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Calibration of radiotherapy ionization chambers using Co-60 is outdated and should be replaced by direct calibration in linear accelerator beams

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POINT/COUNTERPOINT

Suggestions for topics suitable for these Point/Counterpoint debates should be addressed to Colin G. Orton, Professor Emeritus, Wayne State University, Detroit: ortonc@comcast.net. Persons participating in Point/Counterpoint discussions are selected for their knowledge and communicative skill. Their positions for or against a proposition may or may not reflect their personal opinions or the positions of their employers.

Calibration of radiotherapy ionization chambers using Co-60 is outdated and should be replaced by direct calibration in linear accelerator beams

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OVERVIEW

Most medical linear accelerators worldwide are calibrated using ionization chambers that are themselves calibrated by a standards laboratory, or secondary standards laboratory, in a Co-60 beam. Because these chambers are actually used to calibrate high-energy x-ray beams, it has been suggested that calibration against Co-60 is outdated and should be replaced by calibration in linear accelerator beams. This is the claim debated in this month's Point/Counterpoint.

Arguing for the Proposition is Ramanathan Ganesan, Ph.D. Dr. Ganesan earned his Ph.D. in Physics from the University of Mumbai in 2001, having previously worked for many years as Scientific Officer in the Radiation Standards Section, Radiation Safety Systems Division, BARC, Trombay, Mumbai, India. Subsequently, he spent some time working at the National Physical Laboratory, Teddington, Middlesex, UK, and NIST, Gaithersburg, MD, USA, before he moved to his current position as Senior Radiation Scientist, Radiotherapy Section Medical Radiation Services Branch, Australian Radiation Protection and Nuclear Safety Agency, Yallambie, Victoria, Australia. His major research interests are calorimetry measurements of photon and electron beams, calibration of dosimeters, small field dosimetry, development of diamond and diode detectors, and calibration of environmental radiation dosimeters.

Arguing against the Proposition is Malcolm R. McEwen, Ph.D. Dr. McEwen earned his Ph.D. in Radiation Physics from the University of Surrey, UK, in 2002, having previously worked for many years at the Centre for Ionising Radiation Metrology, National Physical Laboratory, UK. He then moved to his current position as Research Officer at the Ionizing Radiation Standards Group, National Research Council of Canada, Ottawa, Canada, where he is Director of the Ottawa Medical Physics Institute and Adjunct Professor within the Department of Physics, Carleton University. Dr. McEwen is Chairman of the Consultative Committee for Ionising Radiation Section I of the Bureau International des Poids et Mesures and has been very active in the AAPM including having served as Chair of the Working Group to review and extend data in the AAPM TG-51 dosimetry protocol for radiotherapy, and he is the current Chair of the AAPM Calibration Laboratory Accreditation Subcommittee. His major research interests are improvements in reference dosimetry for radiation therapy, experimental and theoretical works on the performance and application of secondary dosimeters in high energy photon and electron beams, investigation of novel dosimeters/applications in dosimetry at radiotherapy dose levels, and development of

high-accuracy experimental benchmarks for testing Monte Carlo radiation transport codes used, for example, in the commissioning of medical linear accelerators.

FOR THE PROPOSITION: Ramanathan Ganesan, Ph.D.

Opening Statement

The success of radiation therapy depends on the accuracy of the prescribed dose delivered. The starting point in the dosimetry chain deciding this accuracy is the dissemination of absorbed dose standards in the calibration of radiotherapy reference ionization chambers. Two methods of dissemination are available: one based on direct calibration of ionization chambers in megavoltage photon beams and the other based on the use of a correction factor, k_Q, applied to the calibration coefficient determined in a Co-60 beam.

