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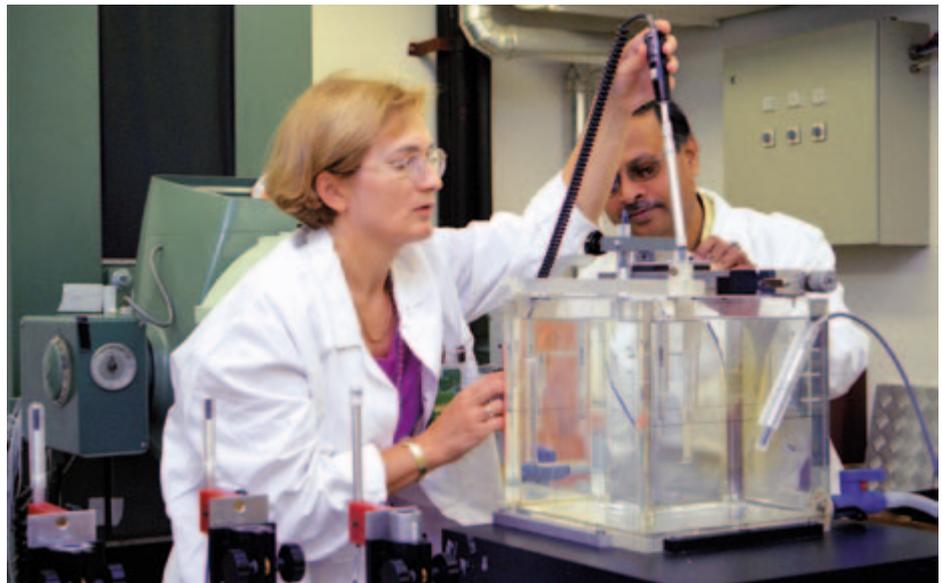
IAEA/WHO Network
of Secondary Standards
Dosimetry Laboratories

Prepared by the Joint IAEA/WHO Secretariat of the SSDL Network
<http://www-naweb.iaea.org/nahu/external/e3/ssdl.asp>



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The IAEA Dosimetry Laboratory, J. Izewska, TLD Officer, and P. Bera, TLD Technician, 2002.

From the editor

This is a Special Issue of the SSDL Newsletter. The original idea to highlight the 40th anniversary of the IAEA/WHO TLD postal dose audit service came from my colleague Joanna Izewska (TLD Officer and Unit Head of the IAEA Dosimetry Laboratory). The Division Director, Mr. Rethy Chhem and myself fully supported the proposal. After forty years of operation, the service has verified the calibration of approximately 8000 radiotherapy beams in about 1700 hospitals worldwide. Several hundreds of dosimetry deviations have been identified and reconciled, thus avoiding potential dose misadministration to patients. The editor would like to thank all contributors to this special issue and Ms. Izewska for putting together the inputs from all of those who have significantly contributed to setting up this valuable service and to those who have supported it.

An announcement of the upcoming International Dosimetry Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS) is included on page 5. IDOS will be held at IAEA Headquarters in Vienna during 9–12 November 2010. Additional information on topics to be covered and deadlines for paper submissions are given in the IAEA website

<http://www-pub.iaea.org/MTCD/meetings/Announcements.asp?ConfID=38093>

Our colleague and friend Frantisek Pernicka passed away on Saturday 2 January 2010 in his home town of Prague, following a heart attack. A tribute to a much appreciated colleague is given on page 4 of this special issue of the SSDL Newsletter.



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International Atomic Energy Agency

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SERVICES PROVIDED BY THE IAEA IN DOSIMETRY AND MEDICAL RADIATION PHYSICS

The IAEA's Dosimetry and Medical Radiation Physics Section focuses on services provided to Member States through the IAEA/WHO SSDL Network and on a system of dose quality audits. The measurement standards of Member States are calibrated, free of charge, at the IAEA's Dosimetry Laboratory. The audits are performed through the IAEA/WHO TLD postal dose audit service for SSDLs and radiotherapy centres.

The IAEA Calibration and Measurement Capabilities (CMCs) have been reviewed and published in the CIPM's (Comité International des Poids et Mesures) Appendix C. The Dosimetry Laboratory's Quality Management System has been reviewed and accepted by the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB).

Additional information can be found at the following web site: <http://kcdb.bipm.org/AppendixC/search.asp?met=RI>

The range of services is listed below.

Services	Radiation quality
Calibration of ionization chambers (radiotherapy, diagnostic radiology including mammography, and radiation protection including environmental dose level)	X rays (10–300kV)* and gamma rays from ^{137}Cs and ^{60}Co
Calibration of well type ionization chambers for low dose rate (LDR) brachytherapy	γ rays from ^{137}Cs (<i>source of traceability has been changed from NIST to PTB (effective January 2009).</i>)
Comparison of therapy level ionization chamber calibrations (for SSDLs)	γ rays from ^{60}Co
TLD dose quality audits for external radiotherapy beams for SSDLs and hospitals	γ rays from ^{60}Co and high energy X ray beams
TLD dose quality audits for radiation protection for SSDLs	γ rays from ^{137}Cs
Reference irradiations to dosimeters for radiation protection	X rays (40–300 kV)* and γ rays from ^{137}Cs and ^{60}Co beams

*** Calibrations in X ray beams will not be available till June 2010, because of X ray equipment replacement**

Member States who are interested in these services should contact the IAEA/WHO SSDL Network Secretariat for further details, at the address provided below. Additional information is also available through the Internet at the web site: <http://www-naweb.iaea.org/nahu/dmrp/ssdl.asp>.

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Note to SSDLs using IAEA calibration and audit services:

1. To ensure continuous improvement in IAEA calibration and audit services, SSDLs are encouraged to submit suggestions for improvements to the DMRP section.
2. Complaints on IAEA services can be addressed to dosimetry@iaea.org.



Frantisek Pernicka

Our colleague and friend Frantisek Pernicka, known to all at the IAEA as Frank, passed away on Saturday 2 January 2010 in his home town of Prague, following a heart attack.

We are all deeply saddened by this unexpected and devastating news. He was with us only a few days before he went on a well deserved leave to be with his family during the holiday season.

Frank worked at the IAEA from 1997 until 2006 and again lately we had the pleasure of him working with us as a consultant. Frank was an outstanding scientist whose experience in his fields of both dosimetry and clinical medical physics was both wide and deep. He touched the lives of those he was in contact with, both colleagues at the IAEA and those with whom he strove to serve, scientists working in dosimetry and health care professionals in Member States. It was a feature of Frank's personality that those who worked with him regarded him as a friend.

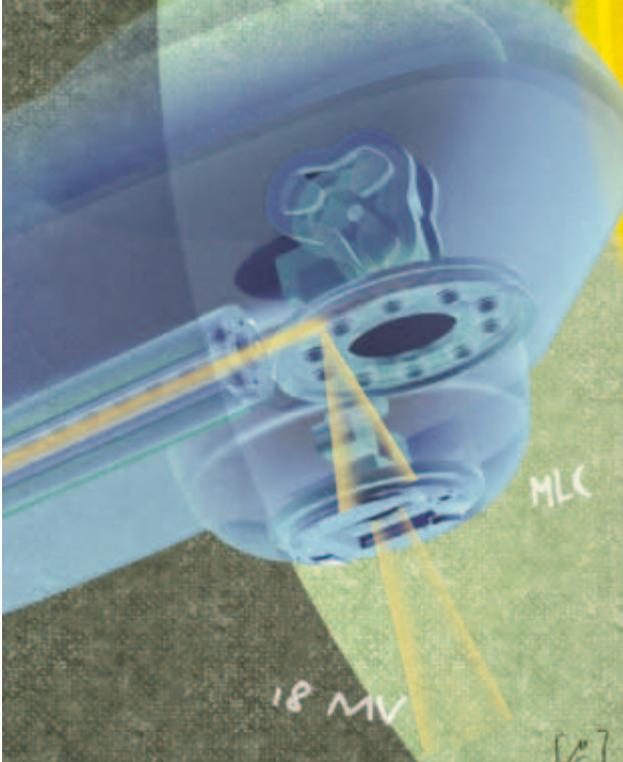
Frank has made a large contribution to the fields of dosimetry and clinical medical physics. One of his proudest achievements has been the production of the International Code of Practice in Diagnostic Radiology Dosimetry, which standardises the concepts of radiation dosimetry in this field. He did extensive work in calibration for diagnostic radiology, radiotherapy, brachytherapy, and for radiation protection monitoring instruments. His breadth of experience in clinical medical physics was often called upon in work for Member States. Frank was an excellent teacher and his generous nature led him to spend long hours working to achieve comprehensive and quality results for those asking for his support. He had a deep understanding of how careful work through the IAEA could make a significant difference for scientists and clinical people working in difficult conditions in their home countries and his work has been an example for others.

From all your work friends at the IAEA, and from those you strove to serve in other countries, we would like to say "Thank you Frank for all you have given, you will be sorely missed".

Staff of the Dosimetry and Medical Radiation Physics Section

INTERNATIONAL SYMPOSIUM
ON STANDARDS, APPLICATIONS
AND QUALITY ASSURANCE
IN MEDICAL RADIATION DOSIMETRY (IDOS)

^{60}Co
192Ir
137I



IN COOPERATION WITH

- AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE (AAPM)
- ASIA-OCEANIA FEDERATION OF ORGANIZATIONS FOR MEDICAL PHYSICS (AFOMP)
- ASOCIACIÓN LATINOAMERICANA DE FÍSICA MÉDICA (ALFIM)
- BUREAU INTERNATIONAL DES POIDS ET MESURES (BIPM)
- EUROPEAN COMMISSION (EC)
- EUROPEAN FEDERATION OF ORGANISATIONS FOR MEDICAL PHYSICS (EFOMP)
- EUROPEAN SOCIETY FOR THERAPEUTIC RADIOLOGY AND ONCOLOGY (ESTRO)
- INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (ICRP)
- INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS (ICRU)
- INTERNATIONAL ORGANIZATION FOR MEDICAL PHYSICS (IOMP)
- INSTITUTE OF PHYSICS AND ENGINEERING IN MEDICINE (IPEM)
- SOCIETY OF NUCLEAR MEDICINE (SNM)
- UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION (UNSCEAR)
- WORLD FEDERATION OF NUCLEAR MEDICINE AND BIOLOGY (WFNMB)

$$\begin{bmatrix} \mu \\ \rho \end{bmatrix} = \begin{bmatrix} \mu \\ \rho \end{bmatrix}_{\text{air}} \cdot \frac{Z}{Z_{\text{air}}} \cdot \frac{A}{A_{\text{air}}}$$

$$\mu_c = \frac{C_{\text{air}}}{Z_{\text{air}}}$$

9-12 November 2010
Vienna, Austria

ORGANIZED BY THE
INTERNATIONAL ATOMIC
ENERGY AGENCY



$D_0 = 15 \text{ MeV} \cdot \text{Ker} \cdot \text{ker}$
 $10 \times 10 \text{ cm}^2, \text{MLC}$
 $6 \text{ MV } h.e. \times \text{rays}$
 $\text{SAD} = 100 \text{ cm}$

TLD

10 x 10 cm

Introductory remarks

Joanna Izewska

International Atomic Energy Agency

This Special Issue of the SSDL Newsletter was put together on the occasion of the 40th anniversary of the IAEA/WHO TLD postal dose audit service. In 1969, the first TLD batch, as documented in the IAEA TLD database, was sent to radiotherapy centres within the project called “Joint IAEA/WHO Dose Intercomparison Service for Radiotherapy”. Obviously, before such a joint service was offered to Member States, it took a few years to set-up the infrastructure, choose a suitable dosimeter for mailing and develop auditing procedures.

The idea of organizing a dosimetry audit for radiotherapy centres by the IAEA, was suggested first time in late 1950s, i.e. over 50 years ago. The IAEA Dosimetry Laboratory was set up in early 1960s and the IAEA Dosimetry Section started its work in 1967. First trial postal dose inter-hospital comparisons, called intercomparisons at that time, were conducted by the IAEA in 1965–1966 involving Fricke dosimeters and TLDs. Eventually, the service was established based on TLDs due to the adequate precision, low cost and easiness of shipment and it has been operated this way until today. WHO joined the IAEA project in 1968 and since then it has actively co-operated for the service implementation worldwide (see WHO statement by S. Groth, this issue).

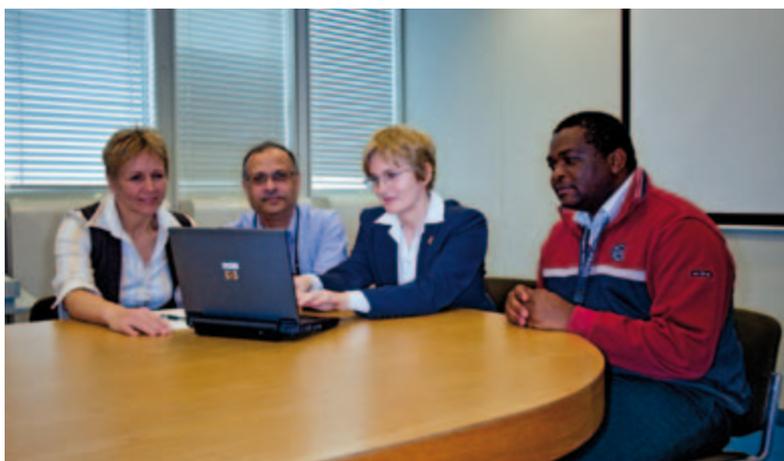
In forty years of its operation, several developments took place in the IAEA/WHO service. These are described by subsequent heads of the Dosimetry Section (the Dosimetry and Medical Radiation Physics Section as of 1996): H. Eisenlohr, H. Svensson, P. Andreo, K. Shortt and A. Meghzifene, from the service inception until 2010.

By 2010, the IAEA/WHO TLD audit service has verified the calibration of approximately 8000 radiotherapy

beams in about 1700 hospitals world-wide. In addition to the IAEA, the auditing services are offered by several dosimetry networks operating at a national level. The largest audit programme is conducted by the Radiological Physics Center, Houston, USA, that serves North American radiotherapy centres, but also some centres in other countries.

Both on-site audit systems and mailed dosimetry programmes have proven to be very useful tools in quality assurance. The significance of dosimetry audit is analysed by D. Thwaites in this issue of the Newsletter. Early developments in dosimetry comparisons for radiotherapy in Europe are described by A. Dutreix, a major architect of postal dosimetry audits in Europe. A few examples of national postal dose audit systems are provided by national laboratories in Algeria, Brazil, Czech Republic, Poland and Japan. Some audit programmes also assess treatment planning systems. An example of a new IAEA project on TPS auditing is given by E. Gershkevitch in this issue.

It is generally agreed, that, without proper accuracy in beam dosimetry and treatment planning the required outcome of the patient’s treatment cannot be achieved. However, it is equally important that the clinical, as well as the physical and technical aspects of patient treatment are adequate. Consequently, a comprehensive audit methodology was developed by the IAEA within the framework of the Quality Assurance Team for Radiation Oncology (QUATRO). As of 2005, QUATRO audit missions have been incorporated in the scope of IAEA activities in quality audits for radiotherapy and a short overview of these activities is included in the current issue of the Newsletter.



The present IAEA TLD Team, from left to right: S Danker (Secretary), P. Bera (TLD Technician), J. Izewska (TLD Officer and Unit Head, Dosimetry Laboratory), G. Azangwe (Dosimetrist).

The significance and impact of dosimetry audits in radiotherapy

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St James's Institute of Oncology, Leeds Teaching Hospitals, Leeds, UK*

Accuracy, quality assurance and quality audit of dosimetry in radiotherapy

Radiotherapy began soon after the discovery of X rays in 1895. It became increasingly obvious to radiation physicists and physicians that clear and consistent methods of measuring, describing, prescribing and reporting dose were necessary, so that radiation treatments could be accurately delivered and so that clinical experience from treatments could be shared, based on agreed approaches to quantifying the amount of radiation given (and also so that radiation protection could be carefully quantified for safe control of radiation environments). This led to a range of fundamental developments that support our dosimetry practice today, including

- The evolution of radiation quantities, initially exposure, later absorbed dose and others; increasingly sophisticated instrumentation to measure these quantities; and bodies such as ICRU being established to review, revise and recommend internationally consistent definitions and approaches to their use;
- The establishment of radiation dosimetry standards and eventually the current extensive and inter-linked world-wide primary and secondary standards dosimetry laboratory network, supported by IAEA/WHO, that underpins the dissemination of consistent dosimetry to all radiotherapy centres;
- Dosimetry protocols (or Codes of Practice) to standardise the theoretical framework and the practical methods used to transfer from dose standards to each radiotherapy centre and to provide recommendations on instrumentation, measurement corrections and other data required;
- A host of other supporting recommendations, e.g. from ICRU on how to consistently protocolise and report radiotherapy doses and dose distributions.

All the above taken together are intended to ensure, as far as is reasonably achievable, a high degree of accuracy, precision, reliability and reproducibility in radiation dose as delivered to patients, which is necessary to ensure safe and high quality treatment and optimised

outcome for each patient. The overall accuracy in the radiation dose delivered to the dose specification point in the patient is generally recommended to be within $\pm 5\%$ or so of prescription at the 95% confidence level (see for example relevant IAEA references [1, 2]). These recommendations are for the end point of the radiotherapy process (i.e. for the treatment as delivered to the patient).

Therefore in each of the many steps of the complex dosimetry chain and radiotherapy process that contribute to its final accuracy, correspondingly smaller values are required such that when all are combined the overall accuracy is met. This means that detailed and continuing quality assurance (QA) of every component is necessary, in order to achieve the required level of accuracy and maintain it consistently. On-going QA is also necessary to minimise the possibility of accidental exposure (radiation incidents, or dose misadministrations). This is particularly important for radiotherapy as it is a high-dose and therefore potentially high-risk procedure, where overdoses can cause significant damage to organs and tissues.

There are many sets of recommendations on QA of equipment, process, etc. from national and international bodies. From around the early 1990s most recommendations were coming together as part of the recommendations to establish comprehensive quality assurance programmes (or quality management systems) to cover all steps from treatment decision and prescription right up to dose delivery and follow-up [as an example, see the ESTRO quality system recommendations [3, 4]. Such comprehensive QA programmes should include not only detailed quality assurance performed by each radiotherapy centre on all its procedures and activities, but also quality audits.

