncertainties. The above results show the feasibility of the use of the diamond detector for traceable absorbed dose to water measurements in photon beams.

6.2 Monte Carlo calculations of $s_{w,\text{air}}$ ratios in radiotherapy photon beams as a function of field size

Photon beams produced by a Clinac DHX Varian accelerator were simulated using the BEAMnrc Monte Carlo Code. The shape, dimension and materials of the various accelerator components were simulated according to the information provided by the manufacturer. A tuning of the incident electron beam characteristics was needed to obtain a good agreement between calculated and experimental depth dose curves and dose profiles. Phase space files were obtained for the 6 MV and 10 MV photon beams and square fields, defined by the accelerator jaws, with side 10 cm, 5 cm, 3 cm, 2 cm, 1 cm. The space files were then utilized as beam source in the EGSnrc/SPRZnrc code for calculating the water–air stopping power ratios for the various field sizes. The $s_{w,\text{air}}$ ratios were determined on the beam central axis at the depth of maximum dose and at the reference depth of 10

cm. The results show only a slight decrease of $s_{w,air}$ ratio with field size. A maximum variation of -0.4% was found between the $s_{w,air}$ values calculated for the reference field size (10 cm x 10 cm) and the smallest field (1cm x 1 cm)..

7. IMPLEMENTATION OF THE QUALITY SYSTEM

The ENEA-INMRI QMS is self declared. We have agreed with the EURAMET TC-Q committee to submit the ENEA-INMRI QMS for peer review by the end of the year.

8. PARTICIPATION IN METROLOGY AND STANDARDISATION ORGANISATIONS

The ENEA-INMRI staff is currently involved in activities in metrological and standardisation organisations, including EURAMET, ICRM, BIPM/CCRI, IEC/TC45, ISO/TC85/SC2.

ANNEX A.1

2009-2011 ENEA-INMRI activity report: articles published in journals or meeting proceedings in the field of photon and charged particle dosimetry

- 1 S. Baccaro, C. Caporali, A.S. Guerra, R.F. Laitano, A. Pasquali, M. Pimpinella: *“Il campione di riferimento dell’INMRI-ENEA per la dosimetria ad alte dosi in applicazioni industriali”*; - Proceedings of the 6th Conference “Metrologia & Qualità”, Turin, Italy, 7-9 April 2009
- 2 M. Pimpinella, A.S. Guerra; R.F. Laitano, G. Conte, *“La riferibilità ai campioni primari nella dosimetria in radioterapia con fasci di radiazione a intensità modulata (IMRT)”*, - Proceedings of the 6th Conference “Metrologia & Qualità”, Turin, Italy, 7-9 April 2009
- 3 M. Bovi, R.F. Laitano, M. Pimpinella, M.P. Toni, K. Casarin, G. Tromba, A. Vascotto: *“Misure assolute di kerma in aria del fascio di luce di sincrotrone prodotto presso l’impianto Elettra di Trieste per applicazioni nella diagnostica medica ad alta risoluzione”*, - Proceedings of the 6th Conference “Metrologia & Qualità”, Turin, Italy, 7-9 April 2009
- 4 M. Bovi, A.S. Guerra, R.F. Laitano, M. Pimpinella, M.P. Toni: *“La riferibilità nelle misure di dose assorbita dal paziente nei trattamenti di brachiterapia”*, - Proceedings of the 6th Conference “Metrologia & Qualità”, Turin, Italy, 7-9 April 2009
- 5 M. Bovi, F. Campanella: *“Specifiche dei “Rapporti di prova” richiesti ai fini autorizzativi per l’impiego delle radiazioni ionizzanti nei luoghi di lavoro”*, - 6th Conference “Metrologia & Qualità”, Turin, Italy, 7-9 April 2009
- 6 R.F. Laitano, M. Pimpinella, M.P. Toni: *“Report to the CCRI Section I on the activity carried out at ENEA-INMRI on photon and charged particle dosimetry in the period 2007-2009”*, Report CCRI(I)/07-29-CCRI(I), BIPM, Sèvres, 18th meeting 14-16 May 2009
- 7 A.S. Guerra, R.F. Laitano, M. Pimpinella, M.P. Toni, *“Development of LDR and HDR brachytherapy absorbed dose standards at ENEA-INMRI”*, BIPM Workshop on Brachytherapy Metrology, Paris, 12 May 2009
- 8 N. Dell’Arena, *“Campionamento nella ISO/IEC 17025 Parte II. Documentazione per il campionamento”*, Tutto Misure Anno XI n° 1 pagg. 77-79, 2009
- 9 H.-M. Kramer, J.-M. Bordy, E. van Dijk, J. Dobrovodsky, S. Duane, G. Durando, R.-P. Kapsch, B. Karaböce, Ch. Koch, A. Kosunen, M. Pimpinella, A. Shaw, *“Metrology in external beam cancer therapy”*, 14th International Congress of Metrology, Paris, 22-25 June 2009
- 10 M.P. Toni et al, *“The project -Increasing cancer treatment efficacy using 3D brachytherapy- in the framework of the action iMERA-Plus of the European Metrology Research programme”* 2009 14th International Congress of Metrology, Paris, France, 22-25 June 2009
- 11 M.P. Toni, I. Aubineau-Lanièce, M. Bovi, J.M. Bordy, J. Cardoso, B. Chauvenet, , F. Gabris, J. E. Grindborg, A. S. Guerra, A. Kosunen, C. Oliveira, M. Pimpinella, T. Sander, H.J. Selbach, V. Sochor, J. Solc, J. de Pooter, E. van Dijk, *“Traceability to absorbed-dose-to-water primary standards in dosimetry of*

