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Servizio di Taratura in Italia

FINAL REPORT

European co-operation for Accreditation (EA)

Interlaboratory Comparison IR3:
Calibration of a Radiation Protection Dosimeter

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1. INTRODUCTION

This report describes the results of the EA Interlaboratory Comparison (ILC) carried out in the period from May 2000 and May 2002 with the title: "*Calibration of a Radiation Protection Dosimeter*" and under the code IR3. The EA Expert Group "Ionising Radiation and Radioactivity" (EG) planned the ILC on September 1999 and it was agreed by the EA General Assembly on December 1999 under the code IR3.

The aim of the ILC was investigate and demonstrate the capabilities of the laboratories accredited in the ionising radiation field for calibration of dosimeters in terms of the quantity Air Kerma (K_{air}) at radiation protection levels.

The need of this ILC resulted from an inquiry carried out in 1998 by the EG among the different Accreditation Bodies (ABs) members of EA or associated to EA. Moreover, the present ILC was a supplement of a previous ILC carried out in the period from May 1993 to September 1994 with the title "*Dosimetry*" and under the code IR1 [1]. The two ILCs, IR1 and IR3, investigated the same measuring field. In fact, the aim of the ILC IR1 was the calibration, in terms of the quantity K_{air}, of a portable environmental doserate monitor operating at radiation protection levels (a Nardeux Babyline 81, type E 793). Eighteen laboratories from twelve countries (members or associated to EA) participated in the ILC IR1 sending to the reference laboratory a total of 241 results. Each laboratory was required to perform measurements in many different experimental conditions: five x and gamma radiation qualities chosen from ISO standard 4037-1979 with eleven values of air kerma or air kerma rate. Some unexpected problems stressed during the IR1 comparison exercises made it difficult the analysis of the results. The most evident of these problems was a significant distance dependence of the circulating instrument response, due to the large volume and the special geometry (truncated conical) of the detector [2]. This distance effect was observed in the results of the participating laboratories and further experimentally investigated by the reference laboratory. This effect resulted function of the distance and the radiation energy, being more evident at higher energies (^{137}Cs and ^{60}Co gamma radiations) rather than at lower energies (x radiations). As the measuring distances used by ILC participants were very different (ranging from 0.4 m to 6 m) the EG decided to consider results obtained for distances ≥ 1 m including a correction to account for the distance effect in the analysis of the ILC result. Of the 241 participants results, only 199 were obtained for distances ≥ 1 m and were analyzed founding satisfactory (i.e. with normalized error $E_n \leq 1$) the 31% of the results incorrect and the 68% of the same results after correction for the distance effect. The conclusion of the EG was to consider the ILC IR1 "*as a first trial*". Some improvements were considered as necessary in order to fulfil the requirements for establishing mutual confidence among calibration services. Each laboratory was recommended to investigate for its proper irradiation conditions and for the effect of distance on the calibration factors. The ILC IR3 was then planned in the same measuring field of the previous ILC IR1, but with a more limited range of experimental conditions and using a more characterized dosimeter of secondary standard level.

2. GENERAL INFORMATION

2.1 Organisation

This ILC was organised according to the EA recommendations [3]. The organisation was arranged by the Italian AB in the ionising radiation field, the SIT-ENEA, in cooperation with the Italian National Metrological Institute in the ionising radiation field, the ENEA-INMRI (1), as the reference laboratory.

Addresses and contact persons responsible for the ILC were given below.

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The contents of the ILC IR3 were determined during the meetings of the EG. The instructions

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of the ILC were prepared by the PTB [(1)] (Germany) and the SIT-ENEA [(2)] (Italy). In January 2000, the SIT-ENEA sent an invitation letter and the preliminary instructions agreed by the EG to all the EA contact persons. Within February 2000, the AB's interested in the ILC nominated the participating laboratories. At the end of March 2000, the EG established the first list of participants (see section 2.3) included in the final ILC instructions.

2.2 Principle of the comparison

The principle of the ILC was the calibration of a dosimeter in terms of the quantity K_{air} due to gamma radiation beams at radiation protection level. The circulating instrument was a dosimeter well characterised as a secondary standard, kindly supplied by the manufacturer as a loan. The measuring assembly includes a voltage source to polarise the ionisation chamber and a high precision programmable electrometer with a display unit. The detector is a 30 cm^3 cylindrical ionisation chamber having walls made of air equivalent plastic with a nominal total thickness of 1.0 mm and a 3.0 mm thick additional build-up cap provided for the energy of ^{137}Cs and ^{60}Co gamma radiations. The effective point of measurement recommended for this detector was well determined as coinciding with the geometric centre of the chamber.

The ILC audit pack consisted of the following items:

a) the ionisation chamber PTW[(3)] type 23361 serial number 0405 (see figure 1a);
b) a build-up cap for the energy of ^{137}Cs and ^{60}Co gamma radiations (see figure 1a);
c) the measuring assembly PTW UNIDOS type 10002 serial number 20383 (see figure 1b);
d) a 20 m extension cable to connect the detector and the measuring assembly (see figure 1b);
e) the instruction manual;
f) the ILC final instructions including report forms, list of participants, time schedule and delivery addresses;
g) the ATA carnet (in the case of transportation out of the European Community).

The participants were asked to calibrate the circulating dosimeter in gamma radiation beams from ^{137}Cs and/or ^{60}Co sources [4] according to the procedures agreed with their AB and to the ILC instructions (see appendix A.2). Accounting for the characteristics of the dosimeter, it was recommended to carry out measurements with values of the air kerma rate, $\dot{K}_{air}$ in the

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[3] Physikalisch-Technische Werkstätten (Freiburg, DE)

range from 1 μGy s^{-1} to 0.5 mGy s^{-1}. For each ^{137}Cs or ^{60}Co source, the participants had to perform the dosimeter calibration at a measuring distances of about 1 m and at a second measuring distance as long as possible (depending on the prescribed lower limit of K_{air}) but lower than 4 m.

The interest quantity to be determined by each participant was the calibration coefficient $(N_K)_{lab}$ of the circulating dosimeter given by

$$(N_K)_{lab} = \frac{(K_{air})_{lab}}{M_C} \qquad (1)$$

where $(K_{\mathrm{air}})_{lab}$ is the air kerma value determined by the laboratory at the effective point of measurement; M_C is the reading of the dosimeter normalised to the reference conditions of temperature (293.15 K) and pressure (1013.25 Pa).

The value of $(N_K)_{lab}$ was expressed in Gy C^{-1}, being the values of $(K_{\mathrm{air}})_{lab}$ and M_C expressed in Gy and in C, respectively.

The participants were asked to estimate and express the measurement uncertainty according to the EA recommendations [5], as expanded uncertainty U with coverage factor k = 2.

In order to facilitate the analysis of the ILC results, it was recommended that participants presented the data relevant for measurements (such as results, uncertainty budget, sources characteristics, irradiation geometry, etc.) in a common way using specific report forms (see appendix A.3) enclosed to the ILC instructions.

Further details about the dosimeter and the measurements modalities are in the ILC instructions (see appendix A.2).

2.3 Participants

The number of participants for each country was limited to a maximum of two laboratories by the need to keep the total time for the dosimeter circulation limited to 18 months as required by the EA [3]. The order of priority for participation was: 1) laboratories which participated in the previous ILC IR1 (see introduction); 2) accredited laboratories from countries members of EA; 3) laboratories in the process for accreditation from countries members of EA; 4) accredited laboratories from countries associated to EA; 5) not accredited laboratories from countries members of EA.

A first list of participants was established during the EG meeting on March 2000. During the course of the ILC, this original list varied with the agreement of the EG members on request of SANAS (South Africa) and NA (Norway). On May 2000, SANAS nominated a laboratory that was added at the end of the circulation scheme. On February 2002 (just after the end of the circulation of the instrument), the NA strongly expressed its interest on the ILC pointing out that the Norwegian laboratory was not included in the originally agreed schedule due to communication problems. The EG recognized the reason of the NA and agreed to allow the Norwegian laboratory to participate in the ILC exercises with such large delay.

A total number of 21 laboratories designated by the ABs of 17 countries were then scheduled to take part in the comparison exercise according to the final scheme given in table 1. Among these laboratories, 18 were from countries members of EA and 3 from countries associated to EA. Moreover, 7 laboratories were not accredited among which 6 were national laboratories.

On March 2001, the DANAK (Denmark) received the audit package but informed the organising AB that its nominated laboratory was "*not able to calibrate the travelling dosimeter within the range specified in the measurement instruction*". Consequently, the Danish laboratory withdrew from the comparison exercise. The laboratory was not yet accredited and it decided to defer the application for accreditation due to the missing result of this ILC.

Finally, 20 laboratories from 16 countries participated effectively in the comparison exercise giving their results to the reference laboratory. Among these participants, 11 laboratories from 10 countries also participated in the previous ILC IR1 (see details in table 1).

2.4 Circulation of the dosimeter

The ILC was substantially of the circular type according to the circulation scheme given in figure 2. First the dosimeter circulated among the participants in the countries of the European Community and then among the other participants. The Norway added at the end of the circulation scheme (see section 2.3). During the whole circulation period, the dosimeter was returned five times to the reference laboratory to check its stability and to establish the reference value.

The circulating dosimeter was dispatched among the participating Abs according to the time schedule given in table 2 and shown in figure 3. Each AB was responsible for the circulation within its country between the nominated laboratories. The time allowed to each participant for the different phases of the ILC was stated in compliance with EA documents [3]: a) two weeks for the travelling time between the ABs of the different countries; b) two weeks for the measurement time at each laboratory in the country (including the travelling time within the country); c) two weeks after the calibration, for the laboratory to send the filled report forms and the formal calibration certificate (or test report) to the relevant AB; d) one month for the relevant AB to send copies of the documents of point c), together with a summary, to the organising AB.

The AB and the laboratories were asked to take special care not to exceed the time allowed.

The whole circulation of the dosimeter took a period of two years, starting in May 2000 and ending in May 2002. This period was a little longer than the recommended period of 18 months [3] as scheduled in the ILC final instructions. The delay was essentially due to the inclusion of two further laboratories at the original list of participants (see section 2.3) and was not due to problems in the dosimeter circulation.

3. RESULTS

3.1 - Reference values

The dosimeter was calibrated at the reference laboratory, according to [6] and to internal procedures assuring the traceability to the national air kerma standards [7, 8] of the ENEA-INMRI. The circulating dosimeter calibration was performed at a measuring distance d = 1 m with a nominal value of $\dot{K}_{air}$ = 1.3 10^{-6} Gy s^{-1} due to ^{137}Cs gamma radiation and at a measuring distance d = 2 m with a nominal value of $\dot{K}_{air}$ = 5 10^{-4} Gy s^{-1} due to ^{60}Co gamma radiation.

During the ILC period of two years, five complete calibration cycles were carried out to establish the reference value and to check its stability (see figures 2 and 3). For each calibration cycle i (i = 1 to 5) and each gamma radiation (^{137}Cs or ^{60}Co), a series of 30 measurements was performed. In the whole, 10 series of measurements were performed each having an experimental standard deviation (denoted as short-term standard deviation) in the range from 0.1 % to 0.3 %. Other measurements were carried out to investigate the circulating dosimeter characteristics. These measurements were not used to assess the reference values and they are described in the appendix 1.

For each radiation quality and referring to the cycle i, the value of the calibration coefficient

N_K^i was given by:

$$N_K^i = \frac{\left(K_{air}^i\right)_{ref}}{M_C^i} \qquad \text{(i = 1 to 5)} \qquad (2)$$

where $\left(K_{air}^i\right)_{ref}$ is the K_{air} value determined by the standard at the effective point of measurement; M_C^i is the mean reading of the circulating dosimeter normalised to reference conditions of temperature (293.15 K), pressure (1013.25 Pa) and relative humidity (50%). The value of N_K^i was expressed in Gy C^{-1} being the values of $\left(K_{\mathrm{air}}\right)_{ref}$ and M_C^i expressed in Gy and in C, respectively.

Five values of the calibration coefficient N_K^i were then determined for each radionuclide, ^{137}Cs and ^{60}Co, corresponding to the five calibration cycles. Table 3 shows the N_K^i obtained and in figure 4 a graphical representation of these data is given. For both radiation qualities, the maximum deviation and the standard deviation (denoted as long-term standard deviation) among the five N_K^i values resulted lower than 0.6% and 0.3%, respectively. The values of the short and the long-term standard deviations were of the same order and this indicated that the circulating dosimeter was stable over the whole ILC duration. All the measurements performed in this period were then comparables.

For each radionuclide, ^{137}Cs and ^{60}Co, the reference values $\left(N_K\right)_{ref}$ for the ILC was determined as:

$$\left(N_k\right)_{ref} = \frac{\sum_1^5 N_K^i}{5} \cdot k_{sat} \cdot k_{geom} = \overline{N}_K \cdot k_{sat} \cdot k_{geom} \qquad (3)$$

where $\overline{N}_K$ is the arithmetic mean of the five values N_K^i obtained for the calibration coefficient; k_{sat} and k_{geom} are the correction factors for ion recombination in the sensitive volume of the detector and for the displacement of the effective measuring point with the source-detector distance, respectively. The values of k_{sat} and k_{geom} are given in table 3. They were determined for use in equation 3 as function of the air kerma rate and the measuring distance, respectively (see appendix A.1).

The values obtained for $\overline{N}_K$ and $\left(N_K\right)_{ref}$ are given in table 3. A graphical representation of these data is also given in figure 4. The expanded uncertainty associated to the $(N_K)_{ref}$ values is not higher than 1.5%, with a coverage factor k = 2. The component of uncertainty due to the long-term stability of the circulating instrument was estimated from the maximum deviation observed among the five values obtained for N_K^i and assuming a rectangular distribution of possible values. Details about the uncertainty budget are given in table 4.

3.2 - Participants values

A total of 60 $(N_K)_{lab}$ results were sent by the 20 participating laboratories to the reference laboratory, but only 58 of them were effectively analysed. In fact, on June 2002 a laboratory stated: "*something wrong was found in the experimental equipment used to obtain two of the results given*". According to the AB responsible, the EG agreed to exclude these wrong results accounting for the fact that the laboratory drew back its results before know comparison results.

For the evaluation of the ILC results, the data given by participants in the report forms were used. The correspondence among these data and those given in the calibration certificate was also checked. Tables 5 and 6 summarize all the results given by participants for the ^{137}Cs and ^{60}Co gamma radiations, respectively. Figures 5 and 6 graphically show the results as function of the calibration period for the ^{137}Cs and the ^{60}Co gamma radiations, respectively. No particular trend was observed on the results $(N_K)_{lab}$ as function of the execution date. The arithmetic mean of all the results $(N_K)_{lab}$ given by participants differs from the reference value $(N_K)_{ref}$ of about the 0.20 % and 0.02 % in the case of the ^{137}Cs and ^{60}Co gamma radiations, respectively.

No laboratory applied correction factors accounting for the dependence of the dosimeter response on the air kerma rate and on the measuring distance.

3.3 – Correction factors

A preliminary analysis of the effects influencing the dosimeter response was carried out by the reference laboratory on the aim to investigate possible influence on the analysis of the ILC results. The effects considered were the dependence of the dosimeter response on the air kerma rate and on the measuring distance. These two effects were experimentally investigated at the reference laboratory in different conditions of K_{air} and *d*. The values of the correction factors for ion recombination in the sensitive volume of the detector, k_{sat}, and for the displacement of the effective measuring point with the source-detector distance, k_{geom}, were determined as function of the air kerma rate and the measuring distance, respectively. Due to the circulating dosimeter characteristics, each of the two above-mentioned effects was expected to have a small influence (less than 0.2 %) on the dosimeter response in the range of K_{air} and d recommended for the ILC measurements (see section 2.1 and appendix A.2). As expected, for the experimental conditions in which the ILC measurements were performed, the factors k_{sat} resulted to be in the range (1.0009 to 1.0012), the factor k_{geom} in the range (1.0003 to 1.0015) and their product ($k_{sat}\,k_{geom}$) in the range (1.0014 to 1.0027). All details are given in the appendix A.1.

The maximum deviation among the results $(\mathrm{N_K})_{\mathrm{lab}}$ given by the participants that was expected as due to the above-mentioned effects was then lower than 0.15 %. The additional uncertainty due to the omission of these corrections in the $(\mathrm{N_K})_{\mathrm{lab}}$ determination, was then considered negligible respect to the overall uncertainty associated to $(\mathrm{N_K})_{\mathrm{lab}}$ given by the participants.

3.4 - Comparison results

Each result $(N_K)_{lab}$ given by the participants was compared with the corresponding reference value $(N_K)_{ref}$. According to EA recommendation [3], the parameter considered to check the measurements compatibility was the error E_n normalised with respect to the expanded uncertainty U (with coverage factor k = 2) given by

$$E_n = \frac{(N_K)_{lab} - (N_K)_{ref}}{\sqrt{U(N_K)_{lab}^2 + U(N_K)_{ref}^2}} \qquad (4)$$

where $U(N_K)_{lab}$ and $U(N_K)_{ref}$ are the expanded uncertainties (k = 2) associated to the values of $(N_K)_{lab}$ and $(N_K)_{ref}$, respectively. Absolute values of E_n less than unity should be obtained for the measurement to be acceptable. It is important to point out that, this analysis is based on the assumption that all the measurement uncertainties were correctly estimated (avoiding overestimate) and that all correlations were accounted for.

