

6 IONIZING RADIATION (P.J. ALLISY-ROBERTS)

6.1 X-and γ-rays
(P.J. Allisy-Roberts, D.T. Burns, C. Kessler* and S. Picard**; P. Roger)

6.1.1 Dosimetry standards and equipment

Replacement high-voltage dividers, having been designed last year, were constructed. One was installed for the medium-energy x-ray facility in September 2003 and the other for the low-energy facility in January 2004. The latter was tested extensively by comparison with the existing divider to allow a more robust estimate of the calibration uncertainty. New measurements of air-attenuation coefficients for both facilities showed no significant changes. A Compton spectrometer using a hyper-pure germanium detector has been assembled and calibrated for energy. Preliminary spectral measurements have been made in low-energy x-rays. A new, high-isolation dc voltage supply was designed and constructed for the anode current measurement in medium-energy x-rays.

The medium-energy x-ray tube, which has served since 1974, was replaced in May 2004 following the re-measurement of half-value layers and reference chamber calibration coefficients using the old tube. Work is underway to re-establish the CCRI reference qualities. Higher air kerma rates will be implemented, requiring a re-evaluation of ion recombination corrections for the primary standard.

Horizontal and vertical beam profile measurements were repeated on the new 250 TBq 60Co source to establish the mechanical stability of the facility. The positions of the beam centre and edges were reproduced to around 0.2 mm. The profiles for the 170 TBq 60Co source were also measured. The results were used to derive non-uniformity correction factors for the primary standard in each beam. An analytic model was developed to derive improved non-uniformity correction factors for spherical chambers. A new water phantom was constructed for the 250 TBq 60Co beam. The ion recombination correction for the BIPM primary standard has been verified in the 250 TBq beam. Two new graphite cavity chamber standards are under construction and should be tested before the end of the year.

Quality assurance calibrations have continued in all of the reference x- and γ-ray beams, as well as at the new mammographic radiation qualities.

Work has begun on a graphite calorimeter standard for absorbed dose measurements. Several low-noise thermistor bridges, a power supply and measuring equipment have been assembled and tested, and a system for precise temperature calibration developed. The current stage consists of an accurate measurement of specific heat capacity for an ensemble of graphite samples that are representative of the calorimeter core. Work is in progress on determining the electrical energy input and on minimizing the corrections for heat losses and sample impurities.

6.1.2 Dosimetry comparisons

Air kerma and absorbed dose to water comparisons in 60Co γ-rays were carried out in November 2003 with the BNM-LNHB (France). Reports of previous air kerma comparisons with the LNMRI (Brazil), NMIJ/AIST (Japan), NPL (United Kingdom) and the PTB (Germany) have been delayed as changes are being made to the various standards. The report for the ENEA (Italy) has been published. The summary report for all previous absorbed dose to water comparisons will be circulated to the CCRI for final approval prior to publication in the KCDB once the NPL result is approved. The reports of the OMH (Hungary) and the VNIIFTRI (Russian Fed.) for this quantity have been published.

Following the agreement of the CCRI(I) in May 2003 on new values for correction factors for the low- and medium-energy x-ray standards, based on Monte Carlo calculations, the new values were published in Metrologia and adopted with effect from 1 October 2003. Degrees of equivalence for key comparison results based on these values were evaluated, verified by each participating NMI and published in the KCDB by the end of November 2003.

The calculations needed to evaluate correction factors for the γ-ray standards are in progress. Calculations of x-ray spectra have also commenced with the modeling of the x-ray tube and collimation.

* A new member of staff since 23 April 2004, previously a Research Fellow.
** Transferred to the Ionizing Radiation section from 22 April 2003. For publications related to the Length section, see Section 2.8.1.
Reports of previous x-ray comparisons with the ARPANSA (Australia), BEV (Austria), NIM (China), NIST (United States) and the NMi (Netherlands) are in preparation. These comparison reports evaluate degrees of equivalence and the results will be included in the KCDB once they have been approved by the CCRI. The four transfer chambers for the high-energy absorbed-dose CCRI key comparison continue to be measured periodically in the BIPM $^{60}$Co beam.

6.1.3 Calibration of national standards for dosimetry

Procedures and technical instructions in accordance with the BIPM Quality manual for the dosimetry calibration services were completed and an external audit of the services carried out in December 2003. No non-compliances were recorded. A total of nine series of calibrations of national standards were made in low- and medium-energy x-rays for the BNM-LNHB (France), CIEMAT (Spain), IAEA, NRPA (Norway) and the STUK (Finland). Twenty-three calibrations of national standards were carried out in the BIPM $\gamma$-ray beams in terms variously of air kerma, absorbed dose to water and ambient dose equivalent, as requested by the CIEMAT (Spain), IAEA, HIRCL (Greece), the KRISS for the KFDA (Rep. of Korea), NRPA (Norway) and the STUK (Finland). The IAEA/WHO dosimetry assurance programme continued to be supported with reference irradiations in the $^{60}$Co beam.

