IAEA SUBPROGRAMME ON DOSIMETRY AND MEDICAL RADIATION PHYSICS (DMRP) REPORT ON ACTIVITIES, 2003–2004

K Shortt, A Meghzifene, J Izewska, F Pernicka, B Zimmerman, S Vatnitsky, P Bera, L Czap, R Girzikowsky

Dosimetry and Medical Radiation Physics Section, Division of Human Health, Department of Nuclear Sciences and Applications, International Atomic Energy Agency (IAEA), Vienna.

Introduction

The subprogramme 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 subprogramme 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 in such areas as industrial radiation processing for sterilization of medical supplies and food.

1. Projects in the DMRP Subprogramme

During the period 2003–2004 the subprogramme was divided into four projects, with the titles as indicated and followed by the objectives in each case:

- **Network of Secondary Standards Dosimetry Laboratories (SSDLs)** (IAEA Project F3.01)

  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, nuclear medicine and radiation protection, that are linked to the international measurement system in accordance with the Mutual Recognition Arrangement (MRA).

- **Quality assurance and dose audits to end-users** (IAEA Project F3.02)

  The objective of this project is to ensure the quality of the entire dosimetric chain in Member States through an independent means of verification of the dose to be delivered to the patients during radiotherapy (using mailed TLDs) and to the products irradiated by industrial processing facilities (using ESR measurements in alanine).

- **Research and development in radiation dosimetry techniques** (IAEA Project F3.03)

  The title of this project was changed to "Development of Radiation Dosimetry Techniques" for the programme and budget cycle 2004-2005.

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

- **Developments in medical radiation physics quality assurance** (IAEA Project F3.04)

  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.

Activities related to activity measurements are reported separately to CCRI(II).

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 11th meeting of the Committee took place in Vienna from 2–5 March 2004, their report was published in the SSDL Newsletter No. 49 (February 2005).

As planned in the 2003 regular programme of the IAEA Office of Internal Oversight Services, a panel of 6 external consultants evaluated the dosimetry work carried out by DMRP during the review period 1998-2002.

2. Services provided by the IAEA

The experimental work of the Dosimetry and Medical Radiation Physics Subprogramme is carried out in the IAEA's Dosimetry Laboratory, which is physically located at Seibersdorf and is part of the Agency's Laboratory (NAAL). 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) ESR-alanine dose quality audits for radiation processing (for SSDLs and facilities). Radiation quality: gamma rays from ^{60}Co. Dose range: 0.1 - 100 kGy.

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

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

The calibration services provided to the SSDLs is the Member States are listed in the IAEA Calibration and Measurement Capabilities (CMCs).

3. Quality system at the IAEA's Dosimetry Laboratory

A Quality Assurance Programme has been established for the Dosimetry Laboratory following the guidelines of ISO 9001, specifically Guide 17025: *General Requirements for the Competence of Calibration and Testing Laboratories* [ISO 1999]. 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.

To support its CMCs, and in compliance with the requirements of the MRA signed by the IAEA in 1999, a panel composed of 4 external consultants conducted an in-depth peer review of the laboratory quality system during 02-06 February 2004. The panel identified some minor deficiencies in the Agency's quality system and provided comments to further improve the documentation. The panel's comments were reviewed and taken into account in the revision of the documentation. The revised documentation was submitted to the panel chair in March 2005.

4. Network of Secondary Standards Dosimetry Laboratories (SSDLs) (IAEA Project F3.01)

Membership in the IAEA/WHO SSDL network is open to laboratories designated by their national competent authority. The network presently consists of 76 laboratories and 6 SSDL national organizations in 64 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 occasionally 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 Participation in comparisons organized by Regional Metrology Organizations (RMOs)

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

4.1.1 IAEA link to the Asian Pacific Metrology Programme (APMP)

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. Two Farmer type ion chambers were used in the comparison. The results obtained are well within the IAEA stated uncertainty of 0.4 % (k=1). Fig. 1 shows the results obtained for one chamber at 100kV. Similar results were obtained for the other chamber and for other beam qualities.

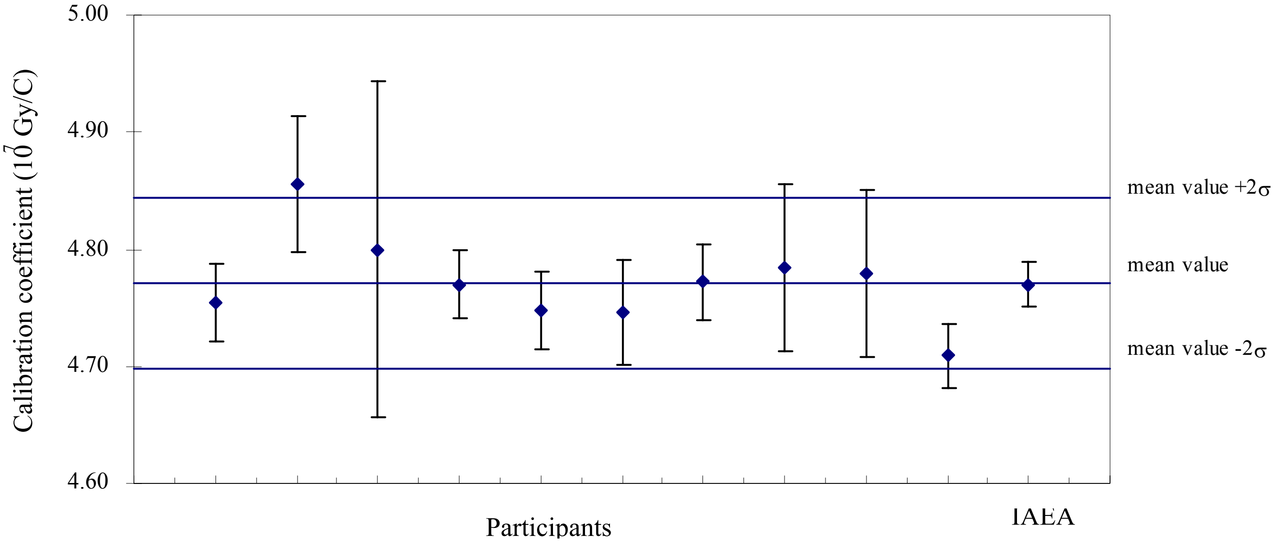

FIGURE 1: APMP comparison: summary of results obtained with a chamber PTW-30001 (S/N 2340 for 100kV).