The uncertainties $U(N_K)_{lab}$ and $U(N_K)_{ref}$ referring to the Italian participating laboratories (IT1 and IT2) were corrected for correlation being the results of these laboratories and the reference value traceable to the same national standard.

The values obtained for E_n (as representing the ILC results) are given in tables 5 and 6 for ^{137}Cs and ^{60}Co gamma radiations, respectively. The same data are graphically shown in figures 7-10 where also the arithmetic mean and the median of the E_n values are shown. Figures 7 and 8 shown the results obtained as function of *d* and $\dot{K}_{air}$ for the ^{137}Cs gamma radiation. Figures 9 and 10 shown the results obtained as function of *d* and $\dot{K}_{air}$ for the ^{60}Co gamma radiations.

4. RESULTS ANALYSIS

4.1 Measurements

The analysis of ILC results E_n *was* satisfactory being $|E_n| < 1$ for 57 of the 58 measurement results analyzed (see tables 5 and 6). In the case of ^{137}Cs gamma radiation, 39 values of E_n were obtained, one being out the acceptance limits. The results were well distributed in the range from +0.9 to –1.3 with arithmetic mean and median equal to +0.13 and +0.22, respectively. In the case of the ^{60}Co gamma radiation, 19 values were obtained for E_n all being within the acceptance limits and well distributed in the range from +0.9 to –0.7 with arithmetic mean and median equal to +0.01 and -0.05, respectively.

Figures 7 to 10 show that the values of E_n are randomly distributed around the arithmetic mean. No particular trend is observed whether as function of *d* or as function of $\dot{K}_{air}$, in both cases the ^{137}Cs and ^{60}Co gamma radiations. The unsatisfactory results ($|E_n| > 1$) was analysed as function of *d* and of $\dot{K}_{air}$, but no particular correlations were found.

4.2 Measurement uncertainty

The uncertainty associated to the comparison result $(N_K)_{lab}$ was expressed by participants as expanded uncertainty $U(N_K)_{lab}$ obtained from the combined standard uncertainty $u[(N_K)_{lab}]$ with a coverage factor k = 2, according to the ILC instructions and the EA recommendations [3]. In figures 11 and 12, a first analysis of the measurement uncertainties $U(N_K)_{lab}$ given by participants is shown for ^{137}Cs e ^{60}Co gamma radiation, respectively. The values estimated for

$U(N_K)_{lab}$ were in the range from 1.2 % to 8.0 %. This range is rather large, but the majority (97 %) of these values were in a more limited range from 1.2 % to 4.0 %.

It was scheduled a more detailed analysis of the uncertainty components accounted for by each participants to obtain $u[(N_K)_{lab}]$. On this purpose, the participants were asked to fill a form (see appendix A.3) with uncertainty budget details. Although all participants were strongly asked about this additional information, only 14 of the 20 participating laboratories (70%) returned the filled form. Moreover, the information given was sometimes not clear and/or not complete. Details are given in tables 8 and 9. For these 14 laboratories, the standard uncertainty $u[(N_K)_{lab}]$ on the laboratory comparison result $(N_K)_{lab}$ was compared with the standard uncertainty $u[(N_{K,ref})_{lab}]$ on the calibration coefficient $(N_{K,ref})_{lab}$ reference standard (given by the national metrological institute) used by the laboratory. The ratio R = $u[(N_K)_{lab}]/\ u[(N_K)_{ref,lab}]$ of these two quantities allowed evaluating the increase of the uncertainty due to one single calibration step at the laboratory. The $u[(N_{K,ref})_{lab}]$ values were in the range from 0.4 % to 3.0 % and the $u[(N_K)_{lab}]$ values in the range from 0.6 % to 4.0 % (see details in tables 8 and 9). The values obtained for R were in the range from 1.1 to 2.8, as shown in table 10 and in figure 13. Il was denoted $(u_{add})_{lab}$ the overall component of the standard uncertainty that was added to $u[(N_{K,ref})_{,lab}]$ in determining $u[(N_K)_{lab}]$, determined as:

$$(u_{add})_{lab} = \sqrt{u[(N_K)_{lab}]^2 - u[(N_{K,ref})_{lab}]^2} \qquad (5)$$

The values obtained for $(u_{add})_{lab}$ were in a large range, from about 0.4% to about 2.7% (details are shown in figure 14). Il would be interesting to correlate these value with the different experimental set-up at the calibration laboratories, but this detail of information was not investigated in the present comparison. Data sent by participants on the uncertainty budged did not allow performing analysis that was more rigorous.

4.3 Measurements parameters

All the participants were asked to present details and information relevant for measurements in a common way using report forms (see appendix A.3) enclosed to the ILC instructions. This recommendation was fulfilled by all the laboratories (see details in table 7).

The 67 % of the results given by participants were for ^{137}Cs gamma radiation beams and the remainder for ^{60}Co gamma radiation beams. Among the 20 participants, only 9 laboratories sent results for both radiation qualities. Overall, 19 laboratories gave results for the ^{137}Cs gamma radiation and 10 laboratories gave results for the ^{60}Co gamma radiation. Some participants sent many set of results obtained using different radioactive sources of the same radionuclide.

The reference standard for $(K_{\text{air}})_{lab}$ determination was an ionisation chamber for the 60 % of the participants and a calibrated reference instrument or field without specify other details for the 30 % of the participants. The remainder 10% did not give any information. The volume of the specified reference chambers was 30 cm^3 for the 20 % of the participants and in the range (300 cm^3 to 1000 cm^3) for the 40 % of them.

The environmental conditions were not much different at the participating laboratories during calibration measurements, as shown in figure 15. The maximum deviation observed among the ambient correction factors k(T,P) applied by the participants was not higher than 0.15%.

The measuring distances *d* were all in the recommended range (1 m to 4 m), being the 50 % of the measurements performed at the lower distance of 1 m and only about the 12 % at the higher limit of 4 m (see figures 16a and 17a).

The majority of the measurements (66 %) were performed with $\dot{K}_{air}$ in the range from 1µGy s^{-1} to 20 µGy s^{-1}, near the lower limit stated for the ILC exercise (see figures 16b and 17b). The higher values used for the measurements were about 0.25 mGy s^{-1} and 1.5 mGy s^{-1} (three times the higher limit recommended in the ILC instructions) for the ^{137}Cs and ^{60}Co gamma radiations, respectively. The corresponding range of the ionization current measured with the circulating dosimeter was about from1 pA to 1.5 nA. A very wide range of measuring time (from 20 s to 600 s) was used (see figures 16c and 17c) with a measured charge in the range from 50 pC to 0.1 µC.

The measuring range selected on the measuring assembly associated to the circulating dosimeter was: not specified in the 46 % of cases; the range “high - 23 nC” in the 50 % of cases and the range “low - 230 pC” in the 4 % of cases.

In figures 16d-f and 17d-f other relevant measurement parameters at participating laboratories are shown for the ILC measurements performed in ^{137}Cs and ^{60}Co gamma radiation beams, respectively.

4.4 Calibration certificates

The contents of the calibration certificates were checked for compliance with the Standard EN ISO/IEC 17025:2000 and the results are given in table 11. All points were accurately verified in order to improve the standardization within the EA and to prevent misunderstanding.

The following points of the standard resulted mostly to be still improved (some comments where also given to clarify):

5.10.1: - the results are reported with an excessive number of digits [1].
-other terms are used instead of "*calibration coefficient*" or "*calibration factor*" (such as "air kerma/charge" or "system factor").
-the result of the calibration is given not as "*calibration coefficient*" or "*calibration factor*", but as two separate values: the "air kerma" and the corresponding "charge" or "instrument reading".
-the calibration coefficient is expressed as (Gy/rdg) instead of (Gy/C).

5.10.2e: -the code of the calibration procedure, agreed by the AB, is not specified in the certificate (sometime just a very short description of the method was given).

5.10.4.1c: -the certificate did not specify the identification of the standard used and/or of the evidence of the traceability.

5. CORRECTIVE ACTIONS AND COMMENTS

According to EA rules [4], the draft report of the present comparison was agreed by the EG. The participating ABs received it on January 2003 with the request of some missing information. They were also asked to inform the participating laboratories about the results of the ILC for explanation and/or corrective actions if required. The organising AB received written agreement and/or comments from ENAC (Spain), SWEDAC (Sweden), SNAS (Slovakia), IPQ (Portugal) and FINAS (Finland). All comments were accounted for in writing the final report. No information was received by participating AB about the outcome of corrective actions for inclusion in the final report. This was probably due to the fact that mostly of the results was satisfactory and some non-conformities were observed only in the calibration certificates. In June 2003 the final report was discussed and agreed by the EG. At

[1] A practical method suggested and adopted by the EG is to report the result with a number of digits corresponding to the first two digit of the associated uncertainty.

the end of June, the laboratory with code FR1 informed its AB and the organising AB that one of its results was not correct due to a wrong value of the ambient pressure with a consequent mistake in determining the corresponding correction factor k(T,P). The value of the third result of FR1 laboratory in table 6 could then change from 9.35 to 9.24. Consequently, the corresponding normalized error E_n in table 6 could change from 0.87 to 0.35. No corrective actions were communicated to prevent this type of problems.

6. CONCLUSIONS

A wide majority (98%) of the participants results were satisfactory giving $|E_n| < 1$. The results are then compatible with the reference value and each other. Moreover the results are well distributed around the reference value giving arithmetic means of the E_n values close to zero for both ^{137}Cs ($\overline{E}_n$=0.13) and ^{60}Co ($\overline{E}_n$=0.01) gamma radiations. The value of the median of the E_n values is very close to that of the arithmetic mean in both cases. Results are statistically distributed and there are not systematic differences. They show no dependence on the execution date or on the different experimental conditions of the air kerma rate and of the measurement distance used by participants.

The difficulty of the participating laboratories to give clear and detailed information on the uncertainty budget did not enable a full analysis of the uncertainty. This was an important point, in fact the use of the normalized error E_n (see section 3.4) to validate the comparison results required a check on the uncertainty budget to avoid overestimate and to account for possible correlations. Moreover, the uncertainty is integrant part of the calibration result and it is a duty of the accredited laboratories to give all information about its uncertainty budget if required by client.

In conclusion, the overall result of the ILC IR3 may be considered satisfactory on the purpose to verify the capabilities and the technical equivalence of the calibration services in the measuring field investigated: the calibrations in terms of air kerma of secondary standard level dosimeters at protection level. In this respect, the present comparison was considered a starting point being performed in the best measurement capability conditions (i.e. at secondary standard level). Once verified the technical equivalence of the calibration services in these favourable conditions, further comparisons should be planned using calibration conditions close to the effective request of the users in the radioprotection field. This measuring field is expected to be more critical for the instruments characteristics, and/or the measurement parameters and procedures.

Table 1 – Participants on the ILC IR3, in alphabetical order (RC = reference chamber; CF = calibrated field; NL = national laboratory)

Country	Accreditation Body	N. lab.	Lab. code	Accredited	Traceable to	Radiation qualities	Standard (RC/CF)	Participant on ILC IR1
Austria	BMwA	1	AT	yes	BEV	^{137}Cs, ^{60}Co	CF	no
Denmark	DANAK	1	DN [(1)]	no	BIPM/NPL	-	-	no
Finland	FINAS	1	FI	no (NL)	BIPM/NPL	^{137}Cs, ^{60}Co	RC: PTW M23361 and Exradin A3	yes
France	COFRAC	2	FR1	yes	BNM	^{137}Cs, ^{60}Co	RC	yes
			FR2	yes	BNM	^{137}Cs	RC: PTW LS01	yes
Germany	DKD	1	DE	yes	PTB	^{137}Cs, ^{60}Co	RC: TM 23361	yes
Greece	ESYD	1	GR	no (NL)	IAEA	^{137}Cs	RC: PTW W32002	no
Ireland	NAB	1	IE	yes	PTB	^{137}Cs	RC: PTW LS-01	no
Italy	SIT-ENEA	2	IT1	yes	ENEA-INMRI	^{60}Co	RC: Exradin A4	yes
			IT2	yes	ENEA-INMRI	^{137}Cs, ^{60}Co	RC: OFZS TK-30	yes
Norway	NA	1	NO	yes	BIPM	^{137}Cs, ^{60}Co	RC: Capintec PR06G	yes
Portugal	IPQ	1	PT	no (NL)	PTB	^{137}Cs	CF	yes
Slovak Republic	SNAS	1	SK	no (NL)	OMH	^{137}Cs	CF	no
Slovenia	SMIS-SA	1	SI	no (NL)	NPL	^{137}Cs	RC: LS-01	no
South Africa	SANAS	1	ZA	yes	CSIR-NML	^{137}Cs	RC: Ionex dosemeter	yes
Spain	ENAC	1	ES	yes	PTB	^{137}Cs	RC: NE 2575	yes
Sweden	SWEDAC	1	SE	no (NL)	BIPM	^{137}Cs, ^{60}Co	RC: Exradin A4	yes
United Kingdom	UKAS	2	GB1	yes	NPL	^{137}Cs, ^{60}Co	RC: NE (600 cc)	yes
			GB2	yes	NPL	^{137}Cs	RC: NE (600 cc)	yes
United States	A2LA	2	US1	yes	NIST	^{137}Cs	CF	no
			US2	yes	NIST	^{137}Cs, ^{60}Co	-	no

[(1)] The laboratory withdrew from the comparison exercise after receiving the audit package (see section 2.3).

Table 2 – Time schedule for the circulation of the ILC IR3 circulating instrument.

Number of weeks	Estimated time schedule	Circulation scheme	Actual time schedule	Number of weeks
0	First measurements	Germany	First measurements	0
1	08 May - 14 May 2000	**Reference lab.**	08 May - 14 May 2000	1
5	15 May - 11 June 2000	Italy	15 May - 31 May 2000	3
7	12 June - 25 June 2000	travelling time	1 June - 5 June 2000	4
9	26 June - 09 July 2000	Spain	6 June - 22 June 2000	6
11	10 July - 23 July 2000	travelling time	23 June - 27 June 2000	7
15	24 July - 20 August 2000	France	28 June - 20 August 2000	15
17	21 August - 03 September 2000	travelling time	21 August - 23 August 2000	16
21	04 September - 01 October 2000	United Kingdom	24 August - 03 October 2000	21
23	02 October - 15 October 2000	travelling time	04 October - 5 October 2000	21
25	16 October - 29 October 2000	Ireland	5 October - 20 October 2000	23
27	30 October - 12 November 2000	travelling time	20 October - 24 October 2000	24
29	13 November - 26 November 2000	Portugal	25 October - 30 November 2000	29
31	27 November - 10 December 2000	travelling time	30 November - 5 December 2000	30
32	11 December - 17 December 2000	**Reference lab.**	07 December - 15 December 2000	32
35	18 December - 07 January 2001	travelling time	15 December - 19 December 2000	33
37	08 January - 21 January 2001	Greece	19 December- 22 January 2001	37
39	22 January - 04 February 2001	travelling time	22 January - 31 January 2001	38
41	05 February - 18 February 2001	Finland	31 January - 18 February 2001	41
43	19 February - 04 March 2001	travelling time	19 February - 22 February 2001	42
45	05 March - 18 March 2001	Denmark	23 February - 19 March 2001	45
47	19 March - 01 April 2001	travelling time	20 March - 22 March 2001	46
49	02 April - 15 April 2001	Sweden	23 March - 19 April 2001	49
51	16 April - 29 April 2001	travelling time	20 April - 23 April 2001	50
53	30 April - 13 May 2001	Austria	24 April - 15 May 2001	53
55	14 May - 27 May 2001	travelling time	16 May - 20 May 2001	54
56	28 May - 03 June 2001	**Reference lab.** (ATA carnet)	21 May – 25 May 2001	55
58	04 June - 17 June 2001	travelling time	25 May – 29 May 2001	56
60	18 June - 01 July 2001	Slovakia	30 May - 15 June 2001	58
62	02 July - 15 July 2001	travelling time	16 June - 21 June 2001	59
64	16 July - 29 July 2001	Slovenia	22 June - 24 July 2001	63
66	30 July - 12 August 2001	travelling time	25 July - 01 August 2001	64
68	13 August - 26 August 2001	USA	02 August - 24 September 2001	72
70	27 August - 09 September 2001	travelling time	25 September – 18 October 2001	75
72	10 September-23 September 2001	South Africa	19 October – 22 November 2001	80
74	24 September- 07 October 2001	travelling time	22 November – 14 January 2002	88
93	Final measurements	**Reference lab.**	15 January – 19 February 2002	93
		travelling time	05 April – 12 April 2002	101
		Norway	13 April – 30 April 2002	103
	Total time: 74 weeks	travelling time	01 May – 7 May 2002	104
		Reference lab.	Final measurements	105
			Total time: 104 weeks	

Table 3 – Reference values $(N_K)_{ref}$ of the ILC IR3, for ^{137}Cs and ^{60}Co gamma radiations. Each value was determined by applying the correction factors k_{sat} and k_{geom} to the arithmetic mean $\overline{N}_K$ of the five measured values of the circulating dosimeter calibration coefficient N_K^i (see details in section 3.1).

