A Personal Dosimetry Intercomparison Study in Asian and Pacific Region

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INTRODUCTION

The IAEA/RCA (Regional Cooperative Agreement) project to strengthen and harmonize radiation protection infrastructures in Asian and Pacific region started in 1988. The number of the RCA member countries is 17 at present. In the early stages of the project, there was little information on the status of radiation protection and their technical abilities of radiation protection measurements in RCA member countries. Since individual monitoring for occupational protection was performed in every country where radiation was used industrially and/or medically, it was thought that the intercomparison of dosimetry services could bring fruitful results and provide a good index of the technical stages of member countries. The first RCA personal dosimeter intercomparison (Phase 1) was conducted during the years of 1990 - 1992. At that time few regional dosimetry services calibrated dosimeters on backscatter phantoms, so the intercomparisons were mainly conducted with the traditional physical quantity, e*xposure*, in units of "R". The results of the first phase RCA personal dosimeter intercomparison were published [1], and the program was seen to have contributed significantly to the technical improvement of personal dosimetry systems of many RCA member countries.

In 1990, the International Commission on Radiological Protection (ICRP) published new recommendations on radiation protection principles [2]. At about the same time, the International Commission on Radiation Units and Measurements (ICRU) defined a the new set of operational quantities for radiation protection [3, 4, 5, and 6]. These were recommended for use in the International Basic Safety Standards [7]. Furthermore, the International Standard Organization (ISO) proceeded with development of recommendations on the calibration methodology for radiation protection instruments for the operational quantities [8]. Increasing international use of the operational quantities was the primary motivation for initiating the second RCA intercomparison program for individual monitoring. In 1994, the RCA Workshop on Calibration of Dosimeters and Survey Instruments for Photons was held in Tokai, Japan and the operational quantities for individual monitoring were also discussed and the second dosimeter intercomparison was proposed and planned for the period 1995 - 1996.

The objectives of the second phase personal dosimeter intercomparison were as follows;

1) To evaluate dosimetry systems abilities for conducting individual monitoring in terms of the ICRU operational quantities for photons. (Performance Assessment)
2) To provide access for the participants to photon field qualities for calibration of their systems.
3) To provide a unique opportunity for regional exchange of information.

In the second intercomparison, the number of participating dosimetry services was expanded to more than 30, whereas only one laboratory for each member country could participate in the first phase intercomparison program. **Table 1** shows the member countries and the number of dosimetry systems which were used in the second phase intercomparison.

During the years of 1995 and 1996, four irradiation laboratories, the Australian Radiation Laboratory (ARL), New Zealand National Radiation Laboratory (NRL), Japan Atomic Energy Research Institute (JAERI) and Japan Nuclear Cycle Development Institute (JNC: former PNC; Power Reactor and Nuclear Fuel Development Corporation), made 12 different sets of irradiations with gamma rays or X-rays for more than 1,000 dosimeters (6 each year). JAERI provided technical coordination and administration for the intercomparison, including collection, distribution and return of the dosimeters; and compilation of the results. This paper summarizes the results of RCA personal dosimeter intercomparison including the dosimeter irradiations and some related discussions.

SUMMARY OF PERSONAL DOSIMETRY PRACTICIES IN RCA MEMBER COUNTRIES

At the beginning of the Intercomparison, a survey was conducted to obtain information on the status of personal dosimetry systems and dosimetry service practices in the RCA Member States. Prior to the conducting the irradiations, questionnaires were distributed to the participants. 38 Participants responded to the survey. The results are summarized below.

Table 1 - Number of Participating Dosimetry Systems

Country	*1995*	*1996*
Australia	**5 (4)**	**2**
Bangladesh	**2 (1)**	**2 (1)**
China	**7**	**7**
India	**1**	**1**
Indonesia	**2 (1)**	**-**
Japan	**5 (4)**	**5 (4)**
Korea	**2**	**3 (2)**
Malaysia	**1**	**1**
Mongolia	**2**	**2**
Myanmar	**-**	**-**
New Zealand	**2 (1)**	**2 (1)**
Pakistan	**1**	**1**
Philippines	**1**	**-**
Singapore	**1**	**1**
Sri Lanka	**1**	**1**
Thailand	**2**	**2**
Vietnam	**3 (2)**	**3 (2)**
Total	**38**	**33**

* The number in parenthesis indicates the number of separate organizations (dosimetry services).

