IAEA SECTION OF DOSIMETRY AND MEDICAL RADIATION PHYSICS (DMRP)

Report on Activities, 2005–2006

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Introduction

The Dosimetry and Medical Radiation Physics (DMRP) section supports the activities of Member States by ensuring international consistency in dosimetry standards and by monitoring the implementation and dissemination of those standards to end-users. Furthermore, it contributes to the increase in scientific and technical capacity in medical physics worldwide by fostering research and development in dosimetry techniques and playing a role in the education of medical physicists. The section also addresses the quality assurance (QA) aspects of the use of radiation in medical applications to ensure its safety and effectiveness. The primary beneficiaries of these activities are hospital patients undergoing radiation therapy and diagnostic radiology, radiation workers who benefit by the standardization of radiation protection measurements and the general public due to improved dosimetry practices.

1. Projects in the Subprogramme on Quality Assurance and Metrology in Radiation Medicine

During the period 2005–2006 the subprogramme was divided into four projects, with the titles as indicated, followed by the objectives in each case:

- **Radiation metrology supporting the network of Secondary Standards Dosimetry Laboratories (SSDLs)** (IAEA Recurrent Project F4.02)

  The objective of this project is to enhance the capability of Member States to achieve and maintain a high level of quality and consistency in radiation measurements and dosimetry standards, used in radiotherapy, diagnostic radiology, and radiation protection, that are linked to the international measurement system in accordance with the Mutual Recognition Arrangement (MRA).

- **Quality audits in radiotherapy dosimetry** (IAEA Recurrent Project F4.01)

  The objective of this project is to ensure the quality of the entire dosimetric chain in Member States at the hospital level, through an independent means of verification of the dose to be delivered to the patients during radiotherapy (using mailed TLDs).

- **Dosimetry codes of practice and guidelines for radiation measurements in radiotherapy, diagnostic radiology and nuclear medicine** (IAEA Project F4.03)

  The objective of this project is to strengthen capabilities and improve implementation of harmonized codes of practice in radiation dosimetry in Member States.

- **Medical physics developments for quality assurance and clinical applications of ionizing radiation** (IAEA Recurrent Project F4.04)

  The objective of this project is to improve quality assurance and dose auditing in Member States through the development of new techniques, methodologies and training material for use in QA and dose auditing.

A standing Scientific Committee established by the Directors General of the IAEA and WHO reviews and evaluates the work of the Dosimetry and Medical Radiation Physics Section, and advises the Director General of the IAEA on the strategies of the Dosimetry Subprogramme of the IAEA that will meet the needs of the Member States. The 12th meeting of the Committee took place in Vienna from 7–10 March 2006; their report was published in the SSDL Newsletter No. 52 (July 2006).

2. Services provided by the IAEA

The experimental work of DMRP is carried out at the IAEA's Dosimetry Laboratory, which is physically located at the Agency's Laboratories, NAAL, in Seibersdorf. The Dosimetry Laboratory is the central laboratory of the IAEA/WHO Network of SSDLs.

The range of laboratory services provided to Member States covers:

i) Calibration of ionization chambers (radiotherapy, mammography, and radiation protection). Radiation quality: X-rays (10 - 300 kV) and gamma rays from ^{137}Cs and ^{60}Co.

ii) Calibration of well-type ionization chambers for Low Dose Rate (LDR) brachytherapy. Radiation quality: gamma rays from ^{137}Cs.

iii) TLD dose quality audits for external radiotherapy beams (for SSDLs and hospitals). Radiation quality: gamma rays from ^{60}Co and high-energy X-ray beams.

iv) TLD dose quality audits for radiation protection (for SSDLs). Radiation quality: gamma rays from ^{137}Cs and ^{60}Co.

v) Reference irradiations for dosimeters for radiation protection. Radiation quality: X-rays (40 - 300 kV) and gamma rays from ^{137}Cs and ^{60}Co.

The calibration services provided to the SSDLs of the Member States are listed in the IAEA Calibration and Measurement Capabilities (CMCs), which can be found at: http://kcdb.bipm.org/appendixC/search.asp?met=RI&reset=1. Under "Direct access to full lists of CMCs by country as .PDF files", choose "International Organization" from the Country drop-down menu, and then click on "Display .PDF file".

3. Quality system at the IAEA's Dosimetry Laboratory

A Quality Assurance Programme has been established for the Dosimetry Laboratory following ISO Guide 17025: *General Requirements for the Competence of Calibration and Testing Laboratories* [ISO 1999 with the update in 2005]. The purpose of the QA programme is to help ensure quality through documented policies and procedures. The document consists of a main QA Manual followed by several Dosimetry Operating Laboratory Procedures (DOLPs). This manual sets out the general requirements of operation for the Dosimetry Laboratory. The manual is meant to create confidence in the quality of the services provided by the laboratory. The first six DOLPs describe the types of dosimetry systems that are maintained in the Dosimetry Laboratory as secondary/reference standards. Each DOLP describes the necessary equipment, the procedure for maintaining and using them at the specified level of quality, documentation to be maintained, the uncertainty associated with the measurements using the dosimetry system, etc. The next nine DOLPs describe the services that are offered to the Member States. Each DOLP delineates the technical as well as the administrative aspects of this service. The last DOLP describes the operation and safety aspects of the various irradiation units and sealed sources that are being used for calibration of dosimeters. Designated members of DMRP staff review the DOLPs at regular intervals to ensure their continuing relevance and effectiveness, and to introduce any necessary

changes and improvements. It is intended that the documentation for the Agency's QA programme be distributed to SSDLs and other institutes of Member States upon request, thereby serving as a model for them to develop their own QA programme.

The process of reviewing the Quality Management System of the Agency's Dosimetry Laboratory (DOL) was conducted during 2004-2006 in accordance with the provisions of the Mutual Recognition Arrangement (MRA). On 2006-10-05, the DOL Quality System was presented to a panel of quality experts sent by the Regional Metrology Organizations at the invitation of the Comité International des Poids et Mesures. The review process was completed the following day, with the JCRB approval as recorded in the minutes of their 17th meeting: "Resolution 17/1: the JCRB accepted the QMS of the IAEA." As a consequence, the DOL's calibration and measurement capabilities remain formally included in the "BIPM key comparison data base" available on the internet at http://kcdb.bipm.org/.

The dissemination of the radiation metrology standards under the MRA assures mutual acceptance of the calibration certificates issued by DOL and other laboratories in countries that are signatories of the MRA. At present the MRA involves 67 metrology institutions and 113 designated bodies worldwide, and over 110 members of the International Laboratory Accreditation Co-operation (ILAC), including all relevant laboratory accreditation bodies. The recent arrangements with ILAC provide for the equivalence of the MRA review process with the accreditation process by the laboratory accreditation bodies, such as ISO.

4. Radiation metrology supporting the network of Secondary Standards Dosimetry Laboratories (SSDLs) (IAEA Recurrent Project F4.02)

Membership in the IAEA/WHO SSDL Network is open to laboratories designated by their national competent authority. The network presently consists of 79 laboratories and 6 SSDL national organizations in 69 Member States, of which more than half are developing countries. The network includes 20 affiliated members, all of which are international organizations or Primary Standards Dosimetry Laboratories (PSDLs). Most SSDLs provide traceable instrument calibrations for radiation protection, radiation therapy, and in some cases, mammography. Some SSDLs also provide quality audits of radiotherapy beams by postal TLD and on-site measurements, and some perform measurements for nuclear medicine. The implementation of such a programme requires that the traceability of the SSDLs to a PSDL or to the IAEA be verified periodically through quality audits and comparisons organized by DMRP.

4.1 IAEA participation in comparisons organized by Regional Metrology Organizations (RMOs)

Another consequence of the MRA is that the IAEA's Dosimetry Laboratory needs to substantiate its calibration and measurements capabilities by participating in regional or bilateral comparisons.

4.1.1 Links to the Sistema Interamericano de Metrologia (SIM) key comparisons

The IAEA participated in a SIM comparison exercise started in 2002 and organized by the National Research Council (NRC) of Canada. Since some of the participating laboratories hold primary standards, the comparison results can be linked to the key comparison reference value maintained by the BIPM. The results obtained by the IAEA confirm its calibration and measurement capabilities for air kerma and absorbed dose to water calibrations in a Co-60 gamma beam. In the case of the air kerma comparisons, the Final report (SIM.RI(I)-K1) will be submitted to the CCRI(I)-2007 for approval.