The IAEA has also participated in APMP Key comparison for air kerma rate in ^{60}Co gamma radiation during November 2004. Three Farmer type ion chambers were used. The results are in the evaluation process.

4.1.2 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 are in the evaluation process.

4.1.3 Planned IAEA comparisons with RMOs

- EUROMET Project 545: supplementary comparison of NMI air kerma standards for ISO 4037 narrow spectrum series radiation qualities (Tube Potentials from 30 kV to 300 kV); planned during October 2005.

- EUROMET Project 813: comparison of air kerma and absorbed dose to water measurements of ^{60}Co radiation in radiotherapy; planned during January-March 2006.

4.2 IAEA support to SSDLs

4.2.1 Setting-up new SSDLs

Under its technical cooperation programme, the IAEA is assisting six Member States to set-up an SSDL (Albania, Croatia, Kenya, Kuwait, Moldova, and Bosnia & Herzegovina). In addition, five SSDLs (Algeria, Argentina, Libya, Syria and South Africa) are being upgraded to introduce new calibration services and strengthen their quality system following ISO-17025.

Efforts are under way to designate two regional SSDLs in Africa to alleviate the IAEA workload there. These regional SSDLs would provide calibration services for hospitals in the region.

4.2.2 Calibration of national measurement standards of the Member States

During 2003–2004, the IAEA calibrated 102 ionization chambers, of which about 25% were for radiation protection level dosimetry and mammography and the remaining 75% for radiotherapy. For low dose rate brachytherapy, the frequency of requests by Member States is very low with only 3 calibration requests during the last 2 years.

4.2.3 Calibration for diagnostic radiology

Activities on the calibration of dosimeters and development of measurement standards for diagnostic radiology x-rays have been divided into: (i) quality control of the mammography standard, (ii) calibration of mammography dosimeters, and (iii) generation of diagnostic beam qualities from a tube with a Tungsten anode operated in the range of 40–150 kV.

Quality control of the mammography standard revealed that values of the HVL deviated from the values established with a former set of attenuators. Experiments were conducted with attenuators from BEV-Austria (Bundesamt für Eich- und Vermessungswesen) and it was concluded that the observed difference in HVLs is probably due to the inadequate purity of the attenuators used previously. A new set of attenuators, with well-defined purity, was selected and new values of HVLs were established.

An additional Radcal 10X5-6M ionization chamber was calibrated at PTB in 2003. This chamber, which is of a new design with a rigid stem, is being considered to become the new IAEA standard. The short and long-term stability of the chamber was investigated. The chamber is scheduled for calibration at NIST (qualities from Mo and Rh targets) in 2005. Starting in 2003, the number of beam qualities for the calibration of mammography dosimeters was reduced from 17 to 7 beam qualities.

Experiments to establish calibration beams for dosimeters used in general radiography (including dental), fluoroscopy and computed tomography continue. Necessary filtration, resulting HVL and beam homogeneity for RQR, RQA and RQT diagnostic beams as defined in IEC 61267 (currently under revision) were established. A calibration of a CT ionization chamber, using the slit method (see Fig. 2), was tested with good results. The laboratory will start with routine calibration services for these beam qualities after the construction of the new facilities.

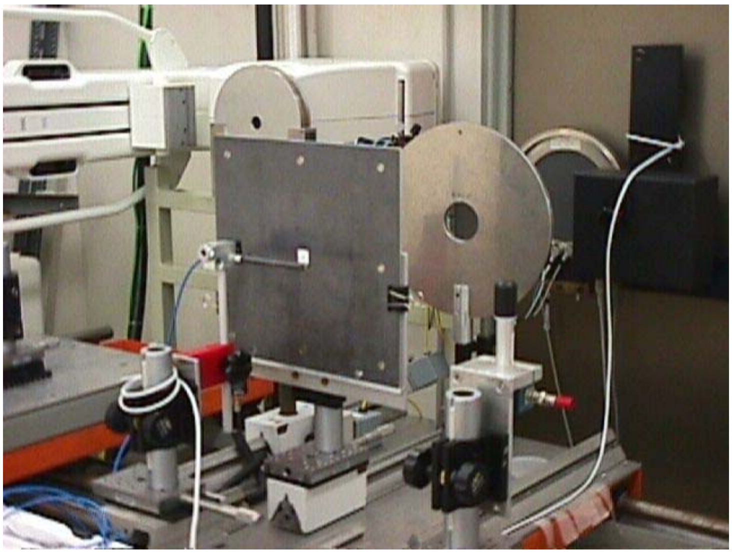

FIGURE. 2: Experimental set-up for calibration of CT chambers at the IAEA's Dosimetry Laboratory.

An Exradin A 3 ionization chamber is being considered as a secondary standard for diagnostic beam qualities (except for mammography). The chamber has been tested for its short-term and long-term stability and good results were obtained. However, recent experiments have also shown that the response of this particular chamber is not symmetrical with respect to its rotational axis. Further investigations are needed before the chamber could be declared as a reference standard.

