REPORT TO THE CCRI SECTION I ON THE ACTIVITY CARRIED OUT AT ENEA-INMRI ON PHOTON AND CHARGED PARTICLE DOSIMETRY IN THE PERIOD 2003 – 2005

R. F. Laitano, M. Pimpinella, M. P. Toni
Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti
ENEA, C. R. Casaccia
c.p. 2400, 00100 AD Roma (Italy)

1. INTRODUCTION

The present report is a short summary of the 2003-2005 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 1.

Table 1. National standards maintained at ENEA-INMRI in the field of photon and electron dosimetry

Quantity	Standard	Radiation Quality	Measurement Range
Exposure and Air-Kerma	-Free-air ion chamber	10-50 kV X-ray	(1 10^{-6} - 7 10^{-3}) Gy s^{-1}
	-Free-air ion chamber	60-300 kV X-ray	(7 10^{-7} - 3 10^{-4}) Gy s^{-1}
	-Cavity ion chamber	^{60}Co gamma-ray	(2 10^{-4} - 7 10^{-3}) Gy s^{-1}
Absorbed Dose to graphite, water and tissue equivalent materials	-Graphite calorimeter	^{60}Co gamma-ray	(2 10^{-3} - 2 10^{-2}) Gy s^{-1}
	-Water calorimeter (under test)	" " "	
	-Extrapolation ion chamber	^{204}Tl, ^{147}Pm, ^{85}Kr and ^{90}Sr/^{90}Y beta sources	(3 10^{-7} - 5 10^{-4}) Gy s^{-1}

2. STANDARDS DEVELOPMENT AND COMPARISONS

2.1. Air- kerma standards

The air-kerma standards at ENEA-INMRI are:
- two free-air chambers for low and medium energy x rays, respectively;
- six cavity ionization chambers (different size, graphite wall) for Co-60 gamma rays;
- a 30 cm^3 ionization chamber (plastic wall) for Cs-137 gamma rays.

2.1.a <u>Low and medium-energy x-ray standards</u>

A re-determination of some important correction factors relevant to both the free-air chambers has been made. These factors regard the corrections for the effects due to scattered photons, k_{sc}, re-absorbtion of fluorescence photons, k_{fl}, and electron loss in the chamber electrodes, k_e. The factors were determined by the Monte Carlo code PENELOPE at the energies in the whole range of interest for measurement by the low and medium-energy free-air chambers. The calculation was made for monoenergetic photons and then extended to the x-ray spectra relevant to the CCRI(I) qualities usually adopted for air-kerma key comparisons. More recently the calculation of the these correction factors has been made also for the NS and HR series of the ISO reference x-ray spectra. The calculation procedure is described in the report presented at the present CCRI(I) meeting. In Tables 2 and 3 the values for the new factors relevant to the CCRI(I) qualities are shown together with the ratio between new and old values.

Table 2. New correction factors (CCRI(I) qualities) for the ENEA-INMRI low-energy free-air chamber calculated by the Monte Carlo code PENELOPE

Radiation Quality	10 kV	30 kV	25 kV	50 kV(b)	50 kV(a)
1st HVL (mm Al)	0.03	0.18	0.25	1.04	2.27-
k_e	1.0000	1.0000	1.0000	1.0000	1.0001
k_{sc}	0.9972	0.9978	0.9980	0.9984	0.9986
k_{fl}	0.9962	0.9972	0.9975	0.9983	0.9988
New/old	0.9992	1.0001	1.0008	1.0001	1.0004

Table 3. New correction factors (CCRI(I) qualities)for the ENEA-INMRI medium-energy free-air chamber calculated by the Monte Carlo code PENELOPE

Radiation Quality	100 kV	135 kV	180 kV	250 kV
1st HVL	4.00 mm Al	0.499 mm Cu	1.001 mm Cu	2.497mm Cu
k_e	1.0000	1.0003	1.0015	1.0036
k_{sc}	0.9941	0.9950	0.9956	0.9967
k_{fl}	0.9985	0.9994	0.9997	0.9999
New/old	0.9996	0.9997	1.0007	1.0012

The correction factors reported in Table 2 and 3 are currently adopted at ENEA-INMRI.
Recently a new vacuum tube mounted between the chamber and the x-ray machine has been built for measurements with the low-energy free-air chamber. It is expected that more accurate and reproducible determination of the air attenuation coefficient will be made by this system.

2.1.b Air-kerma standard for Co-60 gamma-ray beam:

2.1.b.1 The cavity ionization chamber standard: the K_{wall} factor dependence on the spectrum shape of the Co-60 beam

The ENEA-INMRI air kerma standard for Co-60 gamma radiation is presently based on a primary standard chamber with five additional standard chambers of different geometry. The five standard chambers are used to improve the confidence on the value for both the volume and the K_{wall} factor of the primary standard chamber. To this end the air-kerma measurement results obtained by these chambers are compared with each other and their consistency is analysed. *(see relevant X Y Z, CCRI Workshop and BIPM reports*).