Radiation quality	distance (cm)	$\dot{K}_{air}$ (1) (Gy s^{-1})	date	M_C^i (2) (10^{-12} A)	s (3) (10^{-12} A)	N_K^i (10^5 Gy C^{-1})
^{137}Cs gamma radiation	100	1.3 10^{-6}	09/05/00	1.406	0.003	9.19(14)
			10/05/00	1.408	0.003	9.17(14)
			11/12/00	1.400	0.004	9.23(14)
			07/02/02	1.390	0.004	9.20(14)
			15/05/02	1.400	0.003	9.22(14)
	$\overline{N}_K$ (10^5 Gy C^{-1})			9.20(14)		
	$s(\overline{N}_K)$ (10^5 Gy C^{-1}) (4)			0.024		
	k_{sat}			1.0009(20)		
	k_{geom}			1.0014(20)		
	$(N_K)_{ref}$ (10^5 Gy C^{-1})			9.19(14)		
	$U[(N_K)_{ref}]_{(k=2)}$ (%)			1.5		

Radiation quality	distance (cm)	$\dot{K}_{air}$ (1) (Gy s^{-1})	date	M_C^i (2) (10^{-12} A)	s (3) (10^{-12} A)	N_K^i (10^5 Gy C^{-1})
^{60}Co gamma radiation	200	0.7 10^{-3}	09/05/00	7.507	0.010	9.18(14)
			13/12/00	7.493	0.004	9.20(14)
			23/05/01	7.502	0.012	9.18(14)
			22/01/02	7.512	0.009	9.17(14)
			15/05/02	7.505	0.012	9.18(14)
	$\overline{N}_K$ (10^5 Gy C^{-1})			9.18(14)		
	$s(\overline{N}_K)$ (10^5 Gy C^{-1}) (4)			0.011		
	k_{sat}			1.0010(20)		
	k_{geom}			1.0007(20)		
	$(N_K)_{ref}$ (10^5 Gy C^{-1})			9.17(14)		
	$U[(N_K)_{ref}]_{(k=2)}$ (%)			1.5		

(1) The reference date is February 7 2002.
(2) Reading of the dosimeter at the reference ambient conditions (T = 293.15 K, P = 101.325 kPa, H_{rel} = 50% U).
(3) Standard deviation of a series of 30 measurements (denoted as short-term standard deviation).
(4) Standard deviation of the series of five values obtained for N_K^i (denoted as long-term standard deviation).

Table 4 –Uncertainty budget associated to the ILC IR3 reference values $(N_K)_{ref}$. The same uncertainty budget was obtained for both gamma radiations, ^{137}Cs and ^{60}Co

Standard uncertainty component	**Cat. A (%)**	**Cat. B (%)**
Transfer standard (first level measurements)	0.28	0.47
Circulating dosimeter (second level measurements):		
current	0.3 [(1)]	0.25 [(2)]
positioning	0.05	-
Recombination loss	-	0.1
Effective measuring point	-	0.1
Pressure	-	0.02
Temperature	-	0.03
Humidity	-	0.05
Leakage	-	0.05
Radial non-unif.	-	0.15
Stability over the ILC period	-	0.2 [(3)]
Quadratic sum	0.41_3	0.61_0
Combined standard uncertainty, u	0.74 %	
Expanded uncertainty, U (k = 2)	1.5 %	

(1) Estimated as the largest value of the short-term standard deviation.
(2) Estimated by all the available information.
(3) Estimated from the largest deviation among the values of N_K^i obtained (for the ^{137}Cs or the ^{60}Co gamma radiations) and assuming a rectangular probability distribution of possible values.

Table 5 – Results $(N_K)_{lab}$ and associated expanded uncertainty U_{lab} (k = 2) given by the participants on the ILC IR3 for the ^{137}Cs gamma radiation. The corresponding normalized errors E_n are also given as representing the ILC results.

Lab code	$(N_K)_{lab}$ (10^5 Gy C^{-1})	$U_{(k=2)}$ (%)	E_n	**Distance** (cm)	$\dot{K}_{air}$ (Gy s^{-1})
DE	9.28(19)	2.0	0.41	95	$1.2 \cdot 10^{-4}$
DE	9.29(19)	2.0	0.42	130	$6.5 \cdot 10^{-5}$
IT2	9.18(18)	2.0	-0.04[(1)]	100	$1.8 \cdot 10^{-5}$
IT2	9.23(19)	2.0	0.22[(1)]	350	$1.4 \cdot 10^{-6}$
ES	9.29(20)	2.2	0.42	100	$1.5 \cdot 10^{-5}$
ES	9.27(21)	2.3	0.33	384	$1.0 \cdot 10^{-6}$
FR2	9.26(25)	2.7	0.26	102	$1.9 \cdot 10^{-6}$
FR2	9.24(20)	2.2	0.22	401	$1.1 \cdot 10^{-6}$
FR1	9.27(16)	1.7	0.39	100	$2.5 \cdot 10^{-4}$
FR1	9.32(16)	1.7	0.63	350	$1.9 \cdot 10^{-5}$
FR1	9.02(15)	1.7	-0.82	100	$1.8 \cdot 10^{-5}$
FR1	9.14(15)	1.6	-0.22	300	$2.2 \cdot 10^{-6}$
GB1	9.35(29)	3.1	0.51	100	$1.1 \cdot 10^{-4}$
GB1	9.10(28)	3.1	-0.28	300	$1.2 \cdot 10^{-5}$
GB2	9.31(30)	3.2	0.36	100	$1.4 \cdot 10^{-4}$
GB2	9.09(29)	3.2	-0.29	350	$1.1 \cdot 10^{-5}$
IE	9.45(28)	3.0	0.83	100	$1.4 \cdot 10^{-5}$
IE	9.10(27)	3.0	-0.27	300	$1.5 \cdot 10^{-6}$
PT	8.91(17)	1.9	-1.29	100	$1.2 \cdot 10^{-4}$
PT	9.39(17)	1.8	0.92	350	$9.4 \cdot 10^{-6}$
GR	9.20(18)	2.0	0.06	100	$1.3 \cdot 10^{-5}$
GR	9.30(19)	2.0	0.49	200	$3.2 \cdot 10^{-6}$
GR	9.40(19)	2.0	0.91	300	$1.4 \cdot 10^{-6}$
FI	9.08(31)	3.4	-0.32	100	$2.2 \cdot 10^{-4}$
FI	9.27(32)	3.4	0.24	390	$1.4 \cdot 10^{-5}$
SE	9.29(11)	1.2	0.58	100	$1.6 \cdot 10^{-5}$
SE	9.31(10)	1.2	0.69	200	$4.0 \cdot 10^{-6}$
AT	9.19(14)	1.5	0.02	100	$5.9 \cdot 10^{-5}$
AT	9.18(14)	1.5	-0.04	300	$6.4 \cdot 10^{-6}$
SK	9.22(23)	2.5	0.12	100	$1.4 \cdot 10^{-4}$
SK	9.24(23)	2.5	0.19	400	$8.6 \cdot 10^{-6}$
SI	9.18(18)	2.0	-0.03	100	$2.5 \cdot 10^{-6}$
US1	9.01(36)	4.0	-0.46	100	$1.6 \cdot 10^{-4}$
US1	8.99(36)	4.0	-0.52	333	$1.2 \cdot 10^{-5}$
US2	9.28(11)	1.2	0.51	100	$5.0 \cdot 10^{-5}$
US2	9.29(11)	1.2	0.60	230	$9.2 \cdot 10^{-6}$
ZA	8.99(72)	8.0	-0.27	100	$7.5 \cdot 10^{-6}$
ZA	8.95(72)	8.0	-0.32	200	$1.9 \cdot 10^{-6}$
NO	9.15(21)	2.3	-0.15	100	$1.4 \cdot 10^{-6}$
Mean value	9.17	-	+ 0.13	-	-
Standard deviation	1.4 %	-	-	-	-

[(1)] A correlation between the results given by the Italian participants and the reference value was taken into account (see section 3.4).

Table 6 – Results $(N_K)_{lab}$ and associated expanded uncertainty U_{lab} (k = 2)given by the participants on the ILC IR3 for the ^{60}Co gamma radiation. The corresponding normalized errors E_n are also given as representing the ILC results.

Lab code	$(N_K)_{lab}$ (10^5 Gy C^{-1})	**$U_{(k=2)}$ (%)**	**E_n**	**Distance** (cm)	**K_a** (Gy s^{-1})
DE	9.16(18)	2.0	-0.05	100	$1.6 \cdot 10^{-3}$
DE	9.15(18)	2.0	-0.07	300	$1.9 \cdot 10^{-4}$
IT1	9.20(21)	2.3	0.16 (1)	100	$7.1 \cdot 10^{-5}$
IT1	9.15(21)	2.3	-0.08 (1)	300	$7.4 \cdot 10^{-6}$
IT2	9.18(18)	2.0	0.09 (1)	100	$3.0 \cdot 10^{-4}$
IT2	9.20(18)	2.0	0.21 (1)	400	$2.0 \cdot 10^{-5}$
FR1	9.20(15)	1.6	0.16	100	$2.8 \cdot 10^{-6}$
FR1	9.02(15)	1.7	-0.71	100	$1.9 \cdot 10^{-6}$
FR1	9.35(16)	1.7	0.87	150	$1.2 \cdot 10^{-6}$
GB1	9.22(29)	3.1	0.17	100	$1.7 \cdot 10^{-4}$
GB1	9.04(28)	3.1	-0.40	300	$1.8 \cdot 10^{-5}$
FI	9.24(31)	3.4	0.22	100	$6.4 \cdot 10^{-5}$
FI	9.14(31)	3.4	-0.09	382	$4.2 \cdot 10^{-6}$
SE	9.17(13)	1.4	0.02	100	$1.4 \cdot 10^{-6}$
AT	9.19(14)	1.5	0.12	100	$1.2 \cdot 10^{-5}$
AT	9.14(14)	1.5	-0.13	300	$1.3 \cdot 10^{-6}$
US2	9.15(11)	1.2	-0.07	100	$4.5 \cdot 10^{-4}$
US2	9.15(11)	1.2	-0.07	200	$1.1 \cdot 10^{-4}$
NO	9.14(19)	2.1	-0.11	400	$3.3 \cdot 10^{-4}$
Mean value	9.17	-	0.01	-	-
standard deviation	0.8%	-	-	-	-

(1) A correlation between the results given by the Italian participants and the reference value was taken into account (see section 3.4).

Table 7 – Status of each ILC participant with reference to the documents scheduled to be sent for the ILC IR3.

Lab. code	Certificate	Report forms	Unc. budget
AT	yes	yes	missing
DN			
FI	yes	yes	yes
FR1 FR2	yes yes	yes yes	yes yes
DE	yes	yes	yes (1)
GR	yes (2)	yes	yes
IE	yes	yes	yes
IT1 IT2	yes yes	yes yes	yes (1) yes (1)
NO	yes	yes	yes
PT	yes	yes	missing
SK	yes	yes	yes
SI	yes	yes	yes
ZA	yes	yes	yes
ES	yes	yes	yes
SE	yes	yes	yes
GB1 GB2	yes yes	yes yes	missing missing
US1 US2	yes yes	yes partially missing	missing missing

(1) The information sent was not complete.
(2) The certificate given refers to only one results whereas the report forms refer to three different results.

Table 8 –Uncertainty budget estimated by the participating laboratories for the calibration factor $(N_K)_{lab}$ of the circulating dosimeter.

Laboratory code	FI		FI		DE		DE		FR1		FR2		GR		IE		IT1		IT2	
Gamma radiation quality	^{137}Cs		^{60}Co		^{137}Cs		^{60}Co		^{137}Cs		^{137}Cs		^{137}Cs		^{137}Cs		^{60}Co		^{137}Cs	
Standard uncertainty type (%) / **Input quantity**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
1. calibration coefficient of the reference chamber, $(N_{K,ref})_{lab}$	**0.15**	**0.6**	**0.15**	**0.6**		**0.7**		**0.7**	**0.12**			**0.50/ 0.85**		**0.45**		**0.85**	**0.6**		**0.8**	
2. determination of the air kerma rate reference value:										0.80										
2.1 signal reading	0.2	0.06	0.2	0.06										0.10 0.06						0.2
2.2 ambient condition	0.04	0.17	0.04	0.17							0.03	0.17 0.07	0.03	0.01						
2.3 positioning of the: chamber source collimation device												1.07/ 0.05 0/0.24 0.30		0.15		0.40/ 0.13				
2.4 distance effect																				
2.5 reproducibility		0.58		0.58							0.02		0.24							
2.6 time																			0.2/ 0.1	
2.7 field uniformity		0.29		0.29										0.10						
2.8 energy spectra difference		0.29		0.29										0.10						
2.9 leakage current		0.58		0.58																
2.10 stem effect																				
2.11 decay correction																0.20			0.5	
3. circulating dosimeter measurements: 3.1 positioning of the: chamber source collimation device		0.46		0.46						0.1		0.20/ 0.05 0.24 0.30		0.25		0.40/ 0.13			0.16	
3.2 ambient conditions	0.04	0.17	0.04	0.17						0.22		0.17 0.07		0.06 0.02		0.50 0.15			0.1	
3.3 signal reading	0.08	0.11	0.08	0.11								0.02		0.29 0.06	0.13/ 0.20				0.05	0.02
3.4 reproducibility											0.08/ 0.07		0.38							
3.5 field uniformity / fluence difference		1.15		1.15										0.6						
3.6 time																				
3.7 leakage current		0.14		0.14																
Combined standard uncertainty $u[(N_K)_{lab}]$	**1.7**		**1.7**		**1** [(1)]		**1** [(1)]		**0.85**		**1.34/1.1**		**0.99**		**1.4/1.1** [(2)]		**1.25** [(1)]		**1.10/1.15**	
Expanded uncertainty $U[(N_K)_{lab}]$ **(k = 2)**	**3.4**		**3.4**		**2**		**2**		**1.70**		**2.7/2.2**		**1.97**		**2**		**2.5**		**2.2/2.3**	

(1) The components of uncertainty accounted for to obtain the combined standard uncertainty are omitted by the laboratory.
(2) All data in the table are given by the laboratori, but the quadratic sum of the standard uncertainties differi from this value of a component equivalent to 0.8 %.

Table 9 –Uncertainty budget estimated by the participating laboratories for the calibration factor $(N_K)_{lab}$ of the circulating dosimeter.

Laboratory code	**IT2**		**NO**		**NO**		**SK**		**SI**		**ZA**		**ES**		**SE**		**SE**	
Gamma radiation quality	^{60}**Co**		^{137}**Cs**		^{60}**Co**		^{137}**Cs**		^{137}**Cs**		^{137}**Cs**		^{137}**Cs**		^{137}**Cs**		^{60}**Co**	
standard uncertainty type (%) **Input quantity**	**B**	**A**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
1. calibration coefficient of the reference chamber, $(N_{K,ref})_{lab}$	**0.65**		**0.19**	**0.45**	**0.02**	**0.39**		**1.1**		**0.85**		**3.00**		**0.85**	**0.05**	**0.4**	**0.1**	**0.4**
2. determination of the air kerma rate reference value:												2.65						
2.1 signal reading			0.3	0.06	0.3	0.06			0.2	-	0.2		0.24 /0.3		0.08	0.05	0.2	0.2
2.2 ambient condition				0.2 0.02		0.2 0.02				0.03 0.05				0.01 6				
2.3 positioning of the: chamber source collimation device				0.3		0.2				0.1				0.20/ 0.17		0.1		0.1
2.4 distance effect														0.5/ 0.2				
2.5 reproducibility				0.13		0.07								0.1	0.1		0.1	
2.6 time								0.2/ 0.1						0.06				
2.7 field uniformity				0.3		0.2										0.2		0.1 0.1
2.8 energy spectra difference				0.2		0.1										0.1		
2.9 leakage current																		
2.10 stem effect																0.1		0.1
2.11 decay correction								0.5										0.1
3. circulating dosimeter measurements: 3.1 positioning of the: chamber source collimation device				0.4		0.4		0.16		0.1		0.39		0.32/ 0.30		0.1		0.1
3.2 ambient conditions				0.2		0.2		0.1		0.08		-		0.01				
3.3 signal reading				0.4		0.4	0.02	0.05	0.02		0.14		0.034. 0.5		0.1	0.05	0.1	0.05
3.4 reproducibility																		
3.5 field uniformity / fluence difference				0.5		0.5				0.3				0.16/ 0.3		0.3		0.3
3.6 time																		
3.7 leakage current														0.07				
Combined standard uncertainty $u[(N_K)_{lab}]$	**1** [(1)]		**1.1**		**1.0**		**1.24/1.23**		**0.96**		**4.02** [(2)]		**1.10/1.15**		**0.6**		**0.7**	
Expanded uncertainty $U[(N_K)_{lab}]$ **(k = 2)**	**1.2**		**2.2**		**2.0**		**2.5**		**1.9**		**8.04**		**2.2/2.3**		**1.2**		**1.4**	

[(1)] The components of uncertainty accounted for to obtain the combined standard uncertainty are omitted by the laboratory.
[(2)] Some data were deduced by the reference laboratori being not clearly given by the laboratory in the uncertainty form.

Table 10 – Parameters calculated from data in tables 8 and 9 to perform an analysis of ILC uncertainties given in section 4.2.

