

IAEA/WHO
NETWORK OF
SECONDARY
STANDARD
DOSIMETRY
LABORATORIES

SSDL

NEWSLETTER

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EDITORIAL NOTE

The name of the Dosimetry Section at The Division of Human, IAEA has been changed to Dosimetry and Medical Radiation Physics Section (DMRP) to better reflect the activities of the Section.

Recently, the Agency's Dosimetry Laboratory has placed concentrated effort towards establishing a quality assurance programme based on the ISO 9000 series documents. This is reflected in three articles of this issue of the SSDL Newsletter. They describe dosimetry services provided by the Agency through the DMRP Section and contain components of quality assurance. The services are: calibration of ionization chambers for brachytherapy, calibration of ionization chambers used in radiotherapy and radiation protection, dosimetry audits and radiation processing.

The first article describes a new service, "Calibration of ion chambers for brachytherapy". This programme has the objective of establishing traceability of calibration of hospital brachytherapy sources to the International Measurement System through the IAEA/WHO network of SSDLs. A method has been developed for disseminating calibrations to SSDL reference sources and onwards to end users (hospitals). Test runs will now start involving some hospitals and SSDLs. After the test period and fine tuning this new service will be offered to all SSDLs in the Network.

The second article reports on the first (test) run of an ionization chamber calibration factor intercomparison. This service is intended for SSDLs only and it will be offered on a regular basis from 1997. This programme extends the ionization chamber calibration service by the IAEA to cover a quality audit of the service provided by the SSDLs to the hospitals in their countries. The advantage with this calibration factor intercomparison is that it directly reflects the quality of the services provided by various laboratories. During the initial period (some years), it will also be used to identify strengths and weaknesses of calibration of ionization chambers directly in terms of dose to water. However, the dissemination of such calibration factors to hospitals is currently discouraged due to lack of an international dosimetry protocol. Work is in progress to develop a Code of Practice for the use of dose to water calibration factors. Once that is finalized the SSDLs should be prepared to start calibrating ionization chambers in terms of this quantity.

A quality audit service for dosimetry relevant to radiation processing is presented in the third article. The quality audit was initiated as a key element of the High-Dose Standardization Programme of the IAEA. The standardization of dosimetry for radiation processing provides a justification for the regulatory approval of irradiated products and their unrestricted international trade. The need for reliable and accurate dosimetry for radiation processing is increasing in Member States and we can envisage a definite role for the SSDLs in such a programme in near future.

In the Co-ordinated Research Programme "Development of a Quality Assurance Programme for Radiation Therapy Dosimetry in Developing Countries" (E2-40-07), the structure of national External Audit Groups (EAGs), their responsibilities and interactions between different partners was established. The report from a consultants' meeting related to this programme, is the basis of the fourth article. A first draft "Guidelines to prepare a Quality Manual for External Audit Groups on Dosimetry in Radiotherapy" was outlined. When completed, this document can be used as a guide on how to prepare the quality manual for national EAGs in developing countries.

It is our hope that this issue of the Newsletter will give some insight into and understanding of the various dosimetry activities carried out by the DMRP Section. Any reader interested in more detailed information on one or more of the services is welcome to contact the Network secretariat.

Call for contributions to the SSDL Newsletter.

To increase the exchange of information between readers of the SSDL Newsletter and the Network

secretariat, as well as between the members of the Network, readers are encouraged to submit manuscripts describing their work. The largest interest is on new or upgraded activities implemented in laboratories, contributions to Quality Assurance programmes in radiotherapy facilities, etc.

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Standardisation of the calibration of brachytherapy sources at the IAEA Dosimetry Laboratory

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ABSTRACT

A new service to SSDLs has been initiated at the IAEA Dosimetry Laboratory for providing calibrations of well-type ionisation chambers, used in brachytherapy applications, which are traceable to the International Measurement System. Considering that the most common radionuclide used in the developing countries is ^{137}Cs , two such sources of the type used for gynaecological intracavitary applications have been purchased by the Agency and calibrated at the National Institute of Standards and Technology (NIST), USA. These ^{137}Cs reference sources together with a well-type ionisation chamber constitute the IAEA brachytherapy dosimetry standard. Based on the recommendations by a group of experts, a method has been developed for transferring calibrations to SSDLs which is described in this paper. The method is based on the acquisition by the SSDLs of sources and equipment similar to those at the IAEA. The well-type chamber is to be calibrated at the IAEA Dosimetry Laboratory, and this will be used at the SSDL to calibrate its own reference sources. These sources can in turn be used to calibrate well-type chambers from hospital users and to calibrate other type of sources by performing measurements in air. In order to standardise the procedures for the two methods and to provide guidance to the SSDLs, measurements have been carried out at the IAEA Dosimetry Laboratory. The reproducibility of the two type of measurements has been found to be better than 0.5%, and the uncertainty of calibrations estimated to be less than 1.5% (one standard deviation).

1. INTRODUCTION

A common practice in the past for the dosimetry of brachytherapy sources has been to accept the manufacturer's stated source activity without further verification. The suppliers generally base their measurements on well-type ionisation chambers and the quoted accuracy is normally within $\pm 10\%$. As the response of the well-type chambers depends on the photon energy and position of the source within the chamber cavity, the deviation among the response for different types of sources can be severe, especially because of the diversity of the type of radionuclides and chamber designs. Source strength is, however, the key parameter involved in the dosimetry of brachytherapy applications; therefore, to enable reasonably good dose delivery, the accuracy of the specification of the source strength must be kept within reasonable limits.

The unit internationally recommended for the specification of the strength of a brachytherapy source is the Reference Air Kerma Rate (RAKR), defined as the kerma rate to air, measured in air at a reference distance of 1 meter along the perpendicular bisector of the long axis of the source, corrected for air attenuation and scattering [1]. There is, however, no universally accepted protocol for the measurement of this quantity for the different types and activities of sources used in routine clinical practice. Mainly because of the low levels to be measured, it is almost impractical to perform the measurements in the recommended unit. The RAKR of conventional Low Dose Rate (LDR) sources is 4-5 orders of magnitude smaller than the air kerma rate in external beam therapy. A uniform calibration method would provide consistency among users.

This paper describes a new service to SSDLs initiated at the IAEA Dosimetry Laboratory for providing calibrations of well-type ionisation chambers, used in brachytherapy applications, which

are traceable to the International Measurement System. The steps to establish an infrastructure for the traceability of the calibrations through the IAEA/WHO network of SSDLs are described. As in the developing countries the most common use of brachytherapy is in gynaecological intracavitary applications using ^{137}Cs , methods have been developed based on the use of reference sources of this radionuclide both for calibration and to check the long term stability of the measuring instruments.

2. THE CALIBRATION CHAIN

During the meetings held at the IAEA headquarters in Vienna by a panel of experts¹, the following steps were recommended for establishing a traceable calibration chain for the LDR brachytherapy sources from Primary Standard Laboratories (PSDL) to hospital users through the IAEA Dosimetry Laboratory.

- I. The IAEA purchases one or more source(s) of the radionuclide(s) for which calibration is required and have them calibrated at a PSDL in terms of Reference Air Kerma Rate; the sources, together with a well-type ionization chamber, constitute the IAEA brachytherapy dosimetry standard.
- II. SSDLs acquire uncalibrated sources and equipment similar to those at the IAEA; in addition, SSDLs must have at least one source of each type of the radionuclide for which user's calibration will be required. The whole set will constitute the SSDL brachytherapy dosimetry standard.
- III. The SSDL's well-type chamber is calibrated at the IAEA Dosimetry Laboratory using the IAEA brachytherapy dosimetry standard.
- IV. The SSDL measure the strength of its sources using the calibrated well-type chamber. The sources thus calibrated become the source standards of the SSDL.
- V. The SSDL calibrate user's sources using its standard, either directly with the well-type chamber or using in-air measurements with a large-volume spherical ionisation chamber.

The proposed procedure for transferring the calibration from Primary Standards Laboratory to hospital users through the IAEA Dosimetry Laboratory is illustrated in Fig.1.

¹ CT-2352 'Quality Assurance Programme for Brachytherapy Dosimetry' held during 22-24 May, Vienna, 1995 and CS-120 'Quality Assurance and Safety of Brachytherapy' held during 11-15 Dec., Vienna, 1995. The group of experts was formed by G.Marinello, Hopital Henri Mondor, France; M.Stovall (1st meeting), MD Anderson Cancer Centre, USA; A.Visser, Dr.Daniel Den Hoed Cancer Center, The Netherlands; J. Wilkinson, Christie Hospital, UK; J.Williamson, Mallinckrodt Institute of Radiology, USA; G.A.Ezzel (2nd meeting), Harper Hospital and Wayne State University, Detroit, USA.

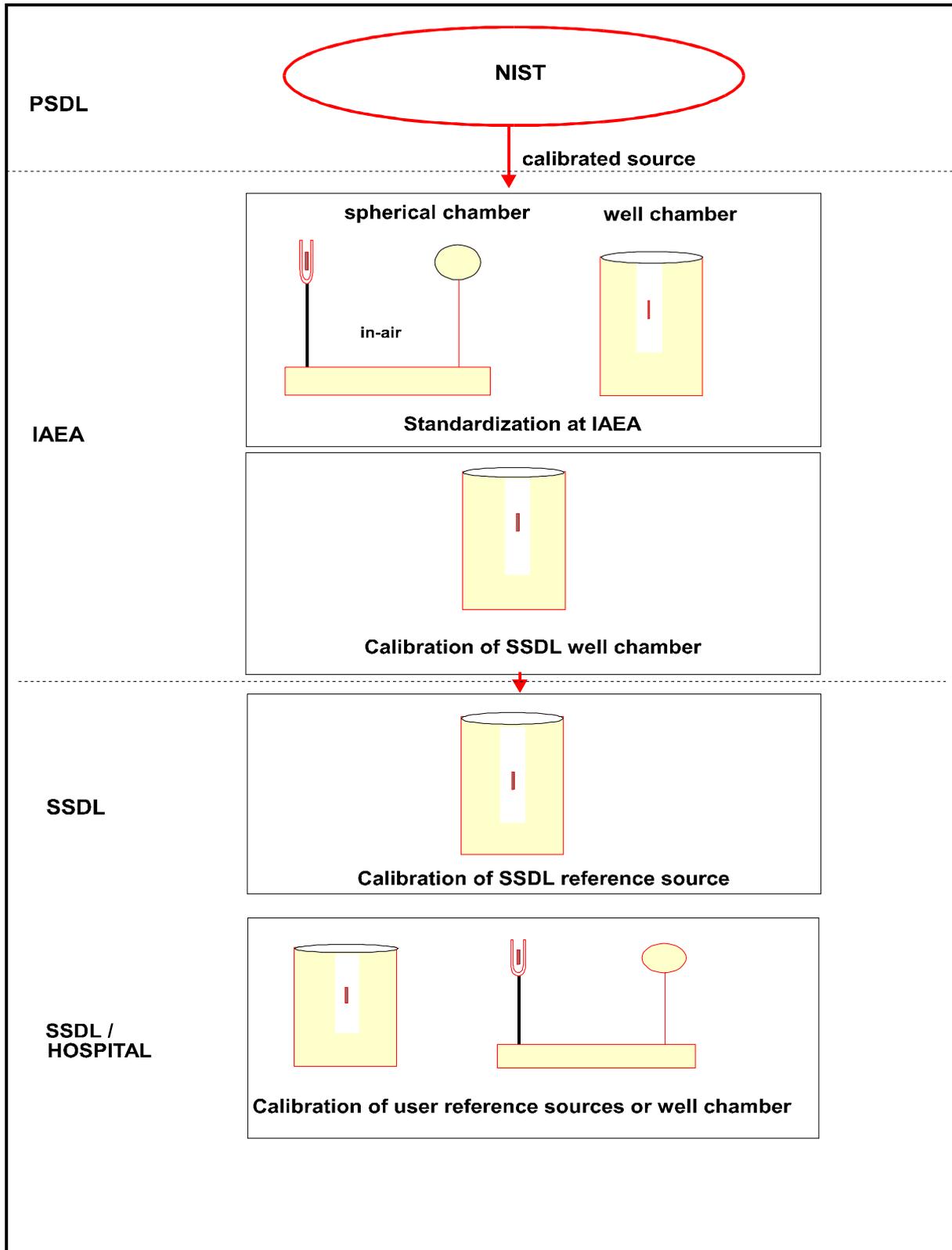


FIG. 1. Calibration chain of brachytherapy sources from PSDL to Hospital

3. PROCEDURES AT THE IAEA DOSIMETRY LABORATORY

3.1. Sources

The IAEA has purchased two types of ^{137}Cs brachytherapy sources from Amersham International. The sources are a CDCS -J type tube and a CDC-1100 type miniature cylinder. The

specifications of these sources are given in Table I.

TABLE I. BRACHYTHERAPY SOURCES AT THE IAEA DOSIMETRY LABORATORY

Radionuclide	Type	Code	Dimensions (mm)		
			Active Length	Total Length	Diameter
Caesium -137	Tube	CDCS - J	13.5	20	2.65
Caesium -137	Mini cylinder	CDC-1100	1.5	8	3.2

The sources have been calibrated in terms of Reference Air Kerma Rate at the National Institute for Standards and Technology (NIST), USA. The calibration of this type of sources at NIST is done by direct comparison with their working standard sources using an external ionisation chamber at distances between 500 and 1000 mm [2]. The NIST working standard sources have been calibrated in air using the NIST cavity chamber exposure standards; these are absolute calibrations similar to those used for a ^{60}Co external beam calibration. The Reference Air Kerma Rate of the IAEA reference sources measured at NIST, normalised as on May 1 1996, are $339 \mu\text{Gy h}^{-1}$ for the CDC-1100 type source and $190.5 \mu\text{Gy h}^{-1}$ for the CDCS-J type source, with an estimated uncertainty of less than 2 % at the 95 % confidence level.