4.2.4 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 2003–2004, 20 SSDLs participated in this ionization chamber comparison programme, compared to 9 SSDLs during 2001-2002. Many Member States now require that SSDLs must demonstrate their performance by engaging in external comparisons. The results are presented in Figure 3. Calibrations both in terms of air kerma and absorbed dose to water were included.

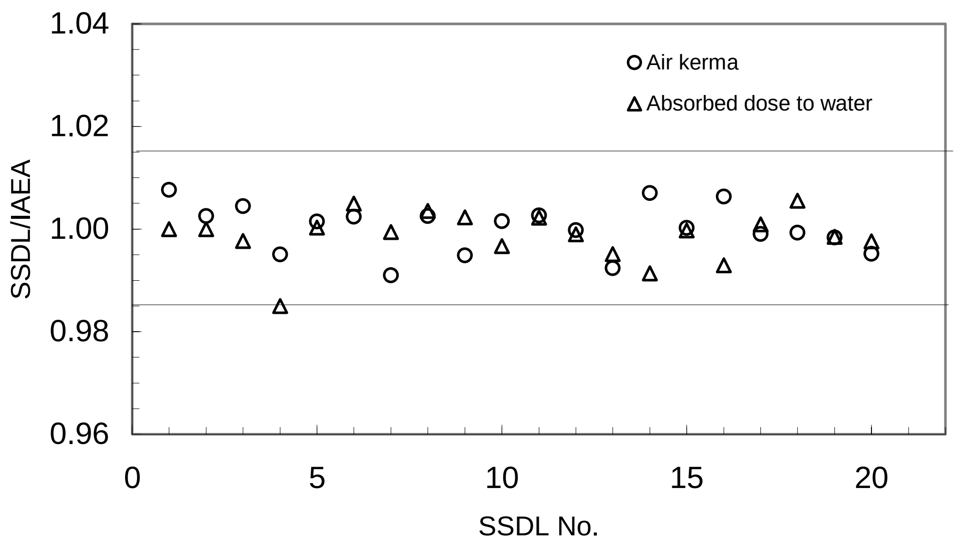

FIGURE 3: Ratios of ion chamber calibration coefficients supplied by the SSDLs to those measured by the IAEA. Circles correspond to air kerma calibration coefficients and triangles to absorbed dose to water factors. Results are considered acceptable if the deviation of the ratio from unity is less than 1.5%.

Many SSDLs have requested that the Agency expand this programme to include x-rays (protection and therapy level). A pilot study (involving 4 SSDLs), to test the procedure, was initiated in November 2004 and two Exradin ionization chambers type A5 are being used.

4.3 X-ray spectrometry

The x-ray spectrometry system used at the IAEA's Dosimetry Laboratory consists of a planar HPGe detector and a digital spectrum multi-channel analyzer. The unfolding software was developed by PTB (Physikalisch-Technische Bundesanstalt). The x-ray spectra were measured for beams at the Agency's Dosimetry Laboratory, except for mammography beams where high photon fluence causes detector saturation, and measurements were done at the BEV dosimetry laboratory. Figure 4 shows the deconvoluted experimental spectra for x-ray beams generated from a Tungsten anode and filtered by Molybdenum, Rhodium and Palladium to create pseudo-mammography beams. A new collimator, made of a TRIAMED material (a Tungsten alloy), with a precision machine-tapered hole of entrance diameter 0.36 mm has been constructed by PTB. This collimator should reduce the fluence of primary photons by about a factor of 10. Together with measurements at larger distance (using an evacuated tube), this will allow for measurements of x-ray beams generated with higher currents.

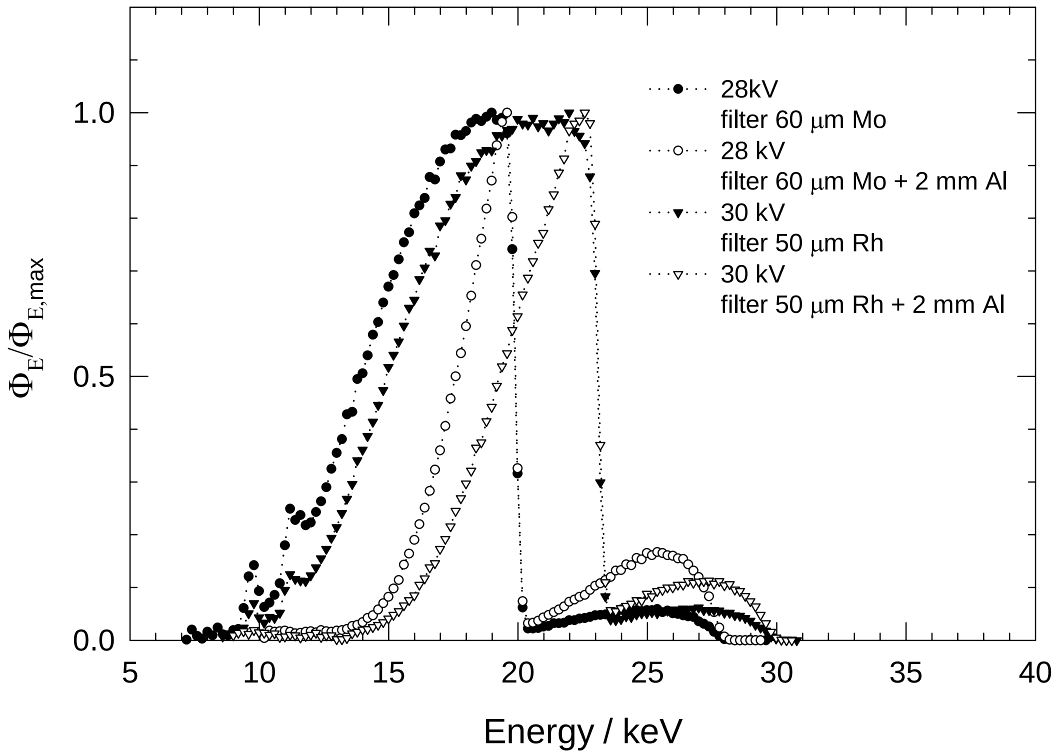

FIGURE 4: Fluence spectra for pseudo-mammography beams generated from a W-anode.