Independent external quality audit is clearly recognised as part of this as an effective method of checking that the quality and accuracy of activities in an individual institution is suitable for achieving the required objectives. Quality audits in radiotherapy are now of a wide range of types and levels, either reviewing the whole process or specific critical parts of it. For example, the IAEA QUATRO (Quality Assurance Team for Radiation Oncology) programme, a recently established system for multi-disciplinary teams to carry out comprehensive audits of the whole radiotherapy structure and

process of a department, has produced guidelines for this overall audit approach [5].

Within the programme there are also specific guidelines for the on-site audit of the whole of a department's medical physics processes [6]. However, the first external audits in radiotherapy were specifically on dosimetry and it is fair to say that the concepts of audit in radiotherapy have largely developed out of such long-standing medical physics audits.

Dosimetry audit in radiotherapy

This issue of SSDL Newsletter contains reviews of some of these dosimetry audit programmes, so they will not be detailed here. In summary, there have been a range of comparisons and audits of dosimetry between centres, regions or across whole countries [1].

There are two main international programmes which make available external audit, based on mailed TLD (thermoluminescent dosimetry), to any local radiotherapy centre within their remit on a regular basis. These are the IAEA/WHO TLD postal dose audit service [7] and the ESTRO (European Society for Therapeutic Radiology and Oncology) EQUAL system [8].

A third mailed TLD audit system that operates internationally is that of the US Radiological Physics Centre (RPC), set up to support clinical trials [9] and funded by the US National Cancer Institute (NCI), but in effect providing a routine service mainly in N. America.

Other currently operating external audit programmes have used mailed dosimeters, on-site visits or a combination of these. They have been either one-off national dosimetry inter-hospital comparison exercises, carried out to test various levels of radiotherapy dosimetry at a specific time; or are on-going regular national audit systems of dosimetry at varying levels. Some are linked with varying degrees of formality to comprehensive audit of radiotherapy centres, including QA programmes, equipment and dosimetry, e.g. Finland, UK. Some have been associated with international or national clinical trial groups, and their audits are in support of general dosimetry infrastructure for entry to clinical trials and also specifically in support of individual trials, e.g. in Europe, the EORTC (European Organisation for Research and Treatment of Cancer); in North America and more widely, the RPC; in the UK, the NCRI-coordinated RTTQAG (UK National Cancer Research Institute; Radiotherapy Trials QA Group). Almost all of these started with auditing only radiotherapy dose in reference conditions, although some included audits of other parameters up to auditing the delivery of dose distributions to be closer to the level of dose delivery to the patient (e.g. [10]).

All have developed with time to widen the scope of the dosimetry parameters and to respond to the demands of evolving complexity of radiotherapy. It may also be noted that many of the audit network systems have closely cooperated at various stages, including by exchanging dosimeters and by carrying out cross-measurements. This is intended to link and compare their performance and results to ensure that there is a close correspondence in outcome. In this way the systems are interlinked to ensure that international and national radiotherapy dosimetry audit networks are working to the same minimum levels and standards. This is a further powerful tool in ensuring the consistency of quality in dosimetry as used and as delivered in radiotherapy centres world-wide.

What has the impact of dosimetry audits been?

Firstly and most directly, in every dosimetry audit programme, measured doses have been observed and reported which have been outside the required tolerances and in some cases significantly so [7, 8]. Therefore audits have been effective in identifying problems in practice, bringing these to the attention of the centres concerned and providing support to find the source of the problems and therefore to rectify them. In this direct way, audits have improved practice and the accuracy of dosimetry in a wide range of radiotherapy centres.

As part of that, audits can reduce the likelihood of accidents and errors occurring or continuing, by identifying underlying problems, thereby reducing their consequences for patient treatment. Audit closes the dosimetry QA loop by testing that the activities relating to dose and their QA do ensure delivery of what is intended. It provides independent assessments of methods, procedures, processes and data, by verifying effectiveness and performance of the overall approach. Audit helps in reducing uncertainties and in increasing the precision and consistency of radiotherapy dosimetry between centres.

It also improves practice over time and helps in maintaining that; e.g. it is the experience of all reported audit systems that better performance (i.e. more centres complying with the required tolerance) is measured at later audits than in the earlier rounds, or performance of an individual centre is improved at a second audit [7, 8, 11]. This is partly because errors identified earlier are rectified and partly because audits give an impetus to departments to focus on quality and performance in a way that continues to deliver benefit. Audit can also provide support and confidence for the introduction of new and complex processes and technologies. Whilst more complex treatments can produce more focussed

radiotherapy treatment, at the same time they require more complex QA and have the scope for additional problems to arise.

Therefore the gradual development and extension of the scope of dosimetry audits, from only beams in reference conditions initially, to include more parameters of dosimetry, equipment performance, complex irradiations, combined beams, treatment planning, new technology, etc. continues to increase the potential benefits. Lastly, dosimetry audit has provided a general environment and example of audit in radiotherapy that has led to the broader acceptance and development of audit concepts and methods and to them then being applied much more widely to radiotherapy processes and their quality improvement.

Conclusion

Overall, dosimetry audit has improved consistency in radiotherapy results and outcomes for patients and provided confidence to clinicians in the dosimetry supporting their practice. Its importance and impact is clearly recognised and its encouragement of and links to other wider radiotherapy audit has been significant.

As it is estimated that a large number of the existing radiotherapy facilities world-wide have not yet participated in some level of independent external dose quality audit, the breadth of uptake of audit is to be encouraged. As the complexity of radiotherapy develops, the scope of what can be included in dosimetry and wider radiotherapy quality audits also needs to continue to increase.

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Statement by R. Chhem, Director of the Division of Human Health, IAEA



Almost half a century of continuous services to patients across the globe through outstanding scientific standards deserves a celebration. During my twenty five years of clinical radiology practice, my activities were supported by two priorities: First, to do a thorough evaluation of any request for radiological tests submitted to

me by the attending doctor. Once the test was clearly justified by the patient's clinical conditions, I tried to obtain the best and optimal image quality to allow me to make an accurate diagnosis of the patient's disease, while keeping in mind that the least dose of radiation is delivered to the patient and health care providers

that are present during the radiological examination; second, to stress the central role of the medical radiation physicist in establishing a quality assurance programme to ensure safe and effective use of X rays in diagnostic radiology.

This priority became a policy during my tenure as Department Chair of Radiology and Nuclear Medicine at the University of Western Ontario. I took my function as the Director of the Division of Human Health in November 2008. The Division includes four sections: Nutrition and Health Related Environmental Studies, Applied Radiology and Radiation Oncology, Nuclear Medicine, and Dosimetry and Medical Radiation Physics. The IAEA/WHO TLD services are implemented within the Dosimetry and Medical Radiation Physics Section. These services are important to IAEA Member States and are valued by all institutions that have been using them for the past 40 years.

Statement by S. Groth, Director of the Essential Health Technologies Dept, WHO



For 40 years now, the IAEA's dosimetry programme has operated a service to validate the calibration of radiation beams in developing Member States using the IAEA/WHO TLD postal dose quality audits. Originally the TLD (thermoluminescent dosimetry) service was developed for Co-60 therapy units, and since 1991 it provides

audits of high-energy photon beams produced in clinical accelerators. The TLD service also monitors activities of SSDLs in radiotherapy since 1981, and it has recently been extended to auditing radiation protection standardization in SSDLs.

The IAEA/WHO Network of Secondary Standards Dosimetry Laboratories (SSDL Network) was established in 1976 as a joint project between the IAEA

and WHO. At present, it includes 80 laboratories and 6 SSDL national organizations in 67 Member States, of which over half are developing countries.

In both programmes, for hospitals and for SSDLs, small TLD dosimeters are distributed by mail to the participants for irradiation and upon their return, they are read in the IAEA's Dosimetry Laboratory. The TLD dose is calculated in the DMRP Section and is compared to the dose stated by the participant. The interpretation of individual TLD results involves also detailed analysis of the dosimetry procedures reported by the participants. When discrepancies occur, a follow-up action is organized to resolve the problems and correct dosimetry at the participating institutions.

The services provided by the two joint IAEA/WHO programmes are extremely important for WHO Member States. WHO looks forward to a continued collaboration between the IAEA and WHO in the field of dosimetry and to an even more comprehensive use of the IAEA/WHO TLD postal dose quality audits in the future.

The IAEA/WHO TLD postal dose audit service: from 1966 to 2010

Horst H. Eisenlohr
Head of the IAEA Dosimetry Section in 1971–1987



Horst H. Eisenlohr. Joined the IAEA in 1963. Head of the IAEA Dosimetry Section in 1971–1987. IAEA co-secretary of the IAEA/WHO SSDL Network 1976–1987.

In the late 1950s Prof. G. Roth from the National Radiation Laboratory of New Zealand, Prof. A. Sanielevici from the Bucharest University, Romania, and Prof. R.G. Jaeger from PTB Braunschweig, Germany, were charged with a task to build a dosimetry programme for the IAEA, and to set-up a dosimetry laboratory for its practical implementation. In this effort, a number of consultants with high level expertise in dosimetry were called to assist them in specific areas in early 1960s. Among them were: Prof. Wideroe (BBC Betatron, Switzerland), Prof. B. Gross (National Institute of Technology, Brazil), Dr. M. Cohen (then London, later McGill University, Canada), Dr. K.C. Tsien (Temple University, USA), and others. At that time, Drs. Tsien and Cohen proposed for the first time that a dose comparison service for radiotherapy centres should be developed and organized by the IAEA.

In 1960–1961 the IAEA's Dosimetry Laboratory was set up with Dr. H. Nagl as head and Mr. Haider as a technical assistant; both from the Technical University, Vienna, Austria. Their task was to design and construct an absorbed dose calorimeter of the type Laughlin/Genna, and to prepare and test a system suitable for a postal dose comparison service, under the supervision of Prof. Sanielevici and (later) Prof. Jaeger. Prof. Sanielevici had a major contribution to the development of the IAEA dosimetry programmes. At that time there

were no dosimetry standards for direct absorbed dose calibrations for radiotherapy, although techniques were developing in a few dosimetry standards laboratories in Germany, UK and the Russian Federation.

I joined IAEA in 1963, initially as a staff member of the Radiobiology Section and with an assignment at the IAEA's Laboratories in Seibersdorf. There, I studied Fricke dosimetry and assisted in comparison measurements using the IAEA calorimeter in radiation beams generated by betatrons at the various institutes in Austria, Switzerland, Germany, UK, Belgium and France. The IAEA's calorimeter was also used for the studies of depth-dose-distributions in various materials. An interesting finding was that accelerators of the same type, even made by the same manufacturer and presumed to be identical, produced significantly different depth-dose-distributions.

The first trial postal dose comparison by the IAEA was organized by Nagl and Sanielevici in 1965 for electron beams using the Fricke dosimeter. In 1966, the IAEA started more systematic investigations in order to develop the methodology for dose comparisons among radiotherapy clinics. Both the Fricke dosimeter and TLD were considered suitable for the purpose and, finally, the TLD was selected as it was inexpensive and easy to mail. Following the very first TLD test run with a few advanced clinics in 1966, three larger-scale TLD pilot comparisons were organized, involving about 50 radiotherapy centres in 13 countries.

The Dosimetry Section was created at the IAEA in 1967 with R. Loevinger as its first head. Having been an IAEA staff member involved in dosimetry work, I joined the Section from its inception. Its working programme was defined and within this programme, the postal dose comparison project for radiotherapy dosimetry was given a priority. Later in 1967, a panel of experts on medical radiation dosimetry met in Vienna and submitted useful recommendations for the operation of the TLD comparison project with the aim of implementing it on a regular basis. Starting in 1967, the UK's NPL provided reference irradiations of TLDs to verify the IAEA dosimetry procedures.

In late 1967, P. Pflanzner became head of the Dosimetry Section. He undertook an extended trip to Argentina, Brazil and Uruguay. There he found great interest in the TLD postal dose comparison programme of the IAEA.

In 1968, about a dozen experts met in Caracas at an IAEA panel to discuss the dosimetric requirements of radiotherapy centres. The representatives of WHO and its regional offices were present at the meeting. The panel proposed the establishment of regional dosimeter calibration laboratories to be supported by the IAEA and WHO. Close cooperation between the two organizations was considered essential. The recommendations of this panel had a strong impact on the future activities of the IAEA and WHO.

WHO decided to join the TLD dose comparison programme in 1968. WHO supported it financially and by assisting in the distribution of the TLDs to radiotherapy clinics. Those in Latin America were served by the Pan-American Health Organization (PAHO). The project received its first official name: 'Joint IAEA/WHO Dose Intercomparison Service for Radiotherapy'. On the WHO side, Drs. Seelentag and Waldeskog were actively involved in the project from its beginning. Dr. Hanson of PAHO made the service known in South America and encouraged radiation oncologists there to improve their dosimetry by participation in the comparisons.

I assumed the duties of head of the Dosimetry Section in 1971. During the following years K. Zsdanzsky, B.-I. Ruden, A.W. Boyd, M. Gustafsson and P. Nette were heads of the Dosimetry Laboratory working with J. Haider, R. Girzikowsky and, later in the 1980s,

P. Bera on implementing the technical aspects of the TLD auditing service.

In order to further assess the accuracy of the TLD measurements and to provide a check of the Co-60 dosimetry performed by the member laboratories in the IAEA/WHO SSDL Network, a voluntary comparison run was carried out 1980-1981 with 22 SSDLs participating. Sixteen of the 22 SSDLs showed results within 2% of the reference dose measured by IAEA. Three SSDLs had deviations above 3% due to errors made by these SSDLs that were explained and corrected.

It is now almost unbelievable that both the SSDL Network and the TLD auditing service after nearly half a century from their first inception not only go on but even flourish. I do not know of any other IAEA programme, besides Safeguards, which has been so successful.

In the early 1980s, all data obtained by dose comparisons for radiotherapy up to 1983 were collected, analysed and evaluated at the IAEA. It appeared that the most common source of minor errors was the use of inaccurate correction factors for the calculation of dose from ionization chamber measurements. However, major errors, up to 25%, were caused when such factors were used in addition to arithmetic mistakes in the dose calculation and erroneous temperature and pressure corrections. When these problems were corrected, the probable cause for the remaining error was seen in the incorrect calibration of the dosimetry systems used at the clinics. These and later evaluations have also shown that the accuracy of dosimetry in radiotherapy centres increased with repeated comparisons.

It is now almost unbelievable that both the SSDL Network and the TLD auditing service after nearly half a century from their first inception not only go on but even flourish. I do not know of any other IAEA programme, besides Safeguards, which has been so successful.

Hans Svensson

Head of the IAEA Dosimetry Section, 1987–1994

The Dosimetry Section of the IAEA began its early investigations with postal dose audit in 1966, during R. Loevinger's tenure as section head. At the end of the 1960s he left the IAEA and returned to the USA, where he assumed responsibility for the Dosimetry Section of the National Bureau of Standards (now National Institute for Standards and Technology, NIST). Since 1970 the TLD inter-comparison service has been conducted on a continuous basis, in cooperation with WHO. This programme had been successfully established by H. Eisenlohr, when I succeeded him as section head in 1987. The Dosimetry Section received during my time

much support and good advice from the SSDL Scientific Committee, then chaired by A. Allisy. He was at that time chairman of the International Commission of Radiation Units and Measurements (ICRU) and represented also the Bureau international des poids et mesures (BIPM).

During the 1970s and the early 1980s I had the opportunity to travel to several countries as an IAEA/WHO expert, where I witnessed first hand several large problems with the dosimetry structures. In one of these countries, where there was only one Co-60 therapy unit,



Hans Svensson, Head of the Dosimetry Section, and Kalman Zsdansky, a staff member of the Dosimetry Section, 1994.

the pneumatic source moving mechanism did not work properly; the source was not moved into place to treat the patient. Radiation therapy had thus been thought to have been given, but in actuality no radiation was delivered, and the need for a dose audit programme was made obvious!

In modern radiotherapy the absorbed dose should be delivered within an accuracy of a few percent. In ICRU Report 65 it is argued that a dose difference as small as 5% may lead to large differences in clinical outcome. Therefore, the absorbed dose to a reference point in a water phantom should be confidently delivered by a hospital with an uncertainty less than $\pm 3\%$, as the dose planning also includes several types of uncertainties that may be added.

The IAEA TLD dose measurement system proved to be a very robust one, as 45 reference dose irradiations in Co-60 γ -beams by PSDLs from 1982 to 1992 gave a mean deviation of only $(D_{\text{TLD}} - D_{\text{PSDL}})/D_{\text{PSDL}} \times 100\%$

Pedro Andreo

Head of the Dosimetry and Medical Radiation Physics Section 1995–2000
Director of the IAEA Division of Human Health 2003–2008

Having had two tenures at the IAEA, working at different levels, has probably given me a perspective which differs slightly from that of my colleagues who preceded and followed me in the role of Head of the Dosimetry and Medical Radiation Physics Section. When I arrived at the IAEA, the operation of the IAEA/WHO TLD postal dosimetry service, as well as of the IAEA/

= 0.04% with $\sigma = 0.8\%$. During the same period 72 SSDLs were tested and 230 irradiations were made. About 10% of these had deviations $>3.5\%$, which indicated that some SSDLs were not capable of delivering adequate calibrations in their countries. A study of 686 therapy centres with data up to 1987 showed that about 50% deviated in absorbed dose in a reference point by more than 5% and that 11% deviated by more than 20%. There was thus an unacceptable spread in absorbed dose delivery compared to what is accepted in modern radiotherapy!

The expansion of radiotherapy has been very rapid. During the 1980s a transfer from Co-60 technology to linear accelerators took place; in the beginning of the 1990s there were in some high income countries 5–10 linear accelerators per million population. It became evident that the audit programme should therefore also cover the beam qualities for accelerators. In response, the IAEA developed several dosimetry protocols for high energy X rays and electrons (e.g. TRS-277 from 1987). It also became necessary to reduce the number of participating hospitals in countries that had their own possibilities for audits, in order to respond to the worldwide needs. The Radiological Physics Centre (RPC) in Houston, USA, started a TLD-service in 1977. In Europe, various TLD audit projects developed in the 1990s, and EC supported from 1998 a new audit, the EQUAL programme; A. Dutreix and I were responsi-

A study of 686 therapy centres with data up to 1987 showed that about 50% deviated in absorbed dose in a reference point by more than 5% and that 11% deviated by more than 20%. There was thus an unacceptable spread in absorbed dose delivery compared to what is accepted in modern radiotherapy!

ble. We had of course close connection to the IAEA and the present IAEA staff member in charge of the IAEA/WHO TLD audit programme, J. Izewska, was at that time involved in early TLD-measurements in Europe.

