Austrian Calibration Service

EA - Interlaboratory Comparison IR 4

Final Report

Calibration of a Personal Dosemeter for Personal Dose Equivalent $H_p(10)$

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1 Introduction

The concept of radiation protection quantities developed by ICRU between 1985 and 1993 [2,5,6] was adopted by the European Union in its Council Directive 96/29/Euratom [7]. The personal dose equivalent, $H_p(10)$, was introduced as the operational quantity for individual monitoring of strongly penetrating radiation. Personal dosemeters of various types are calibrated at calibration laboratories in terms of $H_p(10)$. To investigate and demonstrate the capabilities of such laboratories, an Interlaboratory Comparison (ILC) was proposed at the meeting of the EA[*)] Expert Group (EG) "Ionising Radiation and Radioactivity" on September 10/11, 1998 in Delft, Netherlands and agreed by the EA General Assembly under the code IR4. This ILC was organised according to the EA – document EAL-P7.

[*)] European co-operation for Accreditation

2 General Information

2.1 Organisation

The scope of the ILC-IR4 was determined during the meetings of the EA expert group (EA – EG) on Ionising Radiation and Radioactivity.

The ILC was organised by the Austrian Accreditation Body in co-operation with the Reference Laboratory (REF) given below:

Austrian Accreditation Body:
Bundesministerium für Wirtschaft und Arbeit (BMWA)
Landstrasser Hauptstrasse 55-57
A - 1031 Vienna / Austria
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Officer responsible: R. Dittler
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Reference Laboratory:
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Telephone: +43 1 49 110
Fax: +43 1 49 20 875
Person responsible: J. Witzani
E-mail: J.Witzani@metrologie.at

2.2 Principle of the intercomparison and measurement instructions

Within the scope of this ILC a dosemeter was calibrated at the participating laboratories in terms of the quantity Personal Dose Equivalent $H_p(10)$ using gamma-radiation fields from ^{137}Cs and/or ^{60}Co. The circulating instrument used for this ILC is shown in fig.1. It consists of the following parts:
Display unit PTW DIADOS Typ 11003, Ser.No. 0548,
Detector Type W60004 with Cu-filter, Ser.No. 0547.
The commercially available instrument was originally designed for the measurement of air kerma in diagnostic radiology in the energy range corresponding to X - ray tube voltages from 45 kV to 150 kV. For the purpose of this comparison the energy range of the detector has been extended up to ^{60}Co energy levels by adding a filter of 3 mm copper to its front surface. By this modification the instrument became practically a prototype with completely unknown calibration coefficients, which had been determined the first time at the reference laboratory. Further information on the instrument is given in the measurement instructions (see appendix B), which were accompanying the instrument. Additional information on the energy dependence of the response of the detector (see diagram 1) was also

provided to the participants. Furthermore, a report form describing calibration conditions and parameters was prepared by the EA-EG and attached to the measurement instructions. The calibration of the instrument was requested preferably at two points - one point in the range 1 mSv to 2 mSv and one point in the range 8 mSv to 10 mSv. The calibrations had to be performed according to the normal procedure as agreed with the Accreditation Body. However it was strongly recommended that the calibrations should be conducted according to ISO 4037-3:1999 [1] and/or ICRU Report 47[2].

2.3 Participants and circulation of the instrument

A total number of 19 laboratories (labs) from 15 countries were scheduled to participate in the ILC - IR4 according to the scheme given in table 1.
The reference laboratory was to perform its calibrations at the beginning of the circulation of the instrument and was to trace the stability of the instrument in the middle and at the end of the comparison.
The Irish laboratory didn't participate. The Irish Accreditation Body gave the following explanation: "Originally we had nominated one laboratory and the equipment did arrive and was OK. However the laboratory on examining the instrument did not have the correct phantom and did not perform the calibration and returned the instrument …".
The laboratory FR2 was not able to perform the measurements at the time scheduled. The EA - EG agreed, that this laboratory got a time slot for the measurements at the end of the circulation scheme.
On arrival at the Spanish laboratory the instrument didn't display anything. A loose cable on the display unit caused this failure. After repair and check at the reference laboratory the same instrument continued its planned tour.
Obviously because of communication problems no Norwegian laboratory was planned to participate in the originally agreed schedule. However the EA – EG agreed to include one Norwegian laboratory (code NO) at the end of the comparison, because the Norwegian Accreditation Body had expressed its strong interest to participate some weeks before the end of the circulation of the instrument.

3 Results

3.1 Reference values

The circulating instrument was calibrated several times at the reference laboratory in terms of the quantity Personal Dose Equivalent $H_p(10)$ using gamma-radiation fields from ^{137}Cs and ^{60}Co. The calibration procedure according to the international Standard ISO 4037-3:1999 was applied. The water slab phantom and conversion coefficients $h_{pK}(10)$ from Air Kerma to Personal Dose Equivalent $H_p(10)$ were used as described in this Standard. The results are given in table 2. The mean value of the calibration coefficients for each radiation quality and dose was taken as the reference value for this ILC. The expanded uncertainty of each reference values is 4.5 % (k = 2). The standard deviation given in table 2 is a measure of the dispersion of the calibration coefficients and hence gives an indication of the stability of the instrument over the duration of this ILC. Compared to the expanded uncertainty of the reference value the uncertainty contribution from the stability of the instrument is negligible.

3.2 Results from the participants

For the evaluation of this ILC the results given in the Calibration Certificates from the participating laboratories were used, if available. Additional data were taken from the report form, which was returned by all participants. The characteristic values E_n (see EAL-P7, appendix H) were calculated and are given together with all reported calibration coefficients $N_{Hp(10)}$, expanded uncertainties U_N (k = 2) and measurement parameters in the tables 4 – 7 (each of them contains an embedded diagram). All E_n values are within the acceptance limits of ± 1. Only two labs are at the limit with their calibration coefficients for ^{137}Cs gamma radiation.

All laboratories (except GB2) followed the procedure given in the Standard ISO 4037-3:1999 and used the ISO water slab phantom or a PMMA[*)] phantom. Both phantoms comply with this Standard for calibrations in gamma radiation fields from ^{137}Cs and ^{60}Co, because the difference in the results is not significant, if the overall uncertainty is considered. Although the lab GB2 didn't use a phantom, it obtained results within the acceptance limits. Obviously this lab took the absence of a phantom into account by applying significantly lower conversion coefficients $h_{pK}(10)$. However, it could not be verified within this ILC, if such a procedure is also successful with another instrument, in particular if its response to backscattered radiation is different from the response of the instrument used in this ILC.

*) Polymethylmethacrylat

An important part of a calibration is the uncertainty of the calibration coefficient given by the laboratory. The main uncertainty contribution in a calibration in terms of the quantity Personal Dose Equivalent $H_p(10)$ usually comes from the conversion coefficient $h_{pK}(10)$. This converts the quantity Air Kerma, which can be measured, to Personal Dose Equivalent. The Standard ISO 4037-3:1999 clearly states in paragraph 4.1.2, that "… the conversion coefficients … shall be considered as being associated with a standard uncertainty of ± 2 %", which refers to a coverage factor of k = 1 (paragraph 7.2 of the same Standard). It has to be noted, that according to ISO 4037-3:1999 the numerical values of the conversion coefficients for mono-energetic radiation shall be treated as having no uncertainty. So the standard uncertainty of ± 2 % exclusively reflects the uncertainty for the conversion coefficient of the real photon spectrum at the calibration laboratory. Despite of this fact 7 laboratories gave expanded uncertainties of less than 4 %, which is the lower limit tolerated by the Standard mentioned above.

