



DEPARTMENT OF
HEALTH, HOUSING &
COMMUNITY SERVICES

**Intercomparison of Personal Radiation Monitoring Services
in the Asia/Pacific Region**

by

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**Australian
Radiation
Laboratory**

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ARL/TR110
ISSN 0157-1400
OCTOBER 1992

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ABSTRACT

The Australian Radiation Laboratory in 1991 conducted an International Intercomparison of Personal Radiation Monitoring Services in the Asia/Pacific region. Twenty nine organisations from sixteen countries took part in the study, with the People's Republic of China having the greatest number of participants (11). Both thermoluminescent dosimeters (TLD) and conventional film badge dosimeters were submitted for evaluation. The intercomparison was partially funded by the International Atomic Energy Agency (IAEA).

The intercomparison involved participants submitting 25 dosimeters including transit controls to the Australian Radiation Laboratory for exposure. Seven radiation beams of varying beam quality were used. Both film dosimeters and TLDs were irradiated with ^{137}Cs gamma rays, X-rays and 2.0 MeV maximum energy beta rays from a $^{90}\text{Sr}/^{90}\text{Y}$ source. Seventeen dosimeters were exposed to the photon beams at normal incidence, four at a time, on a slab phantom made from a 5.5 cm thick perspex block backed by 20 cm of paper. Two dosimeters were exposed to beta rays at normal incidence. The delivered dose equivalents were in the range 0.2 to 2 mSv. Participants were requested to assess their dosimeters in terms of the International Commission on Radiation Units and Measurements (ICRU) new operational quantities for personal monitoring, namely the individual dose equivalent, superficial $H_s(0.07)$ and individual dose equivalent, penetrating $H_p(10)$.

Twelve participants estimated the delivered penetrating dose equivalent to better than $\pm 30\%$ for the six photon beams. The majority of participants underestimated both the superficial and penetrating dose equivalents. The scatter in results was greatest for the X-ray beam qualities. Ten participants were able to make good estimates of the energy of all the X-ray and gamma ray intercomparison beams, while nine participants were able to identify that one of the beams was beta rays from a $^{90}\text{Sr}/^{90}\text{Y}$ source. It was noted that there is some confusion regarding the correct method for calculating the new operational quantities. There was little consistency in the use of standard conversion factors to calculate $H_s(0.07)$ and $H_p(10)$.

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1.0 INTRODUCTION

In February 1985 the International Commission on Radiation Units and Measurements (ICRU)⁽¹⁾ recommended new operational quantities for individual monitoring for the purpose of radiation protection from external sources. These new quantities, which are defined for specified depths in the human body, are the individual dose equivalent, superficial $H_s(d)$ and the individual dose equivalent, penetrating $H_p(d)$. The recommended depths (d) in soft tissue below the surface of the body are 0.07 mm and 10 mm respectively. $H_p(d)$ refers to the dose received by deep organs in the body from strongly penetrating radiation whilst, $H_s(d)$ takes account of the dose equivalent to organs irradiated by both weakly and strongly penetrating radiation.

These new operational quantities were introduced to provide a common system of radiation protection monitoring among personal radiation monitoring (PRM) services, thus making it easier to compare the doses received by radiation workers. These operational quantities are also more practical and useful for the majority of radiation workers than the effective dose equivalent which is based on the weighted sum of the dose equivalents in some of the organs and is therefore dependent on revised information regarding the risks due to exposure from ionizing radiation. In contrast with the dose equivalent index, which suffers from the difficulty that it is not additive, the new operational quantities are additive. Thus, if a radiation worker is exposed to several radiation fields at the same time the numerical value of the quantity is obtained by the addition of all the dose equivalents associated with each beam.

Since the introduction of these two operational quantities numerous papers have been published covering all aspects of their use.⁽²⁻¹⁴⁾ Several authors have expressed concern regarding the correct use of the quantities and the actual numerical values of the conversion factors used to calculate $H_p(10)$ and $H_s(0.07)$.^(2,3,13)

Another major concern, first raised by Johns,⁽¹⁶⁾ is the question of the type of phantom to be used for dosimeter calibration. This topic has also been the subject of several papers over the past seven years.^(7,9,17,25) Bartlett et al.⁽¹⁷⁾ put forward several possible

approaches to the calibration of personal dosimeters but recommended that one internationally accepted method be adopted. The adoption of a commonly accepted calibration method would then allow direct comparison of results from service to service, both within a country and internationally.

In 1990, the Australian Radiation Laboratory (ARL), a participating Primary Standards Dosimetry Laboratory in the International Atomic Energy Agency (IAEA) Secondary Standards Dosimetry Laboratory network and the operator of the largest personal radiation monitoring service in Australia, proposed that an intercomparison of personal radiation monitoring services in the Asia/Pacific region be conducted to determine to what extent the ICRU recommendations had been implemented and to test the performance of the participating organisations. The intercomparison was conducted in 1991/1992 and was partially funded by the IAEA.

This report discusses the results of the intercomparison and the performance of participants in terms of the new ICRU operational quantities, $H_s(0.07)$ and $H_p(10)$.

2.0 INTERCOMPARISON PROTOCOL

The first step in the intercomparison was to prepare a list of organisations operating a PRM service in the Asia/Pacific region. These organisations were then contacted and invited to take part in the intercomparison. A total of 29 organisations from 16 countries in the region accepted the invitation. The overwhelming majority of PRM services are operated by government departments. A list of countries from which organisations participated is shown in Table 1.

A questionnaire was sent to these organisations requesting information such as the types of radiations monitored, types of monitors used, minimum detectable dose, accuracy of the service provided, frequency of monitoring and the number of radiation workers monitored. One part of the questionnaire asked for information on the quantity and units normally used by participants in reporting radiation doses. This information was requested in order to determine to what extent the ICRU new operational quantities had been adopted in the Asia/Pacific region. A copy of this questionnaire is given in Appendix 1.

After the information contained in the questionnaires had been collated the intercomparison protocol was planned. Appendix 2 gives a summary of some aspects of participants' replies to the questionnaire.

Participants were requested to send 25 dosimeters to ARL for exposure. Some participants submitted several types of dosimeters incorporating different detector materials and filter combinations. In all 32 types of dosimeter, including both film and thermoluminescent dosimeters (TLDs), were submitted for evaluation. Extremity dosimeters were not considered in this intercomparison.

When dosimeters arrived at ARL they were kept in an area with a background radiation level of approximately 50 nGy h^{-1} . The dosimeters were only removed from this area to perform the intercomparison exposures. All irradiations were performed at the Australian Radiation Laboratory by the Ionizing Dosimetry Standards Group which maintains the Australian Standard for the quantity Exposure. This group is quite distinct from the group which operates the ARL PRM service. The test of the ARL PRM service is therefore as independent as that of any other participant. At the completion of the exposures, dosimeters were returned to participants for assessment with a dose results sheet and some information on the exposure conditions used. A copy of this information is given in Appendix 3. The participants then informed ARL of the results of their assessments and the procedures used to arrive at the dose equivalents.

To ensure the anonymity of participants, each participant was allocated an identification number which was used in all correspondence. Complete confidentiality was maintained between individual participants and the authors of this report. The final stage of the intercomparison involved collating the participants' assessments and the preparation of this report.

3.0 EXPERIMENTAL SET-UP and PROCEDURES

3.1 Intercomparison Beams

After consideration of the replies of the participants to the questionnaire, five

different sources of radiation were selected. Three exposures were made to ^{137}Cs gamma rays (Beams A, B & C), three to X-rays (Beams D, E & F) and one exposure to $^{90}\text{Sr}/^{90}\text{Y}$ beta rays (Beam G) making a total of seven exposures in all. ^{137}Cs gamma radiation was selected as the principal intercomparison beam because it was widely used among participants as the standard calibration source for their PRM services.

The X-ray beams were selected from those recommended in the International Standards Organisation (ISO) document No. 4037, "X and Gamma Reference Radiations for Calibrating Dosimeters and Dose Ratemeters and for Determining their Response as a function of Energy".⁽²²⁾ The effective energies of the beams selected were 33 keV (Beam D), 79 keV (Beam E) and 202 keV (Beam F). Beam D was a very heavily filtered narrow spectrum while Beams E and F were selected from the ISO's heavily filtered series. The maximum beta ray energy from the $^{90}\text{Sr}/^{90}\text{Y}$ (Beam G) at the calibration distance was 2.0 MeV. Full details of the intercomparison beams are given in Table 2 including the magnitudes of the penetrating and superficial dose equivalents.

3.2 Irradiation Conditions

The gamma ray and X-ray intercomparison dosimeters were irradiated at normal incidence on the composite perspex/paper phantom described in Section 3.3. The exposures were performed at such a distance that the radiation field could be considered to be aligned and expanded. The front surface of the phantom was completely irradiated for all exposures. Dosimeters were attached to the front face of the phantom with double sided adhesive tape. Four dosimeters were exposed together, two dosimeters from each of two randomly selected participants. This was done so that there was always a laboratory other than ARL to which a participants' results could be compared. The beta ray exposures were performed at 30 cm from the source exposing two dosimeters at a time, one from each of two randomly selected participants. The ionization chamber and the transmission chamber used in the intercomparison were calibrated against the Australian Primary Standard of Exposure for the radiation qualities used. All intercomparison exposures were performed over a two week period.