3.2 Ionisation chambers and electrometers

The IAEA has also purchased a well-type ionisation chamber and an electrometer to standardise the measurement procedure and provide practical assistance to the SSDLs. The well-type chamber, HDR-1000 Plus, designed by the University of Wisconsin and manufactured by *Standard Imaging Inc.* was recommended for High Dose Rate (HDR) as well as for Low Dose Rate (LDR) brachytherapy source calibrations [3]. The diameter of the chamber is 102 mm, its height 156 mm and it has an active volume of 245 cm^3 . Special inserts are provided for holding the sources, which are cylinders of diameter 35 mm and height 121 mm, with different inner diameters to suit different diameter sources. The outer aluminium wall of the chamber is 20 mm thick, which attenuates most of the scattered low energy photons. A change in chamber sensitivity up to about 1 % has been reported when the chamber is kept in contact with a concrete wall; this is reduced to less than 0.1% when the chamber is moved away 250 mm from the wall and 70 mm from the floor [4]. The chamber has a vent hole to maintain the internal air at ambient atmospheric conditions. The electrometer used with the well chamber is CDX-2000A, a digital portable instrument from *Standard Imaging Inc.* The electrometer allows readings in 8 decades in charge mode (10 pC to 999,999.99 nC) and in 5 decades in current mode (10 pA to 200 nA).

Measurements in air are also described in this work. These are performed using a LS-01 ionisation chamber, designed by the Austrian Research Centre and manufactured by PTW, Germany. The chamber is spherical in shape and has a volume of 1000 cm^3 . The chamber wall is made of polyacetal resin (delrin) and is 3 mm thick. The outside diameter of the collecting volume is 140 mm. The central collecting electrode is spherical in shape and has a diameter of 50 mm. It is made of Styrofoam and is coated with graphite. Teflon is used as the insulating material. As the ionization current to be measured is of the order of a few picoamperes, a *Keithley - 617* electrometer was used for the measurements in air. This electrometer is a highly sensitive instrument designed to measure voltage between 10 μV and 200V, current between 0.1fA and 20 mA and/or charge between 10 fC and 20 nC.

3.3. Source handling devices

A lead-shielded work bench and handling tools have been purchased for the safe handling of the sources. For ease of handling and to minimise radiation hazards, the sources have been loaded in Perspex tubes and held in a fixed position using a Perspex insert rod. The Perspex tubes fit into the well-type chamber holder. A cylindrical lead storage container has been designed to store the sources in the Perspex tubes which is illustrated in Fig. 2. The container has two metallic tubes at the centre to place the source holders. An illustration of the source holders is given in Fig. 3.

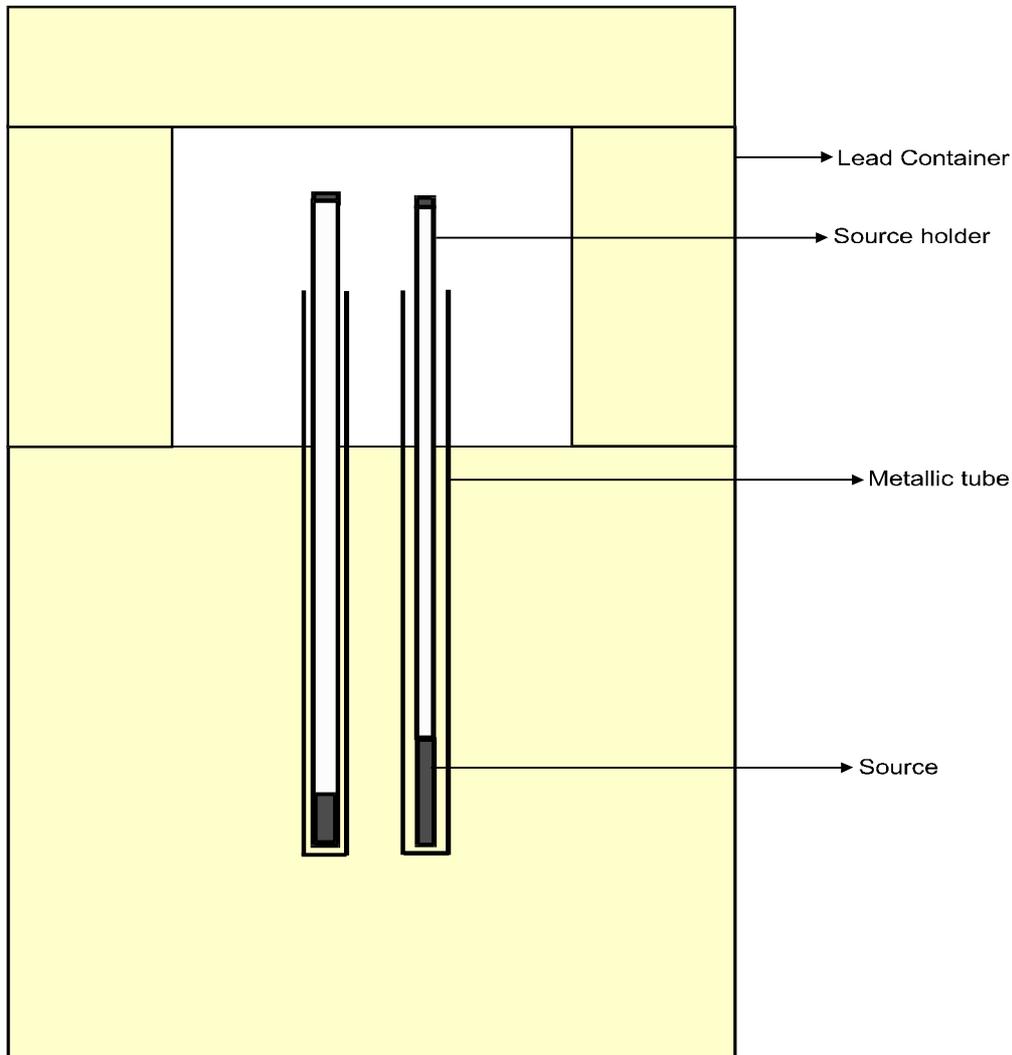


FIG. 2. Lead storage container. A lead cylinder with two metallic tubes in the centre, where the Perspex holders are inserted. The dose level at 1 m from the centre of the container is less than 10 μ Sv/h.

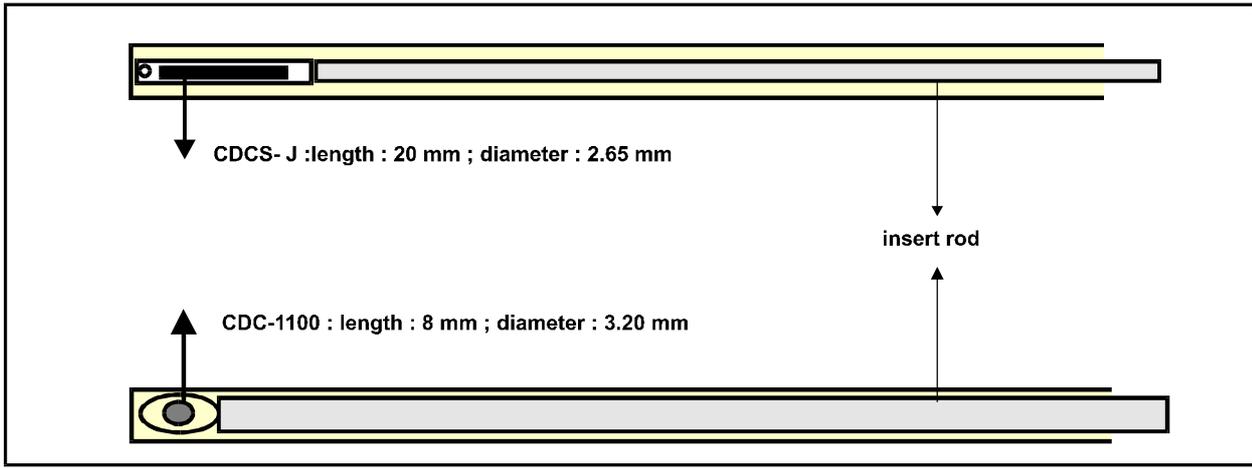


FIG. 3. Perspex holders of the sources. The sources are inserted in Perspex tubes and held in a fixed position using Perspex insert rods.

3.4. Measurements

3.4.1. Standardisation of measurements with the well-type ionisation chamber

One of the most important aspects of the standardisation of measurements with a well-type chamber is the determination of the optimal position of the source within the chamber. For this measurement the chamber was positioned in the centre of the room (minimum distance from the walls was 1.5 meter) and at a height of 1 meter from the floor. Charge measurements were performed varying the position of the source along the axis of the chamber by inserting spacers of known length at the bottom, as illustrated in Fig. 4. The duration of each measurement was chosen so that the uncertainty due to fluctuations in the leakage current contributed less than 0.05% to the collected charge. The relative variation of the chamber response, normalised to the maximum value, is shown in Fig 5. It can be seen that the maximum response of the well-chamber is obtained for the CDCS-J type source (total length : 20 mm) when a 39 mm spacer is inserted at the bottom of the well, whereas a 45 mm spacer is needed for the CDC-1100 type source (total length : 8 mm). This means that the maximum response is obtained when the centre of the source is at 50 mm from the bottom of the well cavity, including the 1 mm thickness of the Perspex source holder. The response decreases by about 0.5 % for a shift of about 8.5 mm on either side of the position of the maximum response.

In order to assess the long term stability of the set-up and the measuring devices, measurements in the optimal position were repeated during a long period. The chamber response was corrected for ambient conditions of temperature and pressure and corrected for the decay of the source using a half life for ^{137}Cs equal to 30.17 years (1 year = 365.25 days). The reproducibility of the well chamber response over several months is illustrated in Fig. 6 where it can be seen the variation is within $\pm 0.5\%$.

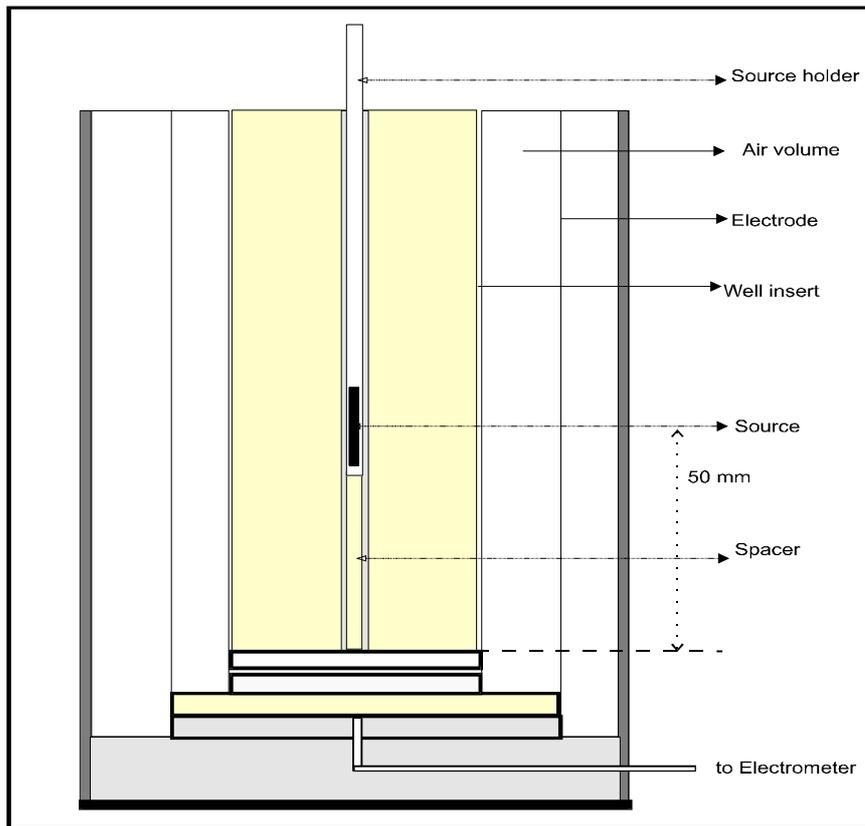


FIG. 4. Positioning of the source and spacer in the well-type ionisation chamber

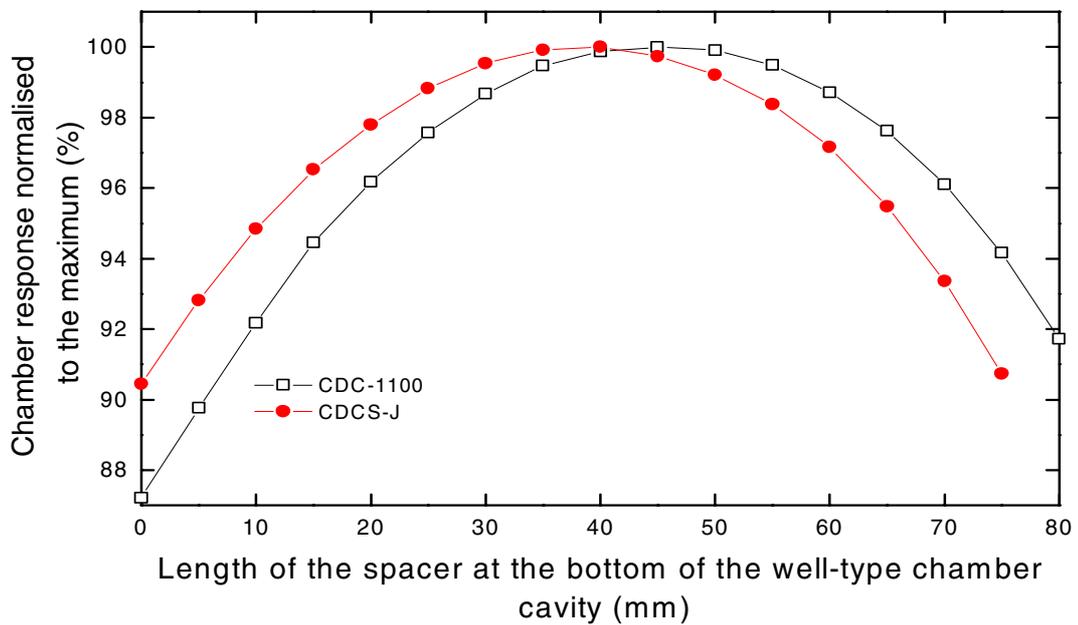


FIG. 5. Variation of the well-type chamber response with the position of the source. To find the position of the centre of the source from the bottom of the well-chamber cavity, add one-half length of the source and the 1 mm thickness of the Perspex tube at the bottom.

