NRC Activities and Publications, 2007-2009
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Compiled by Carl Ross (Group Leader)
Ionizing Radiation Standards
Institute for National Measurement Standards
National Research Council
Ottawa, Canada K1A 0R6

Tel: 613-993-9352, ext. 233
Fax: 613-952-9865
E-mail: carl.ross@nrc-cnrc.gc.ca

Table of Contents

1 Introduction

The Ionizing Radiation Standards (IRS) Group of the National Research Council of Canada (NRC) is part of the Institute for National Measurement Standards (INMS), which is Canada's national metrology institute. The group has twelve full-time staff members, five term appointments, one former staff member who works part-time, one graduate student and four visiting workers.

The group is responsible for Canadian calibration services in the field of ionizing radiation. A listing of the calibration services offered can be found at: http://inms-ienm.nrc-cnrc.gc.ca/calserv/ionizing_radiation_e.html

A searchable database of INMS publications is available at: http://serpent.cisti.nrc.ca/DBTW-WPD/textbase/inms/search_e.html.

Details on research activities related primarily to Monte Carlo modeling can be found at: http://www.irs.inms.nrc.ca/irs.html.

2 INMS Organizational Structure

The management team of INMS comprises a Director General (Jim McLaren) and two Directors, one for Metrology (Alan Steele) and one for Business and Research Support (Katalin Deczky). The Groups Leaders, each of whom is responsible for one or more areas of metrology, report to the Director of Metrology.

3 ISO 17025 Quality System

The IRS quality system has received a Certificate of Approval from the SIM Quality System Task Force (QSTF) and has been formally accredited by the SCC (Standards Council of Canada). Internal audits were carried out in the fall of 2007 and 2008.

4 Air kerma standards

4.1 For kV x-rays

(John McCaffrey, Ernesto Mainegra-Hing and Iwan Kawrakow)

IRS provides kV x-ray calibrations in the energy range from 10 to 300 kV. Two free-air chambers serve as standards, one covering the low-energy range up to about 60 kV and the second covering the range from 60 to 300 kV. A second medium-energy free-air chamber and an Attix free-air chamber are under construction for exploratory studies of correction factors.

IRS participated in a SIM comparison (SIM.RI(I)-K3) of medium-energy x-ray standards piloted by NIST. The preliminary report is expected soon.

A detailed study of free-air chamber correction factors has been carried out using the EGSnrc Monte Carlo code and results are reported in [5]. Calculated corrections for photon scatter and electron loss are found to be in excellent agreement with the measured values. The Monte Carlo technique allows for the investigation of effects that are otherwise difficult to investigate, such as the assumption of charged particle equilibrium within the sensitive volume of the free-air chamber.

4.2 For ^{60}Co and ^{137}Cs

(John McCaffrey)

^{60}Co and ^{137}Cs air kerma standards are based on a graphite cavity chamber. Two additional graphite cavity chambers, one spherical and one plane parallel are under development as complimentary air kerma standards.

IRS participated in the EUROMET Project 813 comparison of air kerma (EUROMET.RI(I)-K1) and absorbed dose to water (EUROMET.RI(I)-K4) for ^{60}Co radiation. The preliminary report has been circulated to participants.

Our new Gammabeam X-200 ^{60}Co irradiator is scheduled for a source change in mid-2009. The new source will have an initial activity of about 280 TBq.

5 Absorbed dose standards

5.1 For ^{60}Co

(John McCaffrey, Malcolm McEwen and Carl Ross)

The absorbed dose rate to water in a ^{60}Co beam is established using a water calorimeter. The Gammabeam X-200 irradiator is used to maintain and disseminate our standard for absorbed dose to water.

5.2 For MV x-rays

(Malcolm McEwen and Carl Ross)

Following from the work on water calorimetry in clinical x-ray beams, a calibration service has been developed for clinical users. Absorbed dose to water calibrations are carried out at the three x-ray energies produced by the linear accelerator maintained at the laboratory. The nominal beam energies are 6, 10 and 25 MV and the corresponding values of $\%dd(10)_x$ ($TPR_{20,10}$) are 67.4(0.681), 72.4(0.731) and 84.0(0.800). The standard for absorbed dose to water is a sealed water calorimeter, which measures the radiation-induced temperature rise at a depth of 10 cm in a water phantom (10 x 10 cm^2 beam, with the surface of the phantom at 1 m from the source). The nominal dose rate at the point of measurement is 300 cGy/min. For reference-class 0.6 cc cylindrical ionization chambers the standard uncertainty in the absorbed dose calibration coefficient is typically 0.5 %. The calibration process includes polarity and recombination measurements, as required for dosimetry protocols such as AAPM TG-51.

