Progress Report on Radiation Dosimetry at NPL

Peter Sharpe
National Physical Laboratory
Teddington, UK

March 2003

1 Facilities

Many of the radiation dosimetry facilities at NPL moved into new purpose built laboratories during 2001. This involved the dismantling and re-installation of the 50 kV and 300 kV x-ray sets and the movement of three self-shielded ^{60}Co irradiators. An extensive program of work was also necessary both before and after the move to demonstrate that the realisation of air kerma from the associated primary standards had not changed as a result of the relocation.

The new laboratories also contain a completely new diagnostic and mammographic facility. This facility is equipped with an Instrumentarium Imaging “Performa” mammographic set, with doped molybdenum anode, and a Comet AG diagnostic set. Commissioning of the facility is now in progress.

Increased space in the new laboratories enabled the installation of new Bruker EMX electron paramagnetic resonance spectrometer for alanine dosimetry. This has a higher sensitivity than the existing spectrometer and it is hoped will enable a reduction in the minimum useable dose (at present ~5 Gy).

2 Calibration Services

The current range of radiation dosimetry calibration services provided by NPL is summarised in Table 1, at the end of this report. During the past three years many of the NPL dosimetry facilities have moved into new buildings and this has caused some disruption to the normal service timetable. All services are now operational again and most have regained third party (UKAS) accreditation, which was voluntarily suspended during the move period.

3 Air Kerma Standards and Calibration Service

3.1 50 kV Free Air Chamber

The 50 kV free air chambers were moved into a new laboratory in May 2001. The new large volume free air chamber for use at protection level air kerma rates has recently developed some persistent leakage problems and work is still continuing to rectify these. The air attenuation and recombination corrections for this chamber will be re-determined when these problems are resolved. The corrections for the lower volume chamber will also be re-determined along with re-measurement of the x-ray spectra. This chamber has been involved in EUROMET comparison No. 526 at mammographic x-ray qualities.

3.2 300 kV Free Air Chamber

The 300 kV free air chamber was dismantled in May 2001 and reassembled later in a new laboratory. This chamber was involved in a comparison between the air kerma standards of NPL and ARPANSA using transfer chambers. The results are still awaited. This chamber, although large and heavy, has been shown to be relatively easily transportable. Therefore it is proposed that it is used for direct bilateral comparisons of medium energy air kerma standards with other primary standard laboratories. These comparisons are expected take place over a number of years.

3.3 Cobalt-60 Cavity Chambers

One of the three chambers that comprise this standard suffered some damage after the move to new laboratories and a significant rebuild of the stem was required. This has now been completed and the comparisons made since indicate there has been no significant change in the sensitivity of this chamber. The correction factors for these chambers have been recalculated but the changes will not be implemented until the new primary standard is adopted (see below).

The initial design of new cavity standards has been agreed and manufacture has begun. The primary standard will consist of four spherical chambers with volumes of 5, 10, 30 and 100 cm^3 which will ensure that they can be used for protection and therapy level services and the ^{192}Ir brachytherapy service. The insulator is expected to be PEEK™ (polyetheretherketone), whose composition is well known, unlike the current chambers, which use amber. Delivery of the chamber components is expected in June 2003 and assembly expected to be completed by September 2003. Determination of the correction factors will then begin and the chambers are expected to replace the current primary standard in the Autumn of 2004.

3.4 Comparisons

NPL has been involved in a EUROMET comparison of air kerma standards at mammographic qualities. The comparison was made via transfer standards circulated to each participating laboratory. The NPL measurements were performed in April 2001 and the comparison completed in May 2002. The final draft of the report has been circulated for comments.

A comparison is underway at medium energy x-rays and ^{241}Am γ-rays between NPL and ARPANSA. The measurements at NPL were carried out in July 2002.

3.5 Brachytherapy source calibrations

Work is continuing to establish traceability to the cavity primary standards. The work has demonstrated the difficulty in making measurements with the current chambers due to their age and small volume. It has been decided that the new cavity standards will consist of chambers of different volumes which will enable them to include measurements with a high dose rate ^{192}Ir brachytherapy source. As an interim measure, the volume of one of the high energy protection level transfer standards has been measured, which will enable this chamber to be used as the primary standard for
^{192}Ir until the new standards are ready. Work on determining the correction factors for this chamber is continuing and the calibration service is expected to be launched later in 2003.

A collimator has been constructed for the high dose rate ^{192}Ir source in order to minimize the scatter correction. The primary standard will be used to determine the dose rate at 1 m (reference air kerma rate, RAKR) for the NPL source. This source, which is expected to be replaced on an annual basis, will be used to calibrate the user well chambers directly, for customers with sources of similar geometry to that of the NPL source. Investigations will also be carried out into the calibration of well chambers when used with sources of different geometry. Calibration of thimble ionization chambers will also be available.