4 Calibration Certificates

All Calibration Certificates submitted were checked for compliance with paragraph 5.10 of the Standard ISO/IEC 17025:1999. Not all Calibration Certificates were bilingual or were translated by the relevant accreditation body. In case of lack of information in the Calibration Certificate or in case of language problems the data given in the report form, which were completed by the participants, were used as an input for this check. The results are given in the tables 3a) and 3b). They indicate some points where improvements can be made by some laboratories including:

- Identification of procedure employed.
- Unambiguity of results.
- Environmental conditions.
- Evidence of traceability.
- Note: Certificate not to be reproduced except in full (recommendation).

5 Corrective actions

As mentioned in this report under item 3.2 seven laboratories gave expanded uncertainties of less than 4 %, which is the lower limit tolerated by the Standard ISO 4037-3. From these seven laboratories the laboratories FR1 and PT gave the explanations given below. No response was received from the laboratories FR2, GB1, GB2, GR and SK, although these laboratories claimed to proceed according to ISO 4037-3.

The laboratory FR1 has given the following explanation and corrective action for its uncertainty budget: "Our investigations make it possible to find out the origin of the uncertainties currently applied to the conversion coefficient for dose equivalent from air kerma. It is a recommendation from the French Bureau National de Métrologie in its note BNM MS n°90/1992. This recommendation specified the values of the uncertainties that have to be taken for these conversion coefficients, i.e. 1% for X-rays and 0.6% for gamma rays respectively. It is foreseen that in a near future we will follow the recommendations given in the international standard ISO 4037-3."

The Italian Accreditation Body took the following corrective actions regarding the non-conformities mentioned in the draft report:

- The laboratory IT2 changed the form of its Calibration Certificate in order to avoid these non-conformities in the future.
- Copies of 20 Certificates issued in the past were checked for non-conformities.
- Inspectors were strongly asked to carefully check the Certificates in the course of the surveillance visits.

The Portuguese laboratory submitted the following comment:
“The lab modified the calibration report model in order to fully respect ISO/IEC 17025 requirements.” The uncertainties given by this laboratory were different in the Calibration Certificates and in the report form. The values from the Calibration Certificates were given in the draft report. However, the laboratory stated, that the values in the report form are correct. Therefore the latter values are also given now in the final report. Furthermore the laboratory clarified, that the values for the field size in the Calibration Certificates refer to the radius. These values have been converted to the diameter in the final report.

The Swedish laboratory explained, that its Calibration Certificate in Swedish language contains the requested information on traceability and the recommended statement, that the Certificate must not be reproduced except in full.

The Slovenian laboratory issued a revised Calibration Certificate, which contains the same calibration data as the original one, but does not show the non-conformities mentioned in the draft report any more.

Although many Accreditation Bodies concerned did not submit comments on the draft report or did not report any corrective action in particular regarding the non-conformities mentioned therein, the EA – EG is confident, that the Accreditation Bodies and laboratories concerned do have the information now in order to ensure full implementation of paragraph 5 of the Standard ISO/IEC 17025:1999 in their accreditation scheme.

6 Conclusions

This EA Interlaboratory Comparison demonstrated the capabilities of the participating laboratories to perform calibrations in terms of the quantity Personal Dose Equivalent $H_p(10)$ using gamma-radiation fields from ^{137}Cs and ^{60}Co. In general the results are satisfactory. Nevertheless, some improvements could be made, as mentioned in this report.

Most of the laboratories followed the procedure given in ISO 4037-3. For consistency reasons the reference laboratory also applied this Standard, particularly in the uncertainty evaluation. However, the EA – EG concluded, that the uncertainty estimate for the conversion coefficient $h_{pK}(10)$ for ^{137}Cs – and ^{60}Co – gamma radiation given in ISO 4037-3 is too high. In this Standard the uncertainty is assumed to be the same for X – rays and gamma rays, but the spectral influence on the conversion coefficient, which causes the uncertainty, is significantly lower for gamma rays than for X – rays. The EA – EG suggests that the Standard ISO 4037-3 being improved with respect to the uncertainty estimate of $h_{pK}(10)$ in the course of the next revision. Further details are given in appendix A.

Finally the organising Accreditation Body and the EA – EG want to express their satisfaction with the fruitful collaboration of the Accreditation Bodies and laboratories participating in this ILC.

References

[1] ISO 4037-3:1999, *X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy – Part 3: Calibration of area and personal dosemeters and the measurement of their response as a function of energy and angle of incidence, International Organisation for Standardisation, Geneva, Switzerland*
[2] ICRU Report 47, *Measurement of Dose Equivalents from External Photon and Electron Radiations, International Commission on Radiation Units and Measurements,* Bethesda, 1992.
[3] ICRU Report 51, *Quantities and Units in Radiation Protection Dosimetry, International Commission on Radiation Units and Measurements,* Bethesda, 1993
[4] Böhm J., Stadtmann H., Strachotinsky Chr., *Calibration of personal dosimeters for photon radiation with respect to the personal dose equivalent $H_p(10)$,* PTB-Report Dos-28, Braunschweig, Germany, 1998
[5] International Commission on Radiation Units and Measurements, *Determination of dose equivalents resulting from external radiation sources*, ICRU Report 39, ICRU Publications, Bethesda, MD, 1985

[6] International Commission on Radiation Units and Measurements, *Determination of dose equivalents from external radiation sources – Part 2*, ICRU Report 43, ICRU Publications, Bethesda, MD, 1988.

[7] European Union, *Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation*, Official Journal, No. L 159, 1-114

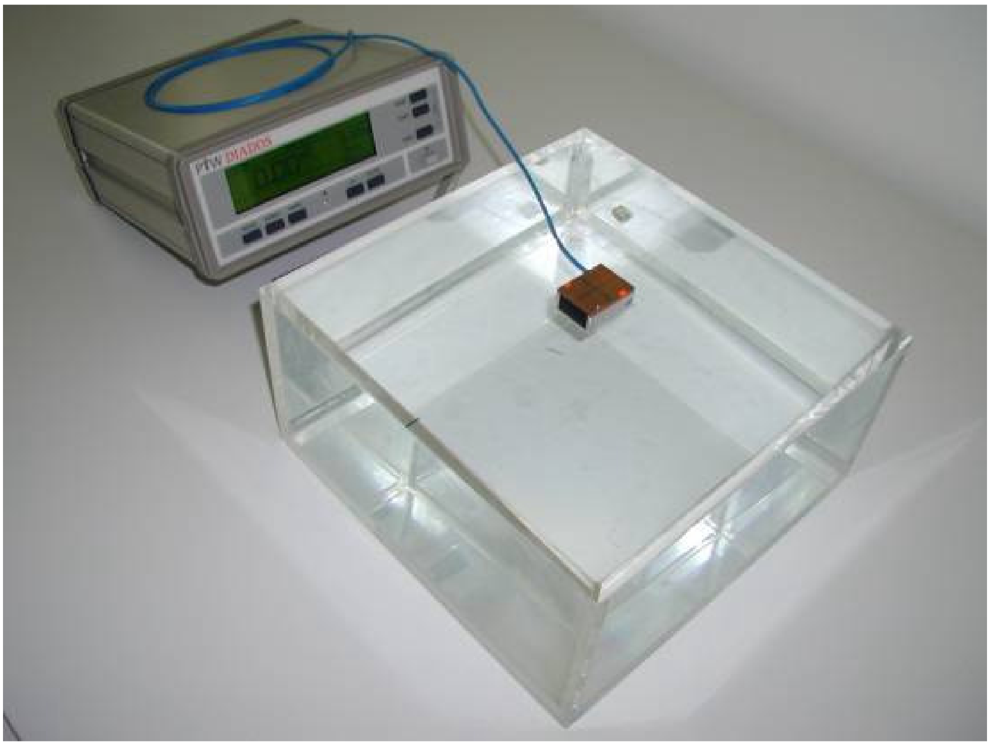

Fig.1: Circulating instrument of the ILC – IR4 with detector on the ISO water – slab phantom