WHO SSDL network, had already acquired a considerable degree of maturity (initiated in 1969 and 1976, respectively) and one could think that there was not much need for improvement. Time soon demonstrated that, as with almost everything, one can always do better. Thanks to the dedication and hard work of the Section and staff members of many SSDLs, the period



Pedro Andreo was the Head of the Dosimetry and Medical Radiation Physics Section in 1995–2000, and Director of the Division of Human Health (NAHU) in 2003–2008. At present, Pedro Andreo is a Professor of Medical Radiation Physics at the University of Stockholm, Sweden.

1995–2000 was one of the most exciting and productive years of the group.

Soon after my arrival, the operational procedures of the Dosimetry Laboratory were considerably enhanced, both in support of the operation of the SSDL Network and the TLD service for radiotherapy institutions and SSDLs, as well as in the dissemination of dosimetry techniques in medical radiation physics. The latter led to a change of the name of the Dosimetry Section to Dosimetry and Medical Radiation Physics Section (DMRP) and culminated with the development of the current IAEA Code of Practice for radiotherapy dosimetry based on standards of absorbed dose to water (Technical Reports Series No. 398, 2000) and its dissemination, the initiation of the Code of Practice for diagnostic radiology dosimetry (Technical Reports Series No. 457, 2007) and multiple publications in medical physics released or initiated.

During the years prior to my tenure as Section Head, the main role of the TLD service was to verify the calibration of therapy beams, both for hospital users and SSDLs. The later service was initiated in 1981. Participants were reported the difference between the dose effectively delivered by them to the dosimeters (TLD readout) and the dose the participant intended to deliver. Based on the information supplied it was not difficult to correct the irradiation parameters for the next participation, but its true impact on the improvement of the dose delivered to patients was difficult to demonstrate.

QUATRO is one of the projects I feel most proud of and I expect its role as a definitive tool for the IAEA's activities in the field of quality assurance for radiotherapy to increase in the years to come.

As of 1996, our goal was to make real differences in the troubled systems that were in place and to achieve clinically relevant improvements through follow-up actions for institutions that showed results outside acceptable levels ($\pm 5\%$). Firstly, we raised the level of communication between the users of the TLD service and the IAEA, designed reports for presenting the results and developed new TLD instructions linked to the treatment of patients. Secondly, we implemented personalized blind follow-up tests, where the user was informed of 'a fault' but not the magnitude of the error, and established a system of site visits for the resolution of anomalies which could not be sufficiently understood from a distance. For the latter we even developed what we called a 'travelling dosimetry kit', with appropriate basic instrumentation for an external expert to carry with them and perform traceable measurements during the site visit. As a consequence of this more dedicated and direct support, the overall result was an increased number of deviations resolved and a dramatically improved return rate of TLDs. The return rate went from approximately 60% in the 1990s to more than 90% in 2000. We also managed to double the number of radiotherapy beams checked annually worldwide, reaching the figure of 500 per year, linked to the expansion of the TLD equipment at the laboratory.

Another major activity, consistent with the IAEA's goals to enhance the native know-how, was the considerable contribution to establishing national TLD-based networks in Member States. This required enhancing the quality assurance of our own TLD system and developing quality assurance manuals that

served as models for other TLD networks. At the same time, the participation and support of the BIPM and PSDLs was increased, and we established communication with other TLD-based networks to implement the mutual exchange of dosimeters as a regular practice.

As a part of our efforts to support the SSDL network in this area, a TLD service for audits in the field of radiation protection was also developed and implemented, then complementing the ionization chamber-based quality audits for SSDLs initiated in 1997. This was a natural consequence of the expansion of the group activities in the fields of diagnostic radiology and radiation protection, which had been initiated with the installation of a clinical mammography unit in the IAEA's laboratory.

Then in 2000, I left the IAEA as Section Head but returned three years later as Division Director. Upon my return, I wanted to look at the entire radiotherapy field

as a whole, which included coordinating the efforts of both physicians and physicists to achieve a single and common clinical goal. This was the beginning of QUATRO, the Quality Assurance Team for Radiation Oncology, an auditing group composed of a physicist, a radiation oncologist, a radiation therapist (RTT) and a specialist in radiation protection. Together, the QUATRO team performs site visits to institutions with a need for improving their clinical practice.

The program provides support firstly to those with proven difficulties in establishing dosimetry in reference conditions (the basis of the TLD service), then to institutions willing to get support to improve their practice, and finally to clinics hoping to get the IAEA's financial support to upgrade their facilities and procure advanced equipment. QUATRO is one of the projects I feel most proud of, and I expect its role as a definitive tool for the IAEA's activities in the field of quality assurance for radiotherapy to increase in the years to come.

Kenneth R. Shortt

Head of Dosimetry and Medical Radiation Physics Section, 2001–2007



Ken Shortt was the Head of Dosimetry and Medical Radiation Physics Section in 2001–2007.

In the first decade of the new millennium, the IAEA strengthened and expanded its activities in dose auditing. The motivation for this was two-fold: to comply with international standards of quality expected of calibration laboratories and to respond to increasing demands from its Member States for assistance to increase their access to and improve the quality of radiation therapy against cancer.

Subsequent to IAEA participation in the Mutual Recognition Arrangement (MRA) under the auspices of the Comité international des poids et mesures (CIPM), a corporate decision was taken by the IAEA that all laboratory services provided to its Member States would be supported by a Quality Management System (QMS). DMRP provides dosimetry calibrations as well as TLD auditing services through its dosimetry laboratory at

Seibersdorf. These two services are independent but complimentary. The calibration of dosimetry systems enables laboratories in Member States to perform dosimetry calibrations for their own clients, which are linked to the international system of measurements (the SI). TLD auditing at the hospital level confirms that dosimetry measurement technology is being disseminated properly to the end user level. The dissemination of radiation dosimetry through SSDLs to cancer treatment facilities is a prerequisite to ensure that radiation therapy can be delivered safely and effectively.

DMRP decided that our QMS would apply equally to both our dosimetry calibration services provided in support of the laboratories in the SSDL network and to our TLD auditing services provided to individual cancer treatment hospitals. The first step to establish a QMS was to document the calibration and measurement capabilities (CMCs) including TLD auditing, to prepare all the standard operating procedures (SOPs) and to arrange for review of the entire set by various Regional Metrology Organizations (RMOs). The second step was to create the Quality Manual and arrange for its review and acceptance by the Joint Committee of the RMOs and the BIPM (JCRB). The IAEA does not list its dosimetry auditing service in the CMCs registered in Appendix B of the BIPM. Nevertheless, the TLD auditing activities were made to be fully compliant with the IEC standard 17025. Other advantages accrued to IAEA Member States as a result of the increased confidence in the quality of IAEA dosimetry auditing services will be discussed further below.

The second motivation for expanding and improving our TLD auditing system was due to the increased demand by Member States to increase their access to radiation therapy by constructing new cancer treatment facilities and to improve the quality of treatment provided by all their clinics. Essentially, this is the same motivation that gave rise to the IAEA's Programme of Action for Cancer Therapy (PACT). Of course, as more

cancer clinics were created, the demand for TLD auditing services increased. In response, a Coordinated Research Project (CRP) was created focusing on refining the TLD auditing technology for deployment in IAEA Member States. The IAEA's QMS for TLD auditing was made available as a template. The Technical Cooperation Fund (TCF) was used to actually implement a TLD auditing network in several demonstration countries. Because not all the demands for additional TLD auditing services could be met by encouraging the establishment of national networks, additional funding was obtained through the regular budget to augment the IAEA's in-house programme by expanding the dosimetry laboratory from 2 bunkers to 4 and increasing the technical staff on site by one position. Other CRPs were implemented to improve the knowledge that could be acquired through TLD auditing, for example, by monitoring the flatness of radiation fields and measuring the slope of radiation fields modified by the addition of field shaping wedges.

Member States with on-going radiation therapy facilities wanted to incorporate new medical techniques (e.g., CT, MRI and PET scanning) for the diagnosis and staging of cancer patients as well as for improvements in localization and monitoring of radiation therapy. Of course, some advanced centres wanted to implement new technologies to improve the delivery of radiation therapy, such as Intensity Modulated Radiation Therapy and dynamic therapy coupled to the real time monitoring of the patient's tumour. The IAEA responded to these changes in emphasis on the delivery of high quality radiation therapy in two ways. Specifically involving the TLD auditing project, new CRPs were inaugurated to investigate methods for in-vivo monitoring of patient doses and for monitoring doses in the case of small and novel radiation fields. The purpose of the former is to enable intervention to correct errors for individual patients. The purpose of the latter is to prevent systematic errors associated with the introduction of new radiation therapy delivery technologies. These CRPs are on-going. At the same time, complementary work was carried out to understand issues associated with computerized treatment planning. This is linked to dose auditing since measurements with TLDs could be

The formal recognition of the Quality Management System of the IAEA Dosimetry Laboratory by the JCRB resulted in the increased confidence in the quality of IAEA Dosimetry Laboratory calibration and auditing services.

used to confirm the correctness of the plans produced. The IAEA's second response to the concern of Member States about the quality of their radiotherapy services was at the more global level through the development and implementation of the concept of the Quality Assurance Team in Radiation Oncology (QUATRO). The comprehensive and more collaborative approach adopted within QUATRO came about as a direct result of adopting the discipline of radiation monitoring made available through the original TLD auditing activities. QUATRO is used to assess the level of technical capability of cancer clinics to adopt new technologies, including its staff, equipment and procedures. Performance on TLD auditing is an integral part of the QUATRO process.

Records have been kept of the results of TLD audits of cancer clinics since the inception of the programme.

Analysis of these data has yielded much interesting information. For example, over a couple of decades, the ability of cancer centres to get the dose right at the hospital level has improved from a failure rate of 30% or more initially to about 5% in more recent years. This improvement is attributable, at least in part, to the IAEA's TLD dose auditing activities.

Of course, hospitals that engage in auditing for the first time perform less well than those that participate on an on-going basis.

Since new hospitals join routinely and some long term participants have transferred to their national networks, the positive impact of the IAEA's activities in dose auditing may not be so obvious in the future. During this decade, analysis of the reasons for poor performance on dosimetry auditing also yielded interesting regional differences. For example, in the case of poor performance on dosimetry auditing in former eastern block countries, the situation appears to be due to the use of out-of-date equipment whereas poor performance in the case of hospitals in Latin America seems to be due to an insufficient number of qualified medical physicists. This type of analysis enables the IAEA to demonstrate to its Member States the positive impact of these activities in TLD auditing of dosimetry.

Ahmed Meghzifene**Current Head of the Dosimetry and Medical Radiation Physics Section**

Ahmed Meghzifene, Head of the Dosimetry and Medical Radiation Physics Section as of 2009; formerly the IAEA SSDL Officer in 1998–2008.

The IAEA/WHO postal TLD audit service remains a high priority project within the subprogramme on Quality Assurance and Metrology in Radiation Medicine, which is part of the IAEA's Human Health Programme. This service is valued by many Member States that have no other means of checking the calibration of their treatment machines. Every year, the service helps identify a few dosimetry deviations which, if not corrected properly, would lead to serious mistreatment of many cancer patients in the affected treatment clinics. For example in 2009, 15 dosimetry deviations were identified and resolved. There is no doubt that the IAEA will continue to support this important service as long as it helps improve clinical dosimetry for the benefit of cancer patients worldwide.

There is no doubt that the IAEA will continue to support this important service as long as it helps improve clinical dosimetry for the benefit of cancer patients worldwide.

40 years of the IAEA/WHO TLD postal dose audits for radiotherapy

Joanna Izewska, Godfrey Azangwe, Pranabes Bera
International Atomic Energy Agency

Developments in the IAEA/WHO TLD postal dose audit service

For more than 40 years the IAEA has operated a service to validate the calibration of radiotherapy beams in low and middle income countries using the IAEA/WHO TLD postal dose audit service [1–6]. This service provides a quality audit of the dose delivered by radiotherapy treatment machines using a thermoluminescent dosimeter (TLD) as a transfer dosimeter. The IAEA is responsible for the technical aspects of the service, whereas the World Health Organization (WHO) help with the local organization and distribution of TLDs to radiotherapy centres in various countries. Hospital

staff irradiate the dosimeters with a prescribed dose under known irradiation conditions and return them to the IAEA for evaluation. The dose given to the dosimeters is determined at the IAEA Dosimetry Laboratory and the result is compared with the dose stated by radiotherapy staff.

Initially, the service was used for monitoring the calibration of ^{60}Co units. In 1991, its scope was expanded to high-energy photon beams produced in clinical accelerators. In addition to auditing radiotherapy centres, since 1981, TLD audits have been used to monitor the consistency of dosimetry practices at SSDLs [7, 8].

Over the 40 years of its existence, the IAEA/WHO TLD postal dose audits have undergone several scientific re-

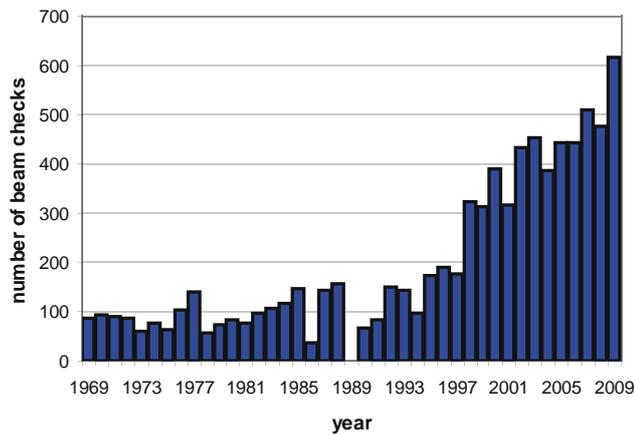


Figure 1. Increase in the IAEA/WHO TLD postal dose audit for radiotherapy centres. The number of radiotherapy beam calibrations checked per year increased significantly since the automatic TLD system was introduced in 1998.

views, technical improvements and changes related to increasing the level of organization and efficiency of the auditing services. Automation of the TLD system in 1998 shortened the time of TLD evaluation and increased the number of hospital beams to be monitored from 100–150 to 300–400 per year (Fig. 1). Nevertheless, the requests from radiotherapy centres steadily increase and they exceeded 600 beams to be checked in 2009. Electronic data sheets were developed to facilitate data collection and handling. They were introduced to the service in 2004.

Differences of less than 5% between the participant-stated dose and the TLD-measured dose are considered acceptable. This 5% acceptance limit defines the maximum discrepancy between stated and measured doses that does not require any further investigation. For radiotherapy centres with results outside the 5% acceptance limit, the IAEA has established a follow-up procedure that uses a second TLD check to give centres a chance to correct the discrepancy. The regular follow-

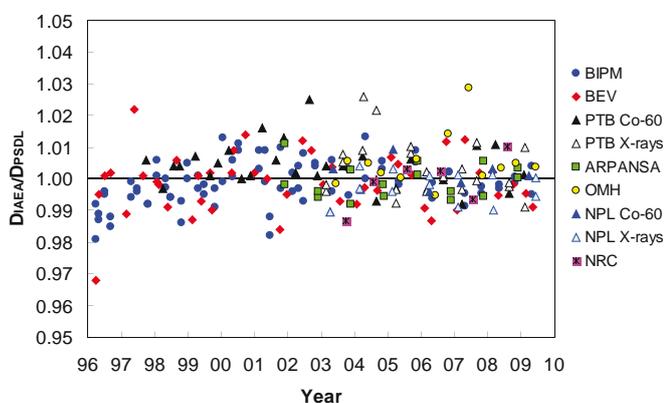


Figure 2. The results of 232 reference irradiations provided by BIPM and PSDLs during 1996–2009. The mean of the distribution is 1.000 and the standard deviation is 0.8% with all data falling between 0.968 and 1.029.

up procedure of poor TLD results was introduced in 1996. Discrepancies between the TLD measured dose and the participant stated dose are resolved through direct interaction with hospital physicists and contacts with local experts where available, or by recruitment of international experts in medical physics. This is an important component of TLD audits that brings improvements in dosimetry practices in radiotherapy centres worldwide.

Quality Assurance of the IAEA TLD system

A thorough set of quality control procedures is maintained for the IAEA TLD system. They are incorporated into the laboratory Quality Management System. For example, the dose response of TLD and fading of the TL signal are verified at the commissioning of every new lot of powder, and the TLD system calibration is verified at every reading session [9]. The QA of the TLD system includes reference irradiations provided by the BIPM, six PSDLs (ARPANSA, BEV, NPL, NRC, OMH and PTB), major TLD audit networks [10–12] and a few academic radiotherapy centres. The results are given in Fig. 2 and Fig. 3, respectively.

Results of the TLD irradiations by radiotherapy centres

Over a period of 40 years the IAEA/WHO TLD programme has verified the calibration of 7890 photon beams in 1666 radiotherapy centres in 121 countries (Fig. 4). These were made in radiotherapy centres in Africa, the eastern Mediterranean, Europe, Latin America and the Caribbean, Southeast Asia and the Western Pacific. Every year, about 50 or more hospitals newly register to the service. Approximately 80%

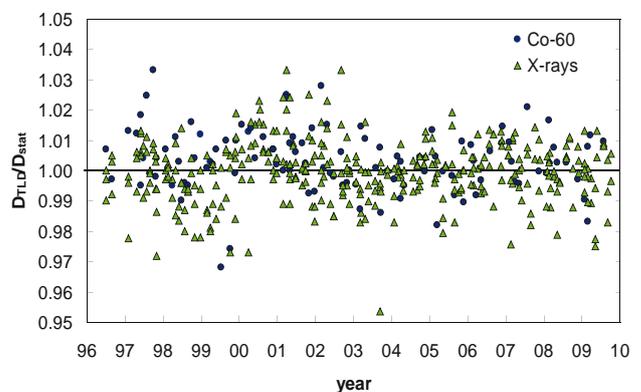


Figure 3. The results of 447 reference irradiations provided by major TLD networks and academic radiotherapy centres during 1996–2009. The mean of the distribution is 1.000 and the standard deviation is 1.0% with all data falling between 0.953 and 1.033.