(i) ^{137}Cs Exposures (Beams A, B & C)

A nominal 88.1 TBq (2380 Ci) source was used for all ^{137}Cs exposures. The distance from the source to the front surface of the phantom was 3.5 m. A Shonka-Wychoff type ionization chamber (Exradin model number A3) of 3.6 cm³ connected to a Keithley 35617 EBS programmable dosimeter was located in the beam for all ^{137}Cs exposures. The ionization chamber was positioned in the centre of the radiation beam (see Figure 1, position P), 1 cm from the front face of the phantom. Dosimeters were placed on the phantom at positions L, M, N and O (see Figure 1). A stop watch was used to time all exposures and the ionization chamber was used as a further check on the absolute magnitude of the exposure. The shortest exposure time was approximately 82 seconds.

For each participant, eleven dosimeters were exposed to the ^{137}Cs gamma rays; 7 dosimeters to Beam A, and 2 each to Beams B and C. Beam A was used to test the reproducibility provided by the service and Beam C was used to test performance near the lower detectability limit of the dosimeter.

(ii) X-ray Exposures (Beams D, E & F)

A Comet X-ray tube operated from a Pantak constant potential generator was used to produce the ISO standard X-ray beams. The dosimeters were exposed at normal incidence on the slab phantom, which was at a distance of 5 m from the X-ray tube. A transmission chamber connected to a Keithley 616 electrometer was used to provide a measure of the free-in-air exposure at the front surface of the phantom. Two dosimeters from each of two randomly chosen participants were exposed together. As for ^{137}Cs this provided a check on the delivered exposures independent of ARL. Dosimeters were attached to the phantom using double sided adhesive tape.

In contrast to the ^{137}Cs exposures, where a stop watch was used to determine the delivered exposure, the charge collected by the transmission chamber was used to determine the magnitude of the exposures. This permitted corrections to be applied to allow for short term output fluctuations from the X-ray tube.

(iii) $^{90}\text{Sr}/^{90}\text{Y}$ Beta Exposures

A National Physical Laboratory (U.K.) Secondary Standard Calibration jig, incorporating a $^{90}\text{Sr}/^{90}\text{Y}$ source (≈ 100 MBq) and a field flattening filter, was used for all beta exposures. The absorbed dose rate to soft tissue at a depth of 0.07 mm (superficial dose) was determined using the procedure specified by the National Physical Laboratory. Two dosimeters, one from each of two randomly selected participants, were exposed on the phantom in turn at 30 cm from the source.

3.3 Phantom Construction

The ICRU⁽¹⁾ recommended that a 30 cm diameter tissue-equivalent sphere was an appropriate phantom for calibration of personal dosimeters. However, it has been recognised that the ICRU sphere is difficult to manufacture and impractical to use, especially if a large number of dosimeters have to be calibrated.^(7,10,13,21)

Other types of phantom such as the ICRU tissue cube, and a water cube have gained popularity over the years. However, the ICRU⁽¹⁸⁾ has recently given preference to the 30 cm x 30 cm x 15 cm (deep) polymethyl methacrylate (PMMA) slab phantom. This type of phantom has been in use in Switzerland⁽¹⁹⁾ and in the United States of America⁽²⁰⁾ for some time.

For many years ARL has used paper phantoms (telephone books) as an inexpensive and simple substitute for the more elaborate commercially available phantoms. For this intercomparison and also for convenience two identical composite phantoms were constructed for the ^{137}Cs and X-ray intercomparison exposures. Each phantom was made from a perspex slab backed by four telephone books. The front face of the phantom was 282 mm high x 242 mm wide. The overall depth of the phantom was 255 mm. The telephone books were held together by shrink plastic and then attached to the perspex slab with adhesive tape. For convenience the composite phantom was mounted on a base which fitted the optical rails used with the ^{137}Cs and X-ray exposure apparatus. Although these phantoms are not identical to those recommended by ICRU (Report 47) it was shown that there was no measurable difference in backscatter factors (see section 3.4) using either the composite or a solid

perspex phantom. A schematic diagram of the phantom is shown in Figure 1.

3.4 Backscatter Factors

Since the phantom used in this intercomparison was not identical to the presently favoured slab PMMA phantom, a series of backscatter measurements were undertaken to determine whether this would have a significant affect on the delivered dose equivalents. Backscatter factors were determined for Beams A to F using the model A3 (3.6 cm³) ionization chamber, TLD-100 powder (LiF:Mg,Ti), TLD-900 teflon discs (CaSO₄:Dy) and TLD-100 hot pressed chips (LiF:Mg,Ti). Exposure measurements, both free-in-air and with the phantom in position were performed at the intercomparison distances, namely 5.0 m and 3.5 m for the X-ray and gamma ray exposures respectively. The front surface of the phantom was fully irradiated during the exposures.

Measurements were performed at positions L, M, N, O and P, with and without the phantom in place. Measurements were also performed at the same locations with the phantom positioned at different distances from the ionization chamber. The TLD measurements involved suspending TLDs on strips of adhesive tape and exposing them both free-in-air and with the phantom in contact with the adhesive tape. The tape was set-up with respect to the phantom so that the TLDs occupied the same position in space as the intercomparison dosimeters. Table 3 shows a summary of the backscatter factors derived using the TLD and ion chamber measurements. The results of Will⁽¹³⁾ are also shown in Table 3 and as can be seen they are in good agreement with the results obtained here.

3.5 Calculation of the Operational Quantities

The superficial, $H_s(0.07)$ and penetrating, $H_p(10)$ dose equivalents are determined at depths of 0.07 mm and 10 mm below a specified point on the surface of the body. These dose equivalents are calculated from the exposure as measured by the personal dosimeter at the position of wearing.

The exposure as recorded by the dosimeter is converted into a free-in-air exposure

(i.e. with the phantom removed) by dividing by the backscatter factor corresponding to the beam of interest. This can be expressed as follows:

$$X_{\text{air}} = \frac{X}{\text{BSF}}$$

where X_{air} is the free-in-air exposure, X is the exposure as measured by the dosimeter and BSF is the backscatter factor for the beam under investigation.

The exposure free-in-air is then converted into air kerma free-in-air using the following equation:

$$K_{\text{air}} = \frac{X_{\text{air}} \times (W/e)_{\text{air}}}{(1-g)}$$

where $(W/e)_{\text{air}} = 33.97 \text{ J/C (dry air)}^{(23)}$ and g is a constant that depends on the energy of the incident beam. The value of g was taken as 1.5×10^{-3} for ^{137}Cs and as 0.0 for all other intercomparison beam qualities.⁽²⁴⁾

The superficial and penetrating dose equivalents are then determined using the appropriate conversion factors from the experimental results of Will⁽¹³⁾ (see Table 2) using the following equations:

$$H_s = K_{\text{air}} \times C_s$$

and

$$H_p = K_{\text{air}} \times C_d$$

where C_s and C_d are the superficial and penetrating dose equivalent conversion factors respectively (also given in Table 2).

4.0 RESULTS

A summary of the results reported by participants is shown in Tables 4 and 5. The results are expressed as the ratio of each participant's reported penetrating or superficial dose equivalent to the delivered penetrating or superficial dose equivalent as calculated by ARL following the method outlined in Section 3.5. Hence, if a participant's ratio is less than 1.0 the dose has been underestimated, whilst if the ratio is greater than 1.0 the dose has been overestimated. The absence of some ratios in Tables 4 and 5 is due to four reasons:

- (i) the participant experienced technical difficulties during assessment,
- (ii) the dosimeter submitted for evaluation was not suitable for the beam under investigation,
- (iii) the dosimeter was damaged in transit, or
- (iv) the participant did not return an assessment.

The reproducibility of a participant's assessment procedures is also shown in Table 4 as the relative standard deviation of the 7 dosimeters used for Beam A.

4.1 Dose Assessments

In the following summary only the results for the penetrating dose equivalent are discussed. A similar discussion holds for the superficial dose equivalent.

(i) Beam A - ^{137}Cs Exposure

The penetrating dose equivalent delivered to the dosimeters for this beam was 1.99 mSv and was expected to be greater than any transit or storage dose. Seven dosimeters from each participant were exposed to this beam and the results used to give an estimate of the reproducibility of the participant's dose assessment procedures.

A frequency distribution of participants results is shown in Figure 2. Of the 30 participants who returned an assessment of this beam, 13 were within $\pm 5\%$ of the delivered penetrating dose equivalent, while 27 were within $\pm 30\%$. Except for two participants, all participants demonstrated a reproducibility, expressed as 1 standard deviation, of better than $\pm 7\%$ (see Table 4). As can be seen in Figure 2 most participants underestimated the penetrating dose for this beam.

(ii) Beam B - ^{137}Cs Exposure

The penetrating dose equivalent was 9.74 mSv and was the largest dose delivered of all the intercomparison beams. A dose of this magnitude was chosen so as to completely eliminate effects due to storage and transit exposures, and to enable a check on the calibration accuracy of participants.

As with Beam A, 13 participants were within $\pm 5\%$ of the delivered dose and 25 (compared with 27 for Beam A) were within $\pm 30\%$. Again more participants underestimated the delivered dose than overestimated. The results for this beam are shown in Figure 3 and in Tables 4 and 5.