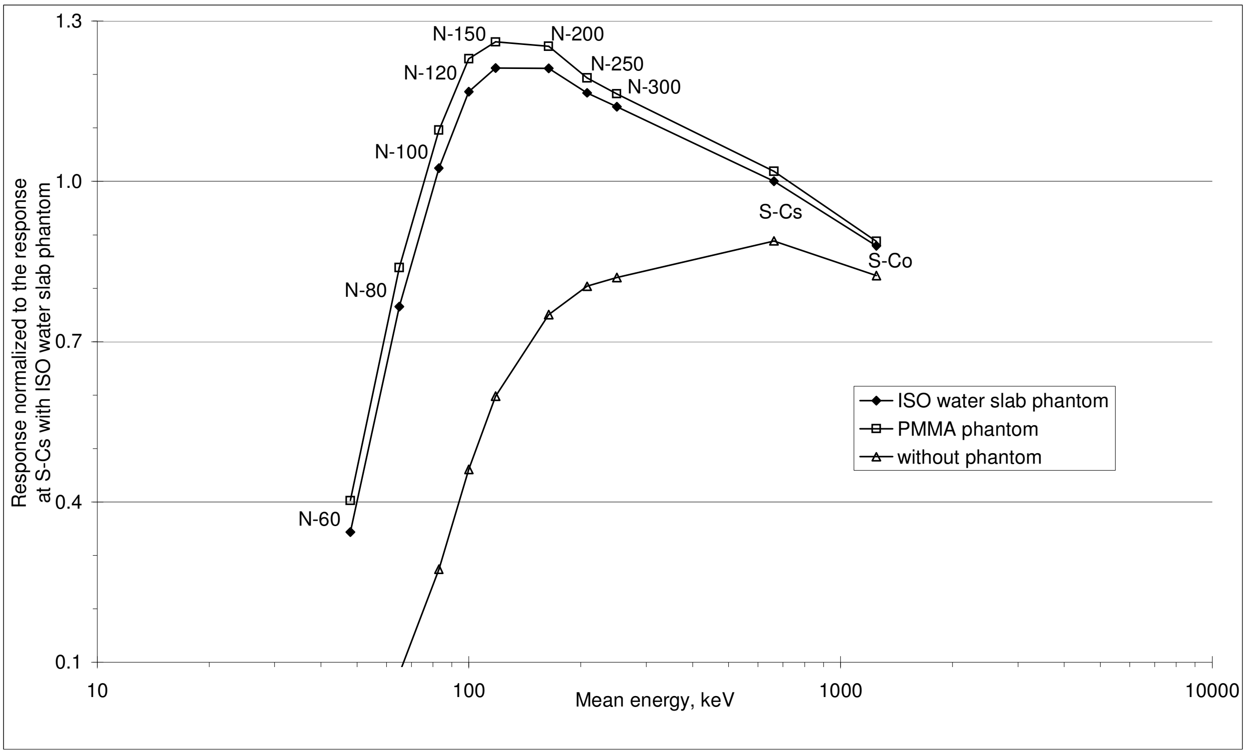

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Diagram1: Response of Detector Type W60004 with Cu-filter, Ser.No. 0547, with respect to Personal Dose Equivalent H_p(10) on different phantoms and without phantom for radiation qualities according to ISO 4037-1 (X-ray narrow spectrum series and gamma radiation from ^{137}Cs and ^{60}Co)

Country	Original time schedule		Weeks	Laboratory	Actual calibration date		Comment
	From	To	allotted	Code	From	To	
Austria	28 Aug 2000	01 Sept 2000	1	REF	29 Aug 2000		
Greece	18 Sept 2000	29 Sept 2000	2	GR	18 Sept 2000	29 Sept 2000	
Italy	16 Okt 2000	10 Nov 2000	4	IT1	26 Oct 2000		
				IT2	10 Nov 2000		
Germany	27 Nov 2000	22 Dec 2000	4	DE1	07 Dec 2000		
				DE2	?		
Great Britain	08 Jan 2001	02 Feb 2001	4	GB1	19 Jan 2001		
				GB2	01 Feb 2001	02 Feb 2001	
Ireland	19 Feb 2001	02 Mar 2001	2	IE	-	-	No actual participation
France	19 Mar 2001	13 Apr 2001	4	FR1	12 Mar 2001	14 Mar 2001	
				FR2	-	-	No calibration by FR2
Austria	30 Apr 2001	11 May 2001	2	AT	21 May 2001		
Austria	14 May 2001	25 May 2001	2	REF	18 May 2001		
Portugal	11 Jun 2001	22 Jun 2001	2	PT	18 June 2001		
Austria	-	-	-	REF	17 Jul 2001		Check after fixing of a loose cable on display
Spain	09 Jul 2001	20 Jul 2001	2	ES	19 July 2001		
Finland	06 Aug 2001	17 Aug 2001	2	FI	15 Aug 2001		
Sweden	03 Sept 2001	14 Sept 2001	2	SE	14 Sept 2001		
Austria	-	-	-	REF	03 Oct 2001		Check on the occasion of Carnet attachment
Slovakia	22 Oct 2001	02 Nov 2001	2	SK	06 Nov 2001		
Slovenia	19 Nov 2001	30 Nov 2001	2	SI	29 Nov 2001	18 Dec 2001	
USA	17 Dec 2001	28 Dec 2001	2	US	31 January 2002(?)		
South Africa	14 Jan 2002	25 Jan 2002	2	ZA	5 April 2002		
Austria	11 Feb 2002	22 Feb 2002	2	REF	03 May 2002		
France	-	-	-	FR2	30 May 2002	31 May 2002	Participation agreed by EA-EG
Norway	-	-	-	NO	21 June 2002	17 July 2002	
Austria	-	-	-	REF	05 Aug 2002	09 Aug 2002	

Table 1: Time schedule for the ILC – IR4 and actual calibration date

Calibration date	Calibration coefficient $N_{Hp(10)}$, µSv/nC			
	^{137}Cs gamma radiation		^{60}Co gamma radiation	
	$H_p(10)$ = 2 mSv	$H_p(10)$ = 10 mSv	$H_p(10)$ = 1 mSv	$H_p(10)$ = 10 mSv
29 Aug 2000	53.7 7	53.7 9	61.4 1	61.4 1
18 May 2001	53.8 1	53.8 0	61.4 9	-
17 Jul 2001	53.8 0	53.8 1	61.5 1	-
03 Oct 2001	53.7 0	53.6 9	61.5 1	-
03 May 2002	53.6 9	53.7 0	61.4 6	61.4 9
07 Aug 2002	53.7 2	53.6 8	61.4 5	61.4 1
Standard deviation, %	0.10	0.11	0.06	0.08
Reference value (mean)	**53.7**	**53.7**	**61.5**	**61.4**
Expanded uncertainty (k = 2)	4.5 %	4.5 %	4.5 %	4.5 %