1) In the participating countries, personal monitoring was used for a range of occupational exposure conditions. Participating dosimetry services reported providing or potentially having to provide monitoring for workers in the following facility or radiation field types:

Occupational Exposure Fields	Number of Participants
Reactors	16
X-rays	27
Accelerators	17
Sealed sources	25
Unsealed radioactive materials	20

Many participants indicated that beta rays and neutrons, as well as various gamma ray energies were also to be monitored. The dominant sources were ^{60}Co (1.25 MeV) and ^{137}Cs (0.662 MeV) in most member countries.

2) The many dosimetry services that participated in the RCA intercomparison monitored more than 50 % of dosimeter users (occupationally monitored workers) in their countries. Two of the dosimetry services covered 100 % users of their countries, but the dosimetry services from three countries monitored less than 10% of their workers.

3) The dosimeters submitted for the program were divided into three types; Thermo-luminescence dosimeters (TLD), Film dosimeters and Radiophoto-luminescence glass dosimeters (RPL). More than 70 % of dosimeters submitted were TLD, in both of intercomparison of 1995 and 1996 and only two of them were RPL. The remains were film dosimeters. Participants with TLD based dosimetry systems reported using equipment from the following suppliers: Harshaw, 44%; Teledyne, 8%; Panasonic, 8%; and others, 40%. Seven different TLD phosphors were used by the participants.

4) About 93 % of the participating dosimetry services calibrated their systems at their own facilities. The calibration sources or fields used were ^{137}Cs (24), ^{60}Co (14), X-rays (3) and others (4). About half of the reference values of the irradiation field had no traceability to the authorized standard dosimetry laboratory

(PSDL or SSDL). About 2/3 participants used a backscatter phantom for calibration. Most of these used either PMMA slabs, with a 15 cm thickness (13), or IAEA (5) or ISO (5) designed water filled phantoms.

5) All the participants measured their dosimeters and evaluate individual doses by themselves. Most of the necessary data for dose evaluation were also obtained by themselves, but some of such data came from the manufacturer. Some participants made corrections on fading and/or energy dependence when they evaluated the dose values. Most of the participants exchanged dosimeters either monthly (16) or quarterly (14). Three participants used 2 month exchanges and two were unspecified.

6) Sixty percent of the member countries had some sort of quality assurance program. Of these, nearly 60 % (in all 36 %) were authorized by their government or relevant academic organizations.

7) Selection of the proper dosimeter position when a lead apron is worn is a common question among dosimetrists. Twenty five participants placed a single dosimeter under the apron, 6 use dosimeters both ouside and under the apron, 3 were them outside the apron, 1 reported not using a dosimeter with aprons, and one did not specifiy.

IRRADIATIONS

Reference field value check

Four irradiation laboratories, which have the good traceability to the primary radiation standards or are, themselves, one of the primary standards, conducted the irradiations. However, preceding the dosimeter irradiations, a mutual check of comparability of reference dose values among 4 irradiation laboratories was carried out with radiophotoluminescence (RPL) glass dosimeters. The RPL glass dosimeter is well known for its excellent precision and good properties such as stability (negligible fading), product uniformity, etc. RPL dosimeters were sent to each irradiation laboratory with background, transit control dosimeters. After irradiation to a known level of dose (air kerma in Gy) using a ^{137}Cs source, they were returned to JAERI to be read out and compared.

A field reference value check was conducted during the first phase RCA intercomparison and the results proved to be very useful. Further technical developments in RPL dosimetry were made at JAERI and JNC after the 1st program and their variation had been reduced to almost 1 %. A better result was, therefore, expected in the 2nd intercomparison. The reference value check was conducted simultaneously with participation of one calibration laboratory from each participating member country, in cooperation with the IAEA Dosimetry Laboratory in Seibersdorf, Austria. It was expected that this reference value check would provide useful information to each participating laboratory on 1) the quality of their basic calibrations, and 2) the potential personal dosimetry errors associated with the calibrations. In this way, calibration quality could be isolated from the dose evaluation results of the following intercomparison.