4.4 EUROMET project on calibration of dosimeters used in mammography

The effect of different x-ray radiation qualities on the calibration of mammographic dosimeters was investigated within the framework of a EUROMET project. The calibration coefficients for two ionization chambers and two semiconductor detectors were established in 13 calibration laboratories for radiation qualities used in mammography. They were compared with coefficients for other radiation qualities including those defined in ISO 4037-1 with first half value layers in the mammographic range. The results indicate that the choice of the radiation quality is not crucial for instruments whose response depends only weakly on the beam energy. However, the radiation quality has to be chosen carefully, if instruments with a marked dependence of their energy response are to be calibrated. The results were published in Radiation Protection Dosimetry in 2004.

4.5 TLD-based monitoring of SSDL measurements

4.5.1 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 98% 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 Fig. 5, where deviations from the IAEA's results are plotted for ^{60}Co and high energy X-rays. During the review period, five SSDL TLD runs (2002/2, 2003/1, 2003/2, 2004/1 and 2004/2) were completed for 59 laboratories, in which 232 beams were checked (153 ^{60}Co and 79 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.

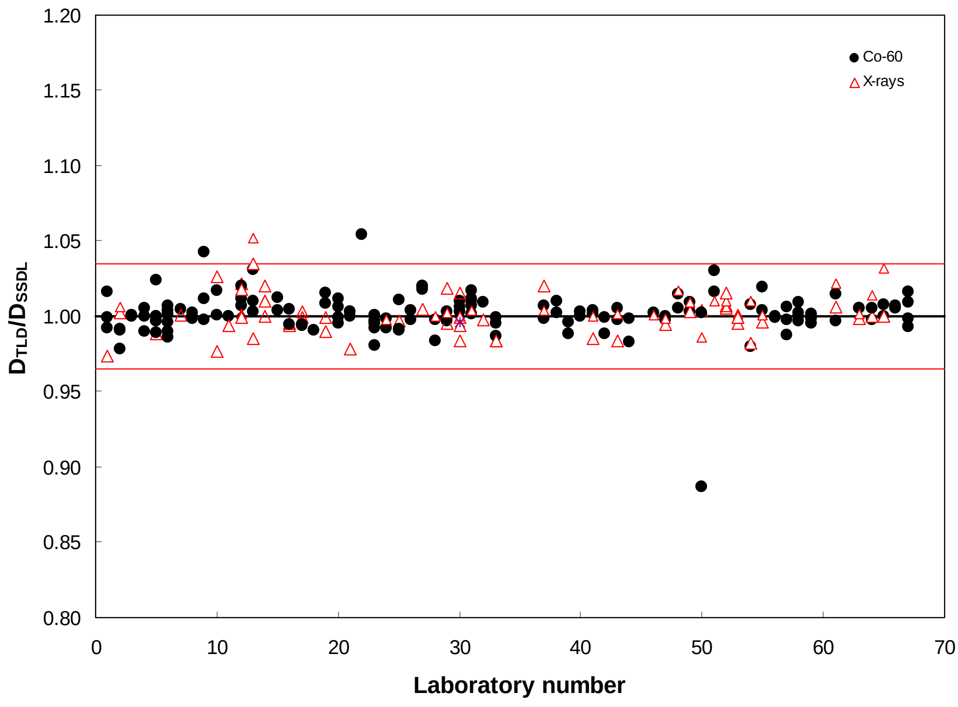

FIGURE 5: Results of the IAEA/WHO TLD postal dose audits for SSDLs for the delivery of dose to water under reference conditions for the TLD runs 2002/2, 2003/1, 2003/2, 2004/1 and 2004/2. Data in the graph correspond to the ratio of the IAEA's determined dose from the TL-response (D_{TLD}) to that stated by the SSDL (D_{SSDL}). Each data point corresponds to the average of three dosimeters. A total of 232 beam calibrations was checked in 59 laboratories, which included 153 ^{60}Co (circles) and 79 high energy x-ray beams (triangles). The number of therapy beams checked in different TLD runs was: 48 beams in 2002/2, 49 beams in 2003/1, 43 beams in 2003/2, 42 beams in 2004/1 and 50 beams in 2004/2. A total of 4 deviations was found outside the acceptance limit of 3.5% (one deviation in the 2002/2 run, one in the 2003/2 run and two in 2004/1 run). All deviations have been explained and corrected.

4.5.2 Protection level

This service for SSDLs engaged in calibration for protection level using ^{60}Co and ^{137}Cs beams started in 1999. It is organized in 2 runs per year; each run involves about 15 laboratories. In addition, 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% 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 1999–2003 are plotted in Fig.6. One can see that about 20% of laboratories still 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.