The effect of attenuation and scatter in the graphite walls of the ENEA-INMRI chambers was formerly determined by a Monte Carlo calculation [9, 10]. In that calculation the photon energy spectrum considered (Rogers et al 1988) was rather similar to that relevant to the old 36 TBq Co-60 beam formerly operating at the ENEA-INMRI. This old Co-60 source was recently replaced by a new 208 TBq source of different size. Thus a different photon spectrum was expected because of the different amount of scattered radiation in the new source. A new k_{wall} determination was then made by using the ^{60}Co photon spectrum obtained by a Monte Carlo simulation of the new ENEA 208 TBq beam. In this occasion a study on the dependence of k_{wall} on the spectrum shape was also made. To this end a number of Co-60 spectra were considered: four of them with a scatter component ranging from 14% to 21 % and one without scatter (a monoenergetic beam). In this energy range the largest variation of the k_{wall} value was about 1.7 x 10^{-3}, according to the chamber. In figure 1 the energy distribution of the four photon spectra with different scatter components are shown. In figure 2 the dependence of k_{wall} on photon energy distribution is shown for 4 of the six ENEA standard cavity chambers. The energy spectra are those referred to in figure 1 with an additional spectrum with no scatter component (monoenergetic). The spectrum ENEA-INMRI, a (14 %) is that referring to the new Co-60 gamma beam presently operating at ENEA. The characteristics of the 4 chambers considered in figure 2 are reported in Table 4.

The new k_{wall} value of 1.0212 (s = 1 x 10^{-4}), adopted for the ENEA-INMRI primary standard, differs by 8 x 10^{-4} from the previously calculated value of 1.0220 (s = 1 x 10^{-4}). The two determinations are different because of some differences in ^{60}Co photon spectra and in the values of the chamber dimensions. In the previous MC simulation these dimensions were rounded to millimeters, whereas in the present one the actual values approximated to 0.01 mm have been used.

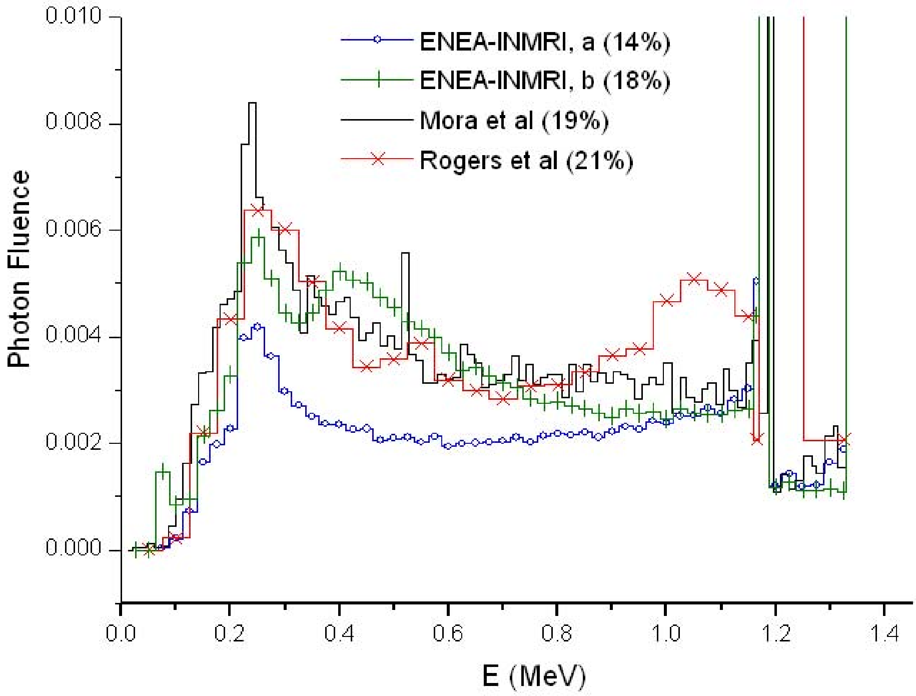

Figure 1 The four energy spectra (photoelectric peaks not completely shown) from different Co-60 gamma beams considered for the investigation of the k_{wall} dependence on photon energy distribution. These spectra are characterized by a different fraction of scattered radiation (percentages in parentheses).