6.2 Radionuclides (C. Michotte and G. Ratel; C. Colas*, S. Courte**, M. Nonis and C. Veyradier***)

6.2.1 International key comparisons of activity measurements

The CCRI(II) has embarked on an extensive programme of international activity comparisons, for most of which the BIPM is the pilot laboratory, to enable NMIs to support their measurement claims. Of the nineteen such comparisons that have been completed in the past, the results of eight are already published in the KCDB, a further five more recent comparisons are at the Draft B report stage and the remaining six are at the Draft A report stage. The BIPM measurement chain for the coincidence method has been redesigned and replaced. The new system, controlled by the atomic clock frequency from the BIPM Time section, includes a more sophisticated dead-time module that has a constant offset of only 4 (1) ns over the whole dead-time range from 2 $\mu$s to 51 $\mu$s, which is an improvement over the original system. The radiochemical laboratory is in the process of being updated to accommodate the additional workload of the comparison programme.

i) Comparison of activity measurements of a $^{192}$Ir solution

The amendments proposed by the participants to the Draft A report of this comparison have been incorporated and a more detailed report including uncertainty budgets is being prepared. The link to the BIPM comparison for $^{192}$Ir has been made and a linking report is in circulation.

ii) Comparison of activity measurements of a $^{241}$Am solution

The activity of the BIPM sample has been measured using the coincidence method with a proportional counter working at atmospheric pressure. No extrapolation was carried out because the counter was set on the alpha plateau and was thus insensitive to electrons as well as to x- and $\gamma$-ray scattering in the counter. This insensitivity was confirmed using a $^{60}$Co source. The activity concentration obtained with a relative standard uncertainty of $1.7 \times 10^{-3}$ is in good agreement with the other participants. This comparison is now complete after some postponements, particularly due to dispatch problems of the solution to a number of the twenty-two participants. The BIPM advised two laboratories of discrepant values, in accordance with the guidelines. Each laboratory has checked their results and resubmitted values with explanations for the changes. These revised results are being incorporated into the Draft A report with a note to identify the practice that has been followed.

* Retired on 31 December 2003.
** Employed since 12 November 2003.
*** Shared with Publications section; retired on 30 September 2003.
iii) Comparison of activity measurements of a $^{54}$Mn solution

The solution of $^{54}$Mn prepared and dispatched by the PTB to 23 laboratories has been measured by 19 laboratories, 18 of them using primary measurement methods. Ten different methods have been used producing 25 independent results. No impurity has been detected in the solution. Apart from one result, all the others are contained in a band covering the range $+1.35\%$ to $-1.2\%$ from the mean value. The results obtained with the CIEMAT/NIST method based on liquid-scintillation used by three laboratories (the BIPM, IRMM and the PTB) exhibit an unusual spread that should be investigated. The Draft A report is in preparation to be sent to the participants during the summer.

iv) Comparison of activity measurements of a $^{125}$I solution

A comparison of activity measurement of a solution of $^{125}$I has just started. The solution has been prepared and dispatched to the participants by the NPL. The BIPM received four extra ampoules with about six times more activity to be measured directly in the SIR ionization chambers. This should allow the outcome of the comparison to be entered in the SIR database. The BIPM is standardizing the solution by means of the liquid-scintillation method. Results are due to be sent to the BIPM by the end of August 2004.

v) Comparison of activity measurements of a $^{90}$Y solution

The BIPM participated in this comparison organized on behalf of the CCRI(II) by the IAEA. The solution of $^{90}$Y was prepared by the NIST. The BIPM measured the solution with a liquid-scintillation spectrometer using the CIEMAT/NIST method. The result obtained by the BIPM is in good agreement with the seven other results and with the mean value of the comparison at one standard deviation. The Draft B report is in circulation.

vi) Comparison of activity measurements of a $^{32}$P solution

Following the recommendations of the CCRI(II), a further comparison of a $^{32}$P solution between the three laboratories that obtained discrepant results in the 2003 comparison is being organized this summer. Another three previous participants will be included to ensure that the new results can be linked to the others and the opportunity is being made to enable some new participants to join this key comparison.

6.2.2 Other key comparisons

The comparison of activity measurements of a solution of $^{65}$Zn is in progress. The Draft A report should be issued this summer.