4 Beta-ray Standards

4.1 Protection Level

As reported previously, the protection level beta-ray primary standard was not moved to the new laboratories and NPL no longer has a primary standard chamber in this field.

4.2 Ophthalmic Applicators

The primary standard extrapolation chamber was moved into a new laboratory in May 2001. The chamber continues to function satisfactorily and work is underway to re-determine the correction factors.

Work is continuing on extending the measurements to curved applicators using thin (0.5 mm) alanine dosimeters as transfer standards, and a calibration service is expected to be operational in June 2003.

5 Absorbed Dose Standards and Calibration Services

5.1 Electron beam dosimetry standards

A collaborative project is being undertaken with the Risø National Laboratory, Denmark to establish standards for low energy (~100 keV) electron beams at industrial dose levels. A prototype total absorption graphite calorimeter has been constructed, incorporating a build-in data logging system. Initial results have highlighted significant heat transfer from the surrounding air and a second calorimeter incorporating a vacuum surround is being constructed to reduce this effect.

5.2 Clinical collimator

A clinical collimator has been installed on the NPL linac and is now operational alongside the original collimator for photon irradiations. The collimator will be used to study the effect of beam filtration on chamber calibration factors.

5.3 Water calorimeter

A number of changes have been made to the water calorimeter vessel and temperature enclosure. The front widow of the calorimeter vessel has been redesigned to achieve a thickness uniformity of better than 0.1%. The calorimeter mount has also been altered to enable more accurate positioning of the calorimeter vessel. It is intended to operate the calorimeter with H_2 saturated water, with the addition of a small amount of O_2. The well documented "spike" in the dose versus response curve can then be used to monitor O_2 depletion and indicate the achievement of a "zero heat defect" condition.

5.4 Graphite Calorimetry

Operation of the primary standard photon calorimeter in thermostatic mode has been demonstrated in the Co-60 facility. In this mode, the electrical heating power to the calorimeter core is switched between high/low values, to compensate for the absence/presence of radiation heating. At the same time, the heating power to the surrounding components (first and second jackets) is adjusted dynamically to maintain their temperatures close to constant. By keeping the difference in temperature between the core and its surround small and (at all times) measurable, the existing uncertainty of the primary standard can be significantly improved. Prototype software has been developed which implements the required control system and demonstrates the feasibility of extending this mode of operation to the beams available from the NPL linear accelerator. An additional benefit of moving from quasi-adiabatic to thermostatic operation is that the characteristic time for the system to reach equilibrium has been reduced from an hour or so to a matter of minutes.

The portable graphite calorimeter has been successfully operated in two hospitals, using Varian 6EX (6MV beam) and Elekta Precise 5786 (4MV, 6MV and 10MV beams), and in the BIPM ^{60}Co beam. In measurements at NPL, the uncertainty obtained with the portable calorimeter is comparable to that of the electron and photon primary standard calorimeters. Improvements are planned to the electrical screening of the calorimeter and consideration is being given to moving to an AC bridge design.

5.5 Proton Dosimetry

A project on proton dosimetry has recently been started in collaboration with Clatterbridge Centre of Oncology, UK. The proposed work will include dose measurements in a 60 MeV beam with ionization chambers, the NPL portable graphite calorimeter and alanine dosimeters.

5.6 Alanine Dosimetry

Work to characterise the response of alanine dosimeters in megavoltage x-ray beams was first carried out at NPL in 1992. Since that time the precision of alanine dosimetry has increased considerably and a further series of experiments were carried out in 2002 to take advantage of these improvements. The results confirmed no significant energy dependence of NPL alanine dosimeters in ^{60}Co and megavoltage x-ray beams (4, 6, 8, 10 and 12 MeV), within the overall uncertainty of the experiment (1.2% (2σ)). There was, however, a statistically significant offset of 0.6% between the response in ^{60}Co and x-ray beams, the response in x-rays being lower. The origin of this offset is not known and will be investigated further.

6 Publications and Reports (April 2001 – March 2003)

Angliss, R. F., Moretti, C. J. and Nutbrown, R. F., 2002, "Proposed specification for a primary standard of air-kerma for ^{60}Co, ^{137}Cs and ^{192}Ir gamma-ray sources", AAPM Symposium Proceedings No. 13, Medical Physics Publishing, Madison, WI, USA, 35-39.