Linear accelerators have totally replaced Co-60 for radiotherapy treatment in many countries and are becoming more common in others. The cost and difficulty in obtaining replacement Co-60 sources caused by increasing security concerns that treat Co-60 therapy sources as high risk, and the need to safely dispose of decayed sources, inhibit their use in hospitals and calibration laboratories.[1]

Several standards laboratories are equipped with Linacs.[2] The experimental measurement of the absorbed dose to water calibration coefficient $N_{D,w,Q}$ and beam quality factor k_{Q,Q_0} for the user chamber at primary standards dosimetry laboratories is the preferred option in IAEA TRS-398.[3] Observed chamber-to-chamber differences, which include the effect of waterproof sleeves (also seen for Co-60), justify the recommendation in IAEA TRS-398 for k_Q values specifically measured for the user chamber.[4] Also, the new formalism by the IAEA/AAPM working group for reference dosimetry of small and nonstandard fields recommends the direct calibration of the dosimeter in a conventional broad beam and machine-specific-reference fields against a primary standard without the Co-60 calibration.[5]

The accuracy of a calculated k_Q factor depends on the precision of the chamber geometry (including any deviations from the specified geometry). To use a measured k_Q only requires that the chamber response be reasonably insensitive to photon energy, so that users can interpolate between beam quality indicies.[6] Relative standard uncertainties for the experimental measurements of k_Q factors for the most commonly used chambers have been reported as 0.3%.[7] Although similar relative standard uncertainties of <0.5% have been achieved recently for Monte Carlo calculated k_Q values,[8] theoretical calculations are limited by the energy-dependent uncertainties of W/e and stopping power values. This is to be contrasted with the combined uncertainty for the direct calibration method such as the uncertainties achieved at the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) that are around 0.6%–0.7%, which are less than the estimated 1.1% with a reference beam quality of Co-60 and the TRS-398 energy correction.[10] Furthermore, for the calibration of flattening filter free beams, the published k_Q factors reported in IAEA TRS-398 have to be corrected,[9] adding to the uncertainties in using Co-60 calibration.

After the release of the IAEA TRS-398 and AAPM TG-51 protocols in 2000, several new ion chambers have been introduced in the market. Direct calibration may be used for these new or rare chamber types for which calculated k_Q factors are not available in IAEA TRS-398 or the addendum to AAPM TG-51.[11]

Calibration of radiotherapy ionization chambers using Co-60 is outdated for the above mentioned reasons and should be replaced by direct calibration in linear accelerator beams.

AGAINST THE PROPOSITION: Malcolm R. McEwen, Ph.D.

Opening Statement

At the heart of this proposition would appear to be the fact that for reference dosimetry of linear accelerator beams, the majority of clinical medical physicists worldwide must use a chamber calibrated in a Co-60 beam together with calculated k_Q factors. These factors, and the method to apply them, are provided by protocols such as AAPM TG-51 or IAEA TRS-398.[11–13] The reason to change from this approach is, presumably, that these calculated factors are used "on faith" and could lead to significant dosimetric errors when combined with any particular ionization chamber.

Fifteen years after the IAEA TRS-398 recommendation that users obtain calibrations in linear accelerator beams, the literature is surprisingly silent on the need to do so. Only one country in the world currently requires calibrations in linear accelerator beams. The National Physical Laboratory in the UK has carried out Linac calibration of ion chambers since 1989, and their own data[14] show no significant variation in chamber k_Q factors, to the extent that one can apply a generic calibration curve with an uncertainty better than 0.2%. Muir *et al.*[15] compared Monte Carlo k_Q factors to measurements and found very good agreement (0.25% or better) for a wide range of chamber types over the full range of Linac photon energies. Andreo *et al.*[4] compared the older TRS-398 calculations to the same experimental data set and concluded that no revision of those semianalytical k_Q factors was required. The National Research Council in Canada has been offering MV calibrations since 2007 and analysis of these data showed that, although one sees up to 1% variations in Co-60 $N_{D,w}$ coefficients, the *standard deviation* of k_Q factors for reference-class ionization chambers was only around 0.15%.[16] One can therefore reasonably ask, "What problem needs to be solved?"

On a more pragmatic note, although it is perhaps easy for the clinical medical physicist to view Co-60 as "outdated," I would argue that Co-60 is the ideal calibration beam. A Co-60 irradiation unit is simple and very reliable to use, has a very predictable output over multiple years, and is much cheaper to operate than a linear accelerator. Leaving the economics of the calibration laboratory aside (although in some areas of the world this is a very important consideration), moving from a Co-60 irradiator to a linear accelerator for calibration

would immediately result in a loss of precision and a loss in the ability to monitor the long-term stability of reference-class ionization chambers. Linear accelerator beams are simply not stable enough to provide that long-term reference field. Since the accuracy gain one might achieve by moving to Linac calibrations is, based on the literature, only a few tenths of one percent, this loss in baseline QA of the detectors results in a negative cost-benefit analysis. Linear accelerators may be the obvious choice for absorbed dose delivery but Co-60 remains the best choice for absorbed dose calibration.