Laboratory code	Gamma radiation quality	$u[(N_K)_{lab}]$ / $u[(N_{K,ref})_{lab}]$	$(u_{add})_{lab} = \sqrt{u[(N_K)_{lab}]^2 - u[(N_{k,ref})_{lab}]^2}$
FI	^{137}Cs	2.8	1.58
FI	^{60}Co	2.7	1.58
DE	^{137}Cs	1.4	0.71
DE	^{60}Co	1.4	0.96
FR1	^{137}Cs	7.1?	0.84
FR2	^{137}Cs	2.2	0.98
GR	^{137}Cs	2.2	0.88
IE	^{137}Cs	1.6/1.3	1.11/0.70
IT1	^{60}Co	2.1	1.10
IT2	^{137}Cs	1.3	0.36
IT2	^{60}Co	1.7	0.80
NO	^{137}Cs	2.3	0.99
NO	^{60}Co	2.6	0.92
SK	^{137}Cs	1.1	0.56
SI	^{137}Cs	1.1	0.45
ZA	^{137}Cs	1.3	2.68
ES	^{137}Cs	1.3/1.4	0.70/0.78
SE	^{137}Cs	1.5	0.44
SE	^{60}Co	1.7	0.57

Table 11 – Analysis of the calibration certificates given by participants for compliance with the Standard EN ISO/IEC 17025:2000. The results of the check are expressed as conformities (+) or non conformities (-).

STANDARD EN ISO/IEC 17025:2000 Section 5.10: reporting the results		**LABORATORY CODE**																			
Paragraph	**Requirement**	**AT**	**FI**	**FR1**	**FR2**	**DE**	**GR**	**IE**	**IT1**	**IT2**	**NO**	**PT**	**SK**	**SI**	**ZA**	**ES**	**SE**	**GB1**	**GB2**	**US1**	**US2**
5.10.1	Result reported accurately, clearly, unambiguously and objectively	+	-	-	+	-	+	+	+	+	+	-	-	+	-	+	+	+	-	-	-
5.10.2a	Title	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5.10.2b	Identification of the laboratory	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5.10.2c	Unique identification of: - the certificate	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	- each page	+	+	+	+	+	+	+	+	+	-	+	-	+	+	+	+	+	+	+	+
	- the end (total number of pages)	+	+	+	+	+	+	+	+	+	-	+	-	+	+	+	+	+	+	+	-
5.10.2d	Identification of the client	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5.10.2e	Identification of the method	+	-	+	-	-	-	+	+	+	-	-	+	-	-	+	-	-	-	+	-
5.10.2f	Identification of the artifact	+	+	+	+	+	+	+	+	-	-	-	+	+	+	+	+	+	-	-	+
5.10.2g	Date of receipt	not relevant																			
5.10.2g	Date of the calibration	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5.10.2i	Calibration results	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	-	+	-
5.10.2j	Authorising person:	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+
	identification signature:	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5.10.2 note	not reproducible except in full	+	+	+	+	+	+	+	+	+	-	-	+	+	+	+	-	+	+	-	+
5.10.4.1a	Conditions for calibration: range	+	+	-	-	-	+	-	-	+	-	-	-	-	-	+	-	-	-	-	-
	Environmental	+	-	+	+	+	+	+	-	-	+	+	+	+	+	+	-	-	+	+	-
	Air kerma rate	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	distance	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5.10.4.1b	Uncertainty of measurement	+	+	+	+	+	+	+	-	-	-	+	+	+	+	+	-	+	+	+	+
5.10.4.1c	Evidence of traceability	+	-	-	-	+	+	-	+	+	-	-	+	-	+	+	-	+	+	-	+
Languages national (N) /English translation (E)		E	E	N	N	N	E	E(N)	N/E	N/E	N	N	N/E	N	E	N	N	E(N)	E(N)	E(N)	E(N)
Additional comments			(1,2,3)	(1,3)	(1,2,3)	(1,2)		(4)	(1,5)	(1,5,6)	(3,5,6)	(1,2,6)	(1)	(1,2)	(1,2,7)	(1)	(1,2,3,5)	(1,2)	(1,2,6,7)	(1,5)	(1,7)

(1) The results are given with a higher (lower) number of digits without a clear specification of those affected by the uncertainty.
(2) The reference of the procedure of the laboratory agreed by the AB and used for calibration is not specified. In some cases, only a very short description is inserted directly on the certificate.
(3) It did not specify the identification of the current calibration certificate for the used standard assuring traceability.
(4) It did not specify the Institute that issued current calibration certificate for the used standard assuring traceability.
(5) The type of uncertainty given is not clear and/or the coverage factor is not specified.
(6) The serial number is missing and/or the only ionisation chamber is specified without the measuring assembly.
(7) The results are not clearly given as calibration coefficients: 1) the terms “air kerma/charge” or “system factor” are used; 2) only the separate value of the “air kerma” and of the corresponding “charge” are given; 3) the calibration coefficient is expressed as (Gy/rdg).

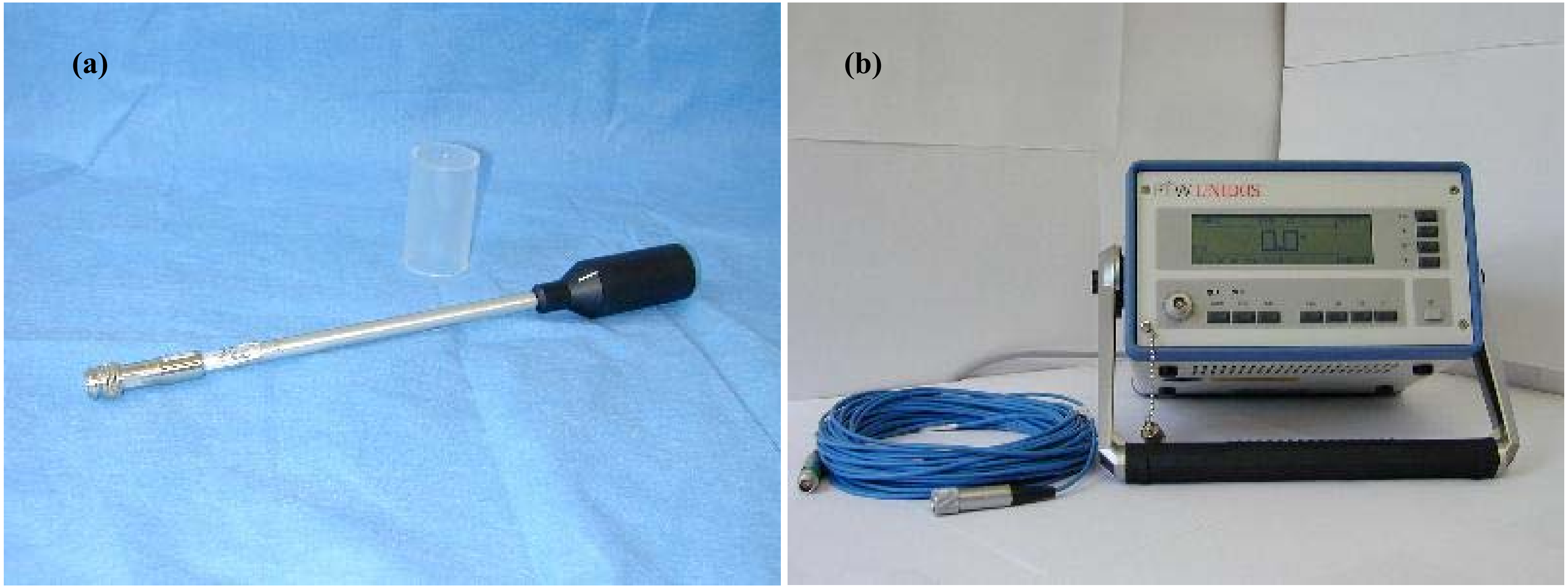


Figure 1 – Circulating instrument consisting on: (figure a) ionisation chamber PTW type 23361with a build-up cap for the energy of ^{137}Cs and ^{60}Co gamma radiations; (figure b) associated measuring assembly PTW UNIDOS type 10002 with a 20 m. long extension cable to connect the detector and the measuring assembly.

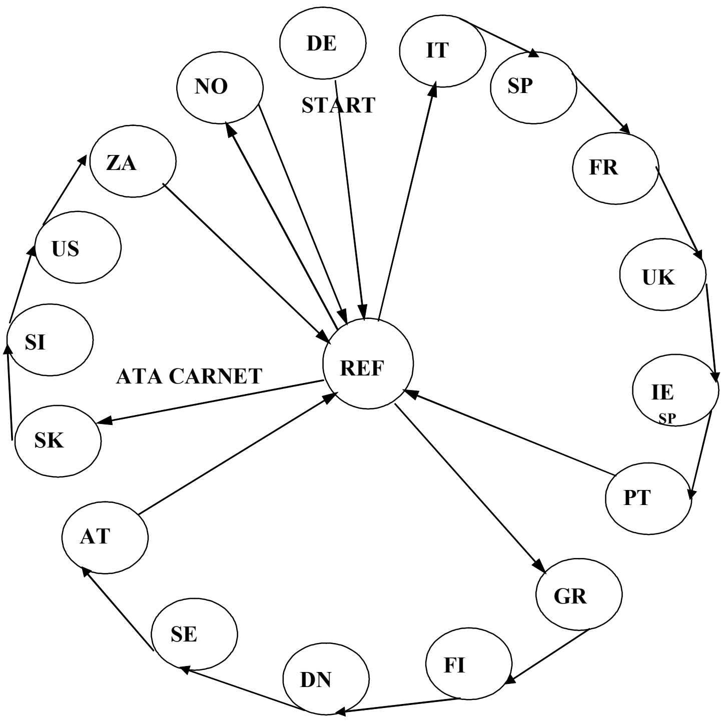


Figure 2 – Scheme for the circulation of the dosimeter among the participants in the ILC IR3.

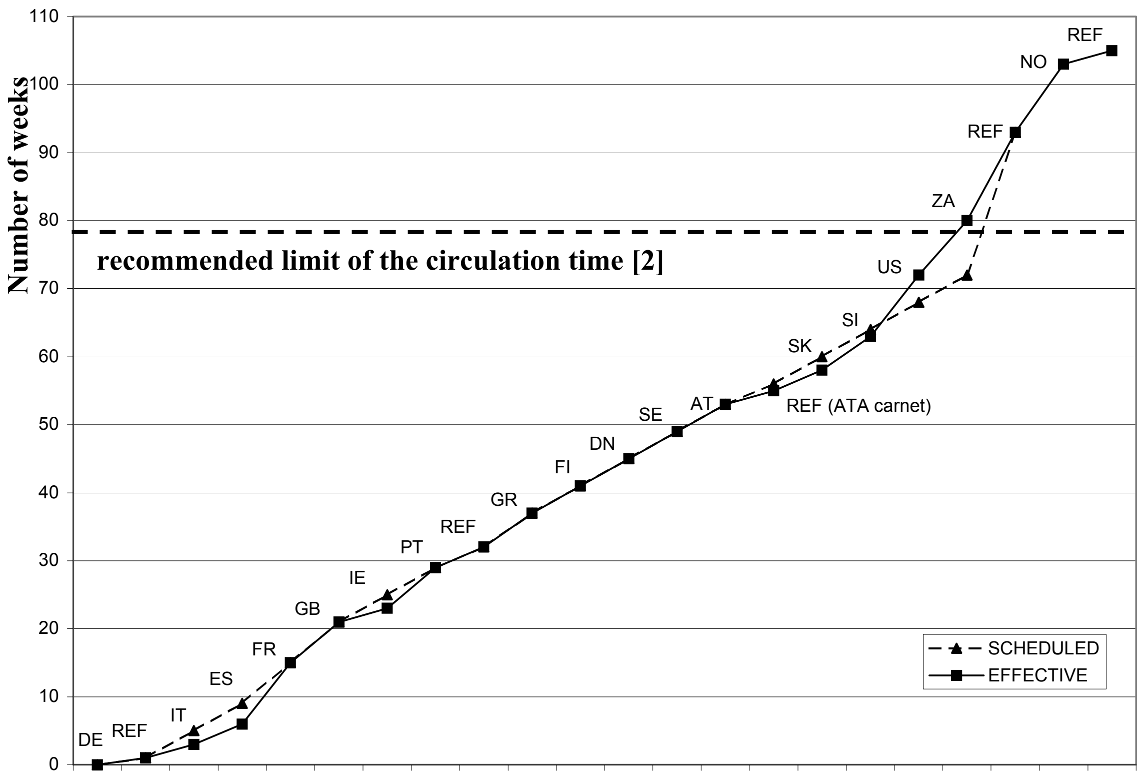


Figure 3 – Graphical representation of the scheduled (triangle) and the actual (square) time for the circulation of the dosimeter among the participants in the ILC IR3.

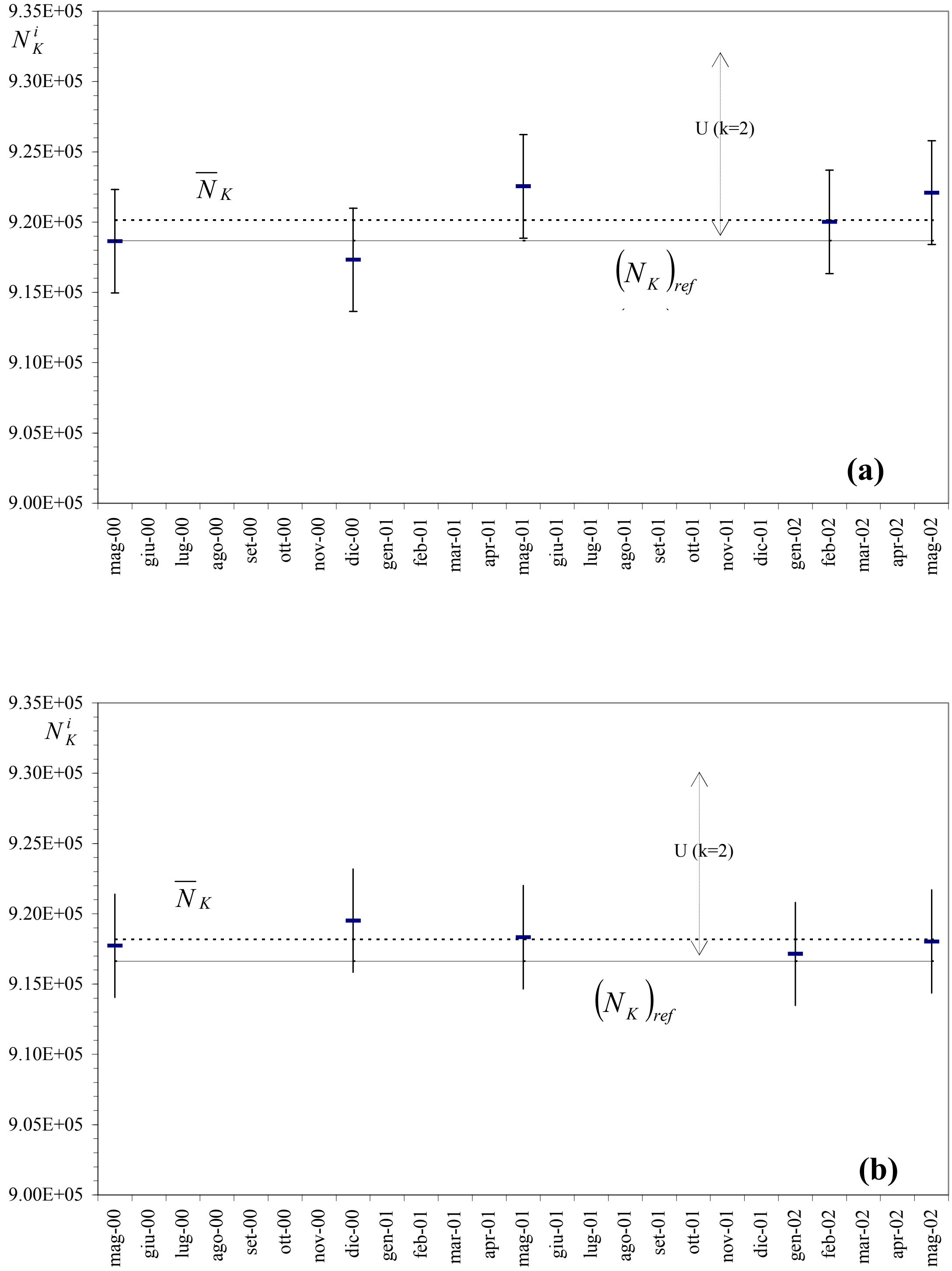


Figure 4 – Calibration coefficients N_K^i of the circulating dosimeter obtained at the reference laboratory for the ^{137}Cs (figure a) and the ^{60}Co (figure b) gamma radiations, during the whole ILC period of two years. The corresponding values of the arithmetic mean $\overline{N}_K$ (dashed line) and the ILC reference value $(N_K)_{ref}$ (solid line) are also shown (see section 3.1). The grey bands show the expanded uncertainty $U_{(k=2)}$ associated to the value of $(N_K)_{ref}$.