(iii) Beam C - ^{137}Cs Exposure

This was the smallest dose of the three caesium beams, with a penetrating dose equivalent of 0.286 mSv. As can be seen in Figure 4 the scatter in the results for this beam was greater than for Beams A and B. In most cases this can be easily explained when the magnitude of the control dosimeters are taken into account. Reported transit and storage doses generally ranged from 0 to 0.3 mGy while one participant reported a value close to 5 mGy. At least thirty percent of participants had a control dose comparable to the delivered dose for this beam. Eight participants were within $\pm 5\%$ of the delivered dose equivalent and 23 were within $\pm 30\%$.

When the magnitude of this beam was chosen it was not anticipated that the control exposure would be so large. It is apparent from the results that some dosimeters were exposed in transit. However, most participants still obtained creditable results even under these difficult circumstances.

It should be noted that the ratios for Beams A, B and C should have been identical, within experimental error, for any given participant.

(iv) Beam D - 33 keV_{eff} X-ray Exposure

This was a very heavily filtered beam and the penetrating dose equivalent of 0.260 mSv was the lowest dose used in the intercomparison. As with Beam C, the control dosimeters had a background reading of a similar magnitude to the delivered dose equivalent. Seven participants were within $\pm 5\%$, while 23 were within $\pm 30\%$ of the delivered dose.

Two participants underestimated the dose by a factor of approximately 10 while another participant overestimated the dose by a factor of 5. The results for Beam D are shown in Figure 5 where it can be seen that in general participants tended to underestimate the delivered dose. The ratio for the participant who overestimated the delivered dose by a factor of 5 is not shown in Figure 5.

(v) Beam E - 79 keV_{eff} X-ray Exposure

The penetrating dose equivalent was 0.931 mSv. The scatter of results for this beam was large (see Figure 6) and only 3 participants were within $\pm 5\%$ of the delivered dose and 23 within $\pm 30\%$. In general, most participants underestimated the delivered dose, with two participants underestimating the delivered dose by a factor of 6 and two overestimating the dose by more than a factor of 2.

(vi) Beam F - 202 keV_{eff} X-ray Exposure

The majority of participants underestimated the delivered dose (see Figure 7). Only 4 participants were within $\pm 5\%$ and 19 within $\pm 30\%$ of the delivered penetrating dose equivalent of 1.560 mSv. Only one participant significantly underestimated the delivered dose equivalent.

(vii) Beam G - $^{90}\text{Sr}/^{90}\text{Y}$ Exposure

Nine participants correctly identified that this beam was produced by beta rays. The ratios calculated from the reported superficial dose equivalent and the delivered dose equivalent varied from 0.73 to 1.68. Four of the nine participants reported a dose within $\pm 5\%$ of the delivered dose.

It is interesting to note, that of the 9 participants who claimed they could perform beta dosimetry only 6 correctly identified Beam G as a beta source, whilst 3 participants who stated in their questionnaire they could not perform beta dosimetry successfully identified Beam G.

4.2 Energy Determination

Table 6 lists the participants' estimates of the energy of the intercomparison beams. As can be seen some participants successfully identified all seven beams while others successfully selected the energy range. Only 9 participants identified that Beam G was beta rays. It is interesting to note that 5 participants thought that Beam G was low energy X-rays, while 4 identified it as high energy photons. Twelve dosimeters submitted for evaluation were not suitable (no open window or low filtration area) for the measurement of beta rays.

5.0 DISCUSSION

It is apparent from participants' results forms that the new operational quantities have not been adopted by the vast majority of participants in the Asia/Pacific region. The results show that only four participants routinely report their results in terms of the ICRU new operational quantities and these results were reported in units of Sv, rem or Gy. Of the remaining participants, 8 routinely report their results in terms of exposure (R or C kg^{-1}), 2 report absorbed dose to the skin or body (Gy or rad), 6 report absorbed dose to air (Gy) and 10 report dose equivalent to skin (Sv). The results also show that some participants report dose equivalent to air (3 participants, Sv) and to water (1 participant, Sv).

The results given in Tables 4 and 5 show that most participants have underestimated the delivered dose equivalents for all seven beams. The results also show that several dosimetry services can satisfactorily measure the new ICRU operational quantities, for radiation at normal incidence. The performance of participants was best for ^{137}Cs gamma rays, whilst the assessment of the unknown X-ray beam qualities proved difficult for the majority of participants.

Since most participants use ^{137}Cs as their standard calibration source it was anticipated that the performance of participants should be best for these beams. This was the case as is clearly shown in Figures 2, 3 and 4. Most participants reported similar ratios for Beams A, B and C. However, several participants reported ratios which varied by approximately a factor of 2 or greater. The reasons for this should be investigated by those participants. It was also noted that in general for all three ^{137}Cs beams the majority of participants underestimated the dose.

The performance of the majority of participants for the X-ray Beams E and F was disappointing with the scatter in the participants assessments greater than that observed for the ^{137}Cs exposures and for Beam D, the 33 keV X-ray beam. Because most participants use ^{137}Cs as their calibration source and since most detectors have a maximum response to photons between 20 to 40 keV, this may account for the better performance for these beams. In addition, problems resulting from the magnitude of the transit and storage doses for some participants may have had some bearing on the error in energy estimation thus leading to poor dose assessments.

Part of the reason for the difficulty in making an accurate assessment of the $H_p(10)$ and $H_s(0.07)$ by participants appears to be that services have used different methods, and different numerical values for the conversion factors. It is therefore very difficult to assess the performance of participants when some have used different conversion factors from those used at ARL to calculate $H_p(10)$ and $H_s(0.07)$, whilst others have used the same factors as ARL, but a different method of calculation. The possibility of the lack of consistency between various PRM services has been commented on by the British Committee on Radiation Units and Measurements.⁽³⁾

Participants results have not been modified to take into account the different

conversion factors and methods used. The combination of different conversion factors and different methods of calculation has the effect that in some cases the agreement with ARL may have been fortuitous.

Eleven participants successfully estimated the energy of the unknown X and gamma ray beams, with one participant demonstrating excellent accuracy. It was clear from the responses received, that many participants have not developed their dosimetry service to a degree where beta radiation can be identified. Because of the different methods and conversion factors used by participants a comparison between those participants using film and those using TLD was not made.

6.0 CONCLUSIONS

- (i) Some confusion exists amongst some participants as to the correct method and the accepted conversion factors for calculating the superficial and penetrating dose equivalents.
- (ii) Beta dosimetry is presently not widely catered for in the Asia/Pacific region.
- (iii) Less than 50% of participants could correctly identify an unknown beam quality.
- (iv) For those participants using the same methods and conversion factors good agreement was obtained.
- (v) The reproducibility of the assessment procedures, expressed as one standard deviation, is better than $\pm 7\%$ for the vast majority of participants.

7.0 ACKNOWLEDGMENTS

The authors would like to thank Dr. John F. Boas and Ms. Heather M. Letwin for their assistance with the intercomparison exposures. The financial assistance of the International Atomic Energy Agency who partly funded this project (Research Contract 6012/R1/RB) is also gratefully acknowledged.

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24. Boutillon, M.T., CCEMRI(I)/85-18 - Working paper for meeting at ref. 23.

25. Selbach, H.-J., Hohlfeld, K. and Krammer, H.M., "Calibration of Personal Dosemeters for X and Gamma Radiation in front of Different Phantoms", *Radiat. Prot. Dosim.*, 1989, 28:69-72.

Table 1: List of countries and their representation in the intercomparison.

Country	No. of Services*	Detector Type
Australia	4	TLD/Film
Bangladesh	1	Film
Hong Kong	1	TLD
India	1	TLD/Film
Indonesia	1	TLD
Japan	1	Film
Korea	1	TLD
Malaysia	1	Film
New Zealand	1	Film
Pakistan	1	TLD/Film
People's Republic of China	11	TLD
Republic of the Philippines	1	TLD
Singapore	1	TLD
Thailand	1	Film
Union of Myanmar	1	Film
Vietnam	1	TLD

* Some services offered more than one monitor type. These have been treated as separate participants in reporting the results in Figures 2 to 7 and in Tables 4 to 6.

Table 2: Intercomparison beams, effective energies, conversion factors C_d and C_s and the corresponding penetrating and superficial dose equivalents used in the intercomparison.

Beam	Radiation Used (Added Filter)	Effective Energy	C_d	C_s	$H_p(10)$ (mSv)	$H_s(0.07)$ (mSv)
A	^{137}Cs	662 keV	1.22	1.21	1.99	1.97
B	^{137}Cs	662 keV	1.22	1.21	9.74	9.66
C	^{137}Cs	662 keV	1.22	1.21	0.286	0.283
D	40 kV _{cp} (0.22 mm Cu + 0.99 mm Al)	33 keV	1.40	1.38	0.260	0.256
E	110 kV _{cp} (2.00 mm Cu + 1.00 mm Al)	79 keV	1.95	1.77	0.931	0.846
F	300 kV _{cp} (6.71 mm Sn + 0.99 mm Al)	202 keV	1.50	1.44	1.56	1.50
G	$^{90}\text{Sr}/^{90}\text{Y}$	beta rays	---	---	---	1.50

Table 3: Backscatter measurements for the composite slab phantom.

