Absorbed Dose and Air Kerma Primary Standards Workshop

General Programme

Programme of Sessions

Paris 9 - 11 May 2007
### Workshop on “Absorbed Dose and Air Kerma Primary Standards”

#### Programme

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**Notes:**
- **Friday, 11 MAY**:
  - Departure for visits of laboratories: 14h00-17h00
  - Visits: 14h00-17h00
  - Round table Ionization chambers: 14h50-15h20
  - General discussion: 16h30
  - End of Workshop: 17h20

- **General discussion:**
  - Conclusions
  - Next workshops
  - Recommendations to CCRI(I)

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- Fax: +32 2 378 36 88
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## Programme of sessions

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Session A and B: Water calorimetry
Application of water calorimetry as absorbed dose to water standards for radiotherapy dosimetry

Achim Krauss

Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

achim.krauss@ptb.de

Oral presentation

At PTB, efforts are being made to apply water calorimetry for radiotherapy dosimetry in various irradiation conditions and in various radiotherapy beams. Besides the primary standard water calorimeter used in $^{60}$Co-radiation to calibrate ionization chambers in terms of absorbed dose to water under reference conditions, a “transportable” calorimeter with a more compact design has been used in high-energy photon radiation at the PTB linac for the investigation of the energy dependent response of ionization chambers in radiation field sizes of 10 cm $\times$ 10 cm and 5 cm $\times$ 5 cm, respectively. Similar investigations will be performed with this calorimeter in high energy electron radiation. Further possible applications of water calorimetry are the determination of absorbed dose to water in medium energy x-ray beams, in high energy heavy ion beams and for photon brachytherapy sources. Corresponding calorimetric experiments have been already carried out in 70 kV, 100 kV and 150 kV x-ray beams, respectively and in close geometry to a 370 GBq $^{192}$Ir-brachytherapy source. Measurements in a scanned 350 MeV carbon ion beam will be done still this year. As the irradiation conditions in all these experiments strongly differ from those of $^{60}$Co-irradiations, an essential step to achieve the absorbed dose to water is the correct interpretation of the time evolution of the thermal signal given by the calorimeter. The paper discusses this topic with emphasis on heat conduction effects occurring during the different calorimetric measurements.
Water calorimeter-based electron beam reference dosimetry and determination of beam quality conversion factors for clinical electron beams

K J Stewart¹, C K Ross², N V Klassen², J P Seuntjens¹

¹Medical Physics Unit, McGill University Health Centre, Montreal, Canada
²Ionizing Radiation Standards Group, National Research Council of Canada, Ottawa, Canada

Corresponding author (name and e-mail address): Kristin Stewart :
(kristins@medphys.mcgill.ca)

Oral presentation

Text: In this paper we describe the development of an Electron Sealed Water (ESW) calorimeter for determination of absorbed dose to water in clinical electron beams and for the measurement of $k_Q$ for ionization chambers. We evaluated the correction factors and performed extensive measurements of $k_Q$. The calorimeter contains a $30 \times 30 \times 20$ cm$^3$ water phantom surrounded by a cooling system for operation at 4°C. The resistance of thermistor probes inside a glass vessel was measured using a lock-in amplifier and AC bridge circuit. Glass perturbation corrections were calculated with Monte-Carlo techniques. Thermal conduction corrections were simulated with Comsol Multiphysics finite element modelling software. Measurements were done for 6 to 20 MeV electron beams and 6 and 18 MV photon beams. Measurements were also taken with a PTW Roos and an Exradin A12 chamber. Corrections were less than 1% for all beams except 6 MeV for which the corrections were 1.024 and 1.018 for glass perturbation and thermal conduction respectively. The standard uncertainty on the mean temperature change for 30 calorimeter irradiations was less than 0.2% for all energies. The standard deviation for 11 separate measurements of the 12 MeV beam was 0.2%.
A High-resolution Ultrasonic Thermometer for Measuring Absorbed Dose in Water Calorimeters

H. Heather Chen-Mayer and Ronald E. Tosh

Ionizing Radiation Division, National Institute of Standards and Technology
Gaithersburg, MD 20899   USA

Corresponding author (name and e-mail address): H. Heather Chen-Mayer : (chen-mayer@nist.gov)

Oral presentation

We are testing a high-resolution ultrasonic thermometer with a noise floor at the µK level to improve the accuracy of radiation dosimetry methods that rely upon water calorimetry as a primary standard. Conventional water calorimeters, based upon the original design of Domen, detect temperature changes in irradiated water with thermistors that are sealed inside a thin sheath of glass. Recovering absorbed dose to water from these measurements requires the application of several correction factors to compensate for spurious heat sources -- due to self-heating of the thermistors and excess heat induced in nonwater materials by the radiation -- and effects of heat transfer due to dose gradients within the phantom. The ultrasonic approach dispenses with nonwater materials inside the water phantom, thereby eliminating or reducing sources of excess heat and the corresponding dose gradients. The prototype instrument, which involves a single ultrasonic transducer and an analog pulsed phase-locked loop, has been tested in $^{60}$Co, and initial measurements have yielded values of absorbed dose to water that are within 10% of the nominal value, with a temperature sensitivity of 10 µK. A digital prototype of this instrument shows considerable promise for improving temperature sensitivity by one order-of-magnitude and for characterizing 3D dose profiles in water.
Vessel Designs and Correction Factors for Water Calorimetry

C. K. Ross, M. R. McEwen and N. V. Klassen

Ionizing Radiation Standards, Institute for National Measurement Standards, National Research Council, Ottawa, ON K1A 0R6, Canada

Corresponding author (name and e-mail address): Carl Ross : (carl.ross@nrc-cnrc.gc.ca)

Oral presentation

Water calorimetry yields directly the absorbed dose to water but is technically complicated because of the need for well-defined aqueous systems. It is also limited in its capabilities to measure the absorbed dose in the presence of strong dose gradients as are encountered in electron beams. We describe the construction and performance of two types of vessels to address these issues. The first is an all-glass vessel which can maintain a high-quality aqueous system indefinitely. This vessel has been used to measure the absorbed dose to water in both photon and electron beams and the results compared to results obtained using vessels in which the aqueous system is frequently changed. The response has remained stable over several years. The second is a parallel-plate vessel which can be used for electron beam dosimetry. Because of the large size of this vessel, a stirrer has been incorporated to reduce the time to achieve thermal equilibration. Different versions of this parallel-plate vessel permit the point of measurement to be moved closer to the entrance window, as required for low energy electrons. The effects of heat conduction on the response of the parallel-plate vessels will be described.
What Spectral Methods Can Tell Us about Heat Transfer Effects in Water Calorimeters