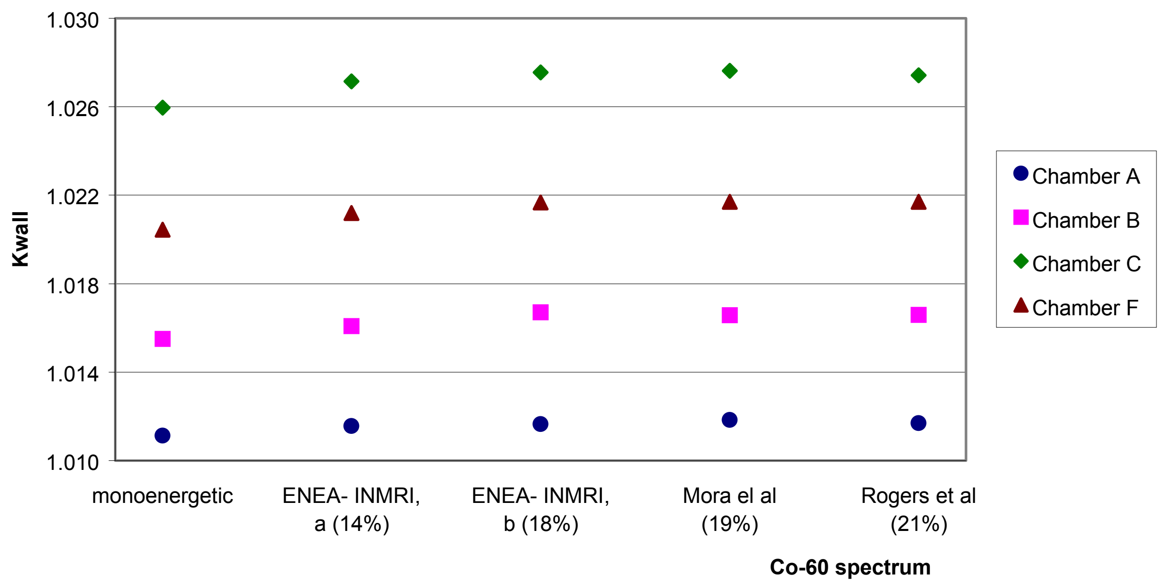

Figure 2. The k_{wall} dependence on photon energy distribution for 4 of the six ENEA standard cavity chambers. The 4 chambers are those specified in Table 4. The energy spectra are those referred to in figure 1 with an additional spectrum with no scatter component (monoenergetic). The factors presently adopted for the ENEA-INMRI standard chambers are those referring to spectrum ENEA-INMRI, a (14%).

Table 4. Characteristics of the four ENEA standard cavity chambers the k_{wall} of which is reported in figure 2.

	A	B	C	F
Chamber dimensions				
Inner diameter (mm)	7.98	10.87	16.01	11.00
Inner length (mm)	15.98	10.86	7.97	11.03
Lateral wall thickness (mm)	3.0	3.0	3.0	4.0
Upper base thickness (mm)	2.97	2.99	3.00	3.97
Lower base thickness (mm)	4.00	4.00	3.99	4.00
Central electrode diameter (mm)	1.96	1.99	1.99	2.00
Central electrode length (mm)	14.98	10.07	7.01	10.13
Air cavity volume (cm^3)	0.77206 (93)	0.9881 (12)	1.5983 (19)	1.0287 (12)

2.1.c Air-kerma standard for Cs-137 gamma rays

The air-kerma standard for the Cs-137 gamma rays (a 30 cm^3 ionization chamber) is derived from the medium-energy x-ray and Co-60 air-kerma standards. Recently the calibration factors regarding the Cs-137 gamma-ray quality have been slightly updated, due to the latest air kerma determinations with the Co-60 standard cavity chamber for which the volume and the k_{wall} correction factor have been more accurately assessed (see above).

2.2 Absorbed dose standards

2.2.a The absorbed-dose-to-water standard based on graphite calorimetry

The standard of absorbed dose to water is currently based on the graphite calorimeter for Co-60 gamma rays. Up until now reproducibility tests on this standard have been made assessing a long term stability better than 0.1% in a period of about five years.

2.2.b The absorbed-dose to tissue standard for beta radiation

The standard of absorbed dose to tissue due to beta radiation is based on an extrapolation ionization chamber. Most work carried out recently on this standard was addressed to improve the reproducibility of the aligning system. A particular effort has been made to design a mechanical device allowing to position the dosimeter under calibration at different angles. The measurements at ENEA-INMRI for an international comparison with this standard were recently completed (see below). The elaboration of results is ongoing.

2.2.c The water calorimeter

The "sealed water" type calorimeter built many years ago at ENEA-INMRI for measurement in horizontal photon and charged particle beams, did not have significative improvements in the period 2003-2005. This was due mainly to the problems met in repairing the ENEA-INMRI 20 MeV Microtron whose beam characteristics (spatial uniformity and stability) are no longer adequate to perform measurements with a reproducibility better than 1%. At present any progress in this respect depends on future budget and staff. Some additional work has been made however in developing a new software to improve the periodical calibration procedure of the temperature probes mounted in the calorimeter.