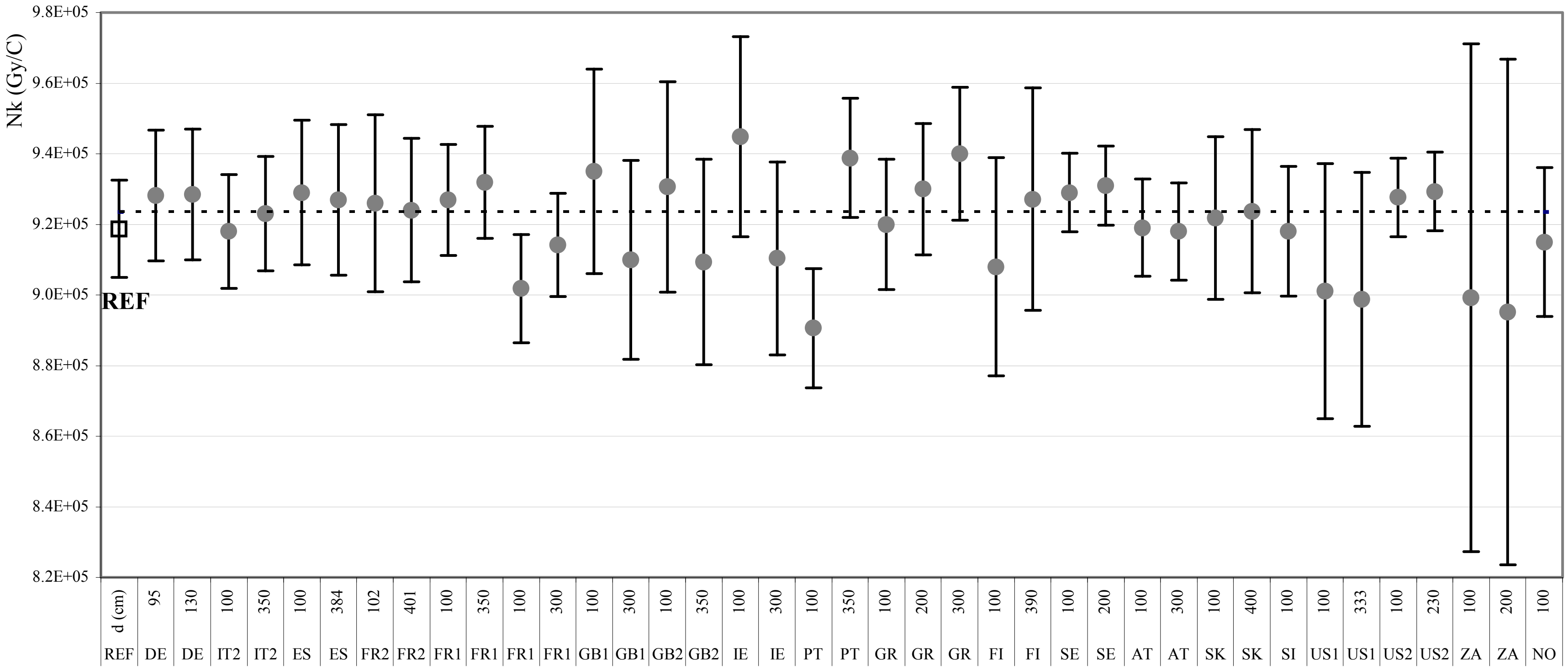


Figure 5 – Results $(N_K)_{lab}$ given by the participants on the interlaboratory comparison exercises (grey circles) for the ^{137}Cs gamma radiation as function of the calibration period and corresponding to different experimental conditions of measuring distances d (specified in the graph) and air kerma rate. The mean value of the results (dashed line) and the ILC reference value (white square) are also reported in the graph showing a difference of about 0.5 %.

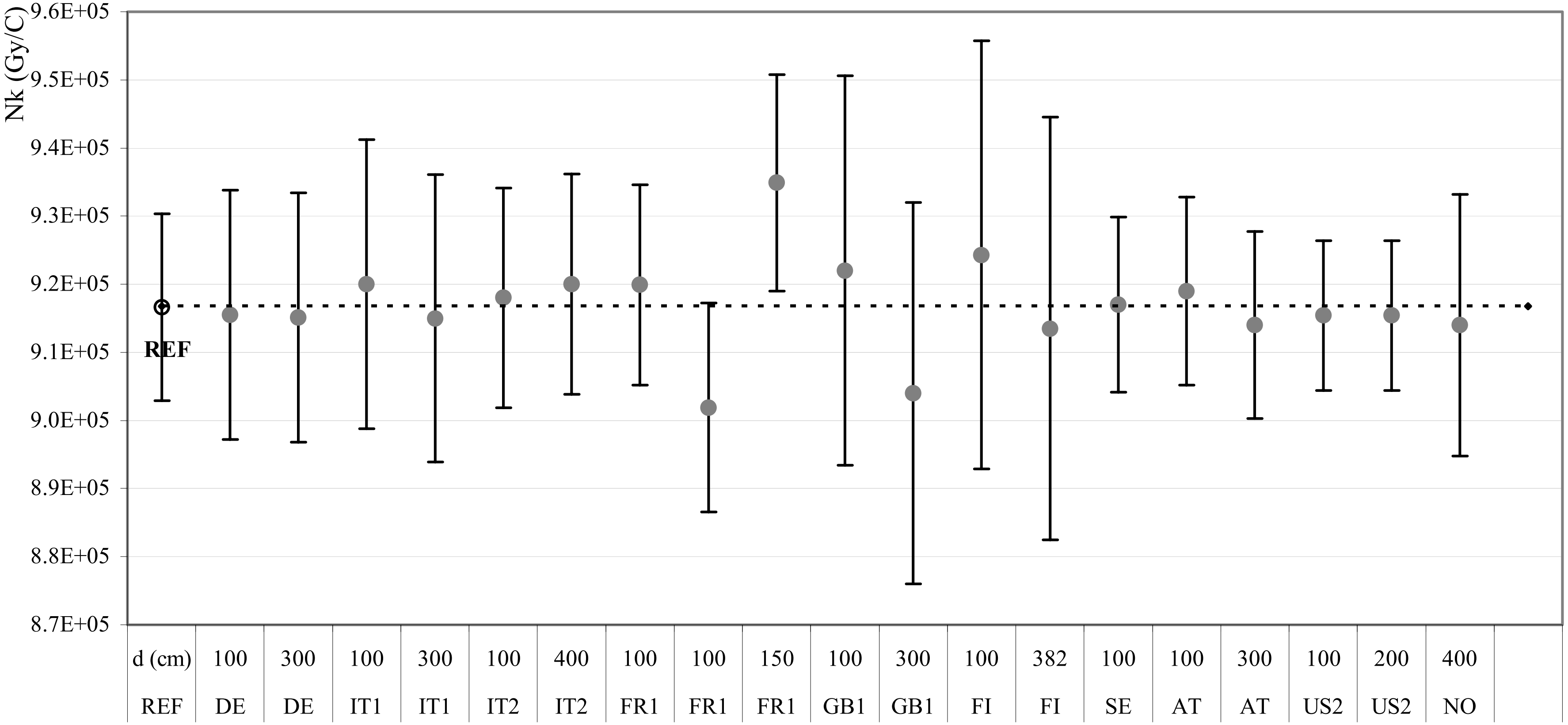


Figure 6 – Results $(N_K)_{lab}$ given by the participants on the interlaboratory comparison exercises (grey circles) for the ^{60}Co gamma radiation as function of the calibration period and corresponding to different experimental conditions of measuring distances d (specified in the graph) and air kerma rate. The mean value of the results (dashed line) and the ILC reference value (white circle) are also reported in the graph showing a difference of about 0.02 %.

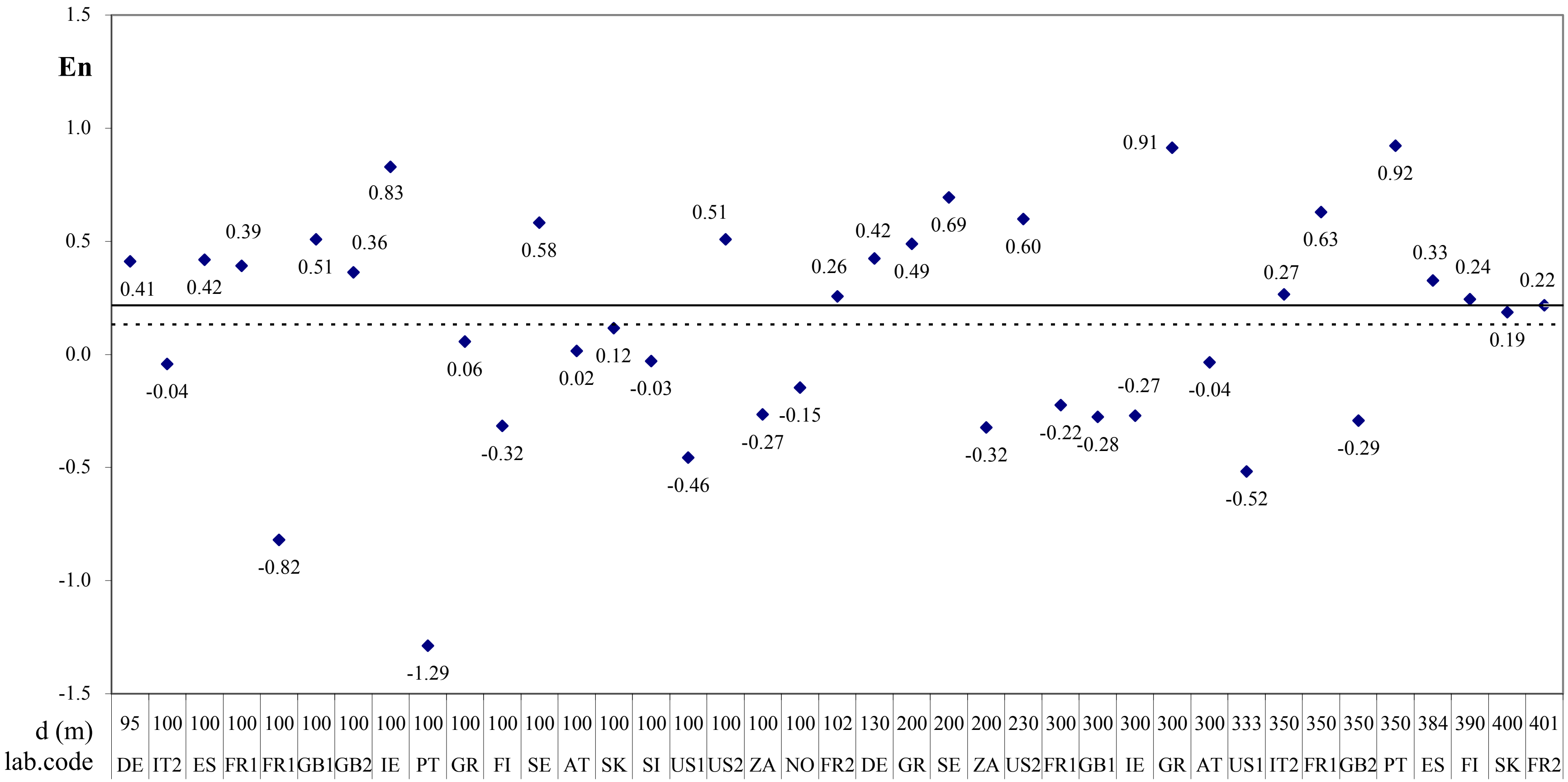


Figure 7 – ILC results, as function of the measuring distance, for the ^{137}Cs gamma radiation expressed as normalized error E_n. The graph also shows the arithmetic mean (dashed line) and the median (full line) of all the E_n results.

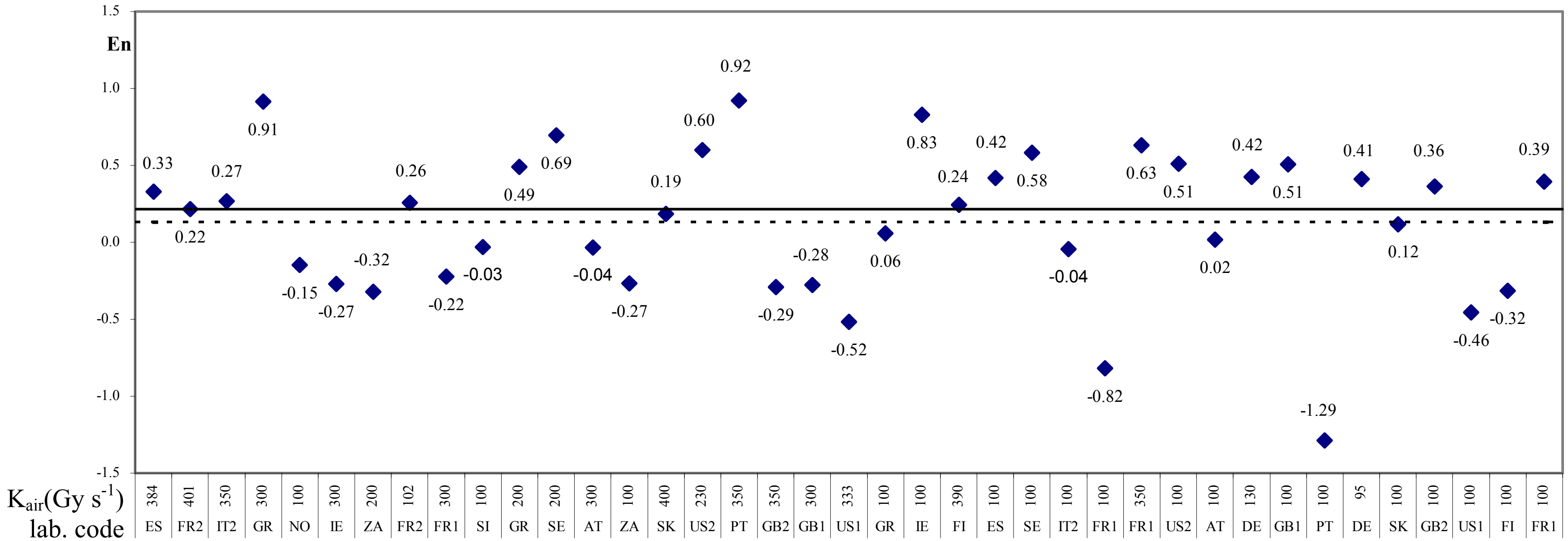


Figure 8 – ILC results, as function of the air kerma rate, for the ^{137}Cs gamma radiation expressed as normalized error E_n. The graph also shows the arithmetic mean (dashed line) and the median (full line) of all the E_n results.

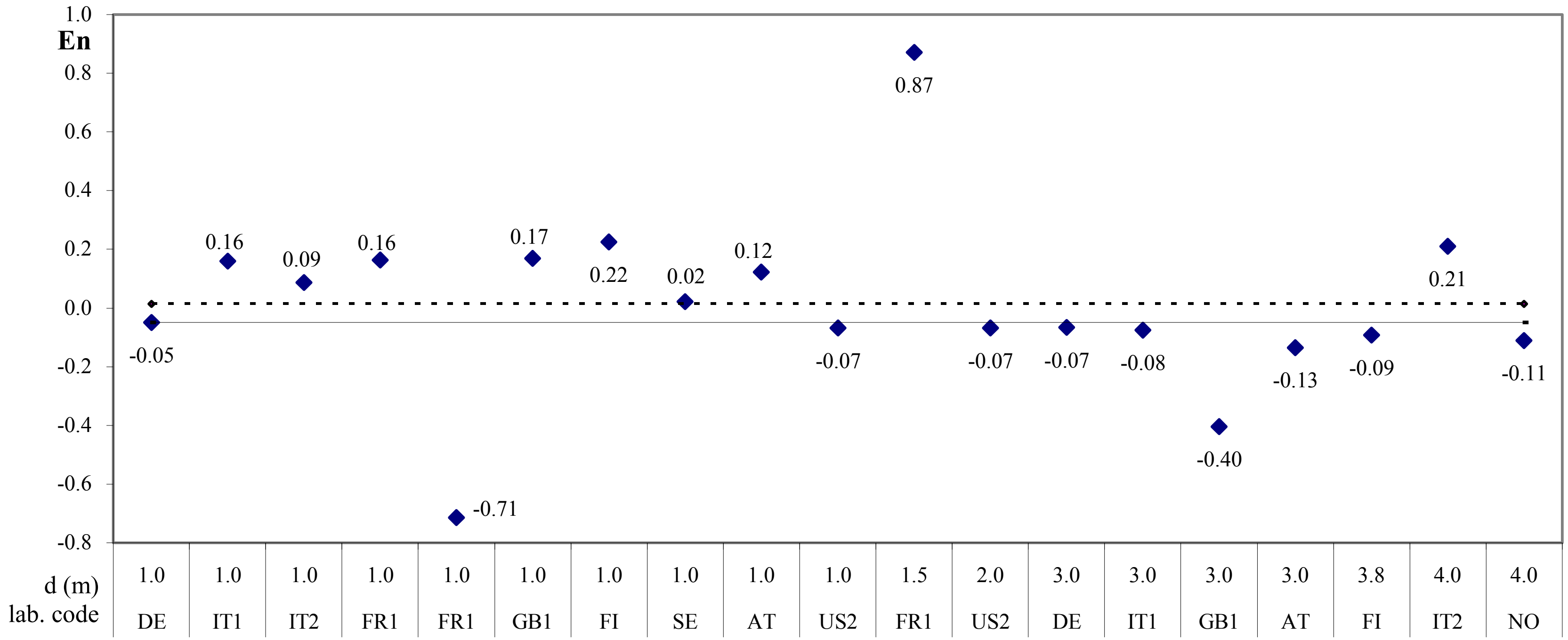


Figure 9 – ILC results, as function of the measuring distance, for the ^{60}Co gamma radiation expressed as normalized error E_n. The graph also shows the arithmetic mean (dashed line) and the median (full line) of all the E_n results.