Rebuttal: Ramanathan Ganesan, Ph.D.

Dr. McEwen has raised several important points regarding the calibration of radiotherapy ionization chambers. However, his comment that "*Fifteen years after the IAEA TRS-398 recommendation that users obtain calibrations in linear accelerator beams, the literature is surprisingly silent on the need to do so*" is not entirely correct. As I mentioned in my opening statement, a number of standards laboratories are installing Linacs, establishing primary standards, and measuring absorbed dose to water, the prime quantity needed for calibration, validated through international intercomparisons (e.g., BIPM.RI(I)-K6).[17] Also, there are a number of publications on experimental measurements of k_Q factors at megavoltage energies for several ionization chambers.[18]

Regarding his point that calibration data from the National Physical Laboratory in the UK show no significant variations in chamber k_Q factors, the chambers (NE 2561/NE 2611) were designed in-house and built specifically as secondary standards. Andreo *et al.*[4] observed significant chamber-to-chamber variations in Co-60 beams in a study of 91 NE 2571 chambers, which are the industry standard. The observation by Muir *et al.*,[15] who compared Monte Carlo k_Q factors to measurements and found very good agreement (0.25% or better), is valid only if possible variations of W/e with energy are ignored and assuming correlated uncertainties in photon cross sections. Larger deviations (~0.5%) between measured and theoretical k_Q factors occur at higher energies.

Dr. McEwen argues that replacement of Co-60 with linear accelerators for calibration would immediately result in a loss of precision and a loss in the ability to monitor the long-term stability of reference-class ionization chambers. This argument is contradictory to his claim that the MV calibration data from the National Research Council in Canada since 2007 have shown the standard deviation of k_Q factors for reference-class ionization chambers to be around 0.15%.

Rebuttal: Malcolm R. McEwen, Ph.D.

The rising cost of Co-60 re-sourcing is indeed a concern for many calibration laboratories but must be considered in the context of the price tag for a linear accelerator, which is the proposed alternative. If you take the optimistic assumption of a 20-yr Linac lifetime, you can do the math and conclude that you do not come close to the same capital costs for a Co-60 irradiator over that time period, even if you re-source every half-life. And that is before accounting for maintenance costs, which are significantly more for a Linac compared to a Co-60 unit. Economics are, therefore, not a driver for a change in the calibration basis.

The chamber-to-chamber variations cited are also illusory. The much larger data set from the US ADCLs analyzed by Muir[19] shows very tight tolerances on $N_{D,w}$ coefficients, and I would reiterate that there are no data in the literature that suggest a significant chamber-to-chamber variation in k_Q for any particular chamber type.

Direct calibrations in MV beams do indeed result in a potentially lower uncertainty in clinical reference dosimetry, although one could argue whether the improvement is significant. However, there is one issue where MV calibrations offer a clear advantage, and I am surprised it was not brought up by my opponent. A calibration in a MV photon beam is also a precise test of the user's chamber in a beam very similar to that in which it will be used. It answers that "*What if my chamber is atypical*?" question and is a QA test clearly missing from the present Co-60-based approach. Whether that, alone, is enough to warrant a wholesale change in calibration practices is for the user community to decide.

[1]IAEA, "The use and management of sealed radioactive sources," in *56th IAEA General Conference Documents* (IAEA, Vienna, 2012), NTR 2012 Supplement http://www.iaea.org/About/Policy/GC/GC56/GC56InfDocuments/English/gc56inf-3-att6_en.pdf.

[2]P. J. Allisy, D. T. Burns, and P. Andreo, "International framework of traceability for radiation dosimetry quantities," Metrologia **46**, S1–S8 (2009).

[3]H. Benmakhlouf and P. Andreo, "Ten years after: Impact of recent research in photon and electron beam dosimetry in the IAEA TRS-398 code of practice," in *Proceedings of an International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS), Vienna* (International Atomic Energy Agency, Vienna, 2011), pp. 139–152.

