REPORT TO THE CCRI SECTION I ON THE ACTIVITY CARRIED OUT AT ENEA-INMRI ON PHOTON AND CHARGED PARTICLE DOSIMETRY IN THE PERIOD MAY 2001 - MAY 2003

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1. INTRODUCTION

The present report summarizes the 2001-2003 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}

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 rays.

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

The experimental assembly regarding the x-ray machines and the free-air chamber systems has been renewed in many aspects. Various mechanical and electronic components have been changed in order to have more accurate systems for beam alignment/collimation and remote control of the x-ray tube variable additional filtration. Some mechanical/electric components of both free chambers (connectors, insulators) have been changed. All of these changes have been made in occasion of extensive restructuring works in the irradiation rooms as requested by the control authority for radiological protection. These works lasted about one year and in this period it has not been possible to carry out the usual research and calibration activity on low and medium-energy x-ray standards. It is envisaged that, as a consequence of the above changes, new international comparisons are necessary for the low and medium energy x-ray standards. The experimental re-determination of the energy distributions of all low and medium energy x-ray qualities used for calibration is being concluded. The new x-ray spectra catalogue including new ISO qualities and the x-ray qualities for radiodiagnostics is also about to be ready and available. All of the x-ray qualities referred to above are listed in table A.1.

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

2.1.b.1 Further investigation on the K_{wall} correction factor for the cavity ionization chamber
The factor K_{wall} to correct for photon attenuation and scatter in the wall of the standard ionization chamber for Co-60 air-kerma measurement was re-determined in 2001 (see CCRI(I)/2001 meeting reports) by a new (analytical/experimental) method other than that used so far. This re-determination agreed with Monte Carlo results. To increase the robustness of such results and give more confidence to their applicability even to chambers of different type the same analytical/experimental method was successively extended to cylindrical chambers of different shape, as described in the relevant ENEA report presented at this meeting. The results of this investigation support the recommendation that for any standard chamber of cylindrical geometry (like those adopted in various national metrological institutes) the K_{wall} factor as determined by the traditional linear extrapolation procedure should be revised. The changes expected after such a revision may be up to about 1% depending on the values for K_{wall} traditionally adopted so far.

2.1.b.2 Re-determination of the air-cavity volume for the cavity ionisation chamber
Seven cavity ionisation chambers were recently built to assess more accurately the procedure so far used for the cavity volume determination. For any chamber the geometry was cylindrical but diameter and height were different from chamber to chamber. The basic design of these chambers was substantially similar (except for the dimensions) to that of the OMH type. From this analysis it resulted that a (small) part of the inner chamber volume, traditionally neglected in other similar chambers, had instead to be included. This result in part was used to modify some data regarding the present ENEA-INMRI standard (see the relevant ENEA report to the present meeting), in part will be accounted for in the new standard chamber(s) that, after a new international comparison, will replace the existing one.

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. Due to the new air-kerma reference value consequent to the revised values for the K_{wall} correction factor and volume for the Co-60 standard cavity chamber (see above), the calibration factors regarding the Cs-137 gamma-ray quality have been accordingly revised.

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 rays was not 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 Water calorimetry

The "sealed water" type calorimeter built at ENEA-INMRI since many years for measurement in horizontal photon and charged particle beams, did not have significative improvements in the period 2001-2003. This was due mainly to the difficulty in re-designing and replacing some critical components of 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.

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 in terms of air-kerma and/or absorbed dose to water. Most calibrations in the future will be made just in terms of absorbed dose to water.

The calibration service for direct calibration of the customer clinical beam by chemical dosimetry has been operational, as in the past, at the ENEA-INMRI. 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.

In the framework of the program "Quality Assurance in Radiotherapy" of the Italian National Institute of Health (ISS), a dosimetry intercomparison among italian radiotherapy centres was carried out on the dosimetry in reference and non-reference conditions for high-energy photon beams. The INMRI-ENEA has been involved in this two-year program for the comparison set up, calibration, data analysis and reporting.

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 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.

3.3 Air-kerma international comparison for calibrated dosimeters

In the period 2000-2002 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 laboratories were 20 from 16 countries. The results of this confirmed the capabilities and the technical equivalence, within the EA stated limits, of the participating calibration services.

3.4 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)		Air kerma rate (6) ($Gy\ s^{-1}$)	u% (7)
				Al	Cu		
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 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.

(2) X-ray tube tension.

(3) The additional filtration is approximately 2.5 mm of Be for the x-ray qualities with H.T.$\leq$ 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 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.$\leq$ 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.

2001-2003 ENEA-INMRI activity report:
articles published in journals or meeting proceedings in the field of photon and charged particle dosimetry

- M. Pimpinella, A.S. Guerra and R. F. Laitano, "Un nuovo servizio dosimetrico dell'INMRI-ENEA per fasci di elettroni e fotoni usati in radioterapia"
Atti del II Congresso Nazionale AIFM, Brescia 12-16 giugno 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 a elettrodi piani paralleli".
Atti del II Congresso Nazionale AIFM, Brescia 12-16 giugno 2001.

- R F Laitano, "Il nuovo protocollo di dosimetria dell'IAEA: aspetti evolutivi per la dosimetria di base in radioterapia"
Atti del II Congresso Nazionale AIFM, Brescia 12-16 giugno 2001. *(invited paper)*

A.S. Guerra, "Principali procedure di misura raccomandate nel nuovo protocollo di dosimetria della IAEA"
Atti del II Congresso Nazionale AIFM, Brescia 12-16 giugno 2001 *(invited paper)*

-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 dosimetry based on standards of absorbed-dose-to-water"
IAEA TSR 398 IAEA Vienna, 2000.

- R F Laitano, "Requisiti per la strumentazione dosimetrica e per la riferibilita' delle misure in radioprotezione"
Atti del Convegno Nazionale di Radioprotezione dell' AIRP: Dosimetria personale ed ambientale, La Maddalena, 26 – 28 settembre 2001. *(invited paper)*

- R. F. Laitano**,** "Strutture e attrezzature metrologiche operanti a livello nazionale per la dosimetria in radioterapia e radiodiagnostica"
Notiziario AIFM (Associazione Nazionale dei Fisici in Medicina) 2001. *(invited paper)*

- R F Laitano, "Guida alla taratura ed al controllo della strumentazione di misura delle radiazioni ionizzanti"
14° Convegno Nazionale dell'ANPEQ : Evoluzione della professione dell'EQ.
Firenze, 23 – 24 ottobre 2001. *(invited paper)*

- R F Laitano, M P Toni, M Pimpinella and M Bovi, "Determination of the K_{wall} correction factor for a cylindrical ionisation chamber to measure air-kerma in ^{60}Co gamma beams." Phys.Med.Biol. 47 (2002) 2411-2431.

- A Piermattei, A Fidanzio, L Azario, A Russo, F Perrone, R Capote and M P Toni, "A standard dosimetry procedure for ^{192}Ir sources used for endovascular brachytherapy" Phys.Med.Biol, 47 (2002) 1-17.

M Bovi, M P Toni and G Tricomi, "Experimental comparison among the laboratories accredited within the framework of the "european co-operation for accreditation" on the calibration of a radiation protection dosimeter in terms of the quantity air kerma." European International Radiation Protection Association (IRPA) congress 2002, Firenze, 8-11 October (2002).

4. ENEA-INMRI STAFF INVOLVED IN THE ACTIVITY ON PHOTON AND CHARGED PARTICLE DOSIMETRY STANDARDS

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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 (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.