

# The IAEA/WHO TLD postal programme for radiotherapy hospitals

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## Abstract

**Background and purpose:** Since 1969 the International Atomic Energy Agency (IAEA), together with the World Health Organization (WHO), has performed postal TLD audits to verify the calibration of radiotherapy beams in developing countries.

**Materials and methods:** A number of changes have recently been implemented to improve the efficiency of the IAEA/WHO TLD programme. The IAEA has increased the number of participants and reduced significantly the total turn-around time to provide results to the hospitals within the shortest possible time following the TLD irradiations. The IAEA has established a regular follow-up programme for hospitals with results outside acceptance limits of  $\pm 5\%$ .

**Results:** The IAEA has, over 30 years, verified the calibration of more than 3300 clinical photon beams at approximately 1000 radiotherapy hospitals. Only 65% of those hospitals who receive TLDs for the first time have results within the acceptance limits, while more than 80% of the users that have benefited from a previous TLD audit are successful. The experience of the IAEA in TLD audits has been transferred to the national level. The IAEA offers a standardized TLD methodology, provides guidelines and gives technical back-up to the national TLD networks.

**Conclusion:** The unsatisfactory status of the dosimetry for radiotherapy, as noted in the past, is gradually improving; however, the dosimetry practices in many hospitals in developing countries need to be revised in order to reach adequate conformity to hospitals that perform modern radiotherapy in Europe, USA and Australia. © 2000 Elsevier Science Ireland Ltd. All rights reserved.

**Keywords:** QA in radiotherapy; TLD audits; Beam output checks; High energy photons

## 1. Introduction

In 1969 the International Atomic Energy Agency (IAEA), together with the World Health Organization (WHO), established the IAEA/WHO TLD postal programme to verify the calibration of radiotherapy beams in developing countries [1,6,23,26]. The main purpose of this programme is to provide an independent quality audit of the dose delivered by radiotherapy treatment machines using a thermoluminescence dosimeter (TLD) as transfer dosimeter. Since 1981 the TLD programme also monitors activities of the Secondary Standard Dosimetry Laboratories (SSDL) with the goal of achieving consistency in basic dosimetry throughout the world [2,13,27]. Originally the programme was developed for Co-60 therapy units and it was extended, in 1991, to high-energy photon beams produced by clinical accelerators. This programme has already been used for more than 3300 radiotherapy beams world-wide, and in many instances significant errors have been detected in the calibration of therapy beams, preventing further mistreatment of patients. It also provides support to various TLD-based

quality assurance national programmes established in developing countries with the assistance of the IAEA.

The TLD audits are implemented through a close collaboration between the IAEA and WHO (or Pan American Health Organisation, PAHO, in Latin America). The IAEA is responsible for the scientific and technical aspects of the programme, including the evaluation of the TLDs and resolving discrepancies detected, whereas WHO (or PAHO) coordinates distribution of the TLDs to radiotherapy hospitals.

The IAEA/WHO TLD programme is supported by the International Bureau of Weights and Measures (BIPM), Primary Standard Dosimetry Laboratories (PSDL), and some advanced radiotherapy centres. The programme includes activities conducted in co-operation with other international and national networks operating in Europe and North America, such as EQUAL (ESTRO Quality Assurance network), EC QA network (European Community Quality Assurance network within the programme 'Europe against Cancer'), EROPAQ (pan-European Radiation Oncology Programme for Assurance of Treatment Quality), EURAQA (pan-European Radiation Quality Assurance) and Radiation Physics Center (RPC) in Houston, TX [4,5,7–9,22,24]. These institutes exchange reference

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irradiations with the IAEA TLD programme, acting as a reciprocal external quality control of the experimental component of the programme.

The results obtained by the IAEA/WHO TLD postal dose audits for photon beams in different periods covering the years from 1969 to 1994 have been discussed in previously published papers [1,2,6,23,26,27]. Results are given in the present paper for the IAEA/WHO TLD programme up to 1999. The activities of the TLD programme including recent developments in laboratory procedures and in the operation of audits are described here.

## 2. The IAEA TLD system

The TL dosimeters used in the IAEA/WHO TLD programme are capsules filled with approximately 155 mg of annealed TLD powder. The IAEA standard capsule is a black polyethylene cylinder of 20 mm inner length, 3 mm inner diameter and 1 mm wall thickness. The outer length, including the plug, is 28 mm.