Beam	Ion Chamber	TLD Chips	TLD Powder	Will ⁽¹³⁾
D (33 keV)◇	1.42	1.40	1.41	1.48
E (79 keV)◇	*	1.63	1.74	1.74
F (202 keV)◇	1.27	1.28	1.31	1.33
A, B & C (¹³⁷ Cs)◆	1.11	1.13	1.15	1.10

- ◇ The backscatter factors for beams D, E and F were not required in this study due to the use of a transmission chamber in the beam.
- ◆ A value of 1.072 was used in the actual determination of $H_p(10)$ and $H_s(0.07)$ in this study as this was the backscatter factor where the ion chamber was located at a point 1 cm from the front surface of the phantom.
- * Not estimated using the ion chamber as the extrapolation for this beam would have been based on data points that were changing very rapidly and would have led to an excessive uncertainty in the estimated backscatter factor.

Table 4: Ratios of each participant's reported penetrating dose equivalent to the delivered penetrating dose equivalent and the reproducibility of the participant's assessment indicated as a % standard deviation.

Participant No.	Beam						
	A	%sd	B	C	D	E	F
1	1.48	4.6	1.53	1.53	0.12	0.17	0.64
2	0.99	1.2	1.00	1.17	1.17	1.48	1.00
3*	0.78	6.9	0.81	0.70			1.41
4	0.36	5.9	0.37	0.20	1.17	0.49	0.39
5	0.47	2.3	0.47	0.39	0.75	0.47	0.48
6	0.92	3.8	0.97	0.87	0.79	1.00	0.96
7	1.01	6.7	1.02	1.00	0.87	0.87	0.85
8	0.71	1.3	0.71	0.71	1.00	0.48	0.40
9	0.92	3.0	0.92	0.98	0.95	0.94	0.84
10*					1.27	2.15	
11	0.93	4.3	1.01	1.05	1.04	2.47	1.15
12	1.04	6.8	1.24	0.79	0.70	0.90	0.75
13	0.96	2.4	0.99	0.98	1.06	0.74	0.71
14	0.92	3.0	1.01	0.76	0.67	1.08	0.77
15*					0.88		
16	0.97	2.4	1.02	1.01	1.01	0.98	0.88
17	0.90	2.6	0.97	0.83	0.87	0.91	0.68
18*							
19	0.98	13.6	0.87	0.96	0.96	0.77	1.14
20	0.85	2.8	0.84	0.89	1.10	0.92	0.78
21	0.93	4.9	0.97	0.59	0.63	0.68	0.71
22*							
23*	1.00	5.6	0.93	1.29			
24	0.95	0.8	0.94	1.08	0.80	0.80	0.90
25	0.79	1.9	0.80	0.83	0.77	0.49	0.65
26	0.99	2.6	0.97	0.93	0.96	0.96	0.86
27	0.98	3.9	1.03	1.05	1.04	1.14	0.84
28	0.70	4.7	1.49	0.36	1.16	0.44	0.04
29	0.98	0.6	0.99	1.05	0.92	0.84	0.97
30	0.92	2.3	0.94	0.90	1.05	0.71	0.69
31*							
32*							
33*	1.05	5.4	0.99			0.66	1.10
34	1.23	2.0	1.29	1.15	0.06	0.15	0.49
35	0.95	13.7	0.52	1.14	5.13	1.34	0.77
36	1.02	2.2	1.10	0.82	1.40	1.56	1.00
38*							

* See Section 4 for an explanation of missing results.

Table 5: Ratios of each participant's reported superficial dose equivalent to delivered superficial dose equivalent.

Participant No.	BEAM						
	A	B	C	D	E	F	G
1*	0.99	1.03	1.01	1.51	1.15	1.01	
2	1.00	1.01	1.18	1.13	1.54	1.01	1.33
3*	0.77	0.80	0.69			1.40	
4*	0.36	0.37	0.20	1.68	0.56	0.41	
5*	0.47	0.47	0.39	0.61	0.47	0.47	
6*	0.93	0.98	0.88	0.84	0.98	0.95	
7*	1.00	1.01	0.99	0.94	0.92	0.85	
8	0.72	0.71	0.71	0.92	0.59	0.44	1.01
9*	0.94	0.94	0.99	1.00	0.95	0.85	
10*				1.34	2.13		
11	0.94	1.01	1.06	1.15	2.48	1.20	0.73
12*	1.05	1.25	0.80	0.90	1.03	0.78	
13*	0.98	1.00	0.99	1.08	0.82	0.75	
14	0.97	1.07	0.77	0.81	1.19	0.87	0.91
15*				1.04			
16	0.96	1.01	0.99	0.95	0.97	0.85	1.68
17	0.90	0.97	0.83	0.87	0.91	0.68	1.19
18*							
19*	0.99	0.88	0.97	1.05	0.75	1.13	
20*	0.85	0.85	0.90	1.19	0.91	0.78	
21	0.84	0.86	0.41	0.74	0.72	0.78	0.97
22*							
23*	1.01	0.94	1.31	1.34	0.85	0.95	
24*							
25*							
26*	0.99	0.98	0.94	1.28	1.10	0.90	
27	0.99	1.04	1.06	1.13	1.25	0.87	0.99
28*	0.70	1.49	0.36	1.16	0.44	0.04	
29*	0.97	0.98	1.06	0.95	0.85	0.97	
30*							
31*							
32*							
33*							
34*	1.04	1.08	0.97	1.09	1.06	1.01	
35*	0.49	0.46	0.80	4.34	2.02	1.04	
36	1.03	1.11	0.83	2.49	1.72	1.04	0.95
38*							

* See Section 4 for an explanation for missing results.

Table 6: Participants estimate of the unknown intercomparison beam qualities.

Participant No.	Beam					
	B	C	D	E	F	G
1	High Energy	High Energy X-rays	Low energy X-rays	Low energy X-rays	Medium Energy X-rays	Very Low Energy X-rays
2	662 keV	662 keV	31 keV	101 keV	274 keV	2.4 MeV betas
6	>500 keV	>500 keV	40 keV	80 keV	200 keV	>500 keV
7	662 keV	662 keV				
8	~1 MeV	~688 keV	32 keV	74 keV	156 keV	beta rays
10			40 keV	85 keV		
11	>200 keV	>200 keV	40 keV	80 keV	160 keV	>3 MeV beta rays
13		16 keV	16 keV	30 keV		1.25 MeV
14	>200 keV	>180 keV	35 keV	81 keV	147 keV	2.3 MeV betas
15			34 keV			
16	>660 keV	>370 keV	37 keV	118 keV	205 keV	beta rays ⁹⁰ Sr
17	gamma rays	gamma rays	X-rays	hard X-rays	hard X-rays	beta rays
19	662 keV	170 keV	29 keV	76 keV	170 keV	36 keV
20	662 keV	662 keV	29 keV	104 keV	400 keV	20 keV
21						beta rays
23	33 keV	beta rays	beta rays	1.25 MeV	200 keV X-ray	200 keV X-ray
26	X-ray 250 keV	X-ray 250 keV	25 keV	70 keV	177 keV	X-ray 15 keV
27	0.5 MeV & 1.2 MeV	0.28 MeV & 1.2 MeV	34 keV	106 keV	205 keV	⁹⁰ Sr betas
33	Co-60			64 keV	160 keV	
34	>400 keV	>400 keV	20-60 keV	60-150 keV	150-400 keV	20-60 keV
35	>400 keV	>400 keV	150-400 keV	150-400 keV	150-400 keV	150-400 keV
36	>350 keV	>350 keV	30 keV	85 keV	170 keV	3 MeV beta
True Quality	662 keV	662 keV	33 keV	79 keV	202 keV	⁹⁰ Sr/ ⁹⁰ Y betas

Note: Participants were told that Beam A was ¹³⁷Cs.

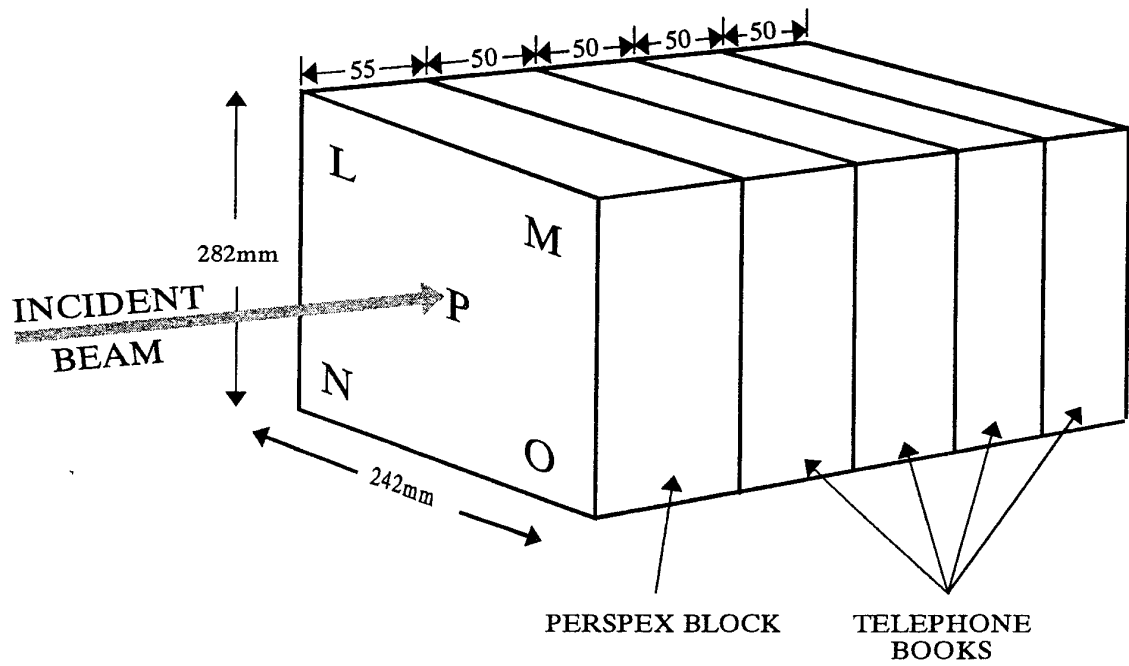


Figure 1: Schematic diagram of the perspex slab phantom backed by telephone books.