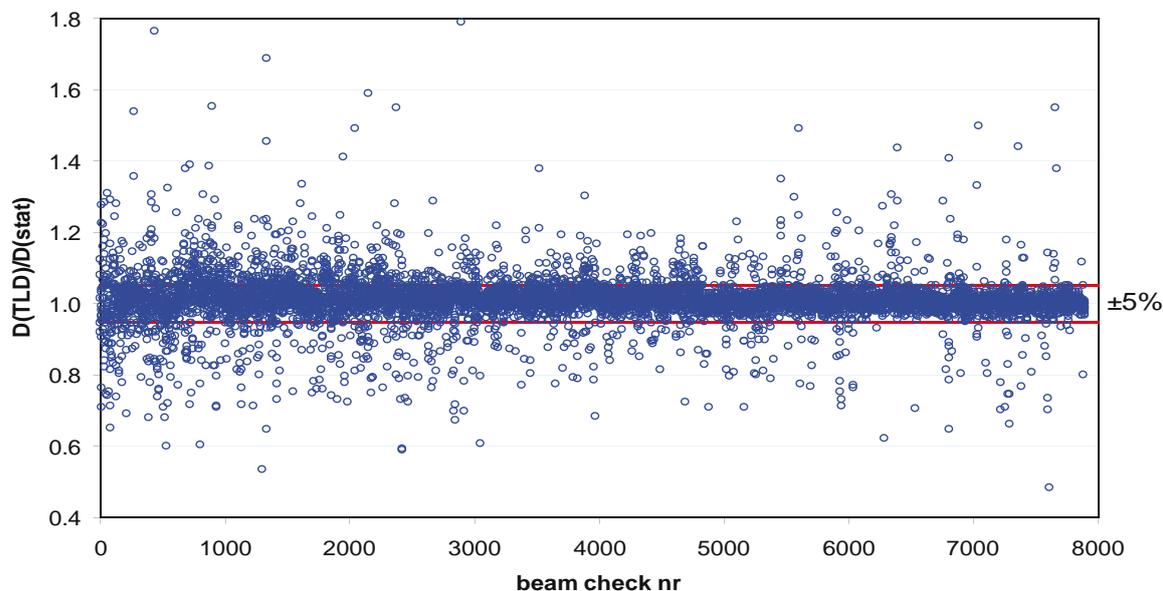


Figure 4. Results of the IAEA/WHO TLD postal dose audits of radiotherapy hospitals for the delivery of absorbed dose to water under reference conditions during 1969–2009.

of the results are within the acceptance limit of 5% in 1969–2009.

There is a systematic growth in the fraction of acceptable TLD results, i.e. those falling within the limit of 5%. The improvement is considerable, with an increase in acceptable results from approximately 50% in the early years of the service, to over 90% at present. This is mainly due to the scientific progress and technical developments in dosimetry, increased interest in quality assurance in radiotherapy and also because of the regular participation of radiotherapy centres in various auditing programmes. Centres that have been participating in the IAEA/WHO and other external dosimetry audits for a longer period achieve better results than do radiotherapy centres that are participating in an audit for the first time [13].

When hospitals have poor TLD results, a follow-up program helps them improve their dosimetry status. Thanks to the regular follow-up of discrepancies in the dose delivery to TLDs, the fraction of acceptable results after the repeat TLD irradiation achieved 96% in 2008 and (Fig. 5). Unfortunately, 4% of the results remained uncorrected either due to a failure to respond to the IAEA efforts or due to local problems that could not be resolved without allocation of appropriate resources.

It is expected that the rate of increase in the percentage of beams within the acceptance limit will slow in the future, as more hospitals with limited resources (having no medical physicists or proper dosimetry equipment) join the TLD program. To bring the new participants to the level of well-performing hospitals, an increased allocation of resources for equipment and for training of medical physicists is required.

Analysis of TLD results and related data sheets

The information that participants provide on the TLD data sheets is systematically analyzed at the IAEA in the context of their TLD results. This is done in order to evaluate the status of calibration dosimetry, to trace the source of any discrepancies in the dose measurement and calculation, and to gain an understanding of the status of use of different dosimetry equipment and procedures and various dosimetry codes of practice (dosimetry protocols).

Table 1 reports the deviations of TLD audit results detected in 1969–2009, and it can be seen that the calibration dosimetry of high-energy X ray beams might be considered more accurate compared to that of ^{60}Co beams, as the radiotherapy centres with linacs usually are supported by a better medical physics service than

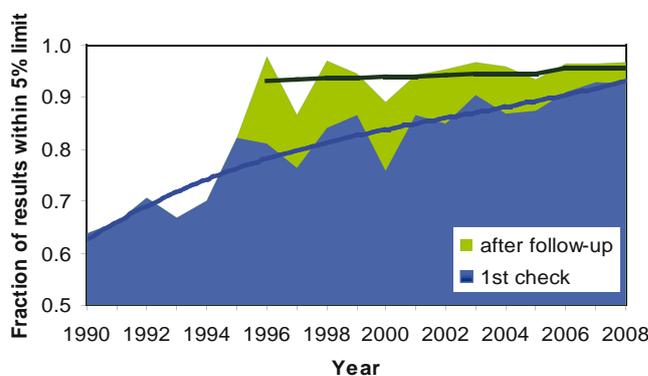


Figure 5. Fraction of the TLD results within the 5% acceptance limit for radiotherapy hospitals. The blue area indicates the results obtained in the first check, and the green area corresponds to the percentage of results improved in the follow-up process.

TABLE 1. RESULTS OF TLD AUDITS IN 1969–2009.

	Co-60 beams (5019)	High-energy X ray beams (2871)
Deviations outside the 5% limit:	27%	8%
> 20%	4%	1%
10-20%	9%	2%
5-10%	15%	5%
Results within the 5% limit	73%	92%

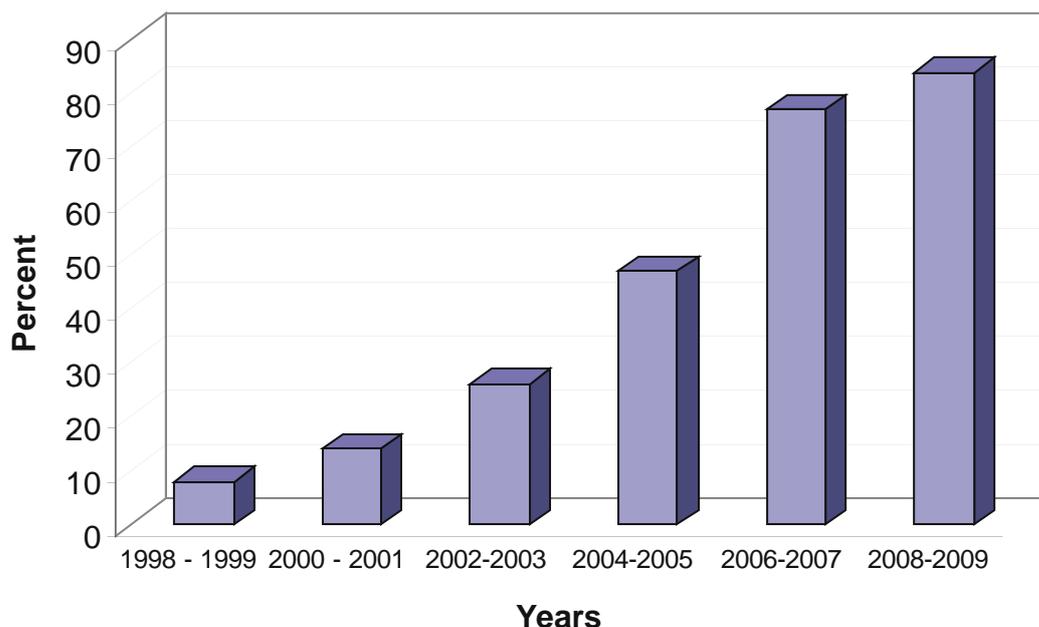


Figure 6. Percent of the participants of the TLD audits that used absorbed dose to water calibration protocols for radiotherapy beam calibration in 1998-2009.

the hospitals with ^{60}Co machines. In addition, the condition of the ^{60}Co machines in some countries exhibits performance deficiencies due to poor technical shape caused by old machine age, inadequate maintenance or too low activity of ^{60}Co sources as documented by the irradiation times needed to deliver 2 Gy to the TLD. For example, over 40% of ^{60}Co machines in Eastern Europe are older than 20 years [14].

For all data sheets, the IAEA verifies the participant's calculation of the dose delivered to the TLD based on the data reported. Any discrepancy between the dose calculated by a participant and the dose calculated by the IAEA is investigated. However, special attention is given to data sheets where discrepancies between the participant's stated dose and the dose determined with the TLD occur. The analysis of recent data sheets has shown that the most common mistakes made by participants pertained to using an incorrect geometry set up for TLD irradiation, incorrect calculation of monitor units (MU) or irradiation time or a combination of various mistakes and errors. About 40% of deviations

had reasons that could not be traced due to lack of information on the dosimetry procedures in the participants' data sheets. Some problems may be caused by improper use of dosimetry equipment or poor treatment machine conditions. Other problems may be due to insufficient training of staff working in radiotherapy. The clinical relevance of severe TLD deviations detected in the audit programme was confirmed in several cases [5], but, fortunately, not all poor dosimetric results reflect deficiencies in the calibration of clinical beams or machine faults. Sometimes it happens that the TLDs received an incorrect dose due to misunderstanding of the instructions on how to perform the TLD irradiation.

Different dosimetry protocols are used in countries around the world, ranging from old exposure-based protocols of the early 1970s, through air kerma-based protocols developed in the 1980s, up to the recently developed modern absorbed dose to water-based protocols. The data reported by the participants show that there is a substantial increase in the use of modern absorbed dose to water calibration protocols (see Fig. 6).

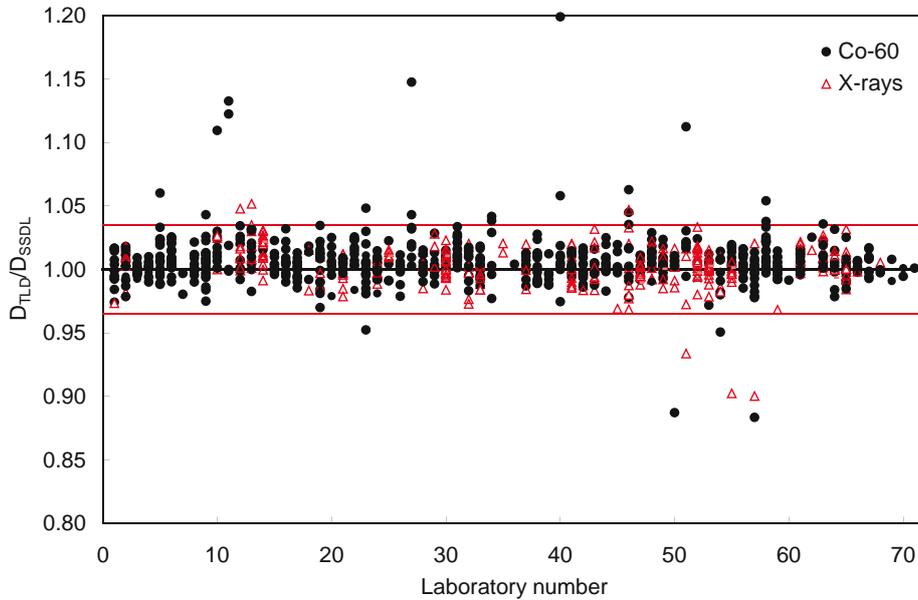


Figure 7. Results of the IAEA/WHO TLD audits in 1997–2009. A total of 988 beam calibrations were checked in 71 laboratories, which include 684 ^{60}Co (circles) and 304 high energy X ray beams (triangles); 29 deviations outside the 3.5% acceptance limit were detected.

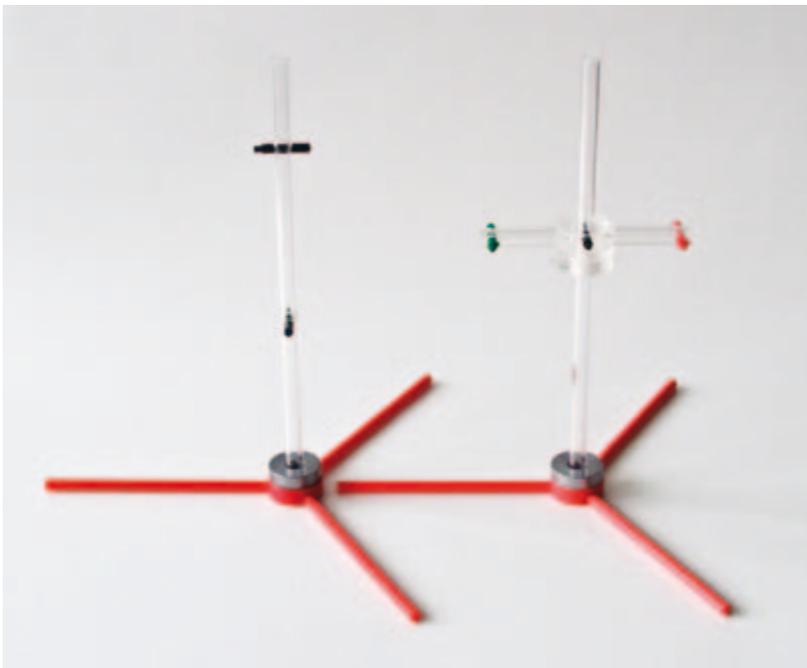


Figure 8. The IAEA TLD holders used for postal dosimetry audits of high energy photon beams: a standard holder for on-axis measurements (left) and a holder used for on- and off-axis TLD measurements in non-reference conditions.



Figure 9. The IAEA TLD holder used for postal dosimetry audits of high energy electron beams.

In 2008-2009, about 84% participants use CoPs based on absorbed dose to water standards. There has been a noticeable decrease in the use of old N_x -based protocols, especially in hospitals in the Latin America region.

Activities in TLD monitoring of SSDL measurements at radiotherapy level

The IAEA/WHO TLD postal dose quality audit service has monitored the performance of the SSDLs in the therapy dose range since 1981. The results for dose

delivery under reference conditions in a water phantom for the laboratories providing therapy level calibrations are presented in Fig. 7, where the ratio of the laboratory's results and the IAEA's results are plotted for ^{60}Co and high energy X rays. Results of this programme in 1997-2009 indicate that about 97% of the results of SSDLs that participate in the TLD audits were within the acceptance limit of 3.5%.

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

deviations outside the 3.5% limit are explained and corrected.

IAEA support to national TLD audit networks for radiotherapy dosimetry

The IAEA has supported the development of methodology and establishment of national TLD-based QA audit networks for radiotherapy dosimetry in order to cost-effectively utilize IAEA resources and to extend the availability of radiotherapy dosimetry audits to as many hospitals as possible throughout the world [13]. A series of Co-ordinated Research Projects (CRPs) has been conducted by the IAEA as of 1995 to assist in developing such national dosimetry audit programmes, initially for beam calibration audits in reference conditions. This work was then extended for audits in non-reference conditions [15], to further improve independent verification of radiotherapy dosimetry in hospitals in participating countries. A new CRP was initiated in 2009 with the aim of expanding the dosimetry audit tools to be suitable for complex treatment techniques used for treatment of cancer patients.

The IAEA Dosimetry Laboratory has actively participated in the experimental part of these CRPs, developed new phantoms and conducted multicentre pilot studies to test the newly developed methodology [15]. In addition, IAEA contributes to strengthening QA of the national TLD systems by exchanging dosimeters with the national laboratories.

Summary

The TLD audit service has already been used for approximately 7900 radiotherapy beams throughout the world, and occasionally significant errors in the calibration of therapy beams were detected and corrected, thereby preventing the mistreatment of patients.

This service is demand-driven and it focuses on providing dose quality audits to these radiotherapy centres that have no other means to verify the output of their radiation treatment units. The annual number of beam audits has increased sixfold since the early years of the service. Expanding the service is in response to requests by hospitals and it corresponds to the growing number of radiotherapy facilities in the world.

The IAEA audit service has witnessed significant improvements in dosimetry practices in low and middle income countries in the last 40 years. However, discrepancies in the beam calibration still occur. They are monitored by the IAEA, and their causes are traced, understood and corrected. However, some radiotherapy centres work within practical limitations such as insuff-

icient availability of qualified medical physicists or lack of adequate dosimetry equipment, which hampers quality. These inadequacies have to be addressed locally.

Dosimetry audits have proven to be a useful tool for the improvement of dosimetry status worldwide. By providing dose quality audits to hospitals in low and middle income countries, the IAEA assists them in achieving the required levels of accuracy in dosimetry for radiotherapy. It is of importance for any radiotherapy centre to have access to long term dosimetry auditing programmes, particularly when installing new radiotherapy equipment.

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Dosimeter calibrations and intercomparisons: from roentgen to gray

Andrée Dutreix

Early calibrations and intercomparisons at Institut Gustave Roussy (1950–1980)

Today, it is hard to imagine the situation of a young physicist entering the field of medical physics sixty years ago. In 1950s at the Institut Gustave Roussy (IGR), we had the imperative task of calibrating a Betatron 25 MV photon beam, at a time when ionisation chambers were calibrated in ‘dose’ expressed in ‘roentgens’ (with a small ‘r’) in a 200 kV X ray beam. To add to the challenge, the only accurate ionisation chambers available were condenser chambers with a handle which was convenient for charging and reading but also presented a small additional volume of air shielded by 1 mm of lead. The shielding was very efficient at 200kV but lead to unexpected large errors in high energy beams.

The concept of absorbed dose in rads (for radiation absorbed dose) had been adopted in 1953 and published in 1959 by ICRU [1]. However, it was not until 1962 that the ICRU [2] introduced a clear distinction between the absorbed dose in rads, and the exposure in Roentgens. In 1975 the General Conference on Weights and



Figure 1. Andrée and Jean Dutreix with small condenser chambers used to measure dose distributions of radiotherapy units at the Institut Gustave Roussy, Villejuif, France, 1961.

Measures decided to rationalize the scientific units and introduced the International System of Units (SI); consequently, the unit of absorbed dose was changed to the gray (Gy) which corresponds to 100 rads.