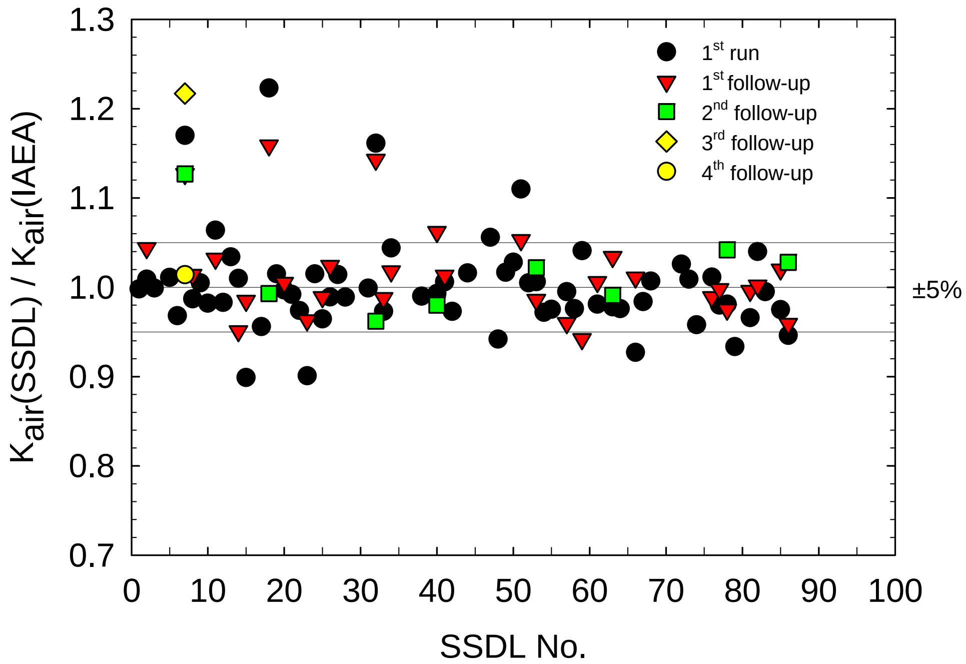

FIGURE 6: Ratios of the air kerma stated by SSDLs to the TLD measured value at the Agency's Dosimetry Laboratory for runs at protection level in 1999–2003 (acceptance limit 5%).

5 Quality assurance and dose audits to end-users (IAEA Project F3.02)

Dose quality audits are conducted for radiotherapy centres and industrial facilities. In both services, users are requested to irradiate the dosimeters with a given dose under known irradiation conditions; the dosimeters are then returned to the IAEA for evaluation.

5.1 The IAEA/WHO TLD postal service

In 2003–2004, the IAEA/WHO TLD postal dose audit service for hospitals continued its previous development related to improving the organization and efficiency of the service. The automation of the TLD system allowed shortening the time of TLD evaluation and increasing the number of hospitals monitored to over 400 per year. Due to the joint effort of the IAEA and WHO, the return rate of the irradiated dosimeters is now approximately 95%.

During this review period, the TLD programme audited 884 beams in 488 radiotherapy centres. The global results are shown in Figure 7. Approximately 90% of the results are within the acceptance limit of 5%.

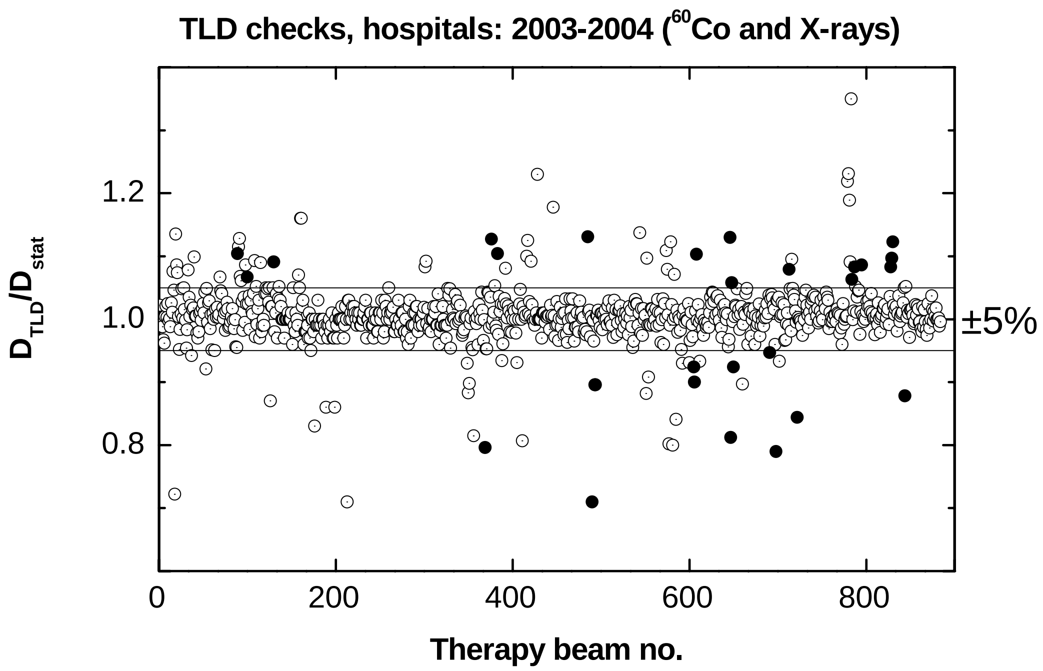

FIGURE 7. Results of the IAEA/WHO TLD postal dose audits of radiotherapy hospitals for the delivery of absorbed dose to water under reference conditions for TLD batches B139 to B158 (from November 2002 to October 2004). Data in the graph correspond to ratios of the IAEA's determined dose (D_{TLD}) relative to the dose stated by the hospital (D_{stat}). Each data point corresponds to the average of two dosimeters. A total of 884 beam calibrations were checked in 488 hospitals. Approximately 10% of the results were found outside the 5% acceptance limit. Of these 6.5% were corrected in the subsequent follow-up action or by experts. The black dots indicate the remaining 3.5% of the results that had not been corrected by April 2005.