2.3. 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”
(measurements completed at ENEA-INMRI in November 2004)

2- EUROMET P 739, KCDB Id: Supplementary comparison EUROMET.RI(I)-S2 "Intercomparison of the personal dose equivalent for beta radiation"
(measurements completed at ENEA-INMRI in March 2005)

3- EUROMET P 738, KCDB Id: Supplementary comparison EUROMET.RI(I)- S5 "Intercomparison of the personal dose equivalent for photon radiation“_(measurements to be carried out at ENEA-INMRI in September 2005)

4- EUROMET P 545, KCDB Id: Supplementary comparison EUROMET.RI(I)- S3 "Intercomparison of NMI air kerma standards for ISO 4037 narrow spectrum series radiation qualities"
(measurements to be carried out at ENEA-INMRI in December 2005)

5- EUROMET P 628 "Direct comparison of primary standards of air kerma for medium energy (300 kV) X-rays“
(measurements to be carried out at ENEA-INMRI in January 2006)

6- EUROMET 813 “Measurement of air-kerma and absorbed dose to water due to Co-60 gamma radiation”
(measurements to be carried out at ENEA-INMRI in May 2007).

3. CALIBRATION ACTIVITY

Calibrations of most protection-level dosimeters are traceable to the air kerma standards for low/medium x rays and Co-60 gamma rays. The photon radiation qualities used for calibrations are shown in Table A.1. Calibrations of therapy-level, and industrial-level dosimeters are traceable to the absorbed-dose-to-water (D_w) standard presently operating only at the Co-60 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.

3.1 Therapy-level calibration service

a) The therapy-level dosimeters used in the italian radiotherapy centres are calibrated in terms of air-kerma and/or absorbed dose to water. In the last two-three recent years most calibrations of ionization chambers are made in terms of absorbed dose to water.

b) The service for direct calibration of the customer clinical beam 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 dosimeters (with their holder) is mailed to the customer for irradiation in water phantom. The absorption and scatter effects in the ampoule wall have been recently re-determined by Monte Carlo calculation to correct for these effects even in electron beams down to 3 MeV energy. This calibration service is particularly requested for intra-operative radiotherapy (IORT) accelerators in which ion recombination corrections cause problems for ionization chambers because of the high dose per pulse (above 10 mGy/p). The electron energy in these accelerators is generally below 10 MeV and no energy-dependence correction is applied to the dosimeter response after calibration in Co-60 beam in terms of absorbed dose to water. The combined standard uncertainty in D_w measurements in photon and electron beams by these reference dosimeters is estimated to be 1.6% including a 0.5% component due to neglecting the energy-dependence correction.

3.2 Protection-level calibration service

The dosimeters used in Italy for radiation protection purposes are currently calibrated both at the ENEA-INMRI and at the SIT calibration centres. The SIT centres are accredited secondary standards laboratories. At present there are 7 SIT centres operating in Italy and three more centres are in course of accreditation. Dosimeter calibrations at the SIT centres are traceable to the ENEA-INMRI national standards and are recognized at the international level in the framework of the EA and ILAC agreements. Protection-level dosimeter calibrations are made in terms of air-kerma and dose-equivalent quantities. The calibration qualities are those reported in Table A.1.

3.3 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 standard (Co-60) gamma cells calibrated in terms of absorbed dose to water by a set of ferrous sulphate and potassium dichromate transfer dosimetry standards.

4. DOSIMETRY IN RELATED AREAS

As in the past years part of the research activity at ENEA-INMRI was devoted to dosimetry in areas of practical interest as radiotherapy and radiation protection. The work carried out in the period 2003-2005 is summarized below.

4.1 Dosimetry in accelerator beams for IORT (intraoperative radiation therapy)

The use of particular accelerators for IORT is increasing in Italy in the last years. The electron beams of these accelerators are somewhat different from those produced by usual clinical linacs. In particular these beams are characterized by a high dose per pulse (up to about 100 mGy/pulse) that make difficult the use of ionization chambers because of not well understood charge recombination effects. Moreover the use of long plastic applicators give rise to a strong scattered component in the electron beam.

These two aspects have been investigated with the objective of:

1- studying, by ferrous sulphate dosimetry as reference dosimeter, to what extent the traditional ion recombination models are valid for ionization chamber dosimetry in these beams;
2- determining, by BEAMnrc and EGSnrc codes, the spectral distribution of the actual beams to compare calculated stopping power ratios with those reported in the dosimetry protocols as a function of the experimental R_{50} and referred to realistic beams of normal clinical linacs.