The TL material currently used is virgin lithium fluoride powder, LiF:Mg,Ti, type TLD-700, enriched in  $^7\text{Li}$  (99.96%  $^7\text{Li}$  and 0.04%  $^6\text{Li}$ ). The TL powder is annealed before it is used for dose measurements in order to optimize the LiF characteristics, and to achieve better stability of powder sensitivity and lower fading. The annealing is performed at 400°C for 1 h followed by fast cooling and subsequent annealing at 80°C for 24 h. Since the dosimetric characteristics of the LiF powder are closely related to its grain size and homogeneity, the powder is sifted after annealing to eliminate the smallest grains (below 80  $\mu\text{m}$ ). The good homogeneity of the powder allows the routine testing of only a small sample in order to determine radiation response characteristics representative for the whole manufacturer's lot. Before its use, the powder is stored for at least 2 weeks after annealing to stabilize its sensitivity.

Since 1998, a PCL3 TLD automatic reader (Fimel, France) has been routinely used in the IAEA for the measurements of TL dosimeters [18]. The PCL3 reader provides fast readings of a large number of TLD samples with a reproducibility of 0.3–0.5% (1 SD). Four readings per TL capsule are made.

Due to the automation of the TLD system and the development of computerized tools for dose calculation from the readings, the IAEA has substantially increased its capacity and almost doubled the annual number of TLD audits.

In order to determine the absorbed dose to water ( $D_w$ ) from the reading of TL-detectors, a calibration of the TLD system is performed and several correction factors and coefficients are applied. These correct for non-linearity in dose response, beam quality and TLD holder attenuation at that quality [21,25], and fading. The calibration characteristics are determined separately for each batch of powder. Samples taken from the same batch are considered to have the same fading, dose response, and energy dependence. In

the IAEA/WHO TLD programme, the fading correction is not relevant because the system calibration is performed at the same time as the irradiation of the dosimeters by the users. For this purpose, the irradiation windows are established. A detailed description of the calibration procedures is given in Ref. [18].

The combined standard uncertainty  $u_C$  [17] of the determination of the  $D_w$  from TLD measurements has two components: (i) the uncertainty of the calibration of the TLD system from the determination of the  $D_w$  using an ion chamber; and (ii) the uncertainty in the TLD procedure itself. The latter includes the uncertainty of the process of reading the TLD (corrected for daily fluctuations of the reader) and the uncertainties of the individual coefficients and correction factors mentioned above. The standard uncertainty of the TLD procedure (ii) is estimated to be 1.7%. It is mainly dominated by the uncertainty in the TLD non-linearity dose response and beam quality corrections. The uncertainty in the calibration of the TLD system (i) arises mainly from the uncertainty of the determination of the absorbed dose in reference conditions from the ionization chamber measurements,  $u(D_w)$ , using TRS-277 [12]. This increases the combined standard uncertainty of the entire TLD process  $u_C$  from 1.7 to 2.3%. It should be noticed, however, that when the same dosimetry protocol is used at a hospital or laboratory to determine the dose given to the TLD, most of its contribution in  $u(D_w)$  cancels out.

The IAEA maintains a strict internal quality control of the TLD system. The system calibration is verified at every reading session and the dose response and fading are verified at the commissioning of every new lot of powder. These are followed by an internal verification (self-test) of the reproducibility in dose determination with the TLDs, which is performed through a 'blind' TLD irradiation. The irradiation of TLDs for deriving the energy response at high energy photon beams is made by one of the reference radiotherapy centres for every batch of powder.

External verifications of the accuracy of the dose determination by the IAEA TLD system are also performed systematically for every TLD batch mailed to radiotherapy hospitals through reference irradiations by the BIPM, two PSDLs (BEV in Austria and PTB in Germany), three international TLD networks operating in Europe and USA (EQUAL/ESTRO – Villejuif, EURAQA – Leuven, RPC – Houston, TX) and two university hospitals with a recognized prestige in dosimetry.

## 3. The organization of the IAEA/WHO TLD audits

All radiotherapy hospitals in developing countries which are member states of the IAEA may participate in the TLD programme. A request is made through the WHO office in Geneva (or PAHO office in Washington for Latin America) which co-ordinates the distribution of TLDs among the

participants. The programme is also offered to all members of the IAEA/WHO SSDL network active in radiotherapy dosimetry. The IAEA/WHO TLD programme is cost free to all participants.

The TLD audits for hospitals are organized annually into eight irradiation runs. The number of beam checks per year have been increased from 100 to 200 in the past to about 300 at present due to automation of the TLD system [19].