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 96.5% in 2003–2004, although 31 deviations (3.5%) have not been corrected. Of these, 19 follow-up TLDs (2%) have not been returned by April 2005 and are still expected. The remaining 1.5% 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 increases continuously. In 2003–2004, 189 additional radiotherapy centres joined the TLD network. Only 83% of the beam checks in hospitals that received TLDs for the first time showed results within the 5% acceptance limit, while 93% of the beam checks in institutions that benefited from a previous TLD audit had results within the 5% limit. The percentage of institution that get the results beyond the 10% limit is twice as high for the new hospitals (8%) as for 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 Co-ordinated Research Project (CRP E2.40.12) initiated in 2001 for national TLD audits in non-reference conditions, continues 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 The International Dose Assurance Service (IDAS) for industrial applications

The International Dose Assurance Service (IDAS) performs dose quality audits for the SSDLs, industrial and pilot-scale facilities, and research laboratories engaged in radiation processing applications. The service is limited to ^{60}Co gamma rays and within the last two years only non-commercial institutions were audited. The overall uncertainty of the alanine-ESR dosimetry system used for this service is 1.7% (k=1). The performance of this dosimetry system is compared with that of a PSDL about once a year, which provides an external quality control. Alanine-ESR dosimeters, supplied by the IAEA, are irradiated at the facilities or laboratories at radiation doses relevant to industrial applications (0.1 to 100 kGy) and then returned for evaluation to the IAEA. The reference irradiation conditions are monitored and this information is forwarded to the IAEA along with the dose values. The dosimeters are then analyzed at the IAEA and the results compared with the user's stated values. IDAS thus provides an independent check of the entire dosimetry system of the participant. In case of a discrepancy greater than 5%, advice is provided as to its possible causes and this is followed by another dose check. Figure 8 shows the results for the last two years. A total of 75 dose checks were performed and approximately 21% of the results were found outside the 5% acceptance limit.

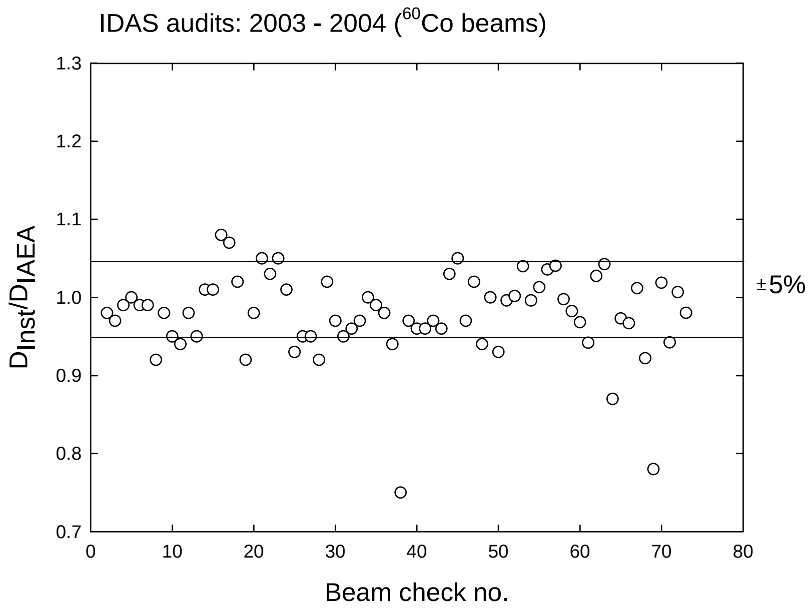

FIGURE 8: Results of the IDAS dose audits for the years 2003 and 2004. Data in the graph correspond to ratios of the dose stated by the institution (D_{inst}) relative to the IAEA's determined dose (D_{IAEA}). Each data point represents the average of three dosimeters.

6. Research and development in radiation dosimetry techniques (IAEA Project F3.03) and Developments in medical radiation physics quality assurance (IAEA Project F3.04)

As of 2003, research and development projects used to support the SSDLs are dealt with under project F3.03 and those used to support quality assurance and dosimetry auditing are under project F3.04. The transfer of dosimetry techniques to Member States is provided through Co-ordinated 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 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's 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 is necessary and is in the process of formulation in order to effectively respond to requests by Members States for a comprehensive audit of the national radiotherapy services or of individual institutions.

QUATRO will, in addition, offer assistance in the resolution of suspected or actual dose misadministrations (over and under-exposures) in radiotherapy, thereby preventing incidents or accidents. It will include the follow-up of inconsistent results detected with the IAEA/WHO TLD postal service. QUATRO will help Member States at a very early stage in the problem-solving process focusing on prevention of accidents in radiotherapy. The structure and systematic approach of QUATRO combined with its low-key problem-solving mode will provide a complement to the operations of the Agency's Radiological Emergency Response Network.

6.2 Co-ordinated Research Projects

Table 2 provides a compilation of the CRPs within the Subprogramme that were operational during the reporting period.

TABLE 2. Co-ordinated Research Projects (CRPs) in Dosimetry, operational in 2003–2004.

Year of commencement	CRP code and title	Year of completion	Participating institutions
2000	**E2 10 03:** Dosimetry in x-ray diagnostic radiology: an international Code of Practice.	2004	5
2001	**E2 10 04:** Development of techniques at the SSDLs for the dissemination of the new standards based on absorbed dose to water for radiotherapy dosimetry.	2004	6
2001	**E2 40 12:** Development of TLD-based quality audits for radiotherapy dosimetry in non-reference conditions	2006	9
2004	**E2 40 13:** Development of procedures for quality assurance of dosimetry calculations in radiotherapy	2007	7
2004	**E2.40.14:** Development of procedures for *in vivo* dosimetry in radiotherapy	2007	8

E2 10 04: CRP on the development of techniques at the SSDLs for the dissemination of the new standards based on absorbed dose to water for radiotherapy dosimetry.