Both the research subjects are currently under investigation. Preliminary results indicate that:

1- The two-voltage analysis to correct for ion recombination does not give consistent results in the high-dose-per-pulse beams considered;
2- The calculated water air stopping power ratios differ in some experimental conditions by up to 1% from those obtained by the usual procedures of the current protocols.

4.2 Dosimetry in synchrotron light beams

A free air chamber has been built for air kerma measurement in the synchrotron light beam produced by the Synchrotron ELETTRA in Trieste (Italy). This beam is to be used for mammography and an accurate dosimetric characterization was requested to this end to ENEA-INMRI. The measurements so far made did not yet allow to draw significative conclusions because of some spatial instabilities of the beam. Further measurements and analysis are thus postponed to June 2005, as at that time the machine staff in Trieste will be able to fix these problems.

TABLE A.1

REFERENCE RADIATIONS FOR CALIBRATION IN TERMS OF AIR-KERMA AT THE ENEA-INMRI

Code(1)	H.V. (2) (kV)	Filtration (3) (mm)	E_m (4) (keV)	HVL (mm) (5) Al	Cu	Air kerma rate (6) ($Gy\ s^{-1}$)	u% (7)
L1	60	4.0 Al + 0.28 Cu	44.5	*4.7*	0.18	$5.4\ 10^{-5}$	0.5
L2	80	4.0 Al + 0.46 Cu	56.3	*7.2*	0.35	$1.0\ 10^{-4}$	0.5
L3	110	4.0 Al + 2.04 Cu	78.5	*14.1*	0.96	$6.4\ 10^{-5}$	0.5
L4	150	4.0 Al + 1.0 Sn	104.0	-	1.85	$1.5\ 10^{-4}$	0.5
L5	200	4.0 Al + 2.0 Sn	136.4	-	3.07	$2.7\ 10^{-4}$	0.5
L6	250	4.0 Al + 4.0 Sn	171.7	-	4.18	$3.4\ 10^{-4}$	0.5
L7	300	4.0 Al + 6.5 Sn	199.0	-	5.10	$4.2\ 10^{-4}$	0.5
S1	10	0.30 Al	8.4	0.05	*.002*	$6.8\ 10^{-7}$	1.0
S2	15	0.91 Al	12.4	0.15	*.004*	$2.2\ 10^{-6}$	1.0
S3	20	1.90 Al	16.6	0.35	*.009*	$3.5\ 10^{-6}$	1.0
S4	25	2.0 AL	20.0	0.66	*.017*	$3.5\ 10^{-6}$	1.0
S5	30	5.50 Al	25.3	1.2	*.032*	$5.3\ 10^{-6}$	1.0
S6	40	4.0 Al + 0.21 Cu	3.,5	*2.7*	0.09	$5.0\ 10^{-6}$	0.8
S7	60	4.0 Al + 0.6 Cu	48.0	*5.5*	0.24	$1.6\ 10^{-5}$	0.8
S8	80	4.0 Al + 2.1 Cu	65.4	*10.9*	0.59	$8.2\ 10^{-6}$	0.8
S9	100	4.0 Al + 5.0 Cu	82.7	-	1.16	$4.6\ 10^{-6}$	0.8
S10	120	4.0 Al + 5.0 Cu + 1.0 Sn	99.0	-	1.73	$5.0\ 10^{-6}$	0.8
S11	150	4.0 Al + 2.5 Sn	116.6	-	2.46	$3.5\ 10^{-5}$	0.8
S12	200	4.0 Al + 2.0 Cu + 3.0 Sn + 1.0 Pb	161.2	-	3.90	$1.4\ 10^{-5}$	0.8
S13	250	4.0 Al + 2.0 Sn + 3.0 Pb	202.5	-	5.20	$1.5\ 10^{-5}$	0.8
S14	300	4 Al + 3.0 Sn + 5.0 Pb	249.6	-	6.20	$1.5\ 10^{-5}$	0.8
A1	10	-	7.4	0.03	*.001*	$2.0\ 10^{-4}$	0.5
A2	20	0.15 Al	12.4	0.11	*.003*	$7.5\ 10^{-4}$	0.5
A3	30	0.52 Al	18.9	0.35	*.009*	$5.5\ 10^{-4}$	0.5
A4	60	3.2 Al	36.4	*2.4*	0.08	$4.0\ 10^{-4}$	0.5
A5	100	3.9 Al + 0.2 Cu	57.3	*6.9*	0.30	$5.1\ 10^{-4}$	0.5
A6	200	4.0 Al + 1.2 Cu	102.4	-	1.70	$1.1\ 10^{-3}$	0.5
A7	250	4.0 Al + 1.6 Cu	124.7	-	2.47	$1.8\ 10^{-3}$	0.5
A8	300	4.0 Al + 2.5 Cu	152.4	-	3.40	$2.1\ 10^{-3}$	0.5
B1	10	0.3 Al	8.5	0.06	*.002*	$1.0\ 10^{-6}$	1
B2	20	2.0 Al	17	0.42	*.010*	$1.0\ 10^{-6}$	1
B3	30	0.18 Cu + 4.0 Al	26	1.46	*.040*	$1.0\ 10^{-6}$	1
B4	35	4.O Al + 0.25 Cu	30.0	2.38	*.070*	$1.0\ 10^{-6}$	0.8
B5	55	4.0 Al + 1.2 Cu	47.9	*5.77*	0.25	$1.5\ 10^{-6}$	0.8
B6	70	4.0 Al + 2.5 Cu	61.1	*9.12*	0.48	$1.3\ 10^{-6}$	0.8
B7	100	4.0 Al + 0.5 Cu + 2 Sn	87.0	-	1.28	$1.4\ 10^{-6}$	0.8
B8	125	4.0 Al + 1.0 Cu + 4 Sn	109.2	-	2.14	$1.3\ 10^{-6}$	0.8
B9	170	4.0 Al + 1.0 Cu + 3 Sn + 1.5 Pb	149.4	-	3.67	$1.1\ 10^{-6}$	0.8
B10	210	4.0 Al + 0.5 Cu + 2 Sn + 3.5 Pb	184.6	-	4.91	$1.3\ 10^{-6}$	0.8
B11	240	4.0 Al + 0.5 Cu + 2 Sn + 5.5 Pb	212.4	-	5.89	$7.8\ 10^{-7}$	0.8