The service has received ISO 17025 accreditation and several client calibration certificates have been issued.

6 New k_Q factors for MV photon beams

(Malcolm McEwen and David Rogers (Carleton University))

Several ionization chambers have come on the market since the publication of the TG-51 dosimetry protocol. They fall into three main groups: waterproof Farmer-type chambers; scanning chambers used for beam commissioning; and micro chambers designed for small field/IMRT dosimetry. The objective of this work was to characterize many of the new chambers over the range of energies applicable to TG-51 and determine whether each type of chamber met the requirements of a reference class instrument. Chamber settling, ion recombination and polarity were investigated and the chamber was compared with the primary standard water calorimeter to determine experimental absorbed dose calibration coefficients. The chambers investigated included:

Exradin:	A12, A12S, A14, A16, A18, A19
PTW:	30010, 30012, 30013, 233642, 31010, 31013, 31014, 31016
Wellhofer:	CC01, CC04, CC13, FC23, FC65-G

The polarity effect was found to be within 0.1 % of unity for all 0.6 cm^3 chambers but was as large as 0.8 % for some micro chambers. Ion recombination was found to be significantly different for different chamber types.

A comparison of measured and calculated values of k_Q for selected chambers is shown in the following table. The calculated values were obtained by Rogers using the same approach as was used for the k_Q values reported in TG-51.

$\%dd(10)_x$	PTW30013 Exp	PTW30013 Calc	A1SL Exp	A1SL Calc	PTW31014 Exp	PTW31014 Calc
	0.6 cm^3		0.06 cm^3		0.015 cm^3	
67.4	0.989	0.990	0.993	0.994	0.992	0.990
72.6	0.980	0.982	0.985	0.987	0.987	0.982
84.5	0.957	0.961	0.966	0.965	0.967	0.960

At low energies, as used for the majority of radiotherapy dose deliveries, there is good agreement (within 0.2%) between measurement and calculation. However, at higher energies there are significant differences that are not limited to the smaller chambers, where one might expect differences.

7 Electron scatter distributions

(Malcolm McEwen, Claudiu Cojocaru and Carl Ross)

This project seeks to provide new data on electron scattering by thin foils to help in the testing of Monte Carlo codes. The work is part of a larger project funded by the NIH and carried out in collaboration with the University of California to develop more accurate accelerator beam models to be used with Monte Carlo based treatment planning systems. Measurements were carried out using 13 and 20 MeV pencil beams of electrons produced by the National Research Council of Canada (NRC) research accelerator. The electron fluence was measured at several angular positions from 0° to 9° for scattering foils of different thicknesses and with atomic numbers ranging from 4 to 79. The angle, $\theta_{1/e}$, at which the fluence has decreased to 1/e of its value on the central axis was used to characterize the distributions. Measured values of $\theta_{1/e}$ ranged from 1.5º to 8º with a typical uncertainty of about 1 %. Distributions calculated using the EGSnrc

Monte Carlo code were compared to the measured distributions. In general the calculated distributions are narrower than the measured ones. Typically, the difference between the measured and calculated values of $\theta_{1/e}$ is about 1.5 %, with the maximum difference being 4 %. The measured and calculated distributions are related through a simple scaling of the angle, indicating that they have the same shape. No significant trends with atomic number were observed.

8 Angular distributions of MV x-rays

(Claudiu Cojocaru, Malcolm McEwen and Carl Ross)

This project aims to provide data on x-ray fluence distributions that can be used to test Monte Carlo codes. It is part of the larger collaborative project already described in the previous section. The experimental data was collected using the NRC's Vickers linear accelerator, which allows for the production of narrow pencil beams of electrons with well known energies, set for this experiment at 20 MeV. The electrons were fully stopped in various thick targets of Be, Al, Cu, Ta and Pb.

