ABSTRACTS
FOR
RADIOThERAPY STANDARDS USERS’ MEETING

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An Overview of Radiotherapy Dosimetry at the NPL

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In relation to radiotherapy applications, The National Physical Laboratory maintains primary standards for absorbed dose to water and air kerma in a wide range of beam qualities.

For high-energy photon and electron beams (covering $^{60}$Co gamma rays as well as a range of electron and x-ray linac beams), the absorbed dose to water standard is based on a graphite calorimeter. For the lower energy range ($^{60}$Co inclusive) air kerma is measured using either graphite-walled cavity ionization chambers or free air ionization chambers. Also for brachytherapy sources the current approach is based on an air kerma measurement using a cavity ionization chamber. A review of the present status of these standards will be given.

At present, a number of new standards are being built either as a replacement of ageing standards or to extend NPL’s coverage of radiotherapy modalities. The progress of three new graphite calorimeters being developed as absorbed dose to water standards will be presented. One of them will replace the existing calorimeters for photon and electron beams. Another quite similar calorimeter will be specifically adapted for off-site measurement in proton and light-ion beams. The third one is the most revolutionary one and will measure absorbed dose at a point in a phantom for $^{192}$Ir HDR brachytherapy sources.

Apart from its main current function as an auditing and quality assurance tool, NPL’s therapy level alanine dosimetry service will play a role of increasing importance in traceable absorbed dose measurements for non-conventional radiotherapy modalities such as tomotherapy and IMRT. Another presentation at this meeting will give a status report on this work. Alanine and other dosimeters such as radiosensitive gels also represent NPL’s initial experience with 3D dosimetry, which will be of growing importance in the future.

Finally, replacements are at present being commissioned for the cavity ionization chambers serving as primary air kerma standards in $^{60}$Co and for $^{192}$Ir HDR brachytherapy sources.
Since May 2004 the NPL has provided a calibration service offering a calibration of either Farmer thimble chambers (with associated calibration jigs) or well chambers and electrometers for use with Ir-192, using a primary standard irradiated with an HDR Ir-192 source. To date 17 well-chambers and 2 farmer ionization chambers have been calibrated using this service, with 3 chambers re-booked for a second calibration after 3 years.

The HDR working party (comprising members of IPEM, RTSIG, BIR and NPL) was set up to help to ensure that the NPL standard can be disseminated and implemented in a consistent way to radiotherapy departments, by means of a Code of Practice.

The working party: Chris Lee (Clatterbridge); Steve Locks (Newcastle); Edwin Aird (Mount Vernon); Thorsten Sander and Rebecca Nutbrown (NPL) and Margaret Bidmead (Royal Marsden) have met several times and are now preparing the text for the Code of Practice. The COP is intended to replace the 1992 BIR/IPSM recommendations that are currently traceable to the NPL 280kVp X-ray quality.

On going investigations in preparation for the text are particularly concerned with:

- The type of source and method to be used for constancy check of a re-entrant chamber
- The measurement of recombination factor which should be performed within the individual hospital
- The recommended frequency of calibration of chamber
- The differences between source construction from different manufacturers and the effect on definitive calibration. (To be investigated by measurement of different sources with an NPL calibrated chamber and by MC simulations)
- The saturation effects of well-chambers with higher currents than measured with farmer chambers
- What constitutes a second, independent check of source calibration?
- Finding the sweet spot of the chamber, which should be performed at the user’s centre for a particular transfer tube.

The content of the process document is to include NPL calibration and in house calibration process.

It is hoped that the Code will be published towards the end of 2008.
Applications of Alanine

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Alanine dosimetry, with dosimeters read using electron paramagnetic resonance spectroscopy, enables the accurate measurement of absorbed dose to water under conditions which are very different from the usual reference conditions. The dosimeter pellets are small, the alanine/binder material is nearly water-equivalent and the dosimeter response is relatively insensitive to photon energy in megavoltage x-ray beams. These properties make alanine / EPR dosimetry well-suited to measurements where there may be some doubt over the validity of an ion chamber calibration determined under reference conditions, perhaps due to steep dose gradients or lack of electron equilibrium. This was the rationale behind our selection of NPL’s alanine reference dosimetry service as the means to provide traceable dosimetry in helical tomotherapy beams. I shall summarise the experience we have gained in delivering this service to tomotherapy users in the UK and overseas, and consider its potential for use in IMRT delivered using conventional machines.
Dosimetry Requirements for IMRT

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Intensity Modulated Radiotherapy presents particular challenges to dosimetry. These arise for the modulation in both the spatial and temporal domains.