(§)

Table A.1 (continued)

Code (1)	H.V. (2) (kV)	Filtration (3) (mm)	E_m (4) (keV)	HVL (mm) (5) Al	Cu	Air kerma rate (6) (Gy s^{-1})	u% (7)
RQR2	40	3 Be+2.5 Al	27.8	1.41	*.039*	3.2 10^{-4}	0.5
RQR3	50	3 Be+2.5 Al	31.9	1.76	*.050*	3.2 10^{-4}	0.5
RQR4	60	3 Be+2.5 Al	35.6	2.09	*.062*	5.3 10^{-4}	0.5
RQR5	70	3 Be+2.5 Al	39.0	2.35	*.069*	5.3 10^{-4}	0.5
RQR6	80	3 Be+2.5 Al	42.5	2.66	*.084*	1.1 10^{-3}	0.5
RQR7	90	3 Be+2.5 Al	45.8	2.99	*.100*	1.1 10^{-3}	0.5
RQR8	100	3 Be+2.5 Al	48.9	3.30	*.110*	1.7 10^{-3}	0.5
RQR9	120	3 Be+2.5 Al	54.5	3.92	*.147*	1.7 10^{-3}	0.5
RQR10	150	3 Be+2.5 Al	61.6	4.88	*.195*	2.5 10^{-3}	0.5
RQA3	50	2.5 Al + 10 Al	37.4	3.78	*.142*	2.1 10^{-5}	0.5
RQA4	60	2.5 Al + 16 Al	-	5.26	-	2.0 10^{-5}	0.5
RQA5	70	2.5 Al + 21 Al	50.7	6.85	*.315*	2.2 10^{-5}	0.5
RQA6	80	2.5 Al + 26 Al	-	8.04	-	3.3 10^{-5}	0.5
RQA7	90	2.5 Al + 30 Al	62.1	9.39	*.494*	3.3 10^{-5}	0.5
RQA8	100	2.5 Al + 34 Al	-	10.06	-	5.6 10^{-5}	0.5
RQA9	120	2.5 Al + 40 Al	75.6	11.92	*.719*	5.6 10^{-5}	0.5
RQA10	150	2.5 Al + 45 Al	87.3	13.58	*.819*	4.8 10^{-5}	0.5
MO1	23	0,060 Mo	-	0.33	-	4 10^{-4}	0.5
MO2	28	0,060 Mo		0.36	-	4 10^{-4}	0.5
MO3	35	0,060 Mo	-	0.39	-	4 10^{-4}	0.5
MO4	40	0,060 Mo		0.41	-	4 10^{-4}	0.5
MOA1	23	0,060 Mo + 2 mm Al	-	0.56	-	1 10^{-5}	0.5
MOA2	28	0,060 Mo + 2 mm Al	-	0.63	-	1 10^{-5}	0.5
MOA3	35	0,060 Mo + 2 mm Al	-	0.90	-	1 10^{-5}	0.5
MOA4	40	0,060 Mo + 2 mm Al	-	1.17	-	1 10^{-5}	0.5
P1	10	-	7.4	0.03	*.001*	2.0 10^{-4}	0.5
P2	25	0.43 Al	15.7	0.25	*.006*	4.0 10^{-4}	0.5
P3	30	0.26 Al	15.4	0.18	*.005*	1.5 10^{-3}	0.5
P4	50	1.07 Al	27.4	1.04	*.027*	7.5 10^{-4}	0.5
P5	50	4.72 Al	33.1	2.27	*.067*	1.2 10^{-4}	0.5
P6	100	3 Be + 3.48Al	50.9	4.00	0.15	9.7 10^{-4}	0.5
P7	135	3Be + 4.08Al + 0.18Cu	68.9	8.70	0.50	8.5 10^{-4}	0.5
P8	180	3Be + 4.06Al + 0.51Cu	86.0	*15.0*	1.00	1.3 10^{-3}	0.5
P9	250	3Be + 4.02Al + 1.72Cu	126.1	-	2.50	1.7 10^{-3}	0.5
Am-241		gamma radiation	59	from 1.2 10^{-8} to 7.55 10^{-8}			0.7
Cs-137		gamma radiation	662	from 2.4 10^{-10} to 2.4 10^{-7}			0.7
Co-60		gamma radiation	1253	from 2.4 10^{-9} to 5.7 10^{-3}			0.5

