Report to the CCRI Section I on the activity carried out at ENEA-INMRI on photon and charged particle dosimetry in the period 1999-2001

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1. INTRODUCTION

The present report summarizes the 1999-2001 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 the following table.

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 -Free-air ion chamber -Cavity ion chamber	10-50 kV X-ray 60-300 kV X-ray ^{60}Co gamma-ray	($1\ 10^{-6}$ - $7\ 10^{-3}$) Gy s^{-1} ($7\ 10^{-7}$ - $3\ 10^{-4}$) Gy s^{-1} ($2\ 10^{-4}$ - $7\ 10^{-3}$) Gy s^{-1}
Absorbed Dose to graphite, water and tissue equivalent materials	-Graphite calorimeter -Water calorimeter (under test) -Extrapolation ion chamber	^{60}Co gamma-ray* “ “ “ ^{204}Tl, ^{147}Pm and ^{90}Sr/^{90}Y beta sources	($2\ 10^{-3}$ - $2\ 10^{-2}$) Gy s^{-1} ($3\ 10^{-7}$ - $5\ 10^{-4}$) Gy s^{-1}

* Measurements in photon and electron beams, produced by a (4-20 MeV) Microtron, are also performed.

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,
- a cavity ionization chamber (1 cm^3, graphite wall) for Co-60 gamma rays,
- a 30 cm^3 ionization chamber (plastic wall) for Cs-137 gamma ray.

2.1.a <u>Low and medium-energy x-ray standards</u>
- The energy distributions of all low and medium energy x ray qualities used for calibration have been re-determined by Ge-detector spectrometry. Detector efficiency was determined both experimentally by calibrated monoenergetic gamma sources and by Monte Carlo calculations. The old Monte Carlo code developped at ENEA-INMRI for early spectrometric measurements in the past years was replaced by the latest version of the EGS code. A new x-ray spectra catalogue is being prepared including new ISO qualities and the x-ray qualities for radiodiagnostics reported in table 1. All of the x ray qualities for which new spectrometry was performed are listed in table A.1.

- Some mechanical components of the x-ray equipments associated to the free-air ionization chambers for low and medium energy x rays have been renewed. In particular the beam filtration system and the beam shutter have been revised to improve their remote control by computer. This change now results in a better long term reproducibility of measurements.

2.1.b Air-kerma standard for Co-60 beam: revision of the procedure to determine the k_{wall} correction factor for the cavity ionization chamber

The k_{wall} factor, accounting for attenuation and scatter in the chamber wall of the cavity ionization chamber was determined up until now by a linear extrapolation of the chamber current to zero chamber wall thickness. When varying the wall thickness by adding (graphite) caps, the actual thickness crossed by a (nearly) parallel photon beam impinging on a cylindrical chamber is not equal to the radial thickness of graphite caps and chamber wall, so making it uncorrect the traditional linear extrapolation methods. This fact was pointed out since the past years by various authors and calculational results in this respect were first provided by Bielajew and Rogers. To obtain for the ENEA cylindrical chamber the k_{wall} factor by a procedure independent of the Monte Carlo calculation by Bielajew and Rogers, a different approach was followed. This approach is based on: a) an estimate of the actual thickness the primary photons travel when crossing the chamber wall, b) an experimental determination of the contributions to photon attenuation and scatter due to the different regions of the cylindrical chamber wall. Moreover a new experimental determination of the graphite attenuation coefficient in Co-60 beam was made to obtain a more accurate value of the k_{cep} factor accounting for the mean origin of electron production in the chamber wall. The experimental results on the factors referred to in b) were then compared with Monte Carlo calculations performed at ENEA-INMRI in the same geometry conditions. Calculational and experimental results are rather consistent with each other and, even if not yet definitive, appear to confirm the Bielajew and Rogers Monte Carlo results.

