Progress Report on Radiation Dosimetry at NPL

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1 Introduction

This report gives a brief overview of radiation dosimetry activities at NPL during the period May 2003 to April 2005. More detailed scientific information can be found in the publications listed in Section 8 and, in a number of instances, in other papers submitted to this meeting of the CCRI(I).

2 Facilities

The new diagnostic and mammographic facility that was installed during the move to new laboratories has been set up and commissioned. It contains two clinical x-ray machines, a 40 to 150 kV diagnostic unit and a 20 to 35 kV mammographic unit, with a new carriage and laser alignment system.

Detailed discussions are being held with funding bodies over the replacement of the ageing NPL linear accelerator. The current plans involve two separate phases: the first being the installation of a therapy accelerator in a new building and the second the replacement of the existing research machine. The therapy accelerator will be commissioned before the existing accelerator is shut down, enabling continuity in the provision of calibration services.

3 Calibration Services

The current range of radiation dosimetry calibration services provided by NPL is summarised in Table 1, at the end of this report. A new calibration service for High Dose Rate brachytherapy was launched in 2004, with direct traceability to a primary standard. A web-based system has been introduced to enable customers to track the progress of industrial dosimetry calibrations. A password-protected database allows transmission of information to and from the customer, including the ability to access provisional results in advance of a formal certificate being issued.

4 Air Kerma Standards

4.1 ISO 4037 qualities

A new range of qualities, the ISO 4037 low air kerma rate series, has been added to the list already offered to the protection community. These qualities were established using both the 50 kV and the 300 kV primary standard free air chambers.

4.2 Cavity standards

Two sets of new primary standard cavity chambers for use with ^{60}Co, ^{137}Cs and ^{192}Ir have been designed and manufacture is almost complete. Each set consists of four spherical chambers with volumes of 5, 10, 30 and 100 cm^3. Once commissioned, they will replace the current (48 year old) cavity chambers and will have their use extended into the protection level area, eliminating the need to use transfer standards, and improving the throughput of the protection level calibration service.

4.3 Brachytherapy

A new primary standard ionisation chamber for High Dose Rate brachytherapy has been designed and commissioned. This is described in more detail in a separate paper submitted to the CCRI(I).

5 Beta-ray Standards

A new method of calibrating curved ophthalmic applicators has been developed. This is based on the extrapolation of depth dose curves determined using thin alanine pellets. Further details of the work on ophthalmic applicators are given in a separate paper submitted to the CCRI(I).

6 Absorbed Dose Standards

6.1 Electron beam dosimetry standards

The graphite electron beam primary standard calorimeter continues to perform well and it is hoped to improve overall accuracy by the inclusion of the results of finite element thermal modelling in the data analysis. Work is also underway on the recalculation of electron stopping powers and perturbation correction factors required for the transfer standards used in the realisation of absorbed dose to water.

A detailed study has been undertaken of the suitability of Advanced Markus and Exradin A10 chamber types for reference electron beam dosimetry. The results are available in NPL Report DQL-RD001.

Good progress has been made in the development of standards for low energy (~100 keV) electron irradiation for industrial applications. Several designs of totally absorbing graphite calorimeter have been developed and their behaviour compared to that predicted from mathematical models of both radiation transport and heat flow. The correlation between experimental and theoretical performance has been used to validate the designs and provide estimates of uncertainties. Preliminary work has been carried out on the use of these calorimeters to calibrate radiochromic dye films and thin film alanine dosimeters.

6.2 Water calorimeter

Following a review of priorities, it has been decided to suspend work on water calorimetry at NPL and in the short term to concentrate efforts on the development of improved graphite primary standard calorimeters.

6.3 Photon Calorimetry

The primary standard photon calorimeter is now being operated routinely in thermostatic mode. In this mode, a control system automatically adjusts the powers of electrical heaters to keep the calorimeter components at constant temperature, even when it is being irradiated. The energy absorbed from radiation can then be obtained from an analysis of the heater powers. Improved software has resulted in reliable operation in high-energy x-rays up to 2 Gy /min. A comprehensive study of the thermal behaviour of the calorimeter has resulted in a re-evaluation of the electrical calibration, this is discussed in detail in a separate paper submitted to the CCRI(I).

6.4 Proton Dosimetry

A very productive collaboration with the Clatterbridge Centre of Oncology in the UK has resulted in significant developments in proton dosimetry, including work on calorimetry, ionisation chambers and alanine. This work is described in a separate paper submitted to the CCRI(I).

6.5 Alanine Dosimetry

A study has been undertaken of the performance of one of the thin film alanine systems (Kodak/Bruker BioMax), which are now becoming commercially available. The small active thickness (120µm or less) means these dosimeters are potentially useful as transfer systems for low energy electron beam dosimetry and the study of interface effects. Many aspects of the performance of the thin film dosimeters, for example temperature coefficients and short and long-term stability, were found to be similar to those of standard alanine pellets. However, the reduced mass of alanine compared to pellets results in the sensitivity of the films being much lower, with a practical lower dose measurement limit of a few hundred gray. The reproducibility of the films (1.2% k=1) was also found to be lower than that of pellets (typically around 0.4% k=1).

7 Comparisons

The first of a series of comparisons involving the transportable 300 kV primary standard has been undertaken with PTB. The work is being carried out under EUROMET project 628 and covers the BIPM reference qualities, the diagnostic entrance and exit qualities, and the ISO narrow spectrum protection level qualities. Preliminary analysis of the results indicates excellent agreement between the NPL and PTB standards, the largest discrepancy being 0.55%.