Ronald E. Tosh and H. Heather Chen-Mayer

Ionizing Radiation Division, National Institute of Standards and Technology
Gaithersburg, MD 20899 USA

Corresponding author (name and e-mail address): Ronald E. Tosh : (rtosh@nist.gov)

Oral presentation

In water calorimetry, numerous ancillary effects -- such as radiation-induced chemical reactions, scattering and excess heat from nonwater materials, and dose nonuniformities within the phantom – complicate the determination of absorbed dose from measurements of radiation-induced heating. Corrections for thermal transport due to excess heat and dose nonuniformities can be difficult to assess because the effects are delayed by variable amounts of time – from seconds to hours – that depend upon the geometry of the probes, the calorimeter vessel and the radiation beam. Typically, such corrections involve finite-element modeling of these elements that is analyzed in the time domain and, accordingly, is sensitive to timing details of the source. We have developed a technique that gets around this difficulty by using periodic modulation of the radiation source and measuring an effective frequency response, or system transfer function, of the calorimeter. By tracing the frequency dependence of systematic deviations from nominal or applied dose rates due to heat conduction, our approach provides a basis for assessing systematic errors for all radiation exposure times, including those that can not be handled by data analysis techniques like midpoint extrapolation.
Development of a water calorimeter for medium-energy x-rays.

L.A. de Prez, E. van Dijk, P.G.M. Damen

Nederlands Meetinstituut, Thijsseweg 11, 2629 JA Delft, The Netherlands

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Oral presentation

In international protocols the quantity kerma-in-air is being replaced by absorbed dose to water. As a consequence, Nederlands Meetinstituut has developed a water calorimeter for high-energy photon beams and is developing a water calorimeter for medium-energy x-rays (100 – 300 kV). The new calorimeter has many features similar to the NMi water calorimeter for high-energy photon beams. The phantom is cooled down to 4 °C where no convection takes place. Inside the phantom a detection cell made of glass is placed in which two thermistor probes are mounted. These two probes measure temperature changes in water at a depth of 2 g·cm⁻². The cell is filled with ultra-pure water, saturated with argon. Correction factors are applied for the effects of excess heat, heat conduction, attenuation and scatter of the beam due to presence of non-water materials. The corrections for heat conduction, attenuation and scatter have been modelled. The attenuation and scatter correction has been measured. In order to measure small resistance changes of the probes (in the order of 50 mΩ) with a standard uncertainty better than 1%, the electrical measurement circuit was optimised for guarding and signal processing. Measurements have been performed at two CCRI-qualities, respectively 100 kV and 250 kV. Preliminary results agree well with the results from an absorbed dose to water calibration coefficient obtained from an air-kerma - dose to water conversion.
Studies of Heat Transport from a Point Source in the NIST Domen Water Calorimeter

H. Heather Chen-Mayer and Ronald E. Tosh

Ionizing Radiation Division, National Institute of Standards and Technology, Gaithersburg, MD 20899 USA

Corresponding author (name and e-mail address): H. Heather Chen-Mayer (chen-mayer@nist.gov)

Poster

In water calorimetry, conduction effects complicate measurements of the true temperature rise at a point in space from direct radiation heating. In general, the effects are removed by correction factors obtained from finite-element simulations under carefully prescribed experimental conditions. We have developed a set of spectral methods for identifying heat conduction artifacts that may lead to a more systematic correction for these artifacts. In order to refine this work, we have sought to isolate the artifacts by stimulating heat conduction in the calorimeter without a radiation beam. In particular, we have devised a thermal point source in the calorimeter vessel by using one of the two small thermistors in the cylindrical Domen detector vessel as a heat source, with the remaining thermistor as a sensor to measure the temperature rise. By modulating the source-thermistor power, we are able to observe conduction-related attenuation and phase shifting of the resulting temperature signal. Finite element simulation is also employed to understand the experimental findings. This study is used to assess the system response function to processes such as thermistor self-heating, excess heat from the wall, external stirring in the outer phantom, and the onset of convection in the detector vessel, all of which affect corrections to the absorbed dose, but can be quantified.
Session C and D : Graphite calorimetry
Improvements in absorbed dose standards at ENEA-INMRI (Italy)

A. S. Guerra, C. Caporali, R. F. Laitano and M. Pimpinella

Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti ENEA – Centro Ricerche Casaccia
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Oral presentation

The standard of absorbed dose to water for Co-60 gamma rays at ENEA-INMRI is based on graphite calorimetry and on ionometric transfer system (thick-walled graphite ionization chamber). The graphite calorimeter is of the Domen type and absorbed-dose-to-graphite measurements can be performed both in the quasi-adiabatic and in the quasi-isothermal calorimeter mode of operation. Recent improvements in absorbed-dose-to-water standard regard the determination of some correction factors, i.e. the correction for the vacuum gaps in the graphite calorimeter and the correction for the photon fluence perturbation occurring in the procedure adopted to transfer the dose from graphite to water. These correction factors have been re-determined by Monte Carlo simulations based on the EGSnrc code. The calculated values of the correction factors are compared with the values, experimentally determined, so far adopted. Other improvements to the absorbed-dose-to-water standard are presented, regarding a new PC-based data acquisition system and the positioning system of the transfer ionization chamber in the scaled water phantom used for determining the absorbed dose to water. The new revised uncertainty budget on the ENEA-INMRI standard of absorbed dose to water for Co-60 gamma rays is discussed.
Test of the new GR9 graphite calorimeter, comparison with GR8

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Oral presentation

The new GR9 graphite calorimeter designed and constructed at LNE-LNHB, the French National Institute of Metrology for the dosimetry, has been thoroughly tested. Its realisation has been completed in 2006. The details of the building are presented on a poster. The part of the lead wires of the thermistors which are not involved in the electrical power substitution has been determined by calculation and a calorimetric measurement way as well. The electrical calibration factor for the quasi-adiabatic mode has been tested over a large range of electrical power dissipated in the core. The reproducibility of the measurements performed in the Quasi-adiabatic and constant-temperature modes will be reported. The second part of the presentation will consist in the comparison of GR8 and GR9 graphite calorimeters, both working in quasi-adiabatic mode and also in constant-temperature mode. The comparison has been performed in the reference cobalt-60 beam.
The comparison of the ARPANSA and IAEA-K4 graphite calorimeters for the measurement of absorbed dose from $^{60}$Co