4.1.2 Links to the Asian Pacific Metrology Programme (APMP) key comparisons

- The Asian Pacific Metrology Programme (APMP) key comparisons: the IAEA participated in a key comparison organized by the APMP on the measurement of air kerma for medium energy x-ray beam qualities (APMP.RI(I)-K3) in 2003. The results were reported during the CCRI(I) meeting in 2004.

- Key comparison for air kerma rate in ^{60}Co gamma radiation: the IAEA participated in a key comparison organized by the APMP on the measurement of air kerma (APMP RI(I)-K1) in 2004 (on-going comparison). In the framework of this comparison, three NE-2571 ionization chambers have been calibrated. The IAEA calibration coefficients were communicated to the APMP pilot laboratory in November 2004. The results of this comparison have not been published yet.

4.1.3 IAEA link to the European Collaboration in Measurement Standards (EUROMET)

- The IAEA participated in a EUROMET supplementary comparison of the personal dose equivalent for photon radiation (EUROMET project No. 738) in October 2004. The results of this comparison have not been published yet.

- The IAEA participated in a EUROMET comparison of air kerma and absorbed dose to water of ^{60}Co radiation in radiotherapy. The IAEA calibrated four ionization chambers. The preliminary results of the comparison from the pilot laboratory substantiate the IAEA Calibration and Measurement Capabilities for air kerma and absorbed dose to water calibrations in ^{60}Co gamma radiation. This comparison is going on.

4.2 IAEA support to SSDLs

4.2.1 Preparation of guidance documents SSDLs

Training material

A stand-alone document that includes training material for SSDL staff is in preparation. The first draft of the document was prepared during a Consultant's meeting held in November 2005. When completed, the document will be published as IAEA reference material and used for training SSDL staff in calibration and related quality control procedures.

Uncertainty of measurements

During the implementation of the ion chamber comparison programme, the IAEA identified important discrepancies in the way SSDLs report their calibration uncertainty. Although general Guidance on the expression of Uncertainty in Measurement (GUM) was published by the International Standards Organization (ISO) in 1995, no specific publication deals with the implementation of the ISO guidance for calibration of dosimeters. The first draft of an Agency document on uncertainty analysis in dosimetry has been prepared and reviewed by an external consultant.

Revisions of IAEA TRS-374 "Calibration of dosimeters used in radiotherapy"

The IAEA TRS-374 "Calibration of dosimeters used in radiotherapy" published in 1994 is being reviewed by a group of three external consultants. The first draft will be reviewed during a consultants' meeting in June 2007.

4.2.2 Setting-up new SSDLs

Under its technical cooperation programme, the IAEA is assisting six Member States to establish four new SSDLs (Israel, Saudi Arabia, Serbia and Uruguay) and to upgrade two SSDLs (Tunisia

and Cuba) by introducing new calibration services and strengthening their quality system following ISO-17025.

Under the Regional Technical Cooperation Programme in Africa, two SSDLs were nominated as Regional Designated Centres, to alleviate the IAEA workload in the region. These regional SSDLs would provide calibration services for therapy and radiation protection, and also conduct on-the-job training for SSDL staff in the region.

4.2.3 Calibration of national measurement standards of the Member States

During 2005–2006, the IAEA calibrated 94 ionization chambers, of which about 70% were for radiotherapy, 18% for radiation protection level dosimetry, 10% for mammography and 2% for low dose rate brachytherapy. Most of the calibrations were done for SSDLs (75%). The calibrations for hospitals have decreased due to the use of other calibration laboratories.

The number of ion chambers calibrated during this period is lower than for the previous period due to the construction work to expand the measurement facilities and install new equipment, which led to a year-end service interruption of about 6 months.

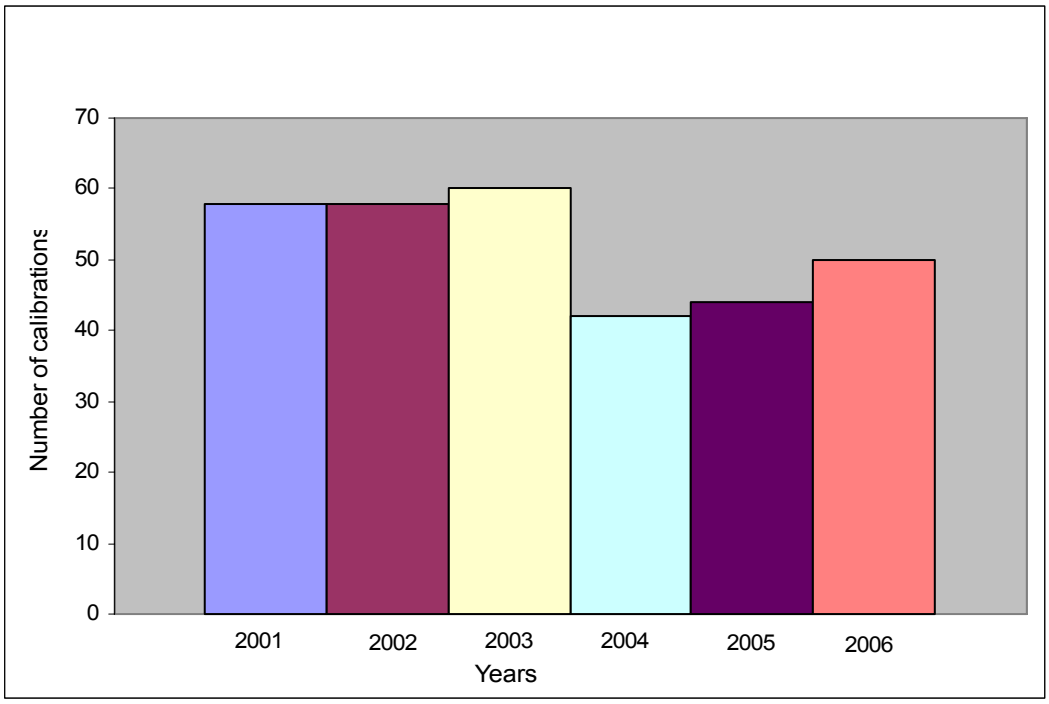

FIG. 1: Number of calibrations done each year.

4.2.4 Calibration for diagnostic radiology

Activities in this area include calibration of ionization chambers in mammography beams and the establishment of diagnostic beam qualities in the range of 40–150 kV, following the IEC61267 standard.

- The calibration of chambers in mammography beams has been included in the IAEA Calibration and Measurement Capabilities since 2002. The calibrations are provided only to SSDLs and represent about 10% of all IAEA calibrations. Although the number of calibrations in mammography beams is relatively low, the IAEA has not promoted this service, due to calibration workload and facility constraints. Presently, the mammography machine is installed in a room with 2 other X-ray tubes, one used for therapy and the other for protection level dosimetry. In addition, the calibration of brachytherapy sources is also

performed in the same room. The number of beam qualities proposed to SSDLs was reduced from 17 to 7 beam qualities and limited to MoMo beams. Upon request, additional beam qualities are available for Mo anode, MoRh (28 & 32 kV) and for Rh anode, RhRh (25-35kV).

- To facilitate the calibration of ion chambers for diagnostic beam qualities, a new bunker was constructed. The room will host 2 X-ray tubes (one for mammography, and another for general diagnostic radiology and computed tomography beams) and a high voltage divider. The equipment has been purchased and will be installed during April 2007. The generation of the diagnostic beam qualities (including mammography) will be initiated as soon as the commissioning and licensing process is completed. Experiments to establish the diagnostic beams in general radiography (including dental), fluoroscopy and computed tomography were conducted in the so called "old" bunker during 2005 and 2006, with the X-ray machine used for protection and therapy level calibrations. The necessary filtration, resulting HVL and beam homogeneity for RQR, RQA and RQT diagnostic beams as defined in IEC 61267 have been successfully established. The experience gained with the measurements in the "old" bunker will be used to setup the diagnostic beam qualities in the newly dedicated X-ray diagnostic radiology bunker. Two reference Exradin ionization chambers (A3 and A4) have been purchased, tested and calibrated at PTB.