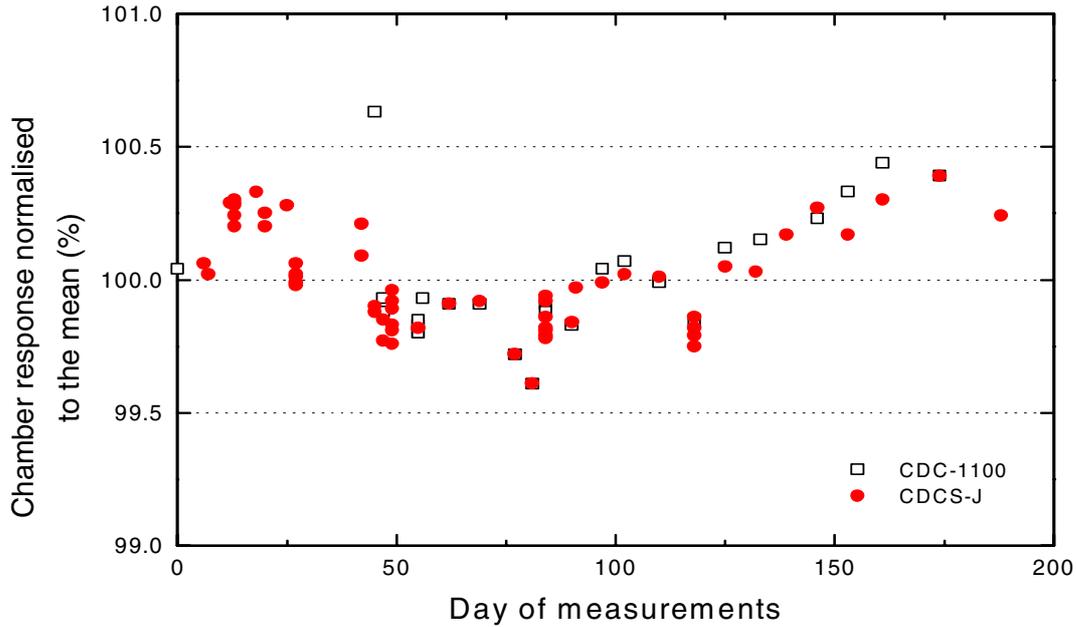


FIG.6. Stability of the well-type chamber response. The variation of the response normalised to the mean over several months of measurement is within $\pm 0.5\%$.

The calibration factor, N_{RK} , of the well-chamber can be related to the Reference Air Kerma Rate of the source, using the following relation [5]:

$$N_{RK} = K_{air} t / M C_{elect} p_{TP} p_s \quad [\mu\text{Gy nC}^{-1}] \text{ alternatively } [\mu\text{Gy h}^{-1} \text{ pA}^{-1}]$$

where

K_{air} is the reference air kerma rate of the source [$\mu\text{Gy h}^{-1}$]

M is the electrometer reading of the charge collected by the well-type chamber in time 't' [scale reading]

C_{elect} is the calibration factor of the electrometer ($\text{nC scale-reading}^{-1}$)

p_{TP} is the correction factor for the temperature (T) and pressure (P) at the time of measurement (departure from reference conditions, $T_0=20^\circ\text{C}$ and $P_0=101.325 \text{ kPa}$); $p_{TP} = \{(273.15+T) / (273.15+T_0)\} (P_0 / P)$

p_s is the recombination correction factor [6],

3.4.2. Standardisation of in-air measurements

The well-chamber can, in principle, be used only for sources of the types for which the chamber has been calibrated. In practice SSDLs will have to provide calibration of different types of sources to hospital users. The most appropriate approach for deriving a calibration is to compare the source to be calibrated with the reference standard in air at large distances, where the geometrical differences between the two type of sources are insignificant. The purpose of the in-air measurement at the IAEA Dosimetry Laboratory has mainly been to assess the accuracy and reproducibility of such procedure before recommending it to the SSDLs.

A 1-litre spherical chamber (type LS-01) designed by Austrian Research Centre, Seibersdorf was used at source-to-chamber centre distances of 500 mm, 750 mm and 1000 mm. The geometry is

illustrated in Fig.7. Metallic rods, identical in size to the sources, were loaded in Perspex tubes identical to the type used for the sources. The dummy source holders were used for the alignment of the source and the LS-01 chamber for such air measurements. As the current to be measured is in the order of a few pA, a very precise and stable electrometer capable of measuring leakage currents in the range of fA is required for air measurements. A *Keithley - 617 electrometer* was used for these measurements, and the leakage current was determined to be less than 0.1% for the lower-strength source at the largest distance. The short and long term stability of the measuring device and the reproducibility of the geometry were obtained by repeated measurements. The chamber response was corrected for the ambient conditions of temperature and pressure, and for the decay of the source. The stability of the chamber response, normalised to the mean value over the period of measurements, is shown in Fig. 8 where it can be seen that the variation is within $\pm 0.5\%$.

3.4.3 Estimation of uncertainties

The overall uncertainty in the calibration of the IAEA reference sources at NIST has been quoted as 2% at the 95% confidence level, i.e. approximately 1% for one standard deviation. Addition of the uncertainty of the measurements at the IAEA Dosimetry Laboratory yields a combined uncertainty of 1.5% (one std dev). This estimate includes the uncertainties due to the positioning of the source (0.03%), stability of the electrometer (0.2%), leakage current (0.05%), scale factor (0.01%), air density (0.06%), the half life of ^{137}Cs (0.13%) and the uncertainty due to the impurity of source (0.90%) which is based on the maximum probable presence of ^{134}Cs quoted by the supplier.

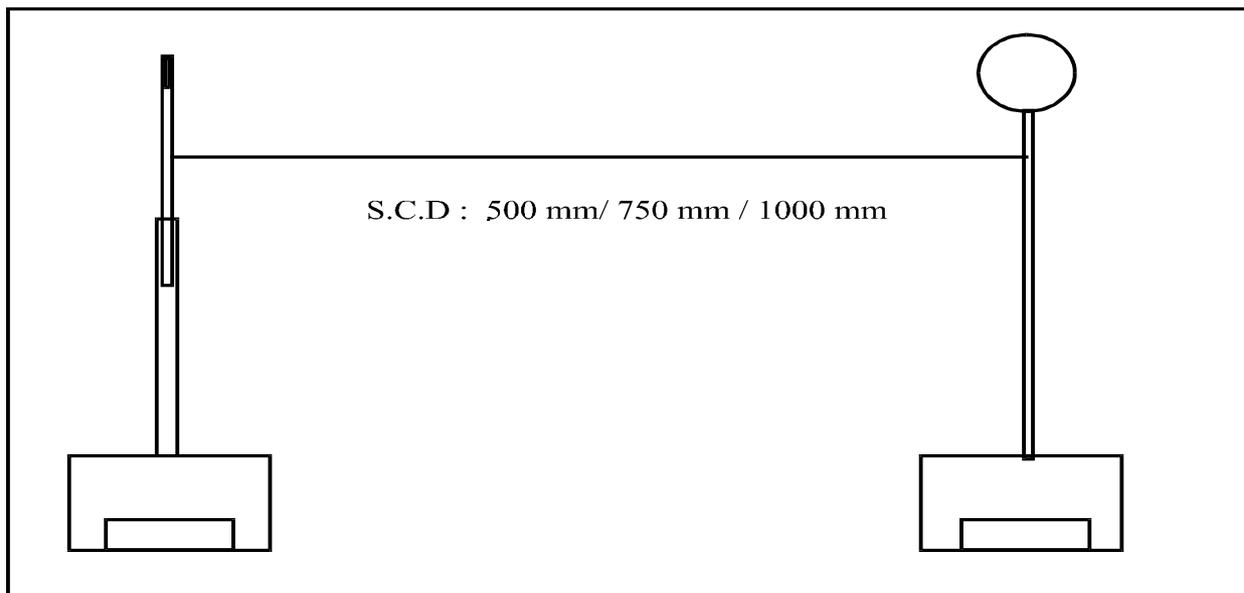


FIG. 7. Alignment of the 1-litre spherical chamber and the ^{137}Cs source for the measurements in air.

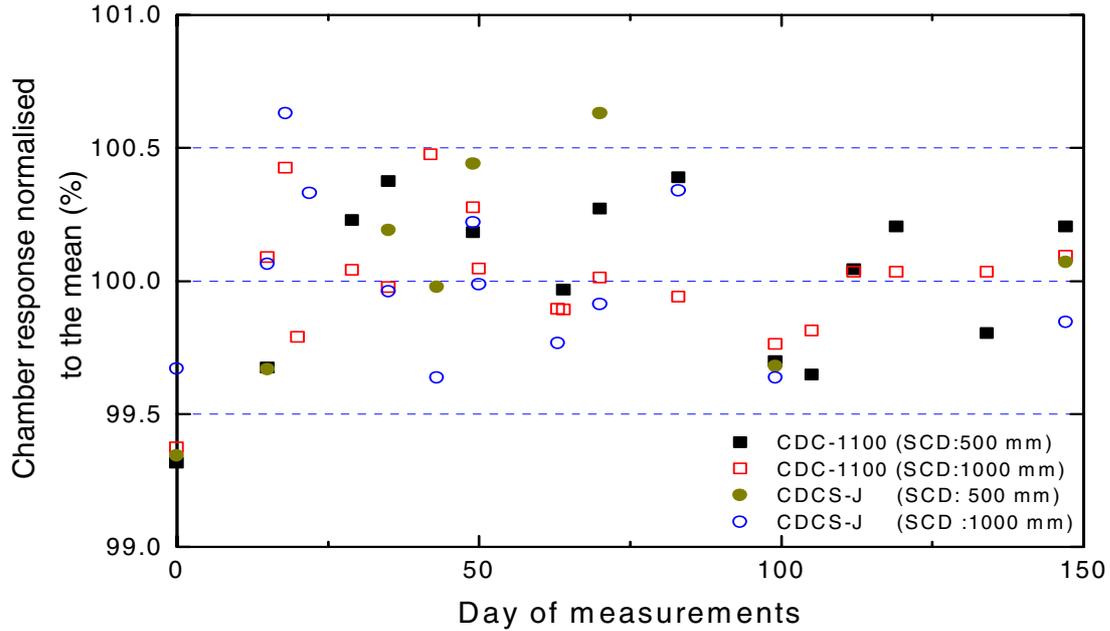


FIG. 8. Reproducibility of in-air measurements at source-chamber distances of 500 mm and 1000 mm. The chamber response for each set of measurement was normalised to the mean response of the respective set over the period of measurement. The normalised response for each set is within $\pm 0.5\%$.

3.4.4. Comparison of the two methods

The calibration factor in terms of $\mu\text{Gy nC}^{-1}$ was evaluated for the well-chamber and for the LS-01 chamber in-air measurements at source chamber distances of 500 mm, 750 mm and 1000 mm; these are given in Table II. For air measurements, the air kerma rates at distances of 500 mm and 750 mm were derived from the reference air kerma rate (air kerma rate at 1000 mm), using the inverse square distance factor.

The advantage of performing air measurements at a large distance for comparing the strength of sources of different construction can be seen in the third row of Table II, where the chamber response for the two types of sources are compared. The difference in chamber response for the two sources is less than 0.1% for air measurements at 1000 mm and increases to about 0.5% at 500 mm; for the well-chamber the difference is about 0.8%.

For air measurements, the mean value of the calibration factor differ by about 3.1% at 500 mm and 1.4% at 750 mm compared to that at 1000 mm. This could be attributed mainly to the scatter contribution, the relative value of which vary at different distances. The influence of the finite size of the chamber contributes by about 0.5% at 500 mm and less than 0.2% at 1000 mm according to the method of Kondo and Randolph [7]. However, the scatter and volume effects become irrelevant if air measurement is used to compare the strengths of two sources in identical geometry, as recommended in this work.

TABLE II. CALIBRATION FACTOR ($\mu\text{Gy nC}^{-1}$) FOR THE WELL-TYPE CHAMBER AND LS-01 SPHERICAL IONISATION CHAMBERS.

	N_{RK} ($\mu\text{Gy nC}^{-1}$) well-chamber	N_{RK} ($\mu\text{Gy nC}^{-1}$) LS-01 chamber (in-air measurements) at distances		
		500 mm	750 mm	1000 mm
CDC-1100	0.1413	24.62	24.23	23.92
CDCS - J	0.1401	24.75	24.30	23.94
CDC1100 / CDCS-J	1.008	0.9947	0.9974	0.9991
N_{RK} (Mean)	0.1407	24.68	24.27	23.93
N_{RK} normal. at 1000 mm	-	1.031	1.014	1.000

4. TRANSFER OF CALIBRATIONS TO SSDLs

The steps involved in transferring the calibration from the IAEA reference sources to the SSDLs sources may be summarised as follows:

- At the IAEA Dosimetry Laboratory, a calibration factor for the SSDL well-type chamber (RAKR/ Scale Reading) is obtained using the ^{137}Cs IAEA reference source(s).
- The SSDL measures the Reference Air Kerma Rate of local sources using the calibrated well-type chamber under the same conditions used for the calibration at the IAEA. The source(s) thus calibrated will be the local standard and will be used by the SSDLs to provide calibration services to hospital users.

As with any other type of chamber calibration, a measurement with a reference check source should be made at the SSDL before and after the calibration at the IAEA for checking the stability of the SSDL well-type chamber.

5. CALIBRATIONS OF OTHER RADIONUCLIDES

In addition to ^{137}Cs , other radionuclides frequently used for gynaecological intracavitary therapy are ^{60}Co and ^{192}Ir . Sources of both radionuclides are commonly used in High-Dose-Rate remote-controlled afterloading units. ^{192}Ir has a very short half life (about 74 days) and therefore necessitates replacement at least every quarter. Therefore, the calibration of HDR ^{192}Ir sources should be carried out on a regular basis by the users themselves. The SSDLs could provide a redundancy check to such measurements.

Presently, no Primary Standard Dosimetry Laboratory offers calibration of HDR ^{192}Ir sources. For routine check of the calibration of these sources, either (or both) of the following methods have been recommended by some organisations [8,9]

1. In-air measurements at a distance of 100 mm using a Farmer type ionisation chamber whose calibration factor for ^{192}Ir gamma rays is determined by interpolating from the response at ^{60}Co , ^{137}Cs and 250 kV X-rays.
2. Using a well-type ionisation chamber calibrated (without traceability) for ^{192}Ir gamma rays.

For the calibration of HDR ^{60}Co sources, any (or both) methods described for the calibration of HDR ^{192}Ir sources could be used.

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INTERCOMPARISON OF IONIZATION CHAMBER CALIBRATION FACTORS IN THE IAEA/WHO NETWORK OF SSDLS

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ABSTRACT

In 1995 an intercomparison of ionization chamber calibration factors was performed. It was open to Member laboratories within the IAEA/WHO Network of SSDLS. The aim of this exercise was to test a new quality audit system for these laboratories. The intercomparison had 17 participating laboratories; calibration factors for 24 ionization chambers were checked. The participants were asked to calibrate the ionization chambers both in terms of air kerma and absorbed dose to water. The results show that most of the SSDLS perform air kerma calibration of acceptable quality, while some misunderstandings regarding calibrations in terms of absorbed dose to water were discovered. This type of intercomparison will from now on become a normal service of the Network secretariat in collaboration with the IAEA dosimetry laboratory. It will be expanded to cover all Member laboratories which perform therapy level ionization chamber calibrations as part of their normal service.

1. INTRODUCTION

For about 30 years a postal service for dose quality audits using mailed TLDs has been provided by the IAEA and WHO for radiotherapy centers. This service was extended to member laboratories of the IAEA/WHO Network of Secondary Standard Dosimetry Laboratories (SSDLs) in 1981. Since then SSDLS are requested to participate in the audits as an independent verification of their activities in disseminating standards at radiotherapy level. The inherent uncertainty of the TLD system maintained by the IAEA is estimated to be 1.8% (one standard deviation) when both the IAEA and the participating SSDLS use the same method to derive the absorbed dose to water, i.e., the International Code of Practice IAEA TRS-277 [1]. This is, however, an undesirable too large uncertainty to verify the traceability of the calibration factors which SSDLS provide to users, usually with a much lower estimated uncertainty. It is also understood that intercomparisons based on TLD measurements are strictly assessments of dose delivery to the dosimeter in reference conditions in water. This is the final step of the calibration of a therapy beam, but not a verification of the calibration factor of the ionization chamber. The absorbed dose to water is determined by using a dosimetry protocol, and contributions other than the calibration factor of the chamber used for the beam calibration play a significant role in the dose delivered to the TLD.

To overcome these limitations an alternative method involving ionization chamber measurements was introduced. A programme called CARE (Coherence and Accuracy of Reference Equipment) was initiated by the IAEA in 1986, where a package of mailable dosimeters, consisting of two thimble ionization chambers and two simple electrometers, was designed with the support of the Austrian Research Center in Seibersdorf. Five such packages were assembled and distributed to SSDLS for the calibration of the dosimeters in a ^{60}Co gamma-ray beam. The two dosimeters in each package were also calibrated at the IAEA Dosimetry Laboratory both prior to and after the calibration by the SSDLS. Results were then compared and reported to the participants of the intercomparison. The uncertainty of the intercomparison with this system was about 0.5 %. The simple electrometers, however, exhibited a rather high malfunction rate. This drawback, together

with high costs for mailing and insurance of the systems, forced the IAEA to modify the programme. In 1995 SSDLs were requested to participate in an intercomparison with their own working standard. The results of this intercomparison are presented and discussed in the present manuscript.

2. MATERIALS AND METHODS

Ionization chambers pertaining to the working standard of the SSDLs were calibrated first by the SSDLs in terms of kerma in air and absorbed dose to water in a ^{60}Co gamma-ray beam. The results were provided to the IAEA. The ionization chambers were then calibrated at the IAEA Dosimetry Laboratory and the results compared and analyzed. Eight different models of commercially available ionization chambers were used for this intercomparison, which included 24 chambers from 17 participants, of which 13 were SSDLs of the Network.

The calibration at the IAEA Dosimetry Laboratory was performed by the substitution method [2] using the IAEA Reference Standard chamber *NE-2561* (#321). This had been calibrated at BIPM in 1994. The geometry for the calibrations in air and in water are shown in Fig. 1 and Fig. 2 respectively.

For the calibrations in water the so-called IAEA standard water phantom (30 cm x 30 cm x 30 cm with fixed chamber positions) was used; The chambers were placed with their center at a reference depth of 5 g·cm⁻² using a PMMA sleeve ## mm thick. The absorbed dose to water at the reference depth was determined using the air kerma calibration factor N_K of the IAEA Reference Standard and applying IAEA TRS-277 [1]. The ionization current was measured with a Keithley 617 electrometer which had been calibrated at BIPM in 1994.

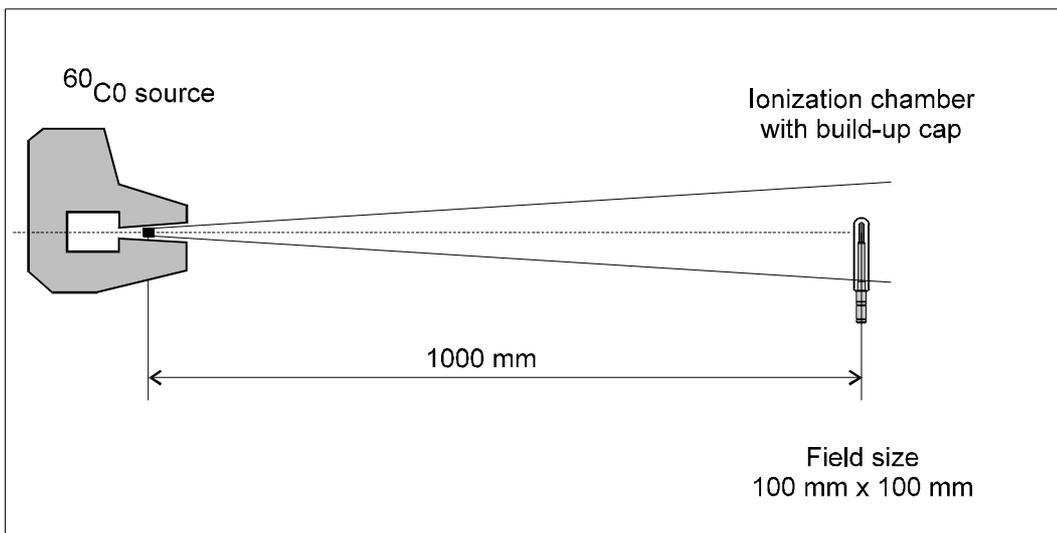


Figure 1. Set-up for the calibration of ionization chambers in terms of air kerma in a ^{60}Co beam at the IAEA Dosimetry Laboratory. The source to chamber distance (SCD) is 1000mm and the field size at the SCD (defined by a dose profile at 5 cm in water) is 100mm x 100mm. To minimize set-up uncertainties calibrations are made using the substitution method [2].

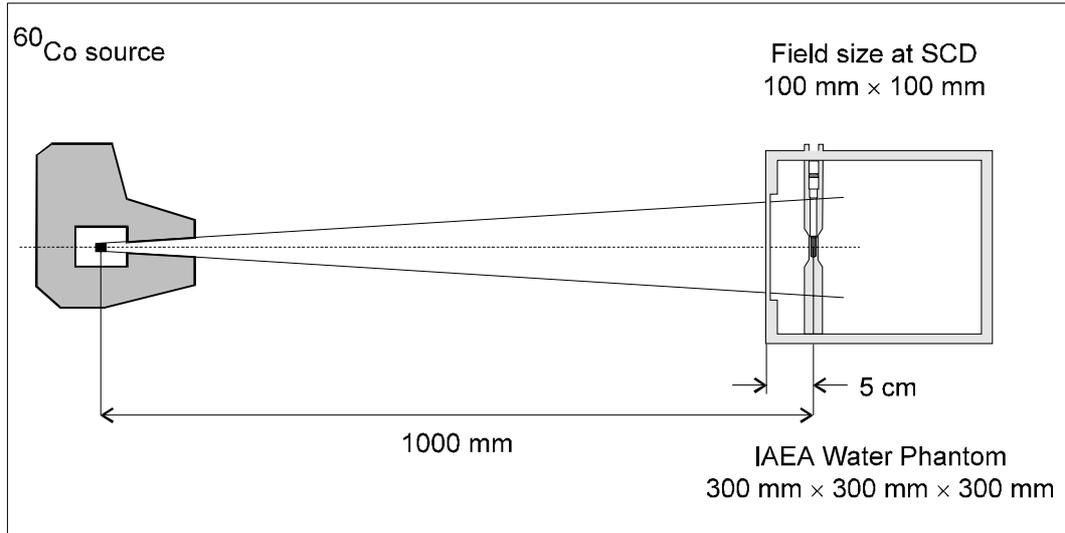


Figure 2. Set-up for the calibration of ionization chambers in terms of absorbed dose to water in a ^{60}Co beam at the IAEA Dosimetry Laboratory. The distance of the source to the center of the chamber is 1000mm, and the chamber center is positioned at a depth of 5 g cm⁻² in the phantom. The field size at the position of the chamber is 100mm x 100mm (defined by a dose profile at 5 cm in water). To minimize set-up uncertainties calibrations are made using the substitution method [2].

3. DETERMINATION OF THE ABSORBED DOSE TO WATER CHAMBER FACTOR

For consistency purposes in the present intercomparison, the formalism given in IAEA TRS-277 [1] was used. The absorbed dose to water at the position of the effective point of measurement of the ionization chamber, $D_w(P_{\text{eff}})$, was determined according to²

$$D_w(P_{\text{eff}}) = M \cdot N_{D,\text{air}} \cdot s_{w,\text{air}} \cdot P_u \cdot P_{\text{cel, gbl}} \quad (1)$$

where

$$N_{D,\text{air}} = N_K \cdot (1 - g) \cdot k_m \cdot k_{\text{att}} \quad (2)$$

and

M = charge collected by the dosimeter (ionization chamber plus electrometer) corrected for influence quantities

$N_{D,\text{air}}$ = absorbed dose to air chamber factor (denoted by N_{gas} in AAPM TG 21[4])

N_K = air kerma calibration factor of the ionization chamber

k_m = factor to take into account the non-air equivalence of the chamber wall and build-up cap during the calibration of the chamber

k_{att} = factor that corrects for attenuation in the ionization chamber walls during the calibration of the chamber.

g = the fraction of the energy of secondary particles lost into bremsstrahlung

$s_{w,\text{air}}$ = stopping power ratio, water to air, for Co-60

p_u = perturbation factor to take into account the non-water equivalence of the wall of the

² Note that for clarity some symbols in TRS-277 [1] have been modified slightly here. This is the case with the $N_{D,\text{air}}$ chamber factor and $p_{\text{cel, gbl}}$, which in TRS-277 are denoted, respectively, by N_D and p_{cel} . The reader is referred to the recent publication IAEA TRS-381 [3], or to the SSDL Newsletter #34, for a detailed description.

ionization chamber during the measurement in water

$p_{\text{cel,gl}}$ = global correction factor to take into account the non-air equivalence of the chamber central electrode, both during the chamber calibration and the in-phantom measurements

The design of the IAEA standard water phantom does not allow positioning the ionization chamber with its effective point of measurement at the reference depth which for the present intercomparison would have added uncertainty to the measurement due to the different radii of the chambers used. Instead, all chambers were positioned in the water phantom with their center at a depth of 5 g cm^{-2} . The absorbed dose to water at the positions of the effective point of measurement and at the center of the chamber can be related by the so-called displacement correction factor, p_{dis} ,

$$D_w(5 \text{ g cm}^{-2}) = D_w(P_{\text{eff}}) \cdot p_{\text{dis}} \quad (3)$$

where $p_{\text{dis}} = 1 - 0.004r$, r being the inner radius of the ionization chamber in mm [5]. This factor takes into account the displacement of the volume of water replaced by the chamber cavity. A common alternative to Eq. (3) to correct for the displacement effect, is to use the ratio of percentage depth-doses at the two depths (chamber center and P_{eff}), using for example depth-dose data from BJR-17 [6]. The choice of the present correction factor resides in its consistency with the data for the shift of P_{eff} recommended in TRS-277 (strictly in the corrigendum given in the SSDL Newsletter #31, 1992, p. 40, where the shift of P_{eff} is given as $0.6r$ towards the radiation source [5]).

The absorbed dose to water factor of the ionization chambers is then obtained from

$$N_{D,w} = \frac{D_w(5 \text{ g cm}^{-2})}{M} \quad (4)$$

The combined standard uncertainty ($k=1$) of the air kerma calibration factors determined at the IAEA Dosimetry Laboratory is 0.3 %. The estimated combined uncertainty ($k=1$) given in TRS-277 for the interaction coefficients k_m , k_{att} , $s_{w,\text{air}}$ and p_u for ^{60}Co gamma rays is 2.4%, which should be combined with that of N_K and M . However, since all participants were assumed to use the same set of interaction data, the contribution of the interaction coefficients to the combined uncertainty in $N_{D,w}$ can be ignored in this intercomparison.

4. RESULTS AND DISCUSSION

The values of N_K and $N_{D,w}$ determined both by the SSDL and the IAEA Dosimetry Laboratory, and the respective relative deviations are given in Table I.

Table I. Values of N_K and $N_{D,w}$ determined by the SSDLs and by the IAEA Dosimetry Laboratory. Percent deviations for each type of factor, relative to the IAEA determinations², are given in columns 5 and 8.

Participant no.	Chamber model	N_K (SSDL) [Gy/ μ C]	N_K (IAEA) [Gy/ μ C]	Δ^2 [%]	$N_{D,w}$ (SSDL) [Gy/ μ C]	$N_{D,w}$ (IAEA) [Gy/ μ C]	Δ^2 [%] calculated
1	NE-2561	95.77	95.26	0.53	104.97	103.34	1.58
2	NE-2571/gr	41.71	41.62	0.22	45.37	45.46	-0.19
3	NE-2571	40.38	40.59	-0.51	44.12	44.29	-0.37
4	NE-2571	42.46	41.33	2.74			
5	NE-2571	41.62	41.56	0.13	45.29	45.26	0.08
6	NE-2571	41.30	41.33	-0.08	44.90	45.09	-0.43
7	NE-2571	41.14	41.02	0.29			
8	NE-2571	41.10	41.16	-0.14	44.80	44.83	-0.06
9	NE-2571	41.60	41.25	0.83	45.31	45.03	0.62
10	NE-2571	42.04	41.66	0.93	45.96	45.46	1.10
11	NE-2571	41.02	41.31	-0.69	40.41	45.02	-10.25
12	NE-2581	52.28	52.41	-0.24	57.20	56.79	0.72
13	W-30001	46.28	46.73	-0.96	50.35	50.93	-1.14
13	W-30001	46.86	47.41	-1.15	51.27	51.55	-0.55
13	W-30001	46.92	47.51	-1.25	51.34	51.64	-0.58
13	W-30001	46.76	47.36	-1.27	51.14	51.45	-0.60
13	W-30002	46.35	46.88	-1.13	50.73	51.04	-0.60
13	W-30002	46.25	46.64	-0.83	50.65	50.79	-0.27
13	W-30002	46.54	47.19	-1.38	51.02	51.25	-0.45
7	W-23333	46.32	46.13	0.40			
14	W-23333	47.88	47.84	0.09	46.47	51.99	-10.61
15	NE-2505/3	39.74	40.38	-1.60			
16	NE-2505/3	40.55	40.75	-0.49	43.70	43.94	-0.55
17	ND-1006	129.00	128.73	0.21	143.00		
				mean:			-1.19
				standard deviation:	0.97		3.33

$$^2 \Delta = \frac{N(SSDL) - N(IAEA)}{N(IAEA)} \times 100\% , \text{ where } N \text{ corresponds to } N_K \text{ or } N_{D,w} \text{ respectively.}$$

Absorbed dose to water factors, $N_{D,w}$ were determined, according to Eq. (4), as the ratio of the absorbed dose to water at the reference depth $D_w(5 \text{ g cm}^{-2})$, and the response of the ionization chamber positioned with its geometrical center (i.e. not with the effective point of measurement) at this point. The factors $N_{D,w}$ are therefore referred to the geometrical center of the chamber. Some

factors $N_{D,w}$ reported by the participant laboratories were, however, related to the effective point of measurement of the chamber, P_{eff} . These factors were therefore recalculated to a $N_{D,w}$ related to the center of the chamber using Eq. (3).

A plot of the deviations relative to the IAEA calibration factors is given in Fig. 3. The consistency of the determination of N_K and $N_{D,w}$ factors is, in general terms, satisfactory except for two data points (indicated by the downwards arrows in the figure) that deserve special comments. The values of $N_{D,w}$ quoted by two SSDLs participating in the intercomparison were wrong by a factor of about -10%. These two laboratories had confused the absorbed dose to water factor, $N_{D,w}$, with the absorbed dose to air chamber factor, $N_{D,air}$. The $N_{D,w}$ values provided by these laboratories are given in Table I but for Fig.3 they were evaluated using TRS-277 [1] according to

$$N_{D,w}(5g\text{ cm}^{-2}) = N_{D,air} \cdot s_{w,air} \cdot P_u \cdot P_{cel} \cdot P_{dis} \quad (5)$$

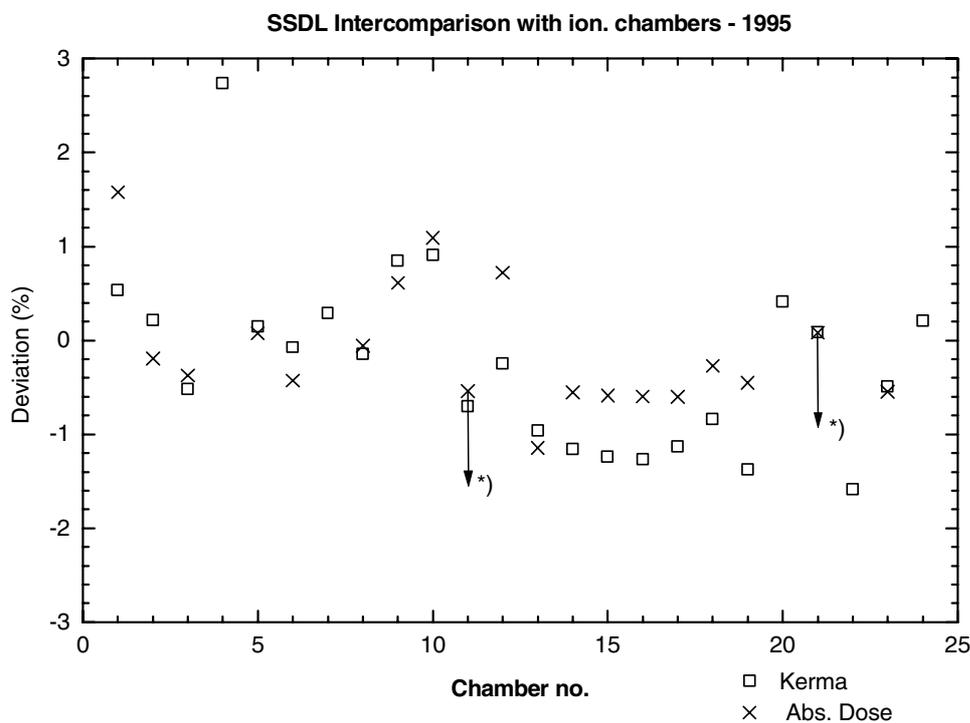


Fig 3: Percent deviations of the ion chamber factors relative to the IAEA values (see footnote to Table I). Symbols correspond to the results for air kerma calibration factors (squares) and for dose to water chamber factors (crosses). The arrows with asterisks correspond to the two outliers in Table I discussed in the text; the crosses for these two participants show the result when the dose to water factors were recalculated according to Eq. (5).

In order to explain partly the differences shown in Fig. 3 it should be noticed that reference standards of the SSDLs are traceable to different PSDLs. Most of them are calibrated in terms of air kerma, and even if the international agreement between air kerma standards is excellent, the influence of the small discrepancies is reflected in the results. Most participants have used a dosimetry protocol to determine the absorbed dose to water and then derive a chamber factor, but the protocol used has not always been IAEA TRS-277 [1]. Some SSDLs have, on the other hand, their reference standard calibrated in terms of absorbed dose to water traceable to BIPM, which started to provide such calibrations in 1991.

The inconsistency between the participants with regard to the reference point of the ionization chamber to which the absorbed dose to water factor is referred to, either the center or the effective point of measurement of the chamber, or the way of transferring the factor from P_{eff} to the chamber center, must be emphasized. As already mentioned there are several methods commonly used for this purpose and, for consistency, we have chosen to use a displacement factor using data from ref. [5]. This is the recommendation in the new IAEA Code of Practice for plane parallel chambers (IAEA TRS-381 [3]) which includes an update of TRS-277. Finally, the change in the shift of the effective point of measurement of the chamber recommended in TRS-277, $0.5r$, versus the value of $0.6r$ recommended in 1992 has to be stressed. New editions of TRS-277 include special pages with the changes already published in the SSDL Newsletter #31.

It has to be clarified that, strictly, the IAEA $N_{D,w}$ factors used in the present intercomparison (i.e. those given in Table I), determined according to Eqs. (4) and (5) are not proper absorbed dose to water calibration factors with regard to traceability. These factors have been calculated upon the knowledge of the calibration factor in terms of air kerma, traceable to air kerma standards, but they are not traceable to standards of absorbed dose to water existing in the International Measuring System. The calculated $N_{D,w}$ factors used in this intercomparison should not be confused with the $N_{D,w}$ calibration factors provided in the calibration certificates issued by the IAEA, or by the BIPM or other Primary Standard Laboratories, which are indeed traceable to standards of absorbed dose to water. The main reason for using calculated factors in the present exercise is to verify the consistency in the procedure for measurements in water in the various SSDLs, which are usually more sensitive to small variations than measurements in air. In addition, as mentioned above, not all SSDLs have traceable $N_{D,w}$ calibrations for their Secondary Standards and this intercomparison aims at achieving homogeneity in the results.

The experience has also shown that referring the calibration to the center of the chamber, as opposed to the effective point of measurement, is not perfectly understood by all SSDLs. The extreme cases of confusing the kind of chamber factor to be used, $N_{D,w}$ versus $N_{D,\text{air}}$, reveals a serious lack of understanding of the principles of dose determination. These two important items suggest that further education is needed for the staff of these laboratories. This is of special importance if the role of the SSDLs to improve the status of radiotherapy dosimetry (the main reason for the creation of the IAEA/WHO SSDL network), interacting whenever possible with hospital physicists, is to be accomplished.

Finally it has to be stressed that among the 17 participants in the intercomparison only 13 were SSDLs. Considering that the IAEA/WHO SSDL Network has 69 member laboratories (out of which 49 perform regularly therapy level calibration for hospitals in their countries), the participation is considered rather low. However, as this was a test run it is considered that the participation was enough to gain experience and adjust the future programme so that full scale intercomparisons will start in 1997. We therefore strongly encourage all SSDLs in the Network to participate in this new programme.

5. CONCLUSIONS

The comparison of calibration factors of ionization chambers between SSDLs of the IAEA/WHO Network and the IAEA Dosimetry Laboratory has, in general terms, shown satisfactory results when the possible sources of discrepancy (primary standards, dosimetry protocols, etc.) are taken into account. The present "test run" intercomparison has shown some weak points along the dosimetry chain which are expected to be improved in the 1997 programme.

For obvious reasons it is natural to try to establish a parallelism between intercomparisons based on ion chamber calibrations and those based on TLD methods. The method of performing an

intercomparison based on ion chambers, and having the IAEA Dosimetry Laboratory serving as an “external quality auditor” has some advantages compared to TLD intercomparisons:

- a) The main service by SSDLs in the field of radiotherapy dosimetry is to provide calibrations of hospitals reference dosimetry systems. The ion chamber intercomparison described in this paper verifies the degree of accuracy of the service given by the participating SSDLs, and therefore guaranties the dissemination of standards to users.
- b) Intercomparisons based on TLD measurements are strictly assessments of the dose delivered to the dosimeter when this is placed at a reference depth in water, a dose quality audit. This is the final step of the calibration of a therapy beam, that is, the verification of D_w using an independent dosimetry system. The absorbed dose to water is obtained by application of a dosimetry protocol, and several components other than the simple N_K of the ionization chamber used for beam calibration play a significant role in the dose to the TLD.
- c) The determination of absorbed dose to water using ionization chambers has higher accuracy than absorbed dose determinations based on TLD.

There also drawbacks in intercomparisons based on ion chambers which should be mentioned:

- a) It involves the transportation of a large number of rather delicate and expensive equipment. Compared to TLD mailing expenses this cost is very high.
- b) The procedures at the IAEA Dosimetry Laboratory are rather time consuming. Each dosimeter checked in this way requires more man-power than a set of 3 TLD capsules in the TLD method.

In consequence although ion chamber intercomparisons will be implemented and the participation of the SSDLs encouraged, intercomparisons and dose quality audits with TLDs will continue as a non-expensive and reliable method to complement ion chamber intercomparisons.

The IAEA has recently emphasized in several communications to the SSDLs that absorbed dose to water calibration factors should not be transmitted to hospitals. The two mistakes (out of 13 laboratories) discussed in this paper, where the absorbed dose to air factor was confused with the absorbed dose to water factor, confirms that the time has not yet come to transfer this type of factors to the end users. However, by including factors in terms of absorbed dose to water in the intercomparisons, mistakes and inconsistencies in the procedures will be identified and clarified. This will in turn gradually increase the understanding of the SSDLs for the new type of calibrations. Present determinations of $N_{D,w}$ can then be considered as a preparation phase for the SSDLs to provide absorbed dose to water calibration factors of ionization chambers in the near future.

It must be emphasized, however, that until a proper IAEA Code of Practice based on calibrations in terms of absorbed dose to water exists, it is strongly recommended not to transmit calibration factors in terms of absorbed dose to water ($N_{D,w}$) to hospitals. Actions towards developing a new IAEA Code of Practice based on absorbed dose to water standards have already been initiated by the Dosimetry and Medical Radiation Physics Section, but this task will still take several years to be accomplished.

6. REFERENCES

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QUALITY AUDIT SERVICE OF THE IAEA FOR RADIATION PROCESSING DOSIMETRY

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ABSTRACT

The mandate of the International Atomic Energy Agency includes assistance to Member States to establish nuclear technologies safely and effectively. In pursuit of this, a quality audit service for dosimetry relevant to radiation processing was initiated as a key element of the High-Dose Standardization Programme of the IAEA. The standardization of dosimetry for radiation processing provides a justification for the regulatory approval of irradiated products and their unrestricted international trade. In recent times, the Agency's Dosimetry Laboratory has placed concentrated effort towards establishing a quality assurance programme based on the ISO 9000 series documents. The need for reliable and accurate dosimetry for radiation processing is increasing in Member States and we can envisage a definite role for the SSDLs in such a programme.

1. INTRODUCTION

Several guidelines and standard practices presently exist that provide recommendations that should be followed for the radiation processes, such as sterilization of health care products and food irradiation. These publications have been developed - and are frequently updated - by the international and regional organizations, such as ISO, WHO, FAO, CEN, ASTM and AAMI¹ [1-5]. One of the principal concerns of all the guidelines is process validation, the objective of which is to establish documentary evidence that the radiation process will reliably achieve the desired results. The key element in process validation is a well characterized, reliable and accurate dosimetry system that is traceable to a Primary Standard Dosimetry Laboratory (PSDL).

To help the developing Member States to establish such a dosimetry system in particular, and the radiation processing technology in general, the IAEA started the High-Dose Dosimetry Programme in 1977 [6]. This program is now firmly established and has created a strong impact on the processing industry. It has helped several laboratories and industrial facilities in the developing countries to install the new technology in a confident fashion. The principal vehicle of the achievement has been the quality audit service called the International Dose Assurance Service (IDAS) which was initiated in 1985 [6].

For the last more than ten years, this service has been operating successfully fulfilling its objectives in the field of radiation processing applications (dose range = 0.1 to 100 kGy). The long-range objective, however, would be to involve the SSDLs in this programme in a fashion similar to

¹ ISO - international Organization for standardization
WHO - World Health Organization
FAO - Food and Agriculture Organization
CEN - European Committee for Standardization
ASTM - American Society for Testing and Materials
AAMI - Association for the Advancement of Medical Instrumentation.

their involvement in the radiotherapy dosimetry. The need for reliable and accurate dosimetry for radiation processing is increasing in Member States, and we can envisage a definite role for the SSDLs in such a programme.

2. OBJECTIVES OF IDAS

The standardization of dosimetry provides a justification for the regulatory approval of irradiated products and the unrestricted international trade of such products. The principal objective of the IDAS is thus to assist Member States in establishing a reliable dosimetry system in their radiation facilities in order to meet stringent requirements for dose measurement, and to achieve quality control in radiation processing. It is expected that the facility has an operating dosimetry system that has been calibrated and hopefully traceable to a PSDL. The IDAS then provides an independent check on all the components of the dosimetry system; for example, dosimeters, analysis equipment, procedure for the use of the dosimeters, any computer software being used, and the skill of the technical staff. This is essential, since having a calibrated dosimetry system is not sufficient for an acceptable QA programme. Thus, participation in the IDAS is the first step, and an important one, towards a comprehensive audit of the dosimetry system in use at a facility. At present, the IDAS is available for cobalt-60 gamma rays only; however, it is anticipated that a similar service for electron beams would be available in near future.

3. PROCEDURE

The IDAS fulfills its objective by providing the transfer standard dosimeters to the participating laboratories and radiation processing facilities. This service is similar to the IAEA/WHO quality audit service for the radiotherapy centres using TL dosimetry. A dosimeter set, used for one dose point, consists of three dosimeters for irradiation and one as a control, where each dosimeter is within its own capsule. The three dosimeters are then irradiated together as a set by the facility operator along with their routine or reference dosimeters under similar irradiation conditions. The irradiated dosimeters and the control dosimeter are then returned to the Agency's Dosimetry Laboratory for evaluation, along with the information on the irradiation conditions, such as the temperature of the dosimeters during irradiation. The dosimeter response is then analyzed, the relative deviation of the participant's dosimetry calculated, and the results conveyed to the participant. The action level is 5%; thus, a follow-up action is initiated if the relative deviation is outside this limit. This would generally involve advice and discussion through letters and a repeat measurement. If the discrepancy persists, an expert from the region may be requested to visit this facility to help correct the situation.

4. TRANSFER DOSIMETER

The transfer dosimeter used for the IDAS is alanine-ESR. The selection of the dosimeter was based on several intercomparisons that were conducted by the IAEA in early 1980s for this specific purpose [6]. Other candidate dosimeters were: radiochromic dye film, ceric-cerous sulphate and ethanol chlorobenzene. Overall, the alanine-ESR was judged to be the most suitable dosimeter for the IDAS for several reasons, for example: near-tissue equivalency, insensitivity to ambient environment, broad useful dose range, non-destructive analysis, and little fading of the response with time.

There were two negative factors against the choice of the alanine-ESR system then: (a) there was not much experience with this system; no PSDL or SSDL was using it on a regular basis, and (b) the analysis equipment, namely the ESR spectrometer was significantly costly. However, a quick review of the field of dosimetry today reveals that both these negative factors have almost disappeared and thus the selection of alanine-ESR as a transfer dosimeter seems to be vindicated:

- almost every PSDL and SSDL is now using alanine-ESR as a reference or a transfer system, and
- the price of the ESR spectrometer has decreased substantially. Today, a dedicated ESR spectrometer for alanine can be purchased for about \$50 000 with an on-line computer system.

The alanine dosimeters presently in use at the Agency's Dosimetry Laboratory are the commercially available Aminogray dosimeters which are rod type: 30mm long and 3mm in diameter. The dosimeter consists of polystyrene (30 wt%) as the binder material and DL- α -alanine (70 wt%). The dosimeter is placed inside a polystyrene capsule which provides the required buildup material to achieve secondary electron equilibrium for the cobalt-60 gamma rays and also provides a controlled environment for the dosimeter.

The response of the alanine dosimeter depends slightly on the irradiation temperature; the value reported by several users for the temperature coefficient varies between 0.15% and 0.30%/°C. We have measured this parameter for our dosimeters for 15 and 45 kGy; and its value for our experimental conditions is 0.23%/°C over this dose range as seen in Fig. 1.

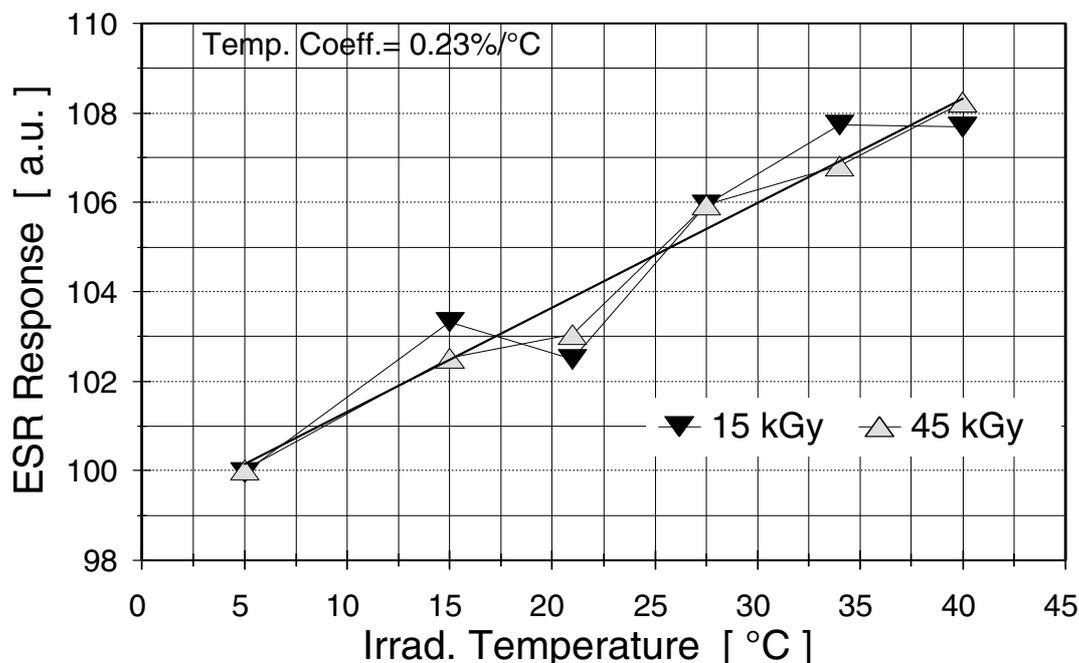


Fig. 1. The effect of the irradiation temperature on the ESR response for the Aminogray alanine dosimeters (∇ 15 kGy and Δ 45 kGy). The two sets of responses are normalised at 27.5°C. Based on these data, the irradiation temperature coefficient is +0.23%/°C.

We have also studied the fading characteristics of the ESR signal with time after irradiation over about 5 months for two dose values and three irradiation temperatures. In all cases, the dosimeters were exposed to about 50% relative humidity for 2 to 3 months before irradiation, and the temperature of storage before and after irradiation was 20-25°C [7]. The observed fading for all the cases investigated is about 1% over this time period (see Fig. 2).

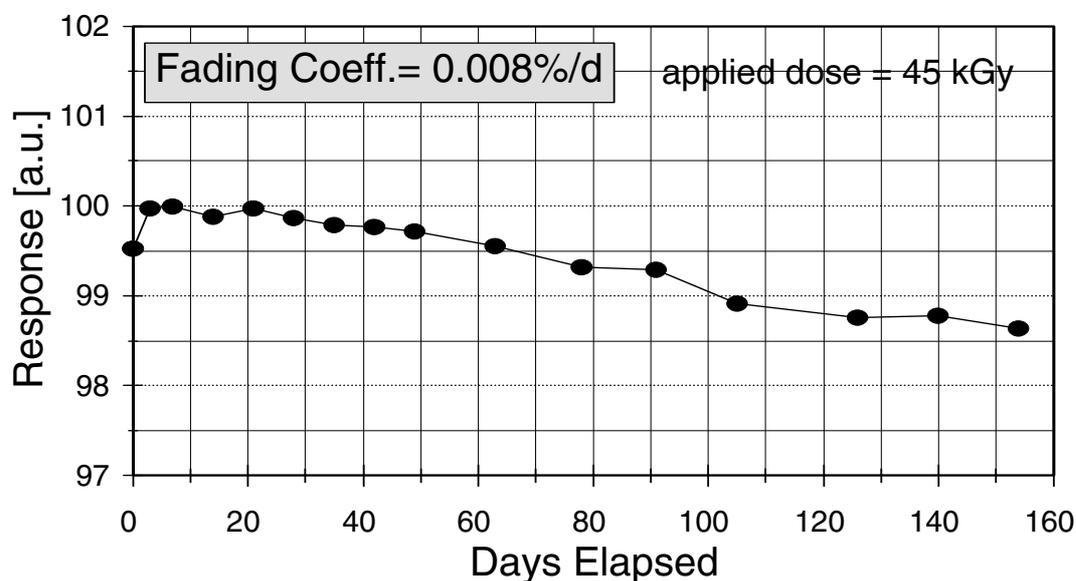


Fig. 2. The slow decrease of the ESR response (fading) for the Aminogray alanine dosimeters over several months after irradiation. The observed degree of fading is similar for the two dose values (15 and 45 kGy) and the three irradiation temperatures (15, 27.5 and 40 °C) used for this study.

5. QUALITY ASSURANCE PROGRAMME

It is the policy of the IAEA to operate the IDAS at the highest possible quality standard. To achieve this, we have placed concentrated effort in recent times towards establishing a quality assurance programme for the Agency's Dosimetry Laboratory. To the extent that is relevant, the technical requirements of the QA programme are based on the guidelines described in the ISO 9000 series documents, specifically GUIDE 25: General Requirements for the Competence of Calibration and Testing Laboratories [8]. The QA programme for the laboratory includes the QA Manual and several Standard Operating Procedures (SOPs) describing the various dosimetry systems in use at the Agency's Dosimetry Laboratory and the services afforded by the laboratory. The two SOPs relevant to radiation processing are:

a) *Maintenance of the Transfer Standard Dosimetry System for Radiation Processing (SOP-3)*. This SOP describes the procedures for the use of the alanine-ESR reference dosimetry system relevant to radiation processing. Such procedures include acceptance criteria, and handling and storage conditions for the dosimeters; analysis methods and calibration procedure; and operation and maintenance of the necessary equipment.

b) *Dose Quality Audit Service for Radiation Processing (SOP-9)*. This SOP describes several aspects of the service, including the objectives of the service, the criteria and procedure for participation, the detailed operating procedures, responsibility for the service, and the nature of the response in case of deviations outside the acceptance limits.

Since the reference dosimetry system is the key to the quality audit service, the quality assurance programme in place at the Agency's Dosimetry Laboratory to maintain this dosimetry

system is elaborated in details here. The purpose of the SOP-3 is to help ensure the quality of the reference dosimetry system through documented policies and procedures. It thus creates an element of trust in the quality of the dosimetry system and the service. The SOP also addresses the four key elements of a quality assurance programme: calibration and traceability, a comprehensive statement of uncertainty in the measurement system, audit checks, and documentation.

Calibration: The alanine-ESR dosimetry system is calibrated over the full useful range of the IDAS, namely from 0.1 to 100 kGy of the absorbed dose to water. The dosimeters are irradiated in the two in-house self-shielded cobalt-60 facilities (Gammacell 220 of AECL) to cover the entire dose range. They are irradiated in a specially designed PMMA phantom such that three dosimeters can be irradiated simultaneously. The temperature of the dosimeters is controlled for all irradiations. A fourth-order polynomial expression provides the best fit to the 18 calibration points.

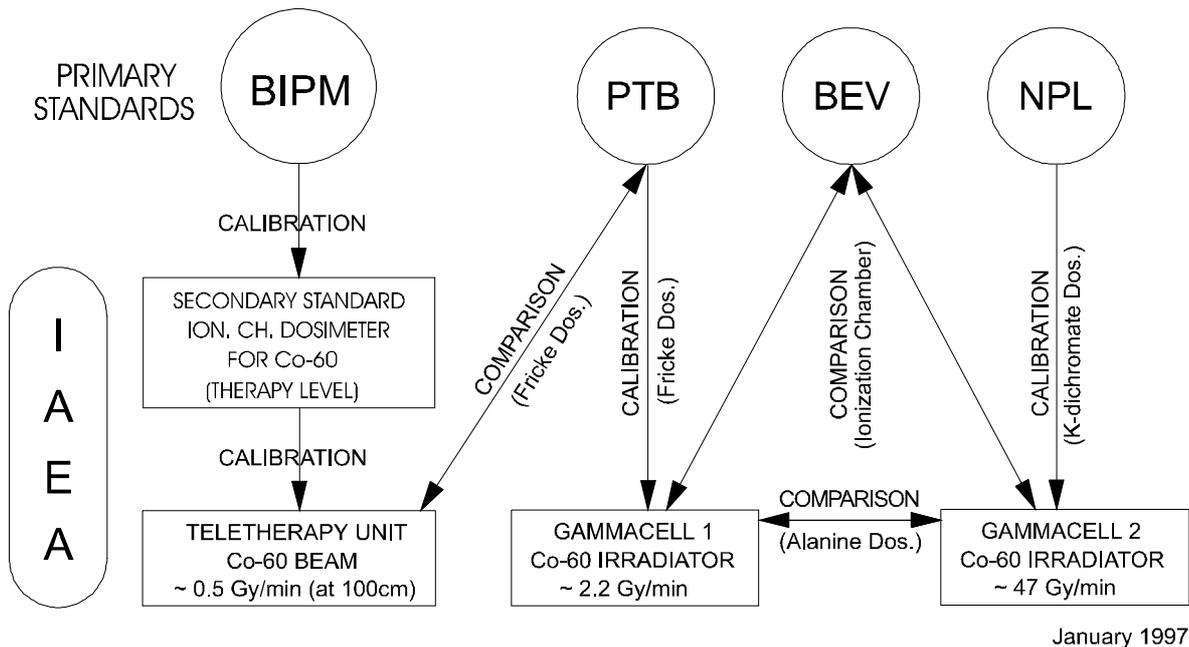
Traceability: The dose rate at a reference point in the gamma field of the high dose-rate Gammacell is traceable to the National Physical Laboratory (PSDL of UK) through dichromate transfer dosimeters. Also, this value of the dose rate was compared with several other PSDLs, namely Bureau International des Poids et Mesures (BIPM), Physikalisch-Technische Bundesanstalt (PTB, German PSDL) and Bundesamt für Eich- und Vermessungswesen (BEV, Austrian PSDL). Fig. 3 shows the network of calibrations and comparisons for the dose rate measurements of the three irradiators of the Agency's Laboratories in Seibersdorf:

- i. teletherapy unit (dose rate ~0.50 Gy/min at 100 cm from the source) is used for calibrating TL dosimeters and ionization chambers,
- ii. Gammacell 1 (dose rate ~2.2 Gy/min in the center of the irradiation chamber) is used for the alanine dosimeters for the IDAS, and
- iii. Gammacell 2 (dose rate ~47 Gy/min in the center of the irradiation chamber) also used for the alanine dosimeters for the IDAS.

These dose rate values are valid for January 1997. The teletherapy unit was calibrated using an ionization chamber that was calibrated at the BIPM. The Gammacell 1 was calibrated using the Fricke dosimetry system from the PTB. This Fricke dosimetry was then compared with the secondary standard ionization chambers (traceable to BIPM) in the teletherapy unit beam; the agreement was within the uncertainty of the dosimetry systems. Recently, the dose rate in both the Gammacells was measured with a small ionization chamber in collaboration with the BEV. Again, the agreement between the values was within the uncertainty of the dosimetry systems.

The QA programme requires that the dose rate measurements in the Gammacell be undertaken by a PSDL at least once in three years. In addition, measurement intercomparisons are also performed between the Agency's Dosimetry Laboratory and other calibration laboratories. For example, in collaboration with BIPM, the IAEA recently carried out a 'double-blind' intercomparison amongst nine high-dose calibration laboratories using its transfer dosimetry system; this was restricted to cobalt-60 gamma rays only. The agreement amongst all the participants was within 2.1% (1σ) at 15 kGy, and 2.4% (1σ) at 45 kGy. Also, the mean of the dose values measured by the Agency's Dosimetry Laboratory was within 1% of the mean of the dose values stated by the participants for both dose levels.

CALIBRATION CHAIN OF THE IAEA IRRADIATORS



January 1997

Fig. 3. The network of calibrations and comparisons for the dose rate measurements of the three irradiators of the Agency's Laboratories in Seibersdorf.

Uncertainty: The result of a measurement is only an approximation or an estimate of the value of the measurand and thus is complete only when accompanied by a statement of uncertainty in that estimate. Following the ASTM Standard Guide for Estimating Uncertainties in Dosimetry for Radiation Processing [9], the entire dose measurement system was divided into various components, sub-components and activities. The contribution to the uncertainty in the measured dose value from each of these activities was identified and the values assigned to Type A and Type B categories [10]. These contributions are then combined to yield the overall estimate of the uncertainty value. The three components and the associated uncertainties (1σ) are:

1. determination of the dose rate at the reference point in the Gammacell (1.05%);
2. calibration of the alanine-ESR dosimetry system (1.11%); and
3. dose measurement at an unknown location using the calibrated dosimetry system (0.35%, for a 3-dosimeter set, and assuming no contribution due to irradiation-temperature or fading correction).

The uncertainty in the first component is largely transferred from the calibration laboratory that measured the dose rate for our reference field. The second component, namely the calibration of our dosimetry system using the in-house reference field, consists of four sub-components: irradiation of the dosimeters, ESR analyses of the irradiated dosimeters, intra-batch variability and polynomial fit of the calibration data. The last component includes: ESR analyses and the intra-batch variability. It assumes here that the effects of the irradiation temperature and fading have been compensated perfectly. Thus, adding the three components in quadrature, the combined uncertainty in the measured dose value is 1.7% (1σ).

Audit Check: To assure and verify that the reference dosimetry system is performing at the highest quality level, the SOP-3 requires that a comprehensive audit be performed at regular intervals. Two different levels of audits are in place:

- Compliance with Procedures: the objective is to review the procedures followed in the laboratory and to ensure that there are no discrepancies between these and the requirements laid out in the QA programme. This audit is conducted by the Internal Audit Group of the Agency's Laboratories in Seibersdorf (RIAL).
- Dosimetry Audit: the objective is to provide the check on the quality of the transfer standard dosimetry system and also on the entire procedure used in the IDAS. The protocol developed and used for this audit is such that the exercise includes checks on all the relevant activities, for example, data transfer, retrieval of the calibration data, data manipulation using computer software and the skill of the technical staff. It is conducted by a Primary Standard Dosimetry Laboratory.

If the audit findings are at a variance with the QA programme requirements, immediate actions are needed as stated in the QA Manual to correct the situation. All audits and the review findings, and any corrective actions that arise from that are documented.

Documentation: A safe and secure recording system is set up to retain all original observations, calculations and derived data, calibration and maintenance records, audit reports and calibration certificates. These records contain sufficient information to permit their revalidation or repetition.

6. CONCLUSION

The International Dose Assurance Service is now well established for the cobalt-60 gamma rays. The quality assurance programme for the reference dosimetry system is nearly established and we are confident that the service provided to the Member States is of high quality. However, we are well aware that it is important to maintain and improve such a programme through constant vigil.

We are addressing this in several ways:

- periodic review of the quality assurance programme for its currency and relevance,
- organizing intercomparisons with calibration laboratories,
- continuously reviewing the uncertainty estimates for various components of the dose measurement system, and
- periodic audit checks as required by the QA programme.

7. FUTURE

It is conceivable that in a near future several members of the present IAEA/WHO SSDL Network would have established the capability for dosimetry for radiation processing. At that time, the Agency's Dosimetry Laboratory would be interested in organising an intercomparison involving interested SSDLs. Also, similar to the radiotherapy dosimetry, some of these SSDLs will be able to assist the IAEA in the quality audit service by helping the IDAS participants in their countries or regions for resolving critical situations. We would like to hear from any laboratory that is planning to expand in this field.

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A QUALITY ASSURANCE PROGRAMME FOR RADIATION THERAPY DOSIMETRY: REPORT OF A CONSULTANTS' MEETING TO REVIEW THE STATUS AND TO PLAN THE DEVELOPMENT

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ABSTRACT

Four national External Audit Groups (EAG) in charge of operating quality audits for radiotherapy dosimetry have been created through a Co-ordinated Research Programme "Development of a Quality Assurance Programme for Radiation Therapy Dosimetry in Developing Countries" (E2-40-07). The present status of the development of the measuring systems and measuring procedures for the EAGs has been compared to the methodology established by Quality Audit Networks operating at present in Europe. To harmonize different EAG procedures, a document entitled "Guidelines to prepare a Quality Manual for External Audit Groups on Dosimetry in Radiotherapy" has been outlined and a first draft prepared. The "Guidelines ..." covers quality policy, quality systems and quality structures including process control following the recommendations of ISO 9000 series and ISO/IEC guide No. 25. When completed, this document can be used as a guide on how to prepare the quality manual for national EAGs in developing countries. Due to increased interest in the project three new participants have been admitted.

1. BACKGROUND

In 1994 a group of consultants were asked to advise the Agency on the expansion of the IAEA/WHO TLD postal dose check service for radiotherapy hospitals by transfer of know-how to the national level. Four consultants came from SSDLs in Algeria, Argentina, China and India and one consultant represented the European Quality Audit Networks operating a TLD service for dosimetry audits in radiotherapy departments in Europe. The consultants considered feasible the transfer of methodology on quality audits with mailed TLDs to some advanced SSDLs in developing countries. The Agency thus decided to initiate the Co-ordinated Research Programme (CRP) to transfer its well established TLD methodology to national centres where existing resources enabled set up of the External Audit Groups - nationally recognised groups in charge of operating external quality audits for radiotherapy dosimetry. An External Audit Group (EAG) includes the SSDL, Measuring Group (MG) and a Medical Physics Group (MPG), these groups should work in close co-operation during all steps of the TLD audits.

The pilot countries, which wished to expand their field of competence in the TLD methodology, chosen for the CRP in 1994 were: Algeria, Argentina, China and India. Due to increasing interest in the programme, in 1996, Czech Republic, Israel and Malaysia were admitted as well.

The scientific scope of the CRP covered the following implementation steps, which were planned for accomplishment in 1995-1996:

- Development of measuring systems and measuring procedures for the EAGs with regard to Co-60 beam calibration checks for dosimetric quality control in radiotherapy departments/centers.
- EAG internal trial runs under the Agency's supervision to test measuring systems and measuring procedures.

- Draft of the EAG Quality Manual (quality policy, quality system and quality practice) with regard to Co-60 beam calibration checks in hospitals using for guidance ISO 9000 Series and ISO/IEC Guide 25.
- External test runs (using the Agency's TLD service and CARE programme)
- Discussions to expand the EAG Quality Manual to cover accelerator beam calibration checks.

Most of the listed tasks were completed during 1996 in the four "pilot" countries prior to this meeting.

2. OBJECTIVES OF THE MEETING

The aim of the meeting was to discuss the degree of implementation of Quality Assurance programmes for radiation therapy dosimetry and to co-ordinate different procedures as reported by the participants and to develop a common draft of the EAG quality manual.

External Participants

Dr. A. Meghzipene (Algeria)
 Lic. M. Saravi (Argentina)
 Prof. A. Dutreix (Belgium)
 Dr. A. Kannan (India)
 Prof. Li Kaibao (China)

Participants from IAEA

P. Andreo (scientific secretary)
 J. Izewska (scientific secretary)
 G. Matscheko
 K. Zsdansky

3. PRELIMINARY DISCUSSIONS

The EAGs have been set-up in participating countries and their structure, responsibilities and interactions between partners have been established. The approval by the Ministry of Health (or equivalent) for conducting joint activities between medical and nuclear energy authorities towards Quality Assurance (QA) in radiotherapy has been obtained by most participants. It has been emphasised, that at the present stage, the EAGs should act on national level and should not expand to neighbouring countries in order to provide better TLD service to the radiotherapy hospitals in their own country. The aim is to speed up of the TLD service and to provide fast and effective resolution of the discrepancies in beam calibrations. Fast response to the participants is vital in maintaining their interest in the QA programme. If the delays in response become excessive, the interest of the hospitals gradually diminishes, which may jeopardise the success of the QA programmes. The number of patients' treatments affected by bad dosimetry practices can be decreased if the delays will be reduced and rapid resolution of the discrepancies provided.

Another topic, which was discussed, regarded the interpretation of large discrepancies detected by the TLD checks and their relation to the clinical data used for patient treatments. It appears that quite often the data reported for the TLD irradiations differ from those used in clinics. The standard instruction sheet of the TLD irradiations sent to the local physicists recommends to measure the beam output immediately before TLD irradiation to determine the dose to water at the position of the TLD. The measured data are reported in the data sheet. This enables to verify the dosimetry protocol and procedure used in the departments, without ensuring that the same procedure and reported data are applied in the clinical routine. To overcome this limitation, it is advisable to introduce changes to the TLD instruction sheets by recommending irradiation of the TLDs in the same clinical conditions as the patients' irradiations, using treatment time or monitor units applied for the routine therapy planning. The beam output can be measured by the physicists on the same day as the TLD irradiation, following the procedure described in the old TLD instruction, but this should be reported as supplementary information independent from the clinically used output.

The results from the external TLD trial runs by Argentina and India using the Agency's TLD service were reported and experiences summarized during the meeting.

4. STATUS REPORTS FROM THE PARTICIPANTS

A presentation on the state of the art of the QA networks operating in Europe was given by Prof. A. Dutreix. Other consultants have presented their status reports on the degree of implementation of the CRP in their countries. A few most relevant items of the presentations are summarised below.

A. Dutreix, Belgium

Four international quality assurance (QA) networks perform dosimetry audits between radiotherapy centres in Europe. These are:

- the European Organisation for Research and Treatment of Cancer (EORTC), which runs clinical trial programmes for advanced radiotherapy hospitals
- the European Union (EU) network - within the project "Europe against cancer"
- pan-European Radiation Oncology Programme for Assurance of Treatment Quality (EROPAQ) - supported by the Flemish government - which covers radiotherapy departments from Czech Republic, Hungary and Poland
- European network for Quality Assurance in Radiotherapy (EURAQ) - supported by European Union within the frame of Copernicus project - which runs TLD audits for radiotherapy centres in Lithuania, Slovakia, Slovenia and Rumania.

The EU network, EROPAQ and EURAQ networks have been implemented on the request of many European centres not involved in clinical research. They have a similar organisation, with one Co-ordinating Centre, one Measuring Centre and one National Reference Centre in each of the participating countries. Such a structure offers a standardised QA programme, the same in all participating countries, provides guidelines and gives a technical back-up to the national structures. Moreover it ensures traceability to the existing standards in dosimetry, set by the most recognised reference bodies, such as BIPM (Bureau International des Poids et Mesures). In the future the EU QA network, EROPAQ and EURAQ will move to decentralised TLD services at the national level. All the practical responsibilities with regard to the TLD audits will be taken over by the national reference bodies. The participating countries will be encouraged to benefit from the international expertise through the methodology, which has been developed at the international level.

Prof. Dutreix pointed out, that principle of confidentiality is followed in the interactions with the radiotherapy centres during all steps of the TLD audits. No details are given in any publication, either on the centres or on the characteristics of the radiation units. The data always appear in an anonymous way and is never transferred to administrative or governmental authorities without full written permission from the centres. The reports to the Ministry of Health, as required in some European countries, contain only names of those hospitals which showed TLD results within acceptance limits, independent how many TLD checks have been done to achieve good results.

From the experience of the European TLD networks it follows, that all beam modalities in clinical use should be audited in each individual radiotherapy department. Deviations have been observed between the calibrations of different beams from the same treatment unit or between different units in the same hospital, either because of errors in procedure or because of the poor maintenance of one particular machine.

A. Meghzifene, Algeria

The External Audit Group was set-up in Algeria in October 1995. It is composed of two groups: Measuring Group (MG), established within the SSDL, and Medical Physics Group (MPG), supported by 2 hospital physicists. The EAG is responsible for carrying out the TLD audits in Algeria.

The MG is responsible for the technical aspects of the TL-dosimetry, including calibration of the TLD system, preparation and reading of the TL-detectors, calculation of absorbed dose from the TL-readings and evaluation of deviations from stated dose. The MG communicates and discusses the deviations with the MPG.

The MPG is responsible for contacts with the participating radiotherapy centres (physicists and radiation oncologists), mailing the TLDs to the participants, analysis of the TLD results, including discussions with the MG, and follow-up actions in case of deviations outside the acceptance limits are detected.

Three major Algerian cancer centres (out of 5) have officially transmitted their approval for the set-up of the EAG and the TLD programme to be conducted.

The MG is in the process of implementation of the IAEA methodology with use of LiF powder. A set of TLD calibration data has been presented. The MG had no experience with the TLD powder before, therefore several problems demanded resolution. The main difficulty, which occurred, was related to the reproducibility in the powder readings. A powder dispensing system was designed and tested, and as a result, 1.5% standard deviation of the readings achieved, which needs to be improved.

M. Saravi, Argentina

The EAG has been set-up in Argentina to assume the responsibilities for carrying out the external dosimetric audits for radiotherapy centres. The EAG is composed of two closely collaborating groups, the MG and the MPG, which are supervised by a Responsible for Quality (RQ). The MG has been established within the SSDL at the National Atomic Energy Commission (CNEA) and is responsible both for ionising radiation metrology activities and TLD measurements. The MPG consists of medical physicist, technician and radiation oncologist from radiotherapy department of National Pediatric Hospital, which, together with a physicist and technician from CNEA, take up the responsibilities for contacts with Argentinean radiotherapy centres. The RQ performs periodic revision of the EAG procedures including EAG Quality Manual as well as audits of the EAG quality system.

A detailed structure and repartition of tasks was given for each of the EAG members (see attachment), with regard to the technical aspects of the TL-dosimetry, organisation of the TLD audits and follow-up actions. The maintenance and update of the database on national infrastructure in radiotherapy and training of the staff in clinical dosimetry were also included.

The EAG and its policy has been approved both by National Atomic Energy Commission and National Ministry of Health and Welfare, that have provided necessary resources for conducting the programmatic activities for radiotherapy centres in Argentina.

The TLD measuring systems and measuring procedures with regard to Co-60 beam calibration checks are well established in Argentina. Since 1978 the SSDL has been running national TLD audits for Co-60 units in radiotherapy centres. The methodology employed by the SSDL was similar to that used in the IAEA/WHO TLD service.

At present the EAG organises TLD audits for all high energy photon beams in clinical use in Argentina, in 4 TLD runs per year. During 1996, 72 beam checks were performed with 57 beam calibrations within acceptance limits of $\pm 5\%$.

During the discussion of the EAG procedures, a few recommendations have been given:

- a TLD methodology for high energy X-rays from linacs should be worked out
- follow up actions should be reinforced.

Li Kaibao, China

The Chinese EAG is composed of 3 interacting groups: SSDL group (2 physicists), TLD Measuring Group (a physicist and a technician from Laboratory of Industrial Hygiene) and Medical Physics Group (a medical physicist and a radiation oncologist from Beijing Cancer Hospital).

The SSDL group is responsible for calibration of ionisation chambers, irradiation of TLDs for calibration, training of the personnel involved in the QA programme and preparation of quality control programme. The MG takes care of the set-up and maintenance of the TLD system, preparation of the TL-detectors, mailings, TLD readings and evaluation of the results, and also communication both with the SSDL and MPG. The MPG organises TLD audits, contacts radiotherapy centres and is responsible for the follow-up actions.

The QA project in China is a subject to governmental regulations and the official seal of approval for conducting TLD audits by the EAG group was given by the Ministry of Health on 15.05.1995.

The TLD measuring system and procedures for Co-60 beam checks have been successfully developed and thoroughly tested. A study on repeatability of the TLD readings for mono- and multi-crystal LiF powder (made in China) was performed together with fading and dose response characteristics. Internal trial runs have been done including blind irradiation tests and 'on site' tests, in which the SSDL group acted as a hospital and the MG as a TLD service centre. Both tests proved the TLD system and procedures are adequate and ready to be implemented for routine TLD audits of Co-60 beams in radiotherapy centres in China. Due to large number of radiotherapy centres to be included, it was recommended to start the project with a limited number of hospitals, to provide proper follow-up, and as a next step, gradually transfer know-how to different provinces.

A. Kannan, India

The TLD postal dose audits of the clinical photon beams in Indian hospitals have been performed by the SSDL for many years. The SSDL is incorporated in the Radiation Standard Section of Bhaba Atomic Research Centre. The EAG in India is composed mainly of SSDL physicists with long experience in TL-dosimetry and radiation measurements standardisation. The EAG includes also a medical physicist from Radiotherapy Department at Tata Memorial Hospital.

The major work related to the TLD audits has been conducted by the SSDL, which is responsible for the technical and organisational aspects of the TLD audits and provides support to the hospitals by making recommendations on clinical dosimetry, on-site calibrations of the beams and training of hospital physicists in radiation dosimetry.

The TLD measuring systems and measuring procedures with regard to Co-60 beam calibration checks are well established in India. The methodology employed by the SSDL is similar to that used in the IAEA/WHO TLD service.

At present the EAG organises annual TLD audits for all Indian radiotherapy hospitals in 2 TLD runs per year.

The main problem, which has been discussed, pertains to long time delays between the TLD

irradiations and communication of the results to the participants.

Similar recommendations, as to the EAG, Argentina, have been given to the EAG India:

- a TLD methodology for high energy X-rays from linacs should be worked out
- follow up actions should be reinforced.

5. DEVELOPMENT OF A COMMON DRAFT

‘Guidelines to prepare a Quality Manual for External Audit Groups on Dosimetry in Radiotherapy’

The meeting continued with substantive discussions on the outline of the scope and structure of national EAG Quality Manuals. It has been decided that a common guidelines to prepare a EAG Quality Manual is drafted, and a quality manual itself should be developed at national levels according to the specific conditions of each country. To help achieve uniformity among different EAGs, facilitate exchange of experiences and follow ISO 9000 and ISO/IEC recommendations, a document developed during this meeting should be followed. A number of appendices to "Guidelines to prepare a Quality Manual for External Audit Groups on Dosimetry in Radiotherapy" will be attached, including questionnaire on radiotherapy infrastructure, TLD instruction and data sheets, detailed flow-charts on the TLD evaluation procedures, forms for reporting the TLD results to the participants, etc. A completed draft will be sent to the CRP participants for their review and comments.

6. FUTURE DEVELOPMENT AND IMPLEMENTATION STEPS

The working schedules for individual participants of the CRP were co-ordinated and goals to be achieved related to subsequent development and implementation steps of the CRP:

Step 1. Development of EAG measuring systems and procedures.

With regard to the EAG measuring systems - this step should include preparation of the methodology for audits of high energy X-ray beams.

With regard to the EAG procedures - the following tasks should be completed. First, data base on infrastructure in radiotherapy should be developed/updated by all "pilot countries" and the results reported to the Agency. Second, TLD evaluation procedures should be modified to speed up the reporting of the results to the participants. Third, detailed follow-up procedures should be developed and implemented.

Step 2. The EAG internal trial runs. This step should be completed by Algeria.

Step 3. Intercomparisons with the Agency’s TLD system for Co-60 beams.

All national EAGs should be audited by external bodies, first by the IAEA and in the future by another EAG from different country. The MGs are included in the IAEA/WHO TLD annual runs for the SSDLs. In addition, the Agency’s Dosimetry Laboratory will irradiate 4 sets of TLDs to be evaluated by each of the MGs.

Step 4. Completion of the "Guidelines to prepare a Quality Manual for External Audit Groups on Dosimetry in Radiotherapy".

Final version should be prepared for approval by the next meeting.

Step 5. Implementation of "Guidelines ..." on national level.

This step requires development and implementation of the national EAG Quality Manuals according to the common "Guidelines...".

Step 6. Development of the methodology for the dosimetry checks of high energy photon beams in non-reference conditions in radiotherapy hospitals. To be developed.

An RCM is planned at the IAEA Headquarters, Vienna, in October 1997. During the meeting the participants will be asked to present their status report on the implementation steps 1-3 and 5. In addition, reports on the status of the TLD routine service will be required. Special emphasis will be given to reinforcement of the follow-up for the hospitals, in which discrepancies in beam calibrations have been detected. All CRP participants are also encouraged to prepare their suggestions for the development step 6.

Three new participants from Czech Republic, Israel and Malaysia will be invited to join the next meeting upon successful accomplishment of the initial steps of the CRP and reaching adequate compatibility with the implementation level of other participants.

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