[4]P. Andreo, J. Wulff, D. T. Burns, and H. Palmans, "Consistency in reference radiotherapy dosimetry: Resolution of an apparent conundrum when ^{60}Co is the reference quality for charged-particle and photon beams," Phys. Med. Biol. **58**, 6593–6621 (2013).

[5]R. Alfonso, P. Andreo, R. Capote, M. S. Huq, W. Kilby, P. Kjäll, T. R. Mackie, K. Rosser, W. Ullrich, and S. Vatnitsky, "A new formalism for reference dosimetry of small and nonstandard fields," Med. Phys. **35**, 5179–5186 (2009).

[6]D. J. Butler, G. Ramanathan, C. Oliver, A. Cole, J. Lye, P. D. Harty, T. Wright, D. J. Webb, and D. S. Followill, "Direct megavoltage photon calibration service in Australia," Australas. Phys. Eng. Sci. Med. **37**, 753–761 (2014).

[7]M. R. McEwen, "Measurement of ionization chamber absorbed dose k_Q factors in megavoltage photon beams," Med. Phys. **37**, 2179–2193 (2010).

[8]B. R. Muir and D. W. O. Rogers, "Monte Carlo calculations of k_Q, the beam quality conversion factor," Med. Phys. **37**, 5939–5950 (2010).

[9]G. Xiong and D. W. O. Rogers, "Relationship between %dd(10)x and stopping-power ratios for flattening filter free accelerators: A Monte Carlo study," Med. Phys. **35**, 2104–2109 (2008).

[10]T. Wright, J. Lye, G. Ramanathan, P. D. Harty, C. Oliver, D. V. Webb, and D. J. Butler, "Direct calibration in megavoltage photon beams using Monte Carlo conversion factor: Validation and clinical implications," Phys. Med. Biol. **60**, 883–904 (2015).

[11]M. R. McEwen, L. Dewerd, G. Ibbott, D. Followill, D. W. O. Rogers, S. Seltzer, and J. Seuntjens, "Addendum to the AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon beams," Med. Phys. **41**, 041501 (20pp.) (2014).

[12]P. Almond, P. J. Biggs, B. M. Coursey, W. F. Hanson, M. S. Huq, R. Nath, and D. W. O. Rogers, "AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams," Med. Phys. **26**, 1847–1870 (1999).

[13]IAEA (International Atomic Energy Agency), "Absorbed dose determination in external beam radiotherapy," IAEA Technical Reports Series No. 398 (IAEA, Vienna, 2000).

[14]S. Duane and M. Simon, Experimental determination of the quality-dependent correction factors, k_Q, for ionisation chambers of type NE 2561 and NE 2611, National Physical Laboratory, Teddington, 2008, www.npl.co.uk/upload/pdf/20081201_rsug_poster_kq_factors_1.pdf.

[15]B. Muir, M. R. Mcewen, and D. W. O. Rogers, "Monte Carlo calculations of the beam quality conversion factor, k_Q, for cylindrical ionization chambers: Comparison with published data," Med. Phys. **38**, 4600–4609 (2011).

[16]National Research Council, NRC Activities and Publications, Report to the CCRI(I) Meeting, BIPM, March 2013, 2011-2013, http://www.bipm.org/utils/common/pdf/CC/CCRI/CCRI24.pdf.

[17]S. Picard, D. T. Burns, P. Roger, S. Duane, G. A. Bass, J. W. Manning, and D. R. Shipley, "Key comparison BIPM.RI(I)-K6 of the standards for absorbed dose to water at 5 g cm^{-2} and 7 g cm^{-2} of the NPL, United Kingdom and the BIPM in accelerator photon beams," Metrologia **52**, 06010 (27pp.) (2015).

[18]A. H. L. Aalbers *et al.*, "Code of practice for the absorbed dose determination in high energy photon and electron beams," NCS Report 18, 2012, http://radiationdosimetry.org/documents/ncs-18-.

[19]B. R. Muir, "Ion chamber absorbed dose calibration coefficients, $N_{D,w}$, measured at ADCLs: Distribution analysis and stability," Med. Phys. **42**, 1546–1554 (2015).