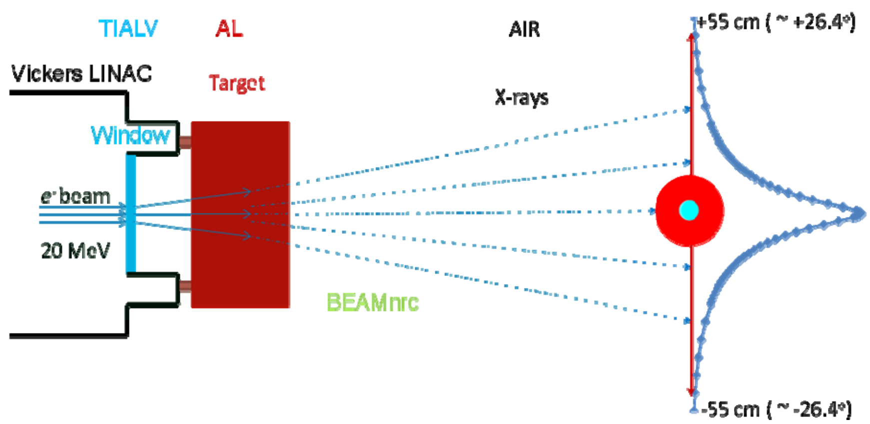

Figure 1. Key features of the setup used to measure photon fluence distributions. A typical lateral profile is shown on the right of the figure.

As shown in Figure 1, lateral ionization chamber response profiles were measured using an ionization chamber fitted with a build-up cap. Several ionization chambers (PTW 30013, Exradin A19, and NE2505) and build-up caps (PMMA, Brass, Cu, Sn and Hevimet) were used. The incident electron current was measured absolutely using a toroidal monitor.

Measured data were compared to simulations carried out using the EGSnrc Monte Carlo code. The ionization chamber and build-up cap were simulated in detail using the EGSnrc user code, cavity. Depending on the x-ray target and build-up cap, differences of several percent between measured and calculated distributions have been observed and the reasons for the differences are still under investigation.

9 Effective point of measurement

(Frédéric Tessier and Iwan Kawrakow)

We are investigating the effective point of measurement (EPOM) of twelve thimble ion chambers, including scanning microchambers and three models widely used for clinical reference dosimetry. The EPOM is the point at which the measured dose would arise in the measurement medium in the absence of the probe: for cylindrical chambers, it is shifted upstream relative to the central axis of the chamber. Although current dosimetry protocols prescribe a blanket upstream EPOM shift of 0.6*R*, with *R* the chamber cavity radius, it has been shown by our group in the last three years that the EPOM does in fact depend on every detail of the chamber design and on the beam characteristics. In the wake of this finding, we propose a comprehensive revision of the EPOM for a series of chambers in water, irradiated by photon beams with nominal energies of 6 MV and 25 MV, and fields sizes of 10x10 cm^2 and 40x40 cm^2. Our results are derived from EGSnrc Monte Carlo calculations, upheld by a full Elekta Precise linac treatment head simulation and ion chambers modeled in realistic detail. The chambers included in our study are: Standard Imaging Exradin A1, A1SL, A2, A12, A12S, A14, A14SL, A16, A18, and A19, Nuclear Enterprises NE2571 and PTW model 30013.

Our EPOM survey will be published shortly. Preliminary results show agreement with previous Monte Carlo and experimental data obtained by our group. Notably, our analysis reveals that the upstream EPOM shift is consistently smaller than the prescribed 0.6*R*, by over 30 % for reference class 0.6 cc chambers, and by up to 70 % to 85 % for microchambers. Interestingly, we also find that some chambers do not lend themselves to a consistent EPOM analysis, indicating that the assumption of depth independence of either the stopping power ratios or the correction factors is not satisfied for those chambers. We are further investigating this matter.

10 β-ray dosimetry

(Patrick Saull, David Marchington and Stewart Walker)

IRS maintains a standard for absorbed dose to tissue in a β-ray field using an extrapolation chamber. This instrument has been fully integrated into an automated data-acquisition system with two PTW β-source irradiators: our original Beta Secondary Standard (BSS1) acquired in the early 1980s, and the newer BSS2 system from Isotrak acquired in 2003. Our primary standard was put to the test in 2005 using the Pm-147, Kr-85, and Sr-Y-90 sources of the BSS2 irradiator, as part of our participation in the EUROMET comparison titled "Supplementary comparison of absorbed dose rate in tissue for beta radiation" (EUROMET project No. 739, BIPM KCDB: EUROMET.R(I)-S2), which involved the participation of six European countries, as well as Canada, the US, and Japan. The final report of this comparison was published in September, 2007.