brachytherapy sources used for radiotherapeutic treatments”, XIX IMEKO World Congress, Lisbon, Portugal 6-11 September 2009

12 Caporali, C., Conte, G., Guerra, A. S.; Laitano, R. F.; Pimpinella, M.: “*Study of a CVD diamond detector for absorbed dose measurement in photon beams with small field sizes*” World Congress of Medical Physics and Biomedical Engineering, Munich, Germany, 7-12 September 2009 - IFMBE Proceedings Vol 25/1 1016 - ISBN 978-3-642-03897-6

13 M.P. Toni, I. Aubineau-Lanière, M. Bovi, J. Cardoso, D. Cutarella, F. Gabris, J. E. Grindborg, A. S. Guerra, H. Jarvinen, C. Oliveira, M. Pimpinella, J. Plagnard, T. Sander, H.J. Selbach, V. Sochor, J. Solc, J. de Pooter, E. van Dijk, “*A Joint Research Project to improve the accuracy in dosimetry of brachytherapy treatments, in the framework of the European Metrology Research Programme*”, World Congress on Medical Physics and biomedical Engineering, Munich, Germany, 7-12 September 2009 - IFMBE Proceedings 25/1 pag. 421 - ISBN 978-3-642-03897-6

14 M. Bovi, C. Caporali, A.S. Guerra, R.F. Laitano, M. Pimpinella, M.P. Toni, I. Astefanoaei, “*Dosimetria in brachiterapia basata su campioni di dose assorbita in acqua: prospettive di sviluppo a livello europeo*”, Proceedings of VI National Congress of the Italian Association of Medical Physics (AIFM), Reggio Emilia, Italy, 16-19 September 2009

15 Caporali, C., Conte, G., Guerra, A. S., Laitano, R. F., Pimpinella, M.: “*Sviluppo di un rivelatore a diamante sintetico per dosimetria di riferimento in fasci di fotoni per radioterapia con campi di piccola dimensione*”, Proceedings of VI National Congress of the Italian Association of Medical Physics (AIFM), Reggio Emilia, Italy, 16-19 September 2009

16 Guerra, A.S., Pimpinella, M, Toni, M.P.: “*Dosimetria di riferimento in brachiterapia*”, Tutto Misure N°1, 2010

17 Radu,D., A S Guerra, A.S., Ionita, C., Astefanoaei, I.:“*Heat loss through the connecting thermistor wires in a 3-body graphite calorimeter*”, Metrologia 47 (2010) 179-191