Dosimeter irradiations

As noted above, dosimeter irradiations were made for 12 different categories (6 for each year of 1995 and 1996). The categories are shown in **Table 2** and the qualities of radiation are consistent with ISO reference radiations [8]. The irradiation distance (for convenience, determined from the center of the source or X-ray tube to phantom surface) was fixed to be 4 meters, and the area of irradiation field was sufficiently large to expose the surface of phantom uniformly. The quantity was the personal dose equivalent, $H_P(d)$, and so all the irradiations were made with backing of ISO water phantom (30 x 30 x 15 cm). The conversion coefficients used to obtain the personal dose equivalent values for each radiation quality were those given by ISO [8]. In the 1995 program, all the irradiations were made with single quality, and conducted at perpendicular incidence. In the second phase (1996), two of 6 categories were performed with mixed qualities (multiple energies). An irradiation category was made using a non-perpendicular incidence (Table 2, category 4).

The dose value delivered was fixed for each category, with a dose range from near the detection limit to the recommended annual dose limit (20 mSv), which is considered to be normally recorded for most occupational radiation workers.

Table 2 - Irradiation Categories for 2nd RCA Personal Dosimeter Intercomparison

Category	1995	1996
1	X-rays ISO Wide Spectrum Series 60 kV (45 keV)	X-rays ISO Wide Spectrum Series 60 kV (45 keV) + 200 kV (134 keV)
2	X-rays ISO Wide Spectrum Series 200 kV (134 keV)	X-rays ISO Wide Spectrum Series 60 kV (45 keV) + ^{60}Co gamma rays
3	^{60}Co gamma rays	X-rays ISO High Air Kerma Rate Series 30 kV (19.7 keV)
4	^{137}Cs gamma rays	X-rays ISO Wide Spectrum Series 110 kV (79 keV) (Non-perpendicular - 60°)
5	X-rays ISO High Air Kerma Rate Series 30 kV (19.7 keV)	^{137}Cs gamma rays (Low Dose ≈ 0.3 mSv)
6	X-rays ISO Wide Spectrum Series 110 kV (79 keV)	^{60}Co gamma rays (High Dose ≈ 20 mSv)

Each dosimeter was read out, and the dose evaluation results were sent to JAERI. JAERI compiled the data, analyzed them using the following equation (1) and reported the results for their dosimeters to each participant. Each participant submitted three dosimeters for each category. The quotient was determined using the mean value of three evaluated dose values. The variation among three evaluated values is one of the other concerns for the present intercomparison, but its analysis is left as a matter for each participant.

$$Deviation = \frac{Measured\ Dose - Delivered\ Dose}{Delivered\ Dose} \quad \cdots\cdots \quad (1)$$

DISCUSSIONS

Figure 1 shows the results of the field reference value check. All the measurements were made with air kerma, in Gy. The measurement data were expressed using the deviation of dose value (JAERI evaluated) from the delivered dose value (participant reported). It is estimated that, considering the maximum uncertainty of RPL glass dosimetry to be around 2 %, some calibration facilities may need to make some improvements. It can be expected that backscattering evaluation or reference dose measurements with a reference ionization chamber could have contributed some errors. In particular, some facilities might use reference dose data as obtained from the source manufacturer or from measurements that are not traceable to primary or secondary radiation standards maintained by Primary or Secondary Standard Dosimetry Laboratories (PSDLs or SSDLs).

A typical example of the intercomparison results expressed as the deviation of evaluated dose values for each participating dosimetry system are shown in **Fig. 2**. **Figures 3(a) and 3(b)** summarize the $H_P(10)$ results for 1996 program of the RCA personal dosimeter intercomparison. For TLDs, most of the largest deviations were indicated in the low energy and non-perpendicular irradiation categories. The trend that the deviations were larger for the low energy categories is consistent with the results of 1995 program. For film dosimeters, however, a somewhat different trend is observed for the lower energies. The dose evaluation results for the lowest energy (30 kV X-rays) was actually better than that of 60 kV. It is considered that this is because the response of most film dosimeters peaks in the energy region of around 50 keV. Dose evaluation is likely to be more difficult for the categories of mixed radiation X-rays and gamma-rays.