To solve our problem of calibration we attempted to perform measurements by calorimetry and later and more successfully by ferrous sulphate dosimetry. Furthermore, we had to face a new challenge with the calibration of high energy electron beams. Fortunately, in the mid sixties, some Secondary Standards Dosimetry

Laboratories in developed countries began to offer calibrations of ionisation chambers in Roentgens in cobalt beams, which was an essential step.

Active scientific relations have been developed with the IAEA since the end of the fifties, and I personally have had the opportunity to participate in several expert meetings, reinforcing the links between our physics department and the IAEA. Considering the difficulties encountered in absorbed dose measurements, we were very eager to compare our own calibrations with other radiotherapy centres [3]. The first international intercomparisons were performed either by physicists visiting multiple radiotherapy centres - bringing their own measurement devices, or with mailed ferrous sulphate dosimeters.

At IGR we received a visit in 1966 by a physicist from the IAEA bringing a calorimeter [4] to measure the output of our 25 MV photon beam, and in 1971, a visit from a Swedish group [5] to compare ionisation chamber calibrations in a Co-60 beam as well as dose measurements and dose distributions in high energy photon and electron beams. We developed ferrous sulphate dosimetry in the sixties and performed our first large intercomparison, which included 20 centers, in 1970 [6]. However, we faced difficulties with ferrous sulphate regarding both the size of the dosimeters (about 2 cm³) and the high dose required to get a convenient accuracy, a minimum of 5 000 to 10 000 rads (50 to 100 Gy). Other practical difficulties were met in shipping and with Customs.

The introduction of thermoluminescent dosimetry (TLD) [7] opened new possibilities. In the following years the technique were developed by several groups, especially the IAEA. We have been very pleased when we have been asked by the IAEA to participate in the first international intercomparisons with TLDs around 1970 [8]. One member of the department (Jean Chavandra) spent a few months in Jack Fowler's department in London, to learn TLD methods and procedures so that we could rapidly set up a TLD programme at the Institut Gustave Roussy.

Birth and development of the EQUAL project

The first comprehensive quality assurance (QA) programmes including external audit of doses were implemented in radiotherapy departments in the eighties as recommended by AAPM [9] and WHO [10]. In 1991 radiotherapy oncologists from five countries in the European Community succeeded in convincing the European Committee 'Europe against Cancer' to support the project of a European Network for Quality Assurance in Radiotherapy. This network performed dose checks

in European centres with mailed TLDs, in close co-operation with the IAEA. The Measuring Centre was set-up in IGR whose previous experience was recognized [11]. For a limited number of years the project was extended to a second measuring center at the Leuven University Hospital, and was known as EROPAQ [12]. In 1997, a permanent structure, EQUAL (for **ESTRO Quality Assurance Network**), was set up in IGR and supported by the European Society for Therapeutic Radiology and Oncology (ESTRO). During the first two years EQUAL checked 235 Co-60 and X ray beams from 102 radiotherapy centers [13]. The scope of this project was extended successively to electron beams and brachytherapy.

In 2004, for administrative reasons, the EQUAL Laboratory was converted into a commercial company owned by ESTRO: EQUAL-ESTRO. However the location of the Laboratory and the measuring procedures remained the same under the responsibility of Attila Veres as chief physicist. Every year EQUAL-ESTRO checks about 700 beam outputs and doses delivered by brachytherapy techniques. Dose checks have also recently been extended to modern radiotherapy techniques such as IMRT or Tomotherapy and proton beams, and will soon cover microbeams and Cyberknives [14].

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The Radiological Physics Center: 40 years of vigilance and quality assurance for NCI sponsored clinical trials

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One wishes to think that healthcare within the USA has improved considerably over the years, but the wide and disturbing range in quality of healthcare in this country is well known and frequently reported upon [1, 2]. Even with the many mechanisms and national standards of care and quality, why is it that radiation therapy patients still receive incorrect doses? During the past few years, a number of significant radiation therapy errors have been reported [2–7]. Several reasons are postulated, including the introduction of, and increasing dependence upon, advanced technologies [8]. Some reported errors stemmed from the introduction of the technologies themselves [9, 10]. There has been at least one publication indicating that the introduction of advanced technology equipment has permitted errors to occur that might otherwise have been detected [11]. There are also indications that the demands of advanced technologies on department resources have drawn resources from simpler or basic functions [4, 12].

Clearly, larger errors have a significant impact on the success of radiation therapy. But smaller errors, while having no discernable affect on the treatment of an individual patient, are very likely to influence the overall success of treatments of large numbers of patients [13–15]. Thus, there is the need for a quality assurance program to monitor institutions participating in clinical trials where small deviations in the delivered dose to many patients from an individual institution may have an impact on the outcome of the trial.

The role of the Radiological Physics Center (RPC)

The RPC was established in 1968 to contribute to the development, conduct, and QA of multi-institutional cooperative group clinical trials. One key aspect to the RPC's function is that it operates as an independent quality assurance office for multi-institutional cooperative group clinical trials.



Figure 1. Three RPC directors. From left to right: R.J. Shalek 1968–1985, W. F. Hanson 1985–2001, G.S. Ibbott 2001–present.

The RPC grant was originally awarded through a competition sponsored by the AAPM. In 1967, a memorandum of agreement was reached between the AAPM and the Committee for Radiation Therapy Studies (CRTS) for clinical radiation dosimetry related to inter-institutional studies. The agreement called for the establishment of a center of operations for the implementation of this scientific program, in other words, the creation of a Radiological Physics Center. The RPC has been funded continuously since 1968 under Dr. Shalek's guidance (1968–1985), followed by Dr. William Hanson (1985–2001) and currently by Dr. Geoffrey Ibbott (2001–present), see Fig. 1.

The RPC currently monitors 1768 institutions that participate in cooperative group clinical trials sponsored by the National Cancer Institute (NCI). These institutions are located primarily in the USA and Canada, but also include participants from 30 other countries. Within the 1768 institutions, there are over 3300 megavoltage therapy machines that are monitored by the RPC QA program.

In 1999, the RPC joined with several other QA offices to form the Advanced Technology Consortium (ATC) [16]. The role of the ATC is to support the development and conduct of advanced technology clinical trials, to facilitate communications among the four QA offices

and to reduce duplication of effort among the quality assurance offices.

The four major components of the RPC's QA program are: 1) the remote TLD audit of machine calibration, 2) on-site dosimetry review visits, 3) credentialing for advanced technology clinical trials, and 4) review of patient treatment records.

Remote audits of machine output calibration

The RPC initiated its TLD program for photon beams in 1977. In 1982 electron beams were included, and in 2007, measurements of proton beams were initiated. RPC measures nearly 14000 beams annually.

The RPC's system is notable for its simplicity (see Fig. 2). On an annual basis, institutions receive a package with a lightweight platform and acrylic mini-phantoms containing several TLD capsules for each radiation beam and irradiation instructions. The blocks and other equipment are returned to the RPC where the TLDs are analyzed. The RPC has established $\pm 5\%$ as a threshold for acceptability. When the TLD measurement disagrees with an institution's stated dose by more than 5%, the RPC initiates a series of activities to resolve the discrepancy. If the discrepancy cannot

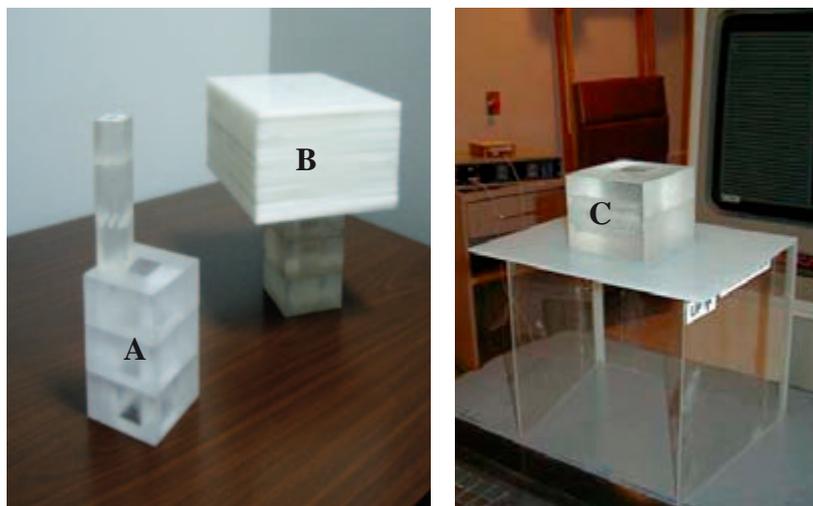


Figure 2. The RPC's mailed TLD reference dosimetry audit system is based on dosimeters held in small acrylic blocks (A – electrons, B – protons and C - photons).

be resolved through telephone calls and the review of procedures, an on-site dosimetry visit is scheduled.

On-site dosimetry review visits

An on-site audit has been recommended by several organizations, including the AAPM and the IAEA. [17–18]. An independent audit is especially important for solo practitioners but is a valuable exercise for all practicing clinical medical physicists. The RPC visit procedure consists of a review of the institution's QA procedures and documentation; a review of treatment records to ascertain the consistency of the procedures used for treatment planning and monitor unit calculations; and dosimetry measurements of the radioactive sources and radiation beams including the basic data required for delivery of IMRT. Procedures for evaluating image-guided radiation therapy (IGRT) are under development, and procedures for visits to proton-beam facilities are currently being implemented.

The RPC has conducted on-site audits for its 41-year history, and has accumulated extensive measured data from 2,350 photon beams grouped into 81 combinations of manufacturer, model, and beam energy. This database of 'Standard Data' enables the RPC to provide assistance by comparing an institution's measured data with the Standard Data. Differences often point to measurement errors and help identify the source of calibration errors detected by a mailed audit.

Credentialing for advanced technology clinical trials

Clinical trials that require the use of advanced technologies such as IMRT, SBRT and prostate brachytherapy are considered sufficiently challenging that institutions are required to demonstrate their ability to use these technologies before being permitted to register patients. Credentialing for such clinical trials generally involves questionnaires; a dosimetry review; a review of the institution's QA and dosimetry procedures and records; and either a benchmark treatment plan or simulation, planning and irradiation of one of the RPC's anthropomorphic phantoms.

Reviews of patient treatment records

In some cases, the RPC reviews the treatment plans prepared by participating institutions for patients registered on the clinical trial to ensure that the treatment plans meet the dosimetric requirements of the protocol. In other cases, the RPC performs retrospective reviews. The RPC relies on measurement made at the institution through the TLD program and on-site dosimetry reviews, or if a visit has not yet been made, its database of measured 'standard' data. Using these data and the treatment parameters (field size, depth, MU setting,

etc.) the RPC can independently calculate the dose received by the patient.

Results from RPC's quality assurance program audits

Annual calibration checks

Approximately 230 new machines are installed each year at institutions participating in clinical trials. New machines are subject to calibration errors as they are put into clinical service, with potentially serious results. Over the years, 5% to 6% of the US megavoltage beams audited with TLD have fallen outside of the RPC's $\pm 5\%$ dose or 5 mm electron depth dose criteria on the first measurement (Fig. 3). The approximately 750 institutions that have been visited to date have contributed about 85% of all clinical trial patients. Among these institutions, each year approximately 20% or 150 have one or more beams outside the RPC's criteria that require an investigation by the RPC (Fig. 4). Of the 900

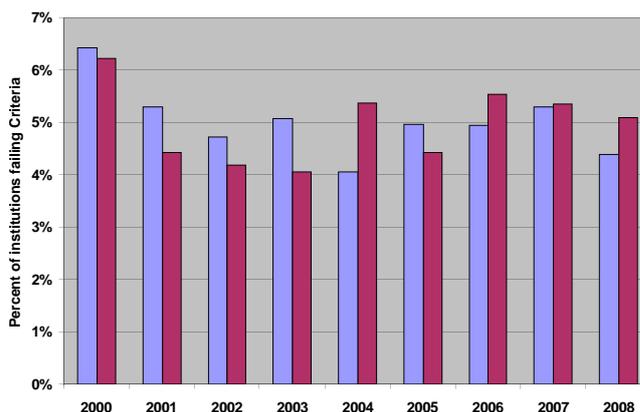


Figure 3. The percent of megavoltage radiation beams at US institutions that fail to meet the RPC's 5%/5 mm criteria for acceptability. The blue bars indicate the proportions at institutions visited by the RPC.

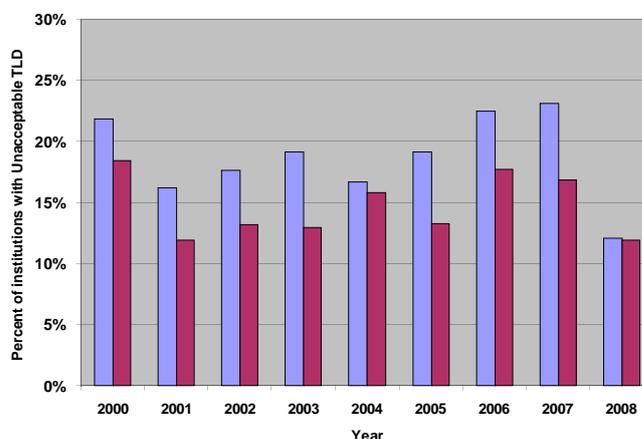


Figure 4. The percent of institutions irradiating TLD in any year that have at least one beam that fails the RPC's 5%/5 mm criteria for acceptability. The blue bars indicate the proportions at institutions that have been visited by the RPC.

TABLE 1: SELECTED DISCREPANCIES DETECTED DURING 2004–2008 DURING RPC DOSIMETRY REVIEW VISITS TO 165 INSTITUTIONS.

Errors regarding	Number of institutions (%)
Review of QA programme	127 (84%)
*Wedge transmission	53 (32%)
*Photon FSD (small fields)	46 (28%)
Off-axis factors, beam symmetry	42 (25%)
*Photon depth dose	34 (21%)
*Electron calibration	25 (15%)
*Photon calibration	22 (13%)
*Electron depth dose	19 (12%)

Note: The parameters indicated by asterisks are considered significant dosimetry parameters.

remaining institutions, 16% have a beam outside of the RPC's criteria each year.

The RPC data also show that 41% of the institutions monitored by the RPC had exactly one discrepancy detected by the TLD program during the last 10 years. Thanks at least in part to the RPC's intervention, a much smaller percentage had two or more discrepancies during this period. As was indicated above, institutions rarely display consistent discrepancies. Instead, significant calibration errors apparently can occur at any institution at any time. These errors can occur as a result of changes in procedures, the recruiting of inexperienced personnel, or with the installation of new treatment equipment.

Measurements of beam parameters

Following a dosimetry review visit, the RPC generates a detailed report describing the observations and measurements that were made and the level of agreement with the institution's planning data. Recommendations are made that demonstrate areas that require attention by the institution. The common recommendations and the frequency with which institutions receive them are shown in Table 1. Of note are the recommendations indicated by asterisks; these are considered important dosimetry parameters. On average, 70% of visited institutions received one or more of these important dosimetry recommendations.

The RPC judges the quality of an institution's QA program against the AAPM's TG-40 [19] recommendations and beginning in 2010 against the TG-142 [20] recommendations.

Significant differences with the AAPM recommendations are found frequently, but in some cases, these are justified by the institution's own procedures and measurements. More often, however, the institution has overlooked some component of recommended QA, or has allowed their program to lapse in some important aspect.

Observations from reviews of patient treatment records

The RPC participates in the QA review of the treatment records of patients treated on protocols managed by several cooperative study groups. Results from the past 5 years of the RPC's reviews are shown in Table 2. The table indicates the frequencies at which the RPC detected several types of errors in patient charts. The data were collected over a 5-year period from 2004-2008 and include 1,506 patients for which doses were calculated at 8,448 points.

Systematic errors are those believed to affect all patients at an institution, who were treated with a specific treatment machine or source, or for which a particular device such as a wedge, was used. Individual errors are those believed to affect only the patient in question. Transcription errors reflect cases in which the data reported to the study group did not accurately reflect data recorded in the treatment record.

All together, 39% of the charts reviewed by the RPC contained one or more of the errors described above. In each case, the error was corrected by the RPC and reported to the study group so that correct information could be used for evaluation of the clinical trial. The results of these reviews were also reported to the institutions promptly, to enable the institutions to take corrective action. When the errors were confirmed, the RPC conveyed the details of its calculations and investigated the reasons for the discrepancy.

TABLE 2. FREQUENCY OF ERRORS FOUND DURING THE RPC INDEPENDENT REVIEW OF TREATMENT RECORDS.

Type of error	Frequency of occurrence
Systematic error	1%
Individual errors	11%
Transcription errors	27%

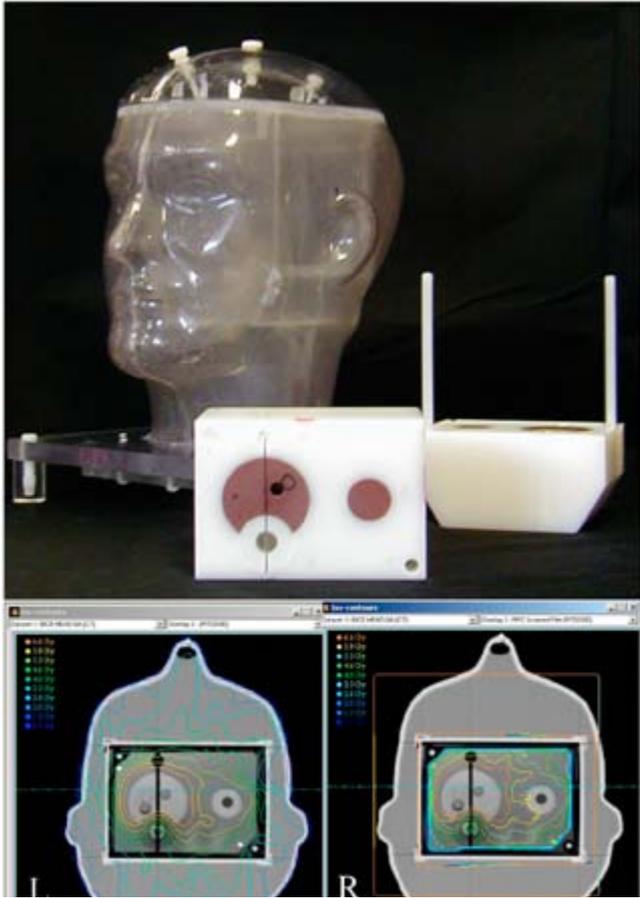


Figure 5. The RPC's H&N phantom is representative of all RPC phantoms. They are water-filled shells containing inserts with imageable target and organs at risk structures. The inserts contain radiochromic film and TLD dosimeters. A comparison between an institution's treatment plan (L) and the delivered dose (R) showing good agreement.