Using the BSS1/BSS2 irradiators and our well-established standard, we have recently established an independent testing facility and taken on the role of "reference calibration centre" as part of the Canadian Nuclear Safety Commission's regulatory standard on quality assurance. As of May 2006, all dosimetry service providers operating in Canada are required to undergo annual independent testing of their extremity dosimeters at NRC.

11 Effective chamber volume

(Carl Ross)

A recent paper (*Phys. Med. Biol.* **53** (2008) 5029-5043) reports on the use of micro-CT to measure the mechanical volume of the A1SL ionization chamber. If the mechanical volume could be accurately related to the volume from which ions are collected, then this could prove to be a useful technique for absolute dosimetry. Unfortunately, the sensitive volume of the A1SL is not simply related to the mechanical volume. Figure 2 shows the electric field lines near the base of the collector and it is clear the sensitive volume is considerably less than the mechanical volume. The problem is compounded because a slight misalignment between the collector and guard electrode, as might be expected during assembly, has a significant impact on the electric field.

There are other chamber designs, such as those used for air kerma standards, for which the mechanical volume is accurately defined by the electric field lines. Although micro-CT has excellent spatial resolution, the authors of the recent paper suggest that the uncertainty of the estimated volume is about 1 %. Unless this uncertainty can be reduced significantly, micro-CT is not likely to be a useful technique for precision dosimetry.

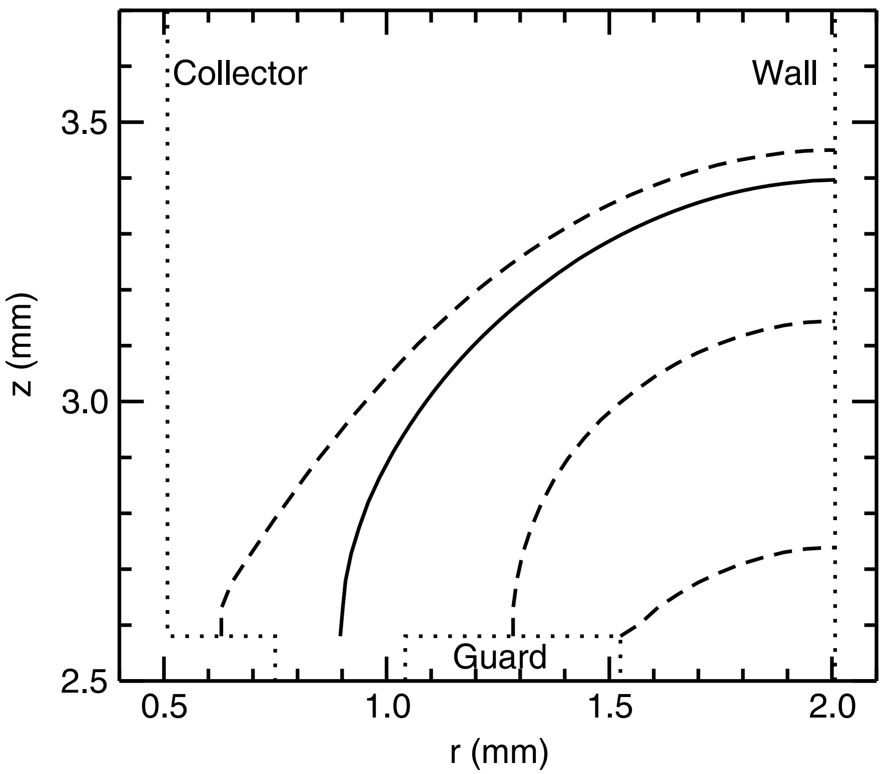

Figure 2. Electric field lines near the base of the Exradin A1SL chamber, calculated using the finite element code, FlexPDE. Ions produced to the right of the solid line will not be collected so this region is not part of the sensitive volume.

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