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The results of the TLD postal dosimetry audits in radiotherapy centres in Poland (period 1991-2001)

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Introduction. The paper presents the results of a survey conducted by the Polish Secondary Standard Dosimetry Laboratory (SSDL) designed to evaluate the development of dosimetry audits in teleradiotherapy in Poland.
Material and methods. In the years 1991-2001, 151 audits, based on TLD (thermoluminescence detectors) dose intercomparisons were performed. The participants of the audits were requested to irradiate TL detectors, delivered by the SSDL, to a predefined dose. The dose was determined with an ionisation chamber in reference conditions. Simultaneously the SSDL irradiated the TL detectors, with their signal serving as reference.
Results. Deviations exceeding 3.5% (i.e. the acceptance level) were found in 18 cases (nearly 12%). They were analysed and discussed with the audited participants. It was stated that in 2 cases the errors in dosimetry resulted in over- or underdosage of a number of patients. In four centres, participating in every audit, the authors detected no deviations exceeding the acceptance level, and in the last run of the audits (electron beams, 2001) all deviations remained below the acceptance level.
Conclusions. The results suggest that it is possible to maintain a high standard of measurements with the ionisation chamber in reference conditions in all centres. The audit programme should be extended to non-standard conditions.

Wyniki auditów dozymetrycznych przeprowadzanych wysyłkową metodą TLD w ośrodkach radioterapii w Polsce (okres 1991-2001)

Wprowadzenie. Przedstawiono wyniki działalności polskiego Laboratorium Wtórnych Wzorców Dozymetrycznych (LWWD), mającej na celu rozwój auditów dozymetrycznych w teleradioterapii w Polsce.
Materiał i metody. W latach 1991-2001 przeprowadzono 151 auditów, opartych na porównawczych pomiarach dawek metodą TLD (detektorów termoluminescencyjnych). Uczestnicy auditów byli proszeni o napromienienie detektorów TL, dostarczonych przez LWWD, określoną dawką. Dawka była wyznaczana za pomocą komory jonizacyjnej w warunkach referencyjnych. W tym samym czasie LWWD napromieniło detektory TL, których sygnał był wielkości odniesienia.
Wyniki. Odchylenia przekraczające 3,5% (przyjęte jako poziom dopuszczalny) stwierdzono w 18 przypadkach (ok.12%). Były one analizowane i dyskutowane z uczestnikami auditu. W 2 przypadkach stwierdzono podanie pewnej liczbie pacjentów zbyt dużej lub zbyt małej dawki w wyniku błędu dozymetrycznego. W czterech ośrodkach, uczestniczących we wszystkich auditach, nie stwierdzono przekroczenia poziomu dopuszczalnego, a ponadto w ostatnim cyklu auditów (wiązki elektronowe, 2001) wszystkie odchylenia miały wartość poniżej dopuszczalnego poziomu.
Wnioski. Wyniki pozwalają żywić nadzieję, że zachowanie wysokich standardów pomiarów komorą jonizacyjną w warunkach referencyjnych, jest możliwe we wszystkich ośrodkach. Zasugerowano celowość prowadzenia dalszych auditów, również w warunkach niestandardowych.

Key words: radiotherapy, dosimetry, quality assurance, audit
Słowa kluczowe: radioterapia, dozymetria, zapewnienie jakości, audit

Introduction

At the International Conference on Radiological Protection of Patients in Diagnostic and Interventional Radiology, Nuclear Medicine and Radiotherapy, held in Malaga in April 2001, some authors expressed the opinion that the system of radiation protection should not be used with reference to radiotherapy patients. The patient undergoing radiotherapy procedures, as prescribed by

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the medical practitioner, is protected by the quality assurance system legally required for medical exposures [1].

Truly, the objective of radiotherapy is to ensure that the target volume is given the prescribed dose, while the dose to surrounding healthy tissues and critical organs is minimal. The success or failure of radiotherapy depends upon the accuracy of dose delivery. The accuracy of dose delivery, which is a complex procedure (from determination of the doses, through localisation of the tumour and treatment planning, to the irradiation of the patient) depends on many factors, and is a major problem in radiation therapy. It requires elaboration of complex methodology, a definition of acceptable tolerance levels for individual parameters, which contribute to the cumulative effect of radiotherapy procedures, and organisation of external audits. A detailed quality assurance system in radiotherapy is presently required by international and national recommendations [2-4]. It has been widely recognised that the audit of beam calibration (determination of the doses in reference conditions) is a key factor in reducing overall uncertainty of the radiotherapy chain, and that metrology institutions, such as the Secondary Standard Dosimetry Laboratories (SSDL) are usually competent in such activity [5, 6].