Results of treatment planning benchmark tests

For some trials, the RPC has agreed with the responsible study group to credential institutions through the use of a treatment planning exercise, called a *benchmark*. The RPC reviews the target volume contours and DVHs, and performs an independent calculation of dose to the target. When benchmark cases failed to meet the criteria, the RPC contacted the institution, explained the discrepancies, and worked with the institution to resolve them.

Results of anthropomorphic phantom irradiation

During the time period 2001 to 2008 the RPC mailed IMRT head-and-neck phantoms (see Fig. 5) to 537 distinct institutions (see Table 3). A total of 763 irradiations were analyzed. Of these, 595 irradiations or 78% successfully met the irradiation criteria. More than 125 institutions failed to meet the irradiation criteria on the first attempt and had to repeat the phantom irradiation.

Of those failing to meet the criteria, the majority failed only the dose criterion. The remaining unsuccessful irradiations failed the distance-to-agreement (DTA) criterion or both the dose and DTA criteria.

The most common TPSs used to plan the irradiations of the phantom were the Phillips Pinnacle and Varian Eclipse systems. The pass rates for these two TPSs were approximately 73% and 85%, respectively. The difference is believed to be due to difficulties in modeling the penumbra at the ends of rounded MLC leaves [21].

Conclusion

As described above, the majority of institutions audited by the RPC meet the acceptance criteria. However, a significant number of institutions fail to meet these standards. The RPC endeavors to understand the reasons for such discrepancies, and to educate the institutions in the procedures needed to resolve them.

Follow-up output audits, calibration and QA record reviews, and re-reviews of treatment records are all intended to confirm that discrepancies are corrected. However, RPC records indicate that additional discrepancies and errors occur each year. This suggests that without an independent review, the number of errors would be greater, and both the time elapsed before their discovery and the number of patients treated incorrectly would also be greater. The RPC remains vigilant and ready to assist institutions participating in NCI sponsored clinical trials to improve the accuracy of dose delivery to their patients.

TABLE 3. PASSING RATES FOR FIVE OF THE RPC'S ANTHROPOMORPHIC PHANTOMS.

Site	Institutions	Irradiations	Pass rate
H&N	537	763	78%
Pelvis	156	175	82%
Lung	133	174	69%
Liver	16	24	50%
Spine	18	16	75%

Note: The criteria for agreement are 7% and 4 mm for all phantoms except the lung phantom, for which the criteria are 5% and 5 mm.

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A quality assurance programme in dosimetry for Algeria: from simple to complex

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The audit of radiotherapy beams was initiated in Algeria in 1992 with a post graduate thesis undertaken at the Secondary Standards Dosimetry Laboratory of Algiers. The idea was to use a Farmer chamber shaped PMMA holder (Fig. 1) capable of holding six TLD-100 chips in a clinical beam. The dosimeters were calibrated in terms of absorbed dose to water by comparison with a calibrated ionization chamber using a 1 mm PMMA waterproofing sleeve. The TLD system was used, along with an ionization chamber, to check the beam calibration of eight cobalt-60 treatment units nationwide.

In 1995, a quality assurance programme was established and was based on the use of LiF TLD-100 powder, calibrated at the Algerian SSDL. This programme was initiated in the framework of an IAEA Coordinated Research Project (E2.40.07), by setting up an External Audit Group (EAG) which is composed of the Measuring Group (MG) within the SSDL, responsible for the technical aspect of the TL dosimetry, and the Medical Physics Group (MPG), responsible for the interactions with the participating radiotherapy centres and supported by two hospital physicists and one oncologist. This programme was implemented to establish the IAEA methodology for the use of TLDs.

The reproducibility of the TLD signals have been studied in Algeria using three different dispensers: a home made dispenser (Fig. 2a), a commercially available (Fig. 2b) dispenser and an IAEA made dispenser (Fig. 2c). Homemade cupels made of aluminum, stainless steel and copper were also studied. For calibration purposes, the TLD capsules were irradiated using a PMMA phantom fixed on a rigid frame that can be inserted on the ^{60}Co calibration unit in a reproducible

manner (Fig. 3). Up to five capsules could be irradiated using a PMMA rod. The powder was evaluated using a Harshaw 4000 readout system.

In 2001, the Algerian EAG participated in a second CRP (CRP E2.40.12) addressing the development of TLD-based audits for radiotherapy dosimetry in non-reference conditions. In this programme, a modified TLD holder with horizontal arms holding three capsules was used allowing for the checking of reference dose rates as well as beam profiles for either symmetric and asymmetric fields.

In addition to the development of methodologies for reference and non reference conditions, the EAG also helped to establish the energy dependence of the TLD-100 powder in high energy photon and electron beams by irradiating the TLD capsules at Algerian radiotherapy centres and outside Algeria, by other CRP participants and a few radiotherapy departments in France, Belgium, Canada and the Czech Republic. All calibration curves were checked with irradiations performed

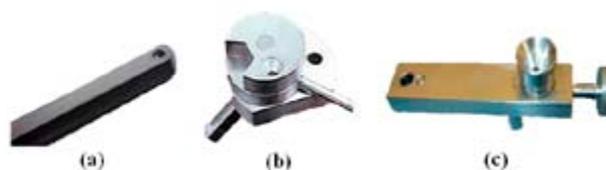


Figure 2. Homemade (a), Harshaw (b) and IAEA (c) dispensers

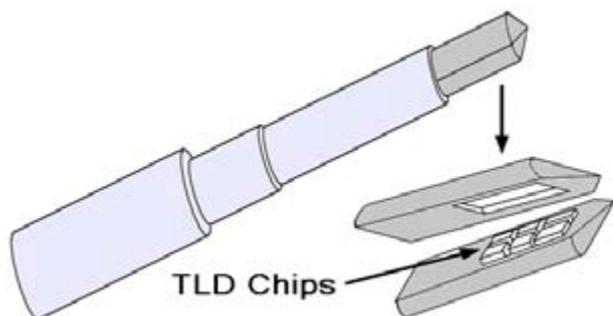


Figure 1. Ionization chamber shaped TLD chips holder.

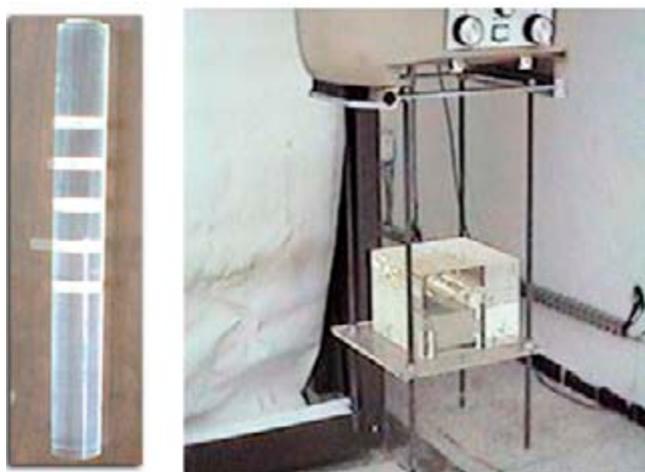


Figure 3. PMMA phantom used for irradiating TLDs.

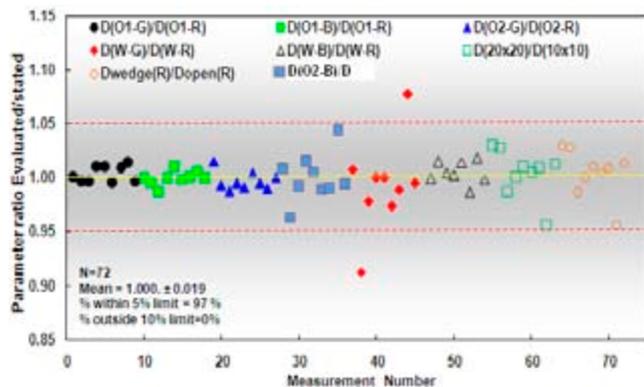


Figure 4. Results of audits in non-reference conditions: dose ratio on-axis for photon and electron beams.

at the IAEA Dosimetry Laboratory and with irradiations performed by other CRP participants.

Since 1995, the EAG has been applying the established methodology for the annual national audit in reference conditions, and since 2001, in non-reference conditions.

As of December 2009, the Algerian infrastructure in radiotherapy is composed of five radiotherapy departments equipped with eight ^{60}Co units and seven linear accelerators, three of which are equipped with multileaf collimators. Furthermore, there is in place a programme initiated by the Algerian Government for increasing the number of radiotherapy departments to nineteen. As a first step in this programme, by the end of 2010, six new modern linear accelerators are planned to be installed and six Cobalt-60 units will be replaced by 6 MV linear accelerators with multileaf collimators.

Expecting the development of radiotherapy treatment modalities that will be implemented in Algeria (conformal treatment, IMRT and other modern techniques), the Algerian EAG has decided to participate in a new CRP launched by the IAEA concerning the development of quality audits for radiotherapy dosimetry for

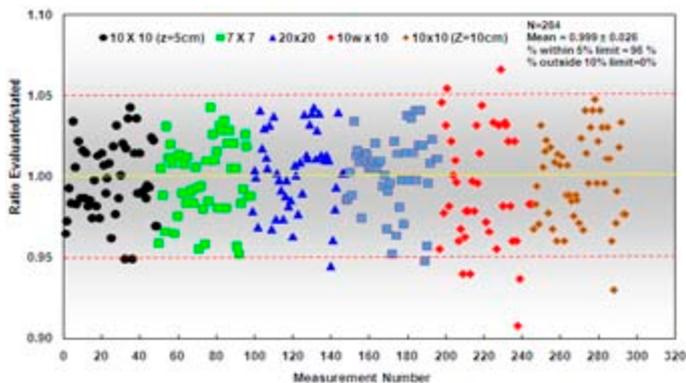


Figure 5. Results of audits in non-reference conditions : off-axis measurements for symmetric beams.

complex treatment techniques. A trial run was organized in September 2009 for MLC audits at two Algerian centers.

From 1997 to 2009, many audits were implemented in which all the Algerian radiotherapy centres participated. In this period, only three discrepancies between the dose stated by the participant and that measured by the EAG were detected, in reference conditions: one for a ^{60}Co beam was due to malfunctioning of a mechanical timer and the two others were in high energy photon beams and poor beam calibration was identified as the cause. Regarding the non-reference conditions (Fig. 5), observed discrepancies were identified as originating either from the capsule positioning, especially for irradiation with wedge filters, and for a few other irradiations based on dosimetric data from the planning systems.

The audits have been very helpful since they are regarded as an independent check for the beam calibration and other parameters by the medical physicists. In many cases, when discrepancies were detected, immediate actions were taken, including an on-site visit with recalibration of beams with an independently calibrated ionization chamber.

The Brazilian experience in postal quality audits in radiotherapy

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Brazil has almost 190 million inhabitants and has 220 radiotherapy centres with 100 ^{60}Co units and 170 linacs.

Since 2003, the Quality Control Programme in Radiotherapy (PQRT) from the National Cancer Institute (INCA), Rio de Janeiro, has implemented a postal dose

audit system in Brazil [1–3], which has also been used by some radiotherapy centres in other countries in Latin America and the Caribbean (Argentina, Chile, Cuba, Ecuador, Guatemala, Honduras, Panama, Paraguay, Uruguay and Venezuela). Each radiotherapy centre that uses our postal system to complement their own quality



Figure 1. TLD holder used in PQRT postal audit system.

control programme is also assessed with an external audit, in accordance with international procedures [4, 5].

The system used for irradiating TLDs (Fig. 1) consists of a lucite support frame and 16 capsules with powder thermoluminescent dosimeters (TLD-100: LiF:Mg,Ti). The frame is fixed within a water phantom. It is possible to irradiate 5 TLD capsules at a time. The system is used for analyses of therapeutic photon beams (^{60}Co and linacs) in reference and non-reference conditions, and evaluates the following parameters:

1. Dose in the central axis in reference conditions;
2. Dose in the central axis at different depths;
3. Dose for rectangular fields;
4. Tray transmission factors;
5. Wedge transmission factors (physical and dynamic/virtual);
6. Beam symmetry;
7. Beam flatness;
8. Beam quality (Linacs).

These parameters were evaluated in Brazil between 2003 and 2008 and count 2894 total tests, in 97 ^{60}Co gamma beams and 292 high energy photon beams. Examples of these measurements are illustrated in Figs 2–3.

The results of TLD measurements for other Latin America and Caribbean radiotherapy centres, in between 2005 and 2008 are given in Figs 4–7:

Our PQRT/INCA has also a local on-site audit group. When the postal systems identify a problem which cannot be solved by phone or email, the local audit group immediately visits the centre in question and performs all the tests recommended by the IAEA-TECDOC-1151 [4] and IAEA-TECDOC-1543 [5], and corrects the problem.

This TLD audit postal system has been used routinely since 2003. From these 5 years of experience we can

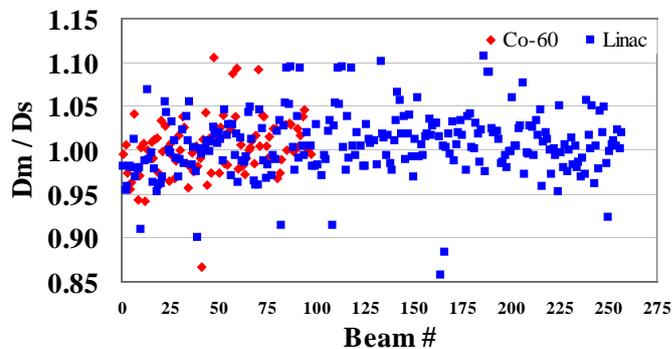


Figure 2. Brazil: measured / stated dose in reference conditions.

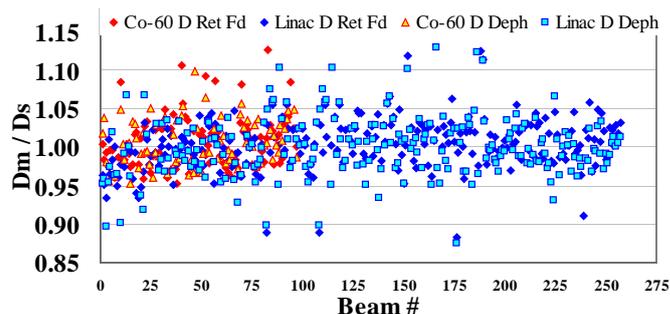


Figure 3. Brazil: measured dose / stated dose in non-reference conditions (rectangular field and depth dose).

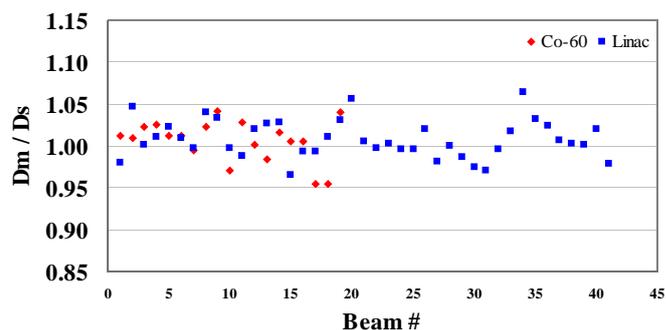


Figure 4. Latin America and the Caribbean: measured / stated dose in reference conditions.

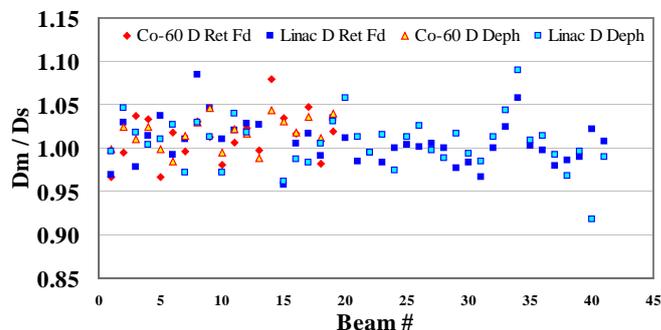


Figure 5. Latin America and the Caribbean: measured dose / stated dose in non-reference conditions (rectangular field and depth dose).

conclude that this system is reliable, and very useful for a large country like Brazil. The system provides information about the main parameters necessary for quality radiotherapy treatment and helps to ensure the quality of a large amount of equipment in a minimal amount

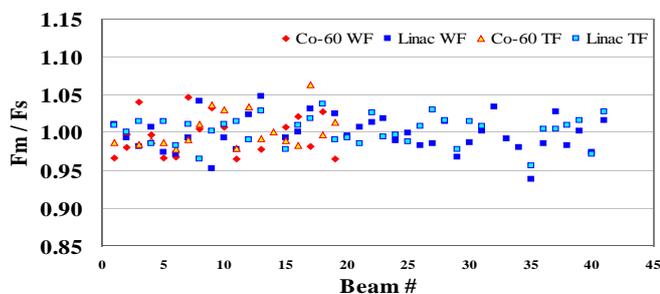


Figure 6. Latin America and the Caribbean wedge and tray factors: measured / stated.

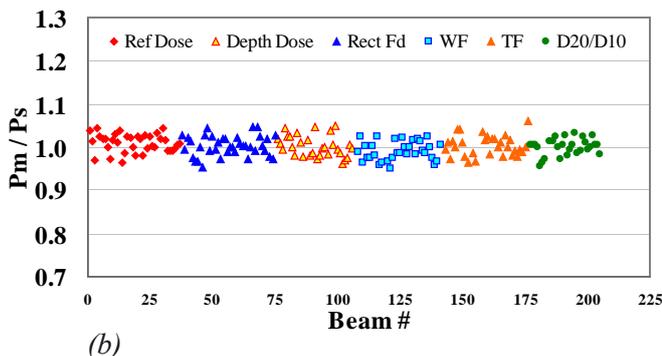
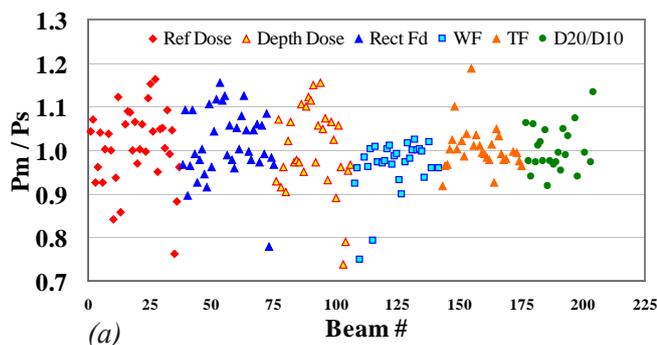


Figure 7. Reference and non-reference measurements (measured parameters / stated parameters): (a) problems in dosimetry, (b) beams from Fig. 7a reanalyzed after sending another postal kit or by phone/email contact.

of time and with a minimal amount of costs. In Fig. 7a TLD results are shown for those radiotherapy centres where discrepancies in one or more beam parameters were found. In Fig. 7b one can see the improvements of the measured parameters in the checked beams after addressing the problems found.