Table 1 - *Mean energies of the x-ray qualities for air-kerma calibrations of dosimeters used in diagnostic radiology (IEC 1267).Values determined experimentally by Ge-detector spectrometry.*

Code	E_{max} (keV)	E_{mean} (keV)	u(1σ) (%)
QR2	40	27.8	1
QR3	50	31.9	1
QR4	60	35.6	1
QR5	70	39.0	1
QR6	80	42.5	1
QR7	90	45.8	1
QR8	100	48.9	1
QR9	120	54.5	1
QR10	150	61.6	1
QA3	50	37.4	1
QA5	70	50.7	1
QA7	90	62.1	1
QA9	120	75.6	1
QA10	150	87.3	1

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

The results regarding the air-kerma standard for the Cs-137 gamma rays (30 cm^3 ionization chamber) are traceable to the Co-60 air-kerma standard. The calibration factors obtained in Cs-137 beams are now being revised according to the new air-kerma reference value consequent to the new k_{wall} correction factor for the Co-60 standard cavity chamber (see above).

2.1.d Comparison on calibration of dosimeters used in mammography

An Euromet comparison was started to compare air-kerma calibrations at different x-ray qualities typical of dosimetry in radiodiagnostics (tube voltages from 20 kV to 50 kV). The experimental conditions adopted at ENEA-INMRI are reported in table 2. This comparison is still in progress and is expected to be concluded by 2001.

Table 2 *The x-ray qualities adopted at ENEA-INMRI for calibrations of dosimeters used in mammography. The experimental conditions are: a) anode material of x-ray tube: tungsten (W), b) focus-detector distance: 50 cm and 100 cm, c) field size: 6.5 cm and 13 cm according to the distance.*

Beam code	Tube voltage (kV)	Half value layer (mm Al)	Mean energy (keV)	Range of air kerma rate (mGy/s)	Range of air kerma (mGy)
S3	20	0.35	16.6	0.002 - 0.05	0.06 - 50
S4	25	0.66	20.0	0.002 - 0.05	0.06 - 50
S5	30	1.2	25.3	0.002 - 0.05	0.06 - 50
S6	40	2.7	32.5	0.002 - 0.05	0.06 - 50
A2	20	0.35	12.4	0.02 - 0.6	0.6 - 1100
A3	30	2.4	18.9	0.02 - 0.6	0.6 - 1100
P2	25	0.25	15.7	0.02 - 0.6	0.6 - 1100
P3	30	0.18	15.4	0.02 - 6	0.6 - 1100

2.2 Absorbed dose to water standards

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

The standard of absorbed dose to water based on the graphite calorimeter for Co-60 gamma ray was not appreciably modified since the last comparison at BIPM (1994). 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 Development of the absorbed-dose-to-water standard based on water calorimetry

A “sealed water” type calorimeter was originally designed and built at ENEA-INMRI for measurement in proton beams, in the framework of a protontherapy project supported by the italian national institute of health. The proton accelerator of this project is not yet ready, then the calorimeter is used in the ENEA-INMRI Microtron (photon and electron) beams. The calorimeter is currently operated at a working temperature of 4 °C. The measurement procedure presently adopted is based on single calorimeter irradiations. This procedure requires an overall measurement time that is longer than that required when performing a sequence of irradiation runs. This procedure however has the advantage to minimize undesirable thermal effects at the reference point. In multiple irradiation runs with electron beams such effects can be not negligible as a uniform irradiation of the calorimeter ampoule is hardly obtained. An example of calorimeter output for a single irradiation in electron beams is reported in figure 1. Measurement reproducibility is at present not better than 1%, mostly because of problems regarding the accelerator beam stability. The solution of these problems is not immediate due to the related costs and this is the major reason for delay in the water calorimetry measurement program. Further heat flow calculations were made (in addition to those previously made to optimize the calorimeter ampoule size) to assess more accurately the effect of heat excess due to irradiation in the glass ampoule. It was also shown from these calculations that heat convection effects in the sealed water ampoule are negligible even if working at ambient temperature with a single irradiation runs, provided that the calorimeter ampoule is uniformly irradiated.