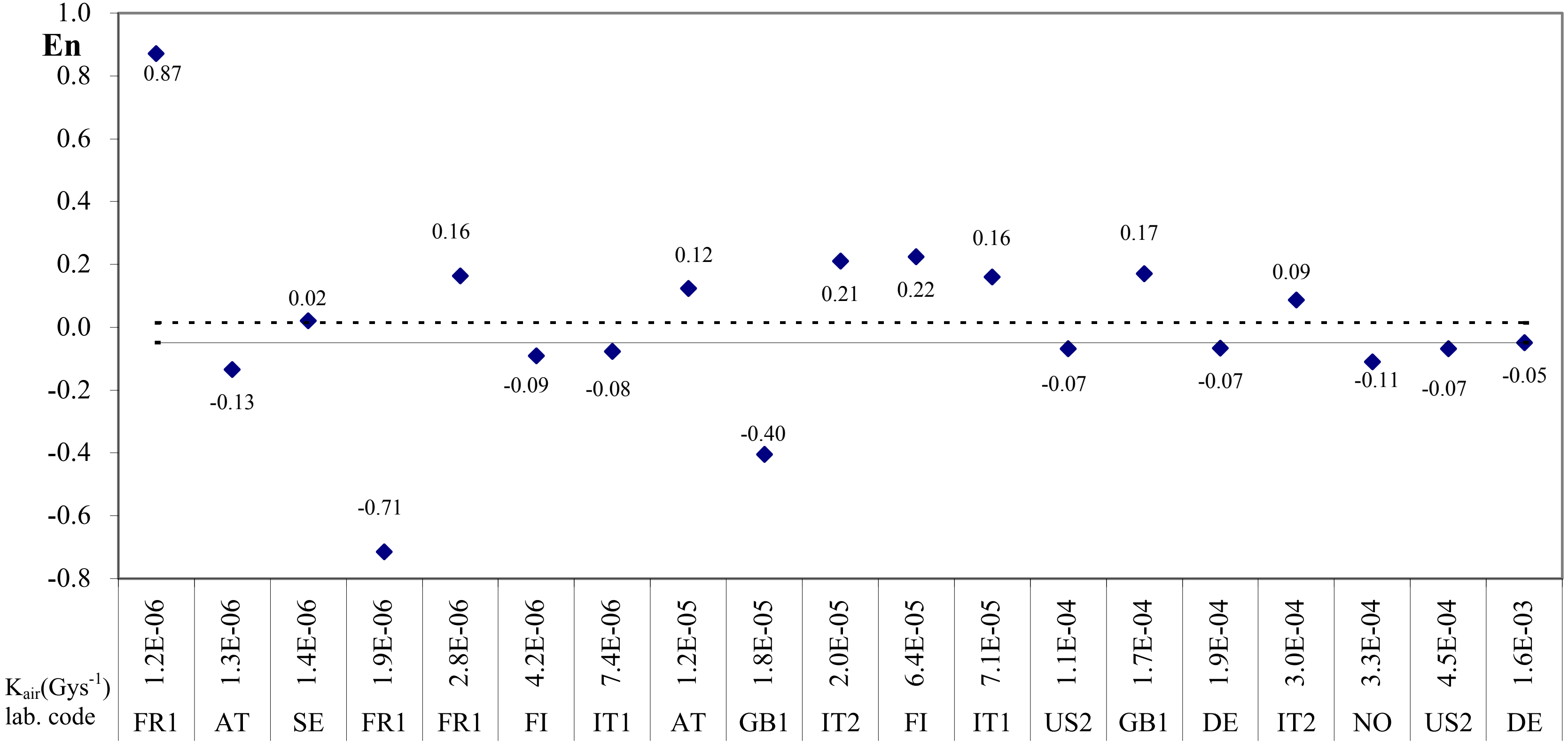


Figure 10 – ILC results, as function of the air kerma rate, for the ^{60}Co gamma radiation expressed as normalized error E_n. The graph also shows the arithmetic mean (dashed line) and the median (full line) of all the E_n results.

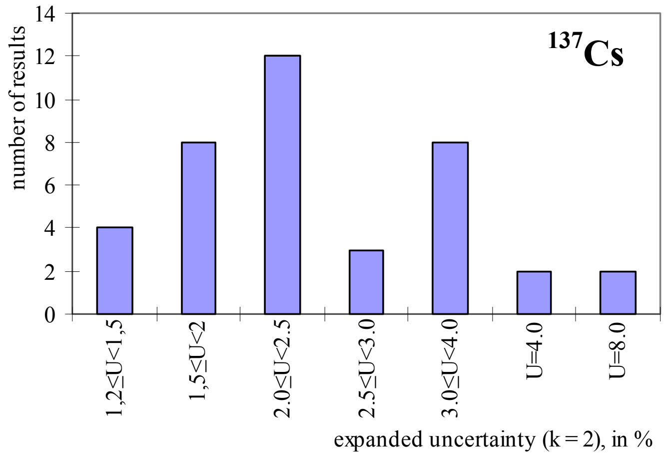


Figure 11 - Analysis of the expanded uncertainty $U[(N_K)_{lab}]_{(k=2)}$ associated to the ILC participating results $(N_k)_{lab}$,.determined in ^{137}Cs gamma radiation beams.

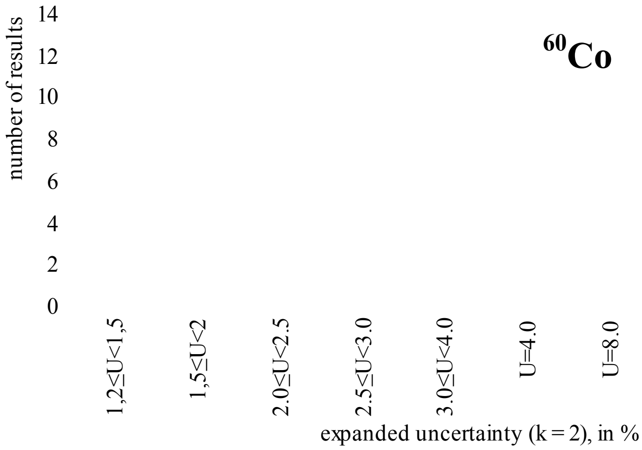


Figure 12 - Analysis of the expanded uncertainty $U[(N_K)_{lab}]_{(k=2)}$ associated to the ILC participating results $(N_k)_{lab}$,.determined in ^{60}Co gamma radiation beams..

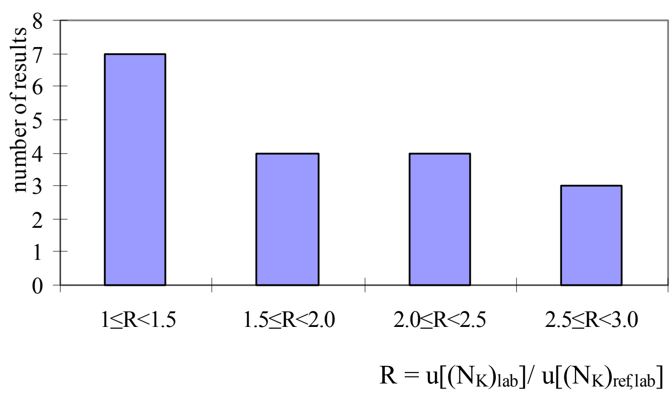


Figure 13 - Analysis of the ratios $R = u[(N_K)_{lab}]/\ u[(N_K)_{ref,lab}]$ for 22 results given by 14 laboratories (see details in section 4.2).

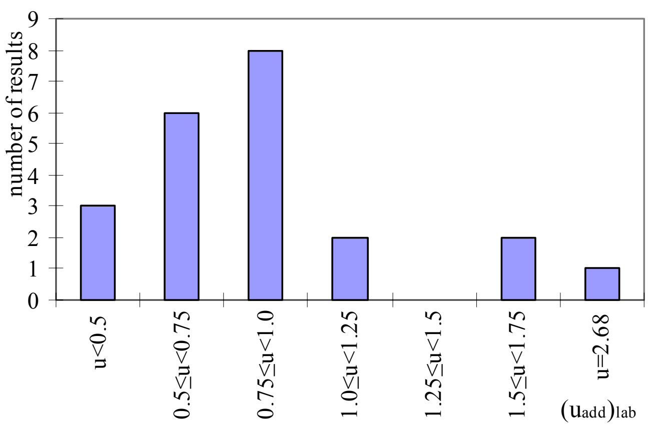


Figure 14 - Analysis of the standard uncertainty $(u_{add})_{lab}$ for 22 results given by 14 laboratories (see details in section 4.2).

^{137}Cs	relative humidity (%)	temperature (°C)	pressure (hPa)	correction factor k(T,P)	^{60}Co	relative humidity (%)	temperature (°C)	pressure (hPa)	correction factor k(T,P)
max	64	24,9	1012,0	1,170	max	66	23,9	1020,0	1,047
min	24	19,0	863,1	0,995	min	29	16,7	974,5	0,997
mean	52	21,5	989,9	1,029	mean	49	20,8	996,8	1,019
st. dev.	9	1,6	30,6	0,034	st. dev.	11	1,8	12,9	0,015
st. dev. %	18	7	3	3	st. dev. %	23	9	1	2

Figure 15 - Analysis of the environmental conditions at participating laboratories for the ILC measurements. Reference ambient conditions were: T_0 = 293.15 K for the temperature; P_0 = 1.01325 x 10^5 Pa = 1013.25 hPa for the pressure and the range 30 % to 70 % for the relative humidity.

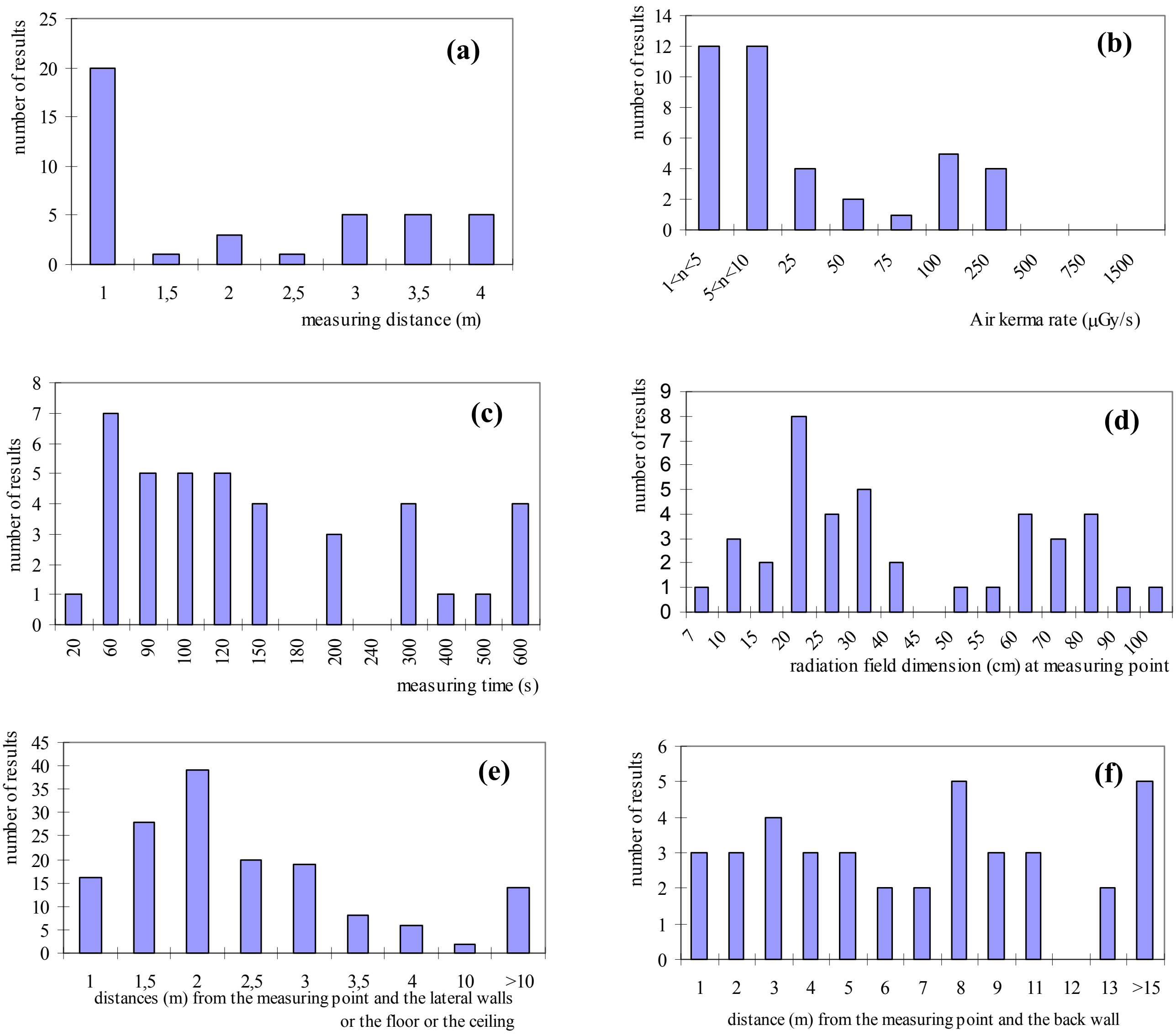


Figure 16 – Analysis of some relevant measurement parameters at participating laboratories for the ILC measurements performed in ^{137}Cs gamma radiation beams.

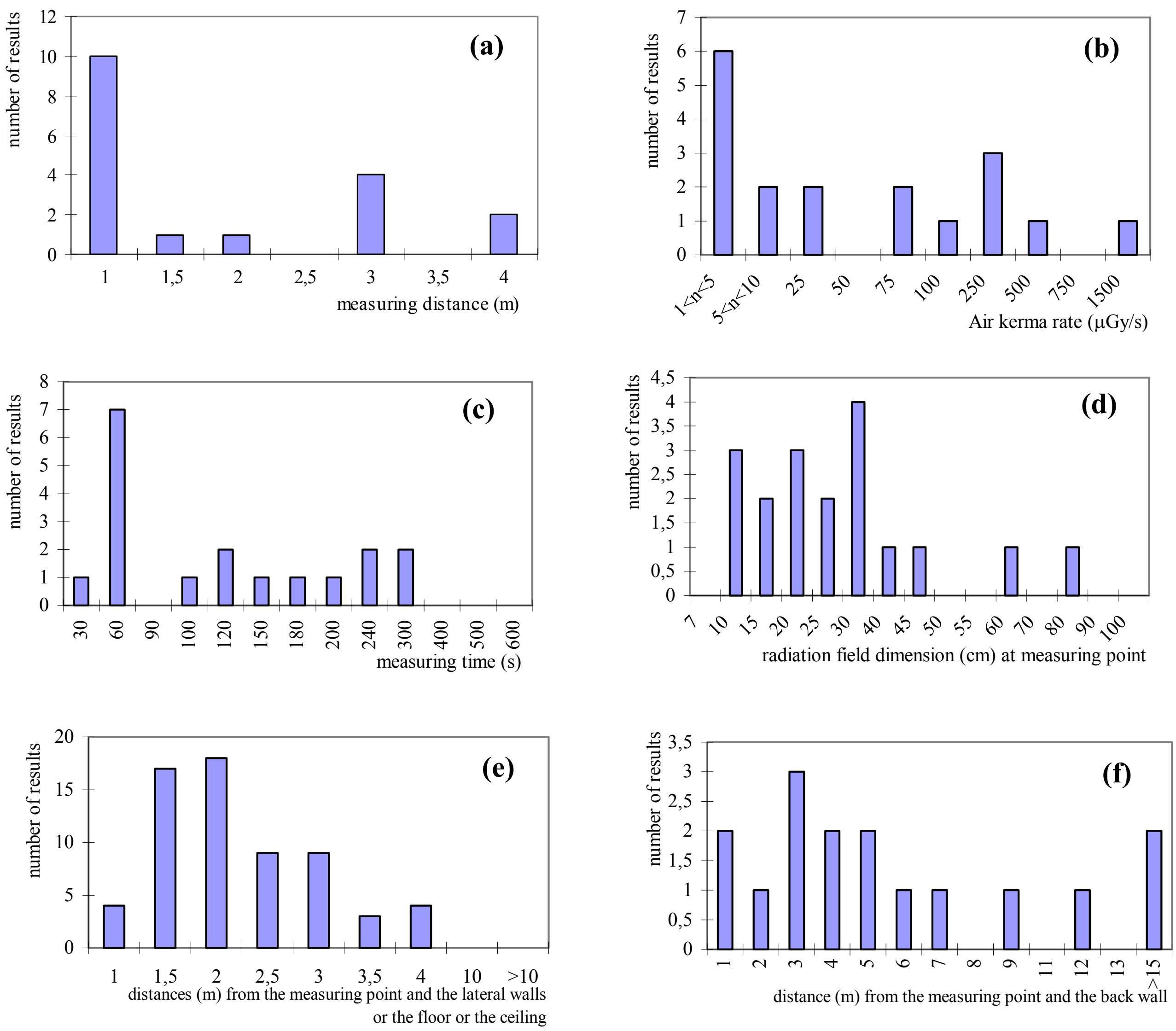


Figure 17 – Analysis of some relevant measurement parameters at participating laboratories for the ILC measurements performed in ^{60}Co gamma radiation beams.