DuSautoy, A., McEwen, M., Rosser, K., Duane, S. and Nutbrown, R., 2002, "Absorbed dose standards at NPL", AAPM Symposium Proceedings No. 13, Medical Physics Publishing, Madison, WI, USA, 88-107.

Hutenburg, R., DuSautoy, A. and Duane, S., 2002, "Energy resolution of in-phantom dose and charge measurement techniques used in reconstruction of electron spectra", NPL Report CIRM 50, National Physical Laboratory, Teddington, TW11 0LW, UK.

Ipe, N., Rosser, K., Moretti, C., Manning, J. and Palmer, M., 2001, "Air kerma calibration factors and k_{ch} values for Grenz, NACP and Roos ionization chambers at very low energies (0.035 mm - 1.0 mm AL HVL)", Phys. Med. Biol., **46**, 2107-2117.

McEwen, M., Duane, S., Thomas, R. and Rosser, K., 2001, "The role of the NPL in monitoring and improving dosimetry in UK radiotherapy", International Conference on Medical Physics & Radiation Safety (ICMP-2K1) & 22nd AMPI Annual Conference on Medical Physics, AMPI Journal of Medical Physics, **26.**

Nutbrown, R., Duane, S., Shipley, D. and Thomas, R., 2002, "Evaluation of factors to convert absorbed dose calibrations from graphite to water for the NPL high-energy photon calibration service", Phys. Med. Biol., **47**, 441-454.

Nutbrown, R., McEwen, M., Thomas, R., Duane, S. and Shipley, D., 2001, "Comparison of conversion factors for x-ray beams from a Philips SL 15 and the NPL linear accelerator", Phys. Med. Biol., **46**, 245-252.

Palmans, H. and Verhaegen, F., 2002, "Calculation of perturbation correction factors for ionization chambers in clinical proton beams using proton-electron Monte Carlo simulations and analytical model calculations", AAPM Symposium Proceedings No. 13, Medical Physics Publishing, Madison, WI, USA, 229-245.

Sephton, J. P., Sharpe, P. and Chu, R., 2002, "The use of ionisation chambers for dose rate measurements at industrial irradiation plants", Radiat. Phys. Chem., **63**, 789-792.

Verhaegen, F. and Das, I. J., 2002, "Interface Dosimetry for kV and MV photon beams", AAPM Symposium Proceedings No. 13, Medical Physics Publishing, Madison, WI, USA, 268-287.

Verhaegen, F., 2002, "Evaluation of the EGSnrc Monte Carlo code for interface dosimetry near high-z media exposed to kilovolt and ^{60}Co photons", Phys. Med. Biol., **47**, 1691-1705.

TABLE 1. NPL Calibration Services in Photon and Electron Dosimetry

	Photon Standards					Electron & Beta-ray Standards			Reference Dosimetry	
	Protection	Diagnostic	Therapy		Industrial	Ophthalmic Applicators	Therapy	Industrial	Dichromate	Alanine
Beam Qualities	x-rays: 8 kV – 300 kV γ-rays: ^{241}Am,^{137}Cs,^{60}Co	x-rays: 25 - 150 kV	x-rays: 8 kV – 280 kV γ-rays: ^{60}Co	x-rays: 4 - 19 MV γ-rays: ^{60}Co	γ-rays: ^{60}Co	beta: ^{90}Sr, ^{106}Ru	electrons: 3 - 19 MeV	electrons: 3 - 10 MeV	^{60}Co	x-rays: > 2 MV ^{137}Cs,^{60}Co e^{-} > 1 MeV
Dose / Dose rate	50 mGy/h	5 – 50 mGy/h	0.1 –1 Gy/min	0.5- 1 Gy/min	0.2 kGy/min	1 - 50 Gy/min	1 Gy/min	< 20 kGy/min	2 - 55 kGy	5 Gy - 70 kGy
Primary Standards	ion chambers: 50 kV free air 300 kV free air ^{60}Co cavity	ion chambers: 50 kV free air 300 kV free air	ion chambers: 50 kV free air 300 kV free air ^{60}Co cavity	graphite photon calorimeter	graphite photon calorimeter	extrapolation chamber	graphite electron calorimeter	graphite electron calorimeter	graphite photon calorimeter	graphite photon calorimeter
Primary Quantity	air kerma	air kerma	air kerma	absorbed dose to graphite	absorbed dose to graphite		absorbed dose to graphite	absorbed dose to graphite	absorbed dose to graphite	absorbed dose to graphite
Calibration Quantity	air kerma	air kerma	air kerma / exposure	absorbed dose to water	absorbed dose to water	absorbed dose to water	absorbed dose to water	absorbed dose to water / silicon	absorbed dose to water	absorbed dose to water