In Figs 7a and 7b we can clearly see how important this program is for improving dosimetry in radiotherapy in our country. The data clearly show that several deviations found in beam parameters measured and stated (Fig. 7a) in different radiotherapy departments could be resolved through a simple telephone call or email which was confirmed by the repeat successful TLD audit (Fig. 7b).

Our success is in large part because of the hard and continuous work from the Postal Audit Group, see Fig. 8.



Figure 8. The Postal Audit Group (from the left): Claudio, Paul, Alfredo, Anna (the head) and our moral stick.

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TLD audit in radiotherapy in the Czech Republic

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The postal TLD audit for radiotherapy beams in the Czech Republic has been pursued by the National Radiation Protection Institute (NRPI) in Prague since 1997. From the very beginning, the aim has not been only to achieve an improvement of clinical dosimetry, but also to provide results to the State Office for Nuclear Safety (SONS), which is responsible for radiation safety in the Czech Republic. According to the Czech national recommendations issued by the SONS, each clinically used beam must undergo a calibration check performed via the postal TLD method at least once per two years. This involves 32 radiotherapy centres encompassing 62 radiotherapy treatment machines. A total of more than 1000 beam checks have been provided in this way since 1997.

The origins of the Czech TLD postal audit date back to 1993. With the support of the Flemish government, a pan-European Radiation Oncology Programme for Assurance of Treatment Quality (EROPAQ) was organized for three central European countries (Poland, Hungary and Czech Republic) to link them to western European countries and to share their lessons and experiences in installing their system of quality assurance in radiotherapy. The EROPAQ coordinating and measuring centre (CMC) was set up in 1994 at the University Hospital Gasthuisberg (Leuven, Belgium) and they worked together with the Czech reference centre established to distribute TLD mailings to Czech radiotherapy centres. The methodology of TLD irradiation and evaluation within the EROPAQ was similar to that developed by the IAEA and EC network [1–3].

In 1996 a total of 26 beams were checked. Only 16 (62%) of them complied with the acceptance level of $\pm 3\%$ which was set for deviation between the measured and stated dose. For 5 (19%) beams major deviations (beyond $\pm 6\%$) were found which required prompt action. After the cause of the major deviations had been explained, the TLD checks were repeated. This led to improvement of the clinical dosimetry at the radiotherapy centres. Simultaneously with the TLD project, an infrastructure study was done. The collected data helped to investigate the correlation between the results of beam output checks and intrinsic structures of radiotherapy departments, staffing and equipment.

The highly successful EROPAQ project [1] was followed by a pan-European Radiation Quality Assurance (EURQA) that started in 1996. Within the frame of the

EURQA, guidelines for organizing TLD audits at the national level were prepared. The participation of the Czech representatives in this project was fundamental in the building of the Czech TLD measuring centre and setting the national system of external independent audits. The TLD measuring centre was established in the NRPI's Department of Dosimetry which was equipped with a manual Harshaw 4000 TLD reader and other accessories. Lithium fluoride powder LiF:Mg,Ti (type MT-N produced by TLD Poland) was chosen as TLD material for the audits. The methodology for the beam calibration check was based on that used in the EC and EROPAQ/EURQA networks. More details about the Czech TLD audits can be found in the literature [4, 5].

Following the creation of a national system for TLD audits, the methodology was further refined and developed, supported by both international and national research projects. At the end of 1998, two multi-purpose phantoms were obtained. After a short testing period where the methodology was checked, the advanced TLD audit was brought into practice in 1999. The audit involved measurements for both reference and non-reference conditions for external photon beams. The methodology of the TLD audits has also developed to accommodate modern computer-controlled linear accelerators with multi-leaf collimators (MLC), which have increasingly been used during the last decade. The MLC portion of the TLD audit covers measurements on the central beam axis in radiation fields formed by the MLC. The first TLD MLC audits were performed in 2003. The methodology is still under development within the framework of an IAEA coordinated project in a Czech project, "Development of postal dosimetry



Figure 1. National Radiation Protection Institute in Prague – the building where the Department of Dosimetry resides.

audits for conformal radiotherapy techniques in the Czech Republic". However, at present these more advanced methods of TLD audits have not been used in practice by SONS, but it is hoped that they may be used within the clinical audits which are in the process of being developed in the Czech Republic.

Our results and experiences show the importance of TLD audits in radiotherapy centres. It is plainly seen that regular audits lead to an improvement of clinical dosimetry. At present, 93% of the audit results are within the $\pm 3\%$ limit for the beam calibration check. Major deviations are rare and can usually be identified as random errors.

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Figure 2. Czech TLD Team: Daniela Ekendahl, Viera Brožáková, Michaela Fábervová with a new TL/OSL system.

Establishment of a postal dose audit system in Japan using a radiophotoluminescent glass dosimeter

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The story behind development of the national audit system

Although over 800 linear accelerators have been clinically used at about 700 radiation therapy facilities in Japan [1], until recently no external audit system existed. Since 2001, several severe accidents from erroneous irradiation in radiation therapy treatments have been made public in Japan [2]. The main reason for these accidents was the misuse of new technology used for radiation treatment, such as treatment planning systems. The demand for quality assurance in radiation therapy

has been growing and a pilot external audit study was initiated by a national group funded by the Ministry of Health, Labour and Welfare [3]. The group chose to use the radiophotoluminescent glass dosimeter (RGD) as a transfer dosimeter rather than a TLD. The new RGD system, Dose Ace (ASAHI GLASS CO.), commercially available in Japan, had stable output, its reproducibility was favorable, and the RGDs had almost no fading effects. The pilot study was undertaken by the National Institute of Radiological Sciences (NIRS; SSDL) and the system was finally established as a postal dosimetry audit [4].



Figure 1. RGD system (RGD elements, reader and the control PC).

In this system, RGDs and a water equivalent solid phantom (Tough Water Phantom, KYOTO KAGAKU CO.) were sent to radiotherapy centres, where the RGDs were irradiated with 1 Gy in a high energy X ray beam at the reference conditions (field size 10 cm × 10 cm, depth 10 cm). Irradiated RGDs were then sent back to NIRS and the dosimeters were analysed by an RGD reader. The RGD system is shown in Fig. 1. The tolerance level was set to $\pm 5\%$, taking into consideration the uncertainty of $\pm 1.6\%$ (1 standard deviation).

The NIRS group conducted the postal audit trial with 106 centres from 2006 to 2007 and the results showed a 1.3% standard deviation for 191 beams, indicating very good consistency in basic dosimetry among Japanese centres [4]. Based on the success of this trial, the postal dose audit service was initiated in November 2007 and it is now operated by the Association for Nuclear Technology in Medicine (ANTM). The audit is not mandatory and the hospitals that participate in the audit are required to pay a fee for two beam checks at the ref-

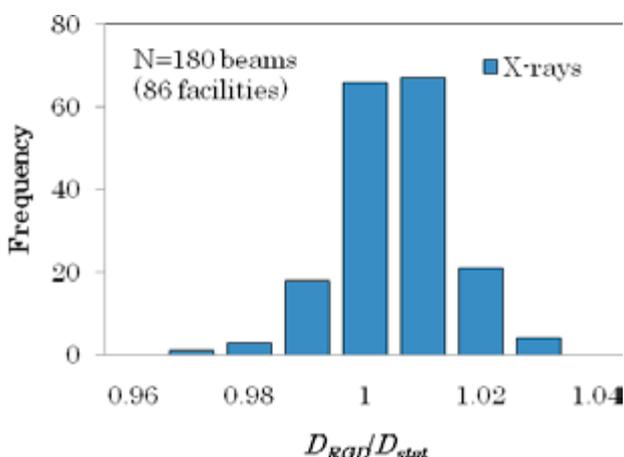


Figure 2. Distribution of the results of the postal dose audits of radiotherapy hospitals for the delivery of absorbed dose to water under reference condition during 2007–2009.



Figure 3. The members of NIRS and the ANTM audit group.

erence conditions. We are recommending that centres participate in the audit every three years.

The audit results

From its inception in November 2007 to November 2009, 86 radiotherapy centres have participated in the audit. This included a total of 102 linear accelerators and 180 checked beams (48 4 MV beams, 54 6 MV beams, 75 10 MV beams and 3 beams of 15 MV).

The distribution of the results is shown in Fig. 2. The results correspond to ratios of the NIRS RGD read dose to that stated by the user, D_{RGD}/D_{stat} . The mean ratio was 1.006, its standard deviation 1.0%, and the outliers ranged between a minimum of 0.974 and a maximum of 1.031.

Future plans

To make the audit more practical, an audit for non-reference conditions has been studied. This includes checks of the dose with respect to field size and wedge transmission. We plan to apply this in the 2010 audits. In addition, future development of an audit system for electron beams or particle beams is also planned.

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History of dosimetry comparisons and audits for radiotherapy centres in Poland in 1936–2009

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The Medical Physics Department at the Centre of Oncology, Warsaw has a long tradition of activities in the field of radiation dosimetry in medicine. The department was created before World War Two, in 1936, in response to Marie Sklodowska-Curie's wish for a measurement laboratory to be established. The department was headed by a disciple of Ms. Curie, Prof. Cezary Pawlowski. The Laboratory was officially inaugurated on the occasion of a visit from Irene and Frederic Joliot-Curie, just after their Nobel Prize ceremony in Stockholm in 1936 (see Fig. 1). The Laboratory performed radiation dosimetry measurements for various institutions throughout the country which, at that time, were using radium-226 or orthovoltage X rays. These activities were limited though, throughout World War Two.



Figure 1. A visit of Irene and Frederic Joliot-Curie to the Physics Department during the inauguration of the Measurement Laboratory in October 1936 (prof. Cezary Pawlowski in the centre). Frederic told a correspondent of a Polish newspaper the following: "Today I was pleasantly surprised by the Physics Laboratory in your Radium Institute. It is a very well organized and methodically installed laboratory. When I was here three years ago in 1933 there was nothing, but today good results can be obtained here". The Joliot couple maintained personal contacts with the institute and continued to support it until after World War Two.

After the war, while Poland was recovering from war time devastation, Prof. Pawlowski reactivated the activities of the laboratory. In the postwar framework, employees of the department were obliged to carry out the measurements of the dose rate or output for X ray machines and check for the possible leakage of radium tubes throughout the country. These activities slowed down for the department when radiotherapy facilities started to employ their own physicists for local measurements.

The activities of the department for the calibration of radiotherapy dosimeters have remained a priority since the department's conception. Such calibration was possible due to the fact that the Physics Department has received, through the United Nations Relief and Rehabilitation Administration (UNRRA), a donation of several dosimeters: the American Victoreen Condenser r-Meters, which also possessed a calibration certificate from the American primary standards laboratory. In 1960s to late 1980s, different dosimetry protocols and codes of practice were used incoherently in Poland, such as ICRU report #24, the Nordic protocol – NACP, the American protocol TG-21 published by the AAPM, and the IAEA TRS-277 protocol. In 1988 Izewska and Gajewski published work which showed that the doses defined in the different protocols could have discrepancies as much as 2%-3% in reference conditions after which the common protocol – the IAEA Report TRS 277 – was put in place for the whole country.

This unification of the use of dosimetry protocols in the country, the relatively good equipment at the laboratory, and the organization of calibration as a separate task of the Department allowed for the department's inclusion in the Network of Secondary Standards Dosimetry Laboratories – the IAEA/WHO SSDL Network in 1988. This was done on the recommendation of the Polish Bureau of Measures.



Figure 2. The dedicated Co-60 unit set-up for calibration of radiotherapy dosimeters and for irradiation of TLD powder.

At the beginning of the 1990s there were about 50 megavoltage radiotherapy units in Poland. Due to the shortage of qualified specialists in medical physics there was a considerable risk of radiation accidents. This was made worse by the fact that megavoltage radiation does not produce distinctive effects on the skin, which is the case for orthovoltage radiation to which most radiation oncologists were accustomed. For this reason the Medical Physics Department petitioned the IAEA to fund the “TLD postal dosimetry audit in radiotherapy centres in Poland” project.

The TLD audit project started in 1991 and was well accepted by the physicists at the regional radiotherapy centres. All deviations greater than $\pm 3.5\%$ were carefully analyzed. During the period 1991-1993 all Co-60 units and photon and electron beams from accelerators were checked. Approximately 24% of the beams exhibited deviations outside $\pm 3.5\%$ acceptance limit. They were followed-up, analyzed and corrected.

In 1994 the Polish SSDL joined and co-organized, through its representative Dr. Joanna Izewska, the pan-European Radiation Oncology Project for Assurance of Treatment Quality (EROPAQ). Over the span of the EROPAQ Project (1994-1995) the percentage of the beams with deviations higher than 3.5% went down to 12%.

There is no doubt that in some cases the deviations were caused by the lack of experience of the local physicist or by his/her errors. All these errors were discussed with the participants, explained and corrected. It was extremely difficult to estimate the number of patients who could be irradiated with doses different to the prescribed ones, because in the opinion of the participants, some of the errors detected might have occurred only during the TLD irradiation. It was stated beyond any doubt that in one case 78 patients were underdosed for about one month (the deviation 5.7%), in another case

the patients were overdosed for about two years (deviation 4.9%).

During the period 1996-1998, when the whole Department was moved to a new building, the audit activity was temporarily stopped. It was restarted in 1999 and through 2001 the doses determined by measurements with ionization chambers in reference conditions were checked using new facilities (see Figs 2 and 3). During that period the number of deviations outside the acceptance limits was below 7%.

In 2002, a new TLD audit approach was introduced. Participants were asked to irradiate TLDs with doses calculated by the treatment planning systems (TPS) rather than following the dose measurement with an ionization chamber. In addition electron beam doses began to be audited using TLDs following the hospital measurements with ionization chambers. In both cases the doses were determined in reference conditions.

As of 2004, the audits of doses determined from the TPS calculations in various non-reference conditions were introduced, in accordance with the IAEA programme for national audit groups. Despite these complex conditions (off axis, irregular fields, non-symmetric fields) the number of deviations is usually small, which is quite satisfactory when compared with the early results (see Figs 4 and 5).

These favorable results of the audits for complex radiation fields prove there is a high level of dosimetric accuracy and TPS performance in Polish radiotherapy centres. The audits also build up the awareness of medical physicists of the importance of precise determination of doses delivered to patients, and therefore increase patient safety. This is confirmed by the decreased deviation of results observed in consecutive audit runs over the years.



Figure 3. The TLD audit team at work on the Fimel PCL3 reader.

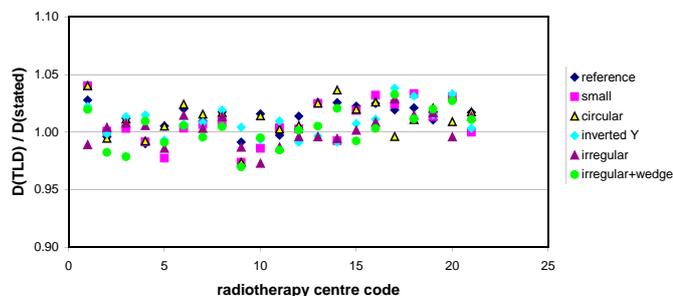


Figure 4. The results of the TLD audit run conducted in 2008 for MLC-formed fields of various sizes and shapes. All results are well inside the 5% tolerance limits, and only two are outside 3.5% acceptance limits.

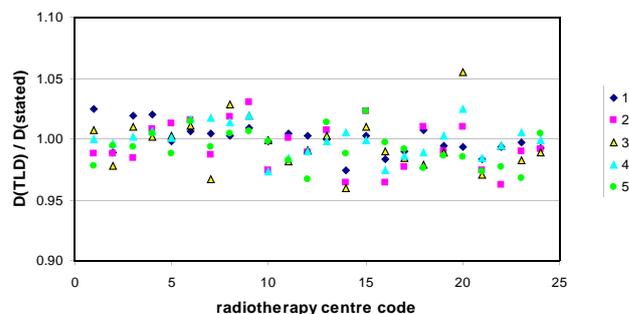


Figure 5. The results of the TLD audit run conducted in 2009 for the off-axis measurement points. Data points numbered 1-5 indicate different field arrangements. All but two results are within 3.5% limits; one result is outside the tolerance limit of 5%.

Audit of 3D conformal radiotherapy treatment planning systems

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Background

Treatment planning systems (TPSs) are an essential part of modern radiotherapy equipment where radiation dose distribution and number of Monitor Units (MU) necessary to achieve it are calculated. Therefore, proper commissioning, implementation and application of TPSs are essential to ensure accurate dose delivery to the patient, and to minimize the possibility of accidental exposure.

IAEA is supporting national and sub-regional TPS audit activities as a new initiative to improve the quality and safety of radiotherapy in Member States.

The audit methodology is based on the outcome of the IAEA coordinated research project E2.40.13 "Development of procedures for quality assurance for dosimetry calculation in radiotherapy" [1]. The pilot runs have been conducted in the Baltic States and Hungarian hospitals.

Methodology

The methodology for the audit focuses on the dosimetric aspects of the treatment planning and delivery processes of radiotherapy, for high-energy photon beams. It assesses the important part of the external beam radiotherapy workflow - from patient data acquisition and treatment planning to dose delivery.