APPENDIX

A.1 EFFECTS INFLUENCING THE DOSIMETER RESPONSE.

The reference laboratory carried out a preliminary analysis of the effects influencing the response of the circulating dosimeter. The correction factor k_{sat}, for ion recombination in the sensitive volume of the circulating dosimeter, and k_{geom}, for the displacement of the effective measuring point with the source-detector distance, were determined at the values of air kerma rate and distance involved in the ILC measurements.

The factor k_{sat} was obtained by measurements performed at values of the air kerma rate ranging from 1 $\mu Gy\ s^{-1}$ to 1 $mGy\ s^{-1}$ and with the chamber polarized at two different voltages [9]. Figure A.1(a) shows the factor k_{sat} obtained as function of the air kerma rate. This factor was in the range from 1.000_9 to 1.001_2 for the values of the air kerma rate involved in the ILC measurements.

The factor k_{geom} was obtained from literature data [2, 10]. Figure A.1(b) shows the factor k_{geom} obtained as function of the measuring distance. This factor was in the range from 1.000_5 to 1.001_5 for the measuring distances involved in this ILC.

It was also investigated the effect of the leakage current of the ionisation chamber at low-level measurements. The leakage current of the circulating dosimeter was automatically suppressed by an automatic zero setting of the associated measuring assembly. However, an additional leakage current of about $5\ 10^{-16}$ A was measured. This current results in any case negligible respect to the lower limit of $1\ 10^{-12}$ A recommended for the current to be measured by the manufacturer and corresponding to the lower limit recommended by the ILC instructions for the air kerma rate to be used.

Measurements were performed to verify experimentally the effectiveness of the corrections estimated. It was used measuring distances in the range from 1 m to 3 m and air kerma rate in the range from 0.5 $\mu Gy\ s^{-1}$ to 0.7 $mGy\ s^{-1}$ due to ^{60}Co sources. The values of the dosimeter response R determined in six different experimental conditions are shown in figure A.2. Each value was determined as the arithmetic mean of five series of 30 measurements carried out during the ILC period. The values obtained in the different experimental conditions are consistent and have a relative maximum deviation of about 0.3% and a standard deviation of about 0.1%. However a slight increase is observed in the case of air kerma rate values lower than $1\ 10^{-6}$ $Gy\ s^{-1}$ (out of the range started for the ILC measurements). The consistency of these values improves after correction for the above-mentioned three effects, giving a relative maximum deviation of about 0.03% and a relative standard deviation of about 0.02%. Moreover, in this case no trend is observed in the whole range of the air kerma values investigated. The mean value of the series of uncorrected data differs from that of the series of the corrected data of about 0.1%. The analysis of these results confirmed that the correction factors determined are effective.

Just as a check, the values of $(N_K)_{lab}$ given by participating laboratories (see tables 5 and 6) were corrected by the reference laboratory by applying the correction factors k_{sat} and k_{geom}. The results obtained were not used in the analysis of the ILC results and they are given in tables A.1 and A.2 for ^{137}Cs and ^{60}Co gamma radiations, respectively. The relative deviation between the arithmetic mean of all the results as given by participants and the arithmetic mean of the corrected results was about 0.2 % in both cases ^{137}Cs or ^{60}Co. The standard deviations of the two series of data (corrected and uncorrected) are of the same order. These results confirmed that the above-mentioned corrections could be neglected at the level of the present ILC measurements leading to an additional component of uncertainty negligible (< 0.2%) compared to the overall uncertainty on the $(N_K)_{lab}$ values.

Table A.1 – Results $(N_K)_{lab}$, given by the participants on the ILC IR3 for the ^{137}Cs gamma radiation (see table 5), corrected by applying the appropriate correction factors k_{sat} and k_{geom} determined at the reference laboratory.

Lab code	**Distance** (cm)	K_a (Gy s^{-1})	k_{sat}	k_{geom}	$(N_K)_{lab} \cdot k_{sat} \cdot k_{geom}$ (10^5 Gy C^{-1})
DE	95	$1.2 \cdot 10^{-4}$	1.0011	1.0014	9.26
DE	130	$6.5 \cdot 10^{-5}$	1.0011	1.0010	9.27
IT2	100	$1.8 \cdot 10^{-5}$	1.0011	1.0014	9.16
IT2	350	$1.4 \cdot 10^{-6}$	1.0011	1.0004	9.22
ES	100	$1.5 \cdot 10^{-5}$	1.0011	1.0014	9.27
ES	384	$1.0 \cdot 10^{-6}$	1.0011	1.0003	9.26
FR2	102	$1.9 \cdot 10^{-6}$	1.0011	1.0013	9.24
FR2	401	$1.1 \cdot 10^{-6}$	1.0011	1.0003	9.23
FR1	100	$2.5 \cdot 10^{-4}$	1.0011	1.0014	9.25
FR1	350	$1.9 \cdot 10^{-5}$	1.0011	1.0004	9.31
FR1	100	$1.8 \cdot 10^{-5}$	1.0011	1.0014	9.00
FR1	300	$2.2 \cdot 10^{-6}$	1.0011	1.0004	9.13
GB1	100	$1.1 \cdot 10^{-4}$	1.0011	1.0014	9.33
GB1	300	$1.2 \cdot 10^{-5}$	1.0011	1.0004	9.09
GB2	100	$1.4 \cdot 10^{-4}$	1.0011	1.0014	9.28
GB2	350	$1.1 \cdot 10^{-5}$	1.0011	1.0004	9.08
IE	100	$1.4 \cdot 10^{-5}$	1.0011	1.0014	9.42
IE	300	$1.5 \cdot 10^{-6}$	1.0011	1.0004	9.09
PT	100	$1.2 \cdot 10^{-4}$	1.0011	1.0014	8.88
PT	350	$9.4 \cdot 10^{-6}$	1.0011	1.0004	9.37
GR	100	$1.3 \cdot 10^{-5}$	1.0011	1.0014	9.18
GR	200	$3.2 \cdot 10^{-6}$	1.0011	1.0006	9.28
GR	300	$1.4 \cdot 10^{-6}$	1.0011	1.0004	9.39
FI	100	$2.2 \cdot 10^{-4}$	1.0011	1.0014	9.06
FI	390	$1.4 \cdot 10^{-5}$	1.0011	1.0003	9.26
SE	100	$1.6 \cdot 10^{-5}$	1.0011	1.0014	9.27
SE	200	$4.0 \cdot 10^{-6}$	1.0011	1.0006	9.29
AT	100	$5.9 \cdot 10^{-5}$	1.0011	1.0014	9.17
AT	300	$6.4 \cdot 10^{-6}$	1.0011	1.0004	9.17
SK	100	$1.4 \cdot 10^{-4}$	1.0011	1.0014	9.20
SK	400	$8.6 \cdot 10^{-6}$	1.0011	1.0003	9.22
SI	100	$2.5 \cdot 10^{-6}$	1.0011	1.0014	9.16
US1	100	$1.6 \cdot 10^{-4}$	1.0011	1.0014	8.99
US1	33	$1.2 \cdot 10^{-5}$	1.0011	1.0004	8.97
US2	100	$5.0 \cdot 10^{-5}$	1.0011	1.0014	9.25
US2	230	$9.2 \cdot 10^{-6}$	1.0011	1.0005	9.28
ZA	100	$7.5 \cdot 10^{-6}$	1.0011	1.0014	8.97
ZA	200	$1.9 \cdot 10^{-6}$	1.0011	1.0006	8.94
NO	100	$1.4 \cdot 10^{-6}$	1.0011	1.0014	9.13
Mean value			1.001_1	1.000_9	9.18_7
st.dev.%			0.00_1	0.05	1.40_3

Table A.2 – Results $(N_K)_{lab}$, given by the participants on the ILC IR3 for the ^{60}Co gamma radiation (see table 6), corrected by applying the appropriate correction factors k_{sat} and k_{geom} determined at the reference laboratory.

Lab code	**Distance** (cm)	**K_a** (Gy s^{-1})	**k_{sat}**	**k_{geom}**	$(N_K)_{lab} \cdot k_{sat} \cdot k_{geom}$ (10^5 Gy C^{-1})
DE	100	$1.6 \cdot 10^{-3}$	1.0012	1.0015	9.13
DE	300	$1.9 \cdot 10^{-4}$	1.0011	1.0005	9.14
IT1	100	$7.1 \cdot 10^{-5}$	1.0011	1.0015	9.18
IT1	300	$7.4 \cdot 10^{-6}$	1.0011	1.0005	9.14
IT2	100	$3.0 \cdot 10^{-4}$	1.0011	1.0015	9.16
IT2	400	$2.0 \cdot 10^{-5}$	1.0011	1.0003	9.19
FR1	100	$2.8 \cdot 10^{-6}$	1.0011	1.0015	9.18
FR1	100	$1.9 \cdot 10^{-6}$	1.0011	1.0015	9.00
FR1	150	$1.2 \cdot 10^{-6}$	1.0011	1.0009	9.33
GB1	100	$1.7 \cdot 10^{-4}$	1.0011	1.0015	9.20
GB1	300	$1.8 \cdot 10^{-5}$	1.0011	1.0005	9.03
FI	100	$6.4 \cdot 10^{-5}$	1.0011	1.0015	9.22
FI	382	$4.2 \cdot 10^{-6}$	1.0011	1.0004	9.12
SE	100	$1.4 \cdot 10^{-6}$	1.0011	1.0015	9.15
AT	100	$1.2 \cdot 10^{-5}$	1.0011	1.0015	9.17
AT	300	$1.3 \cdot 10^{-6}$	1.0011	1.0005	9.13
US2	100	$4.5 \cdot 10^{-4}$	1.0011	1.0015	9.13
US2	200	$1.1 \cdot 10^{-4}$	1.0011	1.0007	9.14
NO	400	$3.3 \cdot 10^{-4}$	1.0011	1.0003	9.13
Mean value			1.001_1	1.001_0	9.149
st.dev.%			0.00_3	0.05	0.75_0

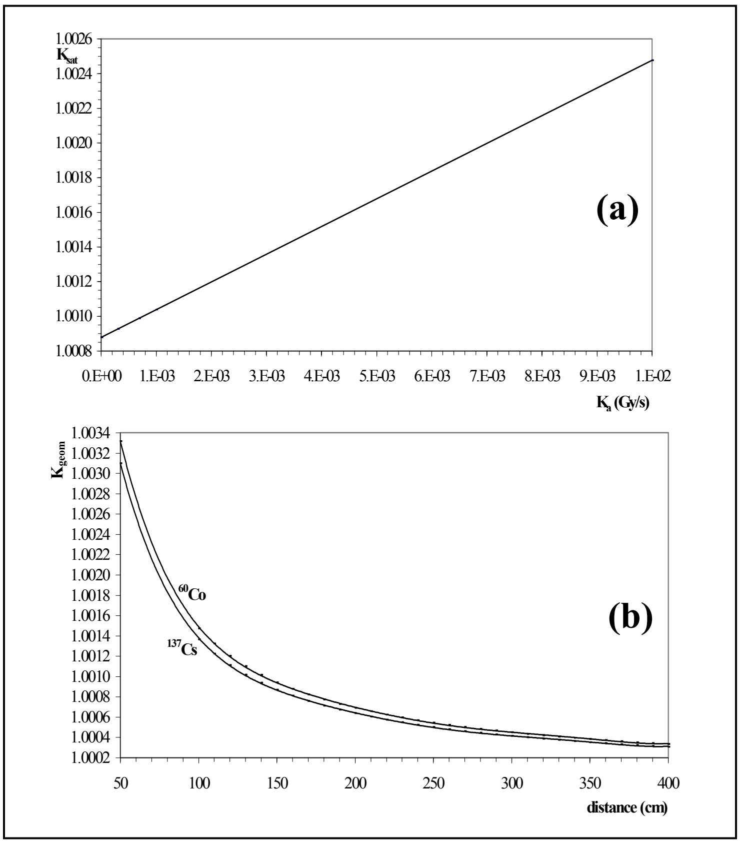


Figure A.1 – Correction factors k_{sat} (figure a) and k_{geom} (figure b) determined at the reference laboratory for the circulating dosimeter. The factor k_{sat}, accounting for ion recombination in the sensitive volume, is given as function of the air kerma rate. The factor k_{geom}, accounting for the effective measuring point, is given as function of the measuring distance.

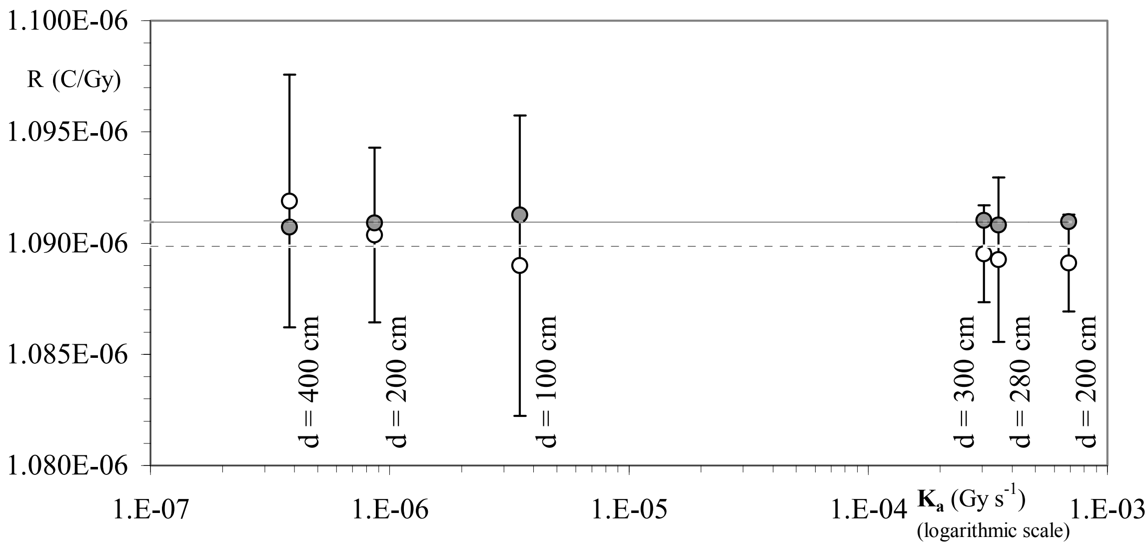


Figure A.2 - Results of measurements performed at the reference laboratory to check for the dependence of the circulating dosimeter response on the values of the air kerma and the measuring distance. The values of the response R obtained in different experimental conditions (with gamma radiation fields from different ^{60}Co sources) are shown (white circles), together with the corresponding values (grey circles) corrected for the effects of ion recombination, displacement of the effective measuring point and leakage current (see details in the text). The mean value of the uncorrected series (dashed line) and that of the corrected series (solid line) differ of about 0.1%.

A.2 INSTRUCTIONS

1. General information

1.1 Important addresses

Accreditation Body:

Servizio di taratura in Italia settore radiazioni ionizzanti (SIT-ENEA)
c/o Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti
ENEA Centro Ricerche Casaccia
Via Anguillarese, 301-00060 S.M. di Galeria (Rm)
Italy
Officer responsible: Maria Pia Toni
Telephone: +39 06 3048 3957
Fax: +39 06 3048 3558
E-mail: toni@casaccia.enea.it

Reference Laboratory:

Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti
ENEA Centro Ricerche Casaccia
Via Anguillarese, 301-00060 S.M. di Galeria (Rm) Italy
Responsible for comparison : Maurizio Bovi
Telephone: +39 06 3048 4524
Fax: +39 06 3048 3558
E-mail: bovi@casaccia.enea.it

1.2 Aim of the interlaboratory comparison

The intercomparison IR3 will be a supplement to the previous intercomparison IR1 to avoid the problems encountered during IR1 (e.g. the unexpected distance dependency of the calibration factor of the Babyline dose rate meter). The new intercomparison has now to be performed with a smaller ionisation chamber well characterised as a secondary standard. In particular, the effective point of measurement of this chamber is better determined and, therefore, any distance effect resulting from an insufficient knowledge of this point (as in the case of the Babyline dose rate meter) is avoided as much as possible.

Moreover the need of this new intercomparison also results from an inquiry carried out by the EA IR Expert Group among the different Accreditation Bodies

1.3 Principle of the interlaboratory comparison

A circulating dosimeter consisting of an ionisation chamber of the type PTW 23361 (30 cm^3) and a measuring assembly UNIDOS (display unit) of the type 10002 (both as a loan of the firm PTW in Freiburg) has to be calibrated by the participating laboratories in a Cs-137 and/or Co-60 gamma radiation field in terms of air kerma per unit of charge at two distances in the range of 1 m to 4 m between the source and the effective point of measurement of the ionisation chamber.

1.4 Participating laboratories

Under the interested laboratories those, which have participated in the previous intercomparison IR 1, are preferred.

2. Device

The device to be circulated consists of the following items:

a) the dosimeter consisting of two parts:
    a. the ionisation chamber of the type PTW W23361, serial number 0405
    b. the measuring assembly UNIDOS type 10002, serial number 20383
b) a chamber build-up cap
c) an extension cable (20 m)
d) an instruction manual

All parts are put out to loan from the manufacturer:

Physikalisch-Technische Werkstätten -PTW

Dr. Pychlau GmbH,

D-79115 Freiburg

The whole device is packed in a box (58 cm x 39 cm x 29 cm) together with an ATA carnet (only for the case of transportation out of the European Community).