4.2.5 Comparison of ionization chamber calibration coefficients for absorbed dose to water and air kerma

A proficiency-testing programme that began in 1995 verifies the ability of SSDLs to transfer a calibration from their reference standard to the user. In this programme, the SSDL calibrates an ionization chamber of its choice, and forwards it to the IAEA for calibration. The chamber is returned to the SSDL where the calibration is repeated to ensure stability of the instrument during transit. During 2005–2006, 10 SSDLs participated in this ionization chamber comparison programme. The results are presented in Figure 2. Calibrations both in terms of air kerma and absorbed dose to water were included. Two discrepancies were identified and resolved, following implementation of corrections for the difference in standards between the BIPM and the 2 PSDLs to which these 2 SSDLs were traceable.

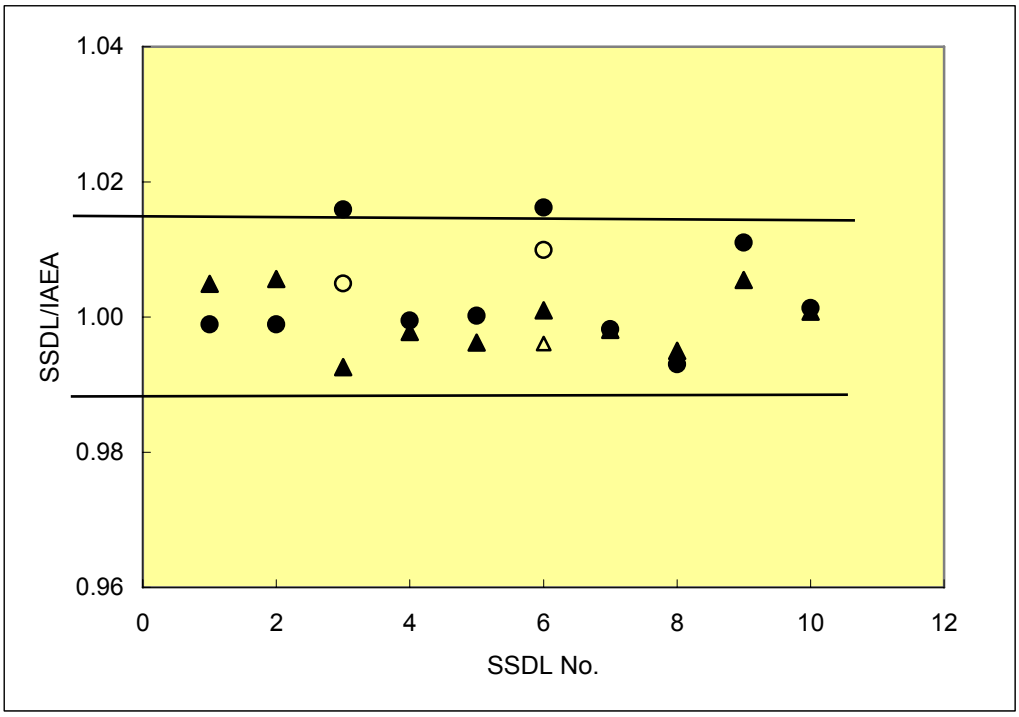

FIG. 2: Ratios of ion chamber calibration coefficients supplied by the SSDLs to those measured by the IAEA. Circles correspond to air kerma calibration coefficients and triangles to absorbed dose to water factors. Results are considered acceptable if the deviation of the ratio from unity is less than 1.5 %. The open symbols show data corrected by taking into account known differences in the standards of the BIPM and the PSDL to which the SSDLs were traceable.

4.2.6 Pilot study in X-ray dosimetry comparison for radiation protection dosimetry in Africa

At the request of the IAEA officers in charge of individual monitoring (Division of Radiation, Transport and Waste Safety), the DMRP provided reference irradiations in support of a regional dosimetry comparison among individual monitoring services in Africa for ^{137}Cs and ISO 4037 X-ray beams. The first comparison results among the individual monitoring services revealed important deviations among the participants. It was decided to verify the calibration and measurement capabilities of the SSDLs that provide traceability to the individual monitoring services in Africa. For ^{137}Cs, the verification was conducted with TLDs. The results were within the 5 % acceptance limit. For the verification of the calibration in X-ray beams, two IAEA Exradin ionization chambers type A5 were used. The 2 chambers were calibrated at the IAEA and at BEV when the X-ray comparison started. The IAEA to BEV ratios were all within 1.2 % (N40-N300). After each calibration by one of the participating SSDL, the 2 ion chambers were sent to the IAEA for a re-calibration before they were sent to the next participant for a blind calibration in ISO-4037 narrow X-ray spectra. The participating SSDLs were Algeria, Ethiopia, Ghana, Tanzania and South Africa. The initial results of the comparison were not satisfactory; deviations up to 15 % were identified. Following these results, it was decided to hold a group training on calibration procedures in X-ray beams at the IAEA Dosimetry Laboratory during 26-30 March 2007.

4.3 TLD-based monitoring of SSDL measurements

4.3.1 Therapy level

The IAEA/WHO TLD postal dose quality audit service has monitored the performance of the SSDLs in the therapy dose range since 1981. Results of this programme indicate that approximately 99% of the SSDLs that participated in the TLD audits in this biennium have results within the 3.5% acceptance limit.

The results for dose delivery under reference conditions in a water phantom for the laboratories providing therapy level calibrations are presented in Figure 3, where ratios of the IAEA's dose to that stated by SSDLs are plotted for ^{60}Co and high energy X-rays. During the review period, three SSDL TLD runs (two in 2005 and one in 2006) were completed for 59 laboratories, in which the calibration of 150 beams was checked (107 ^{60}Co and 43 high energy X-ray beams from medical accelerators).

For laboratories with deviations outside the acceptance limit, a follow-up programme was established to resolve the discrepancies. Those laboratories are informed by the IAEA about the discrepancy, and assisted to understand and resolve the problem. A second (follow-up) TLD set is sent to each of these SSDLs and deviations outside the 3.5% limit are explained and corrected.