The recommendations of TRS-398 are addressed both to SSDLs and to hospitals. The calibration of ionization chambers in terms of absorbed dose to water is realized at SSDLs and disseminated to hospitals. It is important that the SSDLs that have been calibrating ionization chambers in terms of air kerma get specific guidance on the realization of the new quantity, absorbed dose to water in a ^{60}Co gamma ray beam. The CRP aims at assisting SSDLs develop techniques for the realization and dissemination of absorbed dose to water standards needed for the implementation of TRS-398. The CRP ended in 2004. One PSDL and 4 SSDLs have participated in this CRP. An IAEA TECDOC was prepared and submitted for publication.

E2 10 03: CRP on dosimetry in x-ray diagnostic radiology: an international Code of Practice.

Approximately 40% of SSDLs are currently involved in the calibration of ionization chambers used in diagnostic radiology. The manner in which calibrations at diagnostic radiation qualities are performed at SSDLs is not co-ordinated. SSDLs need guidance for which physical quantity and under which conditions different kinds of dosimetric equipment should be calibrated. They need recommendations on the properties of the dosimeters to be used as secondary standards for dosimetric measurements to be performed for the various clinical diagnostic modalities. Such recommendations should include statements on maximum variations of the ionization chamber's response with half-value layer and, where necessary, on further instrument specifications such as dose rate dependence or electromagnetic compatibility.

In order to advise SSDLs and end-users in hospitals on how to calibrate diagnostic dosimeters and determine the dose during x-ray examinations, the IAEA initiated a co-ordinated research project on the development of a Code of Practice (CoP) for dosimetry in x-ray diagnostic radiology (CRP E2.10.03). The draft of the CoP was prepared and specialists in the field were selected to review it. Publication of the CoP is expected in 2005.

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 of 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 the 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.

6.3 Training courses

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

The courses and workshops held during 2003–2004 were as follows:

2003

Regional Training Course on Quality Assurance of Physical and Technical Aspects in Radiotherapy, Argonne National Laboratory, Illinois (USA), 12-23 January 2003

Regional Workshop on Dosimetry of Therapeutic X-ray Beams, Accra, Ghana, 7-11 July 2003 (RAF/6/027)

Regional Training Course on Mould Room Technology, Immobilization and Treatment Planning, Sao Paulo, Brazil, 6-10 October 2003 (RLA/6/046 and RLA/6/049). *This course will be repeated again in 2003, dates of repeated course yet to be fixed.*

Regional Workshop on Acceptance Testing and Commissioning of Radiotherapy Equipment, Tripoli, Libya, 12-19 October 2003 (RAF/6/027)

Workshop on the Implementation of the International Code of Practice for Radiotherapy Dosimetry, IAEA TRS-398, Chiang Mai, Thailand, 17-21 November 2003

Regional Training Course on Evidence-based Radiotherapy, Tlalpán, Mexico City, Mexico, 24-28 November 2003 (RLA/6/046 and RLA/6/049)

Regional Training Course on Stereotactic Radiotherapy (SRT), Sao Paulo, Brazil, 3-6 December 2003 (RLA/6/046)

ISRO-IAEA/RCA regional training course on evidence-based radiation therapy, Beijing, People's Republic of China, 6–9 December (RAS/6/035)

2004

Regional Training Course on Quality Assurance of Physical and Technical Aspects in Radiotherapy, Argonne National Laboratory, Illinois (USA), 12-23 January 2004

Regional Workshop on Internal Dosimetry, Rio de Janeiro, Brazil, 12-23 January 2004 (RLA/9/049, ARCAL LXXVIII).

Regional Training Course on Stereotactic Radiosurgery, Sao Paulo, Brazil 16-19 August 2004 (RLA6049)

Workshop on the Implementation of the International Code of Practice for Radiotherapy Dosimetry, IAEA TRS-398, Minsk, Belarus, 13-15 September 2004 (BYE 6006)

Regional Training Course on Radiation Protection Level Calibration, Almaty, Kazakhstan, 27 September – 01 October 2004 (RAW/9/008 and RAW/9/009)

Regional Training Course on the Implementation of the International Code of Practice for Radiotherapy Dosimetry, IAEA TRS-398, Almaty, Kazakhstan, 30 September-04 October 2004, (RAW/9/008 and RAW/9/009)

Regional Training Course on X-ray Dosimetry, Johannesburg, South Africa, 20-24 September 2004 (RAF6027)

Regional Training Course on Dosimetry of High Energy Photons Beams using TRS-398, Khartoum, Sudan, 14-18 November 2004 (RAF6027)

6.4 IAEA publications in dosimetry and medical radiation physics

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.

TABLE 3. IAEA publications in dosimetry and medical radiation physics, published 2003–2004. (Does not include refereed publications in the archival literature.)

Series and No.	**Title**
Proceedings of an International Symposium. IAEA-CN-96/137, IAEA Vienna, (2003) STI/PUB/1153	Standards and Codes of Practice in Medical Radiation Dosimetry. Proceedings of an International Symposium, Vienna, 25-28 November 2002.
SSDL Newsletter Nos. 47 and 48 (2003)	
IAEA Vienna (2004) STI/PUB/P1180	Accidental overexposure of radiotherapy patients in Białystok.
Technical Reports Series No. 430, IAEA, Vienna (2004) STI/DOC/010/430	Commissioning and Quality Assurance of Computerized Planning Systems for Radiation Treatment of Cancer
TECDOC IAEA, Vienna (2004). No.1274/S	Calibration of photon and beta ray sources used in brachytherapy: Guidelines on standardized procedures at Secondary Standards Dosimetry Laboratories (SSDLs) and hospitals. *In Spanish.*
Technical Reports Series No. 398, IAEA, Vienna (2004)	Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry based on Standards of Absorbed Dose to Water. In *Russian.*
SSDL Newsletter Nos.49 (2004)	

Non-IAEA publications co-authored by staff members of the Dosimetry and Medical Radiation Physics Section are given in Appendix 1.