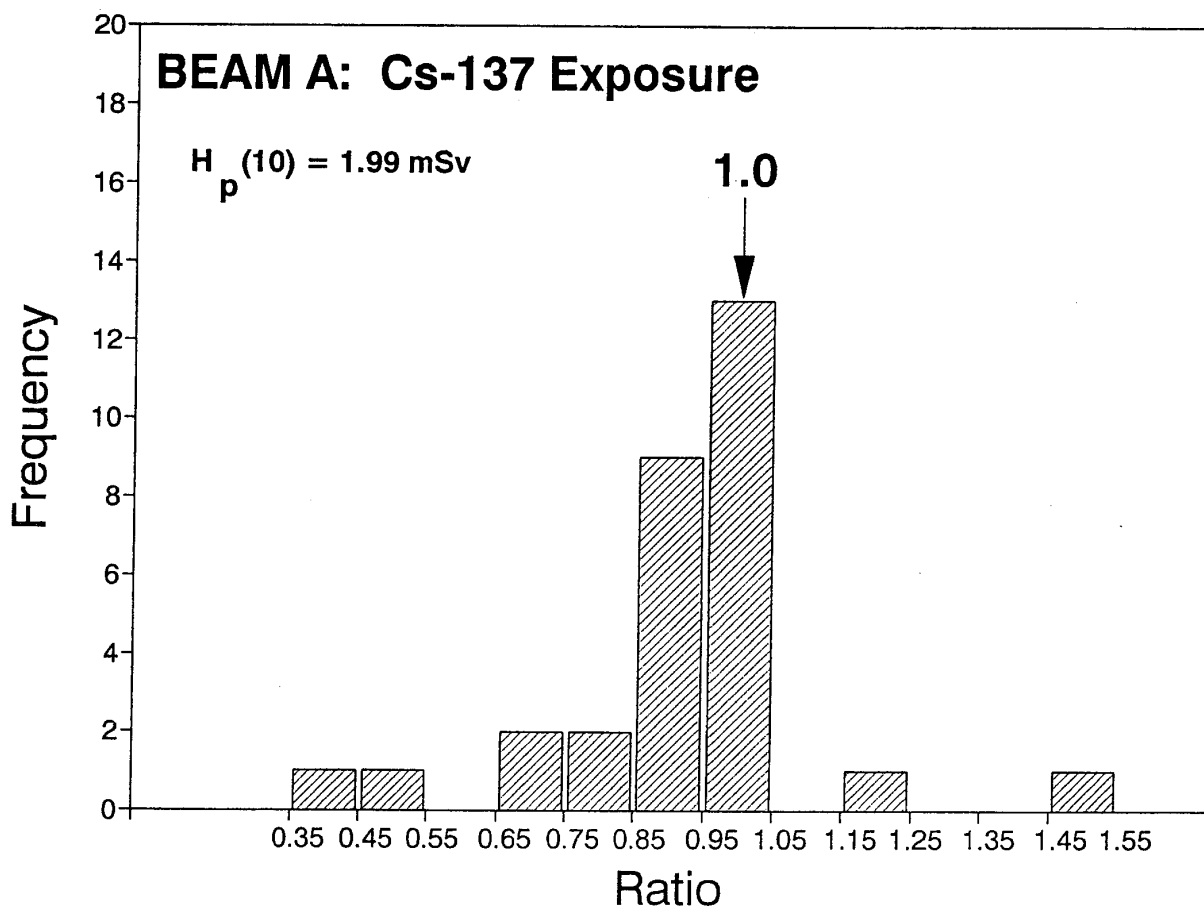


Figure 2: Frequency distribution of the participants' ratio of the reported penetrating dose equivalent to the delivered penetrating dose equivalent for beam A.

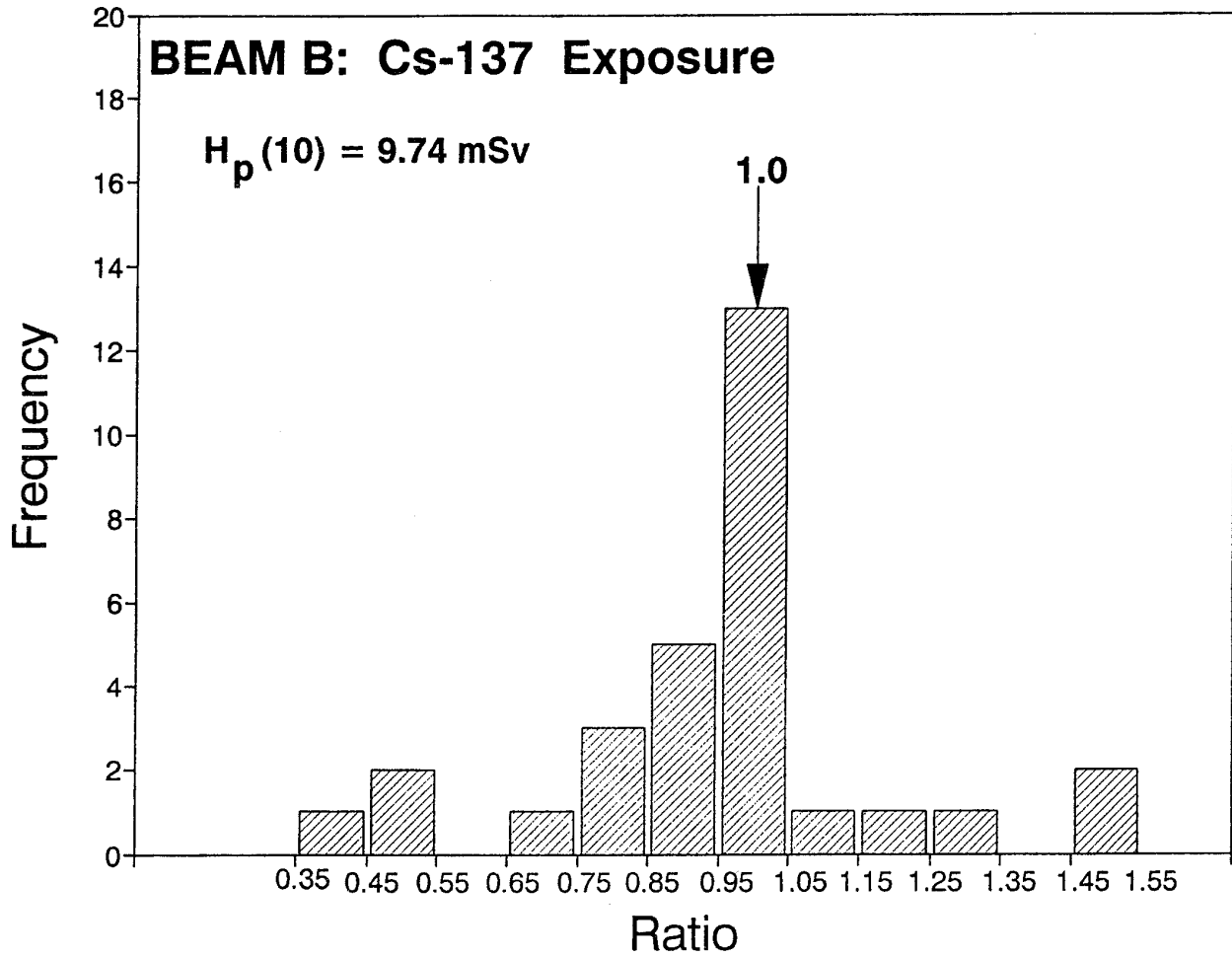


Figure 3: Frequency distribution of the participants' ratio of the reported penetrating dose equivalent to the delivered penetrating dose equivalent for beam B.