Table 2: Calibration of the circulating instrument at the reference laboratory

Standard ISO/IEC 17025:1999		**Participant** status									
Requirement for Calibration Certificate	**Paragraph**	**AT** Accred.	**DE1** No accred.	**DE2** No accred.	**ES** Accred.	**FI** No accred.	**FR1** Accred.	**FR2** Accred.	**GB1** Accred.	**GB2** Accred.	**GR** No accred.
Title of the document	5.10.2a	+	No calibration certificate submitted	No calibration certificate submitted	+	+	+	+	+	No calibration certificate submitted	+
Laboratory identification	5.10.2b	+			+	+	+	+	+		+
Identification of Calibration Certificate (serial number)	5.10.2c	+			+	+	+	+	+		+
Page identification	5.10.2c	+			+	+	+	+	+		+
Identification of end of Calibration Certificate	5.10.2c	+			+	+	+	+	+		+
Identification of the client	5.10.2d	+			+	+	+	+	+		+
Identification of procedure employed	5.10.2e	+			+	+	- [1)]	+	- [1)]		- [1) 2)]
Identification of the device calibrated	5.10.2f	+			+	+	+	+	+		+
Date of calibration	5.10.2g	+			+	+	+	+	+		+
Results	5.10.2i	+			+	+	+	+	+		+
Unambiguity of results	5.10.1	+			+	+	+	+	+		+
Identification of the person responsible	5.10.2j	+			+	+	+	+	+		+
Environmental conditions	5.10.4.1a	+			+	-	+	+	-		+
Uncertainty of measurement	5.10.4.1b	+			+	+	+	+	+		+
Evidence of traceability	5.10.4.1c	+			+	+	+	+	+		+
Certificate not to be reproduced except in full [*)]	5.10.2 note	+			+	+	+	+	+		+

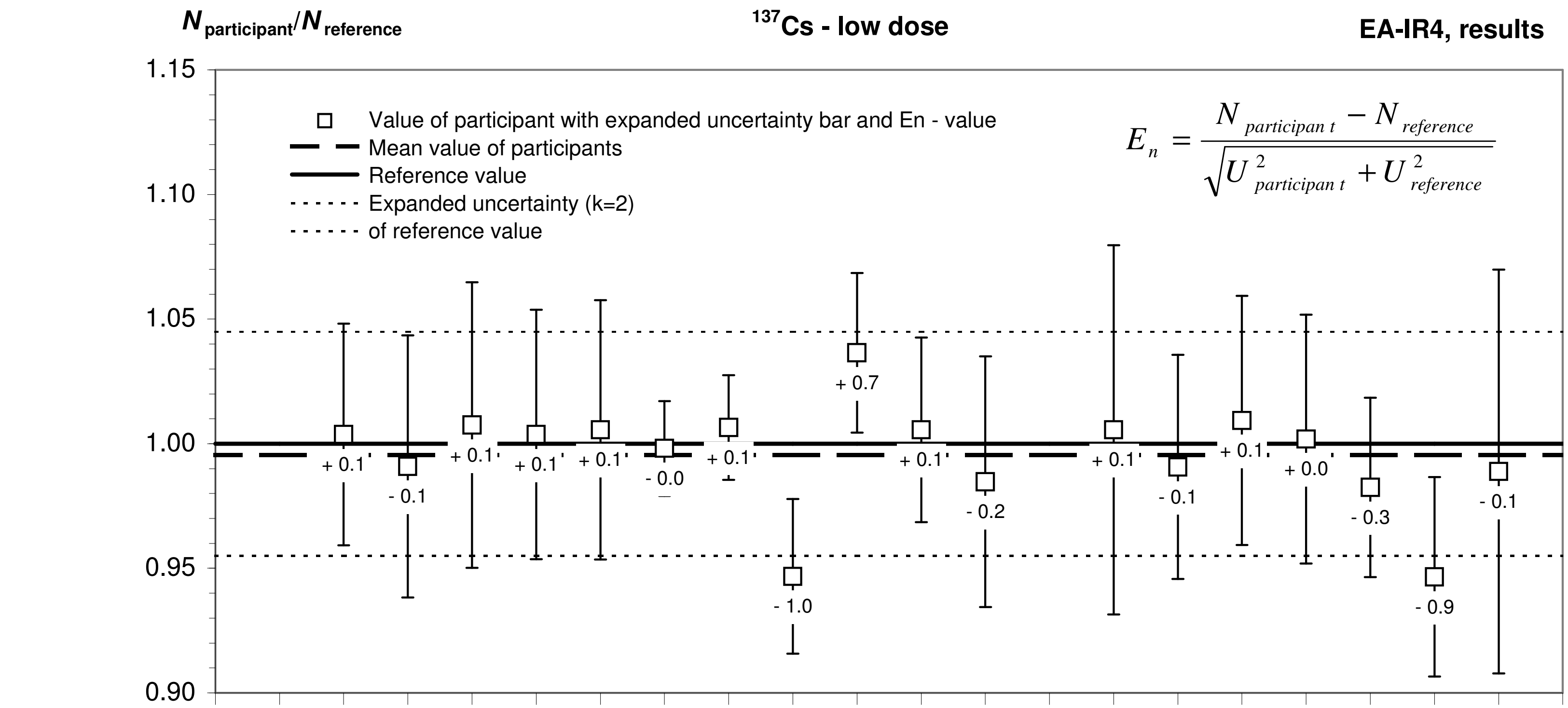
[*)] recommendation
[1)] no phantom or calibration procedure identified
[2)] dose delivered not stated

Table 3a: Conformities (+) and Non-conformities (-) of Calibration Certificates to Standard ISO/IEC 17025:1999

Standard ISO/IEC 17025:1999		Participant status								
Requirement for Calibration Certificate	**Paragraph**	**IT1** Accred.	**IT2** Accred.	**NO** No accred.	**PT** No accred.	**SE** No accred.	**SI** No accred.	**SK** No accred.	**US** Accred.	**ZA** Accred.
Title of the document	5.10.2a	+	+	+	+	+	+	+	+	+
Laboratory identification	5.10.2b	+	+	+	+	+	+	+	+	+
Identification of Calibration Certificate (serial number)	5.10.2c	+	+	+	+	+	+	+	+	+
Page identification	5.10.2c	+	+	+	+	+	+	+	+	+
Identification of end of Calibration Certificate	5.10.2c	+	+	-	+	+	+	+	+	+
Identification of the client	5.10.2d	+	+	+	+	+	+	+	+	+
Identification of procedure employed	5.10.2e	+	- [1]	+	+	+	? [3]	+	+	+
Identification of the device calibrated	5.10.2f	+	+	+	+	+	+	+	+	+
Date of calibration	5.10.2g	+	+	+	+	+	+	+	- [6]	+
Results	5.10.2i	+	+	+	+	+	+	+	+	+
Unambiguity of results	5.10.1	+	+	- [2] [3]	- [2]	+	- [4]	+	+	+
Identification of the person responsible	5.10.2j	+	+	+	+	+	+	+	+	+
Environmental conditions	5.10.4.1a	+	+	-	+	-	+	+	+	+
Uncertainty of measurement	5.10.4.1b	+	+	- [5]	+	+	+	+	+	+
Evidence of traceability	5.10.4.1c	+	+	+	-	? [3]	? [3]	+	+	+
Certificate not to be reproduced except in full [*]	5.10.2 note	+	-	-	-	? [3]	+	+	+	+

[*] recommendation
[1] no phantom or calibration procedure identified
[2] dose delivered not stated
[3] no English translation submitted
[4] no settings of the calibrated instrument given
[5] coverage factor not given
[6] not clear whether date given refers to date of calibration or date of issue of certificate

Table 3b: Conformities (+) and Non-conformities (-) of Calibration Certificates to Standard ISO/IEC 17025:1999