In the 1996 program, there were three unique irradiation categories used to investigate the behavior of each dosimetry system; (1) non-perpendicular irradiation using the 110 kV X-rays, (2) irradiation with a very low dose (close to the detection limit) ^{137}Cs and (3) irradiation with high dose (close to annual limit) using ^{60}Co. The results of such categories were compared with those irradiation categories used in 1995. The results of non-perpendicular irradiation were compared with those for the equivalent perpendicular irradiation used in the 1995 program. For both $H_P(10)$ and $H_P(0.07)$, no obvious difference in results was found between the perpendicular and non-perpendicular irradiations. The comparison of dose evaluation results for ^{137}Cs gamma rays between the two different dose values of 0.32 mSv and 1.92 mSv and the comparison for ^{60}Co gamma rays between 1.74 mSv and 19.66 mSv showed no remarkable evidence of decline in accuracy for lower or higher dose level.

The dose evaluation accuracy for ^{137}Cs gamma rays is better than that of 30 kV X-rays for most dosimetry systems, with a few exceptions (See **Figs. 4(a)** and **4(b)**). As previously mentioned, most of the large deviations for the 30 kV X-ray category in the 1995 and 1996 programs were observed for TLDs. In most of the dosimetry systems whose deviation was larger than others, calibration had been carried out only for the high energy gamma rays such as ^{137}Cs or ^{60}Co. The lack of appropriate calibration fields is considered to be a main reason for the deficiency. For film dosimeters, on the other hand, due to its large energy dependence, more suitable and stricter calibration procedures might be adopted at the calibration facilities.

One of the main objectives of the RCA personal dosimeter intercomparison is the performance assessment of each dosimetry system. The IAEA has recommended use of the "Trumpet Curve" as one way to assess the dosimetry system's performance in its draft Safety Guide on assessment of occupational exposure due to external sources of radiation [9]. **Figure 5** shows the trumpet curve and the distribution of all the evaluated dose results for both 1995 and 1996 programs. **Table 3** also shows the fractions of the number of dosimetry systems, for each category, whose results exceeded ICRP recommendations and those outlined by the IAEA [9]. It is clear that the lowest energy X-ray category (30 kV) has the largest number of dose evaluation results exceeding the recommended values for both phases (1995 and 1996). The best results were achieved for the high energy categories of ^{137}Cs or ^{60}Co gamma-rays. This is most likely because these are the calibration sources most often used by these dosimetry services. The overall results (Table 3) show that the 1996 program results showed slight improvement over those for the 1995 irradiations. However, since some of the participants of the 1995 phase did not take part in the 1996 irradiations, this may not be clear evidence that the personal dosimeter intercomparison programs improved the performance of the participants' dosimetry systems.

Table 3 - The fraction of the number of dosimetry systems with results outside the trumpet curve limits for $H_P(10)$ (in %)

Category Number	1995	1996
1	20.6	12.5
2	12.1	18.8
3	9.1	25.8
4	9.1	16.1
5	21.2	0.0
6	17.6	6.5

When comparing the results for different types of dosimeters - TLD, Film and RPL - no remarkable difference was observed in their performance when calibrations were believed to be suitable and appropriate. As in the first intercomparison [1], most of the large deviations, i.e. deficiencies of dosimetry system, were believed to originate from the lack of suitable calibrations. Some of the member countries may need some technical assistance to improve the performance of their personal monitoring services. For TLDs, overall quality control of the dosimetry system including TLD reader maintenance is necessary, especially, when the exposure to low energies is involved. For film dosimeters, it should be determined what factors primarily affect the dose evaluation; fading, large energy dependence or another equipment problems. In both cases, more data acquisition and data accumulation through dosimeter irradiations by the reliable irradiation laboratories are necessary. The RCA personal dosimeter intercomparison was one of the most useful programs to give such opportunities to every member country and it is hoped to be conducted continuously and regularly in the future. If possible, more systematic quality assurance programs in the member countries would be desired.

CONCLUSION

The first and second RCA personal dosimeter intercomparison programmes have contributed to the technical improvement of individual monitoring of member countries, especially for some laboratories that have not had the benefit systematic calibration procedures as described by ISO. The results of both intercomparison programs show that the individual monitoring in most participating laboratories is at an acceptable level. The intercomparisons have proved that the operational quantities defined by the ICRU and recommended by the IAEA are becoming widely accepted and implemented in the RCA member countries. Some countries, however, need to have more effort to improve their dosimetry systems. These kind of personal dosimeter intercomparison programmes should be continuously conducted to help their effort and to give opportunities to check their dosimetry systems.