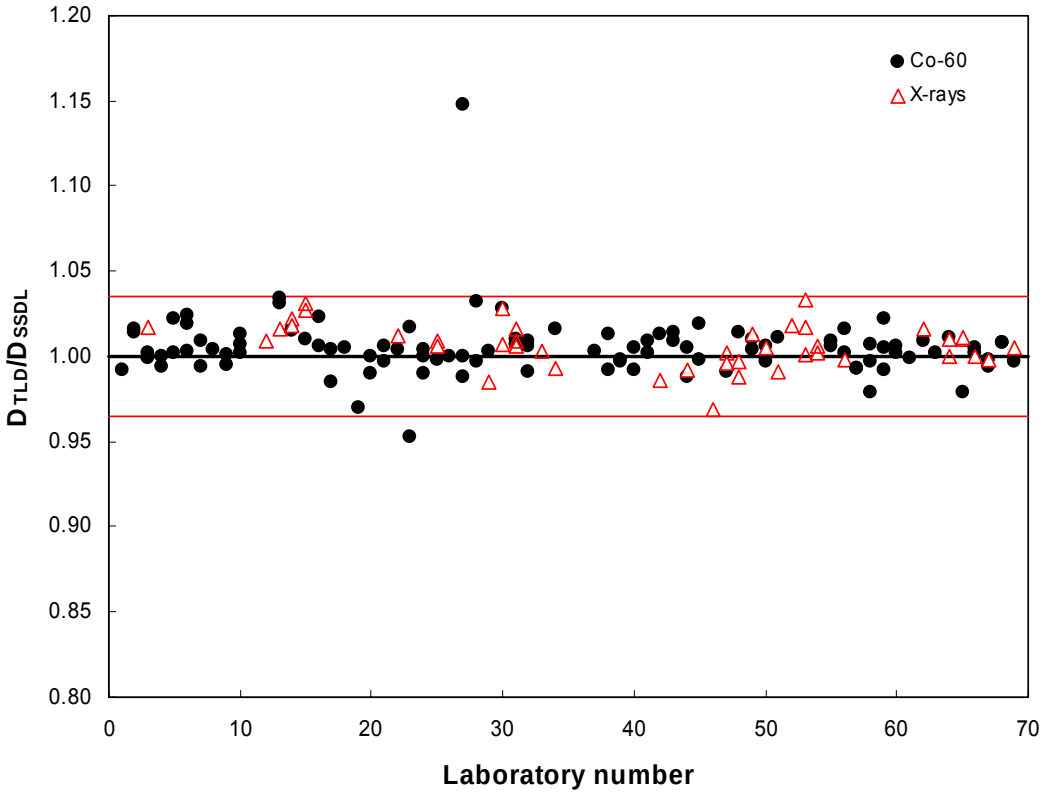

FIG. 3: Results of the IAEA/WHO TLD postal dose audits for SSDLs for the delivery of dose to water under reference conditions for the 2005/1, 2005/2 and 2006 TLD runs. Data in the graph correspond to the ratio of the dose determined by the IAEA from the TL-response (D_{TLD}) to that stated by the SSDL (D_{SSDL}). Each data point corresponds to the average of three dosimeters. A total of 150 beam calibrations was checked in 59 laboratories, which included 107 ^{60}Co (circles) and 43 high energy x-ray beams (triangles). The number of therapy beams checked in different TLD runs was: 46 beams in 2005/1, 51 beams in 2005/2 and 53 beams in 2006. Two deviations were found outside the acceptance limit of 3.5% (both in the 2006 TLD run). The deviations have been explained and corrected.

4.3.2 Protection level

This service for SSDLs engaged in calibration for protection level using ^{60}Co and ^{137}Cs beams started in 1999. Up to 2005, it was organized in 2 runs per year; each run involving about 15 laboratories. Due to limited staff resources, it was decided to conduct only one run during the 2006-2007 cycle.

Selected PSDLs (1 to 2) are supplied with a set of dosimeters and asked to irradiate them at prescribed levels of air kerma. These dosimeters are used as an independent check of the IAEA measurement system. The SSDLs with results outside the acceptance limit of 5%[1] are contacted and support is provided to resolve the discrepancies. As a routine, they are invited to participate again in the next run.

The results of runs in 1999–2006 are plotted in Fig. 4. One can see that about 20% of laboratories exceed the 5% acceptance limit in the first run and most of discrepancies are corrected during the first and second follow-ups. The analysis of these audits shows that the main contributing factors of persistent deviations are inadequate training of staff and lack of traceability of the standards used at their SSDL.

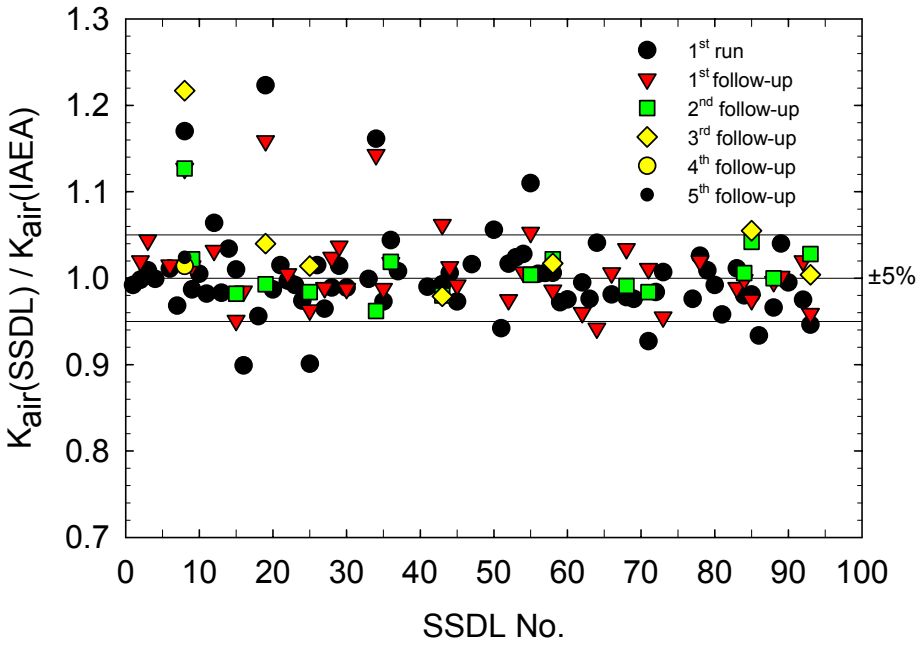

FIG. 4: Ratios of the air kerma stated by SSDLs to the TLD measured value at the Agency's Dosimetry Laboratory for runs at protection level in 1999–2006 (acceptance limit 5 % [1]).

5 Quality audits in radiotherapy dosimetry (IAEA Recurrent Project F4.01)

Dose quality audits are conducted for radiotherapy centres via mailed TLDs. In this service, hospital staff are requested to irradiate the dosimeters with a given dose under known irradiation conditions; the dosimeters are returned to the IAEA for evaluation. A similar service based on ESR-alanine was available for industrial facilities but it was closed in 2006.

5.1 The IAEA/WHO TLD postal service

In 2005–2006, the IAEA/WHO TLD postal dose audit service for hospitals continued its previous development by improving the organization and efficiency of the service. At present the number of hospital beams monitored exceeds 400 per year. Due to the joint effort of the IAEA and WHO, the return rate of the irradiated dosimeters has been maintained at approximately 96%.

[1] Following the advice of the SSC-13, the acceptance limit has now been set to 7% (to be implemented as of 2007).

During this review period, the TLD programme audited 848 beams in 420 radiotherapy centres. The global results are shown in Figure 5. Approximately 89% of the results are within the acceptance limit of 5%.

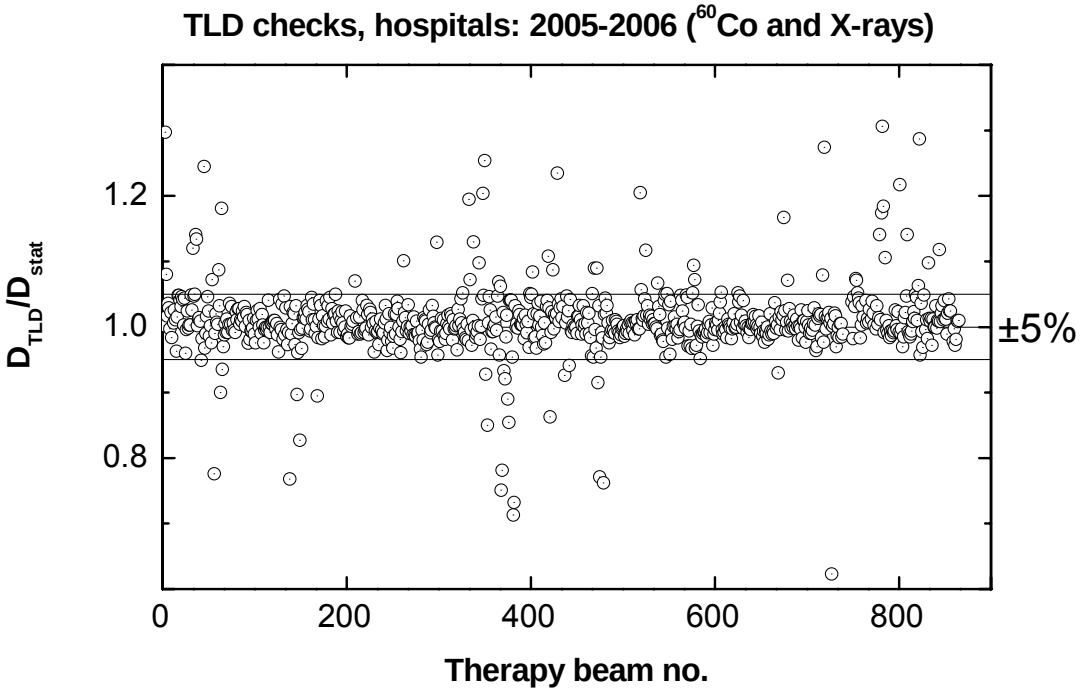

FIG. 5: Results of the IAEA/WHO TLD postal dose audits of radiotherapy hospitals for the delivery of absorbed dose to water under reference conditions for TLD batches B160 to B179 (from December 2004 to November 2006). Data in the graph correspond to ratios of the IAEA's determined dose (D_{TLD}) relative to the dose stated by the hospital (D_{stat}). Each data point corresponds to the average of two dosimeters. A total of 848 beam calibrations were checked in 420 hospitals. Approximately 11% of the results were found outside the 5% acceptance limit. Of these, 5% were corrected by April 2007 due to subsequent follow-up action or by expert visits.