2.2.c CCRI(I) supplementary comparison on calibration of secondary standards in terms of absorbed dose to water in ^{60}Co beam

The measurements regarding the supplementary comparison organized by CCRI (I) on calibration of therapy level dosimeters in terms of absorbed dose to water were completed in 2000. The comparison results will be presented by BIPM. The measurements conditions at ENEA-INMRI are described in table 3.

2.3 Stopping power calculations for proton beams

Monte Carlo calculations of water stopping power for proton beams of clinical interest have been completed for different energies, and SOBP widths. Restricted stopping power ratios water to air were also calculated for comparison with the analogous calculation made by an independent method by Medin and Andreo. The two independent sets of data are in satisfactory agreement within 0.1%. The rather low energy dependence in the 100-250 MeV range is also confirmed for the restricted stopping power ratios water to air. As for the absolute stopping powers, they result to be larger for energy modulated beams than those for non-modulated beams, even if the residual range is the same for the two types of beams. This should be accounted for in dose distribution calculations and in any case in which the absolute values of stopping powers are used.

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

The therapy-level dosimeters used in the italian radiotherapy centres are currently calibrated at the ENEA-INMRI. These calibrations are made in terms of air-kerma and absorbed dose to water. It is foreseen that most calibrations in the future will be made in terms of absorbed dose to water, according to the increasing use of dosimetry protocols based on absorbed dose to water calibrations.

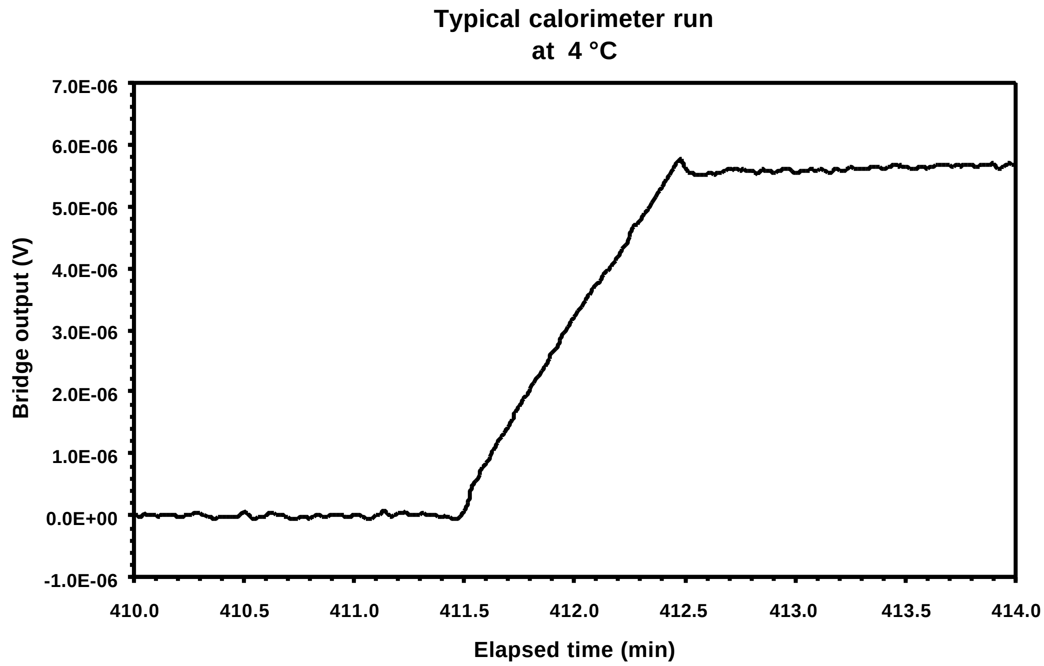

Figure 1. *Water calorimeter output after a single irradiation run in a 18 MeV electron beam. The dose rate is about 2 Gy/min, the field size is 10x10 cm^2 at the water calorimeter tank surface, the irradiation time is 60 s. Operational conditions are at 4 °C.*