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Oral presentation

In 1991 ARPANSA procured a graphite calorimeter based on Domen’s design and built by ARCS/OMH. This calorimeter was established as a primary standard for absorbed dose and it became the Australian standard in 1999. In 1997 the absorbed dose standard was compared with the BIPM. About 4-5 years ago, thermistors on the jacket failed progressively and a remediation program was started. As an interim measure to maintain the standard, the IAEA loaned ARPANSA its K4 calorimeter, an earlier prototype of the current model. The repairs to the ARPANSA calorimeter were successfully completed by early 2006 and the IAEA calorimeter was made fully operational. The two calorimeters have undergone comparative measurements in the ARPANSA $^{60}$Co beam. The calorimeters are similar dimensionally but are made from graphite of a different density so that the response will be proportional to the masses in each case. There are also differences in the electronic control and measurement circuits that must be taken into account. Despite the difference in characteristics, the two calorimeters are found to agree well and are consistent with the earlier results for each unit. They also confirm the continuity of the absorbed dose standard in agreement with that expected from the source decay constant. The experience with these two calorimeters is leading to improved control systems and automated measurements to permit more flexibility and accuracy.
Determination of the Specific Heat Capacity of Graphite Using Absolute and Differential Methods

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Oral presentation

An experimental assembly has been constructed to measure the specific heat capacity of macroscopic graphite samples at room temperature. The same type of graphite constitutes the core of a graphite calorimeter, which is currently being realized at the BIPM. Two different experimental procedures have been applied. In the first method, the specific heat capacity of graphite was measured directly from the temperature rise induced by electrical heating; the measured value is corrected for the influence of added impurities. The second method, to our knowledge never previously applied to macroscopic samples, is based on a series of differential measurements reducing systematic effects and for which no correction for added impurities is needed. The variation of the specific heat capacity for an ensemble of graphite samples is currently being investigated. To gain increased confidence in the accuracy of the measurement, a sample of synthetic sapphire (α-Al₂O₃), commonly used as a reference material for specific heat capacity, has also been studied.
Improvements to the UK Primary Standard Therapy Level Electron Beam Calorimeter

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Oral presentation

The design, electronics, operation and analysis of the UK Primary Standard Calorimeter for Therapy Level Electron Beams have been thoroughly reviewed and improved. Monte Carlo and simple thermal models have been used to review the analysis and deliver significantly improved uncertainties in the final calibration of Working Standard ionisation chamber calibration factors. Further Monte Carlo calculations were carried out using the NPL Grid, to provide an estimate of the calorimeter gap correction. Temperatures are measured using 22kΩ NTC thermistors with newly-designed low-noise DC Wheatstone Bridges. The calorimeter and ion chamber mounts have also been completely redesigned to significantly reduce geometric uncertainties. The techniques used, particularly in the area of electronics and Monte Carlo calculation of the gap correction, are being used in the design of new primary standard calorimeters for electron and photon beams, for proton beams, and for brachytherapy calibrations.
NACP-02 perturbation correction factors for the NPL primary standard of absorbed dose to water in high energy electron beams

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Oral presentation

The National Physical Laboratory (UK) calibrates plane-parallel ionization chambers in terms of absorbed dose to water in electron beams based on a primary standard graphite calorimeter. The calibration process involves a conversion from dose to graphite to dose to water, which requires knowledge of perturbation factors for the NACP-02 plane-parallel ionization chamber in both media. While recent international protocols recommend a value of unity for these perturbation factors, data published by various research groups have shown the contrary.

In our work, perturbation factors $p_Q$, $p_{cav}$, and $p_{wall}$ for the NACP-02 in graphite and water phantoms were investigated for the NPL electron beams ($4$-$19$ MeV). Monte Carlo simulations of the NACP-02 chamber with the EGSnrc code were validated against experiments for different backscatter materials and thicknesses.

For all energies at $z_{\text{ref}}$, $p_{cav}$ in water was approximately 1% below unity while $p_{wall}$ was greater than unity with the largest difference of 2.3% found for the 4 MeV beam. The two combined perturbation factors resulted in a $p_Q$ value greater than unity in water. All three perturbation factors were found to increase with depth. These findings indicate that current protocol data need to incorporate non-unity values for perturbation factors. The perturbation factors for graphite are presently under investigation and will lead to a revision of the NPL absorbed dose to water standard for high-energy electron beams.
Comparisons of calorimetric and ionometric measurements in heavy-ion beams

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Oral presentation

In order to sophisticate the radiotherapy, high accuracy knowledge of the absorbed dose delivered to the patient is essential. Despite the recent progress of particle therapy, the parameters such as w-value and stopping power ratio for ionization chambers in the particles is not obtained accurately. Therefore, that causes the uncertainty in determination of the absolute dose. According to a Japanese dosimetry protocol, the uncertainty of absorbed dose to water for Farmer-type air-filled ionization chamber in carbon beams is approximately 3.2 % (1s).

In the absence of primary standards for heavy-ion beams, the metrological traceability is assured by calibrating secondary standards in 60Co radiation and correcting with calculated beam quality correction factors. For this reason, we developed a graphite calorimeter to obtain high precision absorbed dose and reduce the uncertainty for various beams. The miniature glass bead thermistors were embedded in the sensitive volume to perform active control of temperature. The temperature-measuring thermistor is connected to a Wheatstone bridge and the resistance change is measured by lock-in amplifier and nanovoltmeter. Heat transfer analysis and Monte Carlo Simulations have been performed for various heavy-ion beams. In a similar way, it is intended to carry out the experiments for absorbed dose measurements.
A prototype calorimeter for HDR Ir-192 brachytherapy sources

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Oral presentation

Brachytherapy dosimetry for gamma ray sources is currently based on source calibrations in terms of reference air kerma rate (RAKR) or air kerma strength (AKS). Since patient dosimetry is based on absorbed dose to water, the American Association of Physicists in Medicine (AAPM) published the Task Group 43 protocol and an update (TG-43U1). The overall standard uncertainty in the derivation of dose at a point near the source from RAKR or AKS using the protocol is estimated to be about 5%, which is clinically significant. A project is currently underway at NPL to investigate the feasibility of calorimetry for brachytherapy which will allow a direct measurement of absorbed dose. A prototype calorimeter for the measurement of high dose rate $^{192}$Ir sources is being developed. This presentation will summarise the Monte Carlo simulations and heat transfer simulations that were carried out to arrive at a detailed design. Various design options will be discussed, like suitable absorber media and temperature sensors, different modes of operation (adiabatic, passive or active isothermal) and the measurement problems due to the heat producing radioactive source. Progress on the construction of the calorimeter will be reported.
Recent Advances on the BIPM Absorbed Dose Graphite Calorimeter

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Poster

An absorbed dose graphite calorimeter of new design is currently being constructed at the BIPM. Contrary to other graphite calorimeters at national metrology institutes, the core is of larger diameter and thickness, and the graphite phantom (jacket), composed of two hollowed-out semi cylinders, is smaller than the radiation field. Recent advances on the BIPM calorimeter will be described.
Absorbed dose to graphite at LNHB: From GR8 to GR9
– A detailed making process of GR9

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Poster

Graphite calorimeter is the standard of absorbed dose at the LNE-LNHB the French National Institute of Metrology for the dosimetry in photon and electron beams. One of the essential tasks is to maintain and improve this very specific, highly accurate primary instrument. The new GR9 graphite calorimeter is very similar to the GR8, which has proven its performances and is still perfectly working. Nevertheless we do have to ensure the continuity before improving the technique, by building other models better suited for low energy electron beams for instance.