6.2.3 International reference system (SIR) for gamma-ray emitting radionuclides

During 2003 the BIPM received 15 ampoules, each containing one of eight radionuclides, from six laboratories: the BNM-LNHB (six ampoules filled with three different radionuclides), CIEMAT, CNEA, IRA, NPL (five ampoules filled with three different radionuclides) and the RC. As a consequence, nine new results have been registered for the radionuclides of $^{18}$F, $^{60}$Co (two results), $^{67}$Ga, $^{80}$Y, $^{103}$Ru, $^{153}$Sm, $^{201}$Ti and $^{222}$Rn.

In addition, ampoules prepared for different key comparisons have been measured in the SIR ionization chambers: one ampoule of $^{54}$Mn prepared by the PTB and one ampoule of $^{90}$Y prepared by the NIST. This will allow a direct link of the individual results of each of these comparisons to the KCDB. The measurement of one $^{18}$F ampoule prepared and sent by the NPL will also serve to link an international comparison to the KCDB. Finally, four ampoules of $^{85}$Kr filled with different gas pressures by the BNM-LNHB were measured in the SIR to study the influence of gas pressure on the ionization chamber response. The need for this study was identified during the analysis and publication of the results of the BIPM.Rl(II)-K.I.Kr-85 comparison.

Thirty-one ongoing BIPM comparison reports have been published in the KCDB during the last twelve months, including links for CCRI(II) or RMO comparisons in eight cases. A further five Draft B reports are in circulation and three others are in preparation.

The SIR measurement system is in the process of being updated with the development of new electronics (a Keithley electrometer integrated with a Townsend balance system) and an improved hardware/software interface.

The project, in collaboration with the NPL on the determination of a mathematical solution to the SIR efficiency curve as a function of the $\gamma$-ray energy is progressing well. The objective is to produce
software to calculate the efficiency curves for both beta particles and photons by solving the model
equations by the non-linear least-squares technique. As a first step, a photon efficiency curve has been
produced, using the SIR KCRV’s as input data. The second step is concentrating on including the
correction for impurities in each individual SIR measurement in the model, followed by a detailed
treatment of uncertainties and correlations. Finally, an improved model for the beta efficiency curve
and beta spectrum shapes will be defined. The project should be completed by the autumn 2004.

6.2.4 Gamma spectrometry

Impurity checks have been made for $^{18}$F, $^{51}$Cr, $^{85}$Sr, $^{103}$Ru and $^{131}$I submitted to the SIR. No impurity
was identified in any of these ampoules nor in those submitted for the $^{125}$I activity comparison of the
CCRI(II). The $^{153}$Sm ampoule from the BNM-LNHB was also measured and this identified a numerical
error that occurred in the impurity analysis at that laboratory. The corrected impurity contents are in
agreement with the values measured at the BIPM within one standard uncertainty.

6.3 Publications, lectures, travel: Ionizing Radiation section

6.3.1 External publications

1. Allisy-Roberts P.J., Burns D.T., Mutual recognition arrangement and primary standard dosimetry
comparisons, *Standards and Codes of Practice in Medical Radiation Dosimetry: Proceedings of

2. Burns D.T., Calculation of wall and non-uniformity correction factors for the Bureau International
des Poids et Mesures air kerma standard for $^{60}$Co using the Monte Carlo code PENELOPE, 2003,
*Standards and Codes of Practice in Medical Radiation Dosimetry: Proceedings of an

L3.

4. Burns D.T., Degrees of equivalence for the key comparison BIPM.RI(I)-K3 between national

5. Burns D.T., Degrees of equivalence for the key comparison BIPM.RI(I)-K2 between national

6. Michotte C., Nonis M., Développement d’une porte linéaire conservant les qualités
spectroscopiques d’un spectromètre GeHP (Journées de spectrométrie gamma et X, Saclay,

7. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Gd-153 of activity measurements of

8. Ratel G., Michotte C., Hino Y., BIPM comparison BIPM.RI(II)-K1.Ho-166m of activity
measurements of the radionuclide $^{166}$Ho and the links for the 2000 international comparison

9. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.In-111 of activity measurements of the

10. Ratel G., Michotte C., Los Arcos J.-M., Activity measurements of the radionuclide $^{67}$Ga for the

the radionuclide $^{109}$Cd and the links for the 1986 international comparison CCRI(II)-K2.Cd-109,

12. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Mo-99 of activity measurements of the


6.3.2 BIPM reports


6.3.3 Travel (conferences, lectures and presentations, visits)

P.J. Allisy-Roberts to:

- BIPM Summer school, 21 July – 1 August 2003, to give a lecture on ionizing radiation dosimetry;
- NPL (United Kingdom), 22-24 October 2003, for the DTI Measurement Advisory Committee (MAC); 11–13 November 2003, for the review of the NPL ionizing radiation and acoustics programmes for the MAC;
- London (United Kingdom), 7 July 2003, to attend the Ionizing Radiation Health and Safety Forum; 22 January 2004, for an international prioritization meeting held by the MAC; 28 January 2004 and 30 June 2004, for the editorial board of the *Journal of Radiological Protection*; 23 April 2004, for a meeting concerning high radiation doses at the Department of Health (United Kingdom); 7-10 June 2004, MAC working groups on ionizing radiation and on acoustics; 16 June 2004, to present a paper on ionizing radiation at a meeting for radiation protection advisers;
- Vienna (Austria), 1-5 March 2004, to chair the 11th meeting of the Scientific Committee of the IAEA dosimetry programme;
- BNM-LNHB (France), 10 March and 4 May 2004, to attend their Conseil Scientifique;
- NEL (United Kingdom), 15-16 March 2004, for the MAC.

D.T. Burns to:
• Melbourne (Australia), 19-21 August 2003, to attend the Workshop on Recent Advances in Absorbed Dose Standards;

• Oxford (United Kingdom), 8-12 September 2003, to attend the meeting of the Main Commission of the ICRU;

• Helsinki (Finland), 6-7 November 2003, as the BIPM contact person on ionizing radiation and radioactivity at the EUROMET contact person meeting.

D.T. Burns and C. Kessler to Sydney (Australia), 25-29 August 2003, to participate in the World Congress on Medical Physics and Biomedical Engineering. D.T. Burns presented the paper “Calculation of the wall correction for $^{60}$Co air kerma standards using PENELLOPE” and C. Kessler the poster “Calculation of the wall correction factor for the BIPM air kerma standard for $^{137}$Cs using the code PENELLOPE.”

C. Michotte to:
• BIPM Summer school, 21 July – 1 August 2003, to give a lecture on the metrology of radioactivity;

• Paris (France), 1-5 December 2003, to participate in the VERMI young researchers workshop on primary standardization methods.

S. Picard to:
• BNM-LNHB (France), 18 December 2003, to discuss calorimetry methods with Drs A. Ostrowsky and J. Daures;

• NPL (United Kingdom), 26 January 2004, to discuss calorimetry methods with Drs S. Duane and H. Palmans.

S. Picard and G. Ratel to NPL (United Kingdom), 27-28 January 2004, for a training course on “Scientific computing with Fortran 90/95”.

6.4 Activities related to external organizations

P.J. Allisy-Roberts is the member of the MAC for ionizing radiation and acoustics and is a scientific member of the UK Ionizing Radiation Health and Safety Forum. She is also a member of an ICRU Report Committee, the BIPM representative on the IAEA SSDL Scientific Committee, a member of the editorial board of the Journal of Radiation Protection and a referee for Physics in Medicine and Biology and the Bulletin du BNM.

D.T. Burns is the BIPM representative at the ICRU and is the BIPM contact person at EUROMET for ionizing radiation and radioactivity. He is a referee for Physics in Medicine and Biology and for Medical Physics.

G. Ratel is the BIPM representative at the International Committee for Radionuclide Metrology (ICRM).

6.5 Activities related to the work of Consultative Committees

P.J. Allisy-Roberts is Executive Secretary of the CCRI and its three Sections, and of the CCAUV. She attended the CCRI RMO Working Group. She and D.T. Burns are members of the CCRI(I) working groups on metrological equivalence (key comparisons) and on air kerma correction factors for cavity chambers.

G. Ratel is a member of the CCRI(II) working groups on the extension of the SIR to beta emitters, on key comparisons (attended with C. Michotte) and on measurement uncertainties.

C. Michotte is the contact person at the BIPM and rapporteur for the JCGM/WG1.

6.6 Visitors to the Ionizing Radiation section

• Dr S. Pommé (IRMM), 10 July 2003.

• Mr A. Pearce, Mr S. Judge and Prof. M. Cox (NPL), 5 August 2003.

• Mr A. Pearce and Prof. M. Cox (NPL), 22 September 2003 and 5 May 2004.

• Mrs M.G. Iroulart (BNM-LNHB), 28 September 2003.
6.7 Guest workers

- Mrs C. Lim (KFDA), 17-30 November 2003.
- Mr F. Delaunay (in part) and E. Leroy (BNM-LNHB), 24 November –5 December 2003.
- Dr K. Shortt (IAEA), 8-10 December 2003.
- Mrs A. Gonzalez and Dr A. Brosed (CIEMAT), 12-24 March 2004.
- Dr E.A. Hult (NRPA), 7-8 April 2004.