Comparisons at industrial (kilogray) dose levels are undertaken approximately annually with NIST using alanine dosimeters in ^{60}Co radiation. Comparisons in 2003 and 2004 showed agreement within 2%. This is a larger difference than would be expected from the final results of the previous CCRI high dose comparison and the reasons for this are being investigated.

A comparison of absorbed dose to water standards in high-energy electron beam radiation is underway with METAS. Irradiations of transfer chambers have already been carried out at NPL. Irradiations at METAS are scheduled for 2005.

A comparison of High Dose Rate brachytherapy standards has recently been carried out with LNHB. All experimental work is complete and analysis of the results is underway.

8 Publications and Reports (April 2003 – April 2005)

J P Seuntjens and A R DuSautoy, *Review of calorimeter based absorbed dose to water standards Standards and Codes of Practice in Medical Radiation Dosimetry* (Proc. Int. Symp. Vienna, 2002), IAEA Vienna (2003) IAEA-CN-96-3, Vol. I, 37-66

M R McEwen, S Duane, I Stoker, *Comparison of Graphite Standard Calorimeters in Megavoltage Photon and Electron Beams,* (Proc. Int. Symp. Vienna, 2002), IAEA Vienna (2003) IAEA-CN-96-4, Vol. I, 67-73

M R McEwen, S Duane, *Portable Graphite Calorimeter for Measuring Absorbed Dose in the Radiotherapy Clinic,* (Proc. Int. Symp. Vienna, 2002), IAEA Vienna (2003) IAEA-CN-96-9P, Vol. I, 115-121

M R McEwen, S Duane, R A S Thomas, *Absorbed Dose Calibration Factors for Parallel-Plate Chambers in High Energy Photon Beams,* (Proc. Int. Symp. Vienna, 2002), IAEA Vienna (2003) IAEA-CN-96-28, Vol. I, 335-341

K N Govinda Rajan, S Vandana, M Vijayam, J B Shigwan, M R McEwen, S Duane, *Testing of* N_K *and* $N_{D,w}$ *based IAEA Codes of Practice for Clinical Photon Beams,* (Proc. Int. Symp. Vienna, 2002), IAEA Vienna (2003) IAEA-CN-96-57P, Vol. I, 467-474

R A S Thomas, S Duane, M R McEwen, K E Rosser, *Role of the National Physical Laboratory in Monitoring and Improving Dosimetry in Radiotherapy in the United Kingdom,* (Proc. Int. Symp. Vienna, 2002), IAEA Vienna (2003) IAEA-CN-96-80P, Vol. II, 201-208

K E Rosser, R J Aukett, A G Greener, R M Harrison, A E Nahum, *United Kingdom Code of Practice for Kilovoltage X-Ray Dosimetry,* (Proc. Int. Symp. Vienna, 2002), IAEA Vienna (2003) IAEA-CN-96-22, Vol. I, 271-278

D.Thwaites, A.R.DuSautoy, T.Jordan, M.R.McEwen, A.Nisbet, A.E.Nahum and W.G.Pitchford. *The IPEM code of practice for electron dosimetry for radiotherapy beams of initial energy from 4 to 25MeV based on an absorbed dose to water calibration.* Physics in Medicine and Biology, 48 (2003) 2929-2970

M.R.McEwen and A.R.DuSautoy, *Characterisation of the water-equivalent material WTe for use in electron beam dosimetry.* Physics in Medicine and Biology 48 (2003) 1885-183

H. Palmans, L. Nafaa, N. de Patoul, J-M. Denis, M. Tomsej and S. Vynckier, *A study of absorbed dose to water based dosimetry versus air kerma based dosimetry in three clinical electron beam energies*, Physics in Medicine and Biology 48 (2003) 1091-1107.

M.R.McEwen, J.P.Sephton, P.H.G.Sharpe and D.R.Shipley, *Use of a Range Scaling Method to Determine Alanine/Water Stopping Power Ratios.* Radiation Physics and Chemistry 68 (2003) 1017-1022

H Palmans, *Effect of alanine energy response and phantom material on depth dose measurements in ocular proton beams*, Technology in Cancer Research and Treatment 2 (2003) 579-586

J Helt-Hansen, A Miller, M McEwen, P Sharpe, S Duane, *Calibration of thin-film dosimeters irradiated with 80-120 keV electrons*, Radiation Physics and Chemistry 71 (2004) 355-359

H.Palmans, R.Thomas, M.Simon, S.Duane, A Kacperek, A.DuSautoy, F.Verhaegen, *A small-body portable graphite calorimeter for dosimetry in low-energy clinical proton beams,* Physics in Medicine and Biology 49 (2004) 3737-3749

J Witzani, H Bjerke, F Bochud, I Csete, M Denoziere, W de Vries, K Ennow, J Grindborg, C Hourdakis, A Kosunen, H Kramer, F Pernicka, T Sander, *Calibration of dosemeters used in mammography with different X-ray qualities,* Radiation Protection Dosimetry 108 (2004) 33-45

J A D Pearce, *Characterisation of two new ionisation chamber types for use in reference electron dosimetry in the UK,* NPL Report DQL-RD001, (2004)

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	γ-rays: ^{192}Ir	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	20 - 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	cavity ion chamber	ion chambers: 50 kV free air 300 kV free air ^{60}Co cavity	graphite photon calorimeter	graphite photon calorimeter	extrapolation chamber / graphite photon calorimeter	graphite electron calorimeter	graphite electron calorimeter	graphite photon calorimeter	graphite photon calorimeter
Primary Quantity	air kerma rate	air kerma rate	air kerma	air kerma rate	absorbed dose to graphite	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	reference air kerma rate	air kerma	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