Photon and electron beams from a 4-20 MeV Microtron are available but are not yet used for calibration.

(1) The P series includes the CCRI x-ray reference qualities. The L, S, A and B series include the reference x-ray qualities recommended by ISO 4037 (i.e., wide and narrow spectrum, high and low rate). The RQR and RQA series are the x-ray reference qualities recommended by IEC 1267 for radiodiagnostics. The MO and MOA series are the x-ray reference qualities recommended by IEC 61223-3-2 for mammography.

(2) X-ray tube tension.

(3) The additional filtration is approximately 2.5 mm of Be for the x-ray qualities with H.T.≤ 50 kV and 3 mm Be + 3 mg cm^{-2} of aluminized mylar for the x-ray qualities with H.T.> 50 kV.
(4) Mean energy values calculated from the experimental energy spectrum.
(5) The Al or Cu HVL values *in italics* are not directly measured and are reported here only for comparison with the experimental Cu or Al corresponding values.
(6) Typical air kerma rates for a tube current of 10 mA and a SDD of 100 cm. The field size has a diameter of 15 cm and 10 cm for x-ray qualities generated at H.T.≤ 50 kV and at H.T.> 50 kV, respectively.
(7) Rounded value (%) of the combined standard uncertainty (as recommended in the "Guide to the Expression of Uncertainty in Measurement" ISO(1993)) on the air kerma determination at ENEA.

2003-2005 ENEA-INMRI activity report: articles published in journals or meeting proceedings in the field of photon and charged particle dosimetry

E. Busatti, A.S. Guerra, R.F. Laitano, A. Petrucci, M. Pimpinella, Confronto di misure con camera a ionizzazione e con film radiocromici per la determinazione di curve di dose percentuale profonda in fasci di elettroni ad alta dose per impulso, III Congresso Nazionale Associazione Italiana di Fisica Medica (AIFM), Agrigento, 24–28 giugno 2003

R. F. Laitano, M. Pimpinella, M. P. Toni, M. Bovi, Revisione del valore di riferimento del kerma in aria fornito dall'INMRI-ENEA per la taratura di dosimetri usati in campo medico e radioprotezionistico, III Congresso Nazionale Associazione Italiana di Fisica Medica (AIFM), Agrigento, 24 – 28 giugno 2003

D. Aragno, M. Cattaneo, C. Cavedon, ...R. F. Laitano, S. Onori, A. Petrucci, A. Piermattei, …A. Valentini, V. Viti: "Linee guida per la garanzia di qualità nella radioterapia intraoperatoria: aspetti fisici" _III Congresso Nazionale AIFM, Agrigento 24-28 giugno 2003

E.Busatti, A.S. Guerra, R.F. Laitano, A. Petrucci and M. Pimpinella: "The influence of ion recombination and polarity effects on the R_{50} values determined by ionization chambers in electron beams", Proceedings, World Congress on Medical Physics and Biomedical Engineering, Sydney, August 24-29, 2003.

R.F. Laitano, M. Pimpinella and M.P. Toni: "Re-determination of the correction factor for wall effects in Co-60 air-kerma standard ionisation chambers and related effects in clinical dosimetry", Proceedings, World Congress on Medical Physics and Biomedical Engineering, Sydney, August 24-29, 2003.