Laboratory		REF	AT	DE1	DE2	ES	FI	FR1	FR2	GB1	GB2	GR	IT1	IT2	NO	PT	SE	SI	SK	US	ZA
Accreditation		n.a.	yes	no	no	yes	no	yes	yes	yes	yes	no	yes	-	no	no	yes	no	no	yes	yes
Phantom		ISO	ISO	ISO	ISO	ISO	ISO	ISO	ISO	PMMA	1)	PMMA	ISO	-	2)	PMMA	ISO	ISO	PMMA	PMMA	ISO
$h_{pK}(10)$	$Sv{*}Gy^{-1}$	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.12	1.21	1.21	-	1.22	1.21	1.21	1.21	1.21	1.21	1.21
$N_{Hp(10)}$	$\mu Sv{*}nC^{-1}$	53.7	53.9	53.2	54.1	53.9	54	53.6	54.1	50.8	55.7	54	52.9	-	54	53.2	54.2	53.8	52.8	50.8	53.1
exp. uncert. (k=2)	%	4.5	4.5	5.3	5.7	5.0	5.2	1.9	2.1	3.1	3.2	3.7	5.0	-	7.4	2.4 [3]	5.0	5.0	3.6	4.0	8.1
Irrad.dist.	m	2.0	3.0	2.0	1.4	2.5	4.0	4.5	4.8	4.0	2.5	2.0	2.0	-	2.0	4.0	2.0	2.0	4.0	2.4	1.5
Field diam.	cm	52	78	70	49	50	40	43	43	60	33	56.6	50	-	16	41 [4]	56	60	75	42	39.5
Dose	mSv	2.00	1.9	2.41	1.50	1.37	2.0	1.5	1.5	2.0	1.5	1.5	1.6	-	0.026	1.52	2.00	1.06	2.0	1.77	1.20
Doserate	$mSv{*}h^{-1}$	63.0	28.0	64.4	380	10.2	56.9	6.00	5.11	27.9	35.5	13.9	8.19	-	1.53	30.4	17.2	2.66	37.2	10.6	14.4

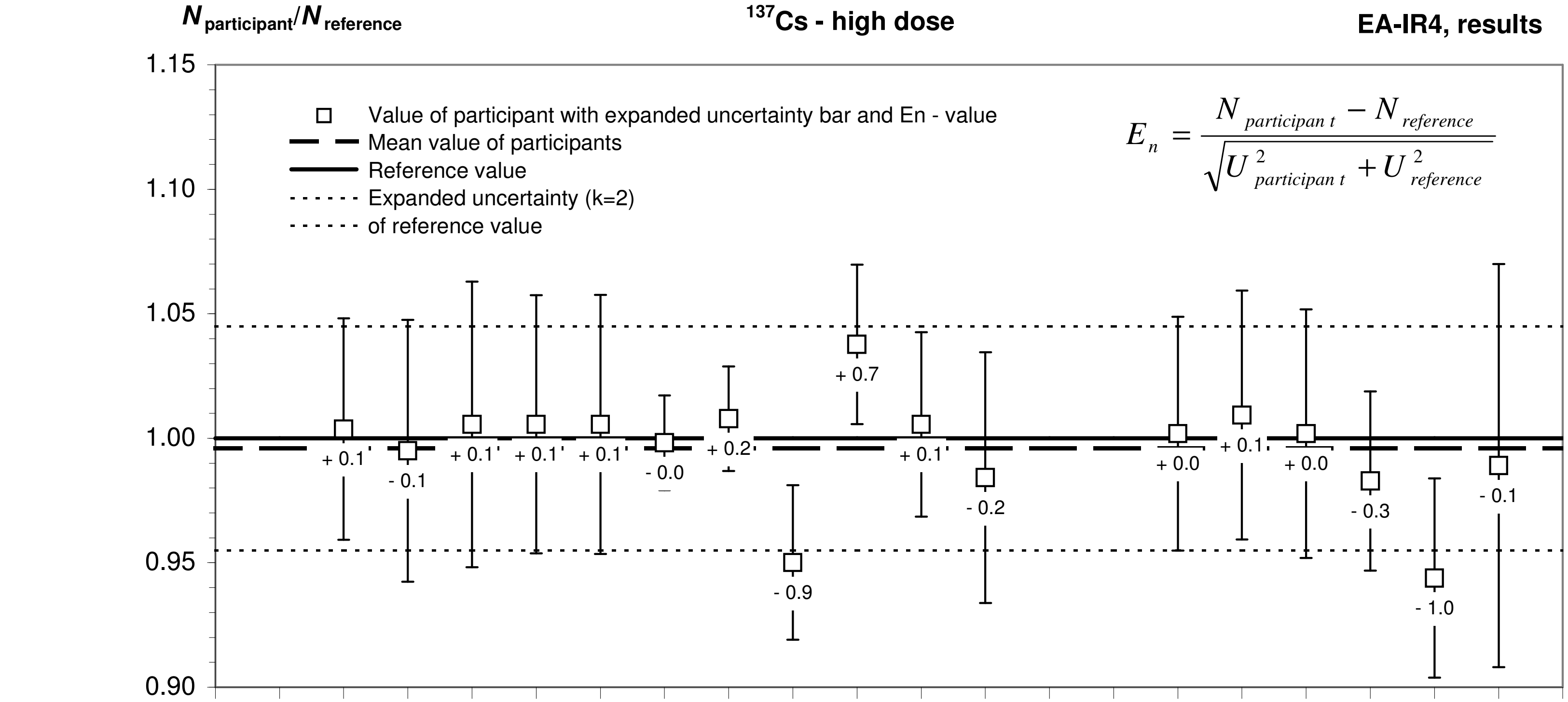
1) Instrument irradiated "free in air" mounted on polystyrene board

2) Water phantom 30 cm x 30 cm x 30 cm with PMMA walls

3) Corrected to 4.5 % by the laboratory, see chapter "corrective actions"

4) Refers to radius, diameter = 82 cm

Table 4: Ratio of calibration coefficients $N_{Hp(10)}$ given by the participants ($N_{participant}$) and the reference laboratory ($N_{reference}$) - ^{137}Cs low dose