The details of the construction will be presented in details. A set of pictures and radiographies would provide a better understanding of the delicate or critical points during the achievement of the calorimeter. New calorimetrists might take advantage of this exhibition if the construction of a graphite calorimeter is in prospect.
Energy range and application enhancement of the BEV graphite calorimeter: first assignments and preliminary results

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Poster

The Austrian primary standard of absorbed dose to water is a graphite calorimeter. It was developed by Witzani et al. based on the design by Domen (NBS) and has been in operation since 1983. The calorimeter is designed for quasi-adiabatic and quasi-isothermal mode of operation. The hardware including all measuring thermistors still works properly. Recently the calorimeter response has been verified by electric calibrations and measurements in the beam of the Co-60 teletherapy unit were successfully done as well. For the evaluation of the temperature drifts, automatic non-linear drift extrapolations based on a new created LabView® evaluation program are used. The conversion from absorbed dose to graphite to absorbed dose to water is done by two methods based on the scaling theorem. These methods are: conversion by calculation and conversion with an ionisation chamber. The aim of the work is the enhancement of the energy and application range of the BEV calorimeter to high energy photon and electron beams concerning field characterisation and calibration. To get application specific correction factors for the BEV calorimeter, Monte Carlo simulations with PENELOPE code are in progress.
Heat Defect in Graphite Calorimeters

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Poster

In graphite calorimetry based standards, the heat defect in graphite is being considered as zero and no uncertainty assigned or the model assumed for the heat defect by the standardisation laboratories around the world. Earlier experimental measurements of heat defect were reported with larger uncertainties. In this paper, a new approach based on theoretical grounds to find out the possibility of the existence of heat defect in graphite is presented. The approach is based on i) A study of point defects in both irradiated and un-irradiated graphite, ii) Evolving a model for radiation energy absorption leading to the formation of defects, iii) Identify the heat release mechanism from the literature on the studies of irradiation of graphite in nuclear reactors, iv) Experimental measurements of stored energy in graphite and changes in properties of irradiated graphite to validate the model of defect formation and heat release, and v) A theoretical estimate of heat release can be made using the estimate of the number of displacements produced based on Kinchin-Pease Model and threshold energy required to produce the displacements. Comparing this with the measured heat release will give an estimate of the heat defect. Possible experimental measurements have been proposed in the paper and an initial estimate based on numerical values from the literature is presented to indicate the possibility of heat defect.
Session E: Ionization chambers – low and medium energies
Investigation of the standard temperature-pressure correction factor at low x-ray energies

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Oral presentation

When using ion chambers with vented cavities, one is required to use the standard temperature-pressure correction factor \( (P_{TP}) \) to correct the measured response to the response expected under reference temperature and pressure conditions. A series of Monte Carlo calculations and experimental measurements have demonstrated that the \( P_{TP} \) correction factor breaks down for low-energy x-rays incident on various chambers with non-air-equivalent walls. The breakdown is negligible for day-to-day variations in pressure but becomes substantial for some chambers used at high altitudes where the average pressure is much lower than at sea level, and where \( P_{TP} \) corrections are large. Following a review of the theoretical justification for using the \( P_{TP} \) correction factor, along with the mechanism by which it breaks down under certain situations, this presentation will discuss the results of both calculations and experimental measurements of ion chamber response over a range of air pressures. The \( P_{TP} \) correction factor will undercorrect or overcorrect the response depending on the wall and electrode materials. For a 40 kV x-ray beam incident on an NE2571 chamber, the calculations predict that the standard \( P_{TP} \) correction factor will undercorrect the response by 2% at an air density roughly corresponding to Denver, Colorado.
Correction for the charge of secondary electrons and Auger electrons during the measurement of air kerma and exposure by free air ionization chambers

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Oral presentation

Air kerma is defined as the sum of the initial kinetic energies of all the secondary electrons emitted by photons per unit mass of air, and exposure is defined as the absolute value of the total charge of the ions of one sign produced in air by the secondary electrons. Absolute measurement of air kerma and exposure is made using free air ionization chambers. Signal charge from free air chambers, however, consists of not only the charge of ion pairs produced by the secondary electrons but also the secondary electrons and the ions which remain after the emission of the secondary electrons. It also consists of the charge of Auger electrons and multiply-charged ions due to Auger electron emission. In the present work, correction factors for the charge of secondary electrons and Auger electrons have been calculated for the measurement of air kerma and exposure of low energy X-rays using free air ionization chambers. It was found that the amount of correction increases with the decrease of the photon energy and becomes several tenth percent for low energy X-rays.
Determination of the absorbed dose to water in water for x-rays below 50 keV

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FB6.22 Dosimetry for radiation therapy
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Oral presentation

The absorbed dose to water for x-rays below 50 keV is generally determined on a phantom surface. The application of soft x-rays is essentially confined to the external treatment of the skin. However in brachytherapy soft x-rays are also used for a treatment inside the body. For this reason developments are under way in the PTB to establish a standard measuring device to determine the water kerma inside a phantom. In this work we introduce a method to determine the water kerma inside a graphite phantom housing an extrapolation chamber. Experimental results are presented and compared with the water kerma obtained from an air kerma measurement in free air and applying a conversion factor to water kerma for the conditions of the experiment as obtained in Monte Carlo calculations. Up to a tube voltage of 50 kV the chamber can be used for the direct measurement of the water kerma. First estimates indicate that the uncertainty is of the order of 1 % (k=1).
Realization of reference air-kerma rate for low-energy photon sources used in brachytherapy

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Oral presentation

For the treatment of localized prostate cancer $^{125}$I and $^{103}$Pd seed implantation has become an increasingly popular method in the last decade. Following the recommendations of the task group 43 of AAPM, the reference air-kerma rate of these sources should be determined as the dosimetric basis for the treatment planning.

In the past, the National Institut for Standardization and Technology (NIST) has been the only primary standard laboratory in the world being able to calibrate these sources. As the demand on calibrated seeds was also rapidly growing in Europe, the Physikalisch-Technische Bundesanstalt (PTB) developed a large air-filled parallel-plate extrapolation chamber (GROVEX) with thin graphite front and back electrodes as a primary standard for the determination of reference air-kerma rate of low-energy interstitial brachytherapy sources. The chamber is suitable for photon energies up to 40 keV. The underlying principle is that the air-kerma rate at the point of measurement is proportional to the increment of ionization per increment of chamber volume at chamber depths greater than the range of the most energetic secondary electrons originating in the entrance electrode.