The audit procedure is based on the use of a CIRS thorax phantom Model 002LFC (Norfolk, VA). The phantom has a body made of plastic water, lung equivalent material and bone equivalent material sections and has 10 holes to hold interchangeable rod inserts for an ionization chamber. The phantom has a set of calibrated electron density reference plugs that enable the verification of the Hounsfield units/electron density (HU/ED) conversion procedure. Computed tomography (CT) is used to image the phantom and the images are transferred to a TPS where planning and dose calculations take place. The clinical test cases cover a range of basic treatment techniques used in 3D conformal radiotherapy (CRT). The tests are structured so that at first, the dose distributions for single beams are considered, then standard multiple field techniques are used, and finally the complex multi-field arrangements are applied. A short description of test cases is given in Table 1, column one, and more detailed descriptions could be found elsewhere [2]. The clinical test case setup conditions are carried out using a treatment machine, and the doses to specific points in the phantom are directly measured with an ionization chamber. These checks are primarily aimed at confirming that the doses calculated by TPS agree with those determined by measurement, within predefined acceptance criteria.

The audit process takes about 15 hours for one accelerator (considering two photon beams and up to three

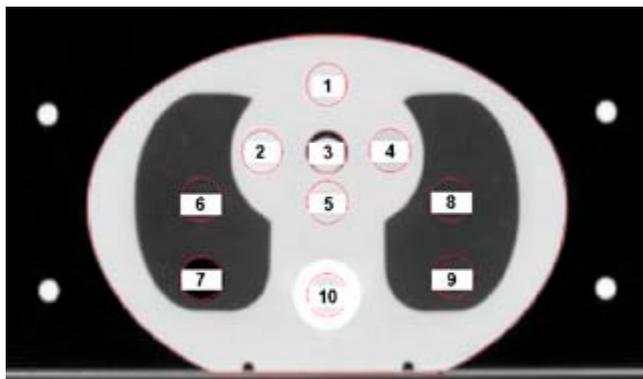


Figure 1. CT image of the CIRS phantom with location of measurement points.

TPS algorithms). In practice it requires two working days. On the first day CT scanning and test case planning is performed. CT scanning requires approximately 45 minutes of scanner time including time necessary for data transfer. The first scan is performed to verify the HU/ED conversion curve used by TPS, and the second scan is performed for treatment planning purposes. The planning of test cases and transfer of the data to

the accelerator record and verify system requires approximately 6 hours. On the second day the irradiation of the phantom will take place, which will require up to 5 hours of accelerator time for a dual photon energy machine. Analyses of the data would require an additional 2 hours.

Audit in the Baltic States

The audit was carried out in the 5 largest radiotherapy departments of the region. It was the same auditor who visited all the radiotherapy departments and ensured that the procedure of IAEA-TECDOC-1583 was followed. The performance of seven TPSs have been evaluated and the measurements were conducted on seven treatment units. Altogether, there were 28 different combinations of photon beams and TPS algorithms/inhomogeneity correction methods tested.

The location of measurement points are shown on Fig. 1 and results are listed in Table 1.

All TPSs tested had a satisfactory performance with deviations less than 3% in the majority of clinical test cas-

TABLE 1. DESCRIPTION OF TEST CASES AND DIFFERENCE BETWEEN TPS CALCULATED AND MEASURED VALUES.

Test description	Measurement point #	Acceptance criteria %	Mean difference % [range]
Standard SSD 10×10cm ² single field	3	2	0.0 [-1.4;1.8]
	9	4	-5.0 [-11.6;0.8]
	10	3	-1.7 [-4.5;4.6]
Extended SSD rectangular field (4×18cm ²)	3	3	-0.5 [-5.2;2.2]
Oblique incidence	1	3	-0.7 [-4.3;4.4]
Field with blocked corners	3	3	-0.2 [-2.1;2.2]
Four field 'box' technique	5	3	-0.4 [-2.5;6.1]
	6	4	1.6 [-6.6;12.0]
	10	4	-2.8[-11.8;8.5]
Customised blocking, large low density inhomogeneity	2	3	0.3 [-1.4;1.8]
	7	4	6.7 [-8.9;19.2]
L-shaped field with blocked central axis	3	3	0.4 [-3.3;7.5]
	10	5	2.0 [-2.8;4.9]
3 field plan with asymmetrical wedged beams	5	3	0.4 [-2.8;4.9]
3 field plan with non-coplanar beam arrangement	5	3	0.1 [-3.9;5.2]

es, with the exception of dose measurements at points located in the lung equivalent material. The deviations of up to 19.2% between measured and calculated doses were discovered for these points. A number of small discrepancies caused by inaccuracies in the input beam data fitting were discovered as well.

The TPS audit in the Baltic States showed mostly acceptable results with, however, a few exceptions related to TPS algorithm limitations.

Audit in Hungary

Prior to the audit, the IAEA loaned a CIRS Thorax phantom to the Hungarian Society of Medical Physics and a one-day workshop was organised at the Uzsoki Hospital in Budapest. At this workshop, the purpose and methodology of the TPS audit was presented to medical physicists from different radiotherapy departments across the country. After the workshop, a physicist from the Uzsoki Hospital visited nine radiotherapy departments and performed the audit. Altogether there were 11 TPSs in nine radiotherapy departments tested, and measurements were carried out on 10 treatment units.

Four TPSs provided results within the acceptance criteria, whereas the others had one or more measurements with larger deviations. Generally, better agreement between calculations and measurements was observed for low energy (6 MV) photon beams than for high energy (15, 18 MV) photon beams.

Following the audit, several areas for improvement were identified, related to TPS data input, CT calibration, beam calibration, and other items.

Conclusion

Audit studies in both regions show that TPS audits can be a useful and efficient approach for assessing the differences between TPS calculations and actual dose measurements. The audits also identified shortcomings in the radiotherapy chain and areas that can be improved. In addition, it also helps the user to appreciate the possibilities of their TPS and to understand its limitations.

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- [2] GERSHKEVITSH E., SCHMIDT R., VELEZ G., MILLER D., KORF E., YIP F., WANWILAIRAT S., VATNITSKY S., Dosimetric verification of radiotherapy treatment planning systems: results of IAEA pilot study, *Radiother. Oncol.*, **89** (2008) 338–346.

QUATRO: comprehensive audit in radiation oncology

J. Izewska

International Atomic Energy Agency



Figure 1. Comprehensive QUATRO audit in the Greatpoland Cancer Centre, Poznan, Poland, 2009.

The radiation treatment outcome is the result of a multifaceted process that involves complex infrastructure, technology and a multi-disciplinary team of professionals trained in radiation oncology, medical physics, radiotherapy technology, radiobiology, and medical case planning and management. They work together to plan and deliver radiotherapy to cancer patients, integrating the radiation treatment with surgery and chemotherapy as needed.

IAEA comprehensive audits assemble teams of professionals (radiation oncologist, medical physicist, radiation therapist) to critically assess radiotherapy practices and management at radiation oncology centres with the aim to improve quality. Called the Quality Assurance Team for Radiation Oncology, or QUATRO, the audits draw on high level experts from IAEA Member States who comprise the auditing team for QUATRO missions. They are supported by a local radiation safety expert.

QUATRO audits aim to help radiotherapy centres attain the best level of practice possible for their country. Audits assess the radiotherapy infrastructure; patient and equipment related procedures; radiation protection; staffing levels and professional training programmes for the local radiotherapy staff. A comprehensive audit methodology is available at the IAEA [1].

By 2010, QUATRO has conducted approximately 50 audits on request, in radiotherapy centres from Central and Eastern Europe, Asia, Africa, and Latin America.

Auditors identify gaps in technology, human resources and procedures, allowing the audited centres to document areas for improvement. Some centres have been acknowledged for operating at a high level of competence, while others have received a comprehensive set of recommendations. Overall, the audits have contributed to significant improvements at centres, and to identifying common issues of concern to address internationally. An example of this is the training of radiation therapists in Central and Eastern Europe, now being implemented through the IAEA's cooperation with the European Society for Therapeutic Radiology and Oncology (ESTRO).

QUATRO, in addition, offers assistance in the resolution of suspected or actual dose misadministrations (over- and under-exposures) in radiotherapy [2]. It includes the follow-up of inconsistent results detected by the IAEA/WHO TLD postal dose audit service. This way radiotherapy centres are offered help at a very early stage in the problem-solving process, focusing on prevention of accidents in radiotherapy.

References

- [1] INTERNATIONAL ATOMIC ENERGY AGENCY, Comprehensive audits of radiotherapy practices: a tool for quality improvement, Quality Assurance Team for Radiation Oncology (QUATRO), IAEA, Vienna (2007).
- [2] INTERNATIONAL ATOMIC ENERGY AGENCY, On-site visits to radiotherapy centres: medical physics procedures, Quality Assurance Team for Radiation Oncology (QUATRO), IAEA-TEC-DOC-1543, IAEA, Vienna (2007).



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**IAEA/WHO TLD POSTAL DOSE QUALITY AUDIT
for Radiotherapy Institutions**

Please complete the form below and return it to DOSIMETRY@IAEA.ORG.

APPLICATION FORM

Name of the institution: _____

Address: _____

Country: _____

Knowing the principles of operation of the IAEA/WHO TLD postal dose audit service, we apply for the participation in the IAEA/WHO postal dose audit _____.

We accept the conditions of the IAEA/WHO audits and agree to follow the procedures established by the IAEA/WHO, in particular the policy on reporting the TLD results and on the required follow-up actions.

We will be able to irradiate TLDs within the scheduled run:

from _____ to _____

a) We request the IAEA/WHO to provide TLDs for the total number of high-energy photon beams____, i.e. ____ Co-60 beams and ____ high-energy X-ray beams

b) We request a standard IAEA holder stand for TLD irradiation: Yes No

Head Radiation Oncologist

Chief Physicist

Name: _____

Signature: _____

Date: _____

Phone/fax: _____

Email: _____

Principles of operation of the IAEA/WHO TLD postal dose audit service for radiotherapy centres

The service is cost free to participants. It spot checks calibration of clinical teletherapy photon beams (Co-60 and megavoltage beams from accelerators). It does not check electron beams, brachytherapy nor orthovoltage x-ray machines.

A hospital can request a number of TLD sets corresponding to the number of clinical photon beams used for teletherapy; not more than three beams will be checked in an irradiation run (irradiation window).

The IAEA/WHO TLD service is organized in 10 irradiation runs per year. Each participant is included in one of these irradiation runs; your country will be participating in the run scheduled on _____.

Your institution is now being contacted to discuss your participation in this irradiation run. Only those institutions that agreed on terms and conditions of the IAEA/WHO postal dose audit service will be provided with the TLDs.

At the same time as the participants, the IAEA Dosimetry Laboratory irradiates reference TLDs (2 Gy, Co-60 beam) for every beam in participating hospitals. Therefore the delays in irradiation by hospitals are not welcome.

In each irradiation run, two reference institutions, such as Primary Standard Dosimetry Laboratories and leading radiotherapy centres, irradiate TLDs with well defined doses to provide proper quality control of the process.

The TLDs irradiated by participants should arrive at the IAEA laboratory not later than 6 weeks after the irradiation, otherwise the hospitals will have to wait for their results due to queues to the TLD reader.

If an individual participant cannot irradiate the TLDs in the scheduled time window, he/she can still do this later. The "late" TLDs will be evaluated individually at a later date. The IAEA should be informed when the "late" participant intends to make the irradiation in order to prepare the reference TLDs.

The TLD results are sent to the participants within 1-4 weeks of receiving the irradiated TLDs at the IAEA, depending on a queue to the TLD reader. The participants receive individual result certificates for each beam checked with TLDs. The results within 5% limit are considered acceptable.

If the results are within the acceptance limit of 5%, the next participation is recommended within 2 years.

The institutions with the results outside the 5% acceptance limit are provided with a second, follow-up TLD for the immediate repetitive irradiation. If the second TLD result is still not acceptable, an expert visit is recommended to resolve the discrepancy.

The results of TLD audits are kept confidential by the IAEA/WHO staff and will not be disseminated without the written permission of the participating radiotherapy centre.

The TLD material sent to your institution represents a significant investment in cost, time and effort to the IAEA/WHO. Failure to return TLDs may be reported to your local authorities or to the Ministry of Health.

Individual requests (outside the irradiation windows) are accepted for the new installations, major repairs of the treatment units, Co-60 source replacements, unusual patient skin reactions and other important reasons. The requests can be made anytime and will be given the highest priority.

INTERNATIONAL ATOMIC ENERGY AGENCY

Dosimetry and Medical Radiation Physics Section Division of Human Health

THE IAEA/WHO NETWORK OF SSDLs CUSTOMER SATISFACTION SURVEY FORM

Please help us in our continuous improvement process by completing this form and returning it to us* as soon as possible.

How do you rate the following:	Excellent	Very Good	Good	Average	Poor	N/A
The quality of our calibration services?	<input type="checkbox"/>					
The appropriateness to your questions and concerns?	<input type="checkbox"/>					
The timeliness of IAEA response?	<input type="checkbox"/>					
The communication with IAEA staff in charge of calibration services?	<input type="checkbox"/>					
The quality of our auditing services?	<input type="checkbox"/>					
The communication with IAEA staff in charge of auditing services?	<input type="checkbox"/>					
Your overall level of satisfaction with our services?	<input type="checkbox"/>					

Additional comments:

To ensure anonymity of response, please do not provide any details on the respondent. If you would like us to follow up with you on a pending matter, please send us a separate e-mail to dosimetry@iaea.org.

**Please send the form (by e-mail, fax or post) to:*

Dosimetry and Medical Radiation Physics Section
International Atomic Energy Agency
Vienna International Centre
P.O. Box 100
A-1400 Vienna, Austria

Tel: +43 1 2600 21662
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E mail: dosimetry@iaea.org



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DIRAC

Directory of Radiotherapy Centres

The IAEA Directory of Radiotherapy Centres — DIRAC — is a web based database of radiotherapy infrastructure worldwide. DIRAC includes data on teletherapy machines, sources and devices used in brachytherapy, and equipment for dosimetry, imaging, patient dose calculation and quality assurance. These data are complemented with the numbers of radiation oncologists, medical physicists and radiation therapists working at the facilities.

To maintain high reliability, the database is updated continuously using questionnaires available from the IAEA. DIRAC is the only centralized database that describes the current capacity for the delivery of radiation therapy worldwide. This unique quality of DIRAC allows extraction of the information necessary for analysis of the status of radiotherapy and estimation of the need for facilities in various countries or regions, or worldwide.



www-naweb.iaea.org/nahu/dirac
dirac@iaea.org

Directory of Radiotherapy Centres

DIRAC

Since 1959, the International Atomic Energy Agency has maintained a register of hospitals and clinical institutions having radionuclide and high energy teletherapy machines, known as the Directory of Radiotherapy Centres (DIRAC).

The present electronic version of DIRAC contains data collected since 1995 and includes data related to teletherapy machines, sources and devices used in brachytherapy, and equipment for dosimetry, patient dose calculation and quality assurance. Staff strength at the facilities (radiation oncologists, medical physicists, and technologists) is also included.

So far, data have been collected from 159 countries for about 7000 radiotherapy centres with over 11000 teletherapy machines (Co-60 units and clinical accelerators) and about 2500 brachytherapy units. However, DIRAC is still an incomplete description of the worldwide status of radiotherapy infrastructure.

Recently, DIRAC has undergone substantial revisions and is being updated in order to make reliable data available to users worldwide via the IAEA web site at:

www-naweb.iaea.org/nahu/dirac

We therefore ask you for your assistance in verifying that the DIRAC data on the hospital infrastructure for your country is complete.

Both individual hospitals and national co-ordinators are most welcome to update their data on-line. You are also welcome to forward the DIRAC link to other hospitals in order for them to update their data.

If you are able to help us in updating the information, please use the link above and follow the instructions to log-in to the DIRAC database. A password is required, which will be generated by our system and sent to you by the IAEA DIRAC Operator.

Please check, correct and complete all data as they appear in DIRAC. Where relevant, please input new records for new installations or new hospitals. If a piece of equipment is no longer operational (e.g. it has been decommissioned), please do not delete it but select the option "non-operational" from the pull-down menu.

It is also possible to update the data off-line. Hospitals not at present in the database may download an empty Excel questionnaire from the web site. Those hospitals already in DIRAC may request the Excel questionnaire for updating by sending an email to DIRAC@iaea.org. The questionnaires should be returned to us, preferably by email.

Hard copies of the DIRAC questionnaire can be sent to those who cannot provide us with records electronically.

Your kind cooperation is appreciated.

Thank you.

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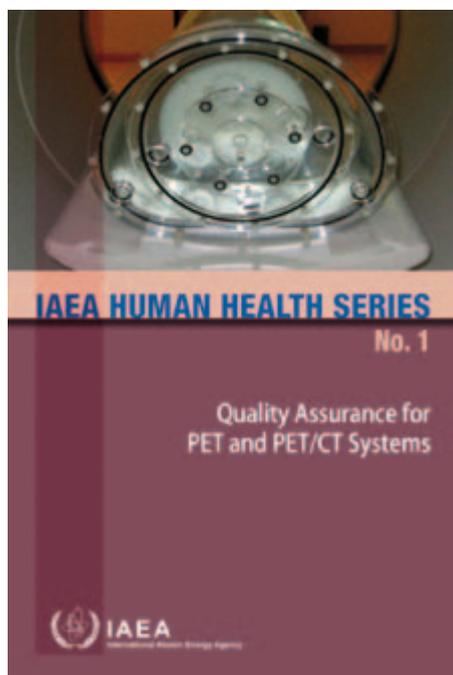
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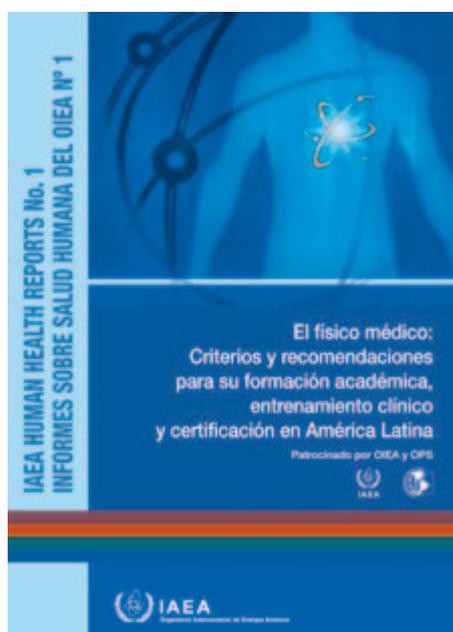
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