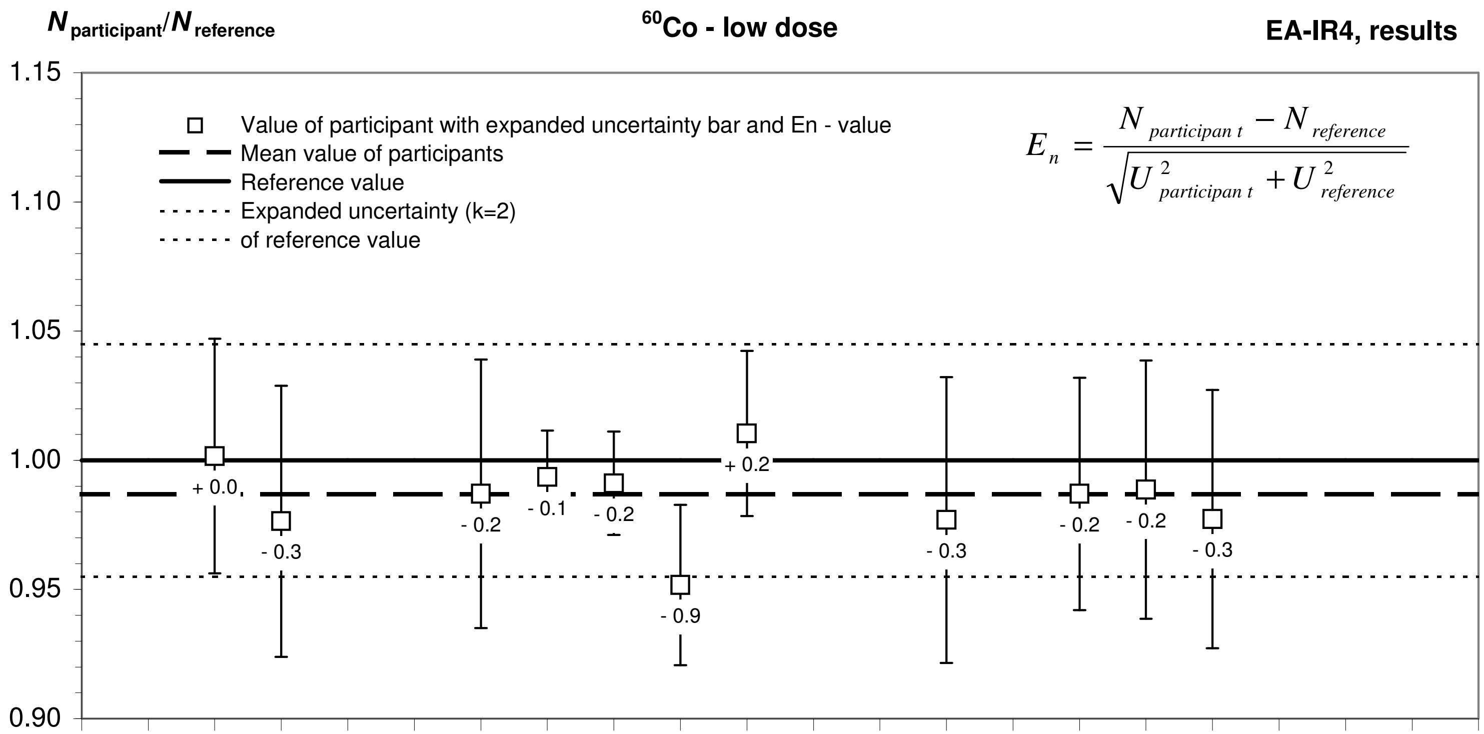
Laboratory		REF	AT	DE1	DE2	ES	FI	FR1	FR2	GB1	GB2	GR	IT1	IT2	NO	PT	SE	SI	SK	US	ZA
Accreditation		n.a.	yes	no	no	yes	no	yes	yes	yes	yes	no	yes	-	-	no	yes	no	no	yes	yes
Phantom		ISO	ISO	ISO	ISO	ISO	ISO	ISO	ISO	PMMA	1)	PMMA	ISO	-	-	PMMA	ISO	ISO	PMMA	ISO	ISO
$h_{pK}(10)$	Sv*Gy^{-1}	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.12	1.21	1.21	-	-	1.21	1.21	1.21	1.21	1.21	1.21
$N_{Hp(10)}$	µSv*nC^{-1}	53.7	53.9	53.4	54	54	54	53.6	54.1	51	55.7	54	52.9	-	-	53.8	54.2	53.8	52.8	50.7	53.1
exp. uncert. (k=2)	%	4.5	4.5	5.3	5.7	5.2	5.2	1.9	2.1	3.1	3.2	3.7	5.0	-	-	2.5 [3]	5.0	5.0	3.6	4.0	8.1
Irrad.dist.	m	2.0	2.0	2.0	1.4	2.0	4.0	4.5	4.8	4.0	2.5	2.0	2.0	-	-	2.0	2.0	1.5	4.0	3.2	1.5
Field diam.	cm	52	52	70	49	40	40	43	43	60	33	56.6	50	-	-	21 [4]	56	45	75	55	39.5
Dose	mSv	10.0	8.5	12.1	9.0	8.0	10.0	9.0	9.0	8.0	9.0	9.0	9.1	-	-	8.3	8.0	8.6	10.1	14.2	8.4
Doserate	mSv*h^{-1}	63.0	63.5	64.4	380	16.1	56.9	6.00	5.11	27.9	87.6	13.9	8.19	-	-	124	17.2	4.75	327	850	14.4

1) Instrument irradiated "free in air" mounted on polystyrene board

3) Corrected to 4.7 % by the laboratory, see chapter "corrective actions"

4) Refers to radius, diameter = 42 cm

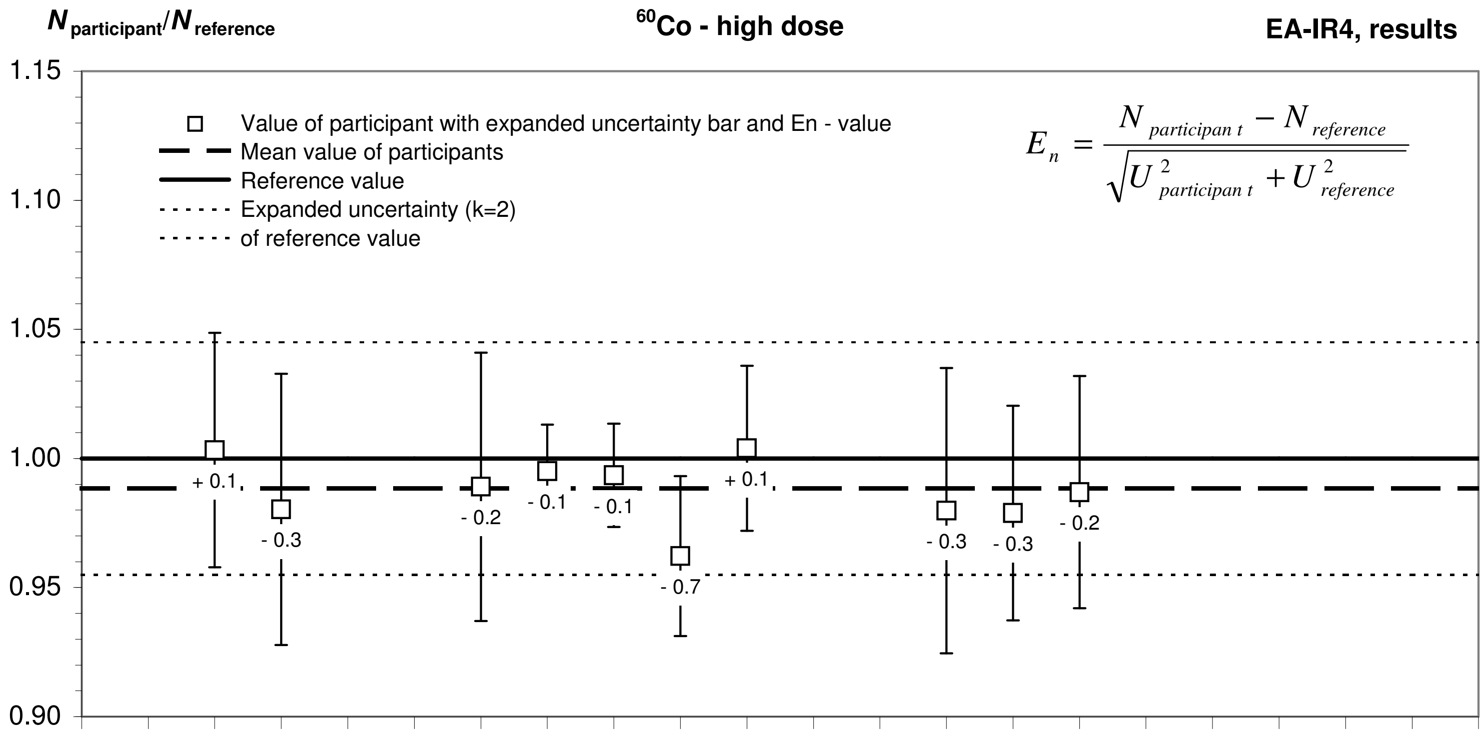
Table 5: Ratio of calibration coefficients $N_{Hp(10)}$ given by the participants ($N_{participant}$) and the reference laboratory ($N_{reference}$) - ^{137}Cs high dose