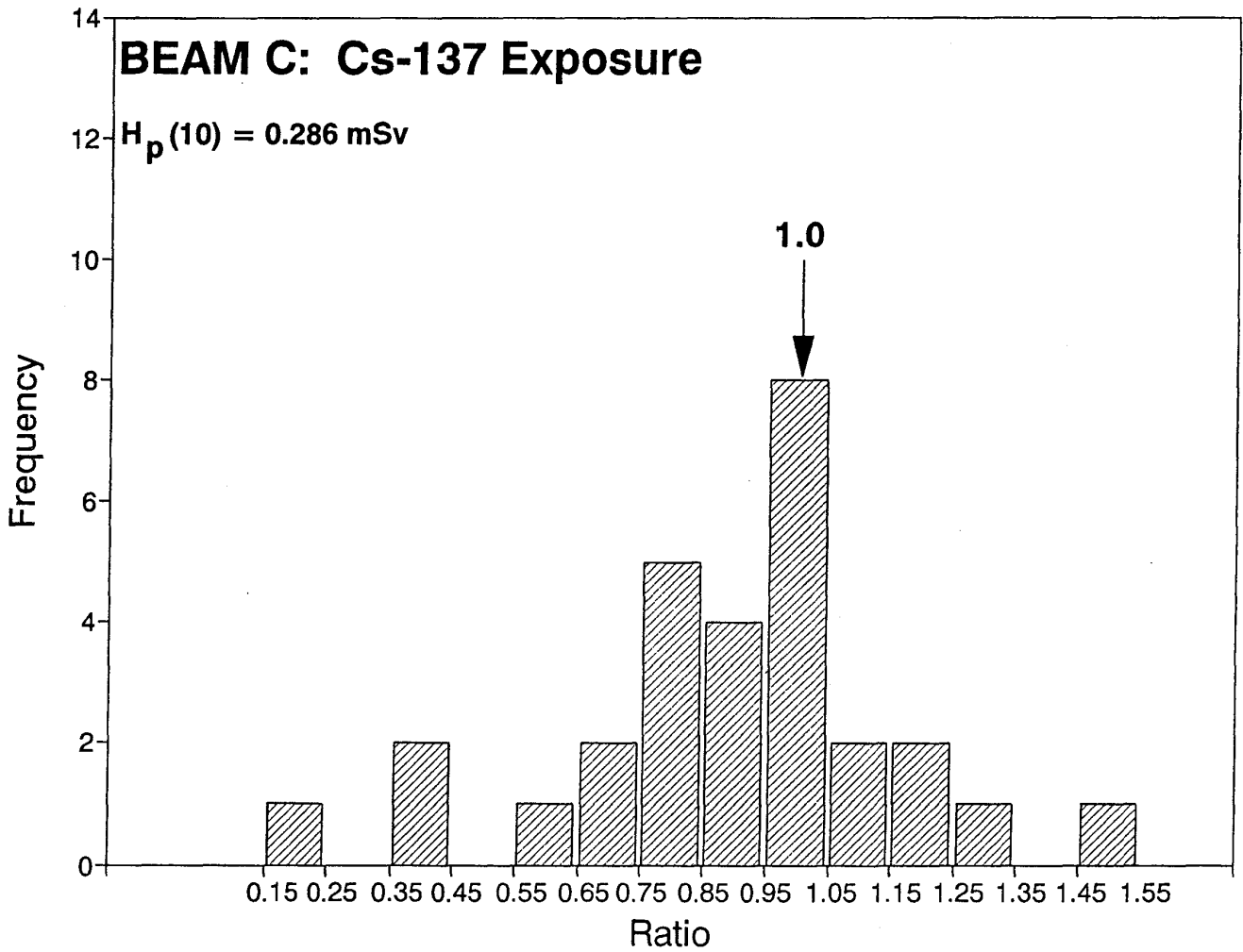


Figure 4: Frequency distribution of the participants' ratio of the reported penetrating dose equivalent to the delivered penetrating dose equivalent for beam C.

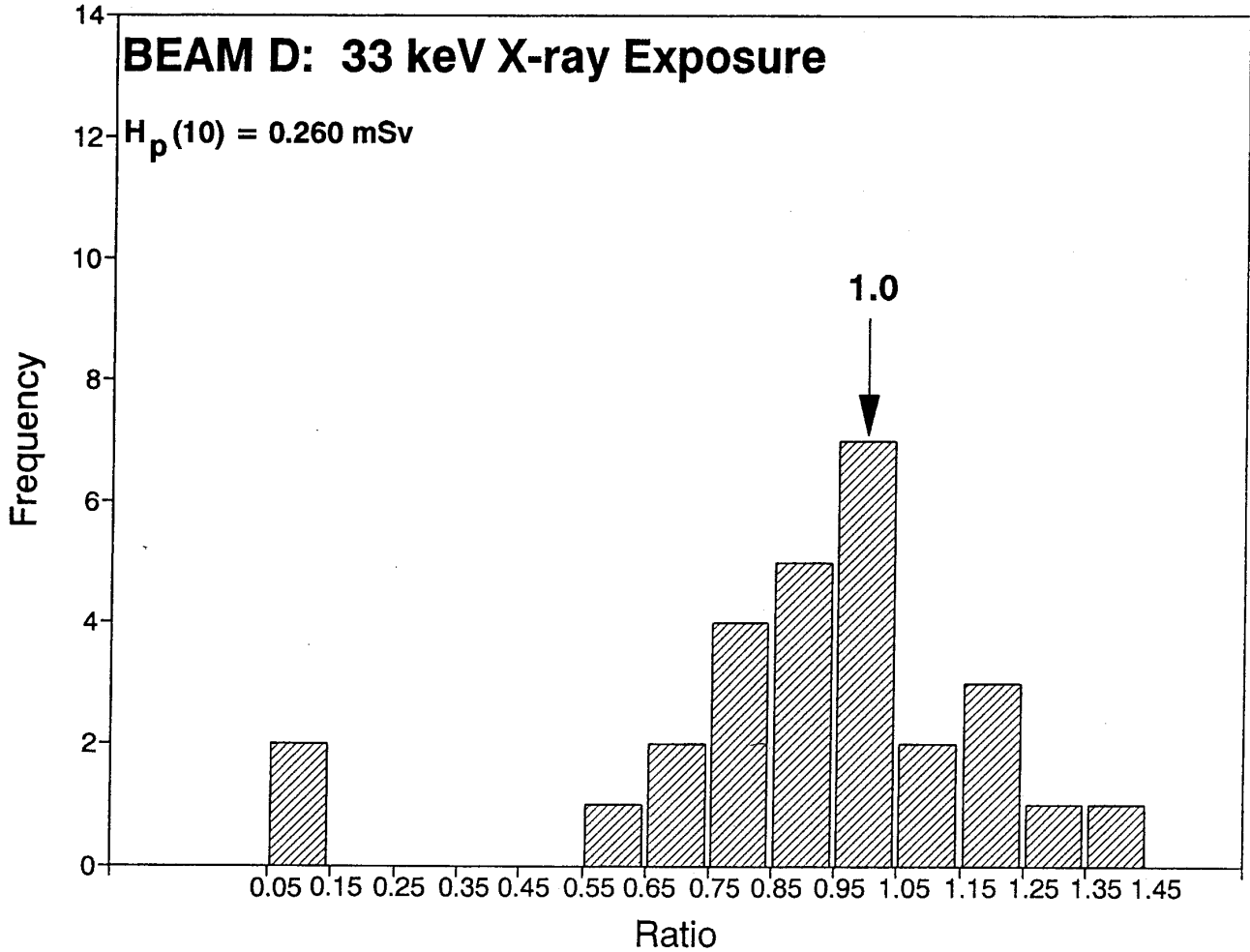


Figure 5: Frequency distribution of the participants' ratio of the reported penetrating dose equivalent to delivered penetrating dose equivalent for beam D. The ratio 5.13 obtained by one participant is not shown.

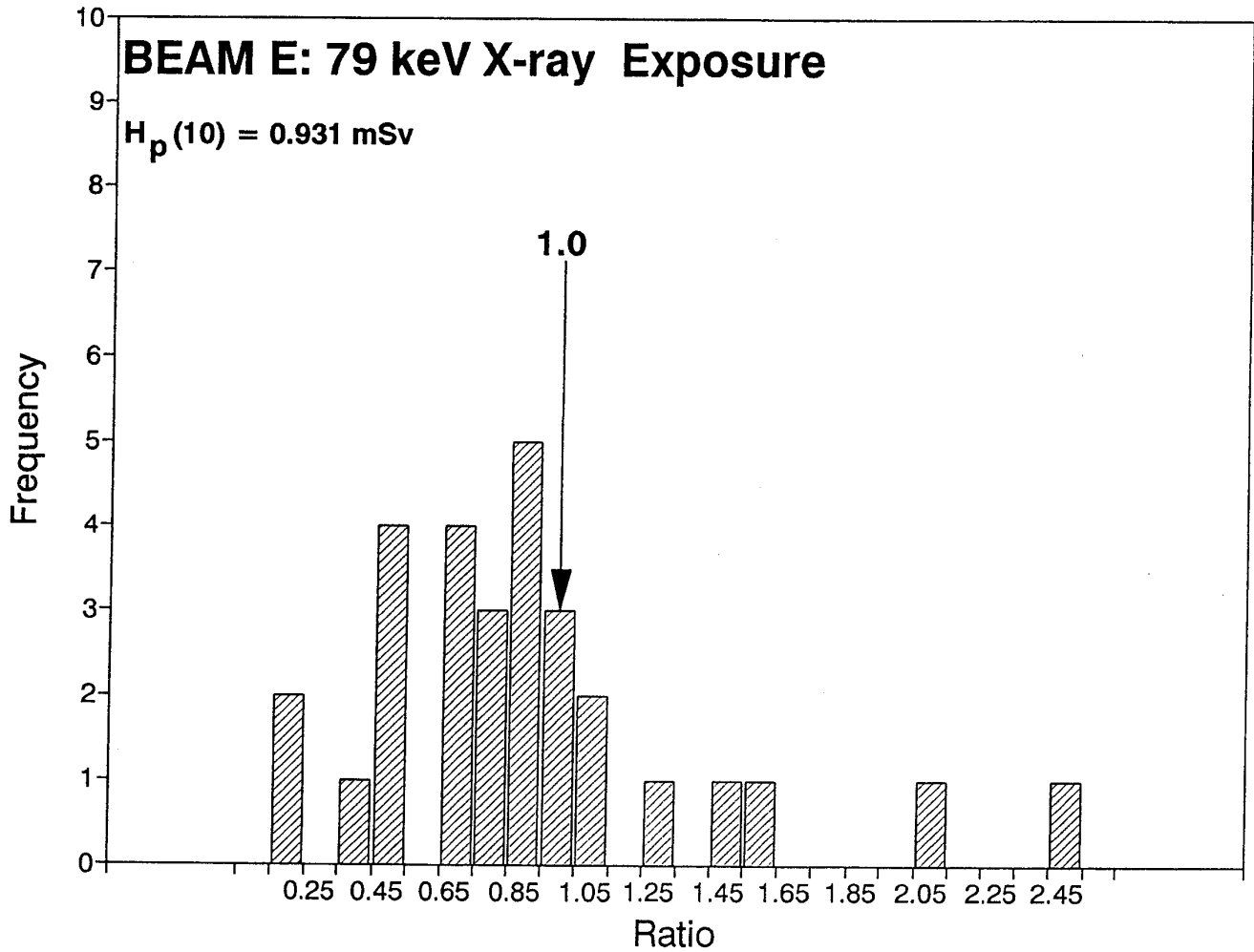


Figure 6: Frequency distribution of the participants' ratio of the reported penetrating dose equivalent to delivered penetrating dose equivalent for beam E.