ACKNOWLEDGEMENT

The authors wish to express their thanks to Dr. N. Hargrave (formerly with the Australian Radiation Laboratory), Dr. V. Smyth (New Zealand National Radiation Laboratory), Dr. T. .Momose, Dr. N. Tsujimura (Japan Nuclear Cycle Development Institute), and their organizations for their support in providing the organization and irradiations for the intercomparison. The authors also wish to extend their appreciation to all the participants for their cooperation in conducting these intercomparison programs.

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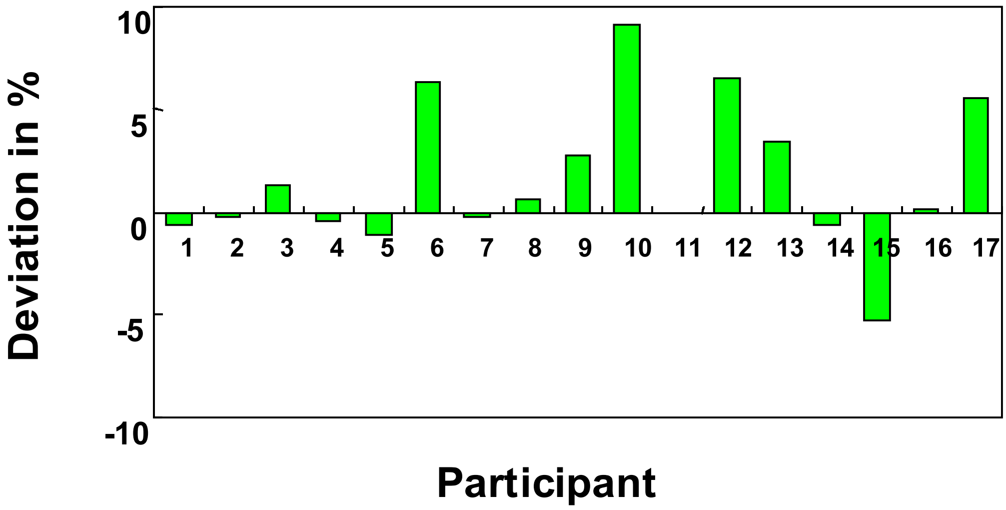