An additional calibration service, in terms of absorbed dose to water, is available at the ENEA-INMRI to allow direct calibration of the customer clinical beam. A set of ferrous sulphate reference dosimeters is mailed to the customer together with a PMMA holder to be used for dosimeter irradiation in water phantom. The dosimeters consist of sealed glass ampoules having external diameter 8.8 mm, height 28 mm (volume of about 1 cm^3) and wall thickness 0.5 mm. The ampoule filling and sealing technique avoid the production of air bubbles in the cylindrical part of the ampoule. Thus the ampoules can be irradiated in vertical beams without significant perturbation of the electron fluence due to possible air bubbles. After absorbance measurements of the irradiated dosimeters, the ENEA-INMRI returns to the customer a certificate reporting for each dosimeter the mean absorbed dose to water in the customer beam in the water volume replacing the glass ampoule. The combined standard uncertainty in D_w measurements in high energy photon and electron beams by these reference dosimeters is estimated to be 1.6%. This calibration service is particularly requested mostly for those accelerators with very high dose per pulse (above 10 mGy/pulse) where ion recombination corrections may present problems for some types of ionization chambers.

3.2 Protection-level calibration service

Dosimeters used in Italy for radiation protection purposes are currently calibrated both at the ENEA-INMRI and in the SIT calibration centres. The SIT centres are accredited secondary standards laboratories. At present there are 6 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.

Table 3. *Measurement conditions at ENEA-INMRI for calibrations in terms of absorbed dose to water and air kerma.*

a) The set of three transfer chambers provided by BIPM for calibration at each NMI.

Chamber type	Serial No.	Applied voltage (V)
ND 1006	8502	+200
NE 2611A	141	-200
NE 2571	2106	-250

b) Reference conditions for absorbed dose to water calibration

Phantom dimension	30 cm x 30 cm x 30 cm
Measurement depth	5 g/cm^2
Source to chamber distance	100 cm
Field size	10 cm x 10 cm
Temperature	20 °C
Pressure	101.325 kPa
Humidity	50 %

c) Reference conditions for air-kerma free in air calibration

Source to chamber distance	100 cm
Field size	10 cm x 10 cm
Temperature	20 °C
Pressure	101.325 kPa
Humidity	50 %

In the period 2000-2001 the ENEA-INMRI organized as reference laboratory, on behalf of the European co-operation for Accreditation (EA), the EA-IR3 interlaboratory comparison on calibration of radiation protection dosimeters in terms of air kerma for the Cs-137 and Co-60 gamma radiation qualities. The participating countries are 16 with 19 laboratories. Measurements are still in progress.

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.

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
RQA5	70	2.5 Al + 21 Al	50.7	6.85	*.315*	$2.2\ 10^{-5}$	0.5
RQA7	90	2.5 Al + 30 Al	62.1	9.39	*.494*	$3.3\ 10^{-5}$	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
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 BIPM x-ray reference qualities. The L, S, A and B series include the reference x-ray qualities reccomended by ISO 4037 (i.e., wide and narrow spectrum, high and low rate). The RQR and RQA series are the x-ray reference qualities reccomended by IEC 1267 for radiodiagnostics.

(2) X-ray tube tension.

(3) The additional filtration is approxmately 2.5 mm of Be for the x-ray qualities with H.T. ≤ 50 kV and 3 mm Be + 3 mg cm^{-2} of alluminized mylar for the x-ray qualities with H.T.> 50 kV.

(4) Mean energy values calculated from the experimental energy spectrum.

(5) The Cu HVL values (*in italics*) are not directly measured and are reported here only for comparison with the experimental Al 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 reccommended in the "Guide to the Expression of Uncertainty in Measurement" ISO(1993)) on the air kerma determination at ENEA.