The follow-up procedure to resolve discrepancies has been strengthened through closer contact with local experts where available (mainly from SSDLs), or by recruitment of external experts in medical physics. Thanks to the follow-up action, the percentage of acceptable results increased to 94% in 2005–2006, leaving approximately 6% of the results that have not been corrected. Of these 6%, 4% of the cases pertain to on-going follow-up action (not completed by April 2007) with the follow-up TLDs that are still expected to be returned from hospitals. The remaining 2% of the deviations persist due to local problems that could not be resolved without the allocation of additional resources.

At present, the main focus in the TLD programme is given to expanding the service to new hospitals since the number of radiotherapy facilities in the world continues to increase. In 2005–2006, 113 additional radiotherapy centres joined the TLD network. Only 75% of the beam checks in hospitals that received TLDs for the first time showed results within the 5% acceptance limit, while 92% of the beam checks in institutions that benefited from a previous TLD audit had results within the 5% limit. The percentage of institutions that get results beyond the 10% limit is very high for the new hospitals (15%) compared to those having participated in previous audits (4%).

To provide appropriate QA for the TLD system, in addition to contacts with BIPM and PSDLs, systematic collaborations with other TLD-based QA networks in Europe and USA are maintained.

The Agency continues to exchange TLDs with EQUAL/ESTRO and RPC-Houston for reciprocal quality control of TLD systems.

In order to foster independence, the IAEA assists Member States to establish national TLD programmes and whenever possible, establishes links between these national programmes and the IAEA's Dosimetry Laboratory. A Coordinated Research Project (CRP E2.40.12) run in 2001-2006 for national TLD audits in non-reference conditions, continued the previous CRP "Development of a TLD based quality assurance programme for radiation therapy dosimetry in developing countries", which dealt with TLD audits under reference conditions.

5.2 Alanine-ESR Dose Quality Audit Service (IDAS) for radiation processing

The International Dose Assurance Service (IDAS) was inaugurated in 1985 to meet the requirement for accurate dosimetry and to achieve a coordinated international effort for quality control in radiation processing. Initially, this service was offered to both commercial and non-commercial irradiation facilities, and to high-dose applied research institutes dealing with radiation processing. Since 1992, the service was offered on a regular basis, but mainly limited to ^{60}Co gamma rays. Given the cost of maintaining the ageing spectrometer and insecurity over its reliability, various external review panels recommended that the Agency consider terminating the service. DMRP limited the service in 2004-2005 to non-commercial facilities only, and after one-year's notice, the service was ceased at the end of 2005. Below, the details of the activities within the IDAS project and results of the audits are summarized for the time period 1992 to 2005.

5.2.1 Activities in the IDAS project

Following Agency procedures, the operators of the facilities to be tested irradiated Agency alanine-ESR dosimeters at radiation doses relevant for industrial applications and returned them to the Agency for evaluation. The dose range was between 0.1 kGy and 100 kGy. The reference irradiation conditions were recorded and reported along with the intended dose values. After analysis, the results were compared with the stated values and a certificate was issued indicating the relative deviation.

About 50 different facilities participated in IDAS at various times in the period 1992-2005. Altogether 636 alanine-ESR dosimeter sets were distributed to regular participants at the rate of 40 to 50 checks per year. The results are given in Figure 6 with approximately 70% within the acceptance limit of 5%. Twenty-five follow up dosimeters were sent to the participants and in 18 cases the discrepancy was resolved. Approximately 80% of the participants represent institutions from developing countries, and one third of the institutions were commercially motivated. In the process of closing, DMRP limited the service to non-commercial facilities only, starting in 2004, and only 10 such facilities participated in IDAS audits during 2005, as shown in Figure 7.

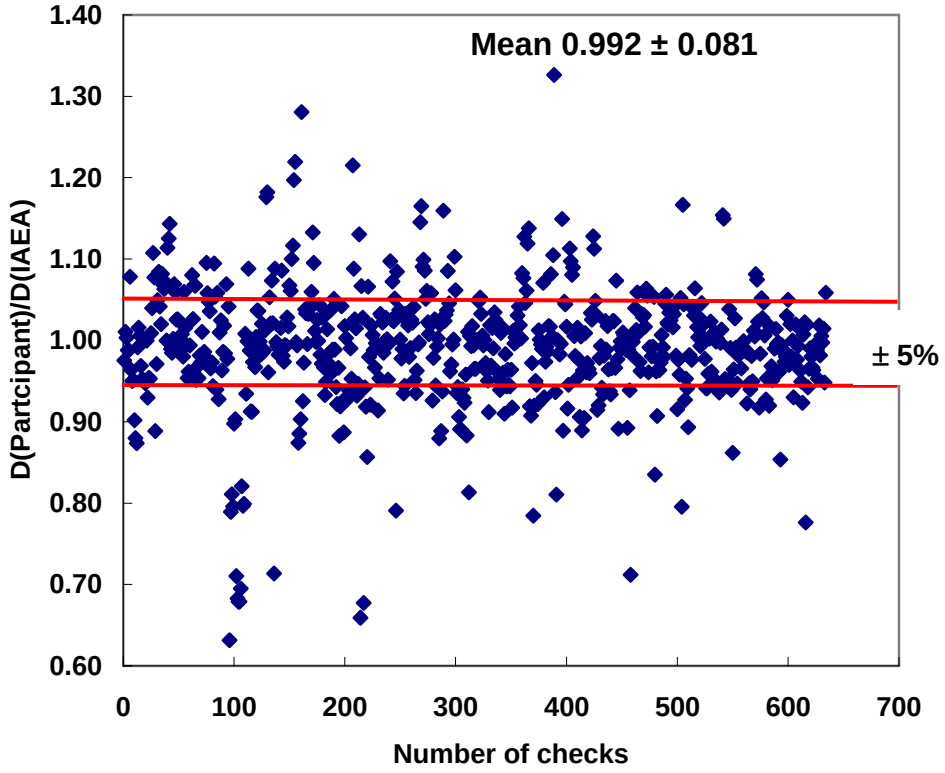

FIG. 6: Results of the IAEA IDAS postal dose audits of radiation processing facilities for the delivery of absorbed dose to water under standard conditions, during 1992–2005. Data in the graph correspond to ratios of the dose stated by the institution ($D_{participant}$) relative to the Agency's determination of dose (D_{IAEA}). Each point corresponds to the average of three dosimeters. A total of 636 beam calibrations were checked. Approximately 30% of the results were found outside the 5% acceptance limit.

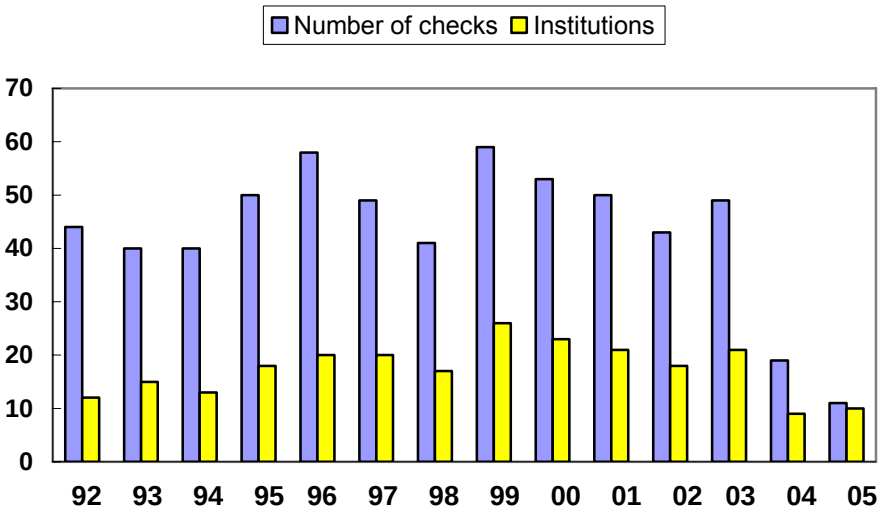

FIG. 7: The distribution of participants and IDAS checks during 1992-2005.