The extrapolation chamber will be described in detail. Special attention will be drawn to the evaluation of the most important correction factors and the importance of influence quantities. Comparisons between the PTB standard and the Wide Angle Free Air Chamber (WAFAC) from NIST are discussed.
Measuring conditions for medical diagnostic X-rays at LNHB

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Poster

The EU directive 97/43 introduces the concept of protection against radiation for patients, associated with the ALARP principle (P stands for practicable). It has been transcribed into French regulation by the decree N° 2003-270. In addition to that the mode of enforcement of this new legislation was defined, on one hand, by the decree of March 3, 2003, relating to the obligation of maintenance and quality control of radiology facilities, and, on the other hand, by the decree of February 12, 2004, which fixes the Dose Reference Levels (RDL) for current radiological examinations.

The knowledge of the doses delivered to patients in medical diagnosis is thus henceforth mandatory. This implies that the measurements with dosemeters used for these must be traceable to national standards through the metrological chain.

The experimental conditions in the radiodiagnostic and mammography X-rays beams used for calibrating user's dosemeters are presented.

Particularly are described :
- free air chambers used for measuring reference air kerma and the corresponding uncertainties;
- typical X-ray beams;
- additional uncertainties due to the effect of short time pulses.
BIPM standard for mammography

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Poster

The BIPM is in the process of installing an x-ray tube with molybdenum target to establish reference mammography qualities for comparisons and calibrations. For these beams, a new primary standard was constructed at the BIPM.

The standard is a parallel-plate free-air chamber; it was designed to be used up to 50 kV and to minimize the correction factors that enter in the air kerma determination.

The correction factors for electron loss, photon scatter and fluorescence inside the chamber, bremsstrahlung, photon transmission through the aperture edge, photon scatter and fluorescence from the aperture and for wall transmission were calculated using the Monte Carlo code PENEOPE [1].

The results for monoenergetic photons were folded with measured and simulated spectra for the BIPM reference qualities.

Comparison with the existing standard for the BIPM reference qualities is in progress.

References

Dosimetric reference for medium energies X-rays range at LNHB:
progress of the project

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Poster

The directive 96/29/Euratom presents the basic standards and requirements related to health protection of population and workers against the dangers of ionizing radiation, and recommends the use of APD (Active Personal Dosimeters) traceable to national standards. For beams of low and medium energy X-rays, the standard measuring instrument is the free air chamber. It enables to characterize the radiation field in terms of air kerma rate and HVL. Since 2003 the previous primary French laboratory was the LCIE at Fontenay aux Roses. The French Authorities have entrusted the LNE with responsibility for French metrology. Then it was decided to send mission to LNHB, at CEA Saclay, to develop new references for low and medium energy X-rays.

A progress report of the dosimetric reference set up is presented:
- the equipment allowing the production of X-ray beams,
- the standard free air chamber and its associated measuring equipment for direct measurement of air kerma,
- the reference radiation qualities used at the BIPM in the range from 100kV to 250kV, recommended by the Consultative Committee for Ionizing Radiations (CCRI),
- the correction factors due to the detector and the ambient parameters with their associated uncertainties,
- a first evaluation of 2 correction factors, for electrons loss, and for scattered photons ($k_e$ and $k_{sc}$ respectively) by numerical modelling of the experimental setup based on the Monte Carlo method.
The effect of scattering photon for x-ray air-kerma calibrations

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Poster

The parallel-plate free-air ionization chambers are used for X-rays air-kerma rate standards at National Metrology Institute of Japan (NMIJ), National Institute of Advanced Industrial Science and Technology (AIST). The diaphragms are used to free-air chambers to fix the air volume of ionizing region in chambers. It means that absolute air-kerma rates are defined for collimated x-ray beams, because most of scattered photons are collimated by diaphragms. On the other hand, calibrated chambers are measured with non-collimated conditions. The variation of calibration constants was observed at different calibration distances and different diaphragm sizes for A5 and A6 Exradion chambers calibrations. The difference of the calibration constants are about 2% for 250kV X-ray beams. We thought that these results could be explained by the effect of scattered photons from the filters. In this study, we evaluate the contribution of scattered photons for free-air chambers and cavity chambers by Monte Carlo simulations, and suggest a new correction factor for evaluation of x-ray standards. The difference of calibration constants decreases below 0.5%.
Session F: Ionization chambers – kerma
A new method to determine effective air volume for the BIPM ionometric standards

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Oral presentation

An experimental parallel-plate ionization chamber of nominally the same design as the BIPM gamma-ray standards has been constructed in such a way that the chamber can be dismantled and reassembled repeatedly, with the possibility to insert graphite rings that modify the air-cavity dimension in the axial direction. This results in a chamber that is effectively of variable volume, but is simple in design with no moving parts and no significant non-graphite components. Such a design lends itself to reliable Monte Carlo modelling.

This chamber has been used in the BIPM reference Co-60 beam to determine air kerma differentially from the measured gradient, $dI / dV$, of the currents $I$ produced for different volumes $V$. Five chamber configurations were used, with volumes from 7 g cm$^{-3}$ to 15 g cm$^{-3}$. Each configuration was assembled at least three times. For each assembly, a 3d coordinate-measuring machine was used to determine the air volume to around 4 parts in 10$^{-4}$. For each configuration, measurements were made of the corrections for ion recombination, polarity and stem scatter, and Monte Carlo calculations were made for the wall and axial non-uniformity corrections, yielding a series of corrected currents $I_{\text{corr}}$.