Activity carried out at ENEA-INMRI in the period 1999-2001: technical reports and articles published in journals or meeting proceedings in the field of interest of CCRI (I): photon and charged particle dosimetry

- R.F. Laitano:
"Specificità dei metodi dosimetrici per l'acceleratore Hitesys-NOVAC 7"
in: La intra operative radiation therapy (IORT) mediante l'utilizzo di acceleratori di elettroni in sala operatoria.
Atti del Convegno, Enea C. R. Frascati, 3 dicembre 1999.
- A.S. Guerra, P. Fattibene, E. Gargioni, R.F. Laitano, S. Onori and A. Petrocchi:
"Preliminary Measurement Results by Water Calorimetry at ENEA"
Proc. NPL Workshop on Recent Advances in Calorimetric Absorbed Dose Standards NPL Report CIRM 42, ed A J Williams and K E Rosser (Teddington,UK: NPL) pp 30-36.
- R F Laitano and M Rosetti:
"Proton stopping powers averaged over energy spectra"
Phys. Med. Biol. 45, 10 (2000).
-P. Andreo, D.T. Burns, K. Hohlfeld, M. S. Huq, T. Kanai, R.F. Laitano, V. Smyth, S. Vynckier:
"Absorbed dose determination in external beam radiotherapy: an international code of practice for radiotherapy dosimetry based on absorbed-dose-to-water standards"
IAEA TSR, (pg 1-178) IAEA Vienna, 2001.
- M. Pimpinella, A.S. Guerra and R. F. Laitano:
"Un nuovo servizio dosimetrico dell'Inmri-Enea per misure di dose assorbita in acqua in fasci di elettroni e fotoni per radioterapia"
Atti II Congresso Nazionale AIFM (Associazione Italiana di Fisica in Medicina)
Brescia, 12-16 June 2001.
- A.S. Guerra, M. Pimpinella and R. F. Laitano:
"Determinazione sperimentale del fattore di perturbazione p_{wall} per due tipi di camere a ionizzazione ad elettrodi piani paralleli"
Atti II Congresso Nazionale AIFM (Associazione Italiana di Fisica in Medicina)
Brescia, 12-16 June 2001.
-M.P. Toni:
"Problemi di riferibilità e stima dell'incertezza di misura"
Atti Giornata di Studio ANPEQ, Misure nei controlli di qualità sulle apparecchiature di radiagnostica, Milano 24 ottobre 2000.
- M.P. Toni:
"Organizzazione del Sistema nazionale di taratura" in: *Atti, Dosimetria delle radiazioni ionizzanti: aspetti metrologici e riferibilità delle misure, Politecnico di Milano, Milano 26-27 settembre 2000.*
- M. Bovi:
"Grandezze dosimetriche operative" in: *Atti, Dosimetria delle radiazioni ionizzanti: aspetti metrologici e riferibilità delle misure, Politecnico di Milano, Milano 26-27 settembre 2000.*
- T.W.M. Grimbergen and M.P. Toni:
"Calibration of dosimeters" in: Dosimetry for radiobiology, chapter 18,
Report EUR 19607 EN, 2000.
- J. Zoetelief, J.J. Broerse, R.W. Davies, M. Octave-Pregnot, J.C. Saez Vergara and M.P. Toni : "Eulep-Eurados protocol for x-ray dosimetry in radiobiology"
Report EUR 19606 EN, 2000.
- D.T. Burns, M.P. Toni and M. Bovi:
"Comparison of the air-kerma standards of the ENEA-INMRI and the BIPM in the low-energy x-ray range"
Rapport BIPM 99/11, 1999.
- D.T. Burns, M.P. Toni and M. Bovi:
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Rapport BIPM 2000/04, 2000.

4. STAFF INVOLVED AT THE ENEA-INMRI IN ACTIVITIES RELATED TO THE DOSIMETRY STANDARDS

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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. Florita (50%)+	florita	3576
Mr. A. Manzotti (50%)+	manzotti	4563
Mr. M. Moscati	moscati	6028
Mr. M. Quini (80%)+	quini	4563
Mr. G. Tricomi	tricomi	3354

(*) Some programs have been carried out in collaboration with guests (1 fellowship) and students (6 students).
Personnel for administrative services and technical assistance for maintaining and repair are supplied by the CR Casaccia central service and are not included in this list.

(+) 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 laboratory accreditation and quality systems.