Average results of the IAEA IDAS postal dose audits of radiation processing facilities for dose delivery under reference conditions during 1992–2005 are given in Figure 8. Data in the graph correspond to the mean ratios of the dose stated by the institutions (D_{part}) relative to the Agency's determined dose (D_{IAEA}) and standard deviations for the group of the participants in each particular year. In 1994 several new facilities started to participate in the IDAS service, and about half their

results were outside the acceptance limit with deviations up to 40%. As can be seen, there is a trend towards improvement of the results through the years, nevertheless approximately only 70% of the results are within the acceptance limit of 5%.

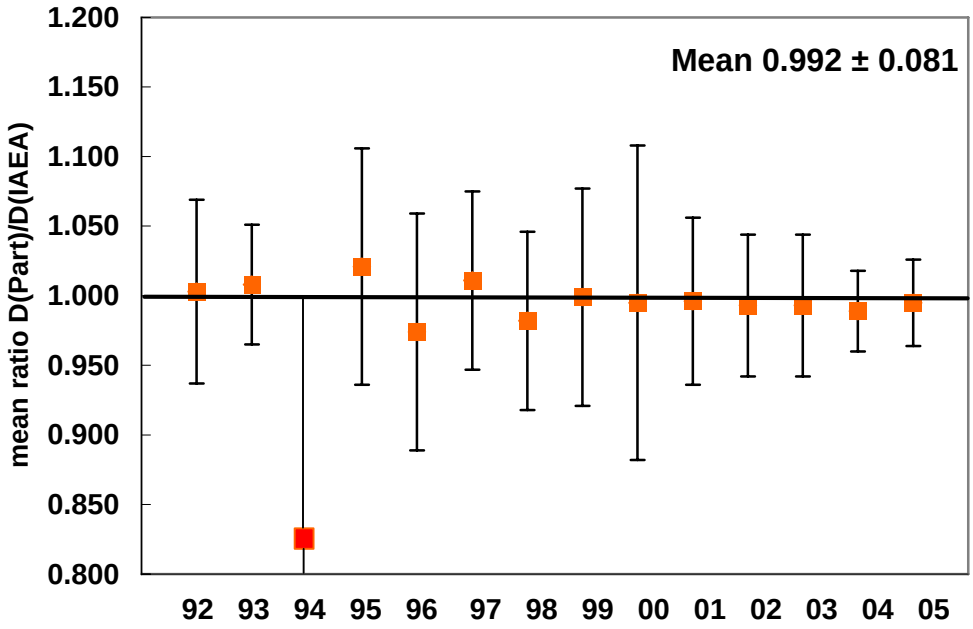

FIG. 8: Results of the IAEA IDAS postal dose audits of radiation processing facilities for the delivery of absorbed dose to water under standard conditions during 1992–2005. Data in the graph correspond to the mean ratios of the dose stated by the institutions (D_{part}) relative to the Agency's determined dose (D_{IAEA}) and standard deviations for the group of the participants in each particular year. The data point for 1994 reflects the results of new participants, with large deviations outside the acceptance limit.

IDAS provided an independent check of the entire dosimetry system of the participant. Participants with results outside the acceptance level of 5% were requested to explain the deviation and offered the opportunity to participate in a second run. The Agency's alanine dosimetry system was traceable to the radiation dosimetry standards of NPL, providing an independent control of the dose and guaranteeing international consistency and harmonization in radiation processing dosimetry.

5.2.2 QA of the IDAS system

The IDAS activities were conducted following procedures described in the procedures manual of the Dosimetry Laboratory. Both "Maintenance of the alanine-ESR reference dosimetry system for radiation processing" and "Alanine-ESR dose quality audit service (IDAS) for radiation processing" were incorporated into the laboratory quality system in 2004. Detailed instructions on how to conduct individual tasks were provided in the instructions manual of the Dosimetry Laboratory (DOLI) and standardized forms were prepared to complement the procedures.

To confirm traceability to NPL (established in 1996), several sets of alanine dosimeters were sent annually to NPL. Since 2001, NIST also provided reference irradiations covering the dose range from 0.5 to 100 kGy, even though participants rarely reported doses larger than 10 kGy. In 2005, reference irradiations were also provided by RISØ National Laboratory. In all these cases, dosimeters were evaluated at the Agency's Dosimetry Laboratory and the process served as an external quality control of the Agency's alanine-ESR dosimetry system. The results are given in Figure 9.

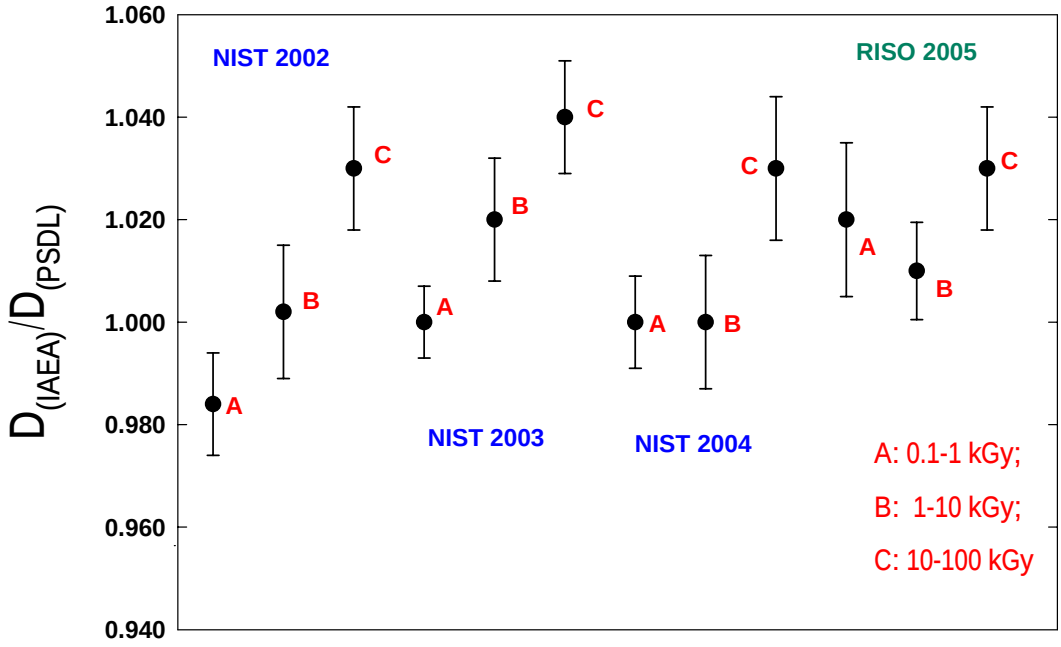

FIG. 9: Results of the reference irradiations during 2002–2005. The symbols correspond to the ratios of the IAEA's determined dose (D_{IAEA}) relative to the dose stated by the PSDL (D_{PSDL}). Each point corresponds to the average of three dosimeters. A total of 12 reference irradiations were provided during this period. The mean ratios for the three dose regions 0.1 – 1.0 kGy, 1.0–10 kGy and 10–100 kGy are 1.00, 1.01 and 1.03, respectively.

5.2.3 Closure of the IDAS service

Following the recommendations of its standing advisory committee, use of the IDAS service was restricted to about 20 long-standing users, mostly from developing countries. It was also recommended to prepare a contingency plan in the event that the service might be suspended because of severe equipment failure. In response to this recommendation, the Agency assisted with the establishment of a reference high-dose laboratory in Cairo, Egypt through a TC project that was supported by DMRP during the 2001-2003 cycle. Currently this high-dose laboratory is able to provide service in the African region. A subsequent review by the standing advisory committee recommended phasing out the service by 2006 due to the cost of replacing the ageing and no longer reliable equipment (unless financial support could be provided by other divisions of the Agency).