The standard deviation of $I_{\text{corr}} / V$ for repeat assemblies of a given configuration was always below 2 parts in 10$^{-4}$. The results for $dI_{\text{corr}} / dV$ indicate that the mechanical measurements for each assembly overestimate the volume by around 10 mg cm$^{-3}$ and yield an estimate of the air-kerma rate that is 2.0 parts in 10$^{-3}$ higher than the present reference value. The standard uncertainty of $dI_{\text{corr}} / dV$ arising from the mechanical measurements is less than 3 parts in 10$^{-4}$. The limiting uncertainty component, around 4 parts in 10$^{-4}$, is that arising from the calculated wall corrections.
THE PRIMARY STANDARD FOR AIR KERMA FOR 60CO PHOTON BEAMS IN THE NETHERLANDS

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Oral presentation

The primary standard for air kerma for $^{60}$Co photon beams in the Netherlands is a spherical Bragg-Gray cavity, having an air volume of 5 cm$^3$. To determine the correction factor for the influence of the graphite chamber wall, measurements were performed using wall thicknesses from 3 mm up to 6 mm. Using a linear extrapolation to zero wall thickness, the correction to eliminate the influence of the graphite walls, $k_{att}$, was determined. The slight overestimation of the effect by $k_{att}$ was compensated by an additional correction for the upstream mean centre of production of electrons, $k_{cep}$. At the end of 2005 Monte-Carlo calculations were performed to estimate the influence of the graphite walls for the 5 cm$^3$ Bragg-Gray cavity. Similar Monte-Carlo calculations were performed for a cylindrical Bragg-Gray cavity having a 2.5 cm$^3$ air volume. Using the Monte-Carlo calculations, this 2.5 cm$^3$ Bragg-Gray cavity was upgraded to a primary standard for $^{60}$Co photon beams. As a result of these changes, the kerma rate of the $^{60}$Co photon beam at the Nederlands Meetinstituut increases by a factor of 1.000245, due to the average change in both primary standards. The related uncertainty has decreased from 0.86 % to 0.5745 % (coverage factor $k = 2$).
Air Kerma Primary Standard: Experimental and Simulation Studies on Cs-137

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Oral presentation

The primary standard for air kerma for the gamma radiation of Cs-137, of the Metrological Laboratory of Ionising Radiation (LMRI), is an ionisation chamber of the type CC01. This instrument was, for the first time, used to characterize the radiation field, in terms of air kerma, produced by a Cs-137 source in an irradiator Shepherd model 81, used mainly for radiation protection calibration purposes. Monte Carlo simulation studies were also made, using MCNP5. These studies intend to characterize the radiation field by simulation of the irradiator and to obtain correction factors for this ionisation chamber.

KEYWORDS: ionising radiation: primary standard; air kerma; metrology; monte-carlo simulation
Session G: Special standards
**Traceability and absorbed dose standards for small fields, IMRT and helical tomotherapy**

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*Oral presentation*

The reference conditions under which primary standards realise absorbed dose specify the measurement point in a beam and a phantom geometry which are rather different from those used in some modern radiotherapy procedures, particularly IMRT, stereotactic treatments and helical tomotherapy. It has become a challenge to make traceable dose measurements which remain relevant to the end use but whose uncertainty is at the level expected of reference dosimetry. Measurements using alanine/EPR dosimeters can resolve this difficulty and restore traceability in cases, such as helical tomotherapy, where it is impossible to realise standard reference conditions or where new reference conditions may be required. Results are presented from measurements performed at four sites and under a variety of non-standard conditions using alanine and ion chambers to determine machine output and chamber calibration in terms of absorbed dose. The calibration uncertainty obtained compares well with that which is routinely achieved in measurements under standard reference conditions.
NPL’s progress towards absorbed dose standards for proton beams

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Oral presentation

External proton beams are increasingly used in clinical radiotherapy. Protons have intrinsic advantages leading to better conformal target dose distributions with better sparing of surrounding tissue compared to x-rays. To exploit these properties to their full potential dosimetry must be at the same level of accuracy which is at present not the case.

NPL contributes in various ways to improved proton dosimetry:
• by measurement of fundamental quantities, such as the mean energy required to produce an ion pair in dry air \( W_{\text{air}} \), and material properties needed for proton dosimetry using ionisation chambers calibrated in \(^{60}\text{Co} \) or high-energy electron beams,
• by calculating chamber dependent perturbation correction factors for proton dosimetry using ionisation chambers calibrated in \(^{60}\text{Co} \), high-energy electron beams or proton beams,
• by developing calorimeters that can potentially serve as primary standards for absorbed dose measurement in proton beams.

Progress in each of these areas will be reported. Measurement of the \( W_{\text{air}} \)-value is put in context of a new ICRU report on proton dose prescription. Calculations and experimental data on ionisation chamber perturbations due to secondary electrons and nuclear interactions will contribute to improved consistency. A new portable calorimeter will serve as an instrument to provide on-site calibrations.
A proposal for primary standards of absorbed dose in a beta field

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Oral presentation

Primary standards for absorbed dose to tissue in a beta-ray field are traditionally based on extrapolation chambers with thin windows and an application of Bragg-Gray cavity theory to a surface cavity with various correction factors. It is more appropriate to use Spencer-Attix cavity theory as used in other primary standards (Co-60 air kerma) and clinical dosimetry protocols. Cavity theory is based on the concept of a cavity in which there is charged particle equilibrium of either all knock-on electrons (Bragg-Gray) or only those electrons below the threshold delta (Spencer-Attix) and thus one needs to have a cavity in the phantom, not just a conceptual dose on the surface. Our approach applies standard electron beam dosimetry techniques using Spencer-Attix stopping-power ratios with $P_{\text{wall}}$ and $P_{\text{repl}}$ correction factors. Ideally measurements are done with the front wall corresponding to the correct depth in the phantom and possibly at only one chamber cavity length. The new technique is internally consistent with detailed EGSnrc calculations but requires a value of $P_{\text{repl}}$ about 0.5% different from unity in addition to the usual divergence correction. Using our EGSnrc calculated correction factors yields absorbed doses for a Sr-90/Y-90 source which differ by 2.3% from results using the methods and parameters recommended by ISO.
Dosimetry in synchrotron radiation beam by ionization air chambers

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Oral presentation

A dosimetric procedure to assure the traceability to the air-kerma standard of measurements performed in synchrotron radiation beams, was implemented at the “Instituto Nazionale di Metrologia delle Radiazioni Ionizzanti” of ENEA (ENEA-INMRI). To this purpose, absolute air-kerma measurements by the ENEA standard free-air chamber for low energy x-rays have been performed in synchrotron light beams to be used for high definition mammography in the framework of the SYRMA project (SYnchrotron Radiation for MAnmography) at the Synchrotron ELETTRA in Trieste, Italy. The radiation beams to be characterized were monochromatic x-rays with energy in the range from 8 keV to 30 keV and the reference point for measurements corresponded to the centre of the breast when the patient is on its support. The absolute air-kerma measurements were also used to calibrate two monitor chambers and an ionization free-air chamber specially designed and realized by ENEA to act as transfer standard in the synchrotron light beams. The irradiation conditions for measurements – both beam quality and geometry – were very different from the reference conditions at the INMRI-ENEA. According to the actual conditions, the diaphragm of the ENEA standard chamber was modified and some correction factors were re-determined by Monte Carlo calculations based on the PENELOPE code or by experimental measurements. In particular the mass air attenuation coefficients of these monochromatic x-rays were experimentally determined to obtain the correction for photon attenuation in air.
The development of a calibration service for ophthalmic applicators

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Poster

In 1992 the UK National Physical Laboratory (NPL) began a programme of work with the aim of providing a calibration service for the surface absorbed dose rate to tissue measurement of Sr-90 and Ru-106 β-ray-emitting ophthalmic applicators. This report gives some details about the extrapolation ionisation chamber initially established as a primary standard for the measurement of planar applicators. It also describes the development of the calibration service to include curved applicators, using thin alanine pellets calibrated in terms of absorbed dose traceable to a calorimetric primary standard. The results of the calibration of several applicators at NPL were compared to the manufacturer’s values and found to give agreement within the uncertainties.
Dosimetry in support of non-intrusive inspection of cargo containers

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Poster

The next generation of non-intrusive inspection systems that will be deployed at the United States border for the purpose of scanning cargo containers and other large items must be designed to minimize dose to persons unexpectedly occupying those containers (stowaways). In order to achieve doses to stowaways compatible with current expectations, a series of calculations and measurements is in progress. One difficulty in performing these studies is their lack of traceability to US national standards. The energies of these beams exceed those used to establish the US national standards for absorbed dose to water and air-kerma (i.e. Co-60 and Cs-137) In fact, these beams utilize the broad spectrum of photons generated by electron beams accelerated in potentials above 6MV. In this poster, we present the results of coupled measurements and computational studies, using the Monte Carlo method, that attempt to resolve ambiguities in the interpretation of the results of this program.
Session H: Ionization chambers – absorbed dose
Evaluation of different methods for determining the magnitude of initial recombination in ionization chambers

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Oral presentation

The incomplete charge collection in an ionization chamber cavity due to volume recombination depends on the dose rate and must be corrected for, whereas the effect of initial recombination does not depend on dose rate. Measuring absolute dose values with lowest possible uncertainty, e. g. when comparing standards or when measuring $k_Q$ values, requires to determine the magnitudes of initial recombination and volume recombination separately.

In this work ionization chamber types commonly used as transfer standards or as reference dosemeters for dose measurements in terms of absorbed dose to water were investigated. The amount of initial recombination was determined both in continuous radiation (Co-60) and in pulsed high energy photon radiation. Different methods were applied. Results are compared with published data and theoretical expectations. Uncertainties and application ranges for the different methods are given.
Monte Carlo calculations for the BIPM ionometric standard for absorbed dose to water

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Oral presentation

Following the calculations for the BIPM air-kerma standard using the Monte Carlo code PENELOPE [1], a series of calculations has been made for the BIPM standard for absorbed dose to water. This standard is a graphite-walled parallel-plate ionization chamber in a waterproof housing, positioned at the reference depth in a water phantom irradiated by a horizontal Co-60 beam. By simulating in detail the chamber and phantom arrangement and the Co-60 source geometry at the BIPM, correction factors have been evaluated for the water-to-graphite collision-kerma ratio, $K_{\text{col},\text{w,c}}$, and for the graphite-to-air stopping-power ratio, $s_{\text{c,air}}$, each of which is in agreement with the value currently in use at the level of around one standard uncertainty. The correction factor, $\beta_{\text{w,c}}$, for the absorbed-dose-to-collision-kerma ratio in water relative to that in graphite differs from the value currently in use by around 2 parts in $10^3$. Smaller corrections for the phantom window and the waterproof housing have also been evaluated and agree closely with the values currently in use.

The largest change arising from the new calculations is in the factor $k_{\text{cav}}$ that corrects for the presence of the air cavity and collector. Although this is currently estimated analytically from calculated photon spectra to be a significant effect, $k_{\text{cav}} = 0.9900(5)$, the present calculations show a much smaller effect, the best estimate being $k_{\text{cav}} = 0.9985(5)$. Because this new evaluation uses a full electron transport calculation, and many additional calculations have been made to demonstrate the ability of the PENELOPE code to calculate cavity dose correctly, confidence in the new result is significantly greater despite the similarity of the stated uncertainties. The combined effect of the new calculations is an increase in the BIPM estimate of absorbed dose to water by 4 to 5 parts in $10^3$.

Comparison of ionometric and calorimetric determination of absorbed dose to water for cobalt-60 gamma rays

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Oral presentation

The absorbed dose rate to water for cobalt-60 gamma rays, $D_w$, was determined with waterproof primary standard graphite cavity ionization chambers by $D_w = \dot{D}_{CAV} \cdot f$, where $\dot{D}_{CAV} = I_{CAV} / m_{CAV} \cdot W / e$ is the absorbed dose rate to the air in the cavity, $I_{CAV}$ is the measured ionization current of the ionization chamber when positioned at the reference point in the water phantom, $m_{CAV}$ is the mass of dry air contained in the cavity, $W$ is the effective energy expended in air per ion pair formed, $e$ is the elementary charge and $f = \left[ D_w / D_{CAV} \right]_{MC}$ is a factor to convert $\dot{D}_{CAV}$ into $\dot{D}_w$, calculated by means of Monte Carlo methods. $f$ is calculated as the ratio of the absorbed dose to water, $D_w$, at the reference point in a water phantom to the deposited dose $D_{CAV}$ in the air cavity of the graphite chamber positioned in the reference depth of a water phantom. The results were compared with $\dot{D}_w$ measured in the same Co-60 radiation field by the PTB water calorimeter. The dose rates determined with the ionization chambers turned out to be significantly higher than those obtained by the water calorimeter by about (1.5±0.5)%. The discrepancy was resolved when the stopping-power values for graphite were changed in the Monte Carlo simulations of the graphite cavity chambers used for the calculation of the conversion factor $f$. 
Monte Carlo Simulation of a Graphite Ionisation Chamber

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Poster

Czech Metrology Institute decided to build a primary standard of air kerma for high energy range of photons ($^{60}$Co). For that purpose, a set of three cylindrical graphite ionisation chamber has been developed. At present, basic dosimetric parameters of the chambers have been determined, both experimentally and by the Monte Carlo calculations using the MCNPX 2.6b code. This paper describes preliminary results of energy dependence and correction factors of wall attenuation and scatter ($k_{wall}$) of a graphite ionization chamber.
Session I: Ionization chambers – linacs
Absorbed dose to water is the universal basic quantity for clinical reference dosimetry in radiotherapy. In the last two decades Primary Standards Dosimetry Laboratories have developed and commissioned absorbed dose to water standards based on water or graphite calorimeters, ionization chambers or total absorption in ferrous sulphate. In Belgium and the Netherlands absorbed dose to water calibration services have been established based on water calorimeters. Although water calorimetry provides a direct way to determine the quantity absorbed dose to water, it is more practical in clinical situations to perform dosimetry using ionization chambers. Since the response of these chambers depends on the beam quality, they need to be calibrated against a primary absorbed dose to water standard at a reference quality, and beam quality correction factors $k_Q$ need to be determined if this reference quality is $^{60}\text{Co}$.

A new Code of Practice (CoP) for external beam radiotherapy in Belgium and The Netherlands based on absorbed dose to water will be issued by the Netherlands Commission for Radiation Dosimetry (NCS). For clinical photon beams the CoP of the NCS will be based on a $^{60}\text{Co}$ calibration factor and measured $k_Q$ factors. This is in agreement with the strong recommendation given in IAEA TRS-398, that preferably experimental $k_Q$ factors should be used. A measurement program was conducted in a set of clinical photon beams in Belgian and Dutch hospitals involving the NMi water calorimeter and four different types graphite walled cylindrical ionization chambers (NE2611A, NE2571, PTW 30012 and Wellhöfer FC65G). Six chambers of each type were used in the measurement program. In parallel with the $k_Q$ measurements beam quality specifiers $\text{TPR}_{20,10}$ and $\%\text{dd}(10)_x$ were determined for all selected clinical photon beams. All ionization chambers were calibrated in terms of absorbed dose to water in $^{60}\text{Co}$, and were characterised in clinical beams (6-23 MV) regarding their saturation and polarity corrections.

The results of the $k_Q$ measurements including a detailed uncertainty analysis and the measured beam quality specifiers $\text{TPR}_{20,10}$ and $\%\text{dd}(10)_x$ will be presented. Our results were combined with other experimental data available from literature to identify a more generic relationship of $k_Q$ as function of $\text{TPR}_{20,10}$ and $\%\text{dd}(10)_x$. 

Experimental beam quality correction factors $k_Q$ determined in clinical high-energy photon beams

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Oral presentation
Direct calibration of ionization chambers in linac electron beams

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Oral presentation

Electron dosimetry, for the majority of clinical dose measurements worldwide, is currently based on an ion chamber calibrated at the standards laboratory in a $^{60}$Co beam. Conversion factors obtained from a protocol such as TRS-398 are then required to derive the dose in a linac electron beam. This paper details the direct measurement of absorbed dose calibration coefficients in electron beams from a clinical linac, which offers a more accurate route to electron absorbed dose.

The NRC primary standard water calorimeter was used to calibrate a set of cylindrical and parallel-plate chambers (NE2571, NACP-02, PTW Roos) in the high energy (> 8 MeV) electron beams from an Elekta Precise linac installed at NRC. Calibration coefficients were also obtained for a 20 MeV electron beam from the Vickers research accelerator, also installed at NRC.

The $N_{D,w}$ values obtained for the two accelerators were in good agreement. The values for the 20 MeV beam were also in good agreement with previous data obtained by Ross in 2001 indicating very high stability of the primary standard water calorimeter. The standard uncertainty in the calibration of an ion chamber is estimated to be 0.35%, a significant improvement over using the calculated values.
Title: Experimental $k_{Q_0G_0}$ electron beam quality correction factors for the type NACP02 and PTW34001 plane-parallel chambers

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Poster: Oral presentation x

Text:

For electron beams only few absorbed-dose-to-water primary standards are available. Recently, calibration coefficients $N_{D_w, G}$ measured directly in electron beams and based on the primary standard chemical dosimeter (Fricke solution) have become available at the METAS in Switzerland [1].

This work gives an overview of the results of experimental electron beam quality correction factors $k_{Q_0G_0}$ derived from the directly measured calibration coefficients of plane-parallel chambers of the types NACP02 and PTW 34001. The chambers were calibrated

- in terms of $N_{D_w, G}$ against the METAS electron-beam primary standard chemical dosimeter at a series of 10 electron qualities ($R_{50} = 1.75 \text{ gcm}^{-2}$ to $R_{50} = 8.54 \text{ gcm}^{-2}$)

- in terms of $N_{D_w}$ against the METAS sealed water calorimeter in a Co beam

In the first case a half value depth of $R_{50} = 7.523 \text{ gcm}^{-2}$ (-20 MeV) was selected as reference quality $Q_0$, whereas in the second case the reference quality was Co. The four sets (two sets for each chamber type) of $k_{Q_0G_0}$ values were derived from the $N_{D_w, G}$ calibrations for the METAS qualities as a function of $R_{50}$.

The uncertainty of the factor $k_{Q_0G_0}$ when using $R_{50} = 7.523 \text{ gcm}^{-2}$ as reference quality is 0.5 % ($k=1$). For the NACP02 chambers the experimental correction factors $k_{Q_0G_0}$ suggest a constant chamber perturbation factor $\rho_0$ in the full energy range investigated. Whereas for the PTW 34001 chamber there is an indication for a deviation of the chamber perturbation factor at the lowest energy ($R_{50} = 1.75 \text{ gcm}^{-2}$).

The uncertainty of $k_{Q_0G_0}$ when using Co as reference quality is 1 % ($k=1$). The wall correction factors $\rho_{wall}$ that can be derived from the experimental $k_{Q_0}$ factors agree with values taken from the International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water, IAEA, TRS-398 [2].

The ratios of calculated (taken from TRS-398 [2]) and experimental (from METAS calibrations) $k_{Q_0G_0}$ values were also determined. The maximum deviation of the ratio from 1 found was < 1.5 % at the lowest energy, being on the average < 0.5 %. The results lie within the uncertainties of the comparison.

References


Procedures for absorbed dose to water determination in high energy photon and electron beams by ferrous sulphate dosimeter at ENEA-INMRI (Italy)

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Oral presentation

Since 1998 the ENEA-INMRI has been using ferrous sulphate dosimeters to perform in-situ absorbed-dose-to-water calibration of radiotherapy clinical beams. The dosimeter consists of a ferrous sulphate solution in sealed glass ampoules of about 1 cm$^3$ and with 0.5 mm wall thickness. The procedure adopted for the absorbed-dose-to-water determination and the recent improvements in the accuracy of the ENEA-INMRI ferrous sulphate dosimetric system are described. The most important improvements regard the standardization of the dosimeter shape and volume and the determination of the correction factor that accounts for the dosimeter non-water equivalence (glass wall and ferrous sulphate solution). The correction factors have been determined in photon and electron beams by Monte Carlo simulations using realistic spectra for the incident beams. The calculated values for the correction factor are reported as a function of the parameters $TPR_{20/10}$ and $R_{50}$ for photon and electron beams, respectively. The new uncertainty budget for absorbed-dose-to-water measurement is reported and the major uncertainty components discussed. At present the ENEA-INMRI ferrous sulphate dosimeter is a reference dosimeter used both for calibration and research activities.