Fig.1 Results of Field Reference Value Check

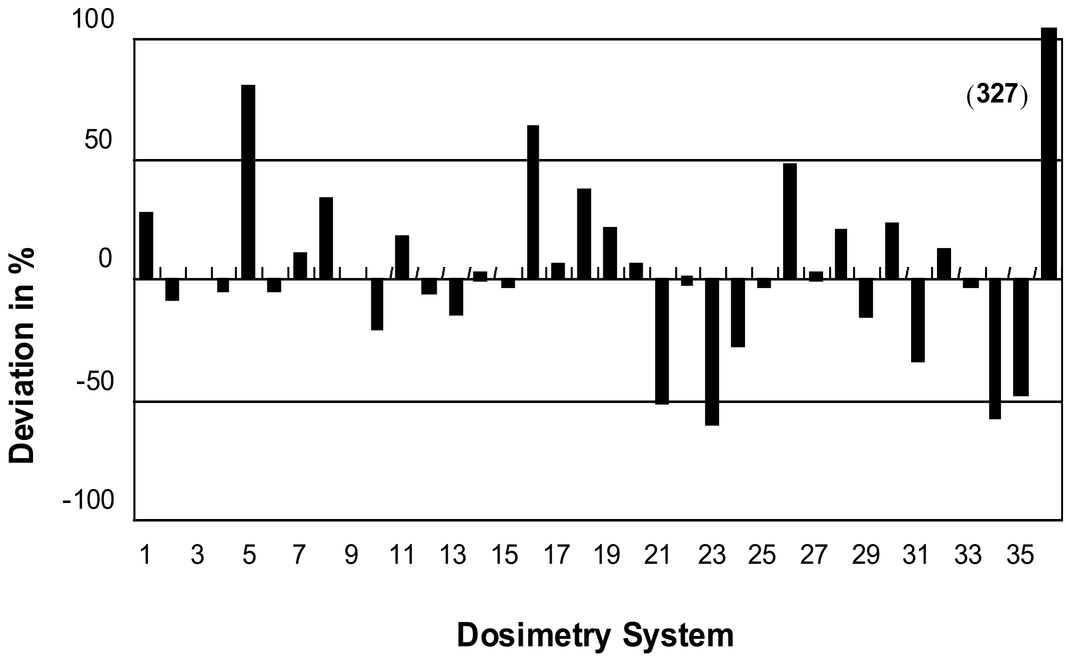
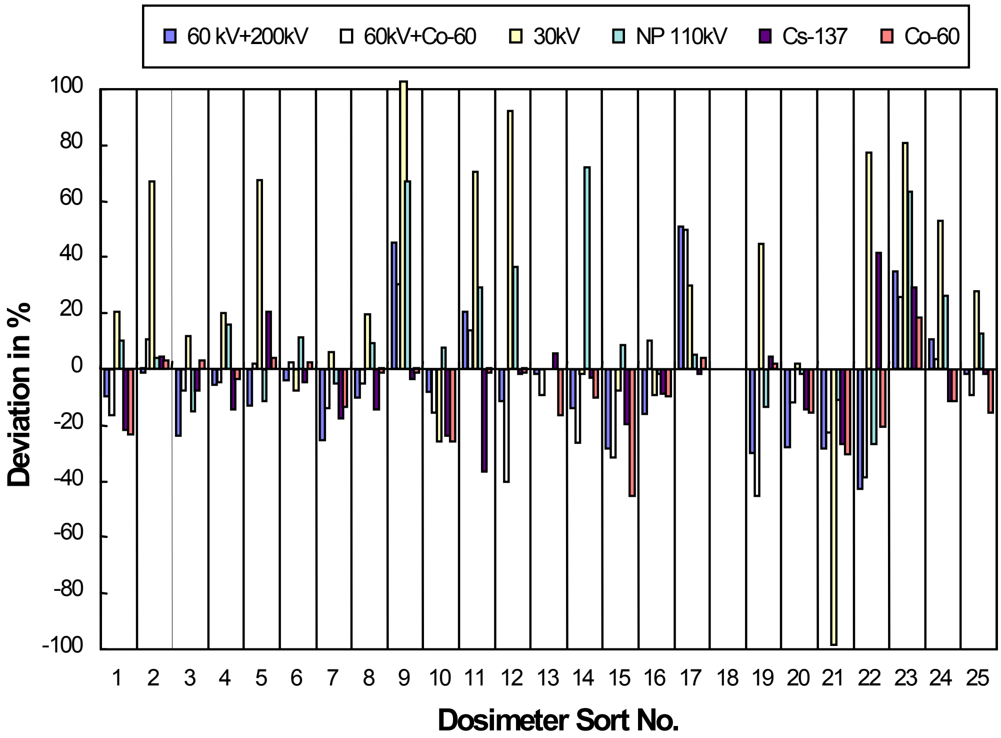
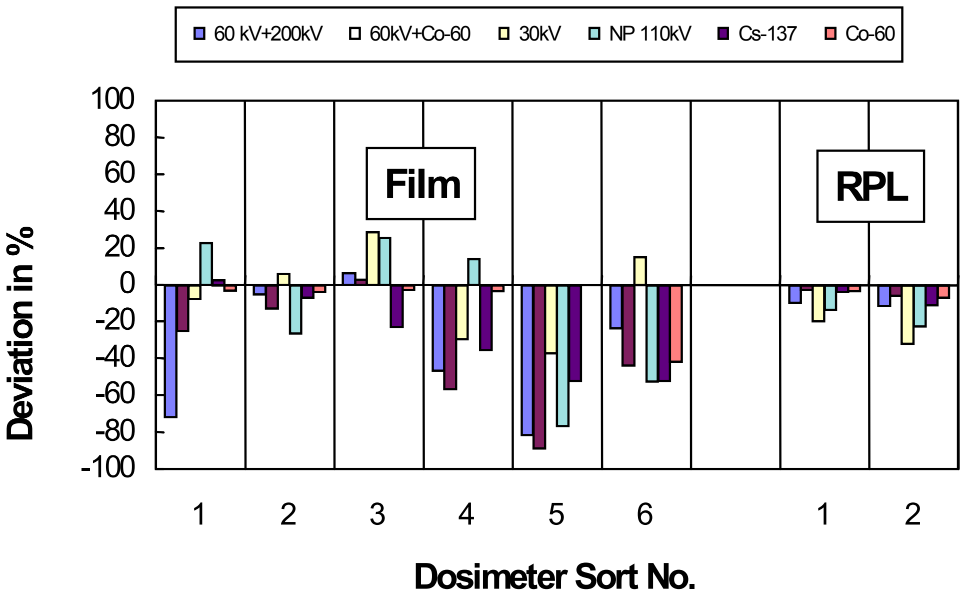