Given confirmation of these recommendations by an internal audit and acceptance by senior management, DMRP closed the service at the end of 2005.

6. Dosimetry codes of practice and guidelines for radiation measurements in radiotherapy, diagnostic radiology and nuclear medicine (IAEA Project F4.03), and Medical physics developments for quality assurance and clinical applications of ionizing radiation (IAEA Project F4.04)

The transfer of dosimetry techniques to Member States is provided through Coordinated Research Projects (CRPs), by the organization of meetings, training courses, fellowships, seminars and symposia and by publication of research done. The maintenance of computer databases also belongs to these projects.

6.1 Quality Assurance Team for Radiation Oncology (QUATRO)

Independent external quality audits, forming part of a comprehensive QA programme, are widely recognized as an effective method to verify that the quality of radiotherapy practice in a department is appropriate. Following the recommendations of the IAEA Basic Safety Standards and the European Council Directive 97/43/Euratom, several Member States are in the process of adopting regulations on quality assurance in radiotherapy, thereby making audits compulsory for radiotherapy departments. Quality audits include a wide range of types and levels of review, either of the entire radiotherapy process or of specific critical parts of it, such as radiotherapy dosimetry.

Although vital for the radiotherapy process, accurate beam dosimetry and treatment planning do not guarantee by themselves, successful patient treatment. Since QA of the entire radiotherapy process must be taken into account, a new approach has been developed and named "Quality Assurance Team for Radiation Oncology (QUATRO)".

The operation of QUATRO is based on the use of four different types of experts in the quality audit teams: a medical physicist, a radiotherapy clinician, a radiotherapy technologist and a radiation safety expert. The principal aim of QUATRO is to review the entire radiotherapy process, including the organization, infrastructure and clinical and medical physics aspects of the radiotherapy services. It also includes reviewing the department's professional competence, with a view to assist Member States to improve the quality of radiotherapy services. A formal framework for QUATRO has been established under the IAEA Technical Cooperation programme in order to effectively respond to requests by Members States for a comprehensive audit of their radiotherapy services.

QUATRO, in addition, offers assistance in the resolution of suspected or actual dose misadministrations (over and under-exposures) in radiotherapy, thereby preventing incidents or accidents. It includes the follow-up of inconsistent results detected with the IAEA/WHO TLD postal service. QUATRO helps Member States at a very early stage in the problem-solving process focusing on prevention of accidents in radiotherapy.

6.2 Coordinated Research Projects

Table 1 provides a compilation of the CRPs within the Subprogramme that were operational during the reporting period.

TABLE 1. Coordinated Research Projects (CRPs) in dosimetry, operational in 2005–2006.

Year of commencement	CRP code and title	Year of completion	Participating institutions
2001	**E2 40 12:** Development of TLD-based quality audits for radiotherapy dosimetry in non-reference conditions	2007	9
2004	**E2 40 13:** Development of procedures for quality assurance for dosimetry calculations in radiotherapy	2008	7
2004	**E2.40.14:** Development of procedures for *in vivo* dosimetry in radiotherapy	2007	8
2004	**E2.10.05:** Harmonization of quality practices for nuclear medicine radioactivity measurements	2008	8
2005	**E2.10.06:** Testing of the implementation of the Code of Practice for dosimetry in X-ray diagnostic radiology	2007	11

E2.40.12: CRP on TLD-based Quality Audits for Radiotherapy Dosimetry in Non-reference Conditions:

The IAEA/WHO have supported more than 100 countries over many years by providing them with thermoluminescence dosimetry (TLD) based quality assurance audits of radiotherapy dosimetry. Recently, the IAEA has extended these activities by encouraging the development of national audit programmes. Several countries have established national External Audit Groups (EAG) to audit calibration of radiotherapy beams in hospitals with assistance from the IAEA. Recently, the IAEA initiated a research project that extends the scope of activities of the national audit programmes from TLD audits in reference conditions to include complex audit measurements in a variety of clinically relevant irradiation geometries, i.e., in non-reference conditions.

The strategy for national TLD programmes has been developed involving three subsequent audit steps (i) beam output in reference conditions for high-energy photon beams (ii) dose reference and non-reference conditions on the beam axis for photons and electron beams, (iii) reference and non-reference conditions off-axis for open and wedged symmetric fields with an option for asymmetric fields for photon beams.

Based on the IAEA standard TLD holder for high-energy photon beams, a special TLD holder with horizontal arm was developed that enables off-axis measurements. Three TLDs can be irradiated at a time, two off-axis TLDs placed at ±5 cm from the central TLD. New procedures were developed for the TLD irradiation at hospitals. The off-axis measurement methodology for photon beams was tested in a few irradiation runs by the participating countries.

The expertise established in this project for the audit of dose in non-reference conditions will be adapted by the national EAGs to the specific conditions in each participating country. This involves scientific investigations leading to new developments at national levels.

E2.40.13: CRP on the development of procedures for quality assurance for dosimetry calculations in radiotherapy:

The objective of the CRP is to create a set of simple and practical tests for verification of dosimetry calculations, defined in a dedicated protocol, which can be followed at hospitals with limited resources. With the introduction of more sophisticated radiation treatment techniques, this set of basic tests should be extended to guarantee the safe and consistent implementation of the advanced techniques. The practicability of the developed quality assurance guidelines will be assured through trial use in clinical facilities of varying size. Reduction of extensive published quality assurance recommendations to a QA programme that is feasible in hospitals with limited resources will be achieved without loss of comprehensiveness by appropriate and optimized division of effort between treatment planning system vendors and hospital staff. The expected outputs will be an increase in the safe use of radiation therapy treatment planning systems for external beam therapy and reduction of the number of potential mis-administrations of the dose to patients undergoing radiotherapy treatments.

E2.40.14: CRP on the development of procedures for *in vivo* dosimetry in radiotherapy:

This CRP has an emphasis on patient dose studies, both to evaluate the clinical value of *in vivo* dosimetry and to compare different techniques for *in vivo* dosimetry in a clinical setting. Phantom studies to characterize new dosimeters and develop the relevant methodology will complement the patient studies. In order to determine efficacy under the local conditions in Member States, established dosimetry methods based on TLD and semiconductor diodes will be compared to new devices based on MOSFET and OSL technologies.

The expected outputs will increase expertise in radiation dosimetry in the clinical environment leading to increased precision of treatment delivery, better detection of systematic errors and the prevention of radiation accidents in radiotherapy.

E2.10.05: CRP on the harmonization of quality practices for nuclear medicine radioactivity measurements:

This CRP will harmonize nuclear medicine radioactivity measurement practices in Member States and will extend radioactivity calibration and auditing services to end users in their country. Among the outputs expected from the CRP are protocols for the comparison and auditing of measurement results between secondary laboratories, the Agency, and end users. Additionally, a greater knowledge of factors that influence the quality of radioactivity measurements by end users will be attained so that improvements can be made. The result will be an overall increase in the safety and efficacy of nuclear medicine practice in participating Member States.

E2.10.06: CRP on the testing of the implementation of the Code of Practice for dosimetry in x-ray diagnostic radiology at SSDLs and hospitals:

The objective of the continuation CRP is to test the implementation of the Code of Practice for dosimetry in x-ray diagnostic radiology being developed under CRP E2.10.03. The CRP will focus on: 1) Testing the establishment of calibration facilities for diagnostic x-rays and the calibration of selected instruments. 2) Testing measurement procedures with phantoms and on patients in hospitals. 3) Publication of a TECDOC that will contain the results of experiments as well as suggestions for the practical implementation of the procedures described in the CoP. A special emphasis will be paid to the implementation of the CoP in developing countries.

6.3 Training courses

The Dosimetry and Medical Radiation Physics Section placed considerable emphasis on organizing training courses and coordinating fellowships for medical radiation physicists and staff from SSDLs within the framework of IAEA Technical Cooperation projects.

The courses and workshops held during 2005–2006 were as follows:

2005

Workshop on Training of Audit Teams for Comprehensive Audit in Radiotherapy, Vienna, Austria, 9-11 May 2005.

AFRA Workshop on In-vivo Dosimetry, Algiers, Algeria, 21-26 May 2005.