In Poland, in 1966 a SSDL was established at the Medical Physics Department (MPD) of the Institute of Oncology. In 1988, the Laboratory was approved as a member of the IAEA/WHO network of SSDLs. This SSDL has been supported by the IAEA in the framework of the research contracts and technical assistance, and has also been regularly audited by the IAEA. The SSDL plays an important role in supervision of the dosimetry procedures.

The main activities of the SSDL are:

- collecting data concerning the infrastructure of radiotherapy in Poland,
- calibration of dosimeters from all radiotherapy centres in Poland,
- external postal quality audits of dosimetry in radiotherapy centres in Poland,
- preparation of protocols and recommendations on dosimetry in radiotherapy,
- training of physicists and radiotherapists in order to adhere to the increasing complexity of modern radiotherapy procedures.

As far as the external dosimetry quality audits in radiotherapy are concerned, the first study of TLD postal dose inter-comparison in Poland was organised by the SSDL in 1991 (supported by the IAEA, research contract no 6013/RB). In 1994, the Polish SSDL joined the *pan-European Radiation Oncology Project for Assurance of Treatment Quality* (EROPAQ). The SSDL participated in the organisation of the EROPAQ, taking responsibilities for the organisation of the audit in Poland, clearing up the deviations of the results beyond acceptable levels, undertaking corrective actions, and helping to remeasure and recalculate the doses when necessary. In 1999, the SSDL organised a third postal dose inter-comparison program for radiotherapy centres in Poland (supported by the IAEA, research contract no 10796/RO). In 2001 the fourth study started (supported by the IAEA, research contract 11018/RO). In all these investigations, described in this paper, the doses were determined with ionisation chamber measurements in reference conditions.

In 2000, a special body, the External Audit Group – EAG (for radiotherapy) was set up at the Medical Physics Department, as suggested by the IAEA [7, 8]. The EAG, apart from SSDL representatives, includes medical physicists, and a radiation oncologist, as it has been noticed that to gain wide acceptance and collaboration of the medical centres, it is essential to obtain the approval of the medical community. The EAG-radiation oncologist is to be informed of all confirmed major deviations in dose evaluation and is responsible for notifying the radiation oncologist from the audited centre.

The major deviations are defined by the international bodies (IAEA, ESTRO) as such, that might have a significant negative impact on patient treatment, while the minor (intermediate) deviations as those, which occurr beyond the upper limit of acceptable deviations and below the threshold for major deviations. The acceptance limits define the maximum acceptable discrepancies between the doses stated by the audited participating centre and the doses measured at the Measuring Laboratory (in our case – the SSDL). These discrepancies do not require any further investigations, since there is a high probability that the deviations are caused by the uncertainty in the audit procedure, rather than in the statement of the dose by the participant [9, 10]. The acceptance limits of the IAEA/WHO audits for hospitals are ±5%. These limits are slightly higher than the entire TLD expanded standard uncertainty (σ=2,3% and coverage factor k=2) [3, 11]. The acceptance limit of ±5% follows the „classical" tolerance value given by the ICRU Report 24 [12]. The European Organisation for Research and Treatment of Cancer (EORTC), throughout wide investigation covering 357 beams, set an acceptable level of ±4.0% [13]. The same level was adopted in a national Swiss investigation [13]. The European Quality Assurance Network for external radiotherapy defined the acceptance level corresponding to a deviation <3%, and the action (intervention) level corresponding to a deviation >6% (i.e. twice the acceptance level) [15].

The acceptance level used in this study (being also an intervention level) remains consistent with the IAEA-audits of the SSDLs, in which the deviations of ±3.5% are considered acceptable [11]. The Polish SSDL picked an intervention level as low as ±3.5%, which was possible due to the small number of radiotherapy centres and easy contact with them.

This paper summarises our studies performed during the years 1991-2001. They were aimed at testing the accuracy and consistency of basic dosimetry – calibration of radiotherapy beams with an ionisation chamber, in reference conditions. Subsequent steps will cover dosimetry checks of radiation beams in more complicated

situations, called non-standard conditions (e.g. including the estimation of the dose by the radiotherapy treatment planning systems, measurements outside the central axis, MLC fields etc.) in which additional errors may originate.

Material and methods

The participation in the audits was voluntary, but a majority of centres (70-100% in particular runs) agreed to co-operate. In order to keep all results confidential each participating centre was identified by a code number.

The determination of the beam output in gamma beams of Co-60 units, X-ray and electron beams of linear accelerators were checked in the listed investigations. The number of audits performed and the percentage of audited centres from among those which possessed functioning megavoltage unit at the time of audits are presented in Table I. As can be seen from our data a total of three TLD runs for Co-60 units, three for high energy X-rays, and two TLD runs for electron beams were performed. In the years 1994-1995 and in 2001 some centres took part in the audit twice, or checked more than one beam.

Each radiotherapy centre taking part in the audit was provided with:

- four waterproof perspex capsules filled with lithium fluoride thermoluminescent virgin powder. LiF powder type MT-F (Polish production – Institute of Nuclear Physics, Cracow) was used in the first, third and fourth run, LiF powder type PTL 717 (French production – Desmarquest CEC) – in the second run. Each TLD capsule contained an amount of powder sufficient for 10 independent readings;
- a perspex holder stand, designed and provided by the IAEA, in which TLD capsules were placed for irradiation;
- an information sheet describing the irradiation procedure;
- a data sheet for reporting the specifications of the treatment unit and measuring instruments, the method used for absorbed dose to water determination, coefficients and factors applied, results of dose measurements, and the details concerning the irradiation of TLD capsules. This data allowed to check whether the dosimetry protocol was properly followed, and to detect possible errors in dose calculations.

In each investigation the participants were asked to check the beam output with their dosimeters, and to irradiate the TLD capsules in sequence, in water phantom, in reference conditions (using the IAEA perspex holder), to an absorbed dose as close as possible to 2 Gy. One capsule served as a background record.

At nearly the same time (within 10 days interval), the SSDL (Measuring Centre of EROPAQ in the second run) irradiated the TLD capsules, the signal of which served as the reference. In the first, third, and fourth runs the TLD readings were evaluated at the Polish SSDL (with a Harshaw TLD reader), in the second one, at the EROPAQ Measuring Centre in Leuven (with a PCL3-Fimel TLD reader). To evaluate the absorbed dose to water from irradiated TL-detectors, several correction parameters were investigated and determined (reader's daily fluctuations, distribution of TL-detectors response, fading, dependence of TL-detectors response on the heating rate, dose and energy), and combined uncertainty in dose calculations determined [16, 17]. The absorbed dose to water was calculated on the basis of the ionisation chamber measurements (at the point of the centre of a TLD capsule), in the water phantom, according to the IAEA TRS 277 dosimetry protocol [18]. The details on measurement methods were described in earlier publications [16, 17, 19-21].

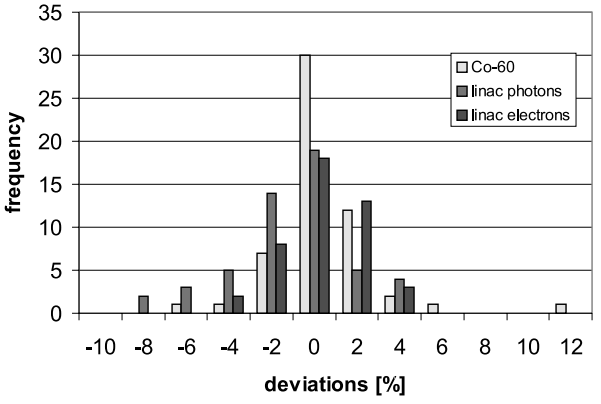

Fig. 1. Cumulated distribution of the deviations recorded during the TLD dosimetry audits in Poland in 1991-2001 (absorbed dose determination with an ionization chamber in reference conditions)

The deviation of the dose reported by the participant and the dose measured by the SSDL were calculated according to the formula:

$$\text{Dev}\ (\%) = 100\ (D_p - D_{SSDL}) / D_{SSDL} \quad (1)$$

where D_{SSDL} is the dose determined by the SSDL (or EROPAQ Measuring Centre).
D_P is the dose reported by the participant.

Results and Discussion

Figure 1 and Table II presents all deviations, calculated according to the formula [1]. The deviations exceeding the acceptable level of 3.5% are marked in bold. The empty fields indicate that the particular centre did not take part in the investigation, or had no megavoltage units installed at that time. If the results were beyond the acceptance level the representative of the SSDL contacted the physicists from the participating centres in order to try to identify the origins of the discrepancies, and to help to solve problems or difficulties. It was frequently possible to

Table I. The number of TLD dosimetry audits in radiotherapy centers in Poland held between 1991 and 2001 (absorbed dose determination with an ionization chamber in reference conditions)

Years	Number of audits		
	Co-60 photons	Linac photons	Linac electrons
1991-1993	11 (70%)	11 (70%)	12 (80%)
1994-1995	32 (100%)	24 (100%)	–
1999-2000	12 (70%)	17 (90%)	–
2001	–	–	32 (100%)
Total	55	52	44

The percentage of audited centers from among those, which possessed functioning a megavoltage unit at the time of audits is given in brackets.

Table II. Results of the TLD dosimetry audits in radiotherapy centers in Poland in 1991-2001
The numbers indicate deviations in percent, according to formula /1/
(absorbed dose determination with an ionization chamber in reference conditions)

Centre	SSDL Co-60_91	SSDL X_92	SSDL e_93	EROPAQ Co-60_94/95				EROPAQ X_94/95			SSDL Co-60_99	SSDL X_2000	SSDL e_2001	
				Deviations [%]										
I	1.0	0.8	1.0	-0.8	1.8			-1.7	-1.7			0.1	-0.3	
II	0.4	-2.6	-2.5	1.4	2.2			-2.5	-0.1	-0.1	-0.9		1.6	1.7
III		**-7.2**	-0.5	-1.6				1.7				0.7	-0.7	1.9
IV	1.5	0.9	**-4.9**	-0.4				**4.7**				-1.0	-0.6	0.0
V	-0.7	**-6.4**	-2.1	-2.6	1.6			0.9			-1.3	**-5.5**		
VI	**12.1**		-2.9	0.2	0.5			0.1			0.2	-0.2	2.2	-2.2
VII	2.5	-0.6	2.0	-0.1				-1.7			-0.9	**-7.0**	-1.5	
VIII		**4.1**						**-5.0**				-0.3	0.2	2.3
IX	0.4	-3.5	**-3.8**	-0.5				-2.3				**-4.2**	-2.9	0.9
X	0.9	-1.0	1.8	0.7	1.0	2.2		-1.8	-0.8	-0.3	0.0	2.4	-1.5	-1.4
XI	-0.5	-0.6	2.0	-1.2	-0.4	-0.1	0.3	**-4.5**			-0.1	-0.1	-0.6	3.1
XII	**-5.0**	-3.2	0.0	0.4	3.1	**5.7**		-0.3	**4.8**		-1.2	2.9	0.7	2.7
XIII	-1.5		**4.7**	0.1	1.8			**4.2**			1.5	-1.1	3.4	-0.6
XIV				-3.4	1.3			**-4.9**			0.3	-2.5	0.0	2.9
XV											0.3	-1.3	0.9	0.8
XVI				-2.8							**4.3**			
XVII				2.3							-0.3			
XVIII				0.3	1.0			0.1				-2.4	2.0	-0.5
XIX				-0.7	1.1			-0.9	0.2	1.9				
XX												2.0	-0.8	1.2
XXI												1.7	-0.2	2.9

Table III. Explanation of the discrepancies occurring during the TLD dosimetry audits in Poland between 1991-2001
(absorbed dose determination with an ionization chamber in reference conditions)

Centre	Beam	Deviation	Explanation
III	X	-7.2	Wrong positioning of the TLDs
IV	e	-4.9	Unexplained
	X	4.7	Unexplained
V	X	-6.4	Wrong positioning of the TLDs
	X	-5.5	Unexplained
VI	Co-60	12.1	Exposure coefficient N_x instead of absorbed dose coefficient N_D was used; some calculation errors
VII	X	-7.0	Measurements and calculations performed by an inexperienced physicist
VIII	X	4.1	Unexplained
	X	-5.0	Unexplained
IX	e	-3.8	Unexplained
	X	-4.2	Unexplained
XI	X	-4.5	Unstable beam, reported to the SSDL
XII	Co-60	-5.0	Wrong indication of the telemeter
	Co-60	5.7	Error in multiplication of the coefficients
	X	4.8	Unstable beam but also some calculation errors
XIII	e	4.7	Many errors: the physicist made a large error (19%) in chamber perturbation correction factor; a value for a diameter was used as the value for chamber radius. There were also other mistakes: in the applied value of stopping powerwater-to-air ratio, in the applied value of the displacement of the effective point of measurement, calculation errors. Luckily, the other errors in combination with 19% error cancelled off giving as a result the error of 4.7%.
	X	4.2	The ionization chamber measurements performed in the polystyrene phantom at the depth different than the correct reference depth
XIV	X	-4.9	Increase of calibration coefficient by 3.9% since the last chamber calibration (not controlled by the physicist with the Sr-90 source) and the use of a wrong value of the perturbation factor
XVI	Co-60	4.3	Unexplained

In all cases of unexplained deviations the measurements were repeated

solve the problem over a telephone conversation, however if considered necessary, the physicist from the SSDL visited the participating centre to verify the measurements using a SSDL dosimeter with an ionisation chamber.

Table III presents explanations of the discrepancies found during the audits, as discussed with the participants, and analysed by the SSDL.

There is no doubt that in 10 cases the discrepancies were caused by lack of experience of the physicist or by his/her mistakes. Among 8 unexplained deviations, 7 concerned the beams of the Neptun accelerators. The participants complained about the instability of these machines. This explanation is probable, especially if the beam output was not measured immediately before the TLD irradiation. In those cases where a logical explanation of discrepancies could not be found the measurements were repeated. In some other cases the reported data sheets revealed not only deviations exceeding the acceptance level, but also calculation errors, mistakes in reading the coefficients from the data in the dosimetry protocol, and lack of full understanding of the protocol. Luckily, some of the errors cancelled off each other. All these errors and misinterpretations were discussed with the participants, explained and corrected. In case of three centres (I, II, X, in Tab. III), participating in all the audits, we detected no deviations beyond the acceptance level. In the case of centre XI (deviation of 4.5%), the physicist irradiated the capsules being aware of the beam instability and reporting this to the SSDL (the treatments were stopped). The results from these four centres confirm their high standards in dosimetry and quality assurance. The results of the latest run (2001) give hope that such high standards may be maintained in all centres.

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 doubt that deviations of 12.1% and -5.0% (first audit of Co-60 units in centres VI and XII respectively) did not influence the patients. In both cases the mistakes were made during the audit. In the first case, however the physicist did not compare the output used for patient treatment with that reported in the TLD data sheet. It was also stated that in two cases the errors in dosimetry resulted in over or underdosage of the patients. In the case of centre XII (a deviation of 5.7%), the error was reproduced in the output used for patient treatments: 78 patients were underdosed for about one month. In the case of centre XIV (a deviation of 4.9%) the patients were overdosed for about two years.

Conclusions

1. The establishment of a voluntary, TLD based postal audit system for dosimetry in radiotherapy has proved to be effective in assuring the quality of dose determination in radiotherapy.
2. The results of the study demonstrate that it is possible to keep the dose determination (using an ionisation chamber in reference geometry) within acceptance limits by implementation of correct methodology and carefully carried-out measurements and calculations of doses.
3. A detailed data sheet allows to evaluate the impact of procedural errors on the final results, and should be introduced in every kind of a TLD postal audit.
4. The audits should be extended to non-standard conditions, especially such, in which the dose is also determined by the treatment planning system (TPS).
5. The experience gained from these investigations indicates that there is a need for physicists employed in radiotherapy centres to undergo continuous training in dosimetry.

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