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DOSIMETRY
LABORATORIES

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## CONTENTS

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# EDITORIAL NOTE

Pedro Andreo, Head of the Dosimetry and Medical Radiation Physics Section from August 1995 till November 2000, returned to Sweden (University of Stockholm-Karolinska Institute/Karolinska Hospital). A farewell message of Pedro Andreo was published in the SSDL Newsletter No.44 (January 2001).

Ken Shortt was appointed Section Head of the Dosimetry and Medical Radiation Physics Section in August 2001.

**A short CV**

Ken Shortt was employed at the National Research Council (NRC) in the Ionizing Radiation Standards Group (IRS). One of his principle tasks there was the development of radiation metrology standards and their dissemination to cancer therapy clinics within Canada. Ken's undergraduate studies were in physics at McMaster University in Hamilton Ontario (1970). His M.Sc. thesis research involved a study of the resistivity of water under irradiation at the University of Western Ontario in London Ontario (1972). For three years he worked as a clinical medical physicist at the BC Cancer Agency before returning to study the dosimetry of pions for cancer therapy at the TRIUMF project. His Ph.D. from UBC in Vancouver was awarded in 1979. This was followed by one year at the pion therapy facility of the Swiss Institute for Nuclear Research (now called the Paul Scherrer Institute) in Villigen Switzerland and twenty-one years at NRC. There, his main research activities included Fricke dosimetry, ionization chamber comparisons and some aspects of gel dosimeters, thermoluminescent dosimeters and other solid-state devices such as MOSFETs (Metal Oxide Semiconductors Field Effect Transistors). During the last few years, he acted as chair of the Metrology Working Group on ionization radiation standards for the Sistema Interamericano de Metrología (SIM).

The first article of this issue of the SSDL Newsletter is about intercomparison of air kerma and absorbed dose to water calibration factors between the SSDLs of Norway and Cuba. The intercomparison covered Co-60 gamma rays (for air kerma and absorbed dose to water) and x-ray beams (air kerma at medium and low energy). The results are presented in this article. The Secretariat of the IAEA/WHO SSDL Network encourages this type of exercise between the SSDLs as it reinforces confidence in the measurement system. The IAEA also provides intercomparison services to its Network members, using ionization chambers. Although the service is presently limited to Co-60 gamma rays, it will soon be expanded to cover x-ray beams. For this purpose, a consultants' meeting will be held soon in Vienna to advise the IAEA on the methodology to be adopted.

The second article is a report by the SSDL of Iran on the design, construction and calibration of plane parallel ionization chambers. This article presents the design characteristics of the chambers and the results of their calibration as well as dose determination of electron beams by air kerma based and absorbed dose to water based dosimetry procedures using these chambers.

The third article is a report of a Nordic dosimetry meeting (Oslo, 19 January 2001) on the implementation of the new international Code of Practice based on absorbed dose to water standards (TRS-398). This report summarizes the main discussions and conclusions of the meeting. The editor wishes to draw the attention of the readers to the recommendations adopted in section 3 of the report. In addition, the Secretariat of the Network would appreciate receiving reports or minutes of meetings organized by SSDLs and hospitals on the implementation of TRS-398.

The last article is a report of a consultants' meeting, held at the IAEA Headquarters in May 2001, on the calibration of well type ionization chambers for High Dose Rate $^{192}$Ir quality. The conclusions and recommendations are summarized in the report.

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# SERVICES PROVIDED BY THE IAEA PROGRAMME 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 range of services is listed below.

| Services | Radiation quality |
|---|---|
| 1. Calibration of ionization chambers (radiotherapy, diagnostic radiology including mammography, and radiation protection, including environmental dose level). | 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). | $\gamma$ rays from $^{137}$Cs |
| 3. Intercomparison of therapy level ionization chamber calibrations (for SSDLs). | $\gamma$ rays from $^{60}$Co |
| 4. TLD dose quality audits for external radiotherapy beams for SSDLs and hospitals. | $\gamma$ rays from $^{60}$Co and high energy X-ray beams. |
| 5. TLD dose quality audits for radiation protection for SSDLs. | $\gamma$ rays from $^{137}$Cs |
| 6. ESR-alanine dose quality audits for radiation processing (for SSDLs and industrial facilities), through International Dose Assurance Service (IDAS). | $\gamma$ rays from $^{60}$Co, dose range: 0.1-100 kGy |
| 7. Reference irradiations to dosimeters for radiation protection (for IAEA internal use). | X-rays (40-300 kV) and $\gamma$ rays from $^{137}$Cs and $^{60}$Co |

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

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# INTERCOMPARISON OF THE AIR KERMA AND ABSORBED DOSE TO WATER THERAPY CALIBRATIONS PROVIDED BY NRPA AND CPRH SSDLs

J.A. Morales[1], H Bjerke[2], C. Jensen[2], R Campa[1]

## 1. INTRODUCTION

The primary goal of any calibration laboratory is to routinely provide calibration services of the highest accuracy. To this end, the laboratory should be equipped with measuring standards of the highest metrological quality traceable to the international measuring system, should establish the appropriate calibration conditions and implement good measuring and working practices. In the case of the Secondary Standard Dosimetry Laboratory (SSDL) members of the IAEA/WHO Network of SSDLs, a great deal of the service quality relies on the appropriate laboratory design and implementation of the recommended calibration practices [1,2]. Different approaches have been used by SSDLs to guarantee the traceability of the reference standard to the international measurement system. These include calibration of their standards at the IAEA Dosimetry Laboratory, direct calibration at a primary standards laboratory or at a national calibration laboratory. The stability of reference and working standards is usually checked by means of radioactive check source measurements [2]. The most comprehensive way that a laboratory could test its overall measurement competence is by taking part in comparisons with other laboratories of the same or higher metrological level. Regular efforts have been done at the regional scale by organizing such intercomparison exercises where the evaluation of the accuracy of secondary standards or the validation of new calibration methods has been the main objectives [3,4]. Perhaps, the most important contribution to the assessment of SSDLs quality has been the periodical external measurement audit provided by the IAEA [5] during the last years. Most of these efforts have, however, only been focused on in-air and recently in-water calibration at the $^{60}$Co radiation quality.

An intercomparison of the therapy calibration services available at the SSDLs of the Norwegian Radiation Protection Authority (NRPA) and of the Center for Radiation Protection and Hygiene (CRPH) was organized in February 2000. The comparison comprised the calibration of a field class ionization chamber in terms of air kerma at low and medium-energy kilo voltage X-ray qualities and $^{60}$Co as well as the calibration in terms of absorbed dose to water (at $^{60}$Co radiation quality). The intercomparison represents for the CPHR the validation of the newly implemented calibration service at X-ray qualities. The NRPA SSDL has in recent years participated in EUROMET and IAEA dosimetry intercomparisons with satisfactory results. Experiences derived from the present comparison are discussed and summarized in this report. Recommendations to the SSDL members of the IAEA/WHO Network in order to encourage regional cooperation by organizing similar intercomparison exercises as well as the possibility for the IAEA to extend the present audit services, to cover certain X-ray beam qualities, are also commented.

## 2. MATERIAL AND METHODS

The exercise was based on the comparison of both air kerma calibration factors obtained for the thimble ionization chamber type NE-2571 (No.1881) at $^{60}$Co and several therapy level X-ray beam qualities, and absorbed dose to water calibration factors at $^{60}$Co radiation quality. Details on radiation generators and the qualities, used at each SSDL to derive calibration factors, are presented in Table 1. Table 2[3] shows general information on the secondary standards used by each SSDL in the intercomparison.

Calibration of the NE-2571 (No.1881) chamber at CRPH was carried out using the substitution method. Measurements of the ionization current for

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[1] Centre for Radiation Protection and Hygiene, Havana, Cuba

[2] Norwegian Radiation Protection Authority, Oslo, Norway

[3] S*ee Appendix I for Figure 1 and Tables 1 and 2.*

both the standard and chamber under calibration were carried out with the reference electrometer type NE-2590 Ionex Dosemaster working in charge mode. Collecting times were set with the electrometer timer starting the integration always after the start of irradiation. This practice avoids the necessity of applying transit time corrections to the collected charges. Calibrations at X-ray beam qualities were done without a transmission monitor chamber. The IAEA 30 x 30 x 30 $cm^3$ fixed depth water phantom was used for in water calibration. Both sleeves, for the NPL and NE-2571 chambers, were made of PMMA and had a maximum wall thickness of 1 mm. Chambers were positioned inside the water phantom at a depth of 5 $g/cm^2$.

Calibrations at NRPA were also done using the substitution method. Ionization currents were measured with the electrometer type Keithley 35040, working in current mode. Measurements of the ionization current, ambient temperature and pressure were carried out at NRPA by means of an automatic acquisition and data processing system. Results of each current measurement series are the average values calculated from 50 or 100 instant current readings sampled at 1 Hz. Air temperature and pressure were just sampled at the beginning of each measurement series. Substitutions of the reference and chamber to be calibrated were carried out more than four times for each radiation quality. The measurements started few seconds after setting the beam on. A graphical representation of the sampled current allowed sensing the stability of the measured current and detecting any trend. Water calibration at NRPA was done in a variable depth 30 x 30 x 30 $cm^3$ water tank locally developed. The geometrical centre of both chambers, the reference and the chamber to be calibrated, were positioned at a depth of 5 $g/cm^2$ by means of a micrometer driven holding device. The same chamber sleeve was used for the NRPA reference chamber and the field chamber. The sleeve was made of PMMA with a nominal thickness of 1.5 mm (at chamber cavity level).

Both SSDLs previously agreed to evaluate the significance of the observed deviations by means of the same figure of merit $E_n$ used by EUROMET [4] in a similar intercomparison:

$$En = \frac{100}{Ur} \cdot \frac{\left| N_{NRPA} - N_{CRPH} \right|}{N_{NRPA}}$$

where $N_{CRPH}$ and $N_{NRPA}$ were the calibration factors reported by each laboratory and Ur is the expanded uncertainty (k = 2) of the ratio $N_{CRPH}/N_{NRPA}$ calculated by the expression:

$$\mathrm{Ur} = \sqrt{\mathrm{U_{NRPA}}^2 + \mathrm{U_{CRPH}}^2}$$

where $U_{NRPA}$ and $U_{CPHR}$ were the expanded uncertainties (k=2) of the reported calibration factors. According to this formalism, deviations are not considered significant if the value of En is less than unity. The NRPA has direct traceability to BIPM. The CRPH has traceability to the IAEA, which is traceable to the BIPM. Then, both the NRPA and the CRPH are traceable to the BIPM, which means that there is a correlation in the uncertainty of the calibration factors reported by NRPA and CRPH. To take into account this correlation in the statistical evaluation of the calibration factor, it is necessary to exclude, in the evaluation of $U_{NRPA}$ and $U_{CRPH}$, the common figure of the standard uncertainties reported by the BIPM [6,7]. However, the uncertainty added by the IAEA Dosimetry Laboratory during the calibration of the CRPH standard has been considered and estimated from the quadratic difference of the IAEA and BIPM reported combined uncertainties. Uncertainties of the calibration process existing at NRPA and CRPH were evaluated and combined in accordance with IAEA and ISO recommendations [2,8].

The chamber NE-2571 used in the comparison belongs to the CRPH. It was transported to the NRPA by one of the participants in the comparison. The chamber was surrounded with sufficient protective material and care was taken during its transportation to avoid shocks, continuous vibration or exposure to extreme temperatures.

# 3. RESULTS AND DISCUSSION

## 3.1 Stabilization times of the NE-2571/1881 chamber and corrections to polarity, recombination and the influence of the air humidity

Preliminary measurements carried out at NRPA showed a very long stabilization time of the NE-2571 chamber. The technique used for current measurements at NRPA made it possible to quantify the stabilization time. It was observed a transient of the initial ionization current measured immediately after the start of the chamber irradiation until final saturation is reached (0.15% at 670 mGy/min). The effect was more pronounced at a very low dose rate (0.7% at 140 mGy/min). Absolute differences between the first and the saturation current values at both air kerma rates did not vary and was 0.25 pA. The air kerma necessary for the stabilization was estimated, from the experiments, to 10 Gy. A final series of measurement were always taken when an acceptable degree of stabilization (no trend observed) was achieved. Uncertainties in the current measurements performed by this method at NRPA were assumed to be unaffected by the influence of the stabilization effect. The calibration procedure established at the CRPH SSDL required pre-irradiation of both the standard and field chamber under calibration at a minimum air kerma of 5 Gy. In practice however the total pre-irradiation dose exceeded the 10 Gy.

A similar situation was found during the measurements of the polarity effect at NRPA. A very high (at least 45 min) voltage stabilization time was required compared to the very low figure (typical values of 15 minutes) for the reference standard chambers existing at NRPA. The magnitude of the polarity correction was less than 0.1% after waiting for full voltage stabilization. But, errors in the determination of the polarity effect could range to a maximum of 0.2% if a sufficient delay between measurements at both polarities were not considered.

The need for such long periods would dramatically affect the time schedule of the comparison, limited also by service workload at the NRPA. Considering that the polarity effect was not corrected at CRPH, it was agreed to carry out all measurements at NRPA at the same polarity used at the CRPH (-250 V applied to the outer electrode of the chamber).

The magnitude of the recombination effect for this chamber was studied at the CRPH in the Co-60 calibration beam. The effect at the nominal air kerma rate of 0.94 Gy/min and –250 V polarization was less than 0.05%. It was decided in the rest of the calibration process at CRPH SSDL not to apply a correction factor to this effect. Neither were corrections for the ion recombination applied at NRPA.

Corrections for the influence of air humidity are not applied in routine calibrations at NRPA nor are they applied at CRPH. The approach seems to be justified due to the fact that users are commonly working in an environment where the actual relative humidity is close to that existing at the SSDL. In this intercomparison, it was necessary to evaluate the influence of this effect due to the large difference in the relative humidity existing at CRPH (typical values around 85%) and at the NRPA (values around 15%). However, the respective corrections for the influence of air humidity on the chamber response differed by less than 0.05% [8]. It was agreed not to correct the calibration factors for the humidity effect.

## 3.2 Estimated combined uncertainties of the calibration factors reported by the SSDLs

A summary of the uncertainty analysis, based on a detailed evaluation of the relevant sources affecting both the reference and NE-2571, chambers is presented in Table 3 (Appendix 1). The combined uncertainties associated with NRPA calibration were generally lower than those of CRPH calibrations. The major sources of uncertainty responsible for this difference were the air density corrections and the X-ray output short-term stability. Measurement of temperature and pressure are based in the CRPH on the use of analogue instruments (mercury thermometer and aneroid barometer). The resolutions of these instruments together with the temperature gradient inside the calibration rooms are the main cause of this situation. The added uncertainties of the CRPH and the IAEA did result in quite similar figures. However, hardware, calibration methods and degree of redundancy existing at the IAEA Dosimetry Laboratory is closer to those existing at NRPA. This could indicate that the uncertainty evaluation at the IAEA Laboratory is very conservative compared to that of NRPA. This remark is consistent with the results of the air kerma and absorbed dose to water comparison organized by EUROMET in 1998 [4]. Differences found in the calibration factors reported by NRPA and the IAEA were not significant, if the same combined uncertainty of the NRPA would be used to derive the figure of merit En (an "En" equal to 0.4 in air kerma calibration and 0.7 in absorbed dose to water calibration).

### 3.3 Differences in air kerma calibrations at $^{60}$Co and medium-energy kilovoltage X-ray qualities

Percentage deviations of the $N_K$ and $N_{D,w}$ calibration factors obtained at the CRPH and NRPA are listed in Table 3. A very good agreement was obtained for the air kerma calibration factors. Differences would not be significant if the combined uncertainty (k =1) instead of the expanded (k=2) uncertainties of the calibration factors had been used to calculate En.

### 3.4 Difference in absorbed dose to water calibrations at $^{60}$Co

Differences in the derived absorbed dose to water calibration factors were also not significant. The two major differences in the calibration set up used at NRPA and CRPH were the thickness of the chamber sleeves and the source to chamber distance. In order to estimate the magnitude of the correction for the extra 0.5 mm PMMA used at the NRPA, it was assumed that the ratio of the $N_{D,w}$ at both sleeve thickness was proportional to the $p_{wall}$ perturbation correction factor (IAEA TRS 277) [9]. The perturbation correction factor takes into consideration the different fraction of electron coming to the chamber air cavity from the sleeves ($\tau$) and the non-water equivalence of the PMMA. Correction obtained by this method resulted in 1.0001 showing the practical irrelevance of the difference in sleeve thickness. The influence of using different source chamber distances SCD (80 and 100 cm) on $N_{D,w}$ was not experimentally studied in the present comparison. However, from the quite good agreement of the reported absorbed dose to water calibration factors the effect seems to be in practice negligible.

### 3.5 Differences of the air kerma calibrations at 50 kV/1 mm Al HVL radiation quality

Difference in the reported air kerma calibration factors, at this radiation quality, was significant in terms of the expanded uncertainty of the ratio of the two reported factors. There is a difference of 6% in the HVLs established at NRPA and at the CRPH. The magnitude of the field size diameter at the chamber position in both SSDLs also differs by 1 cm. First, it was suggested that the change in the calibration factors was caused by a high-energy dependence of the NE-2571chamber at these very low photon energies. Typical energy dependence of chamber response reported by the manufacturer is 4% between 50 and 100 kV generated radiation qualities. The manufacturer does not recommend the use of the NE-2571 chambers at X-ray voltages below 50 kV. In order to know if the difference of the calibration factors for this particular chamber was at least partially explained by the air kerma energy dependence, it was decided to carry out a further calibration covering the other low energy X-ray qualities available at NRPA (see Table 5, Appendix 1). The energy dependence of the calibration factors is shown in Figure 1. The change in $N_K$ from the HVL 1.057 to 1.00 mm Al was estimated from the fit of the energy dependence. The energy dependence of the chamber could be responsible for a deviation of 0.25% but in the opposite direction compared to the observed difference. It was concluded that the chamber energy dependence was not responsible for the difference.

It is interesting to note that if the time stabilization effect of the NE-2571 chamber had been present during the calibration at the CRPH, where the nominal kerma rate at chamber position was 50 mGy/min, the ionization current would have been overestimated by about 2%. The stabilization effect was however not seen at the other X-ray qualities, where the same measurement procedure was used, and accordingly, it is unlikely to be the reason for the difference in the calibration factors.

In order to exclude the possibility of having a systematic deviation in the calibration factor of the

CRPH PTW 23344 secondary standard, a calibration of the secondary standard (NE-2561) at the same radiation quality was carried out at CRPH. A difference of 0.15% compared to the calibration factor of the NE-2561 chamber given by NPL in 1990 was obtained. Later calibration of the NE-2561 chamber at IAEA in 1998 did not cover the 50 kV/1 mm Al radiation quality but the differences in the reported $N_K$ calibration factors at $^{60}$Co and other medium-energy X-ray beam qualities were lower than 0.3%. No other redundant calibrated chamber at this low energy quality is available, neither at CRPH nor at NRPA.

## 4. CONCLUSION

The comparison shows that voltage and polarization stabilization dose/time for a particular radiotherapy field chamber can be far away from general values given by manufacturers. Visual evaluation of this effect by means of real-time monitoring of the ionization current trend is a very useful tool to assess when a required stabilization state has been achieved. Recommendation on this issue, given by SSDLs to the user when appropriate, can also help avoid systematic errors in the dosimetry of the clinical beams, calibrated by such chambers. This effect has different implication on the comparison exercises. For a comparison of measurement standards between SSDLs, it is highly advisable to study first the chamber response and behaviour in order to establish all correction factors or measuring conditions. However if the aim of the comparison is to evaluate the measurement capability of an SSDL, an alternative approach could be to use chambers with non-typical behaviour.

A very good agreement between the calibration factors reported by both SSDLs, at Co-60 and medium-energy X-ray therapy qualities, was achieved. The result is especially important for medium-energy X-ray qualities where there exists a recently growing interest among users from radiotherapy departments. There is also a lack of dosimetry intercomparison and there can be a diversity of factors affecting the accuracy of the whole calibration (kV inaccuracy due to misuse of filters, lack of accuracy in HVL determinations or just poor beam geometry). Differences between absorbed dose to water calibration factors issued by different laboratories were expected to be higher taking into consideration the presence of many other influence factors, such as phantom alignment and deformation with the time, accuracy of chamber positioning in water, realization of reference depth and air density corrections. Results of the present intercomparison however show that a similar accuracy, as in air kerma calibration, can be achieved in the absorbed dose to water calibrations.

A significant difference, 2%, was obtained at the very low energy quality 50 kV/1 mmAl. It was found in both SSDLs a lack of redundant reference standards, which could help to explain this difference. The implementation of a detailed assessment at each SSDL regarding the stability and accuracy of the reference standards is highly recommended before calibration service are provided to the users. For future comparisons at the low-level energy x-ray beam qualities, it is recommended to use plane parallel chambers, which reduce the influence of the chamber energy dependence. However, the use of Farmer type NE-2571 chambers seems to be appropriate for radiation qualities down to 50 kV (1 mm Al HVL).

The IAEA should consider the possibility for extending the on-going audit service to include some X-ray beam qualities at routine basis or at the user's request. An intercomparison is necessary to demonstrate the laboratory measurement capabilities. The results are usually more important to the laboratory itself than to any other body. The organization of bilateral comparison can be an additional opportunity to learn from the measurement methods used by other laboratories and identify own limitations. The present intercomparison was a result of the collaboration of two SSDLs at different technological levels and located in distant geographical areas. Both laboratories however were pleased to cooperate and learn from each other. SSDLs can play an important role at the regional level in the harmonization of the metrology system, improvement of the quality level and the integration towards the solution to common problems. The costs of this kind of intercomparison based on a circulation of a set of field chambers are not even significant. A change from bilateral comparison SSDL–IAEA used in the present IAEA calibration audit to a regional approach, where a common set of instruments would be circulated among SSDLs of the same region and the IAEA taking part as a reference laboratory could promote and stimulate a regional cooperation in a more effective way.

## ACKNOWLEDGEMENTS

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# APPENDIX I

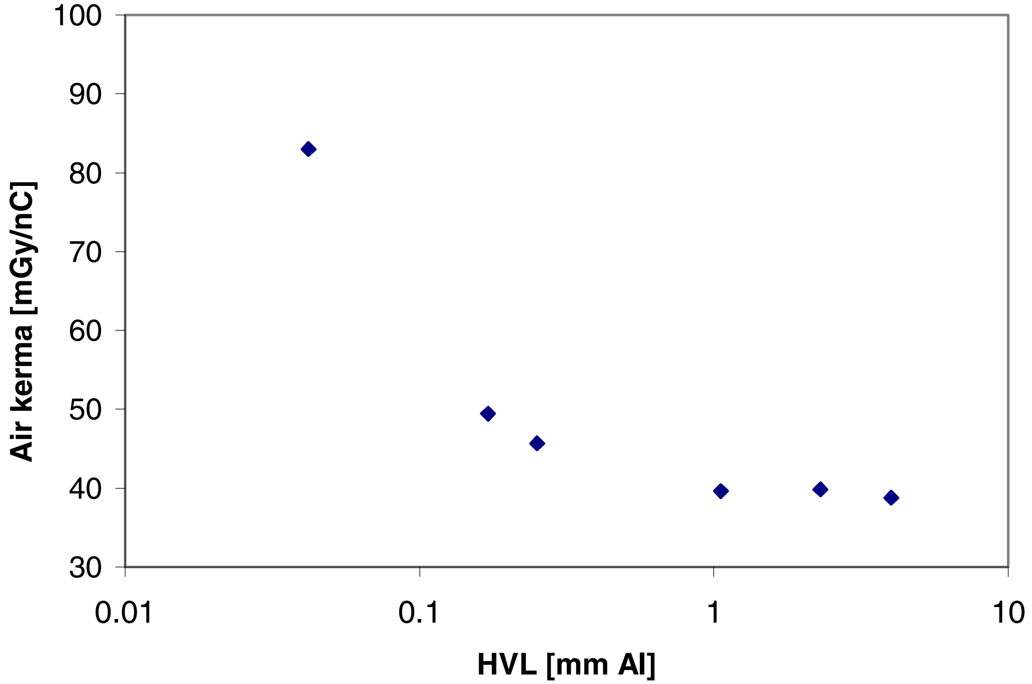

*FIGURE.1. Energy dependence of the air kerma calibration factor for the chamber NE-2571/1881.*

TABLE 1. RADIATION GENERATORS AND CALIBRATION CONDITIONS USED AT NRPA AND CRPH.

| Radiation quantity | Institution | Radiation generator | kV | Fixed filtration | Additional filtration | HVL or radionuclide | Field size [cm x cm] | SCD[b] [cm] | Dose rate[c] at SCD [mGy/min] |
|---|---|---|---|---|---|---|---|---|---|
| Air kerma | NRPA | PANTAK HF320C | 135 | | 2.03 mm Al + 0.236 mm Cu | 0.49 mm Cu | Ø = 10 cm | 50 | 157 |
| | | | 100 | | 3.52 mm Al | 0.15 mm Cu | Ø = 10 cm | 50 | 163 |
| | | | 50 | | 0.998 mm Al | 1.06 mm Al | Ø = 10 cm | 50 | 138 |
| | | SIEMENS GAMMTRON 3 | | | | Co-60 | 10 x 10 | 100 | 329 |
| | CRPH | PANTAK HF160C | 135 | 4.8 mm PMMA | 1 mm Al + 0.3 mm Cu | 0.50 mm Cu | Ø = 9 cm | 100 | 50 |
| | | | 100 | 4.8 mm PMMA | 3.4 mm Al | 4.00 mm Al | Ø = 9 cm | 100 | 51 |
| | | | 50 | | 1 mm Al | 1.00 mm Al | Ø = 9 cm | 100 | 50 |
| | | THERATRONICS PHOENIX | | | | Co-60 | 10 x 10 | 80 | 938 |
| Absorbed dose to water | NRPA | SIEMENS GAMMTRON 3 | | | | Co-60 | 10 x 10 [a] | 105 | 300 |
| | CRPH | THERATRONICS PHOENIX | | | | Co-60 | 10 x 10 [a] | 80 | 938 |

a Field size at phantom surface
b Source chamber distance
c Nominal air kerma or absorbed dose rate to water during calibration

TABLE 2. REFERENCE STANDARDS USED BY NRPA AND CRPH FOR THE CALIBRATION OF THE CHAMBER NE-2571/1881

| | | NRPA | CRPH |
|---|---|---|---|
| Chamber type | 50 kV | NE2536/3 | PTW23344 |
| | 100 kV | NE2561 | NE2561 |
| | 135 kV | | |
| | Co-60, $N_K$ | CAP PR-06G | |
| | Co-60, $N_{D,w}$ | CAP PR-06G | |
| Traceability | | BIPM, 1996 | IAEA, 1998 |
| Electrometer | | Keithley 35040 | NE2590 Ionex Dosemaster |

TABLE 3. SUMMARY OF THE UNCERTAINTIES EVALUATION. ALL FIGURES ARE GIVEN IN PERCENT.

| Radiation quality | BIPM[1] | IAEA[2] | NRPA | | | CRPH | | |
|---|---|---|---|---|---|---|---|---|
| | | | Type A | Type B | UNk[3] (k=1) | Type A | Type B | UNk[3] (k=1) |
| 50 kV | 0.27 | 0.54 | 0.13 | 0.23 | 0.27 | 0.03 | 0.36 | 0.36 |
| 100 kV | 0.21 | 0.21 | 0.11 | 0.11 | 0.15 | 0.03 | 0.23 | 0.23 |
| 135 kV | 0.21 | 0.21 | 0.11 | 0.11 | 0.15 | 0.03 | 0.23 | 0.23 |
| Co-60, $N_K$ | 0.34 | 0.21 | 0.06 | 0.11 | 0.12 | 0.03 | 0.18 | 0.18 |
| Co-60, $N_{D,w}$ | 0.44 | 0.24 | 0.09 | 0.11 | 0.14 | 0.03 | 0.24 | 0.24 |

[1] Combined standard uncertainty (k=1) reported by BIPM in the calibration certificate of the IAEA reference standard.

[2] Combined standard uncertainty (k=1) added by the IAEA in the calibration of the CRPH secondary standards. This has been calculated from quadratic difference of the combined standard uncertainties reported in the IAEA calibration certificate of the CRPH secondary standard and the BIPM uncertainties listed in first column of the table

[3] Combined standard uncertainty (k=1) of the calibration factors reported added by NRPA and the CRPH (without considering the uncertainties given by BIPM and IAEA respectively for secondary standards used in the comparison)

TABLE 4. AIR KERMA AND ABSORBED DOSE TO WATER CALIBRATION FACTORS OBTAINED AT NRPA AND CRPH USING THE CHAMBER NE-2571

| Calibration quantity | Radiation quality[1] | Calibration factors obtained [mGy/nC] | | Difference[2] (%) | Ur[3] (%) | En[4] |
|---|---|---|---|---|---|---|
| | | NRPA | CRPH | | | |
| Air kerma | 50 kV | 39.64 | 38.82 | -2.07 | 1.41 | 1.5 |
| | 100 kV | 38.77 | 38.87 | 0.25 | 0.69 | 0.4 |
| | 135 kV | 39.77 | 39.63 | -0.35 | 0.69 | 0.5 |
| | Co-60 | 41.18 | 41.23 | 0.12 | 0.61 | 0.2 |
| Absorbed dose to water | Co-60 | 45.11 | 45.07 | -0.10 | 0.73 | 0.1 |

[1] Details on the radiation qualities used in the intercomparison are presented in Table 1

[2] 100x(CRPH-NRPA)/NRPA

[3] Expanded uncertainty (k = 2) of the ratio of the calibration factors stated by NRPA and CRPH

[4] Differences divided by Ur

TABLE 5. REFERENCE LOW ENERGY X-RAY BEAM QUALITIES ESTABLISHED AT NRPA USED IN THE CHARACTERIZATION OF THE ENERGY DEPENDENCE OF THE NE-2571/1881 CHAMBER. (CALIBRATION FACTORS, WHICH WERE OBTAINED, ARE ALSO SHOWN. THE STANDARD UNCERTAINTY OF THE REPORTED CALIBRATION FACTORS IS ESTIMATED TO BE LOWER THAN 0.4%).

| Generating potential [kV] | Total filtration [mm Al ] | HVL [mm Al] | $N_k$ [mGy/nC] |
|---|---|---|---|
| 10 | 0.000 | 0.042 | 82.98 |
| 25 | 0.292 | 0.251 | 45.66 |
| 30 | 0.208 | 0.171 | 49.42 |
| 50a | 3.989 | 2.300 | 39.84 |
| 50b | 1.007 | 1.057 | 39.62 |

# DESIGN, CONSTRUCTION AND CALIBRATION OF PLANE-PARALLEL IONIZATION CHAMBERS AT THE SSDL OF IRAN

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**Abstract.** Two plane-parallel ionization chambers (PPICs) have been designed, constructed, tested and calibrated at the SSDL of the Atomic Energy Organization of Iran. The chambers are calibrated in $^{60}$Co and electron beams in comparison with the response of a reference calibrated cylindrical chamber and a commercial type PPIC. This paper presents the design characteristics and the results of calibration of the PPICs as well as dose determination of electron beams by air kerma based and absorbed dose to water based dosimetry procedures using these chambers.

## 1. INTRODUCTION

There are a number of codes, reports and protocols by national and international organizations, including IAEA, which provide physicists with a systematic approach to dosimetry of high-energy photon and electron beams [1-7]. Most of these dosimetry recommendations have explicitly recognized the advantages of using plane-parallel (or parallel-plate) ionization chambers (PPICs) for dosimetry of therapeutic beams, especially for electron beams with energies below 10 MeV. These chambers are found to be also suitable for use above 10 MeV.

Medical electron accelerators are used widely in developed countries and to a lesser extent in developing countries. Regarding the possibility of installing more medical linacs in radiotherapy departments in Iran (now only 3 units), attempts have been made at the SSDL to construct and make use of PPICs according to the IAEA TRS-381 [2] and the new IAEA code of practice, based on absorbed dose to water standards, TRS-398 [3].

## 2. DESIGN AND CONSTRUCTION OF PPICs

The constructional details of PPICs are described in IAEA TRS-381 (based on the International Standard IEC 731 [8]). The design characteristics, mainly the shape and height of the collecting volume, make PPICs theoretically ideal for ionization measurements in regions with sharp dose gradients in the beam direction or whenever the uncertainty in the position of the effective point of measurement of the ionization chamber is to be minimized. PPICs may be designed so that the chamber samples the electron fluence incident through the front window, the contribution of electrons entering through the sidewalls being negligible. The effective point of measurement, $P_{eff}$, is taken to be at the centre of the front inner surface of the air cavity. For practical purposes it is also convenient to choose the reference point of the chamber at the same position.

Based on recommended design and dimensions, two fully guarded PPICs, PP1 and PP2, suitable for measurements in plastic phantoms, were constructed at the SSDL. The chamber bodies and inner and outer electrodes are all made of PMMA with only a thin graphite coating on electrode surfaces (<0.02 mm). The diagram and basic design characteristics of PP1 and PP2 are given in Fig. 1 and Table 1. For comparison purposes, recommended dimensions and also those of a commercial PPIC, PTW W-34001, are also given in Table 1.

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TABLE 1. DIMENSIONS OF THE PLANE-PARALLEL CHAMBERS, PP1 AND PP2.

| | Recommended | PP1 | PP2 | PTW, W-34001 |
|---|---|---|---|---|
| Front window thickness, $t_w$(mm) | ≤1 | 1 | 1 | 1 |
| Collecting electrode diameter, $\phi_i$ (mm) | ≤20 | 13.5 | 14 | 15.6 |
| Cavity height, *a*(mm) | ≤2 | 1.8 | 2 | 2 |
| Ratio of guard width to cavity height, *g*/*a* | ≥1.5 | 2.8 | 2.4 | 2 |
| Sensitive volume (cm3) | 0.05 - 0.5 | 0.258 | 0.308 | 0.35 |

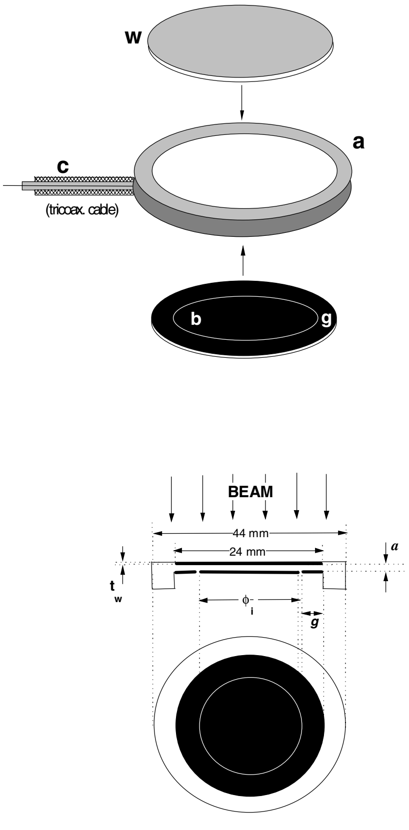

*FIGURE 1. Schematic diagram and dimensions of plane-parallel chambers, PP1 and PP2. w is the outer electrode, b inner electrode, g guard ring and a the cavity height.*

## 3. PRELIMINARY TESTS

Leakage current, short-term stability, cable effect and angular dependence of the chambers PP1, PP2 and W-34001 were all tested and found to be in consistency with the international standard (IEC 731) (ion collection efficiency and polarity effect were determined during calibration of the chambers in $^{60}$Co or electron beams).

An electrometer type PTW UNIDOS 10002 was used for all measurements and tests. Also, a $^{60}$Co therapy unit, type Picker V9, was used as a radiation source. For all tests, except test of angular dependence, the chambers were placed at a depth of 4.5 cm in a PMMA phantom. The PMMA phantom is constituted from 25 cm × 25 cm PMMA slabs with a thickness varying from 1mm to 20 mm.

*Leakage test*

The pre and post-irradiation leakage currents for chambers PP1 and PP2 were about $\pm 5 \times 10^{-15}$ A and $\pm 1 \times 10^{-14}$ A respectively. The pre and post-leakage currents for W-34001 were found to be about $\pm 1\times 10^{-15}$ A and $\pm 5\times 10^{-15}$ A respectively. Also, within 5 seconds after a 10-min irradiation, the transient leakage currents of the chambers decreased to less than 1% of the ionization currents during the irradiation.

*Short-term stability*

The relative standard deviation calculated from ten successive measurements was less than 0.5% in most cases.

*Cable effect*

The PPICs, PP1, PP2 and W-34001 were irradiated in a rectangular field, 4.5 cm × 22.5 cm (at phantom surface) in two situations. First, the cable was positioned parallel to the larger side of the irradiation field. In the second irradiation, the cable was positioned perpendicular to the larger side of the field. For both situations, the difference of the collected signals for both chambers was less than 1%.

*Angular dependence*

The chambers PP1, PP2 and also the commercial type PPIC, PTW W-34001, were irradiated in air at 80 cm distance from the source. The responses of the chambers were then obtained for several incident angles (θ) from –90° to +90°. The results of the measurements showed that the response variations of the chambers with respect to the incident angle, at least from –35° to +35°, were not significant (Fig.2).

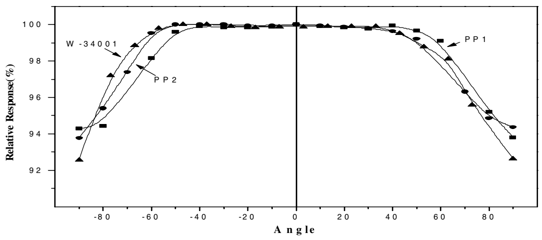

*FIGURE 2. Angular dependence of responses of plane-parallel ionization chambers P1, PP2 and PTW W-34001 in a $^{60}$Co radiation beam*

## 3.1 Ion collection efficiency and polarity effect

Ion recombination corrections were performed during calibration (section 4) of the PPICs, W-34001, PP1 and PP2, according to the two-voltage method. Two polarizing voltages, V1 = -200 V and V2 = -50 V, were used to determine the recombination correction factors, $k_s$, for the PPICs in $^{60}$Co (Picker V9) and pulsed-scanned electron beams of a CGR Saturn 20 medical linac. The results are shown in table 2.

The PPICs were tested for polarity effect and the results were found to be acceptable in $^{60}$Co beam. With the electron beams, after changing the polarity from -200 V to +200 V, establishment of charge equilibrium was not successful during irradiation time available for the SSDL. The experiments need to be repeated in the future to observe the polarity effect in electron beams. Yet, we have used the same polarity (negative) in all calibrations and measurements in order to minimize this effect.

TABLE 2. ION RECOMBINATION AND POLARITY EFFECT CORRECTIONS FOR PPICs.

| Radiation beam | $k_s$ | | | $k_{pol} = (M_{-}+M_{+})2M_{-}$ | | |
|---|---|---|---|---|---|---|
| | W-34001[a,c] | PP2[b,c] | PP1 | W-34001 | PP2 | PP1 |
| $^{60}$Co | 1.0003 | 1.002 | 1.003 | 0.998 | 1.009 | 0.996 |
| 17 MeV | 1.011 (1.010) | - | - | - | - | - |
| 13 MeV | 1.008 (1.008) | 1.012 (1.011) | - | - | - | - |
| 9 MeV | 1.009 (1.0085) | 1.010 (1.009) | - | - | - | - |
| 6 MeV | 1.007 (1.006) | 1.005 (1.004) | - | - | - | - |

[a] Performed in a water phantom. For $^{60}$Co $k_s = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - (M_1/M_2)}$, for pulsed-scanned electron beams $k_s = a_o + a_1(M_1/M_2) + a_2(M_1/M_2)^2$ where $M_1$ and $M_2$ are dosimeter readings at $V_1$ and $V_2$ respectively and $a_o = 1.468$, $a_1 = -1.200$ and $a_2 = 0.734$ are taken from TRS-381 [2].

[b] Performed in a PMMA phantom

[c] Values in parentheses were derived from $k_s - 1 = \frac{M_1/M_2 - 1}{V_1/V_2 - 1}$

## 4. CALIBRATION

There are two general approaches, i.e. air-kerma based and absorbed dose to water based dosimetry codes of practice, to the absorbed dose determination in high-energy photon and electron beams. The use of an ionization chamber for the determination of the absorbed dose to water in high-energy electron beams, requires the chamber to have either an absorbed dose to air chamber calibration factor, $N_{D,air}$, or an absorbed dose to water calibration factor at the radiation quality Q, $N_{D,w,Q}$ [2].

When the chamber has an $N_{D,air}$ factor, the absorbed dose to water, $D_w$, at the reference depth, $z_{ref}$, is given by:

$$D_{w,Q}\,(z_{ref}) = M_Q\, N_{D,air}\, (s_{w,air})_Q\, p_Q \tag{1}$$

Where $M_Q$ is the dosimeter reading corrected or influence quantities, $(s_{w,air})_Q$ is the stopping power ratio at the electron beam quality Q (defined by $\overline{E}_o$ and $z_{ref}$) and $p_Q$ is the overall perturbation factor.

When the chamber has a calibration factor in terms of absorbed dose to water at the reference quality $Q_o$, $N_{D,w,Qo}$, the absorbed dose to water at the reference depth is given by

$$D_{w,Q}(z_{ref}) = M_Q\, N_{D,w,Q_o}\, k_{Q,Q_o} \tag{2}$$

Where $k_{Q,Qo}$ is a chamber-specific factor which corrects for differences between the reference beam quality $Q_o$ and actual beam quality Q .

We have used and compared different calibration methods for the PPICs, W-34001, PP1 and PP2. Two Farmer type cylindrical chambers, NE-2571 and PTW W-30001, were used as reference chambers. Both of them were calibrated at the IAEA dosimetry laboratory in terms of air kerma and absorbed dose to water at $^{60}$Co radiation quality.

### 4.1 Determination of $N_{D,air}^{PP}$

In order to determine the $N_{D,air}^{PP}$ factors of PPICs, the $N_{D,air}^{ref}$ factors of the reference cylindrical chambers should be known. They were calculated by using the expression [2]

$$N_{D,air} = N_K(1-g)k_{att}k_m k_{cel} \tag{3}$$

Where $N_K$ is the air kerma calibration factor provided by the standard laboratory, $(1\text{-}g)$ = 0.997 (for $^{60}$Co), $k_m\, k_{att}$ are given for various cylindrical chambers in the IAEA TRS-277 and TRS-381 and $k_{cel}$ is equal to 1.006 for 1mm aluminium central electrode (farmer type). For the two ion chambers NE-2571 (#2695) and PTW W-30001 (#851), calibrated at the IAEA dosimetry laboratory, the results are shown in Table 3.

TABLE3: AIR KERMA CALIBRATION FACTORS

| Ion Chamber | $N_K$ (mGy/nC) | $k_{att}\, k_m$ | $k_{cel}$ | $N_{D,air}$ (mGy/nC) |
|---|---|---|---|---|
| NE 2571<br>(# 2695) | 41.1<br>± 0.5%<br>(IAEA, 1998) | 0.985<br>± 1% | 1.006<br>± 0.1% | 40.6<br>± 1.1% |
| PTW,<br>W-30001<br>(# 851) | 47.4<br>± 0.6%<br>(IAEA, 1997) | 0.972<br>± 1% | 1.006<br>± 0.1% | 46.21<br>± 1.2% |

The factors $N_{D,air}^{PP}$, for PP1 and PP2 chambers, were determined by comparing them with the chamber PTW W-34001 in a PMMA phantom. The latter was itself calibrated in comparison with the calibrated cylindrical chambers NE-2571 and PTW W-30001 in a water phantom. Calibration in $^{60}$Co gamma ray beam was performed for all three PPICs. But with the electron beam method, only the W-34001and PP2 chambers were calibrated.

### *4.1.1 Calibration in a $^{60}$Co gamma ray beam*

To determine the $N_{D,air}^{PP}$ factors of PP1 and PP2 in a $^{60}$Co gamma ray beam, the $N_{D,air}^{PP}$ factor of PTW W-34001 was first determined by comparing its response with that of a calibrated Farmer chamber, NE-2571, in a 30 cm × 30 cm × 30 cm water phantom in a gamma beam of a $^{60}$Co Picker V9 unit. The Source to Surface Distance (SSD) was 100 cm and the field size 10 cm × 10 cm at the phantom surface. The effective point of measurement of the PPIC, PTW W-34001, i.e. the centre of the front surface of the air cavity, and the centre of the reference Farmer chamber were positioned at the depth of 5 g/cm$^2$ respectively.

The $N_{D,air}^{PP}$ of the PPIC, PTW W-34001, is obtained from:

$$N_{D,air}^{PP} = N_{D,air}^{ref} \frac{M^{ref}}{M^{PP}} \frac{p_{wall}^{ref} p_{cel}^{ref} p_{dis}}{p_{wall}^{PP}} \qquad (4)$$

$M_{ref}$ and MPP are average electrometer readings for the two chambers (corrected for influence quantities temperature, pressure, ion recombination, polarity effect and leakage). The displacement factor $p_{dis}$ is obtained according to the relation [2] $p_{dis}$ = 1- 0.004 r, where r is the inner radius of the farmer chamber (in mm). For the NE-2571, $p_{dis}$ = 0.9874. The perturbation factor of the Farmer chamber is obtained according to (5) below:

$$p_{wall}^{ref} = \frac{\alpha s_{wall,air} (\mu_{en} / \rho)_{med,wall} + \tau s_{sleeve,air} (\mu_{en} / \rho)_{med,sleeve} + (1-\alpha-\tau) s_{med,air}}{s_{med,air}}$$

Substituting for ionization fractions (α and τ), stopping power ratios and mass energy absorption coefficients, we obtain $p_{wall}^{ref}$ = 0.9924. The central electrode correction factor for Farmer chamber is $p_{cel}$ = 0.994. The perturbation factor $p_{wall}^{PP}$ for W-34001 was estimated to be 1.003 in water (for $^{60}$Co). Substituting for the quantities in equation (4), the $N_{D,air}^{PP}$ of PTW W-34001 was determined to be :

$$N_{D,air}^{w-34001} = 72.00\ (mGy/nC) \pm 2.62\%$$

The $N_{D,air}^{PP}$ factors of PP1 and PP2 were determined by comparing their response with that of PTW W-34001 chamber in $^{60}$Co beam in a PMMA phantom. The irradiation conditions were the same as those used for calibration of PTW W-34001, except for the depth of measurement in PMMA which was $d_{pl}$ = 4.5 cm (≈5.05 g/cm$^2$). The dimensions, material and front window thickness of PP1, PP2 and PTW W-34001 are nearly identical so that:

$$N_{D,air}^{PP1\&2} = N_{D,air}^{W-34001} \left( \frac{M^{W-34001}}{M^{PP1\&2}} \right) \qquad (6)$$

The $N_{D,air}^{PP}$ factors for PP1 and PP2 were determined in this way to be:

$$N_{D,air}^{PP1} = 107.6\ (mGy/nC) \pm 2.85\%$$

$$N_{D,air}^{PP2} = 80.66\ (mGy/nC) \pm 2.85\%$$

### *4.1.2 Calibration in Electron Beams*

To perform a calibration in an electron beam, first the qualities of electron beams (CGR Saturn 20 medical linac) were determined. This linac produces electron beams with nominal energies of 6, 9, 13, 17 and 20 MeV. The plane-parallel chamber W-34001, was used to measure depth ionization distributions in a 30cm×30cm×30cm water phantom (Fig. 3). For all measurements, the SSD was set at 100 cm. The field size on the surface of the phantom was 12 cm × 12 cm for 6, 9 and 13 MeV electron beams, and 20 cm × 20 cm for 17 MeV. (Due to some trouble in the linac system, the electron beam with energy 20 MeV was not accessible at the time of conducting the measurement.)

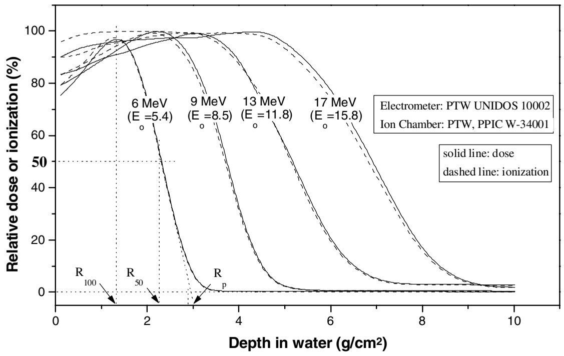

*FIGURE 3. Depth-dose and ionization distributions of a CGR Saturn 20 medical linac.*

The mean energies of electron beams at the phantom surface, $\overline{E}_0$, were calculated from the polynomial [2]:

$$\overline{E}_o (MeV) = 0.818 + 1.935 R_{50,\,ion} + 0.040\, (R_{50\,,ion})^2 \qquad (7)$$

The beam characteristic parameters $R_{50,\ ion}$, $R_{100,\ ion}$ and $R_{p,\ ion}$ were all obtained from depth-ionization curves and the depth-dose distributions were then obtained from ionizations multiplying by stopping-power ratio at each depth for each electron beam quality, $s_{w,air}(\overline{E}_0, z)$. All beam characteristic parameters derived from depth-dose and ionization distributions are given in Table 4. The values for $R_{50}$ *,dose* calculated from the relation $R_{50,\ dose} = 1.029\ R_{50,\ ion} - 0.06\ g/cm^2$, and suggested reference depth $z_{ref} = 0.6\ R_{50,dose} - 0.1\ g/cm^2$ (recommended in the IAEA TRS-398 and AAPM TG-51) are also given and compared with $R_{50}$ and $R_{100}$ obtained from depth-dose curves. However, we chose $R_{100}$ as the reference depth in this work, both for calibration and also for absorbed dose determination (section 5).

TABLE 4: BEAM CHARACTERISTIC PARAMETERS FOR A CGR SATURN 20 MEDICAL LINAC

| $E_0$ | $\bar{E}_0$ | $R_{50}$ $(g/cm^2)$ | | $R_{100}$ $(g/cm^2)$ | | $R_p$ $(g/cm^2)$ | | $z_{ref}$ $(g/cm^2)$ |
|---|---|---|---|---|---|---|---|---|
| (MeV) | (MeV) | *ion* | *curve*<br>$dose_{calc}$ | *ion* | *dose* | *ion* | *dose* | $=0.6\,R_{50}-0.1$ |
| 17 | 15.8 | 6.8 | 6.9<br>7.0 | 4.3 | 4.4 | 8.3 | 8.4 | 4.0 |
| 13 | 11.8 | 5.1 | 5.2<br>5.2 | 3.1 | 3.1 | 6.4 | 6.5 | 3.0 |
| 9 | 8.5 | 3.7 | 3.7<br>3.7 | 2.2 | 2.3 | 4.5 | 4.6 | 2.1 |
| 6 | 5.4 | 2.3 | 2.3<br>2.3 | 1.3 | 1.3 | 3.0 | 3.0 | 1.3 |

The electron beam with energy 17 MeV ($\bar{E}_o$ = 15.8 MeV) was used for calibration. The effective points of measurement of the cylindrical ion chamber, PTW W-30001, and the PPIC, PTW W-34001, were positioned at the same reference depth, $z_{ref} \approx 4.4$ cm ≈ R100, in a water phantom. The factor $N_{D,air}^{PP}$ of PTW W-34001 is obtained from:

$$N_{D,air}^{PP} = N_{D,air}^{ref} \frac{M^{ref}}{M^{PP}} \frac{p_{wall}^{ref} p_{cav}^{ref} p_{cel}^{ref}}{p_{wall}^{PP} p_{cav}^{PP}} \tag{8}$$

The perturbation factors, $p_{wall}^{ref}$, $p_{cav}^{PP}$ and $p_{wall}^{PP}$, are considered unity for the reference and PPIC in the electron beam method. The factor $p_{cel}^{ref}$ is 0.998 for a 1 mm diameter aluminium electrode. The factor $p_{cav}^{ref}$ (perturbation due to the air cavity of cylindrical chamber) is calculated from

$$p_{cav}^{ref}(\bar{E}_o, r) = 1 - 0.02155\, r\, e^{-0.02155\bar{E}_z} \tag{9}$$

Where r is the cavity radius in mm and $\bar{E}_z$ is the mean electron energy at depth z in water which can be obtained from and $R_p$ (practical range) using the relation:

$$\bar{E}_z \approx \bar{E}_o(1 - z / R_p) \tag{10}$$

Substituting r = 3.05 mm, $z_{ref}$ = 4.5 cm, Rp = 8.3 cm and $\bar{E}_o$ = 15.8 MeV, we obtain from Eqs. (9) and (10) that $p_{cav}^{ref}$ = 0.973.

Substituting for quantities in equation (8) would result in the factor $N_{D,air}^{PP}$ of PTW W34001 to be:

$N_{D,air}^{W-3400}$ =70.90 (mGy/nC) ± 1.92%

The two $N_{D,air}^{W-34001}$ factors, derived from $^{60}$Co method and electron beam method, differ by about 1.5%.

The factor $N_{D,air}^{PP}$ for PP2 chamber was determined by comparing its response with that of W-34001 in a 13 MeV electron beam in a PMMA phantom. This comparison is also repeated for 9 and 6 MeV electron beams.

$$N_{D,air}^{PP2}(mGy/nC) = \begin{cases} 79.5 \pm 2.22\% & (13\,\mathrm{MeV}) \\ 78.8 \pm 2.22\% & (9\,\mathrm{MeV}) \\ 79.0 \pm 2.22\% & (6\,\mathrm{MeV}) \end{cases}$$

## 4.2 Determination of $N^{PP}_{D,w,Co}$

In order to calibrate the PPICs, PP1 and PP2, in terms of absorbed dose to water at $^{60}$Co, we first determined the $N^{PP}_{D,w,Co}$ factor of W-34001 by comparing it with the response of the cylindrical chamber NE 2571(#2695), for which the $N_{D,w}$, at $^{60}$Co factor is known. The factors of PP1 and PP2 were then determined by comparing their response with that of W-34001 in a PMMA phantom. For this purpose, the same experimental set-up was used, and actually the same reading data (M) given in section 4-1-1.

The factor of W-34001 was obtained from:

$$N^{PP}_{D,w,Co} = N^{ref}_{D,w,Co}\left(\frac{M^{ref}}{M^{PP}}\right) \qquad (11)$$

The reference Farmer chamber, NE-2571(#2695), has an absorbed dose to water calibration factor ($^{60}$Co) $N_{D,w}$, = 45.1 mGy/nC ± 0.7% (IAEA, 1998). Using the same value for the ratio Mref/MPP as in section 4-1-1, the factor for the W-34001 was determined to be

$N^{W-34001}_{D,w,Co} =$ 83.17 (mGy/nC) ± 1.32%

Similarly, by using the $N^{W-34001}_{D,w,Co}$ factor and the same values for the ratios MPP1&2/MW-34001 as in section 4.1.1, the $N^{PP}_{D,w,Co}$ factors for PP1 and PP2 were determined to be:

$$N^{PP1}_{D,w,Co} = 123.15\, mGy/nC \pm 1.73\%$$

$$N^{PP2}_{D,w,Co} = 91.59\, mGy/nC \pm 1.73\%$$

Following the cross-calibration procedure, the calibration factor of the W-34001 chamber was also determined (in terms of absorbed dose to water) at the cross-calibration electron beam quality $\overline{E}_o$ = 15.8 MeV, R50 ≈ 7.0 g/cm2, against the cylindrical chamber W-30001. This chamber has an absorbed dose to water calibration factor ($^{60}$Co ) $N^{D,w}$ = 51.87 ± 0.52 mGy/nC (IAEA 1996). The calibration factor in terms of absorbed dose to water for the chamber under calibration, at the cross-calibration quality $Q_{cross}$ is given by:

$$N^{W-34001}_{D,w,Q_{cross}} = \frac{M^{W-30001}_{Q_{cross}}}{M^{W-34001}_{Q_{cross}}} \cdot N^{W-30001}_{D,w,\,Co} \cdot k^{W-30001}_{Q_{cross},\,Co} \qquad (12)$$

Where $M^{W-30001}_{Q_{cross}}$ and $M^{W-34001}_{Q_{cross}}$ are dosimeter readings for the reference chamber (W-30001) and the chamber under calibration (W-34001) respectively, corrected for influence quantities. $k^{W-30001}_{Q_{cross},Co}$ is the beam quality correction factor for the reference chamber. Substituting for the terms in Eq. 10, i.e. $N^{W-30001}_{D,w,Co}$ = 51.87 mGy/nC, $k^{W-30001}_{Q_{cross},Co}$ = 0.902 (IAEA $N_{D,w}$CoP, p. 80, Table

7-III) and the same value for the ratio $\frac{M^{W-30001}}{M^{W-34001}}$ as in section 4-1-2, we obtain:

$N^{W-34001}_{D,w,Q_{cross}}$ = 73.48 (mGy/nC) ± 1.75%

Finally, we determined the beam quality correction factors, $k_Q$, at 6, 9 and 13 MeV electron beams for PP2 by comparing its response with that of W-34001 in a PMMA phantom, $k_Q^{PP2}$.

$$k_Q^{PP2} = \left(\frac{M^{W-34001}}{M^{PP2}}\right)_Q \cdot \left(\frac{N^{W-34001}_{D,w}}{N^{PP2}_{D,w}}\right)_{Co} \cdot k_Q^{W-34001} \qquad (13)$$

$k_Q$ for PP2 and W-34001 are given in Table 5.

TABLE 5. BEAM QUALITY CORRECTION FACTORS FOR W-34001 AND PP2

| Beam Energy (MeV)<br>*$R_{50}$ (g/cm$^2$)* | | 6<br>*2.3* | 9<br>*3.7* | 13<br>*5.2* |
|---|---|---|---|---|
| KQ | W-34001 | 0.946 | 0.930 | 0.916 |
| | PP2 | 0.943 | 0.927 | 0.916 |

Whereas the relative uncertainty associated with $k_Q$ values for W-34001 is given to be 1.7% (IAEA TRS-398, Table 7.VII), the uncertainty for $k_Q^{PP2}$ values are estimated to be around 2.2%.

## 5. DETERMINATION AND COMPARISON OF ABSORBED DOSE TO WATER IN ELECTRON BEAMS USING $N_K$ AND $N_{D,W}$ BASED METHODS

Equations (1) and (2) are used to determine absorbed dose to water rate at the central axis of electron beams in reference conditions. For all beams the reference conditions were taken to be at an SSD of 100 cm, field size at the phantom surface of 10 cm × 10 cm and $z_{ref} \approx R_{100}$. Table 6 shows the results of measurements of the PPIC and W-34001.

In order to estimate the overall uncertainty in the absorbed dose determinations, we have to combine uncertainties due to the various parameters and measurements. Depending on the method of absorbed dose determination (equations 1 or 2), the sources of uncertainties and estimated values are given in Tables 7A, 7B and 7C.

TABLE 6: RESULTS OF ABSORBED DOSE TO WATER DETERMINATION IN ELECTRON BEAMS OF A CGR SATURN 20 MEDICAL LINAC (USING A W-34001 ION CHAMBER).

| E(MeV) | | 6 | 9 | 13 | 17 |
|---|---|---|---|---|---|
| $D_w$ (cGy/100 m.u.)=<br>$M \cdot N_{D,air} \cdot s_{w,air} \cdot p_Q$ | $N_{D,air,Co}$ (3.4%)* | 124.4 | 142.0 | 72.2 | 96.5 |
| | $N_{D,air,Q}$ (3%)* | 122.5 | 140.8 | 71.1 | 95.0 |
| $D_w$ (cGy/100 m.u.)=<br>$M \cdot N_{D,w} \cdot k_Q$ | $N_{D,w,Co}$ (2.8%)* | 123.2 | 143.2 | 72.1 | 97.8 |
| | $N_{D,w,Q_{cross}}$ (2.6%)* | 121.2 | 141.5 | 71.3 | 96.7 |
| | avg. | 122.8±1.1% | 141.9±0.7% | 71.7±0.8% | 96.5±1.2% |

* Combined standard uncertainty

TABLE 7A. SOURCES OF UNCERTAINTIES RELATED TO THE USE AN ION CHAMBER WITH AN $N_{D,AIR}$ OR AN $N_{D,W,Q}$ FACTOR

| | Uncertainty (%) |
|---|---|
| Experimental set-up (establishment of reference conditions) | 1 |
| Dosimeter reading corrected for influence quantities, *M* | 1 |
| Long-term stability (overestimated) | 1<br>(W-34001)<br>2<br>(PP1&2) |

TABLE 7B. SOURCES OF UNCERTAINTIES RELATED TO THE USE OF $N_{D,AIR}$

| | Uncertainty (%) |
|---|---|
| $N_{D,air}$ | $^{60}$Co method<br>$\begin{cases} \text{W} - 34001: 2.62 \\ \text{PP1} \& 2: 2.85 \end{cases}$<br>electron beam method<br>$\begin{cases} \text{W} - 34001: 1.92 \\ \text{PP2}: 2.2 \end{cases}$ |
| $s_{w,air}$ | 0.7 (theoretical)<br>1 (selected) |
| $p_Q$ | 1 |

TABLE 7C. SOURCES OF UNCERTAINTIES RELATED TO THE USE OF $N_{D,W,Q}$

| | Uncertainty (%) |
|---|---|
| $N_{D,w,Q}$ | $^{60}$Co method<br>$\begin{cases} \text{W} - 34001 : 1.32 \\ \text{PP1} \,\&\, 2 : \quad 1.73 \end{cases}$<br>electron beam method :1.9<br>(W-34001, $N_{D,w,Qcross}$) |
| $k_{Q,Qo}$ | W-34001<br>$\begin{cases} 1.7 \quad (k_Q) \\ 0.6 \quad (k_{Q,Q_1} \quad Q_1 = 17\ MeV) \end{cases}$<br>PP2 : 2.2 ($k_Q$) |

The standard deviation of the mean value of the absorbed doses as measured by W-34001 and determined by different methods for each energy is significantly less than the estimated combined uncertainties, which suggest a good agreement of the results regardless of the applied methods, and associated uncertainties.

The combined relative standard uncertainties related to the absorbed dose determined by different methods are presented in Table 8.

TABLE 8: ESTIMATED COMBINED UNCERTAINTY

| Calibration procedure | $N_{D,air}$ | | | | $N_{D,w}$ | | |
|---|---|---|---|---|---|---|---|
| | $^{60}$Co beam | | electron beam | | $N_{D,w,Co}$ | | $N_{D,w,Qcross}$ |
| Combined | W-34001 | PP1&2 | W-34001 | PP2 | W-34001 | PP1&2 | W-34001 |
| Uncertainty in $D_w$ (%) | 3.4 | 3.9 | 3.0 | 3.6 | 2.8 | 3.7 | 2.6 |

## 6. CONCLUSION

Plane-parallel ionization chambers (PPICs) are found to be very suitable for dosimetry of electron beams in radiotherapy and their use is recommended by most of the dosimetry protocols. Following IAEA dosimetry recommendations in TRS Nos. 277, 381 and the new international Code of Practice, TRS-398, we constructed two PPICs and calibrated them in comparison with the responses of calibrated commercial type cylindrical and plane-parallel ionization chambers. We also determined and compared absorbed dose in a few electron beam qualities, of a medical linear accelerator, using air-kerma based and absorbed dose to water based methods. This work may be considered as a valuable experience and exercise for SSDL staff, who conduct dosimetry and quality audits for radiotherapy centres.

## ACKNOWLEDGEMENTS

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# REPORT OF A NORDIC DOSIMETRY MEETING ON THE IMPLEMENTATION OF THE NEW INTERNATIONAL CODE OF PRACTICE FOR RADIOTHERAPY DOSIMETRY, TRS-398.

Participants.

| | | |
|---|---|---|
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Norwegian National Radiation Protection Authority (NRPA), Oslo, January 2001 (Chairperson: Hans Bjerke.)

## 1. BACKGROUND

For the last few years the SSDLs in the Nordic countries have developed secondary standards for radiation measurements based on the physical quantity "absorbed dose to water", traceable to the Bureau International des Poids et Mesures (BIPM). While this development has built up the capability of the Nordic SSDLs to initiate a new service to radiotherapy dosimetry users, so far calibrations in terms of absorbed dose to water have not been disseminated in the Nordic countries due to the lack of an international dosimetry protocol based on such standards. This has been in consistency with the advice given in 1995 to all laboratory members of the IAEA/WHO Network of SSDLs [1].

On behalf of the IAEA, WHO, PAHO and ESTRO, the IAEA has developed an international Code of Practice for the dosimetry of radiotherapy beams based on standards of absorbed dose to water, that provides recommendations for electron and photon beams, including kV x-rays, as well as for the less common proton and heavy ion radiotherapy beams. The Code of Practice has been issued as the publication IAEA TRS-398 [2].

A Nordic dosimetry meeting was convened in Oslo on January 19 2001 in order to discuss the possibility of adopting the international Code of Practice in a coordinated approach by all the Nordic countries and to develop, whenever possible, common strategies for its implementation. This report summarizes the main discussions and conclusions of the meeting.

Major points of discussion:

There was unanimous agreement among the participants that the situation was ripe for the dissemination of $N_{D,w}$ calibrations in the Nordic countries, as in most western European countries that have not yet adopted these standards, and that the international Code of Practice, IAEA TRS-398, should be adopted. Specific recommendations for the implementation are given below. The advantages described in TRS-398 for the Code of Practice (CoP), namely a simplified formalism, reduced uncertainty, robustness of the system of standards, and harmonized procedures for all types of beams, were emphasized. Major arguments discussed were:

### 1.1 In favour of not adopting the CoP

The CoP will change reference dosimetry of photon and electron beams very little, compared with the procedures currently in use at the Nordic hospitals. The costs and work required could be regarded as excessive considering its potential benefit.

### 1.2 In support of the implementation of the CoP

1. There are at present several international dosimetry protocols in use that potentially lead to a lack of homogeneity in reference dosimetry (beam calibration). Whereas the implementation of the first version of IAEA TRS-277 (1987) was harmonized in the Nordic countries, the updated version of TRS-277 (second edition, 1997) and the Code of Practice for plane-parallel chambers (IAEA TRS-381) may or may not have been implemented at the Nordic hospitals, except in Finland (where both the updated TRS 277 and TRS 381 have been implemented).

2. Updating the knowledge of medical physicists in basic dosimetry by incorporating into clinical use the most recent scientific developments in Standard Laboratories and basic dosimetry. This also motivates awareness among users of the advances in radiation dosimetry made in recent years.
3. New equipment is available today for which no dosimetry data exists in current protocols. Information and dosimetry data for new ionization chambers and phantoms has been included in the international CoP for equipment available commercially at the end of 2000.
4. Countries like UK and Germany have based their reference dosimetry on absorbed dose to water standards (ADWS) for approximately 10 years, and these countries are the major manufacturers of equipment for reference dosimetry. Such equipment is often supplied with $N_{D,w}$ calibrations. Some users may have switched to ADWS-based dose determinations at hospitals without the existence of a national recommendation. The adoption of the new Code of Practice at national level decreases the likelihood of "outliers".
5. As for costs, the SSDLs (except for Sweden) recommend a cost-free calibration of ionization chambers in terms of $N_{D,w}$ to users that request a $N_K$-calibration during the implementation period (i.e., $N_K$ and $N_{D,w}$ calibration factors will be supplied).

## 2. RECOMMENDATIONS

The following recommendations emerged from the discussions:

1. The international Code of Practice for radiotherapy dosimetry, IAEA TRS-398, should be adopted in the Nordic countries. The entire Code of Practice should be implemented (i.e., also for low and medium-energy kV x-rays).
2. The transition from the $N_K$-based dosimetry protocol, currently in use, to $N_{D,w}$ can be made gradually, according to the availability of calibrations supplied by the SSDLs, but not later than 2002-12-31. From that date on SSDLs will not supply $N_K$ calibrations on a routine basis.
3. SSDLs will commence calibrating chambers in terms of $N_{D,w}$ simultaneously with requests for $N_K$ calibration factors. The $N_{D,w}$ factors will be provided to the users by the SSDL according to an established national schedule. The $N_{D,w}$ calibration factor will include an informative brochure on the adoption of TRS-398 and recommendations for its use.
4. In order to make the transition as smooth as possible, users without $N_{D,w}$ calibrations are recommended to gain experience on the new CoP by using $N_{D,w}$ factors calculated from $N_K$ calibration factors. This can be done using eq. (A.10) of IAEA TRS-398.

## 3. SPECIAL RECOMMENDATIONS FOR THE SSDLs

1. The SSDLs will inform users of the availability of the new type of calibrations at the time that information on the present meeting is disseminated.
2. The SSDLs will prepare an informative brochure on the adoption of TRS-398 and recommendations for its use. Special attention will be given to the avoidance of confusion with regard to the physical quantity and dosimetry procedures that apply to $N_K$ and $N_{D,w}$ calibration factors.
3. The SSDLs will compile information on the differences in reference dosimetry at national level resulting from the adoption of the new international CoP for different beam qualities and beam types. The information will be disseminated so that users can be aware of the expected differences for beams and dosimetry equipment similar to theirs.
4. The SSDLs will exchange information on their experience implementing the Code of Practice in their respective countries.

## 4. CLINICAL IMPACT

The change in the calibration of radiotherapy beams, i.e. the determination of absorbed dose to water in reference conditions, is estimated to be around 1% for high-energy photon beams and 1.5% for the majority of electron beams. The largest contribution, close to 1%, arises from the adoption of the new type of standard by the laboratories ($D_w$ versus $K_{air}$), which is consistent with the current trend world wide among standard laboratories. The adoption of the international Code of Practice introduces, per se, only minor changes compared with the use of the second version of TRS-277 and TRS-381 as most basic data are identical (see Appendix A in the Code of Practice). It should be noted that the changes would be slightly larger for users who still use the first version of TRS-277 (the changes will be larger for institutions outside the Nordic countries where the North American protocol AAPM TG-21 is being used [3]).

## 5. SUPPORT TO USERS FOR THE IMPLEMENTATION OF THE CODE OF PRACTICE

In addition to supplying ionization chamber calibration factors in terms of $N_{D,w}$, the SSDLs in the Nordic countries will adopt strategies that vary from one country to another. Meetings with national associations and groups of medical physicists will include sessions on the implementation of the new Code of Practice. Plans have been devised for supporting the training in other ways, and for example, in Norway site visits will be organized before July 2001, in Sweden a national course will be organized probably before the summer of 2001, and in Finland both site visits and meetings will be organized.

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# CALIBRATION OF WELL TYPE IONIZATION CHAMBERS FOR HIGH DOSE RATE (HDR) $^{192}$IR QUALITY[1]

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## 1. INTRODUCTION

Since 1996, the IAEA has maintained standards for Low Dose Rate (LDR) brachytherapy dosimetry. These standards consists of two $^{137}$Cs sources, calibrated at the National Institute of Standards and Technology (NIST), USA. Detailed data are shown in Table 1.

TABLE 1. $^{137}$Cs LDR STANDARDS FOR BRACHYTHERAPY DOSIMETRY AT THE IAEA.

| Source | Capsule | | Active | KR |
|---|---|---|---|---|
| | Length (mm) | Diameter (mm) | Dimensions[2] (mm) | (01-05-96) (µGy/h) |
| CDCS J5 | 20 | 2.65 | 13.5 | 190.5 |
| CDC1100 | 8.0 | 3.2 | 2.2 | 339 |

Thus, calibration of well type chambers using the sources shown in Table 1, yields traceability to NIST.

For the maintenance of the standards, a well type chamber (HDR 1000 Plus, Standard Imaging, USA) and a dedicated electrometer (CDX-2000A, Standard Imaging, USA) are used.

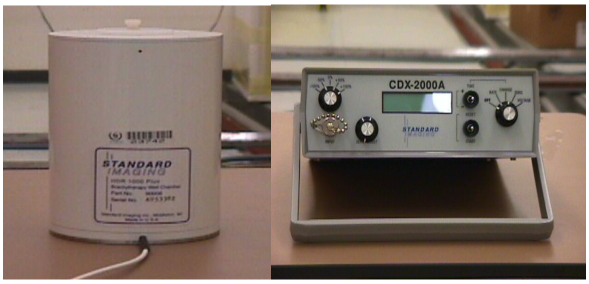

*FIGURE 1. The HDR 1000 Plus well type chamber and the CDX-2000A electrometer.*

## 2. CALIBRATION OF WELL TYPE IONIZATION CHAMBERS AT THE IAEA DOSIMETRY LABORATORY

The IAEA has provided well type chambers to Secondary Standard Dosimetry Laboratories (SSDLs) and to radiotherapy centres since few years. The initial calibration of the chambers for LDR $^{137}$Cs and HDR $^{192}$Ir qualities is made by the Accredited Dosimetry Calibration Laboratory (ADCL) at the University of Wisconsin, USA.

The IAEA TECDOC-1079 [1], recommends that well type chambers should be calibrated every 5 years or when indicated by the periodic constancy checks.

The re-calibration for LDR $^{137}$Cs quality can be obtained from the IAEA Dosimetry Laboratory. However, the IAEA Dosimetry Laboratory does not maintain standards for HDR $^{192}$Ir quality and cannot do so within a foreseeable future because of the high costs associated with it.

Those SSDLs that have a calibration service for (HDR) $^{192}$Ir quality and need to re-calibrate the well type chamber may do so by sending the chamber to the ADCL mentioned above. This, however, is related with relatively high costs that may be an obstacle for some SSDLs. This means that some SSDLs are faced with problems: the needs of providing traceable calibrations to the radiotherapy centres and at the same time keeping the metrological quality at the highest possible level.

The conclusions and recommendations worked out with the consultants can be summarized as follows:

The complicated energy spectrum of Ir-$^{192}$ HDR includes about 40 energies falling approximately

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[1] This follows a Consultants' Meeting held during 7-11 May 2001 at IAEA, Vienna. The Scientific Secretary of the meeting was Mr. H. Tölli.

[2] The CDCS J5 source consists of 9 active pellets, each with a 1.5 mm diameter. The CDC1100 consists of a single active pellet with 2.2 mm diameter.

between 50 keV and 700 keV and with an average energy of 397 keV. Checks of the well type chambers response at the 'end' energies, i.e. 50 keV and 700 keV should be performed. If the response of the chamber does not change significantly with time at these energies, it may be concluded that the chamber's calibration factor for Ir-192 HDR remains unchanged. In practice, it is possible to use Am-241 (average energy 60 keV) and Cs-137 (average energy 661 keV) check sources for this purpose.

The recommendations given by the Consultants were:

- The IAEA continues to provide calibrations for $^{137}$Cs LDR quality
- During each calibration at the IAEA, a constancy check of the well type chamber, using an $^{241}$Am source shall be made
- Upon receipt of a well type chamber, the SSDL shall make a check of the chamber's response using e.g. the sources mentioned above.

The Consultants realized that the recommended method is not of the highest metrological quality, but is the best possible with regard to the financial constraints that are present. It was also mentioned that the situation is similar to that in external beam dosimetry; ionization chambers are often calibrated for $^{60}$Co quality only but are frequently used at other qualities.

## 3. CONSTANCY CHECKS OF THE WELL TYPE IONIZATION CHAMBER

The recommendations worked out together with the Consultants means that the well type chamber's response should be checked at energies that envelope the HDR $^{192}$Ir energies. Suitable sources for this purpose are those given in the previous section, even though other options may be present. Figure 2 below shows the constancy checks of the IAEA Dosimetry Laboratory's well type chamber using a $^{241}$Am source. These checks have been performed for few months. For comparison, constancy checks made during the same period using a $^{137}$Cs LDR source are shown in the same figure.

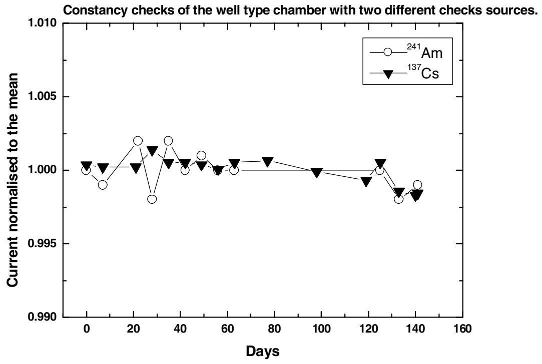

*FIGURE 2. Constancy checks of the IAEA well type chamber during a period of 140 days.*

From figure 2 it can be seen that a $^{241}$Am source is suitable as a check source.

The activity of $^{241}$Am check sources is generally rather low and the measured current will therefore be lower than that obtained with a LDR $^{137}$Cs source. An indication of this can be seen in figure 2, in which the scatter for $^{241}$Am measurements is slightly higher than for $^{137}$Cs. The scatter is due to effects of the system leakage (well chamber and electrometer) that is more significant at lower activities. The activity of the source used for measurements shown in figure 2 was about 10mCi and the measured current was of the order of 5pA. For comparison, the measured current with the $^{137}$Cs check source was approximately 650pA. To make the measurements meaningful, the electrometer needs to be able to measure currents in this range. Suitable electrometers are e.g. UNIDOS T10002 Universal Dosimeter or Keithley 617. The CDX-2000A, which is designed more for high currents, is not suitable for this purpose.

## 4. CONCLUDING REMARKS

The IAEA Dosimetry Laboratory has received requests for re-calibration of well type chambers for HDR $^{192}$Ir quality. As is mentioned in the previous section, the IAEA does not maintain standards for this quality. Such standard is rather expensive, requiring an afterloading unit to be installed in the irradiation bunker. Due to the short half-life of $^{192}$Ir (approximately 74 days) makes the useful life-time of the source rather short. Frequent source exchanges are another issue that may turn out to be problematic.

In order to solve the problems associated with HDR $^{192}$Ir calibrations, the Dosimetry and Medical Radiation Physics Section organized a Consultants' Meeting. It can be expected that the recommendations given by the Consultants, as described in the previous sections, should be sufficient in order for the SSDLs to provide calibrations of well type for HDR $^{192}$Ir quality and at the same time keeping the metrological quality at a highest possible level.

In the future, all well type ionization chambers that the IAEA provides to the SSDLs will first be sent to the IAEA Dosimetry Laboratory for calibration at LDR $^{137}$Cs quality and for determination of the chamber's response to $^{241}$Am. When the chamber returns to the IAEA for re-calibration for LDR $^{137}$Cs, a new constancy check will be made using the $^{241}$Am source. If both the re-calibration with LDR $^{137}$Cs and the constancy check using the $^{241}$Am agree to within certain limits with their previous values (e.g. ± 0.5 %), it can be concluded that the chamber's calibration factor for HDR $^{192}$Ir has not changed.

## REFERENCE

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# COURSES AND MEETINGS TO BE HELD DURING 2001

## Training courses in the field of dosimetry and medical radiation physics

| | |
|---|---|
| September 10-14 | RCA Regional Training Course on Radiobiological and Physical Aspects of LDR and HDR Brachytherapy in Uterine Cervix Cancer, Jaebashi, Japan (dates to be confirmed) (RAS/6/035) |
| October 8-12 | Workshop on use of Treatment Planning Systems type Theraplan plus, Freiburg, Germany, (RAF/6/027) |
| October 8-12 | Regional Workshop on the calibration of protection level dosimetry instruments, Riga. Latvia (RER/1/004) |
| November | Quality Assurance and Quality Control in X-ray Diagnostics, Yerevan, Armenia (two weeks, dates to be fixed) (ARM/6/004) |

**ESTRO courses under RER/6/012:**

| | |
|---|---|
| August 29- September 2 | Modern Brachytherapy Techniques (with Russian translation), Bratislava, Slovakia |
| August 26-30 | Physics for Clinical Radiotherapy, Leuven, Belgium |
| October 7-11 | Evidence-Based Radiation Oncology; Principles & Methods, Cairo, Egypt |
| October 7-11 | Basic Clinical Radiobiology, Tenerife, Spain |

**Meetings**

- Programme Committee Meeting for the 2002 International Symposium on standards and codes of practice in medical radiation dosimetry, 1-3 October 2001, IAEA Headquarters, Vienna.

- Consultants' Meeting on Intercomparison of ionization chamber calibration factors in X-ray beams. 22-25 October 2001, IAEA Headquarters, Vienna.

- First Research Co-ordination Meeting on the development of techniques at SSDLs for the dissemination of absorbed dose to water standards. 5-9 November 2001, IAEA Headquarters, Vienna.

- Second Research Co-ordination Meeting on EPR biodosimetry (E2.40.11), 26-30 November 2001. IAEA Headquarters, Vienna.

- Consultants' Meeting on establishing procedures for on-site review visits, 5-11 December 2001. IAEA Headquarters, Vienna.

- Consultants' Meeting to develop QA methods for radiotherapy dose calculations and computerized treatment planning systems, 12-16 November 2001, IAEA Headquarters, Vienna.

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[1] Kindly notify the Dosimetry and Medical Radiation Physics Section if the information here is incorrect or changes.

# COLLABORATING ORGANIZATIONS ASSOCIATED WITH THE IAEA/WHO NETWORK OF SSDLs

International Bureau of Weights and Measures (BIPM)
International Commission on Radiation Units and Measurements (ICRU)
International Electrotechnical Commission (IEC)
International Organization of Legal Metrology (IOML)
International Organization of Medical Physics (IOMP)

## AFFILIATED MEMBERS OF THE IAEA/WHO NETWORK OF SSDLS

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| Bundesamt für Eich und Vermessungswesen (BEV) | Vienna, AUSTRIA |
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| National Research Council (NRC) | Ottawa, CANADA |
| Laboratoire de Metrologie des Rayonnements Ionisants (LMRI) | Saclay, FRANCE |
| Physikalisch-Technische Bundesanstalt (PTB) | Braunschweig, GERMANY |
| National Office of Measures (OMH) | Budapest, HUNGARY |
| Ente per le Nuove Tecnologie L'Energia e L'Ambiente (ENEA) | Rome, ITALY |
| Electrotechnical Laboratory (ETL) | Tsukuba, JAPAN |
| Rijks Institut voor Volksgesundheid (RIVM) | Bilhoven, NETHERLANDS |
| National Radiation Laboratory (NRL) | Christchurch, NEW ZEALAND |
| Scientific Research Institute for Physical-Technical and Radiotechnical Measurements (VNIIFTRI) | Moscow, RUSSIAN FEDERATION |
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| Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) | Madrid, SPAIN |
| National Physical Laboratory (NPL) | Teddington, UNITED KINGDOM |
| National Institute for Standards and Technology (NIST) | Gaithersburg, USA |