Fig.2 An Example of the Intercomparison Results

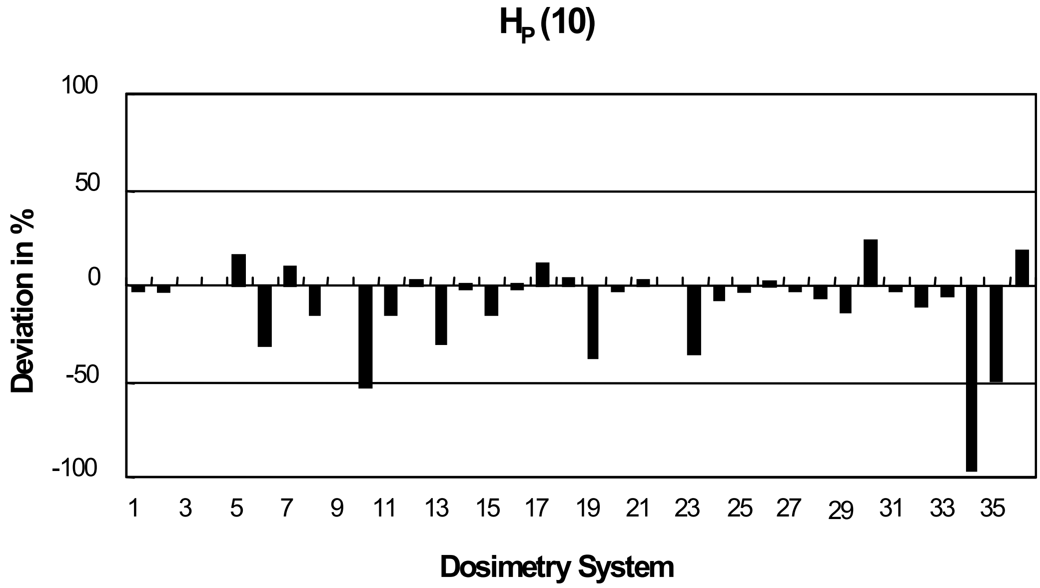


(a) 1996 Intercomparison Results - TLDs

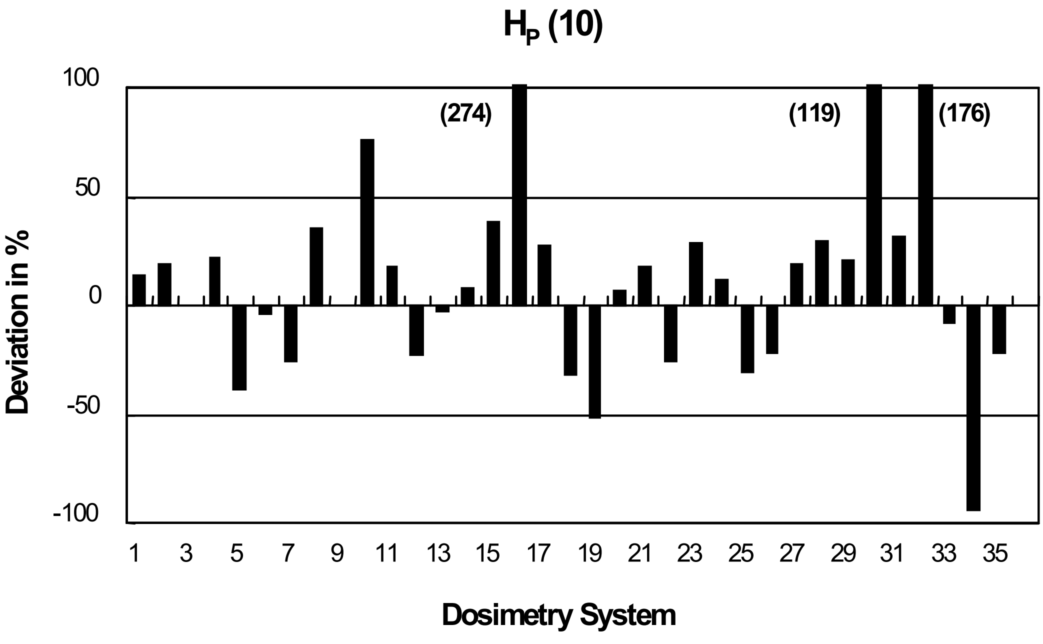


(b) 1996 Intercomparison Results - Film and RPL glass dosimeters

Fig.3 RCA personal dosimeter Intercomparison Results

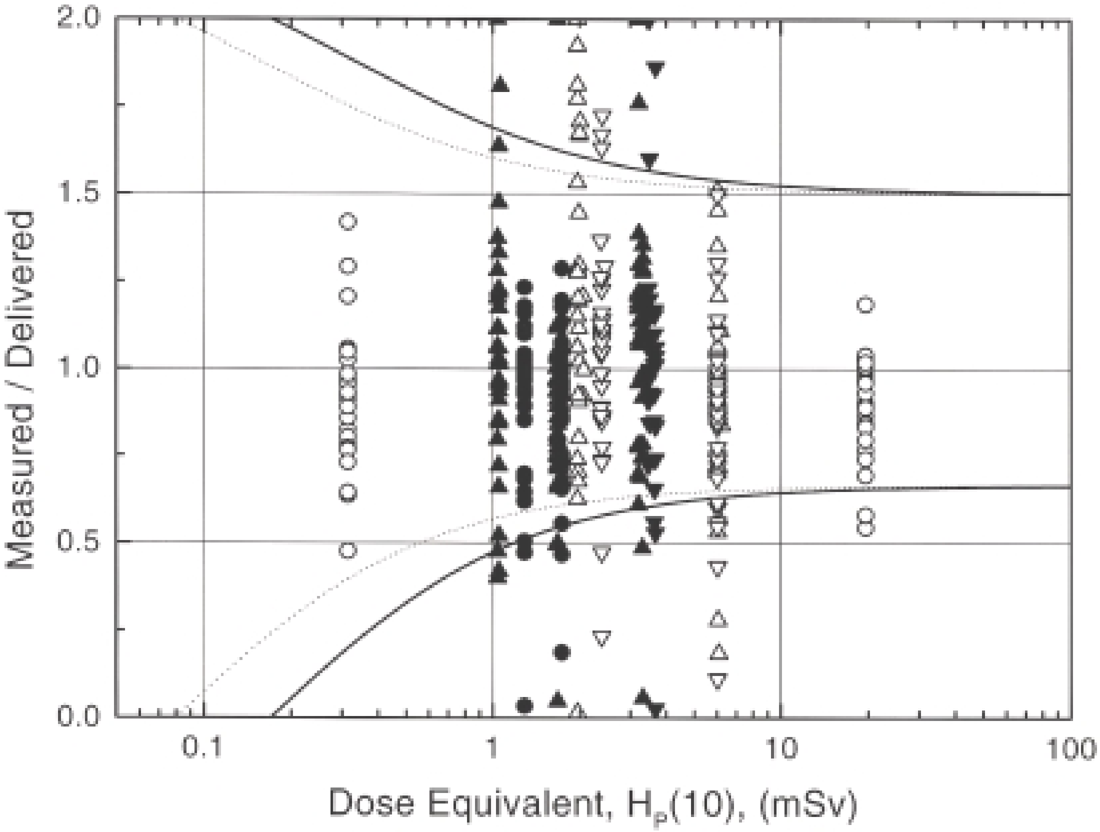


(a) ^{137}Cs Gamma rays



(b) 30 kV X-rays (E=19.7 keV)

Fig.4 Comparison of intercomparison results for different photon energies



▲▼ Xrays in 1995 program △▽ Xrays in1996 program

● Gamma rays in 1995 program ○ Gamma rays in 1996 program

(Broken lines: monthly monitoring periods; solid lines: two-month monitoring periods)

Fig.5 Overall results of RCA Intercomparison (1995-1996)