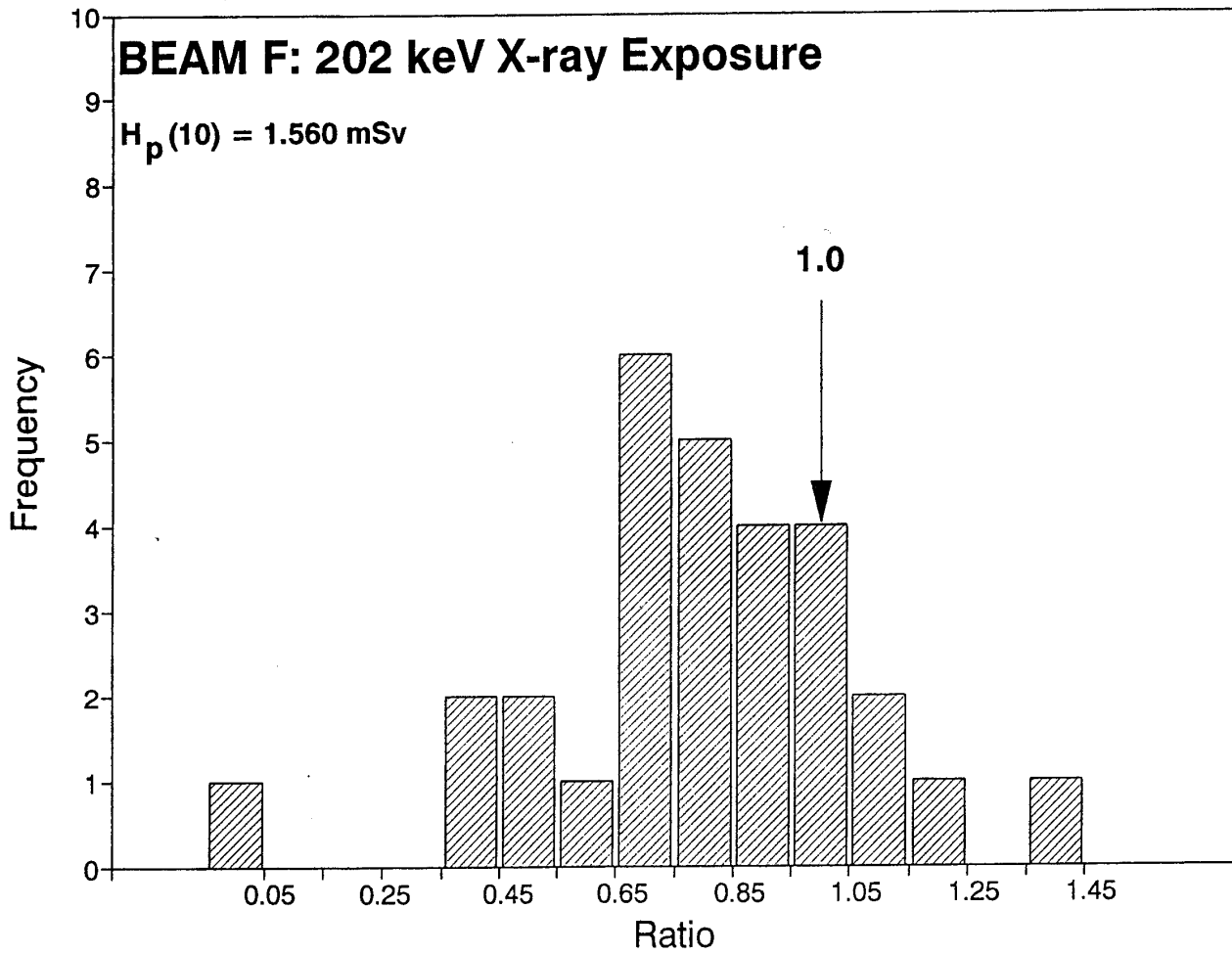


Figure 7: Frequency distribution of the participants' ratio of the reported penetrating dose equivalent to delivered penetrating dose equivalent for beam F.

Appendix 1

Copy of the intercomparison questionnaire.

Questionnaire

to be completed by
Services wanting to take part in an

**Intercomparison of Personal Radiation Monitoring Services
in the Asia/Pacific Region.**

In this questionnaire the term "monitor" is used to describe the combination of a dosimeter such as TLD or film and a badge case or holder.

To help us with the planning of this study would you please send us a sample of each type of monitor you wish to submit for testing when you return this questionnaire. All monitors will be returned at the conclusion of the study.

Please complete the following questions and December 24, 1990 to:

Mr Neville J Hargrave
Ionising Radiation Standards and Dosimetry Group
Australian Radiation Laboratory
Lower Plenty Road
Yallambie Vic 3085
AUSTRALIA

Telephone: + 61 3 433 2211

Telex: + AA 31726

Facsimile: + 61 3 432 1835

In the above "+" is used to indicate your International Access Code.

A. Administrative address information.

Name and address of service:

Person to whom correspondence should be addressed:

Name and Address of any other person(s) to whom copies of correspondence should be sent:

Name and address of anyone else who you would like us to keep informed. For example, a senior person who should be informed of the progress of the intercomparison.

For shipping purposes, should the package containing the monitors be labelled in any special way in order to make its passage into your country easier? Please give details.

B. Sources of exposure.

Please indicate (✓) which of the following radiation sources are monitored by your service.

(i) Medical radiations

Dental X-rays

Diagnostic X-rays.

Special techniques: Mammographic

High kV techniques.

Other, please specify.

Superficial therapy X-rays (up to 130 kV).

Orthovoltage X-rays (up to about 300 kV).

Teletherapy gamma-rays

caesium-137

cobalt-60

Megavoltage X-rays

High energy electrons

Sealed radioactive sources

Gamma (please specify isotopes used)

Beta (please specify isotopes used).

Other (please specify)

C. Technical information on monitors.

Please complete a copy of the following tables for each type of monitor that you want included in the tests. If you have more than one type of monitor, please make extra copies of Section C.

Monitor Type.....(your designation)

Dosemeter Type:

Film

TLD

Other, please specify

Please specify film type, TLD phosphor, etc.:

Badge case:

Please list the type of badge case in use and supply a description and diagram of it if possible. If there is a publication giving this information, please send us a copy of it.

Badge case filters:

Please state the materials, thicknesses and arrangement of all filters in the badge case.

Materials	Thickness (mm)

Future use of monitor:

Do you expect to discontinue the use of this monitor in the near future?

Yes

No

If yes:

When do you expect to cease use of the monitor?

With what monitor do you intend to replace it?

Please indicate the radiation types for which the monitor is used. If the monitor is not used for a particular type of radiation please state "n/a" in the table (as an abbreviation for "not applicable").

Radiation Type	Energy Range (MeV)	Dose Range (gray)	Minimum Detectable Dose (microgray)
Beta rays			
X and Gamma rays			
Neutrons			

In what quantity and unit do you report "doses"?

For example, you may report "doses" in terms of:

Exposure (mR, or C/kg) to the air immediately above the skin;
 absorbed dose (rad, cGy, mGy, etc.) to the skin;
 dose equivalent (Sv, μ Sv, etc.) at some depth; or
 effective dose equivalent.

D. Service provided.

Approximately how many monitors are assessed per year by your service?

Approximately how many radiation workers are monitored regularly by your service?

For each type of monitor in use in your service, please indicate in the table below the length of time for which monitors are issued for wearing, the radiations which they are used to monitor and the approximate percentage of people using your service to which the data applies.

Monitor Type	Wearing Period	Radiation Type	Percentage of Wearers

E. Operation of the service.

- (i) Do you recommend where monitors should be worn?

Yes No

If yes, where do you recommend that monitors be worn?

- (ii) Do you make any recommendations about the wearing of monitors above or below protective devices such as lead rubber aprons?

Yes No

If yes, please state your recommendation.

- (iii) Do you normally issue any unexposed monitors to act as controls or to monitor for stray radiation or unintentional exposure of monitors while not being worn?