The selection of hospitals to be included in the different TLD runs is the responsibility of the WHO (PAHO) through their country co-ordinators, who inform the IAEA when new radiotherapy facilities come into existence or when a facility discontinues its radiotherapy program. The continuous update of this information ensures that all interested radiotherapy facilities in a country are included in the TLD audit programme.

The dosimeters are sent to hospitals along with instructions and data sheets for Co-60 beams and high energy X-rays. These documents have been recently revised to ensure that the TLDs in a water phantom are irradiated in the same way as a patient is irradiated in normal clinical practice. It has been emphasized that the calculation of the dose delivered to the dosimeters must be made in the same way as for patient treatments; this is intended to reflect the clinical situation. The irradiation technique used can be either a source–skin distance (SSD) or an isocentric (SAD) technique, depending on the normal practice of the hospital. The TLD irradiation is to be performed either by medical personnel (treatment unit staff) or, if available, by a medical physicist. In addition to the technical explanations, the general information requested in the data sheets is such that the hospital staff are always able to complete the data sheets, even if problems with personnel or equipment are encountered. If the hospital has a physicist and dosimetry equipment available, an ion chamber measurement of the dose or the dose rate can be made following a TLD irradiation. A statement of confidentiality is included in the instructions. This assures the medical physicist and radiation oncologist that efforts are made to minimize the number of individuals with access to the TLD results. The IAEA TLD audit group, WHO (PAHO) country co-ordinator, local medical physicist and radiation oncologist, and (possibly) a follow-up expert, are the only ones aware of each individual hospital's TLD results.

When the irradiated TLDs arrive at the IAEA, they are analyzed and the doses are computed for each set. The results are sent to the participant within 1–3 weeks through WHO (PAHO) channels. Information is provided on the participant's stated dose, the IAEA TLD determined dose, the relative deviation and the ratio of the TLD determined to the participant's stated doses.

The acceptance limits of the IAEA/WHO TLD audits for hospitals are  $\pm 5\%$  and these define the maximum discrepancy between stated and measured doses which does not require any further investigation. These limits correspond approximately to the expanded standard uncertainty [17] of

the entire TLD system ( $u_C = 2.3\%$  and coverage factor  $k = 2$ ). The acceptance limits of  $\pm 5\%$  follow the 'classical' tolerance value given by ICRU Report 24 [15].

Prior to 1996, participants were informed of their deviation and outliers repeated a TLD irradiation in the next TLD run. It was noticed that on many occasions participants simply corrected the beam output by the number equivalent to the error detected, using the TLD as a remote calibration of their treatment machine. Since 1996, detailed follow-up procedures have been implemented. When the result of a participating centre falls outside the acceptance limits of  $\pm 5\%$ , the centre is requested first to try to identify the reasons for the deviation; it is not informed about the actual magnitude of the deviation (blind conditions) but is offered a second TLD check. If the deviation cannot be resolved remotely by the local radiotherapy centre or the national SSDLs, then an on-site visit is suggested which, if accepted, is made by an IAEA expert in clinical dosimetry. The on-site visit includes a review of the data and dosimetry techniques, corrective measurements and ad hoc training. The reasons for the deviation are then traced, explained, corrected and reported. New TLDs are sent to the hospital in the next cycle to confirm that the deviations do not reoccur.

#### 4. The operation of the IAEA/WHO TLD network for radiotherapy hospitals

In the period 1969–1998, 1003 hospitals in 101 countries in Africa, the Eastern Mediterranean, Europe, Latin America, South-East Asia and the Western Pacific participated in the IAEA/WHO TLD postal dose audit programme. At the beginning, the TLD programme was offered to both developing and developed countries. At present, the IAEA/WHO TLD programme is offered only to radiotherapy hospitals in developing countries for whom this is the only opportunity to participate in an external audit programme. The worldwide TLD-based QA networks for radiotherapy are shown in Fig. 1.

The distribution of the number of beams checked per region in 1969–1998 is shown in Fig. 2. Following the criteria of WHO (PAHO) to assign different priorities to different regions in the developing world, 38% of the beams were checked in Latin America and 2% in Africa. Most TLD audits in European countries were performed before 1987, and after 1996 have been reactivated to include countries of Eastern and Southeastern Europe, such as Armenia, Bosnia-Herzegovina, Estonia, Lithuania, FYR Macedonia, Ukraine and Yugoslavia. On two occasions (1992 and 1998), single TLD batches were distributed, on special request, to hospitals in Australia [10,11].

The participation frequency in the TLD programme is of special interest because of its strong relation to the results: 12% of the radiotherapy beams were checked only once,

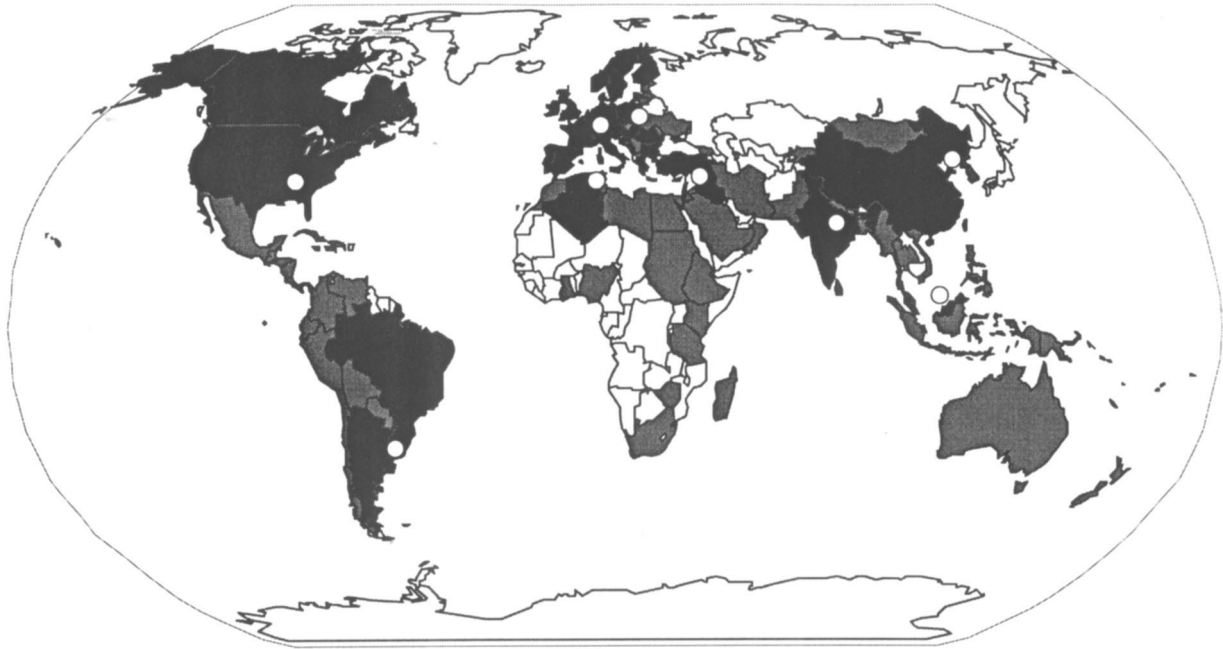


Fig. 1. The world-wide TLD-based quality assurance networks for radiotherapy. Countries marked in grey participate in the IAEA/WHO TLD postal dose audit programme. Countries marked in black have either their national TLD networks or participate in an international network other than the IAEA/WHO. White dots indicate TLD networks co-operating with the IAEA. Countries not coloured either do not have radiotherapy or do not participate in the existing TLD networks.

11% twice, and the remaining 77% beams three times or more in 1969–1998.

Before 1991, the IAEA/WHO TLD audits were provided only for Co-60 beams but since then, high energy X-ray beams from clinical accelerators have been included. The percentage of the TLD audits performed for high energy X-rays is 31%, which is roughly half of the audits made for Co-60 units (see Fig. 3). Most X-ray beams do not exceed 15 MV nominal accelerating potential.

The delay between the TLD irradiations by participants and the information on their results is approximately 1–3 months. The longest delay occurs during the collection of the irradiated TLDs by country co-ordinators and regional offices of WHO (PAHO). Close co-operation of the IAEA

with WHO (PAHO) has resulted in a systematic improvement in the return rate of irradiated TLDs from hospitals (see Fig. 4). At present, more than 90% of TLDs sent for irradiation return to the IAEA: all TLDs from some world regions, but only 60–70% from other regions. Some TLDs never reach hospitals, or when irradiated, are not returned to the IAEA for analysis due to problems with local post.

**5. Results of the TLD audits**

The global results of 3307 beam output checks performed by the IAEA/WHO TLD postal programme in 1969–1998 are shown in Fig. 5. They include 2906 results for Co-60 beams and 401 results for high energy X-rays. They are

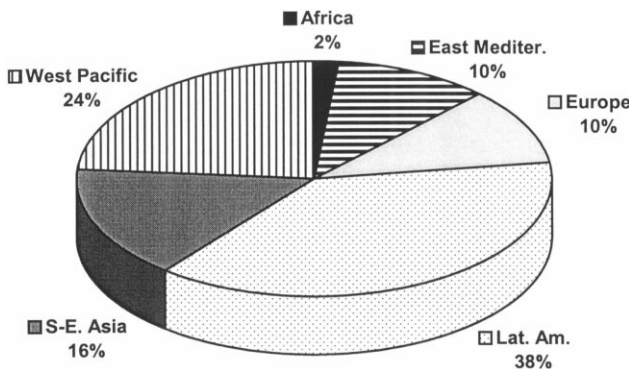


Fig. 2. The distribution of the percentage of beam checks in different regions in 1969–1998. The results pertain to 101 countries, 1003 hospitals in which 3307 beams were checked.

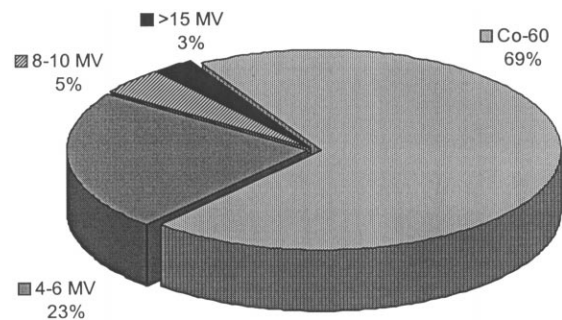


Fig. 3. Percentage of TLD audits for different photon beam qualities, Co-60 and high energy photons up to 25 MV, which were checked in 1991–1998, i.e. since the high energy X-rays were included in the TLD programme. The results pertain to 1338 beam checks.

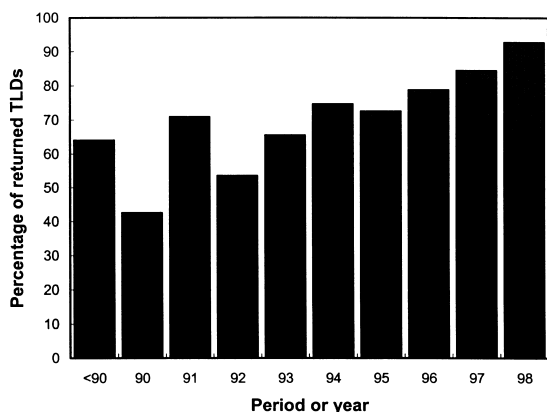


Fig. 4. Improvement in return rate from hospitals in the IAEA/WHO dosimetry programme.

expressed as ratios of the TLD measured (IAEA) to stated (user) doses,  $D_{TLD}/D_{stat}$ . Each value in the graph represents the average of three TL dosimeters (since 1998 the average is for two dosimeters). The mean of the distribution is 1.013 and the standard deviation is 8.8%. The deviations vary between a minimum  $D_{TLD}/D_{stat}$  ratio of 0.535 and a maximum of 2.188. Only 68% of the global results are within the acceptance limits of  $\pm 5\%$ .

During the last 3 years, the percentage of the deviations within the acceptance limits has increased to 81% (Fig. 6). All results outside the acceptance limits were followed up. Many participants improved their results in the follow-up irradiation (39% of results), but still 18% of the discrepancies persisted. Regrettably, 43% of the follow-up TLDs have not been returned to the IAEA for evaluation. The black dots in Fig. 6 indicate deviations which have not been corrected, due

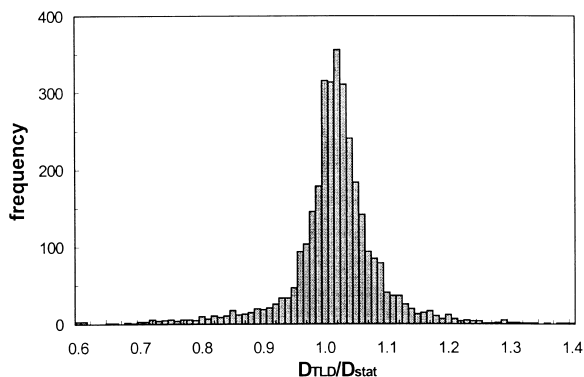


Fig. 5. Distribution of the results of the IAEA/WHO TLD postal dose audits of radiotherapy hospitals for the delivery of absorbed dose to water under reference conditions during 1969–1998. Data in the graph correspond to ratios of the IAEA’s determined dose ( $D_{TLD}$ ) relative to the dose stated by the hospital ( $D_{stat}$ ). Each data point corresponds to the average of three dosimeters (two after 1998). A total of 3307 beam calibrations were checked in 1003 hospitals. The mean distribution is 1.013 and the standard deviation is 8.8%. The deviations vary between a minimum  $D_{TLD}/D_{stat}$  ratio of 0.535 and a maximum of 2.188. Fifteen deviations outside  $\pm 40\%$  are not shown in the graph. Approximately 32% of the results are outside the  $\pm 5\%$  acceptance limits.

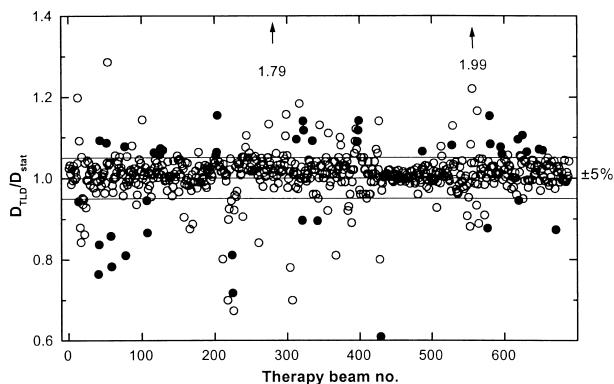


Fig. 6. Results of the IAEA/WHO TLD postal dose audits of radiotherapy hospitals for the delivery of absorbed dose to water under reference conditions during 1996–1998. Data in the graph correspond to ratios of the IAEA’s determined dose ( $D_{TLD}$ ) relative to the dose stated by the hospital ( $D_{stat}$ ). Each data point corresponds to the average of two dosimeters (three before 1998). A total of 688 beam calibrations were checked. Approximately 19% of the results were found outside the  $\pm 5\%$  acceptance level. The black dots indicate the deviations which have not been yet corrected in follow-up actions. The two extreme deviations have been explained and corrected:  $D_{TLD}/D_{stat} = 1.79$  was due to an accident in radiotherapy;  $D_{TLD}/D_{stat} = 1.99$  was due to double irradiation of the TLDs and had no clinical relevance.

either to a persistent discrepancy or to a failure to respond to efforts by the IAEA to help resolve the problem. The IAEA is in the process of establishing a mechanism to investigate and resolve the persistent TLD deviations and determine why some follow-up TLDs have never been returned for analysis. Until the discrepancies are resolved and changes have been implemented by hospitals to ensure that the deviations do not reoccur, the safe and effective delivery of radiation doses to patients is questionable.

In the last 3 years, 102 radiotherapy facilities in 92 hospitals, mainly from Eastern Europe and Asia, which had never been audited before, were included in the IAEA/WHO TLD programme. Only 65% of the results of a first participation are within the  $\pm 5\%$  limits. These results are consistent with those of the EC network [4,5] and EROPAQ [22]. The large discrepancies observed in some hospitals can be attributed mainly to insufficient professional training of the hospital staff, but also to obsolete radiotherapy machines and inappropriate dosimetry equipment. In old Co-60 units, for example, many errors were caused by irreproducible shutter functioning and difficulties with the measurement of the distance from the source.

An example of the results for hospitals in Latin America (Fig. 7) shows a clear improvement in the dosimetry practices in the region, whereas the results in Africa have not improved over the years (Table 1). The results for Latin America, where most hospitals have participated regularly in the programme, prove that the implementation of systematic quality audits improves the quality of radiotherapy dosimetry leading to an increase in the number of acceptable results from approximately 60% in the past to 84% in 1998.

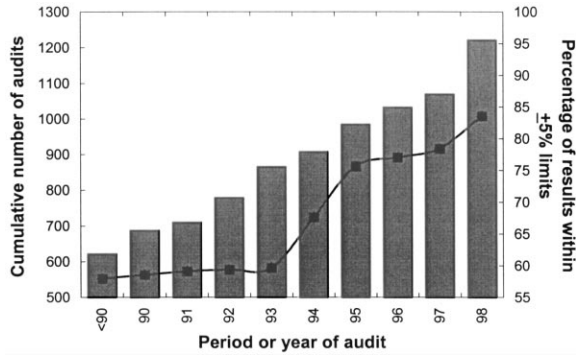


Fig. 7. The TLD results for Latin America and Caribbean region. The column bar graph shows the cumulative number of the beam audits in the region. The curve shows the percentage of beams checked in each period with the results within the  $\pm 5\%$  acceptance limit. The results pertain to 1221 beam checks in 1969–1998.

During recent years, not only has the return rate increased significantly but also the TLD results have improved. Data for 1996–1998 are compared in Fig. 8 with those obtained in 1969–1998. The data in Fig. 8a pertain to 3307 TLDs returned to the IAEA for analysis in 1969–1998 which corresponds to 64% of all TLDs distributed to hospitals; the remaining 36% could not be traced by the WHO (PAHO) country co-ordinators. In this period, only 2245 results were found to be within  $\pm 5\%$ , which corresponds to 68% of the evaluated TLDs. The data in Fig. 8b concern 688 TLDs evaluated in 1996–1998, which corresponds to 86% of the distributed TLDs. Eighty-one percent of the evaluated TLDs were within the acceptance limits, but the percentage of major deviations (outside  $\pm 10\%$ ) remained, regrettably, significant.

It should be noted that the poor TLD results do not always reflect errors in the beam output routinely used in clinics. It has been observed that sometimes mistakes in the calculation of the dose given to the TLD or in the geometry set-up for the TLD irradiation have no direct impact on patient treatments. This occurs when TLDs are irradiated with doses of no clinical relevance. Unfortunately, in several instances large TLD deviations have confirmed clinical

Table 1  
Percentage of beams checked in Africa in 1969–1998 with results within the  $\pm 5\%$  acceptance limit

Year	% of successful checks
$\le 1990$	58
1991	67
1992	80
1993	86
1994	73
1995	65
1996	78
1997	69
1998	88
Average	65

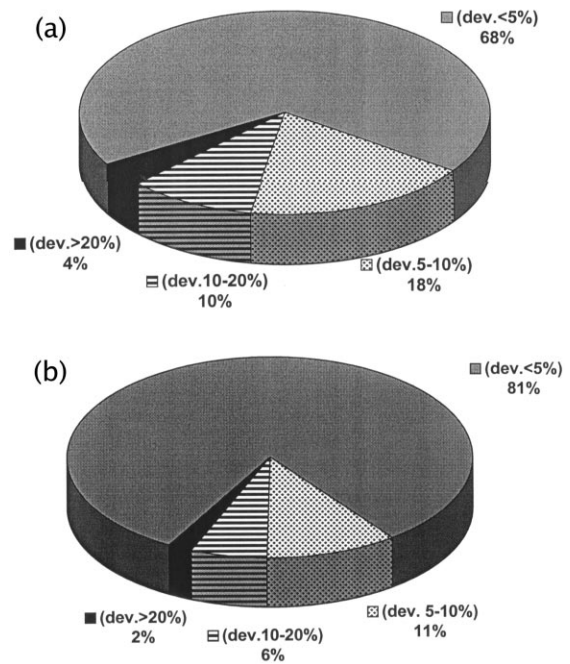


Fig. 8. The percentage of results of beam audits within  $\pm 5\%$ , 5–10%, 10–20% and outside 20%. The upper pie chart (a) shows the results for 1969–1998 and the lower one (b) shows the results for 1996–1998. The results within  $\pm 5\%$  correspond to the required level for ‘acceptable radiotherapy treatment’ [15]. The results within 5–10% limits are considered within the ‘tolerable’ category, whereas for the results within 10–20% benefit from the radiation treatment is questionable; the results showing discrepancies larger than 20% might be considered accidents in radiotherapy.

observations of deficient dosimetry practices in hospitals, or even registered accidents in radiotherapy, such as the overexposure of patients in Costa Rica in 1996 [20] where during 1 month more than 100 patients were given almost twice as high a dose as prescribed. On the other hand, a patient under-dosage, which leads to the decrease in the local tumour control rate and jeopardizes the success of radiotherapy treatment [16], cannot be detected by clinical observation for several years; therefore, the TLD audit is a very useful tool to recognize and correct the problem.

From the analysis of the TLD data sheets and discussions with local physicists, staff from SSDLs and follow-up experts, the IAEA was able to identify the most frequent reasons for discrepancies in the audits.

Large errors are usually caused by an incorrect calculation of the dose at the position of the TLD. The dose is calculated as if the TLD is located at the depth of dose maximum, e.g. 5 mm for Co-60 (10  $\times$  10 cm field, 80 cm SSD) and not at 5 cm, where the TLD capsules are placed for irradiation. Therefore, the stated dose should be decreased by the factor equivalent to the attenuation of the beam by 4.5 cm of water (typically 0.785 for Co-60). This type of mistake yields a discrepancy in the stated and measured doses of 15–23%, depending on the quality of photon beams.

Errors of 10–13% in the beam calibration have recently

been observed in a rather systematic way. They were caused by a misinterpretation of the calibration coefficient of a dosimeter provided by a calibration laboratory. Hospitals are accustomed to the  $N_K$  air kerma calibration coefficient, from which they derive the  $N_{D,air}$  absorbed dose to air chamber factor (this factor was called  $N_D$  in TRS-277 [12] but the subscript 'air' was added in TRS-381 [14] to specify without ambiguity that it refers to the air in the chamber). The present trend of disseminating the  $N_{D,w}$  calibrations has been implemented prematurely in some developing countries by calibration laboratories providing hospitals with the  $N_{D,w}$  calibrations [3] without a proper explanation of their use. The  $N_{D,w}$  and  $N_{D,air}$  factors differ by the water to air stopping power ratio (1.133 for Co-60), resulting in an error of approximately 10–13%, depending on the photon beam quality.

Another common mistake is caused by the incorrect use of temperature and pressure corrections derived from chamber readings in a Sr-90 reference check source. Some electrometers automatically adjust their sensitivity according to the readings of the chamber inserted in the Sr-90 source. These readings, when corrected for the Sr-90 decay, depend only on the actual temperature in the source and the air pressure. An error is introduced when the temperature of water in a phantom differs significantly from the air temperature in the Sr-90 source.

These mistakes, and many others, indicate that the biggest problem in hospitals in developing countries is the insufficient training of staff in dosimetry. In several centres, there are no medical physicists; in others, due to the large rotation of staff, inexperienced physicists are recruited. In most such centres, the calibration – if any – of treatment machines is irregular. In an extreme case, the Co-60 beam output had not been measured for about 10 years; instead, it was calculated from the source activity given in the certificate by the manufacturer.

To enable hospitals in developing countries to have better access to external quality audit programmes, the IAEA promotes the setting up of national TLD-based quality audit networks. Guidelines have been prepared for setting up national TLD networks to apply the IAEA TLD methodology on a national level, including measurement procedures, organization of the network and analysis of hospital data. Four countries (China, India, Argentina, and Algeria) have already established TLD programmes with a formal link to the IAEA in order to audit hospitals on a national level; three other countries (Czech Republic, Israel, and Malaysia) are in the process of establishing national QA programmes.

## 6. Conclusion

The IAEA/WHO TLD postal programme for monitoring the calibration of radiation therapy beams at hospitals world-wide has been strengthened with new procedures

and equipment that improve the overall efficiency of the programme. The IAEA/WHO have been able to significantly reduce the total turn-around time for the postal TLD, partly through in-house improvements at the IAEA, but principally through efforts in dissemination of the postal packs, co-ordinated by WHO (PAHO). During recent years, the return rate for the TLD has increased significantly (to 90% in 1998) due to the joint efforts of WHO (PAHO) and the IAEA.

The significance for a hospital to participate regularly in external audits to reach and maintain an adequate level of dosimetry has been observed. Typically, only 65% of the hospitals that receive TLD for the first time have results within the acceptance limits ( $\pm 5\%$ ), while 81% of the institutions participating regularly in the audits have results within the  $\pm 5\%$  limits.

For the results outside the  $\pm 5\%$  acceptance limits, the IAEA has established a follow-up programme, contacting the hospital either directly or through WHO (PAHO). All hospitals with poor results are contacted but many have not yet responded to efforts by the IAEA to help them identify and resolve the problems. The efforts on follow-up of TLD deviations will be pursued for those hospitals still outside the acceptance limits.

Following the positive feedback to IAEA assistance in setting up national TLD programmes for quality assurance in radiotherapy on a national level, further countries will be assisted in starting their national activities.

Due to the support given to hospitals by the IAEA in cooperation with WHO (PAHO) and the local SSDLs in developing countries, the unsatisfactory status of the dosimetry for radiotherapy, as noted in the past [23,26,27], is gradually improving; however, the dosimetry practices in many hospitals in developing countries need to be revised in order to reach adequate conformity to hospitals that perform modern radiotherapy in Europe, USA and Australia [7–11].

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