Laboratory		REF	AT	DE1	DE2	ES	FI	FR1	FR2	GB1	GB2	GR	IT1	IT2	NO	PT	SE	SI	SK	US	ZA
Accreditation		n.a.	yes	no	-	-	no	yes	yes	yes	yes	-	-	yes	-	no	yes	no	-	-	-
Phantom		ISO	ISO	ISO	-	-	ISO	ISO	ISO	PMMA	1)	-	-	ISO	-	PMMA	ISO	ISO	-	-	-
$h_{pK}(10)$	$Sv*Gy^{-1}$	1.15	1.15	1.15	-	-	1.15	1.15	1.15	1.15	1.08	-	-	1.15	-	1.15	1.15	1.16	-	-	-
$N_{Hp(10)}$	$\mu Sv*nC^{-1}$	61.5	61.6	60.1	-	-	60.7	61.1	61.0	58.5	62.1	-	-	60.1	-	60.7	60.8	60.1	-	-	-
exp. uncert. (k=2)	%	4.5	4.5	5.2	-	-	5.2	1.8	2.0	3.1	3.2	-	-	5.5	-	2.7 3)	5.0	5.0	-	-	-
Irrad.dist.	m	2.0	2.0	2.0	-	-	4.0	4.5	4.8	3.0	1.5	-	-	4.5	-	2.0	2.0	1.0	-	-	-
Field diam.	cm	52	52	70	-	-	40	43	43	47	20	-	-	50 2)	-	18 4)	56	30	-	-	-
Dose	mSv	1.00	1.9	2.29	-	-	2.0	1.5	1.5	2.0	1.5	-	-	1.93	-	1.62	2.00	1.03	-	-	-
Doserate	$mSv*h^{-1}$	11.2	11.8	35.6	-	-	14.8	11.7	8.77	11.6	1.34	-	-	321	-	3.2	1.41	0.46	-	-	-

1) Instrument irradiated "free in air" mounted on polystyrene board
2) Square field 50 cm x 50 cm
3) Corrected to 4.5 % by the laboratory, see chapter "corrective actions"
4) Refers to radius, diameter = 36 cm

Table 6: Ratio of calibration coefficients $N_{Hp(10)}$ given by the participants ($N_{participant}$) and the reference laboratory ($N_{reference}$) - ^{60}Co low dose



Laboratory		**REF**	**AT**	**DE1**	**DE2**	**ES**	**FI**	**FR1**	**FR2**	**GB1**	**GB2**	**GR**	**IT1**	**IT2**	**NO**	**PT**	**SE**	**SI**	**SK**	**US**	**ZA**
Accreditation		n.a.	yes	no	-	-	no	yes	yes	yes	yes	-	-	yes	no	no	-	-	-	-	-
Phantom		ISO	ISO	ISO	-	-	ISO	ISO	ISO	PMMA	1)	-	-	ISO	2)	PMMA	-	-	-	-	-
$h_{pK}(10)$	$Sv{*}Gy^{-1}$	1.15	1.15	1.15	-	-	1.15	1.15	1.15	1.15	1.08	-	-	1.15	1.15	1.15	-	-	-	-	-
$N_{Hp(10)}$	$\mu Sv{*}nC^{-1}$	61.4	61.6	60.2	-	-	60.7	61.1	61	59.1	61.6	-	-	60.2	60.1	60.6	-	-	-	-	-
exp. uncert. (k=2)	%	4.5	4.5	5.3	-	-	5.2	1.8	2.0	3.1	3.2	-	-	5.5	4.2	2.7 4)	-	-	-	-	-
Irrad.dist.	m	2.0	2.0	2.0	-	-	4.0	4.5	4.8	3.0	0.6	-	-	4.5	4.0	2.0	-	-	-	-	-
Field diam.	cm	52	52	70	-	-	40	43	43	47	8	-	-	50 3)	40 3)	18 5)	-	-	-	-	-
Dose	mSv	10.0	8.50	11.5	-	-	10.0	9	9.00	8.0	9.0	-	-	8.87	17	9.00	-	-	-	-	-
Doserate	$mSv{*}h^{-1}$	11.2	11.8	35.6	-	-	14.8	11.7	8.77	11.6	8.49	-	-	321	1030	3.2	-	-	-	-	-

1) Instrument irradiated "free in air" mounted on polystyrene board
2) Water phantom 30 cm x 30 cm x 30 cm with PMMA walls
3) Square field
4) Corrected to 4.5 % by the laboratory, see chapter "corrective actions"
5) Refers to radius, diameter = 36 cm

Table 7: Ratio of calibration coefficients $N_{Hp(10)}$ given by the participants ($N_{participant}$) and the reference laboratory ($N_{reference}$) - ^{60}Co high dose

APPENDIX A: Uncertainty of the conversion coefficient $h_{pK}(10)$

In this intercomparison exercise most of the laboratories used the ISO water - slab phantom in the calibration. Some laboratories used the PMMA - phantom. Only one laboratory performed the calibration without a phantom. In order to investigate the uncertainty u_h of the conversion coefficient $h_{pK}(10)$ and its possible correlation in the case of the ISO water - slab phantom the following variation in the data analysis was performed:
For the laboratories, which stated an expanded relative uncertainty of the calibration coefficient of $U_N \geq 4$ % (k = 2), the correlated part of the uncertainty of u_h was assumed to be 2 % (k = 1), which is the value recommended in the Standard ISO 4037-3:1999 for the uncertainty of the conversion coefficient $h_{pK}(10)$. This correlated part was completely removed in the analysis by subtracting it in the quadratic sum of the uncertainties. In this case one gets the reduced uncertainties $U_{N,0}$ and the corresponding characteristic values $E_{n,0}$, which are given in table 8 and 9 for the calibration at the requested "low dose" for ^{137}Cs and ^{60}Co, respectively. The original values for U_N and E_n of the comparison are also given in these tables.

Laboratory	U_N (k = 2) %	$U_{N,0}$ (k = 2) %	E_n	$E_{n,0}$
REF	4.5	2.1	-	-
AT	4.5	2.0	+ 0.06	+ 0.13
DE1	5.3	3.4	- 0.13	- 0.23
DE2	5.7	4.1	+ 0.10	+ 0.16
ES	5.0	3.0	+ 0.06	+ 0.10
FI	5.2	3.3	+ 0.08	+ 0.14
IT1	5.0	3.1	- 0.23	- 0.42
SE	5.0	3.0	+ 0.14	+ 0.25
SI	5.0	3.0	+ 0.03	+ 0.05
ZA	8.1	7.0	- 0.12	- 0.15

Table 8: Uncertainties U_N and $U_{N,0}$ for the calibration coefficient and characteristic values E_n and $E_{n,0}$ for ^{137}Cs low dose

Laboratory	U_n (k = 2) %	$U_{n,0}$ (k = 2) %	E_n	$E_{n,o}$
REF	4.5	2.1	-	-
AT	4.5	2.2	+ 0.03	+ 0.05
DE1	5.2	3.4	- 0.35	- 0.60
FI	5.2	3.3	- 0.19	- 0.34
IT2	5.5	3.8	- 0.33	- 0.54
SE	5.0	3.0	- 0.17	- 0.32
SI	5.0	3.0	- 0.34	- 0.64

Table 9: Uncertainties U_N and $U_{N,0}$ for the calibration coefficient and characteristic values E_n and $E_{n,0}$ for ^{60}Co low dose

The fact, that all absolute $E_{n,0}$ – values are still below one, is a strong indication, that the uncertainty of u_h can be reduced as described above without underestimating its contribution to the uncertainty of the calibration coefficient. This finding supports the statement in the conclusions of this report, that the uncertainty estimate for the conversion coefficient $h_{pK}(10)$ for ^{137}Cs – and ^{60}Co – gamma radiation given in ISO 4037-3 is too high.

APPENDIX B: Measurement instructions of ILC – IR4

1. **Quantity to be measured:** Personal Dose Equivalent $H_p(10)$ in soft tissue as defined in ICRU 51 [3] below a specified point on the body at the depth of 10 mm for monodirectional radiation under 0° incidence relative to the reference direction of the detector.

2. **Radiation quality:** Gamma radiation from ^{137}Cs and/or ^{60}Co

3. **Prescribed calibration point(s) and range**
   The calibration is to be performed preferably at two points - one point in the range 1 mSv to 2 mSv and one point in the range 8 mSv to 10 mSv.