Regional Training Course on Quality Assurance of Physical and Technical Aspects in Radiotherapy, Argonne National Laboratory, Illinois, USA, 6-17 June 2005.

Regional Training Course on Monitor Unit Calculations, Tunis, Tunisia, 10-15 September 2005.

Regional Training Course on Physical Aspects of SPECT Imaging (RAF), Cairo, Egypt, 16-21 September 2005.

2006

Regional Training Course for the IAEA/TRS-430 Implementation: Quality Assurance in TPS (RLA/6/051), Bogotá, Colombia, 6-11 March 2006.

Workshop on Comprehensive Audits in Radiotherapy (Quality Assurance Team for Radiation Oncology (QUATRO), IAEA, Vienna, 20-22 March 2006.

National Workshop on Improvement of Quality Assurance in Radiation Oncology, Prague, Czech Republic, 26-27 April 2006.

Regional (AFRA) Training Course on QA in Non-Imaging Nuclear Medicine Instrumentation (RAF/6/032), Algiers, Algeria, 6-10 May 2006.

Regional (AFRA) Training Workshop on the Organization and Performance of Audit Missions in Radiotherapy (RAF/6/031), Rabat, Morocco, 5-9 June 2006.

Regional Training Workshop on Clinical Usage of Telemedicine Network (RLA/6/048), Santiago, Chile, 24-28 July 2006.

Regional (AFRA) Workshop on the Organization and Performance of Audit Missions in Radiotherapy (RAF/6/031), Johannesburg, South Africa, 25-29 September 2006.

IAEA/RCA Regional Training Workshop on Implementation of IAEA TRS-430 in Quality Assurance for Radiotherapy Treatment Planning Systems, Hong Kong, China, 9-14 October 2006.

Regional (AFRA) Training Workshop on QC of Simulators and Computed Tomography for Radiotherapy Treatment Planning (RAF/6/031), Cairo, Egypt, 15-19 October 2006.

6.4 IAEA publications in dosimetry and medical radiation physics

Below is the list of publications that appeared in 2005–2006 (it does not include referred publications in the archival literature). In addition to the titles below, an IAEA SSDL Newsletter is published biannually and distributed among the members of the SSDL network and the scientific community. The Newsletter is also available on the Internet.

2006 Control de Calidad en Mamografía (TECDOC-1517, Spanish).

2006 Quality Assurance for Radioactivity Measurement in Nuclear Medicine (Technical Reports Series No. 454) (STI/DOC/010/454).

2006 Radiation Protection in the Design of Radiotherapy Facilities (Safety Reports Series No. 47) (STI/PUB/1223).

2006 Applying Radiation Safety Standards in Diagnostic Radiology and Interventional Procedures using X Rays (Safety Reports Series No. 39) (STI/PUB/1206).

2006 Applying Radiation Safety Standards in Radiotherapy (Safety Reports Series No. 38) (STI/PUB/1205).

2005 Applying Radiation Safety Standards in Nuclear Medicine (Safety Reports Series No. 40) (STI/PUB/1207).

2005 Implementation of the International Code of Practice on Dosimetry in Radiotherapy (TRS-398): Review of testing results (TECDOC-1455).

2005 Commissioning and Quality Assurance of Computerized Planning Systems for Radiation Treatment of Cancer (Technical Reports Series No. 430) (STI/DOC/010/430).

2005 Radiation Oncology Physics: A Handbook for Teachers and Students (STI/PUB/1196).

2005 Determinación de la Dosis Absorbida en Radioterapia con Haces Externos: Un Código de Práctica Internacional para la Dosimetría basada en Patrones de Dosis Absorbida en Agua (Colección de Informes Técnicos No. 398) (STI/DOC/010/398/S, Spanish).

Non-IAEA publications authored or co-authored by staff members of the Dosimetry and Medical Radiation Physics Section are listed in the appendix.

6.5 Directory of Radiotherapy Centres (DIRAC)

Since 1959, the IAEA has maintained a register of radiotherapy hospitals and clinical institutions having radionuclide and high-energy teletherapy machines. This was initially available in printed form only, last published in 1968. The present electronic version of the Directory of Radiotherapy Centres (DIRAC) is a joint effort with WHO. It is updated continuously, based on replies to questionnaires circulated to users. It includes data on teletherapy machines, sources and devices used in brachytherapy, and on equipment for dosimetry, treatment planning systems and quality assurance. Staff strength at the installations (radiation oncologists, medical physicists, technicians, etc.) is included as well.

The DIRAC database was released in electronic form (Access 2000) both for internal and public use. The Internet version with on-line updating is now operational. The DIRAC data are verified and updated on a routine basis.

Appendix: Non-IAEA publications authored or co-authored by staff members of the IAEA Dosimetry and Medical Radiation Physics (DMRP) Section, 2005–2006

2005

SALMINEN, E., IZEWSKA, J., ANDREO, P., IAEA's role in the global management of cancer-focus on upgrading radiotherapy services, Acta Oncologica, **44,** 816-824 (2005).

ZIMMERMAN, B.E., RATEL, G. Report of the CIPM key comparison CCRI(II)-K2.Y-90, Metrologia, **42**, *Tech. Suppl.,* 06001 (2005).

WIESER, A., DEBUYST, R., FATTIBENE, P., MEGHZIFENE, A., ONORI, S., BAYANKIN, S.N., BLACKWELL, B., BRIK, A., BUGAY, A., CHUMAK, V., CIESIELSKI, B., HOSHI, M., The 3rd international intercomparison on EPR tooth dosimetry: Part 1, general analysis, Appl Radiat Isot. **62** (2), 163-171 (2005).

2006

THIERRY-CHEF, I., MARSHALL, M., FIX, J.J., BERMANN, F., GILBERT, E.S., HACKER, C., HEINMILLER, B., MURRAY, W., PEARCE, M.S., UTTERBACK, D., BERNAR, J., DEBOODT, P., EKLOF, M., GRICIENE, B., HOLAN, K., HYVONEN, H., KEREKES, A., LEE, M-C., MOSER, M., PERNICKA, F., CARDIS, E., The 15-country collaborative study of cancer risk among radiation workers in the nuclear industry: study of errors in dosimetry, Radiation Research (2006), in press.

SHORTT, K.R., HUNTLEY, R.B., KOTLER, L.H., BOAS, J.F., WEBB, D.V., A comparison of Australian and Canadian calibration coefficients for air kerma and absorbed dose to water for ^{60}Co γ radiation, APESM, **29** (2), 206-215 (2006).

IZEWSKA, J., VATNITSKY, S., SHORTT, K.R., Postal dose audits for radiotherapy centers in Latin America and the Caribbean: trends in 1969–2003, Rev Panam Salud Publica, **20** (2/3), 161-172 (2006).

ZIMMERMAN, B.E., Radionuclide metrology in the life sciences: recent advances and future trends, Appl. Radiat. Isot., **64**, 1351-1359 (2006).

SCHULTZ, M.K., HAMMOND, M., CESSNA, J.T., PLASCJAK, P., NORMAN, B., SLAZAK, L., GARMESTANI, K., ZIMMERMAN, B.E., UNTERWEGER, M.P., Assessing the ^{210}At impurity in the production of ^{211}At for radiotherapy by ^{210}Po analysis via isotope dilution alpha spectrometry, Appl. Radiat. Isot., **64**, 1365-1369 (2006).

CASSETTE, P., AHN, G.H., ALZITZOGLOU, T., AUBINEAU-LANIECE, I., BOCHUD, F., GARCIA TORANO, E., GRAU CARLES, A., GRAU MALONDA, A., KOSSERT, K., LEE, K.B., LAEDERMANN, J.P., SIMPSON, B.R.S., VAN WYNGAARDT, W., ZIMMERMAN, B.E., Comparison of calculated spectra for the interaction of photons in a liquid scintillator. Example of ^{54}Mn 835 keV emission, Appl. Radiat. Isot., **64**, 1471-1480 (2006).

ZIMMERMAN, B.E., Monte Carlo calculations of spectra and interaction probabilities for photons in liquid scintillators for use in the standardization of radionuclides, Appl. Radiat. Isot., **64**, 1492-1498 (2006).