Yes No

If yes, how many controls do you issue and how are they intended to be used?

(iv) Do you correct for any of the following:

(a) transit doses

Yes No

If yes, please give details.

(b) background doses

Yes No

If yes, please give details.

(c) fading of the stored signal which may result in an underestimate of the dose

Yes No

If yes, please give details.

(d) any other effect to which monitors may be exposed when not being worn

Yes No

If yes, please give details.

F. Quality control.

(i) Under what extremes of environmental conditions do you regard your dosimeters as able to provide reliable results?

(ii) Do you perform regular quality control tests?

Yes

No

If yes,

(a) do these tests involve the checking of the performance of the dosimeters under conditions similar to those encountered in their normal everyday use? Please give details.

(b) do these tests include a regular test of any changes of sensitivity of the dosimeter? Please list tests, together with approximate frequency of these tests.

(c) do these tests involve the checking of the performance of the device used to assess the dose, for example the TLD reader device or the photographic densitometer? Please give details.

(iii) Does your service have to meet any particular performance standards (for example the US Standard N 545-1975, or some local standard) ?

Yes

No

If yes, please name the standard and if possible send a copy of it to us at ARL, or else give an indication of where a copy of it is published.

G. Assessment uncertainty and dose ranges.

- (i) For each monitor to be included in this project, please give the following information for each broad type of radiation monitored. The radiation types listed above in Section C can be used as a guide.
 - (a) Minimum detectable dose and uncertainty associated with it.

 - (b) Maximum routinely assessable dose and its associated uncertainty.

 - (c) Maximum assessable dose and uncertainty associated with it, if special procedures are used.

- (ii) If reported doses are rounded, for example if 1002 would be reported as 1000 or 96 as 100, please give:
 - (a) Minimum level of dose reported.

 - (b) Degree of rounding at various dose levels as appropriate.

- (iii) If you normally report doses in steps rather than continuously, please indicate the dose steps you use.

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

Appendix 2

Summary of some of the participants replies to the questionnaire shown in Appendix 1.

Participant No.	No. of People Monitored	Complex Holder	Radiations Monitored				Minimum Dose Detected (mSv)
			X	γ	β	n	
2	>20,000	yes	Yes	Yes	Yes	Yes	0.1
16		yes	Yes	Yes	No	No	0.1
19		yes	Yes	Yes	Yes	Yes	0.1
20		yes	Yes	Yes	Yes	Yes	0.1
27		yes	Yes	Yes	Yes	Yes	0.1/0.07*
1	>1000 but <10,000	yes	Yes	Yes	No	No	0.15
6		yes	Yes	Yes	No	No	0.04
8		yes	Yes	Yes	Yes	Yes	0.2
9		no	Yes	Yes	No	No	0.03
12		no	Yes	Yes	No	No	0.02
13		no	Yes	Yes	No	No	0.003
14		yes	Yes	Yes	Yes	Yes	0.5/0.02*
15		yes	Yes	No	No	No	0.02
17		yes	Yes	Yes	Yes	Yes	0.3
21		yes	Yes	Yes	Yes	Yes	0.05
23		yes	Yes	Yes	No	Yes	0.1
29		no	Yes	Yes	No	No	0.05
34		yes	Yes	Yes	Yes	Yes	0.1/0.05*
35		yes	Yes	Yes	Yes	Yes	0.1/0.05*
3		<1000	no	No	Yes	No	No
5	no		Yes	Yes	No	No	0.15
6	Yes		Yes	Yes	No	No	0.04
7	no		No	Yes	No	No	0.005
18	no		Yes	Yes	No	No	0.05
24	no		Yes	Yes	No	No	0.001
28	yes		Yes	Yes	No	No	0.1
30	?		Yes	Yes	Yes	Yes	0.02
31	no		No	Yes	No	No	Background
33	no		Yes	Yes	No	No	0.03

* Where two values are given the smaller value refers to X-rays and the larger to gamma rays.

Appendix 3

Dose assessment forms and instruction sheet sent to all participants.

In a letter to participants the following information was provided together with the following forms and instruction sheet;

"Your personal radiation monitors have been exposed to a range of collimated ionizing radiation beams at the Australian Radiation Laboratory. All monitors were exposed between 7 May and 16 May on a flat perspex (poly methyl methacrylate) phantom. The monitors are being sent back to you under separate cover and will be despatched in 2 to 3 days time.

The exposed monitors were only separated from the control monitors for the duration of each exposure. While in the laboratory they were stored in a low background environment where the radiation level was constant about 50 nano-gray per hour. The humidity was about 50 percent and the temperature close to 20 degrees celsius.

When you have assessed the monitors would you please complete the Table included with this letter and return it. In order for us to be able to compare all services we have asked you to report the shallow dose at 7 mg cm^{-2} and the deep dose at 1000 mg cm^{-2} in units of milligray.

Although we asked you to send us 25 monitors only those indicated on the Results Table have been exposed. We wanted to have some spare monitors in case mistakes occurred in the exposure of the monitors at this laboratory.

When all participants have returned their results we shall distribute a preliminary report to all participants for comment and return. A final report will then be prepared."

INSTRUCTIONS FOR COMPLETING THE RESPONSE FORM
FOR THE 1991 ASIA/PACIFIC PERSONAL RADIATION
MONITORING INTERCOMPARISON

1. Column 1 identifies the 7 beams used in the intercomparison. Seven (7) dosimeters were exposed to beam A and two (2) dosimeters to each of beams B,C,D,E,F and G.

2. Column 2 indicates which of your dosimeters have been exposed to what beams. This column has already been completed by the Australian Radiation Laboratory (ARL).

3. In column 3 please record your estimate of the type of radiation beam used to expose your dosimeters. The seven dosimeters exposed to beam A were exposed to gamma radiation with an energy of 662 keV (i.e. ^{137}Cs) - we have completed this for you.

4. In column 4 please record your results as you would normally issue them to your clients. Please ensure that you complete the "units" and "medium" columns so we know what your results refer to.

5. The estimated uncertainty in your results should be recorded in column 5 and should be expressed in terms of 1 standard deviation. All known uncertainties should be included e.g. imprecision, calibration uncertainties, fading corrections etc.

6. In column 6 please indicate (yes or no) if you apply any corrections to your results.

7. Column 7 refers to the exposure your control dosimeters received during transit to and from AUSTRALIA and the exposure they received while they were stored at the ARL. Please state the magnitude of the transit and storage exposure and the units used.

8. In column 8 please list the correction factors you applied to your results in column 4 to derive the shallow (7 mg.cm^{-2}) and the deep (1000 mg.cm^{-2}) doses in columns 9 and 10.

9. Column 9 is your estimate of the shallow dose at 7 mg.cm^{-2} in tissue in units of milligray.

10. Column 10 is your estimate of the deep dose at 1000 mg.cm^{-2} in tissue in units of milligray.

The reason for obtaining the information in columns 9 and 10 is so that we can compare all personal monitoring services with a common parameter.

RESULTS FOR THE PERSONAL RADIATION MONITORING SERVICE INTERCOMPARISON

Participant:

Please complete this form and return it as soon as possible to:

Mr. Neville Hargrave
 IONIZING RADIATION DOSIMETRY GROUP
 AUSTRALIAN RADIATION LABORATORY
 LOWER PLENTY ROAD
 YALLAMBIE Vic. 3085
 AUSTRALIA

Identification No.:

column 1 BEAM IDENTIFIER	column 2 MONITOR ID No.	column 3 TYPE AND ENERGY OF RADIATION	column 4 RESULTS AS YOU WOULD NORMALLY REPORT TO A CLIENT		column 5 ESTIMATED UNCERTAINTY (1 standard deviation)	column 6 CORRECTIONS			column 7 CONTROL DOSE (units)	column 8 CONVERSION FACTORS TO OBTAIN RESULTS IN COLUMNS 9 & 10	column 9 SHALLOW DOSE AT 7mgm.cm ⁻² (mGy)	column 10 DEEP DOSE AT 1000mgm.cm ⁻² (mGy)
			RESULTS	UNITS		MEDIUM	None Applied	Fading Correction				
BEAM A	1.	7. 662keV										
	2.	7. 662keV										
	3.	7. 662keV										
	4.	7. 662keV										
	5.	7. 662keV										
	6.	7. 662keV										
	7.	7. 662keV										
BEAM B	1.											
	2.											
BEAM C	1.											
	2.											
BEAM D	1.											
	2.											
BEAM E	1.											
	2.											
BEAM F	1.											
	2.											
BEAM G	1.											
	2.											

GENERAL INFORMATION

(a) DOSEMETER

- (i) Reader/Densitometer type (manufacture and model no.):
- (ii) Film/TLD material used and its form:
- (iii) Annealing procedures if applicable (times and temperature):
- (iv) Readout cycle if applicable (times, temperature and temperature ramp rates):

(b) CALIBRATION DETAILS

- (i) What source(s) do you use to calibrate your dosemeter system?
- (ii) What form is the source
 - collimated beam
 - point source
 - other (give details)

(c) FUTURE INTERCOMPARISONS

- (i) Would you be interested in participating in future intercomparisons of this type?
- (ii) Do you have any comments on this or future intercomparisons?
- (iii) Do you have any particular tests you would like incorporated in future intercomparisons?

THANK YOU FOR COMPLETING THIS FORM AND PARTICIPATING IN THIS INTERCOMPARISON.