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 and its last edition was 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) for internal use and the Internet version is in preparation. The DIRAC data are verified and updated on a routine basis.

Appendix 1: Non-IAEA publications co-authored by staff members of the IAEA Dosimetry and Medical Radiation Physics (DMRP) Section, 2003–2004

2003

DAVIS, S.D., ROSS, C.K., MOBIT, P.N., ZWAN, L.-VAN-DER., CHASE, W.J., SHORTT, K.R, The response of LiF thermoluminescence dosimeters to photon beams in the energy range from 30 kV X rays to ^{60} Co gamma rays, Radiat. Prot. Dosim. **106** (1), (2003) 33-43.

IZEWSKA, J., ANDREO, P., VATNITSKY, S., SHORTT, K.R., The IAEA/WHO TLD postal dose quality audits for radiotherapy: a perspective of dosimetry practices at hospitals in developing countries, Radiotherapy and Oncology **69**, (2003) 91–97.

STABELL BERGSTRAND, E., SHORTT, K.R., ROSS, C.K., OLAUG HOLE, E., An investigation of the photon energy dependence of the EPR alanine dosimetry system, Phys. Med. Biol. **48**, (2003) 1753–1771.

WOJCIK, A., COSET J.-M., CLOUGH, K., GOURMELON, P., BOTTOLIER, J.-F., STEPHAN, G., SOMMER, S., WIECZOREK, A., SLUSZNIAK, J., KULAKOWSKI, A., GOZDZ, S., MICHALIK, J., STACHOWICZ, W., SADLO, J., BULSKI, W., IZEWSKA, J., The radiological accident at the Bialystok Oncology Center: cause, dose estimation and patient treatment, Book of Abstracts from the DEGRO Congress, Strahlenther. Onkol. 179, Sondernummer **1**, (2003) 77.

PERNICKA, F., SHORTT, K., IZEWSKA, J., MEGHZIFENE, A., TÖLLI, H., VATNITSKY, S., ZIMMERMAN, B., BERA, P., CZAP, L., GIRZIKOWSKY, R., IAEA activities in dosimetry and medical radiation physics, Proceedings of the World Congress on Medical Physics and Biomedical Engineering, Sydney, Australia, 24-29 August 2003.

PERNICKA, F., DREW, J., Enhancing medical physics in the Asia and Pacific region, Proceedings of the World Congress on Medical Physics and Biomedical Engineering, Sydney, Australia, 24-29 August 2003.

2004

TARR, N.G., SHORTT, K., WANG, Y., THOMSON, I., Sensitive, temperature-compensated, zero-bias floating gate MOSFET dosimeter, IEEE Transactions on Nuclear Science **51,** (2004) 1277-1282.

McCAFFREY, J.P., MAINEGRA-HING, E., KAWRAKOW, I., SHORTT, K.R., ROGERS, D.W.O., Evidence for using Monte Carlo calculated wall attenuation and scatter correction factors for three styles of graphite-walled ion chamber, Phys. Med. Biol. **49,** (2004) 2491-2501.

PERNICKA, F., ALM CARLSSON, G., DANCE, D.R., DeWERD, L.A., KRAMER, H-M., NG, K.H., ORTIZ LOPEZ, P., Code of Practice for dosimetry in diagnostic and interventional radiology, European Radiology **14,** (2004) 275.

WITZANI, J., BJERKE, H., BOCHUD, F., CSETE, I., DENOZIERE, M., DE VRIES, W., ENNOW, K., GRINDBORG, J.E., HOURDAKIS, C., KOSUNEN, A., KRAMER, H-M., PERNICKA, F., SANDER, T., Calibration of dosimeters used in mammography with different X-ray qualities. EUROMET Project No. 526, Radiat. Prot. Dosim., **108,** (2004) 33.

JÄKEL, O., HARTMANN, G.H., KARGER, C.P., HEEG, P., VATNITSKY, S., A calibration procedure for beam monitors in a scanned beam of heavy charged particles, Med. Phys. **31** (2004), 1009-1013.

IZEWSKA J., VATNITSKY S., and SHORTT K., IAEA/WHO postal dose audits for radiotherapy hospitals in Eastern and South-Eastern Europe, Cancer Radiotherapy **8** Suppl. 1, (2004) S36-S43.

THIERRY-CHEF, I., MARSHALL, M., FIX, J.J., CARDIS, E., BERMANN, F., COWPER, G., GILBERT, E., HACKER, C., HEINMILLER, B., MURRAY, W., OHSHIMA, S., PEARCE, M.S., PERNICKA, F., UTTERBACK, D., International Collaborative Study of Cancer Risk among Radiation Workers in Nuclear

Industry – Study of Errors in Dosimetry, 11th International Congress of the International Radiation Protection Association, (Proc. Symp. Madrid, 2004)), IRPA, Madrid, (2004) 113-114.

IZEWSKA J., BERA P., SHORTT K., TLD-based quality audits for radiotherapy dosimetry in non-reference conditions: and IAEA co-ordinated research project, Proceedings ESTRO-23, Amsterdam, the Netherlands, 24-28 October 2004, Rad. Onc., vol. 73 (Suppl. 1) 2004, p. 112