In conventional radiotherapy reference dosimetry is carried out under conditions that ensure charged particle equilibrium, avoid the steepest dose gradients and with a dose rate, which is reasonably constant. In IMRT reference conditions cannot be so well defined and, even for the same modulation, the dosimetric issues that have to be addressed depend on the method of delivery.

In conventional radiotherapy, at least in the case of plain (unwedged) fields, the mapping of dose distributions can be carried out by measurement of the variation in dose rate relative to a fixed reference detector. In IMRT the dose at a point is determined by the integration of dose from the varying fluence over the total time of the irradiation. It is therefore necessary to map dose distributions by repeated integral measurements relative to an integral measurement at the reference point.

These differences between conventional and Intensity Modulated Radiotherapy require careful consideration in the selection and use of the instrumentation employed.

Measurement in dose gradients raises questions about the photon spectrum and the need for detectors with an acceptable flat energy response. High spatial resolution is, for many detectors, achieved at the expense of sensitivity, which increases susceptibility to dark current leakage and noise. Even if normal detectors are used irradiation times for IMRT are typically 2-3 times longer than for conventional treatments so leakage currents are a consideration.

Two and three dimensional dosimeter systems are used in the mapping of dose distributions, particularly in the development and validation of clinical IMRT techniques. They also have potential application in the validation of patient specific modulations as part of the pre-treatment checking procedure. While this is useful in the early stages of a technique it suggested that the continual reliance on detailed patient-by-patient measurement is an indication of an insufficiently robust planning and delivery technique. The availability of sophisticated dosimetry systems, while desirable is not an alternative to stable and predictable irradiation conditions.

Many aspects of IMRT can be considered as the integration of many small fields. Small being applied in the geometric and dosimetric (m.u.) sense. The issues around small field dosimetry including the temporal stability during very short exposures are interesting but particular attention must be given to the inter-relationship between the design (planning) of beam modulation and the dosimetric consequences. As a general rule dosimetric problems can be avoided or at least minimised by ensuring that, at any point in the distribution as much of the dose is delivered from large rather than small segments.
Improvements to the UK Primary Standard Therapy Level Electron Beam Calorimeter

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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 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.

Temperature rises in the calorimeter 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. A summary of the design of the new primary standard graphite calorimeter for therapy-level electron and photon beams will also be given.
NPL/IPEM reference dosimetry audits.

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Since 1994, at the invitation of IPEM, NPL has conducted reference dosimetry audits of UK radiotherapy departments. These audits enable regular checks on the dissemination of the national standard to the end of the calibration chain and improve confidence in the accuracy as well as the consistency of dosimetry for radiotherapy.

The NPL audits initially focused on the 1990 MV photon code and were subsequently extended to include electron beam dosimetry for both the 1996 and 2003 codes of practice. More recently, audits in the medium- and low-energy kV range have also been conducted.

In 1992 Thwaites et al [1] reported a dosimetric comparison of MV photon beams in all UK radiotherapy centres, obtaining a mean value for the ratio audit/local dose of 1.003 with a standard deviation of 1.5%. However, a significant number of measurements differed from unity by 3% or more.

Nisbet et al [2] carried out a second national comparison in 1997 for both photon and electron beams. They found agreement within ± 1% for photons and within ± 2% for electrons, although the proportion of measurements that showed large differences (>2.5%) was smaller than in the first national comparison.

One of the aims of the IPEM programme of regional interdepartmental audits together with the NPL reference dosimetry audits was to improve the consistency of dosimetry in the UK. NPL’s audit results to date also indicate an improvement in consistency in comparison to the earlier study. With the clinical implementation of the IPEM 2003 electron code of practice it is hoped that another national comparison will be undertaken.

The uncertainty of dosimetry using alanine/ESR for therapy-level doses has improved to the point where this provides a valuable quality-independent check, and has been successfully used for measurements on a Gamma Knife, in the CCO proton therapy beam and helped in the commissioning of the first UK Tomotherapy unit.

In recent discussions of the project formulation for the next NPL Radiation Dosimetry three-year programme (2007-2010) a strong case has been made to maintain funding for the audits.