18 Spadaro, S., Conte, G., Trucchi, D. M., Pimpinella, M., Guerra, A.S., Laitano, R.F. : “*Dynamic response of diamond sensors to ionizing radiation*”, Poster at E-MRS Spring meeting, Strasbourg, France, 7-11 Jun 2010

19 C Kessler, P J Allisy-Roberts, D T Burns, A S Guerra, R F Laitano and M Pimpinella -*Comparison of the standards for absorbed dose to water of the ENEA-INMRI (Italy) and the BIPM for 60Co γ rays*-Metrologia, 47 (2010), Tech. Suppl., 06002 doi: 10.1088/0026-1394/47/1A/06002

20 Pimpinella,M., De Coste, V., Conte, G., Guerra, A.S., Mangiacotti, F.P., Petrucci, A.: “*Performance of a CVD diamond detector for dosimetry radiotherapy photon beams*” Book of Extended Synopses of International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry – IAEA- CN-182, Vienna, Austria 8-12 November 2010

21 Pimpinella, M., Guerra, A.S., De Coste, V., Petrucci, A., Consorti, R.: “*Caratterizzazione di due tipi di micro-camere per misure di dose assorbita in radioterapia*”, Proceedings of the VII Congress “Metrologia & Qualità”, Turin, Italy, 13-15 April 2011

- 22 Burns D T, Allisy-Roberts P J, Desrosiers M F, Sharpe P H G, Pimpinella M, Lourenço V, Zhang Y L, Miller A, Generalova V, Sochor V, 2011, *Supplementary comparison CCRI(I)-S2 of standards for absorbed dose to water in ^{60}Co gamma radiation at radiation processing dose levels*, Metrologia 48 (2011) Tech. Suppl. 06009 doi:10.1088/0026-1394/48/1A/06009
- 23 Spadaro, S., Conte, G., Trucchi, D. M., Pimpinella, M., Guerra, A.S., Laitano, R.F. : “*Dynamic response of diamond sensors to ionizing radiation*”, Sensors and Actuators A: Physical, in press, doi:10.1016/j.sna.2010.12.017
- 24 Kessler C., Allisy-Roberts P. J., Burns D. T., Guerra A. S., Laitano R. F., and Pimpinella M., “*Comparison of the standards for absorbed dose to water of the ENEA-INMRI (Italy) and the BIPM for ^{60}Co gamma rays*”, Metrologia 47 (2010) doi:10.1088/0026-1394/47/1A/06002
- 25 Toni, MP: “*New brachytherapy standards paradigm shift*” Book of Extended Synopses of International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry – IAEA- CN-182, Vienna, Austria 8-12 Nov 2010

ANNEX A.2**ENEA-INMRI STAFF INVOLVED IN THE ACTIVITY ON PHOTON AND CHARGED PARTICLE
DOSIMETRY STANDARDS**

Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti

ENEA, C. R. Casaccia

c.p. 2400, 00100 AD Roma (Italy)

Fax: ++39 06 3048 3558

Phone: ++39 06 3048 (EXTENSION)

E-mail: username@enea.it

STAFF	E-mail username	Phone extension
Head (Institute director)		
Dr P. De Felice	pierino.defelice	4580
Section co-ordinator		
Dr M. P. Toni	mariapia.toni	3957
Scientists		
Dr M. Bovi	maurizio.bovi	4524
Dr C. Caporali	claudio.caporali	6240
Dr. M D'Arienzo (since May 2010)	marco.darienzo	4118
Dr A. S. Guerra	antonio.guerra	3552
Dr S. Loreti (20%)	stefano.loreti	4950
Dr M. Pimpinella	maria.pimpinella	6680
Dr M. Pinto (sice May 2010)	massimo.pinto	4662
Technicians		
Mr GL Cappadozzi	gianluca.cappadozzi	4563
Mrs V. De Coste	vanessa.decoste	3831
Mr M. Quini (80%) ⁺	maurizio.quini	4563
Mrs C. Silvestri	claudia.silvestri	3354

Temporary staff		
n.1 Postgraduate fellow		
n.1 Ph.D Student		

Personnel for administrative services and technical assistance for maintenance and repair are supplied by the CR Casaccia central service and are not included in the ENEA-INMRI staff.