4. **Instrument description**
   The instrument to be circulated is a direct reading electronic dosemeter. It consists of a semi - conductor detector and a separated display unit. Both must be connected via the enclosed extension cable. The commercially available instrument was originally designed for use in diagnostic radiology in the energy range corresponding to X - ray tube voltages from 45 kV to 150 kV. Therefore many parts of the manufacturer's manual refer to the use of the instrument as a dosemeter in X - ray diagnosis imaging.
   For the purpose of this comparison the energy range of the detector has been extended up to ^{60}Co energy levels by adding a filter of 3 mm copper to its front surface. This filter provides the desired secondary electron equilibrium at these high energies and an energy response with respect to the quantity Personal Dose Equivalent $H_p(10)$ (for monodirectional radiation under 0° incidence relative to the reference direction of the detector) of ± 30 % relative to the response at ^{137}Cs in the energy range from 60 keV to 1.3 MeV.
   Because of the mechanical modification of the detector its outer dimensions are:
   40 mm x 30 mm x 17 mm.
   The reference direction of the detector is perpendicular to its front surface which contains a cross for positioning.
   The reference point of the detector is **8.7 mm** below the cross on its front surface.
   Warning: Due to the modifications mentioned above the reference point given in the manufacturer's manual is not valid any more.

5. **Calibrations**
   The calibrations have to be performed according to the normal procedure as agreed with the Accreditation Body. The angle of radiation incidence is always 0° relative to the reference direction of the detector.
   Calibration of the device is strongly recommended according to ISO 4037-3:1999 [1] and/or ICRU Report 47[2]. General procedures and a practical example are given in [4]. The irradiation of the detector should be performed on a phantom, preferably the ISO water - slab phantom of outer dimensions 30 cm x 30 cm x 15 cm with PMMA walls (front wall 2,5 mm thick, other walls 10 mm thick) filled with water. A solid PMMA slab of the same outer dimensions may be used. When these phantoms are employed as described in ISO 4037-3:1999, no correction factors shall be applied to the reading of the instrument under test, due to the possible differences in back-scatter properties between these phantoms and those of ICRU tissue. Contrary to ISO 4037-3, no build-up plate shall be used in front of the detector.
   The quantity to be measured shall be determined from air kerma at the point of test by application of the relevant conversion coefficient. Air kerma can be measured by positioning the reference point of a standard instrument (without a phantom) at the point of test. Then the reference point of the detector under test should be positioned together with the phantom at the point of test with its reference direction oriented parallel to the direction of radiation incidence.

6. **Standard calibration conditions**
   The calibrations shall be carried out under the following standard calibration conditions:

Influence quantities	Standard calibration conditions
Angle of radiation incidence	Reference direction ± 5°
Irradiation distance	1.5 m to 4 m [a)]
Personal dose equivalent rate	1 mSv/h to 300 mSv/h
Contamination by radioactive elements	Negligible
Radiation background	Ambient dose equivalent rate *H**(10) less than 1 µSv/h
Ambient temperature	18 °C to 23 °C
Relative humidity	50 % to 75 %
Atmospheric pressure	86 kPa to 106 kPa
Stabilization time	> 15 min
A.C. power supply voltage	85 V to 265 V
Frequency	50 Hz to 60 Hz
Electromagnetic field of external origin	Less than the lowest value that causes interference
Magnetic induction of external origin	Less than twice the value of the induction due to the earth's magnetic field

[a)] The point of test shall be chosen at a distance from the source such that the field size in the plane of measurement is sufficiently large to allow the irradiation of the entire phantom front face.

7. Instrument set up

For the purpose of this comparison the instrument described above shall be calibrated in the (electrometer) Mode "CHARGE" and Range "Low 2.4 nA" for the quantity Personal Dose Equivalent $H_p(10)$. The instrument shall be set up in the following way:

a) Position the detector on the phantom in the radiation beam in the desired distance from the source. The fixing material (for instance adhesive tape) shall have a negligible effect on the response of the detector.
b) Position the display unit outside the beam and connect it to the detector with the enclosed extension cable.
c) Connect the instrument to the mains power supply. Alternatively the instrument may be operated in battery mode if interference from the mains supply is suspected. In this case however the instructions concerning the NiCd - accumulators of the instrument in the manufacturer's manual (subclause 6.2.2) must be obeyed.
d) Switch on the instrument and allow for 15 min warm up.
e) Verify the following settings in the Set up menu:
   Unit: C
   AutoOff: Off
   Language: English
   RS232: Off
f) Select the (electrometer) Mode "CHARGE" and Range "Low 2.4 nA".
g) Zero the instrument by pressing the ZERO - button. This can be repeated, if necessary, between measurements.
h) Reset and start the instrument before each irradiation manually by pressing the RESET - and START - button.
i) After irradiation the collected charge will be displayed.
j) Apply <u>no</u> correction to the reading of the instrument when calculating the calibration factor.

8. Report

Each participating laboratory shall, within two weeks after the calibration, send to the office of the relevant Accreditation Body a completed copy of the enclosed calibration report (Appendix 1) and a formal calibration certificate.
The Accreditation Body will send copies of these documents, together with a summary, to the 9organising Accreditation Body.

9. Uncertainty

The calculation of uncertainty shall be carried out according to the method prescribed in EA-4/02, respectively. Additional guidance to the identification and evaluation of components of uncertainty for this type of calibration is given in ISO 4037-3:1999 (subclause 7.2).

APPENDIX 1

Calibration Report

EA - Interlaboratory Comparison IR 4

Calibration of a Personal Dosemeter for Personal Dose Equivalent $H_p(10)$

1. **Date/period of calibration:**
2. **Calibration performed according to standard:**

   ☐ ISO 4037-3

   ☐ ICRU 47

   ☐ other (if yes, please specify):

3. **Standard instrument used for determination of air kerma at the point(s) of test:**

4. **Traceability of standard instrument to which national laboratory:**

5. **Phantom used for calibration, including dimensions- if no phantom is used, please describe calibration procedure:**

6. **Conversion coefficient(s) used from air kerma to personal dose equivalent $H_p(10)$:**
   h_{pK}(10; S-Cs; 0°) for ^{137}Cs: . . . . . . Sv/Gy
   h_{pK}(10; S-Co; 0°) for ^{60}Co: . . . . . . Sv/Gy

7. **Correction factors if applied:**

8. **Display unit controls of circulating instrument:**
   Mode:
   Range:

Setup Menu:

Unit:

AutoOff:

Language:

RS232:

9. Additional information:

10. Calibration data:

Calibration point	Source / beam code to be assigned by participating laboratory	Radio-nuclide	Beam colli-mated ?	Irradiation distance m	Field size at point of test	Personal dose equivalent rate mSv/h	Personal dose equivalent mSv	Calibration factor with expanded uncertainty $N_{Hp(10)}$ µSv/nC (k = 2)	Remarks
~~0~~	~~S 5~~	~~^{137}Cs~~	~~Yes~~	~~2,0~~	~~45 cm diam.~~	~~10.0~~	~~2.0~~	~~XXX ± XX~~	~~Example~~
1									
2									
3									
4									

Additional remarks:

11. Uncertainty budget for calibration factor $N_{Hp(10)}$ (please use separate forms if uncertainty budgets are different for various calibration points):

Calibration point *): ☐ 1 ☐ 2 ☐ 3 ☐ 4 *) please mark relevant point(s)	**Uncertainty**		**Remarks**
Input quantity / Influence quantity	**Type A** %	**Type B** %	
1. Reference value of ☐ air kerma / ☐ air kerma rate **) **) please mark relevant quantity			
2. Conversion coefficient h_{pK}(10; S-Cs; 0°), h_{pK}(10; S-Co; 0°)			
3. Reading of circulating instrument			
4.			
5.			
6.			
7.			
8.			
Relative combined standard uncertainty of $N_{Hp(10)}$ (k = 1)			
Relative expanded uncertainty of $N_{Hp(10)}$ (k = 2)			

Additional remarks: