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CONTENTS

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EDITORIAL NOTE

The IAEA's Dosimetry Laboratory is the central laboratory of the IAEA/WHO Network of SSDLs. In addition to the calibration of secondary standards, intercomparisons and dose quality audit services are also provided to Member Sates. An overview of the services available is given in this issue of the Newsletter. For detailed information, interested readers are advised to consult our Internet web site (http://www.iaea.org/programmes/nahunet/e3/) or contact the Network secretariat.

The first article is a synopsis of the Ph.D. thesis submitted by Karen Rosser to the University of London in May 1996. If the reader would like the complete version of the thesis, he/she should contact the author at NPL. Readers are reminded that a second edition of the IAEA TRS-277 was published in 1997 and the related changes together with the scientific manuscripts were also published as IAEA TECDOC-897. The update concerns primarily the dosimetry of kilovoltage x-rays.

The second article presents the IAEA standards for radiation protection and diagnostic radiology. It is worthwhile mentioning that although about 80% of the SSDL members conduct both radiotherapy and radiation protection calibrations, only few protection level secondary standards are calibrated at the AIEA. During 1998, calibration of protection level secondary standards represented only a few percent of the therapy level calibrations. It is hoped that this article will give some insight into the radiation protection level dosimetry where proper traceability of measurements with a defined level of uncertainty is equally as important as in radiotherapy.

The last article is the report from a Consultants Meeting related to dosimetry in diagnostic radiology, held in May 1999. The consultants overview the scientific achievements in the filed and made recommendations to the Agency on the need for further developments.

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SERVICES PROVIDED BY THE IAEA IN DOSIMETRY AND MEDICAL RADIATION PHYSICS

The IAEA's Dosimetry and Medical Radiation Physics programme is focused on services provided to Member States through the IAEA/WHO SSDL Network and dose quality audits. The measurement standards of Member States are calibrated, free of charge, at the IAEA's Dosimetry Laboratory. The audits are performed through the IAEA/WHO TLD postal dose assurance service for SSDLs and radiotherapy centres, and the International Dose Assurance Service (IDAS) for SSDLs and radiation processing facilities, mainly for food-irradiation and sterilisation of medical products.

The wide range of services provided by the Dosimetry and Medical Radiation Physics are listed below:

Services	**Radiation quality**
1. Calibration of ionization chambers (radiotherapy, diagnostic radiology including mammography[1], and radiation protection, including environmental dose level).	Radiation quality: x-rays (10-300kV) and gamma rays from ^{137}Cs and ^{60}Co
2. Calibration of well-type ionization chambers for brachytherapy Low Dose Rate (LDR).	Radiation quality: gamma rays from ^{137}Cs
3. Intercomparison of therapy level ionization chamber calibration factors (for SSDLs)	Radiation quality: gamma rays from ^{60}Co
4. TLD dose quality audits for external radiotherapy beams for SSDLs and hospitals.	Radiation quality: gamma rays from ^{60}Co and high energy x-ray beams.
5. TLD dose quality audits for radiation protection for SSDLs.	Radiation quality: gamma rays from ^{137}Cs
6. ESR-alanine dose quality audits for radiation processing (for SSDLs and facilities), through International Dose Assurance Service (IDAS).	Radiation quality: gamma rays from ^{60}Co, Dose range: 0.1-100 kGy
7. Reference irradiations to dosimeters for radiation protection (for IAEA internal use).	Radiation quality: x-rays (40-300 kV) and gamma rays from ^{137}Cs s and ^{60}Co

Member States who are interested in these services should contact the IAEA/WHO Network secretariat for further details. Additional information is also available through Internet at the web site: http://www.iaea.org/programmes/nahunet/e3/

[1] Routine calibration services are expected to start in October 1999.

MEASUREMENT OF ABSORBED DOSE TO WATER FOR MEDIUM ENERGY X-RAYS

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Abstract

This paper evaluates the characteristics of ionization chambers for the measurement of absorbed dose to water for medium energy x-rays. The values of the chamber correction factor, k_{ch}, used in the IPEMB 1996 Code of Practice for the UK secondary standard (NE2561/NE2611) ionization chamber are derived.

The comparison of the chamber responses in-air revealed that of the chambers tested, only the NE2561, NE2571 and NE2505 exhibit a flat (within 5%) energy response in air. Under no circumstances should the NACP, Sanders electron chamber ([10,11]) or any chamber that has a wall made of high atomic number material be used for medium energy x-ray dosimetry.

The measurements in water reveal that a chamber that has a substantial housing such as the PTW Grenz chamber, should not be used to measure absorbed dose to water in this energy range.

The value of the perturbation correction, p_u for a NE2561 chamber was determined by measuring the absorbed dose to water and comparing it with that for a NE2571 chamber, for which p_u data has been published. The chamber correction factor varies from (1.023 ± 0.03) to (1.018 ± 0.001) for x-ray beams with HVL between 0.15 and 4 mm Cu. The values agree with that for a NE2571 chamber within the experimental uncertainty.

1. INTRODUCTION

Dosimetry for medium energy x-rays is based on using a suitable ionization chamber that has been calibrated in terms of air kerma [1,2,3]. The absorbed dose to water is then determined at the reference depth in water by applying appropriate correction factors (for example, see equation 1). For radiotherapy purposes it is essential that each stage of this process is precise so that the dose received by a patient is accurate to within 3% [4] to 5% [5].

In 1987, the IAEA revived the debate on the measurement of absorbed dose to water using medium energy x-rays by publishing a Code of Practice [2]. Before the publication of this code, dosimetry in this energy range had not been addressed since the publication of ICRU Report 23 in 1973 [1]. The IAEA code (IAEA TRS-277) contributed greatly to the understanding of medium energy dosimetry by separating the old F-factor into its constituent parts, namely the ratio of mass energy absorption coefficients of water to air $\left(\overline{m}_{en}/r\right)_{W,air}$ and the perturbation factor (p_u).

According to IAEA TRS-277 [2], the absorbed dose to water (D_W) is given by:

$$D_W = M_u . N_K . k_u \left[\left(\frac{\overline{m}_{en}}{r}\right)_{W,air}\right] p_u \qquad (1)$$

where:

M_u	is the instrument reading corrected to the same ambient conditions as the calibration factor,
N_K	is the air kerma calibration factor of the instrument for standard ambient conditions and for the radiation quality of the incident beam in air,
k_u	is a factor that accounts for variations in spectral distribution of x-rays used for the ionization chamber calibration free in air and that used by the user in water,
$\left(\overline{m}_{en}/r\right)_{W,air}$	is the ratio of the mass energy absorption coefficients of water to air averaged over the photon spectrum at 5 cm depth in water.
p_u	is the perturbation factor.

There is some discrepancy in the International Codes of Practice on the definition of medium energy x-rays; the IPEMB Code [3] defines it as 0.5 to 4 mm Cu HVL, whereas the IAEA Code [2] ranges from 100 to 280 kV (0.17 to 3.37 mm Cu HVL). The interesting dosimetry problems occur below 0.5 mm Cu HVL, therefore in this paper medium energy x-rays will be defined as beams with HVL ranging from 0.15 to 4 mm Cu.

The main problem associated with the use of the original edition of IAEA TRS-277 [2] is that the value of the absorbed dose to water so determined is greater than that obtained using other codes by as much as 12.5% at 0.15 mm Cu HVL (see Figure 1). This is due to the proposed values of $\left(\overline{m}_{en}/r\right)_{w,air}$ and the most controversial is the large value of the perturbation factor, quoted in IAEA TRS-277.

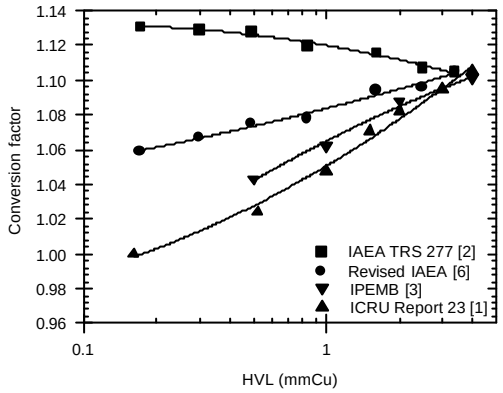

Figure 1 Comparison of the factors to convert the air kerma measured using an ionization chamber to absorbed dose to water at 5 cm depth in water.

Since the introduction of IAEA TRS-277, many groups have investigated these problems; in 1992 the IAEA [6] revised their values of the perturbation factor and re-issued IAEA TRS-277 in 1997. In the UK, the IPEMB [3] has published a new Code of Practice.

The aim of this work was to investigate ionization chambers for their suitability for use in medium energy x-ray dosimetry and to determine the perturbation factor for the UK secondary standard chamber (NE2561/NE2611).

2. IONIZATION CHAMBER SUITABLE FOR MEDIUM ENERGY X-RAY

2.1. REQUIREMENTS OF AN IONIZATION CHAMBER

According to ICRU Report 23, the desirable features of an ionization chamber for the measurement of absorbed dose to water are:

1. The variation in response of the chamber in-air should not exceed 5% over the medium energy x-ray range.
2. The internal diameter should be about 5 mm and length 15 mm, chambers with dimensions more then twice these values should not be used.
3. The stem of the chamber should not significantly affect the response of the chamber.
4. The wall thickness should be greater than the range of the secondary electrons to ensure that the electrons entering the cavity originate in the wall and not in the surrounding medium.
5. The polarizing potential should be high enough so that ion recombination is negligible in the chamber.

In addition, a chamber with good spatial resolution would be an advantage, in view of the rapidly changing shape of the depth dose curves over this range of x-ray beam qualities.

Generally, ICRU points 3, 4 and 5 are not normally a problem with modern ionization chambers. Initially, the energy response in air of a number of chambers (those that achieve points 2 to 5 of the above ICRU recommendations) were investigated.

2.2. MEASUREMENT OF IONIZATION CHAMBER RESPONSE IN-AIR

Three types of parallel-plate and four types of cylindrical ionization chamber were calibrated in-air over the medium energy x-ray qualities (see Table 2) by direct comparison with the primary standard free air chamber at the National Physical Laboratory (NPL). The measurements were made with the reference point of the chamber 75 cm from the source, with a beam diameter of 6 cm. The details of the ionization chambers are given in Table 1.

The thin window of the PTW Grenz chamber was not thick enough to stop the secondary electrons produced in the surrounding medium entering the chamber cavity. It was therefore calibrated with a 1 mm thick Perspex (PMMA) plate over its window.

TABLE 1. Ionization chambers calibrated in-air

Type	Manufacturer	Sensitive volume(cm3)	Chamber wall	Polarizing potential (V)
Parallel plate chambers				
Grenz Type M23344	PTW	0.2	0.03 mm CH3	-200
Sanders electron chamber (E5)([11],[12])	NPL	0.3	35 ìm Cu on 1 mm Perspex	-200
NACP electron chamber	Scanditronix	0.16	0.5 mm graphite + 0.1 mm Melinex	-200
Cylindrical chambers				
Farmer type 2505/3	N E Technology	0.6	approx 0.5 mm graphite	-200
Farmer type 2515/1	N E Technology	0.22	0.3 mm graphite	-200
NE2561 (NPL secondary standard)	N E Technology	0.3	0.5 mm graphite	-200
Experimental*	NPL	0.3	approx. 0.5 mm Al	-200

*Design based on a NE2561 chamber but with the graphite wall replaced by one made of aluminium.

TABLE 2. Primary in-air x-ray qualities.

Generating Potential (kV)	Half Value Layer		Added filters (mm)
	mm Al	mm Cu	
(a) Inherent filtration 2.5 mm Be + 4.8 mm Perspex			
100	4.0	0.15	4.4 Al
105	5.0	0.20	0.10 Cu + 1.0 Al
135	8.8	0.50	0.27 Cu + 1.0 Al
(b) Inherent filtration 4 mm A1 equivalent + 4.8 mm Perspex			
180	12.3	1.0	0.42 Cu + 1.0 Al
220	16.1	2.0	1.20 Cu + 1.0 Al
280	20.0	4.0	1.4 Sn + 0.25 Cu

2.3. RESULTS AND DISCUSSION

Some of the chambers investigated in this paper were not designed for use in medium energy x-ray beams. However, all of the chambers have their own unique characteristics that were interesting to investigate over the medium energy x-ray range.

Figure 2b shows that for the cylindrical graphite walled chambers investigated in this work, the NE2561 and the two Farmer type chambers, have a response in-air that does not vary by more than 5% over the medium energy x-ray range.

However, it can be seen from Figures 2a and 2b, that the PTW Grenz chamber, NACP electron chamber, the Sanders electron chamber and the NE2561 chamber with an aluminium wall are unacceptable for accurate medium energy x-ray dosimetry, as their air kerma energy responses vary by more than 5% over the medium energy range of x-ray beam qualities. The large variation in response of the Sanders electron chamber and modified NE2561 chamber is due to the wall of the chambers being made of high atomic number material. The PTW Grenz chamber is almost within the limit; in this case the additional 1 mm perspex window will attenuate the beam and some compensation is provided by backscatter from the perspex housing. The NACP chamber does not contain any high atomic number materials and therefore its response falls at low energies due to attenuation of the primary beam.

There are components of an ionization chamber that can be altered to achieve a response that is independent of energy; the chamber wall and the central electrode. The material of the wall should be air equivalent and its thickness must be greater than the maximum electron path to achieve charged particle equilibrium (transitory). This creates problems at the lower photon energies since the incident photons will be attenuated by the wall. To compensate for this attenuation, the central electrode can be made of a higher-atomic number material, such as aluminium, that emits photo-electrons at low energies. Chambers such as the NE2561, NE2571 and NE2505 use this method to achieved the desired beam quality response.

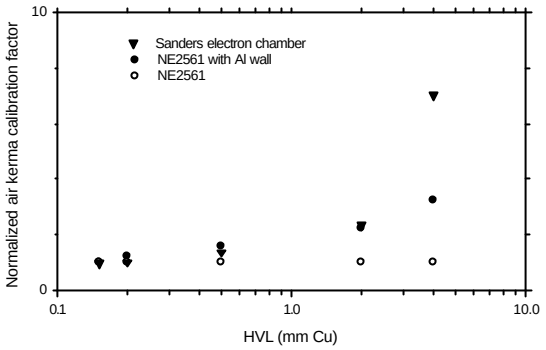

Figure 2a Comparison of the response of the Sanders chamber, a NE2561 with an Aluminum wall and a NE2561 chamber.

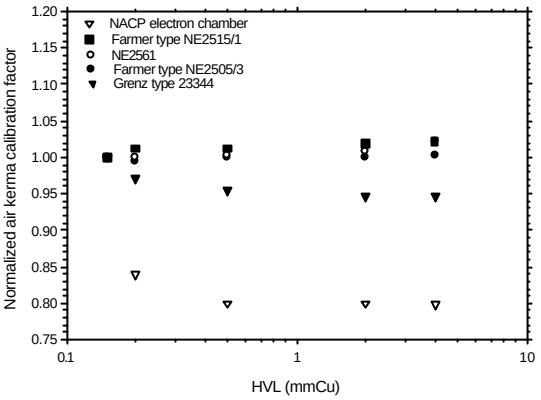

Figure 2b Comparison of the response of ionisation chambers in air

3. THE PERTURBATION FACTOR

There has been considerable debate about the definition of the perturbation factor (p_u). IAEA TRS-277 states that the values quoted for the perturbation correction are due to the replacement of the phantom material by the air cavity of the ionization chamber solely. Whereas, the review of the data [6] by the IAEA states that the perturbation factor accounts for any differences in the response of the chamber when calibrated in air and used in a water phantom.

It is clear from this definition that the perturbation factor will depend on the type of ionization chamber, the field size, depth in water and the waterproof sleeve.

There are two controversial aspects of the perturbation correction given in IAEA TRS-277, namely, it has a value greater than unity and has a value as large as 10% at 0.15 mm Cu HVL.

The physical reasons for the perturbation correction being greater or less than unity are as

follows. Liden [7] considered that the replacement effect (known as the perturbation factor in IAEA TRS-277) would be due to the combination of three effects namely:

a) the decreased attenuation of the primary beam,

b) the decreased attenuation of the scattered radiation,

c) the reduced scattering from the displaced volume.

The first two effects are important at very low energies (less than 30 keV), whilst the third effect plays an increasing role at higher energies. Over the medium energy x-ray range one would expect the first two factors to increase the photon fluence in the cavity and the third to decrease it. These effects partly cancel but will probably result in the photon fluence at the centre of the chamber being too high and so the replacement correction is expected to be less than unity. Harrison [8] confirmed this by sandwiching a sheet of water equivalent Gafchromic radiation sensitive film between two blocks of solid water equivalent material. Each block contained half a cavity corresponding to the outer dimensions of a NE2571 chamber. The phantom was then irradiated with a 10 x 10 cm^2 field at SSD 100 cm at beam qualities of 60, 90, 140 kVp (2.2, 3.3 and 5.2 mm Al HVL respectively). Harrison found that the cavity showed a higher optical density than its surroundings, showing a replacement correction less than unity.

To avoid confusion, in this article the definition of the perturbation factor is given by:

$$p_u = k_a . k_{st} . p_{rep} . k_{sleeve} \qquad (2)$$

where

k_a corrects for the energy and angular dependence of the response of the ionization chamber in the water phantom compared to its calibration in air,

k_{st} accounts for the influence of the stem on the response of the ionization chamber free in air and in water,

p_{rep} accounts for the replacement of the phantom material by the active volume of the ionization chamber, (this corresponds to the perturbation correction in IAEA TRS-277),

k_{sleeve} accounts for the effect of the waterproof sleeve on the response of the ionization chamber.

4. DETERMINATION OF THE PERTURBATION FACTOR

4.1. PRINCIPLE

The perturbation factor for an ionization chamber can be found by comparing the absorbed dose to water with that measured using a chamber with a known perturbation factor. From equation (1), for two different chambers.

$$\frac{(D_W)_1}{(D_W)_2} = \frac{\left(M . N_K . \left(\frac{\bar{m}_{en}}{r} \right)_{W,air} . P_u \right)_1}{\left(M . N_K \left(\frac{\bar{m}_{en}}{r} \right)_{W,.air} . P_u \right)_2} \qquad (3)$$

Hence:

$$\frac{(p_u)_1}{(p_u)_2} = \frac{(M . N_K)_2}{(M . N_K)_1} \qquad (4)$$

The subscripts 1 and 2 refer to the different types of ionization chambers. The most recent data published for the perturbation factor is that for a Farmer type NE2571 ionization chamber (Seuntjens [12], Seuntjens [13], Ma [11]); therefore, this will be taken as chamber 2. The construction of a Farmer type NE2571 chamber and type NE2505/3 are identical.

4.2. METHOD

The responses of the Farmer type 2515/1, the PTW Grenz, the aluminium walled NE2561 and the NE2561 chambers were compared with the response of the Farmer type NE2505/3, 3A (graphite wall) chamber, both in-air and at 2 cm depth in water. The measurements in water were carried out using the same primary beam qualities (see Table 2) and geometry as used for the calibrations in-air. The water phantom had a cross-sectional area of 31 x 41 cm and was 31 cm deep. This phantom contained a thin entrance window 2 mm thick.

4.3. RESULTS

Figure 3 shows that the values for the perturbation factor, p_u, for the graphite walled chambers are very similar. The aluminium walled NE2561 chamber shows a maximum deviation of 12% from unity at 2mm Cu HVL. This is due to its large energy dependence (see Figure 2) and the change in the photon spectrum in the phantom.

Figure 3 also shows that the variation of the perturbation factor for the PTW Grenz chamber compared with the perturbation factor for the Farmer chamber varies by 8% between 0.15 and 4 mm Cu HVL.

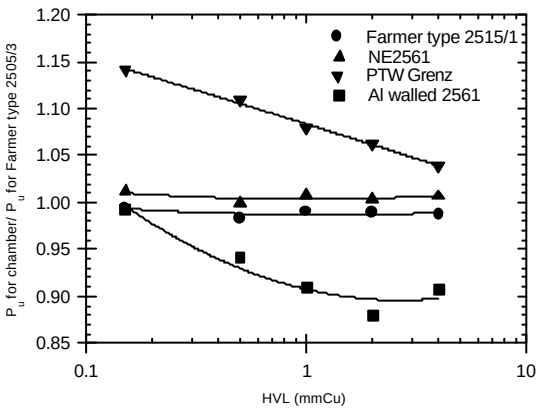

Figure 3 Comparsion of perturbation factors.

5. THE PERTURBATION CORRECTION FOR A NE2561 CHAMBER

The perturbation factor for a NE2561 ionization chamber was determined using the method described in Section 4. Values of p_u for a NE2571 ionization chamber have been recently published (Seuntjens [12], Seuntjens [13], Ma [11]). Unfortunately, the data differ by up to a maximum of 3.9% at 0.5 mm Cu HVL. In this paper, the perturbation factor for a NE2571 has been taken as the arithmetic mean of these factors and the uncertainties increased accordingly.

The values of p_u, for the NE2561 chamber given in Table 3, were derived from equation (4) and have been adopted in the new IPEMB 1996 Code of Practice [3].

TABLE 3. MEASURED P_U FACTORS FOR A NE2561 CHAMBER.

HVL		p_u,2561	Uncertainty (1ó) (%)
mm Al	mm Cu		
4.0	0.15	1.023	3
5.0	0.20	1.023	2
8.3	0.5	1.023	1.7
11.9	1.0	1.022	1.5
15.2	2.0	1.020	1.5
19.3	4.0	1.018	0.1

6. THE RATIO OF MASS ENERGY ABSORPTION COEFFICIENTS OF WATER TO AIR

The differences between the values of the ratio of mass energy absorption coefficients of water to air $\left(\overline{m}_{en}/r\right)_{W,air}$ given in IAEA TRS-277, ICRU Report 23 and IPEMB [3] are mainly due to the method of averaging the monoenergetic values of the mass energy absorption coefficient over the spectrum at the point of measurement in water. ICRU Report 23 obtained values of $\left(\overline{m}_{en}/r\right)_{W,air}$ by using an equivalent photon energy. This was defined as the energy of a monoenergetic beam that had the same half value layer (HVL) as the radiation being considered. The effect on the equivalent photon energy due to scattering and filtration at a depth in the water phantom was allowed for by using factors given in ICRU Report 10b [14]. The values of $\left(\overline{m}_{en}/r\right)_{W,air}$ given in IAEA TRS-277 and the IPEMB Code of Practice were calculated using a two-step process. Firstly, the photon fluence spectrum at the reference depth in the phantom was calculated using Monte Carlo techniques based on a typical clinical 'in air' spectrum. Then the monoenergetic values of the mass energy absorption coefficients were averaged over the

photon fluence spectrum at the reference depth in water.

Another minor difference between the codes is the value adopted for the monoenergetic mass energy absorption coefficient. IAEA TRS-277 [2] and the IPEMB Code of Practice used values given by Hubbell [15] whereas ICRU Report 23 used values given by Berger [16]. The maximum difference between the two sets of monoenergetic values is 1% for energies between 10 keV and 300 keV.

Figure 4 shows that recent values of $\left(\overline{m}_{en}/r\right)_{W,air}$ published in the literature support the values given in IAEA TRS-277, except for those published by Ma [11] whose values at the lowest energy are closer to those given in ICRU Report 23 [1].

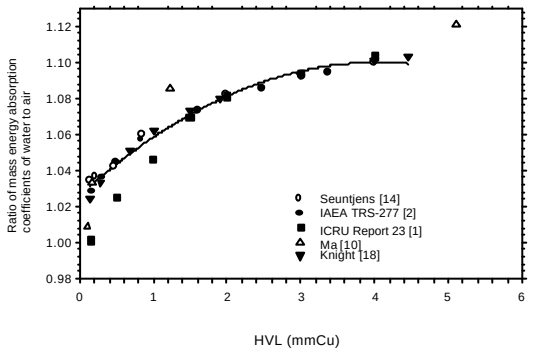

Figure 4: Comparison of the ratio of mass energy absorption coefficients of water to air.

7. CONCLUSION

In this paper the comparison of the chambers response in-air revealed that of the chambers tested only the NE2561, NE2571 and NE2505 exhibit a flat (within 5%) energy response in-air. Under no circumstances should the NACP, Sanders electron chamber or any chamber that has a wall made of high Z-material be used for medium energy dosimetry with an air kerma based Code of Practice.

The measurements in water reveal that those chambers with a substantial housing, such as the PTW Grenz chamber, should not be used to measure absorbed dose to water. In air, the chamber is measuring a large contribution due to backscatter as the housing is acting as a small phantom. In the water phantom, the chamber is measuring a similar backscatter contribution as in air. Therefore, p_u should have a value close to that of the backscatter factor.

A useful method of determining an unknown perturbation factor is by comparison with a chamber with a known perturbation factor. The measurements reported here indicate that the values of p_u for a NE2561 agree with those known for a NE2571 within the large experimental uncertainty. These values of the perturbation factor for the NE2561 and NE2571 have been adopted in the IPEMB 1996 Code of Practice. The large uncertainty (±3%) attached to the value of the perturbation factor for the NE2571 chamber limits the precision with which the perturbation factor for the NE2561 can be determined. This result should not be used to imply that all chambers used for therapy level x-ray dosimetry have the same value of perturbation factors.

7.1. DESIRABLE FEATURES OF AN IONIZATION CHAMBER USED TO MEASURE ABSORBED DOSE TO WATER

For an air equivalent ionization chamber the desirable features are given in ICRU Report 23. Additional characteristics have become apparent whilst performing this work and are listed below.

1. The chamber should be watertight to eliminate the need for a waterproof sleeve.
2. To reduce the stem correction factor k_{st}, the diameter of the chamber stem should be as small as possible and the material used to manufacture the stem should have a low atomic number.
3. The components used to construct the ionization chamber should have as low an atomic number as possible.
4. The size of the chamber should be as small as possible, provided the ionization current can be measured with the required uncertainty.
5. The wall of the chamber should be just thick enough to ensure all electrons entering the cavity originate in the wall of the cavity and not in the surrounding medium; wall thicknesses greater than this should never be used.
6. The amount of material in the vicinity of the sensitive volume of the chamber should be minimized to reduce backscatter into the cavity.

7. For chambers to exhibit a flat (within 5%) energy response in-air some method of compensation is required. Chambers without any compensation, such as those used for electron dosimetry, should not be used for medium energy x-ray dosimetry.

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STANDARDS FOR RADIATION PROTECTION AND DIAGNOSTIC RADIOLOGY AT THE IAEA DOSIMETRY LABORATORY

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1. INTRODUCTION

International standardization in dosimetry is essential for the successful exploitation of radiation technology. The IAEA dosimetry programme is focused into services provided to Member States through the IAEA/WHO Network of Secondary Standard Dosimetry Laboratories (SSDLs), to radiotherapy centres and radiation processing facilities [1].

Radiation protection quantities defined by ICRU [2, 3] and ICRP [4] are used to relate the risk due to exposure to ionizing radiation to a single quantity, irrespective of the type of radiation, which takes into account the human body as a receptor. Two types of quantities, limiting and operational, can be related to basic physical quantities which are defined without need for considering specific aspects of radiation protection, e.g. air kerma for photons and fluence for neutrons.

The use of a dosimeter for measurements in radiation protection (including diagnostic radiology) requires a calibration in terms of a physical quantity together with a conversion from physical into protection quantities by means of a factor or a coefficient.

Diagnostic radiology has become the largest contributor to the exposure of the public from man-made ionizing radiation. This is partly due to an enormous development in imaging technologies over past decades that allows to detect many diseases in their early stages thus increasing the probability of a successful treatment. Such systems require comprehensive quality assurance programmes. The physical aspects of any quality assurance programme in diagnostic radiology can be divided into two basic groups: (i) image quality assurance and (ii) radiation protection of patients and staff. Both activities within groups have to be balanced so that the optimal situation is achieved when the probability of obtaining correct diagnosis is maximized while the patient exposure is minimized. In practice, this requires the measurement of a number of technical and physical parameters of the system and/or procedure that can influence the resulting image and dose. Due to the variety of imaging techniques, the dose descriptors may also vary from one technique to another. In one case it is an air kerma-area product (KAP) that is used to describe the patient exposure, in another case it is the entrance surface dose, etc; as in the case of radiation protection quantities; these dose descriptors require a calibration of the instrument in terms of basic physical quantities. It is one of the main tasks of the SSDLs to disseminate units of the basic physical quantities through appropriate instrument calibration.

2. THE IAEA/WHO NETWORK OF SSDLs

The IAEA Dosimetry Laboratory is the central laboratory of the SSDL Network, establishing the link between the users and the International Measurement System. The SSDL Network presently includes 69 laboratories and 6 SSDL national organizations in 58 Member States; the Network also includes 20 affiliated members, mainly PSDLs, ICRU, BIPM, and other international organizations.

The SSDL Network has the responsibility to assure that the services provided by the laboratory members follow internationally accepted metrological standards. At present, this is achieved by providing traceable calibrations for therapy, radiation protection and diagnostic radiology instruments by the IAEA. The traceability is accomplished first with the dissemination of calibration factors for ionization chambers from the BIPM or PSDLs through the IAEA. As a second step, follow-up programmes and dose quality audits (intercomparisons using ionization chambers and TLDs) are implemented for the SSDLs to assure that the standards transmitted to

users in Member States are kept within the levels required by the International Measurement System. Data collected between 1985-1998 show on the average that approximately 8% of the laboratories conduct radiotherapy calibrations only, 12% conduct radiation protection calibrations only, and nearly 80% of the laboratories do both type of calibrations. Introduction of quality assurance programmes for diagnostic radiology in many countries requires the calibration of a large amount of measuring equipment; some SSDLs have already started such calibrations while others are considering to start this activity soon.

3. IAEA STANDARDS FOR RADIATION PROTECTION AND DIAGNOSTIC RADIOLOGY

The Dosimetry and Medical Radiation Physics Section provides the programmatic responsibility, supervision and manpower required for the measurements at the IAEA Dosimetry Laboratory, where all the equipment is located. This consists of a set of reference radiation beams and instruments for the calibration of ionization chambers and radiation detectors for radiotherapy, radiation protection and diagnostic radiology, thermoluminescence dosimetry (TLD) systems, electron spin resonance (ESR) equipment, and ancillary equipment. Besides, the laboratory has access to two ^{60}Co gammacells for calibration of dosimeters used for radiation processing. The layout of the calibration rooms is shown in Figure 1.

The two irradiation rooms are equipped with the radionuclide and x-ray sources that are operated remotely through their respective control panels located in the control room. This room also contains monitors coupled to video cameras in the irradiation rooms. The ionization chambers or other radiation protection instruments are positioned on the calibration benches where they can be moved into a required distance from the source. Their position is fixed at the calibration distance using a telescope. All high voltage (HV) generators are situated in one room and they are interconnected with the respective x-ray tubes by HV cables. The control room also accommodates a system for measuring the ionization current and/or charge, that consists of electrometers, digital voltmeters, capacitors, bias supplies, barometer and thermometers.

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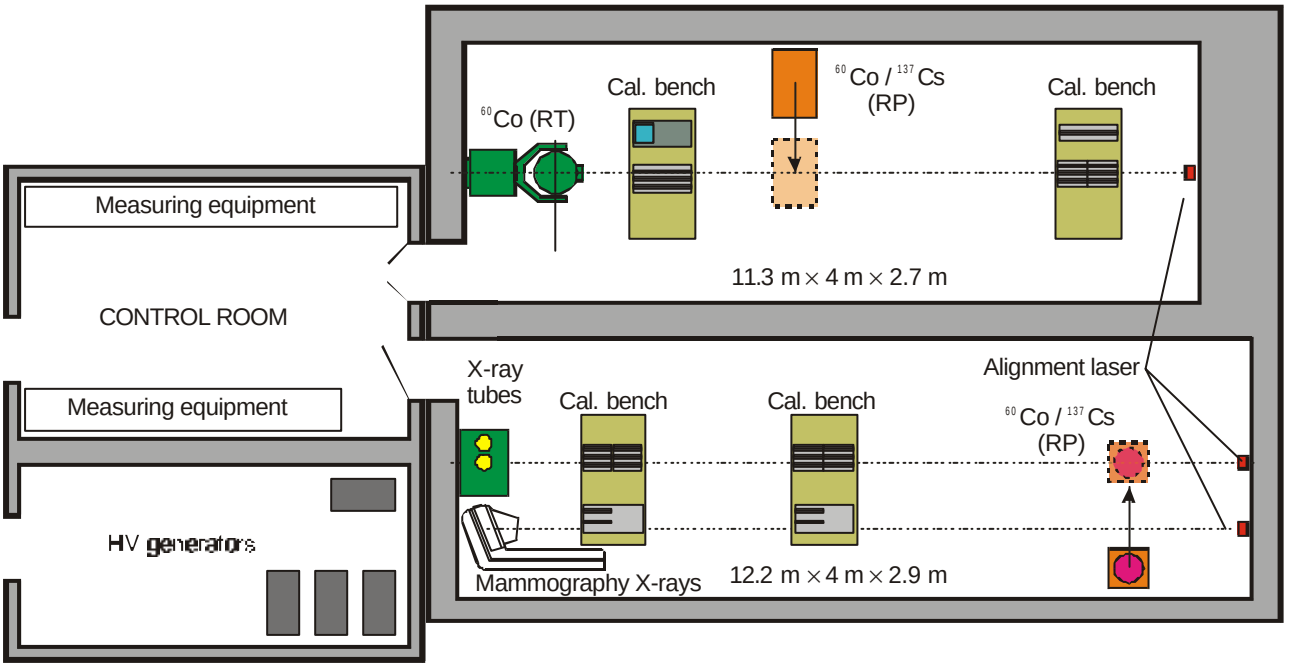

Figure 1. Layout of the IAEA Dosimetry Laboratory calibration rooms

Measurements are computer controlled via an IEEE-488 interface using a LabView application to collect data from ionization chambers and monitors; the computer is also used for a basic evaluation of the measurement. The data are shared with other computers through a local Network.

3.1. REFERENCE RADIATION

Secondary standards of basic physical quantities for radiation protection and diagnostic radiology are realized at the laboratory through appropriate reference radiation beams and instruments.

The laboratory system of reference radiations include collimated ^{137}Cs and ^{60}Co photon beams produced by a mobile irradiator Buchler OB 85, x-ray beams produced by a Philips MG 164/324 x-ray unit and mammography x-ray beams produced by a Senographe DMR unit. A detailed description of the various sources of reference radiation used at the IAEA for calibrations of radiation protection instruments is given in Appendix I.

In addition to these reference collimated beams, the laboratory also has a panoramic Buchler OB 34 irradiator. It contains a total of seven ^{137}Cs and ^{60}Co γ-sources with activities ranging from 3.7 MBq to 7.4 GBq that produce uncollimated radiation fields. This unit is mainly used for routine checks of radiation protection and environmental monitors.

3.1.1. ^{137}Cs and ^{60}Co gamma ray beams

The photon beams from the ^{137}Cs and ^{60}Co sources in the Buchler OB 85 irradiator are collimated with a circular collimator; the resulting diameter of the beams is 750 mm at a distance of 3 m from the source.

The instrument to be calibrated is positioned with its reference point on the beam axis and its response compared with that of the reference ionization chamber using the substitution method. Both instruments are positioned in the beam using an alignment system consisting of a calibration bench, a laser beam and a telescope. The calibration set-up for the Buchler OB 85 irradiator is schematically shown in Figure 2.

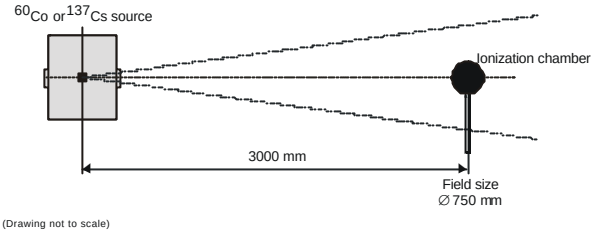

Figure 2. Calibration set-up used at the IAEA Dosimetry Laboratory for the calibration of radiation protection secondary standards in ^{137}Cs and ^{60}Co reference gamma ray beams.

3.1.2. ISO narrow spectrum series x-ray beams

The two x-ray tubes of the Philips MG 164/324 x-ray unit are used to generate ISO narrow spectrum series x-ray reference radiation [5]. Their beam characteristics are shown in Table I, where the values of the mean energies have been adopted from the ISO document (they have not been established from spectrometry measurements). The laboratory has recently acquired a new high purity germanium (HPGe) spectrometry system that will be used for spectral evaluation of all x-ray reference beams at the laboratory.

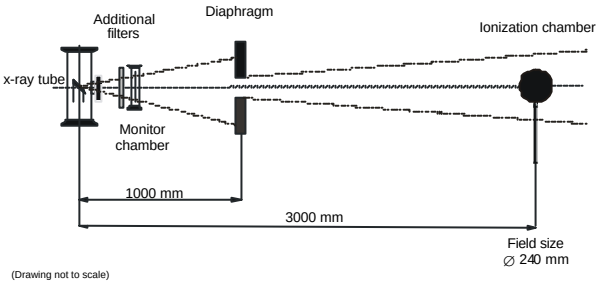

Figure 3. Calibration se-up for ISO x-ray beam qualities at the IAEA Dosimetry Laboratory.

The x-ray beams are collimated with a set of circular diaphragms, the resulting diameter of the beams is 240 mm at a distance of 3 m from the focus. The calibration set-up for the x-ray beams is shown in Figure 3. As for the Buchler OB 85 irradiator, the substitution method is used for the calibration of instruments. The output of the x-ray machine is monitored using a transmission ionization chamber PTW 786-073 and the measurements are corrected for fluctuations.

TABLE I. ISO NARROW SPECTRUM SERIES X-RAY BEAMS AT THE IAEA DOSIMETRY LABORATORY

Radiation quality	Mean energy	Tube potential	Added filtration				1st HVL	
	[keV]	[kV]	[mm Al]	[mm Cu]	[mm Sn]	[mm Pb]	[mm Al]	[mm Cu]
N-40	33	40	1.00	0.22	-	-	2.70	
N-60	48	60	1.00	0.59	-	-		0.24
N-80	65	80	1.00	1.85	-	-		0.59
N-100	83	100	1.00	5.30	-	-		1.15
N-120	100	120	1.00	5.00	1.00	-		1.74
N-150	118	150	1.00	-	2.50	-		2.40
N-200	164	200	1.00	2.00	3.00	1.00		4.06
N-250	208	250	1.00	-	2.50	2.50		5.21
N-300	250	300	1.00	-	3.00	5.00		6.19

3.1.3. Mammography x-ray beams

During its meeting in 1996, the SSDL Scientific Committee had recommended extending the experience of the IAEA in the field of standardization at radiotherapy and radiation protection level for the SSDL Network, to the field of diagnostic radiology x-rays.

As a first step, a mammography x-ray unit was acquired because of the importance of mammography examinations world-wide. The mammography reference x-ray qualities at the laboratory are generated by a GE Senographe DMR unit. A high frequency HV generator is used to power the x-ray tube with a useful range of 22-49 kV.

The Senographe DMR is a clinical unit equipped with a Statorix x-ray tube, model M52.2/GS412-49, having a dual track rotating anode. One track is of molybdenum and the other of rhodium. Electrons emitted from the cathode can be focused into a small and/or large focus, but only the large focus (0.3 x 0.3 mm) is used for calibration purposes. The inherent filtration of the tube is 0.8 mm of beryllium. The unit is equipped with a filter wheel that has three interchangeable filters made of aluminium (1 mm), molybdenum (0.03 mm) and rhodium (0.025 mm). The unit arm with the tube has been fixed in a horizontal position and adapted to the existing calibration set-up of the x-ray calibration room. This arrangement allows positioning the measuring equipment on the existing calibration bench and also makes use of the available alignment system. The calibration set-up is shown in Figure 4.

Seventeen beam qualities have been established for tube voltages between 23 kV and 40 kV that are equivalent to the NIST mammography calibration beams [6]. The beam parameters are given in Table II.

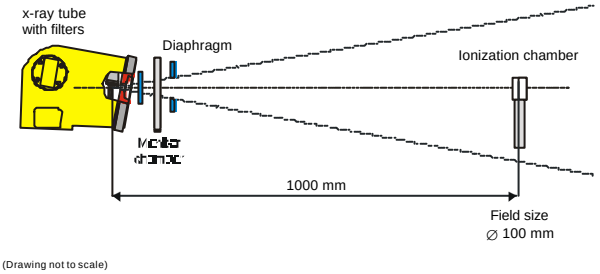

Figure 4. Calibration set-up used at the IAEA Dosimetry Laboratory for the calibration of mammography secondary standards.

3.2. REFERENCE INSTRUMENTS

Ionization chambers and other equipment are calibrated at the IAEA Dosimetry Laboratory mainly in terms of air kerma free in air. Reference conditions are T=20.0 ^{0}C, P=101.325 kPa and R.H.=50%. Calibrations are either made for a system composed of a detector (ionization chamber)

plus a readout instrument (electrometer) or for a detector only. All calibrations are performed by the substitution method, comparing the response of the detector to be calibrated with that of a reference instrument.

3.2.1. Ionization chambers and electrometers

The secondary standards for radiation protection are based on two 1000 cm^3 spherical ionization chambers, LS-01 and HS-01 designed and manufactured at the Austrian Research Center at Seibersdorf (ÖFZS). The energy response of the LS-01 chamber is optimized for measurements of air kerma, K_{air}, while that of the HS-01 is optimized for the measurement of ambient dose equivalent, H^*. The chambers are calibrated in terms of K_{air} or H^* at ^{137}Cs, ^{60}Co and a number of x-ray beam qualities at PTB and BIPM every two years. The energy dependence of the air kerma calibration factor, N_K, for the LS-01 chamber (# 114) based on the PTB calibration is shown in Figure 5. Reference ionization chambers used for calibrations of radiation protection instruments are listed in Appendix II.

The ionization current from the ionization chambers is measured with a Keithley 6517 or Keithley 617 (for x-rays) electrometer. The leakage current for the system ionization chamber plus electrometer is considered negligible (typically 20-25 fA). The measured current is corrected for temperature and pressure dependence. No corrections for saturation and humidity are applied in the case of radiation protection calibrations, as they are insignificant.

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TABLE II. MAMMOGRAPHY REFERENCE BEAMS AT THE IAEA DOSIMETRY LABORATORY

Radiation quality*	Tube potential [kV]	Added filtration [mm]	1st HVL [mm Al]	Homogeneity coefficient** [Al]
Mo anode				
Mo/Mo23	23	0.03 Mo	0.272	0.78
Mo/Mo25	25	0.03 Mo	0.297	0.77
Mo/Mo28	28	0.03 Mo	0.328	0.78
Mo/Mo30	30	0.03 Mo	0.348	0.79
Mo/Mo35	35	0.03 Mo	0.382	0.80
Mo/Rh28	28	0.025 Rh	0.394	0.82
Mo/Rh32	32	0.025 Rh	0.423	0.83
Mo/Mo25x	25	0.03 Mo + 2 Al	0.582	0.98
Mo/Mo28x	28	0.03 Mo + 2 Al	0.611	0.94
Mo/Mo30x	30	0.03 Mo + 2 Al	0.663	0.96
Mo/Mo35x	35	0.03 Mo + 2 Al	0.699	0.84
Rh anode				
Rh/Rh25	25	0.025 Rh	0.336	0.77
Rh/Rh30	30	0.025 Rh	0.414	0.76
Rh/Rh35	35	0.025 Rh	0.469	0.75
Rh/Rh40	40	0.025 Rh	0.514	0.76
Rh/Rh30x	30	0.025 Rh + 2 Al	0.797	0.92
Rh/Rh35x	35	0.025 Rh + 2 Al	0.854	0.88

** The beam codes are those used by NIST. They are a combination of the chemical symbol followed by the potential of the tube in kilovolts and a letter "x" for beams attenuated by 2 mm of aluminium.*

*** The homogeneity coefficient is defined as the ratio of the 1st HVL to the 2nd HVL.*

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The stability of the chamber plus electrometer system is checked at regular intervals using a ^{90}Sr check source. The ionization current of the LS-01 chamber, measured during the period 1995-1999, has varied by ± 0.3 % around the mean value. During each calibration provided by the IAEA, the air kerma at the reference point is measured with the secondary standard; this value is systematically compared with previous measurements as an additional check of the stability of the system. Results of the measured air kerma rates at the reference point during the period 1997-1999, corrected for the decay of the source are shown in Figure 6. All values measured are within ± 0.11 % for the ^{137}Cs source and ± 0.25 % for the ^{60}Co source. The acceptance limit for these measurements is set at $\pm$ 2 standard deviations of all measurements; if a measurement falls outside this limit, the reasons are investigated and the measurement repeated.

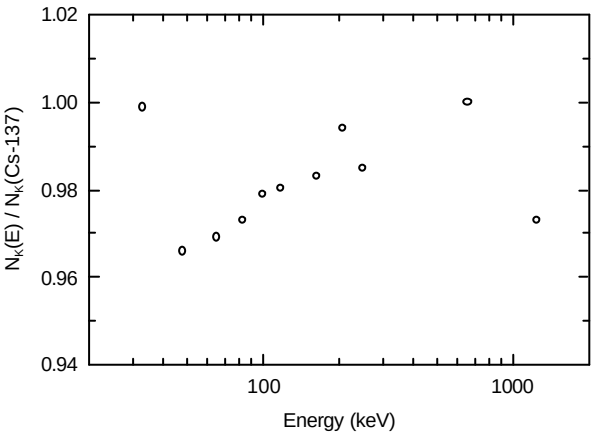

Figure 5. Energy dependence of the air kerma calibration factor, $N_{K,}$ for the LS-01 reference ionization chamber.

A 6 cm^3 ionization chamber Radcal 10X5-6M, has been selected as reference for the calibration of mammography equipment. The charge generated in the chamber during the duration of a pulse is collected by a capacitor and measured with a Keithley 617 electrometer. The relatively large volume of this chamber allows its use for both *entrance* and *exit* beam measurements. The traceability of the beams is to be achieved through its calibration at a PSDL.

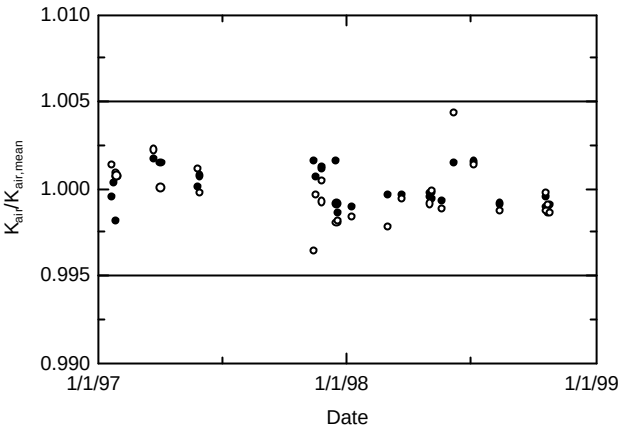

Figure 6. Measured values of the air kerma at the reference point corrected for source decay for the ^{137}Cs (•) and ^{60}Co (○) beams of the Buchler OB 85 irradiator.

3.2.2. Ancillary equipment

In addition to the reference radiation beams, ionization chambers and electrometers, the calibration of radiation protection and diagnostic radiology instruments includes diverse instruments such as thermometers, barometers, phantoms, additional ionization chambers and electrometers, etc. These are generally used for routine measurements and various research and development activities in the laboratory. This equipment is listed in Appendix II together with a brief description of its use.

3.3. UNCERTAINTIES OF MEASUREMENTS

General guidance on the basic requirements for the calibration and use of radiation protection instruments, e.g. the quantities to be measured, their overall accuracy, etc. has been given by international bodies like ICRU [3, 7], ICRP [4, 8], and IAEA [9]. The overall accuracy of any dosimetry system is determined from the combined effects of a number of uncertainties.

The uncertainty of measurements pertaining to the calibration of dosimeters carried out at the IAEA Dosimetry Laboratory has been estimated following the ISO recommendation [10]. Determination of uncertainties is not made for

each instrument calibrated at the laboratory. Typical values of the type A and type B uncertainties for various components contributing to the overall uncertainty of radiation protection calibrations have been derived, based on measurements of many types of instruments calibrated at the laboratory. They are given in Appendix III together with the combined standard uncertainty (k=1) for ^{137}Cs / ^{60}Co beams and for the narrow spectrum x-ray beams. A similar evaluation of uncertainties for diagnostic radiology level calibration is in preparation.

3.4. QUALITY CONTROL

The general need for traceability of radiation measurements is now well established worldwide. This basic principle has become the foundation for all standards. In addition, the quality of sources of traceability has to be controlled and assured by using an appropriate quality assurance programmes. The purpose of such a programme is to ensure quality of measurements through documented policies and procedures.

The IAEA Dosimetry Laboratory is operated under an established quality assurance programme [11]. The technical requirements of the programme are based on the guidelines described in the ISO 9000 series documents, specifically Guide 25 [12]. The QA programme includes a quality assurance manual that describes the reference standards available at the laboratory and procedures for their maintenance, the equipment and procedures used for the calibration services and key elements of the quality control programme. The quality control programme defines the stability checks applied to the IAEA secondary standard system, the checks and tests to be performed before the calibration of instruments and the verification of the results of the calibration. It also includes quality audits that are held at regular intervals and record keeping procedures.

4. TLD DOSIMETRY AUDITS AT RADIATION PROTECTION LEVEL

A TLD system has been developed within the IAEA Dosimetry programme to verify calibrations provided by SSDLs at the quality of ^{137}Cs γ-rays. A series of experiments was conducted to optimize different components of the system and involved a total of five different types of TL materials.

A blind test of the system was carried out at the end of 1997. It was followed by two pilot runs in March and June 1998. Twenty five SSDLs were randomly selected to participate in this experiment, the strategy being to cover all continents in each run. During each of the two runs, selected PSDLs were also supplied with sets of dosimeters and asked to irradiate them at 1,5 and 10 mGy air kerma. These dosimeters were used as an independent check of the system.

The results of these two runs are shown in Figure 7, where ratios between the air kerma stated by the SSDLs and that measured at the IAEA Dosimetry Laboratory are given. Most of the results are within ±3.5% limits. This limit has been set up as an acceptable deviation and is based on the estimated uncertainty of the TL measurements, evaluated at 1.8%. Participants deviating by more than 3.5% were asked to check their calibration system and invited to participate in the next run.

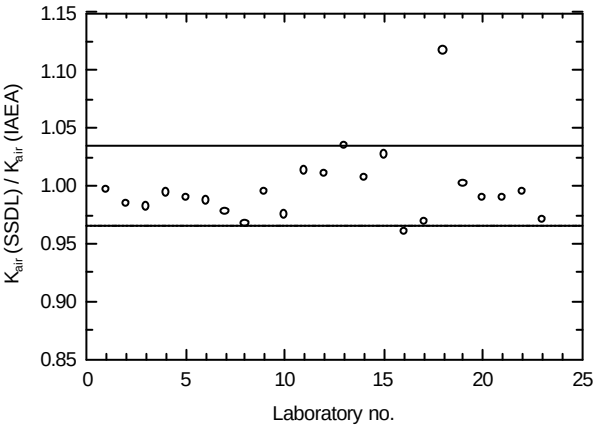

Figure 7. Ratios of the air kerma stated by SSDLs to the TLD measured value at the IAEA Dosimetry Laboratory during the pilot study. The acceptance limit is ±3.5%.

Following the results achieved under this pilot study and the positive feedback from the SSDLs,

this service is now established on a routine basis to all SSDL Network members. Its first run was completed in June 1999. The results show that about 30% of the SSDLs were outside the acceptance limit of ±3.5%. Those SSDLs were immediately contacted and supported to resolve the discrepancies. The second run is scheduled for the autumn 1999. A complete report on the results of the 1st and 2nd run will be published in this SSDL Newsletter.

5. NEW DEVELOPMENTS

The ISO document [4] states that *"For the low air kerma rate, the narrow-spectrum series and the wide-spectrum series, a reference laboratory shall verify, by a spectrometric study, that the value of the mean energy produced is within ±3%, and the resolution of the spectra is within ±10% of the value listed in the document."*

The measurement of x-ray spectra is not a simple task and it requires special equipment. As mentioned above, the IAEA Dosimetry Laboratory has recently acquired a spectrometry system for this task. It consists of a HPGe detector and a multichannel analyzer. At present, the response matrix of the detector is being evaluated and the software for spectra deconvolution prepared.

In May 1999, the Dosimetry and Medical Radiation Physics Section organized a consultants meeting whose purpose was to overview the field of dosimetry in diagnostic radiology and advice the IAEA on needs for further developments. The meeting resulted in a number of recommendations; its full report is published in this issue of the Newsletter. As a first step, a secondary standard ionization chamber, to be used for calibrations in 5-150 kV diagnostic x-ray beams, has been purchased. Actions to develop a range of diagnostic x-ray qualities, based on the IEC recommendation [13], have also been initiated.

6. CONCLUSIONS

The need for traceability of radiation protection measurements is now well established world-wide. Many Primary Standard Dosimetry Laboratories and the BIPM are offering a calibration service for measurement standards at radiation protection and/or diagnostic radiology level. This basic principle of traceability should not be interpreted as a requirement for an accuracy level comparable to that needed in radiotherapy. Instead, it should imply that radiation protection and diagnostic radiology measurements have to be linked to a primary standard through an unbroken metrology chain. It is only under this conditions that comparisons of radiation measurements made with different instruments and under different conditions can be made.

In the past, the IAEA has recommended that the "traceability principle" be followed for the calibration of radiation protection instruments [14]. More recently, a similar recommendation was emphasized in the International Basic Safety Standards [9].

In support of the IAEA/WHO Network of SSDLs, the Agency has set up a central Dosimetry Laboratory. The IAEA maintains measurement standards at radiation protection level for the calibration of national standards through the Network of SSDLs. Photon beams at energies ranging from the ISO 4037 narrow spectrum series to ^{60}Co gamma ray beam quality are available for the calibration of instruments. That range of beam qualities is now in the process of being extended to cover mammography beam qualities. In addition, audit programmes, using postal TLDs, are now offered to SSDLs to verify the quality of their calibration services.

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APPENDIX I

REFERENCE RADIATION BEAMS FOR THE CALIBRATION OF RADIATION PROTECTION AND DIAGNOSTIC RADIOLOGY EQUIPMENT AT THE IAEA DOSIMETRY LABORATORY

Buchler OB 85

Radionuclide	^{60}Co
Activity	20.5 GBq (99-01-01)
Air kerma rate at the calibration position	21.04 µGy/min (99-01-01)
Radionuclide	^{137}Cs
Activity	630.3 GBq (99-01-01)
Air kerma rate at the calibration position	83.66 µGy/min (99-01-01)
Height of the source center above the floor	110 cm
Field size	∅75 cm at 300 cm
Source-to-detector distance	300 cm
Dose equivalent rate of leakage radiation at 100 cm	<1 µSv/h

Philips MG 164/324 x-ray unit

Metal-ceramic tube MCN 165 with beryllium window, oil cooling	
Target material	tungsten
Generating potential	continuously adjustable up to 160 kV
Tube current	continuously adjustable 0.1 to 18 mA
at 160 kV	
Inherent filtration	1 mm beryllium
Added filters, changeable	medium or heavy filtration
Height of x-ray focus above floor	110 cm
Field size	∅24 cm at 300 cm
Focus-to-detector distance	300 cm
Leakage dose equivalent rate through shutter	
at 100 cm distance from focus	< 6 µSv/h
Metal-ceramic tube MCN 321 with beryllium window, oil cooling	
Target material	tungsten
Generating potential	continuously adjustable 16 to 320 kV
Tube current	continuously adjustable 0.1 to 10 mA
	at 320 kV
Inherent filtration	3 mm beryllium
Added filters, changeable	medium or heavy filtration
Height of x-ray focus above floor	110 cm
Field size	∅24 cm at 300 cm
Focus-to-detector distance	300 cm
Leakage dose equivalent rate through housing	
at 100 cm distance from focus	< 6 µSv/h

Senographe DMR mammography unit

Dual target GS 412-49 x-ray tube	
Target material	molybdenum (vanadium-doped), rhodium
Target angle with respect to the reference axis	f 0.1 - 6°, f 0.3 - 20°
Nominal focal spot values	0.1 and 0.3
Generating potential	22 to 49 kV in steps of 1 kV
Tube current	20 to 130 mA
Inherent filtration	0.8 mm Be
Added filters, changeable	1 mm Al, 0.03 mm Mo, 0.025 mm Rh
Height of x-ray focus above floor	120 cm
Field size	∅10 cm at 100 cm
Focus-to-detector distance	100 cm

APPENDIX II

INSTRUMENTS USED FOR THE CALIBRATION OF RADIATION PROTECTION AND DIAGNOSTIC RADIOLOGY EQUIPMENT AT THE IAEA DOSIMETRY LABORATORY

Reference instruments

Instrument	Ser. no.	Measured quantity	Traceability
1000 cm^3 ionization chamber LS-01	114	K_{air} for x-rays (40-300 kV), ^{137}Cs, ^{60}Co	BIPM, PTB
1000 cm^3 ionization chamber HS-01	102	H^* for x-rays (40-300 kV), ^{137}Cs, ^{60}Co	BIPM, PTB
1000 cm^3 ionization chamber LS-01	130	K_{air} for ^{137}Cs and ^{60}Co	PTB
6 cm^3 ionization chamber Radcal 10X5-6M	8362	K_{air} for x-rays (23-40 kV) produced on Mo or Rh target	NIST
electrometer Keithley 6517	0599918	current, charge	BEV
electrometer Keithley 617	435176	current, charge	BEV
electrometer Keithley 617	511853	current, charge	BEV
capacitor General Radio1404A	1202	collected charge	BEV
voltage cell Eppley Laboratory No.121	3267	voltage standard	BEV
mercury barometer Lambrecht 604	944016	air pressure	PTB
thermometer Keithley 8696	0707095	air temperature	BEV

Ancillary equipment

Instrument	Use of instrument
1 cm^3 ionization chamber Standard Imaging M1	measurement of K_{air} for mammography x-ray beams
1 cm^3 ionization chamber Exradin TW-11	measurement of K_{air} for mammography x-ray beams
0.2 cm^3 ionization chamber PTW23344	measurement of K_{air} for mammography x-ray beams
monitor chamber PTW 30 363	monitoring output of x-ray generators
HV sources (IAEA made)	power sources for ionization chambers and monitors
electronic barometer/thermometer MR 5031/6100	measurement of the pressure and temperature in ^{60}Co irradiation room
precision mercury thermometer Pinco	measurement of temperature in the x-ray room
precision aneroid barometer Negretti & Zambra MK 2	measurements of pressure
kVp meter Gammex RMS 232	kVp measurements on mammography unit
attenuation filters of defined purity (material from Goodfellows)	filtration of x-ray beams
HVL filters of defined purity (material from Goodfellows)	measurements of HVLs for x-ray beams
water phantom PTW 4322	dose measurements in water

APPENDIX III

ESTIMATED STANDARD UNCERTAINTIES FOR THE CALIBRATION AT RADIATION PROTECTION LEVEL OF IONIZATION CHAMBERS AT THE IAEA DOSIMETRY LABORATORY

Calibration in terms of air kerma and ambient dose equivalent in ^{137}Cs / ^{60}Co beams

	Source of uncertainty	Type A (%)	Type B (%)
1	**Uncertainties related to the IAEA secondary standard**		
	[1]N_K from BIPM (or PSDL)	0.85	
	[2]Temperature and air pressure correction)	0.04	0.06
	[3]Current measurements		
	voltage	0.01	0.02
	capacitance	0.04	0.04
	time base		0.01
	[4]Leakage current	0.00	0.00
	Long term stability of the secondary standard	0.2	
	Uncertainties related to the instrument to be calibrated*		
	[6]Positioning in air at the calibration distance		0.02
	[7]Current measurement (user's electrometer)	0.1	0.06
	[8]Field inhomogeneity		0.1
	[2]Temperature and air pressure correction	0.04	0.06
	[4]Leakage current (user's electrometer)	0.00	0.00
	Relative combined standard uncertainty	**0.9**	

Calibration in terms of air kerma and ambient dose equivalent in x-ray beams

	Source of uncertainty	Type A (%)	Type B (%)
1	**Uncertainties related to the IAEA secondary standard**		
	[1]N_K from BIPM (or PSDL)	0.75	
	[2]Temperature and air pressure correction	0.04	0.06
	[3]Current measurements		
	voltage	0.01	0.02
	capacitance	0.04	0.04
	Time base		0.01
	[4]Leakage current	0.00	0.00
[5]Difference in x-ray spectra (BIPM/PSDL-IAEA)			0.1
	Long term stability of the secondary standard	0.2	
2	**Uncertainties related to the instrument to be calibrated***		
	[6]Positioning in air at the calibration distance		0.02
	[7]Current measurement (user's electrometer)	0.1	0.06
	[8]Field inhomogeneity		0.1
	[2]Temperature and air pressure correction	0.04	0.06
	[4]Leakage current (user's electrometer)	0.00	0.00
	Relative combined standard uncertainty	**0.8**	

***** *The values are given for a typical dosimeter and may change slightly with different types of dosimeters.*

[1]The values are given in the calibration certificates issued by BIPM/PSDL.

[2]The standard deviation for the temperature reading is assumed to be 0.1°C. It is also assumed that the real temperature inside the chamber air cavity does not deviate by more than 0.3°C of the measured temperature.

[3]The current, I, is integrated on an external capacitor until a specified voltage, U, is reached, during a time interval t. The current is determined according to I=C U/t.

[4]For secondary standard class instruments, leakage is negligible.

[5]This corresponds to the estimated difference between the spectra of the IAEA ^{60}Co beam and that of BIPM/PSDL.

[6]The centers of the two chambers are assumed to be within ± 0.1mm at the same distance from the source.

[7]This component uncertainty applies only to system calibration where the ionization current is read from the user's electrometer. The uncertainty is based on a typical value of secondary standard class electrometer.

[8]Lateral displacement of the two chambers and their different sizes can give rise to a small difference in response due to field non-uniformity

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Report of a Consultants meeting on Dosimetry in Diagnostic Radiology

IAEA, Vienna, 10-14 May 1999
Scientific Secretary: F. Pernicka

Dosimetry and Medical Radiation Physics, IAEA

1. INTRODUCTION

During its biennial meeting in 1996, the Standing Advisory Committee "SSDL Scientific Committee", recommended extending the long experience of the Agency in the field of standardization and monitoring dosimetry calibrations at radiotherapy and radiation protection level for the Secondary Standard Dosimetry Laboratory (SSDL) Network, to the field of diagnostic x-ray dosimetry. It was emphasized that *"Measurements on diagnostic x-ray machines have become increasingly important and some SSDLs are involved in such measurements. The Agency's dosimetry laboratory should, therefore, have proper radiation sources available to provide traceable calibrations to the SSDLs."*

2. OBJECTIVES OF THE CONSULTANTS' MEETING

The purpose of the consultants' meeting was to advise the Agency on dosimetry in diagnostic radiology. They were specifically requested to overview scientific achievements in the field and to give advice to the Agency on the need for further developments. The list of participants in the meeting is given in Appendix II.

3. BACKGROUND

3.1. CLINICAL DOSIMETRY

Medical ionizing radiation sources give by far the largest contribution to the population dose from man-made sources. In developed countries it is comparable to that from the natural background excluding radon. About 90% of this contribution is due to x-ray diagnostics and 10% to nuclear medicine. Since the risk for stochastic effects (induction of cancer and genetic disorders) is believed to be without a threshold, the detriment to the population increases with increasing population dose. An increasing part of the dose [1] from diagnostic x-rays is due to the use of dose-demanding procedures such as fluoroscopy, interventional radiology and computerized tomography (CT). Patient dose measurements are therefore becoming increasingly important. For example, in the International Basic Safety Standards [1] it is stated that representative dose values shall be determined in radiological examinations. The European Union has adopted a directive towards "health protection of individuals against the dangers of ionizing radiation in relation to medical exposures" which requires extensive dose measurements [2]. There is therefore a need to control this dose and to optimize the design and use of x-ray imaging systems. It is generally recognized that even a 10% reduction in patient dose is a worthwhile objective for optimization. In this context it is important to note that the image quality should always be sufficient for the clinical need.

It is clear from the above that it is essential to standardize the procedures for dose measurement in the clinic. In many situations, it is of interest to make measurements directly on the patient, but for the control of technical parameters, for the comparison of different systems and for optimization it is preferable to make measurements using a standard phantom to simulate the patient. With the exception of mammography, where there is a European protocol [3], there is hardly any international advice available for the performance of such measurements or for the selection of phantoms to be used in different situations.

3.2. THE NEED FOR SPECIALIZED INSTRUMENTATION

Various examination techniques are used in x-ray diagnostics. They include fluoroscopy, including interventional radiological procedures, mammography, CT, dental and conventional[2] radiography. In some cases specialized dosimeters are required, whose design and performance must be matched

[1] Whenever the terms dose or patient dose are used without qualification, they are used in a generic sense.
[2] In this document the term conventional radiology is used to cover all x-ray imaging modalities other than dental radiography, fluoroscopy, mammography and CT.

to the needs of the clinical measurement. The use of such dosimeters and/or the interpretation of the results obtained may require specialized techniques and knowledge, but with the exception of mammography (ibid.) limited international guidance is available. In addition there are special requirements for the calibration of such instruments at the SSDLs. Methods to perform such calibrations are not yet completely developed.

3.3. DEVELOPMENTS AT PSDLs AND SSDLs

The need for establishing and offering an extended range of calibration conditions in order to meet the widened requirements as expressed in diagnostic clinical practice has previously been recognized by some Primary Standard Dosimetry Laboratories (PSDLs) and SSDLs. It is being taken into account by an increasing number of PSDLs and SSDLs.

Calibrations directly traceable to primary standards are currently available for most radiation qualities employed in mammography, fluoroscopy, and conventional radiography, both as unattenuated beams and as beams simulating the field behind the patient. Also dedicated instruments such as CT-chambers (see below) used in computerized tomography are calibrated against primary standards. Recently conducted intercomparisons between several PSDLs have demonstrated the mutual equivalence of the primary standards also for the radiation qualities developed in order to meet clinical requirements.

Some SSDLs have attempted to establish diagnostic calibration services and others have requested guidance on doing so. The radiation qualities available and ionization chambers used for measurement are variable among the SSDLs. Some use qualities that are applicable to this activity; however, the chambers employed would be questionable according to the requirements needed for the diagnostic application. A greater uniformity amongst the SSDLs is needed for these applications.

3.4. PRESENT STATUS OF IAEA DOSIMETRY PROGRAMME IN DIAGNOSTIC RADIOLOGY

Due to the increased need for quality assurance in diagnostic radiology, it has become important to provide traceability of measurements in this field. As noted above, the SSDL Scientific Committee recommended in 1996 extending the experience of the IAEA in the field of standardization at radiotherapy and radiation protection levels for the IAEA/WHO Network of SSDLs, to the field of x-ray diagnostics. This recommendation has led the Dosimetry and Medical Radiation Physics (DMRP) Section to start the development of the necessary facilities and procedures for the calibration of ionization chambers. Recognizing that their currently used ISO qualities are not appropriate for diagnostic applications, the DMRP is implementing suitable qualities. Because of the importance of mammography examinations world-wide, as the first step in this process the IAEA Dosimetry Laboratory has acquired a mammography x-ray unit and the necessary measuring equipment. Seventeen radiation qualities have been established with tube voltages between 23 kV and 40 kV that represent entrance and exit beams for molybdenum and rhodium targets. A suitable ionization chamber has been selected as a reference standard. At present, the necessary steps are being undertaken to calibrate this chamber at a PSDL. This will allow the IAEA to provide a new service to SSDLs in member states. The IAEA Dosimetry Laboratory will ensure traceability in the measurement through the calibration of their secondary standards at mammography radiation qualities.

4. MEETING FORMAT

After the welcome and introductory remarks defining the objectives of the meeting by P. Andreo and F. Pernicka, the four consultants each gave a one hour presentation:

- Properties and measurement of radiation qualities and x-ray tube potential by H.-M. Kramer
- Instruments and their calibration for diagnostic Applications by L. A. DeWerd
- Clinical dosimetry in diagnostic radiology, part 1 by G. Alm Carlsson
- Clinical dosimetry in diagnostic radiology, part 2 by D. R. Dance.

The presentations were followed by an in-depth discussion of the current situation in clinical dosimetry and of the consequences resulting thereof in view of services to be provided within

the IAEA Dosimetry Programme and by SSDLs. As a result of this discussion, the consultants made six recommendations. These are explained and justified in this report, which was prepared by the consultants during the remainder of the meeting.

5. JUSTIFICATION

This section provides explanation and justification for the recommendations made by the consultants.

5.1. DEFINITIONS AND SCOPE OF INSTRUMENTATION

The most common type of radiation detector for diagnostic radiological dose measurement is a parallel plate ionization chamber. Parallel plate ionization chambers (also known as plane-parallel chambers) use two parallel, flat electrodes separated by a few millimeters. They are calibrated with their plates oriented perpendicularly to the beam axis, which is also the orientation in which they should be used.

Ionization chambers are made in different designs for specialized applications such as those listed above. There may be special requirements for the calibration and use of each type of chamber. All ionization chambers should have a sufficiently flat response over the range of the relevant radiation qualities. Mammographic ionization chambers generally require a thin entrance window and a construction using low atomic number materials, e.g. air equivalent or plastic materials. A CT-chamber, often called a pencil chamber, has an active volume in the form of a thin cylinder about 100 mm in length. Its response should be uniform along its entire axial length. In fluoroscopy there is a need to measure the input air kerma rate to the image intensifier and the patient dose. The chambers used for each aspect need to be of adequate design and size. Air Kerma Area Product (KAP) meters are also used in fluoroscopy. These are parallel plate chambers which are optically transparent. They are mounted on the x-ray head and their sensitive area extends over the entire cross-section of the beam. The signal from a KAP meter is proportional to the product of air-kerma and field size at any plane perpendicular to the beam axis. Dental ionization chambers need to be cylindrical so they are suitable for panoramic applications. The chambers should also be suitable for x-ray tube voltages between 50 kV and 80 kV. Chambers designed for conventional radiographic and fluoroscopic applications should have a flat response over the range of tube voltages 50 kV to 150 kV.

Although ionization chambers are the main devices used for dosimetric measurements, other devices with special properties are frequently used. Important examples are semiconductor diodes and thermoluminescent dosimeters (TLDs). Because of the inherent problems involved in the use of these two devices, they should not be used for calibrations at SSDLs. They are used for quality control and in clinical dosimetry. In each case, the response of the dosimeters needs to be carefully considered to achieve accurate measurements.

The contrast in a radiographic image is mainly determined by the x-ray tube voltage. It is standard practice, therefore, to measure this voltage as part of quality control. Non-invasive instruments are mostly used for this purpose. Such instruments require calibration.

Because of the increasing importance of interventional radiology, the consultants wish to note explicitly that the requirements for these procedures are the same as those for fluoroscopy.

5.2. REQUIREMENTS FOR CALIBRATIONS AT SSDLs

Approximately 40% of SSDLs are currently involved with calibration of diagnostic ionization chambers. At present the manner in which calibrations at diagnostic radiation qualities are performed at SSDLs is not co-ordinated. Many use different radiation qualities and standards, some of which may be unsuitable. Quality control can only work satisfactorily if correct measurements are made. This speaks to the need for a Code of Practice (CoP) to give guidance to these laboratories and to those that may wish to join them in the future.

The chamber and electrometer (or charge-measuring device) both need to be calibrated, either separately or as a system. Generally they are calibrated as a system; if the chamber and electrometer are calibrated individually, the system factor is the product of the electrometer factor and the chamber factor. The quantity for which the calibration was performed must be stated.

Past work has indicated a significant energy dependence of response of some chambers. For this reason the SSDLs need to establish radiation

qualities suitable for each area. It is recommended that radiation qualities given in IEC 61267 be used and a reference radiation quality be chosen as in IEC 61674. Where such recommendations do not exist, appropriate radiation qualities must be identified. The CoP should include the requirement that each SSDL have chambers calibrated at the reference radiation qualities and a ratio to other qualities be included. For example, for the conventional diagnostic range this would include a quality at 70 kV (RQR5) and at least two other qualities covering the range from 50 kV (RQR 3) to 120 kV (RQR 9). For a chamber with a sufficiently flat energy dependence, interpolation can be done for any intermediate point. In this context sufficiently flat means a maximum variation within $\pm$3% at most across the energy range of use.

The range of tube voltages in x-ray diagnostics extends from 22 kV to 150 kV. For mammography (22 kV to about 35 kV) anode materials different from tungsten are frequently used. Radiation qualities are usually designated by tube voltage, first and second half value layer (HVL). Measurements of HVL are performed with ionization chambers. These measurements can be affected by the energy dependence of response [4], and by the beam diameter used. Directions need to be given in the CoP for the correct measurement of HVL and other parameters of the fields. It is also important to measure the temperature and pressure at the time of calibration, unless the chamber is sealed to the atmosphere or if the electrometer device automatically corrects for the density of air. The CoP should describe the methodology to check if the correction is done appropriately.

The CoP should elaborate on the procedures and requirements for the calibration of non-invasive tube voltage measuring instruments. It is suggested that as a minimum, the SSDLs should obtain two such devices, instead of purchasing an invasive voltage divider. The two meters will act as quality control devices for each other. Other non-invasive tube voltage measuring instruments can thus be calibrated against the standard.

Recommendation: ***SSDLs need a CoP which provides guidance on the establishment of radiation qualities and on the conduct of calibrations***.

5.3. SEPARATE REQUIREMENTS FOR MAMMOGRAPHY, FLUOROSCOPY, DENTAL RADIOGRAPHY, CT AND CONVENTIONAL RADIOGRAPHY

specialized techniques in diagnostic radiology often require special dosimetric and radiation generating equipment. A new CoP must take this situation into account and should provide guidance to SSDLs for which physical quantity and under which conditions different kinds of dosimetric equipment should be calibrated. An example of situations in which guidance will be needed is the calibration of CT-chambers and of KAP-chambers. Although this can be performed with a CT- or a KAP-chamber, as appropriate, which can play the role of a secondary standard, this is not the only method of performing such a calibration. It can also be achieved with another calibrated ionization chamber. The CoP should give recommendations on the properties of the dosimeters to be used as secondary standards for dosimetric measurements to be performed for the various clinical diagnostic modalities. Such recommendations should include statements on maximum variations of the ionization chamber's response with half-value layer and, where necessary, on further instrument specifications such as dose rate dependence or electromagnetic compatibility etc..

Another point requiring attention in a new CoP concerns recommendations on the equipment of SSDLs with x-radiation sources both in terms of anode material and in terms of available dose rates. An example where the anode material is of importance is mammography and the dose rate can become relevant in high output fluoroscopy or in radiography. Guidance on these points will have to take into account the acceptable maximum uncertainties of measurements and the costs of setting up the various radiation fields at the SSDLs.

Recommendation: ***The CoP should identify separately the requirements for mammography, fluoroscopy, CT, dental and conventional radiology.***

5.4. INSTRUMENTATION REQUIREMENTS AND METHODOLOGY FOR CLINICALLY BASED DOSIMETRY

5.4.1. Instrumentation

When choosing an instrument for dosimetry in diagnostic radiology, it is important to match the instrument to the task. This will include the size and sensitivity of the instrument and its response to different radiation qualities. The use of an appropriate instrument is essential. In some cases, the commercially available instrumentation marketed for general or particular applications does not meet these requirements [4] and there may be no internationally agreed specification. This can create difficulties, particularly where there is no local expertise available.

The majority of dose measurements in diagnostic radiology are made with ionization chambers (including KAP meters) and TLDs. The ionization chambers must be calibrated at the appropriate available radiation qualities at the SSDL, or locally against a chamber that has been calibrated at the SSDL (tertiary calibration). On the contrary, TLDs must be calibrated frequently and SSDL calibration is impracticable. TLDs should be preferably calibrated at a radiation quality close to that used for the dose measurement and with an instrument which has a secondary or tertiary calibration. The calibration of TLDs is well documented [5], but for completeness, details should be included in any guidance document. The need for a protocol for calibration of ionization chambers at the SSDL is noted above, but there is also a need to include a procedure for local transfer of this calibration to a tertiary instrument.

The KAP meter is a very useful instrument for dosimetry in diagnostic radiology as 'dose-area product' is more directly related to radiation risk than dose itself. It is a practical and relatively cheap device, which allows real - time monitoring of the patient dose. It is the instrument of choice for complex examinations where the size and the position of the field varies during the examination. It is now being routinely installed at hospitals in many countries.

Opinion is divided about the calibration of KAP meters, whether they should be calibrated at the SSDL or *in situ*. There are inhomogeneities in the x-ray field due to the heel effect and the presence of extra focal radiation whose magnitude will be equipment dependent. Examples of calibration procedures are given by IPEM [5] and by Larsson et al. [6]. This subject needs further research, but it is likely that a CoP for use at the SSDL and guidance for calibration in the clinic are both required. It is pointed out that in any case, separate calibration is required for the use of the x-ray tube under and above the couch [7].

Some x-ray equipment manufacturers supply instruments which measure field area from the collimator setting and estimate the dose from stored information. They produce a reading which purports to be 'dose area product' but is in fact a measurement of area to which a conversion factor has been applied. In such a situation there is great potential for a false reading and a quality control procedure is needed.

The concept of 'dose-area product' is less familiar than the concept of 'dose' and it is suggested that some guidance on the interpretation of this quantity should also be provided. This should include conversion to energy imparted, mean absorbed dose and effective dose. In this connection, it is noted that the conversion factors depend upon the radiation quality and the size of the patient.

Semi-conductor devices are now available. Such devices can be as small as TLDs and have the advantage that they allow real time measurement. A problem is that the inherent response of semi-conductor devices is not sufficiently flat. This problem is compensated for by the software corrections in the instrument. There is limited experience on the calibration, quality control and use of these instruments.

Film dosimetry may also be of use in some situations, especially where dose distributions are required. When using film, it is important to control the optical density. Film has a significant energy dependence and this needs to be accounted for unless qualitative measurements are being made.

5.4.2. Measurements with phantoms

For the control of technical parameters, for the comparison of different systems and for optimization, it is preferable to make dose measurements using a phantom to simulate the patient. When a phantom is used, the measured dose will depend upon the phantom shape and size and it is essential that the phantom is Standardized

so that such variations are avoided. Standard phantoms must be designed so that they offer the same primary attenuation and scatter production as a representative patient. It is important to consider both of these aspects. It is desirable that such phantoms are inexpensive and constructed from readily available materials. Some compromise may be necessary. ICRU Report 48 [8] describes most of the phantoms presently available. The NEXT programme in the USA has used such phantoms in its national surveys of patient dose [9]. It is recommended that advice is given as to the choice of phantoms for selected standard examinations, which could include adult chest, lumbar spine, fluoroscopy, mammography and CT. The latter two procedures have received much attention and are treated below. Dosimetry for paediatric radiology is also of interest. It is suggested that phantoms for such examinations are developed at a later stage.

The consultants wish to note that it is only necessary for the phantom to be representative of a typical patient. It is not the intention that the result of dose measurements with phantoms should equal that from measurements with patients.

When a phantom is used to simulate the patient, the x-ray equipment should be set up in the same way as for the real examination. There are some protocols in use which recommend the dose for a fixed optical density on the film (e.g. the Nordic mammography protocol [10] recommends the use of net OD 1.0). The consultants prefer the use of the clinical settings.

When the phantom is exposed, the dose may be determined using a dosimeter placed at a defined position on its upper surface. Alternatively the exposure conditions may be noted and the dose calculated from measurements using a dosimeter free-in-air. Practical guidance on methodology should be included in the CoP.

The doses measured using the above procedures must be specified for a standard material. Several choices are available including water, air, striated muscle, and other soft tissues. The choice of air has the advantage that no conversion factors need be applied for measurements with an ionization chamber.

Dose measurements made at the surface of the phantom include backscatter whereas those made free in-air do not. It is desirable to standardize the dose specification to avoid ambiguity. Whichever prescription is adopted, a table of standard backscatter factors appropriate to the phantom geometries should be established. This may require customized Monte Carlo calculations.

It is pointed out that the introduction of standard measurement procedures and phantoms will facilitate local and international comparison of doses and the future establishment of reference doses (see for example the recent European Directive [2]). The Agency may wish to co-ordinate such comparisons once the use of the proposed CoP has been established.

5.4.3. Mammography

During the past few decades there have been significant advances in the equipment used for mammography. Even when the latest equipment is used, there is considerable variation from centre-to-centre in the choice of imaging parameters and techniques. Thus, there may be quite large differences in breast dose. A review of the development and current status of dosimetry for mammography is given in Dance et al. [11].

The most practical dose measurement for mammography is an estimate of the incident air kerma at the surface of the breast (with or without backscatter). Since a low energy x-ray spectrum is used for the examination, the dose decreases rapidly with increasing depth in the breast. More appropriate quantities for specifying breast dose have therefore been suggested. ICRP [12] recommend the use of the average dose to the glandular tissues within the breast (AGD) and this has been generally adopted.

Direct measurement of AGD is not possible. Instead, use is made of conversion factors that relate measurements of entrance air kerma to AGD. These factors may be derived from measurements on phantoms, but it is more usual to make use of the results of Monte Carlo calculations. Several authors have made such calculations. The resulting factors depend on the model and input data used and there are differences of the order of 10-15% between the results of different workers. The factors themselves depend upon the radiation quality, breast thickness and breast glandularity, though the latter variation is sometimes ignored.

Several countries have introduced protocols for dosimetry in mammography but there is wide

variation in the methodology suggested. In addition, there is limited agreement for the material and size of a standard breast phantom. The consultants believe that the phantom introduced in the recent European protocol [3] could also be adopted by the CoP. They further recommend that the AGD be used as the dosimetric quantity for mammography. A standard set of conversion factors should be used to relate the measured entrance dose for the standard breast phantom to this quantity. It is noted that this conversion factor is quality dependent and is tabulated as a function of HVL. The determination of dose therefore includes a measurement of the HVL. It is suggested that guidance for the measurement of HVL be provided.

5.4.4. Computerized Tomography (CT)

CT examinations constitute about 4% of all radiographic examinations but can contribute 40% of collective dose [13]. It is therefore of considerable importance to monitor the dose for such examinations.

In conventional CT scanning, the patient dose is built up from that received from each individual CT slice. It has proved convenient to specify dose in terms of the computer tomography dose index (CTDI) for a single slice. This is a dose integral along a line perpendicular to the scan plane normalized to the nominal width (T) of the slice. The most frequently used definition is that employed by the Food and Drug Administration in the USA.

$$CTDI = \frac{1}{T}\int_{-7T}^{+7T} D(z)\,dz$$

The CTDI may be measured using a CT chamber, a stack of TLD chips or film. CTDI can be measured in-air on the scanner axis without a phantom, or in a phantom and at various distances from the scanner axis. The relationship between in-air and in-phantom measurements of CTDI is scanner dependent because of differences in x-ray spectra, specialized beam filtration and scanner geometry. It can be argued that in-phantom measurements are more representative of the patient dose and the consultants therefore recommend the use of a phantom for these measurements. Standard phantoms are available for both body and head examinations and are in common use. For phantom measurements, the CTDI will vary with the distance from the beam axis. It has been suggested in a CEC working document that a weighted combination of CTDI measurements at the phantom centre and surface be used to represent the average CTDI [15]. The consultants recommend that guidance is given for the measurement of CTDI in the standard American Association of Physicists in Medicine (AAPM) phantoms. Within the last decade helical CT scanning has been introduced. Care must be taken to ensure that the guidance is appropriate for this imaging configuration.

It is also of interest to measure the dose profile of a CT slice. This can be achieved using TLD or film.

With knowledge of the CTDI, the number of slices, slice thickness and separation, the patient dose for a complete CT examination may be estimated. The procedure for this may not be straightforward and some guidance is required.

Recommendation: ***The CoP should include guidance on the requirements for instrumentation and methodology for clinically based dosimetry.***

5.4.5. International standards

There are few international standards related to the proposed CoP whose outline is given in Appendix I. Some are mentioned in the previous sections. Some are in preparation; for example, IEC 60580 for KAP meters and IEC 61676 for non-invasive x-ray tube voltage measurement devices. There are some national standards in the diagnostic radiology field, specifically some protocols for mammography dose measurements.

Recommendation*: All relevant international standards and protocols should be taken into account. National protocols should also be considered.*

5.4.6. Impact of suggested recommendations on the IAEA Dosimetry Programme

In order to fulfil calibration requests for all x-ray diagnostic modalities, the scope of the services of the IAEA Dosimetry Programme must be

extended. This includes a widening of the scope of the radiation qualities to be offered and of the secondary standards to be available.

Radiation qualities for the calibration of dosimeters for radiotherapy, for radiation protection and for mammography have already been successfully established at the IAEA Dosimetry Laboratory. The establishment of further radiation qualities is needed, suitable for the calibration of instruments to be used for dosimetry in dental radiography, CT, fluoroscopy and conventional radiography. The x-ray generating equipment available in the Laboratory could be used to develop the radiation qualities required. However, attention needs to be paid to the spare capacity of the calibration facility in the light of the expected significant increase in the number of calibrations per year.

There are also some requirements in terms of additional dosimetric instrumentation to enable the Laboratory to comply with the extended scope of calibrations and the increasing workload.

Recommendation: ***The IAEA Dosimetry Programme should be further extended to support the activities of the SSDLs recommended in this document.***

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APPENDIX I

Outline of the Structure and contents of the proposed new IAEA CoP

Dosimetry in Diagnostic Radiology: An International Code of Practice

Foreword

CONTENTS

1. INTRODUCTION: Set the context, need, scope and limitations, both for SSDLs and clinics
2. DEFINITIONS: Full definition of symbols, terms and quantities used
3. SCOPE: Application to diagnostic radiology and its specialities. Outline of each field and its specialities. Methodology to perform measurements, e.g. HVL
4. FRAMEWORK
   a) International system of measurement; dissemination of standards; uncertainties
   b) Measurements in the clinic using phantoms
   c) Choice of dosimeter: ionization chamber, TLD, semi-conductor, or film
5. CONVENTIONAL APPLICATIONS
   a) SSDLs: Types of chambers and generators allowed, giving requirements on energy dependence of response of chambers, anode, filtration and radiation qualities
   b) Clinical application: Choice of dosimeter and phantom; measurement methodology; interpretation of results
6. MAMMOGRAPHY APPLICATIONS
   a) SSDLs: Types of chambers and generators allowed, giving requirements on energy dependence of response of chambers, anode, filtration and radiation qualities
   b) Clinical application: Choice of dosimeter and phantom; measurement methodology; interpretation of results
7. CT APPLICATIONS
   a) SSDLs: Types of chambers and generators allowed, giving requirements on energy dependence of response of chambers, anode, filtration and radiation qualities
   b) Clinical application: Choice of dosimeter and phantom; measurement methodology; interpretation of results
8. FLUOROSCOPIC APPLICATIONS
   a) SSDLs: Types of chambers and generators allowed, giving requirements on energy dependence of response of chambers, anode, filtration and radiation qualities
   b) Clinical application: Choice of dosimeter and phantom; measurement methodology; interpretation of results
9. DENTAL APPLICATIONS
   a) SSDLs: Types of chambers and generators allowed, giving requirements on energy dependence of response of chambers, anode, filtration and radiation qualities
   b) Clinical application: Choice of dosimeter and phantom; measurement methodology; interpretation of results
10. CALIBRATIONS OF NON-INVASIVE X-RAY TUBE VOLTAGE MEASURING INSTRUMENTS
    Methodology of measurement and instrumentation to be used for each specialised application

REFERENCES

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Training Courses in the field of Dosimetry and Medical Radiation Physics

- Interregional Training Course on treatment planning in radiotherapy using ROCS system (RER/6/008), Palanga, Lithuania, 7-18 June 1999
- AFRA Workshop on harmonized methods of beam calibration in external radiotherapy (C7-RAF/6/014-015), Rabat, Morocco, 21-25 June 1999
- Regional Training Course on the basis of for clinical quality assurance in radiation oncology (RAS/6/027-003), Manila, Philippines, 5-9 July 1999 (in collaboration with Applied Radiation Biology and Radiotherapy Section)
- Regional Training Course on Modern Techniques and Dosimetry in Brachytherapy (RAF/6/020), Cairo, Egypt, 18-29 September 1999
- Interregional Training Curse on Calibration Procedures and Quality Assurance in SSDLs (C7-INT-1.053), Havana, Cuba, 27 September-8 October 1999

Other meetings

Research Co-ordination Meeting on Development of a Code of Practice for Dose Determination in Photon, Electron and Proton Beams Based on Measurement Standards of Absorbed Dose to Water	Brussels	3-7 May 1999
Consultants Meeting on Dosimetry in Diagnostic Radiology.	Vienna	10-14 May 1999
Consultants Meeting on High-Dose Dosimetry Techniques.	Vienna	17-21 May 1999
Consultants Meeting on Quality Assurance for Radiotherapy Hospitals.	Vienna	24 Sept-1 Oct 1999
Consultants Meeting on Teaching Medical Physics	Vienna	4-8 October 1999
Consultants Meeting on Calibration of Beta Sources and Low Energy Photon Sources.	Vienna	1-5 November 1999
Consultants Meeting on Radiotherapy Treatment Planning.	Vienna	15-19 November 1999
Research Co-ordination Meeting on Development of a Quality Assurance Programme for Secondary Standard Dosimetry Laboratories	Vienna	29 Nov-3 Dec 1999
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