M. Bovi, M.P.Toni, "Risultati della partecipazione dei Centri SIT a confronti interlaboratorio organizzati in ambito nazionale ed internazionale per la verifica della riferibilità nella radioprotezione ambientale ed individuale", del XXXII Congresso Nazionale di Radioprotezione, Bari, 17-19 Settembre 2003.

P.J. Allisy-Roberts, D.T. Burns, R.F. Laitano, M.P. Toni and M. Bovi: "Revised comparison on the standard for air-kerma of the ENEA-INMRI and the BIPM for Co-60 gamma rays", Rapport BIPM-2003/10, Bureau International des Poids et Mesures, Sèvres, 2003

M. Bovi ,M.P. Toni, L.Florita "Nuovo campione trasportabile messo a punto dall'ENEA-INMRI per taratura "in loco" di rivelatori per dosimetria ambientale", Atti del XXXIII Congresso Nazionale di Radioprotezione, AIRP, Verona, Settembre 2003

M. Bovi e M. P. Toni, Attività dell'INMRI-ENEA, nel settore dosimetria a basse dosi, Riunione dei Centri di taratura SIT nel settore delle radiazioni ionizzanti, Roma, 4 maggio 2004.

R. F. Laitano, Recenti sviluppi nei settori della metrologia e dell'accreditamento a livello nazionale e internazionale, Riunione dei Centri di taratura SIT nel settore delle radiazioni ionizzanti, Roma, 4 maggio 2004.

A. S. Guerra, Relazione sulle attività del settore di dosimetria alte dosi, Riunione dei Centri di taratura SIT nel settore delle radiazioni ionizzanti, Roma, 4 maggio 2004.

M. Pimpinella, Simulazioni Monte Carlo nel settore dosimetria delle Radiazioni Ionizzanti Riunione dei Centri di taratura SIT nel settore delle radiazioni ionizzanti, Roma, 4 maggio 2004.

A.S. Guerra, R.F. Laitano, M. Pimpinella, E. Busatti, A. Petrucci,

"Confronto nella misura di dose assorbita in fasci di elettroni con camera a ionizzazione Wellhöfer PPC05 e con sistemi dosimetrici di riferimento", Atti del IV Congresso Nazionale AIFM, Verona 14-17 giugno 2005.

Guerra, A.S., Laitano, R.F., Pimpinella, M., Begnozzi, L., Bufacchi, A., delle Canne, S., Malatesta, T. "Effetti di ricombinazione ionica sulla determinazione degli indici di qualità per fasci di fotoni ($TPR_{20,10}$) e di elettroni (R_{50}) mediante camere a ionizzazione", Atti del IV Congresso Nazionale AIFM, Verona 14-17 giugno 2005.

M. Bovi, M.P. Toni, M. Quini, C. Silvestri, K. Pasciuti "Taratura in termini di dose assorbita in tessuto dovuta a radiazione beta di dosimetri utilizzati in radioprotezione", Atti del XXXIV Congresso Nazionale di Radioprotezione, AIRP, Catania, Settembre 2005

M. Bovi , R.F. Laitano, M. Pimpinella M. Quini, M.P. Toni, "Revisione del campione nazionale di kerma in aria dovuto a radiazione fotonica", Atti del XXXIV Congresso Nazionale di Radioprotezione, AIRP, Catania, Settembre 2005

M. Bovi, L.Ceravolo, C. Silvestri, M.P. Toni, "Taratura dei dosimetri utilizzati nei controlli di qualità in mammografia", Atti del XXXIV Congresso Nazionale di Radioprotezione, AIRP, Catania, Settembre 2005

4. 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@casaccia.enea.it

STAFF*	E-mail username	Phone extension
Scientists		
Dr. M. Bovi	bovi	4524
Dr. C. Caporali	caporali	6240
Dr. A. S. Guerra	guerra	3552
Dr. R.F. Laitano (50%)+	laitano	3559
Dr. M. Pimpinella	pimpinella	6680
Dr. M. P. Toni	toni	3957
Dr. N. Dell'Arena(+)	dellarena	3555
Technicians		
Mr. L. Ceravolo	ceravolo	3576
Mr. A. Manzotti (50%)+	manzotti	4563
Mr. M. Moscati	moscati	6028
Mr. M. Quini (80%)+	quini	4563
Mrs. C. Silvestri (40%)	silvestri	3354

(*) Some programs have been carried out in collaboration with guests (postgraduate fellowships) and students (stagers for thesis).
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-INMRIstaff.

(+) Due to the shortage of personnel some technicians share their activity (e.g., mechanical workshop) among the different sections of the Institute.
The activity of R.F. Laitano include the institute management (50%) and the scientific work on dosimetry standards (50%). The activity of N. Dell'Arena deals only with the INMRI quality system.