3. Transportation

The device has to be sent by road, train or air freight; whichever appears safest for the device. The items should be unpacked immediately after receipt and checked for damage.

4. Customs (if relevant)

For customs purposes, the device is provided with an ATA carnet in the case of transportation out of the European Community. Customs procedures must be followed exactly. When the package enters or leaves the country, the appropriate forms have to be filled in very carefully under the auspices of the two Accreditation Bodies concerned. As the ATA carnet is valid for a limited period of time (frequently one year), special care has to be taken not to exceed the time allowed for the interlaboratory comparison.

5. Measurements

5.1 Some properties of the dosimeter

The PTW 23361 chamber is a cylindrical ionisation chamber with an effective volume of about 30 cm^3.

The chamber voltage applied must be +300 V.

The reference point of the ionisation chamber is situated on the central axis of the chamber, at a distance of 27 mm from the tip of the chamber without the build-up cap (or 30 mm from the tip, if the build-up cap is attached).

The ionisation chamber has to be arranged in the radiation field perpendicular to the central beam and the reference point has to be adjusted on the intersection of the chamber axis and the central beam with the marking facing the radiation source.

The dosimeter has a response of about 10^{-6} C/Gy. Its leakage current is smaller than 10^{-14} A. It follows, therefore, that the air kerma rate should be higher than 1 µGy/s (resulting in a chamber current of about 10^{-12} A) to get reliable results. On the other hand the dose rate should not be higher than 0.5 mGy/s to avoid any saturation correction.

5.2 Conditions for the Calibration

Quantity: Calibration factor in terms of air kerma per charge in Gy/C (standardised to the reference atmospheric conditions of temperature and air pressure).

Radiation qualities: Gamma radiation from Cs-137 and/or Co-60 sources (according to ISO standard 4037-1 (1996)).

Prescribed conditions

Range of air kerma rate: 1 µGy/s to 500 µGy/s
Range of distance: 1 m to 4 m

The calibration has to be performed at two distances:

a) at nominal 1 m
b) at a second distance as long as possible but less than 4 m (depending on the prescribed lower limit of the air kerma rate).

Note: The ionisation chamber has to be used with the build-up cap for Cs-137 and Co-60 gamma radiation.

Reference conditions

Temperature: T_0 = 293.15 K (20.0 ° C)
Pressure: $P_0 = 1.01325 \times 10^5$ Pa = 1013.25 hPa
Relative humidity: in the range from 30 % to 70 %

5.3 Setting of the Dosimeter [see also the Instruction Manual]

a) Check the adjusted voltage on the sticker at the rear (115 V/ 230 V), before connecting the unit to the mains.

b) Connect the unit to the mains, if you do not prefer to use the battery mode. The battery mode is automatically switched on, when the power supply cable is not connected.

   Press the ON/OFF button to switch on the UNIDOS.

   After this, the measuring window appears.

c) Select the English language.

   For the display of the UNIDOS you can select either the English or the German language.

   To select the English language:

   1. Set the cursor on the position ”SETUP” by using one of the two arrow keys and then press ENT.

2. If the display is already written in English:

   press ESC and you go back to the measuring window.

3. If the display is written in German:

   go to the line “Verschiedenes” by using one of the arrow keys;

   press ENT (you see the menu display VERSCHIEDENES);

   go to the line “Sprache” and press ENT;

   by using an arrow key you can select “Englisch”;

   press again ENT and go back to the measuring window by pressing ESC two times.

d) Select the chamber polarity:

   the polarity must be set by a switch at the rear panel.

e) Select the chamber voltage:

   set the cursor on the position ”CHAMBER” in the measuring window by using one of the two arrow keys and press ENT;

   if the correct voltage (+300 V) is indicated then press ESC;

   if not, set the cursor to the line ”Voltage”, press ENT and select the correct voltage by using the arrow keys, press ENT for confirmation and go back with ESC.

f) Select the unit:

   set the cursor on the position ”SETUP”;

   press ENT to display the menu;

   if the unit is not indicated as ”Electrical” go with the cursor to the position ”Units”, press ENT and set with the arrow keys the position ”Electrical”;

   confirm with ENT and go back with ESC.

g) Select the charge mode:

   switch the key MOD to the position ”CHARGE”;

   switch the key RGE to the position ”High 23 nC”;

   press ENT.

h) Connect the ionisation chamber with the measuring assembly using the extension cable.

i) Select the measuring time:

   1. The measuring time is selected by the following test measurement in the radiation field.

      Test measurement:

      Open the shutter or bring the radioactive source in the irradiation position.

      Start the UNIDOS with INT.

      Wait until the reading has at least a value with four digital positions.

      Finish the measurement with the key HLD.

      The measuring time is indicated at the display.

If the time is too long, repeat the measurement after setting the key RGE to the position ”Low 230 pC”.

2 Select a suitable measuring time taking into account the result of the test measurement.

Note: The maximum charge being accumulated is:

about 240 pC in the charge mode “Low 230 pC”

about 23 nC in the charge mode “High 23 nC”
If these ranges are overranged, “OL” (Overload) is indicated and the reading is cancelled.

3 Setting of the internal clock:
Set the cursor again on the position ”SETUP” and press ENT.
Set the cursor to the position ”Interval Time” and push ENT.
Set the selected measuring time using the arrow keys, push ENT and go back with ESC.

5.4 Preliminary checks [see also the Instruction Manual]

Before start with measurements, check that:

a) the ionisation chamber is correctly connected with the measuring assembly using the extension cable.
b) the main power supply is applied or the battery mode is in function.
c) the correct voltage is applied to the chamber.
d) the setting of the polarity switch at the rear panel is correct.
e) the UNIDOS is in the charge mode.
f) the build-up cap is added to the chamber.

5.5 Measurement

a) Switch on the power supply by pressing the ON/OFF button.
b) Wait at least 15 minutes.
c) Be sure that the chamber is connected with the UNIDOS via the extension cable but *not irradiated.*
d) Start the “automatic zeroing” by pressing the key NUL (the required time is about 75 s)
e) Start the measurement by pressing the key INT (the measurement stops when the set time is over).
f) Read the value of the accumulated charge indicate (uncorrected reading).
g) Measure the air pressure and the temperature nearby the ionisation chamber.
h) Correct the uncorrected charge reading by applying the air density correction.

The quantity to be determined, for each measuring point, is the calibration factor N_K in terms of air kerma per unit of charge defined by:

$$R_C = R \cdot k(P,T)$$

with

$$N_K = \frac{(K_{air})_{ref}}{R_C}$$

where:

$(K_{air})_{ref}$ is the reference value of the air kerma
R_C is the corrected reading of the dosimeter in Coulomb
R is the uncorrected reading of the dosimeter in Coulomb

k(P,T) is the correction factor for the air density correction (reference value of air pressure:1013.25 hPa, reference value of the temperature: 293.15 K or 20.0 °C)

Note: The leakage current of the ionisation chamber is suppressed in the UNIDOS by using the "automatic zeroing" (key NUL) before each separate measurement series.

In order to facilitate the analysis of the results of the intercomparison, it is recommended to present the data in a common way by:

a) using the same sheet for the summary of results of the measurement (see Appendix A.3)
b) using the same information sheet for the results of the measurement (see Appendix A.3)
c) using the same chart for the measuring conditions (see Appendix A.3)

6. Circulation scheme

The circulation will be carried out in two phases. The dosimeter will circulate among the participating countries of the European Community (first phase) and then among the other participating countries (second phase). Before starting the circulation the dosimeter will be calibrated by the Reference Laboratory. The same will take place at the end of the first phase and at the end of the complete circulation. According to a time schedule, the dosimeter will be sent from the Accreditation Body of country A to the Accreditation Body of country B and so on. For the circulation within a country between several calibration laboratories the Accreditation Body of the respective country has to be responsible.

7. 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 forms and formal certificates.

The Accreditation Body will send copies of these documents, together with a summary, to the organising Accreditation Body.

8. Uncertainty

This calculation has to be carried out according to the method prescribed in EA-4/02.

Circulation scheme

Number of weeks	Period		Country
0	First measurements		Germany
1	08 May - 14 May	2000	**Reference lab.** (Italy)
5	15 May - 11 June	2000	Italy
7	12 June - 25 June	2000	travelling time
9	26 June - 09 July	2000	Spain
11	10 July - 23 July	2000	travelling time
15	24 July - 20 August	2000	France
17	21 August - 03 September	2000	travelling time
21	04 September - 01 October	2000	United Kingdom
23	02 October - 15 October	2000	travelling time
25	16 October - 29 October	2000	Ireland
27	30 October - 12 November	2000	travelling time
29	13 November - 26 November	2000	Portugal
31	27 November - 10 December	2000	travelling time
32	11 December - 17 December	2000	**Reference lab.** (Italy)
35	18 December - 07 January	2000/01	travelling time (Christmas)
37	08 January - 21 January	2001	Greece
39	22 January - 04 February	2001	travelling time
41	05 February - 18 February	2001	Finland
43	19 February - 04 March	2001	travelling time
45	05 March - 18 March	2001	Denmark
47	19 March - 01 April	2001	travelling time
49	02 April - 15 April	2001	Sweden
51	16 April - 29 April	2001	travelling time (Easter)
53	30 April - 13 May	2001	Austria
55	14 May - 27 May	2001	travelling time
56	28 May - 03 June	2001	**Reference lab.** (Italy) ATA carnet
58	04 June - 17 June	2001	travelling time
60	18 June - 01 July	2001	Slovakia
62	02 July - 15 July	2001	travelling time
64	16 July - 29 July	2001	Slovenia
66	30 July - 12 August	2001	travelling time
68	13 August - 26 August	2001	USA
70	27 August - 09 September	2001	travelling time
72	10 September-23 September	2001	South Africa
74	24 September- 07 October	2001	travelling time (Christmas)
	Final measurements		**Reference lab.** (Italy)

A.3 REPORT FORMS

In this section the ILC IR3 report forms are given. These forms were sent to the participants on the ILC (as enclosed to the ILC Instructions and/or by e-mail) with the purpose to have all the information useful for the analysis of the ILC results presented clearly and in a common way.

The list of the enclosed report form was:

1) Summary of laboratory results
2) Results of the measurement
3) Description of measuring conditions
4) Information on receipt of the package
5) Uncertainty budget

All the listed forms are reported in the following

1/1

Summary of laboratory results

EA Interlaboratory Comparison No. ____________________

SUMMARY OF RESULTS, taken from Certificate No. ____________________

Participating laboratory ____________________________________

____

____

Accreditation No. ____________________

Code number ____________________
(to be assigned by the participating Accreditation Body)

Date/period of calibration ____________________

SUMMARY OF THE RESULTS			
Radionuclide	Distance (m)	Calibration factor (Gy/C)	Expanded uncertainty (k = 2) (%)

Brief description of the method used to determine the expanded uncertainty:

____

____

Remark on the deviation of stated expanded uncertainty of measurement from the best measurement capability, if applicable:

____

____

1/1

Results of the measurement
(Please use a separate form for each source)

Identification of the radioactive source :

Radionuclide (Cs-137 or Co-60):

CALIBRATION DISTANCE	**1** **(at nominal 1 m)**	**2** **(at the other distance)**
Date of measurement		
Distance source to point of test (m)		
Air kerma rate (ref. value) (Gy/s)		
Measuring time (s)		
Air kerma (Gy)		
Uncorrected reading of the dosimeter (C)		
Relative air humidity (%)		
Mean value of temperature (°C)		
Mean value of pressure (hPa)		
Correction factor k(p,T)		
Other correction factors if applied		
Corrected reading of the dosimeter (C)		
Calibration factor (Gy/C)		
Rel. expanded uncertainty (k=2) of the calibration factor (%)		

1/2

Description of the measuring conditions

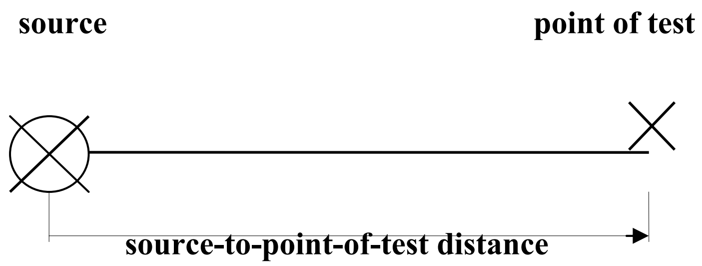
Irradiation device	
Radionuclide (Cs-137 or Co-60)	
Collimator (yes or no)	
Type of reference standard (calibrated reference instrument or calibrated field)	
Traceable to which National Laboratory	

CALIBRATION DISTANCE	**1** **(at nominal 1 m)**	**2** **(at the other distance)**
Field size at the point of test		
Contribution of scattering (if known)		
Distance between the point of test and the back wall		
Distance between the point of test and [(1)] a) the left side wall, b) the right side wall, c) the floor, d) the ceiling e) other scattering surfaces		
Remarks		

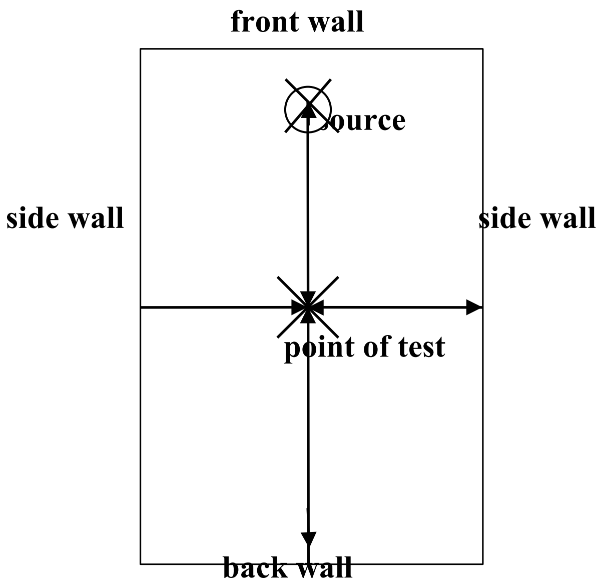
[(1)] See the enclosed schematic drawing.

2/2

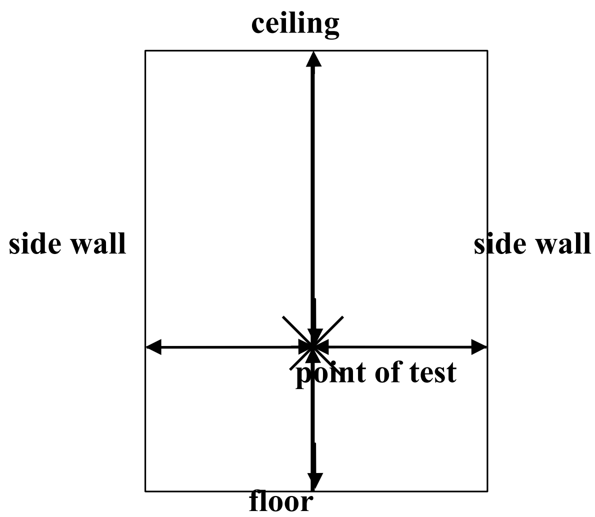
Description of the measuring conditions



a) Ground-plan



b) Elevation



1/1

Receipt form on Interlaboratory Comparison Number **IR3**

To be returned to:

Dr. Maria Pia Toni
Servizio di taratura in Italia settore radiazioni ionizzanti (SIT-ENEA)
c/o Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti
ENEA Centro Ricerche Casaccia - Italy
FAX +39 06 3048 3558

In order to be able to monitor the progress of the interlaboratory comparison, we ask each Accreditation Body (or laboratory), on receipt of the Interlaboratory Comparison Package, to kindly fill in the following Report form.
Please send this form by telefax. Thank you in advance for your co-operation.

The package of Interlaboratory Comparison Number **IR3**

was received on (date) ☐

The package seems, after short inspection, to be **not damaged** ☐

damaged ☐

If damaged: **- is this serious?** **yes** ☐ **no** ☐

- are the contents probably still suitable for use? **yes** ☐ **no** ☐

Remarks: ☐

Accreditation Body or laboratory receiving the package: ☐

Contact person: ☐

Telephone: ☐

Telefax: ☐

1/1

Uncertainty budget

Uncertainty budget for calibration factor $(N_k)_{lab}$ as determined for the EA IR3 ILC (please use separate forms if the uncertainty budget changes with the calibration point):

Accreditation body: ____

Laboratory: ____

Certificate number: ____

Calibration point characteristics: ☐ Co-60 ☐ Cs-137

Distance (cm): ______________________

air kerma rate (C kg^{-1} s^{-1}): ______________________

Input quantity / Influence quantity	Uncertainty	
	Type A %	Type B %
1. Standard uncertainty (from calibration certificate) (specify the standard type ______________________)		
2. Reference value of ☐ air kerma / ☐ air kerma rate Describe the relevant components of uncertainty to obtain 2 from 1: 2.1 ______________________ 2.2 ______________________ 2.3 ______________________ 2.4 ______________________ 2.5 ______________________		
3. Positioning of the circulating instrument		
4. Ambient conditions during measurements		
5.		
6.		
7.		
Relative combined standard uncertainty of N_k (k = 1)		
Relative expanded uncertainty of N_k (k = 2)		

(*) Please mark relevant point(s) (**) please mark relevant quantity

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