ELSEVIER

Radiotherapy and Oncology 55 (2000) 273–284

RADIOTHERAPY & ONCOLOGY
JOURNAL OF THE EUROPEAN SOCIETY FOR THERAPEUTIC RADIOLOGY AND ONCOLOGY

www.elsevier.com/locate/radonline

The ESTRO-QUALity assurance network (EQUAL)

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Received 15 March 1999; received in revised form 25 June 1999; accepted 6 July 1999

Abstract

Background and purpose: ESTRO has set up a Quality Assurance network (EQUAL) to check the dose delivered on axis in reference and non-reference conditions for external radiotherapy. The external audits covered by the network are based on measurements made with mailed thermoluminescent dosimeters (TLD).

Material and methods: The TLD consist of LiF powder type DTL 937 read with a PCL 3 automatic TLD reader. The participating centres are instructed to deliver to the TLDs absorbed doses of 2 Gy calculated with the Treatment Planning System used in clinical routine. A maximum of three photon energies by participating centre have been checked with 10 on-axis points per beam. The quantities checked include the reference beam output, beam output variation with collimator opening, depth dose data and wedge transmission factor.

Results: During the 1998 EQUAL programme 102 centres have been checked corresponding to 235 beams (28 ^{60}Co beams and 207 X-ray beams). About 3% of the outputs in reference conditions show deviations outside tolerance level ($> \pm 5\%$). A similar rate of deviation is noted for the percentage depth doses. A rate of deviation (6%) has been observed for the beam output variation (open and wedged beams) and the wedge transmission factor. The analysis of the results shows that for 24 out of the 102 centres, a deviation outside tolerance level is observed at least in one point, mainly for the large and rectangular field sizes and for the wedged beams.

Conclusions: The results for the EQUAL programme show the importance of a quality assurance network in Radiotherapy especially for the non reference points even if they are only located on the beam axis (In order to participate in this network, please contact EQUAL secretariat or download the attached application form ESTRO web site: Dr I.H. Ferreira or Mrs Aline Mechet, EQUAL-ESTRO, Physics Department, Institut Gustave-Roussy 39 Rue Camille Desmoulins, F-94805 Villejuif Cedex, France. e-mail:equal@igr.fr or http://www.estro.be/). © 2000 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Quality assurance network; Dosimetry intercomparison; Mailed dosimeters; Thermoluminescent dosimeters

1. Introduction

External audits on dose in reference conditions have been proposed for many years by several organisations [7,8,17–19]. For 1991, a few programmes on Quality Assurance networks have been sponsored by the European Union Committee 'Europe against Cancer', on external audits by mailed dosimetry [7]. The first projects were based on the IAEA/WHO experience [17] on mailed dosimetry, and covered the check of beam output and quality in reference conditions with a mailed TLD procedure [4]. The feasibility and the relevance of such a programme have been clearly demonstrated [6]: in the Centres having benefited from an external audit during the past 5 years, no large deviation was observed, as opposed to a 17% rate of large deviations in the other centres. In addition, the standard deviation and the incidence of major discrepancies of results decreases in repeated intercomparisons [13]

During the following years these projects were extended to measurements in non-reference conditions with multipurpose phantoms including either TLD [3], ionisation chamber [14] or TLD and films [15]. The pilot studies [3] showed a significant increase in the number of large deviations for measurements in non-reference conditions, both for on axis and off-axis points.

In the minutes of the ESTRO board meeting in Vienna 1996, it can be read 'since they (i.e. the dose QA programmes) will expire in 1997, professor van der Schueren asked the Board if they would accept to support the continuity of these programmes by integrating them into a structure of ESTRO'. The board agreed and funded the

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0167-8140/00/$ - see front matter
PII: S0167-8140(99)00101-2

ESTRO-QUALity assurance network (EQUAL) at the end of 1997.

The ESTRO board had the opinion that it was time for the European radiotherapy centres to extend the external audits to dose checks in non reference conditions. The EQUAL scientific committee reviewed the various phantoms which have been designed and tested for mailed dosimetry during the past years. All these phantoms present the disadvantage of high manufacturing cost, significant mailing expenses because of their weight and/or bulk, as well as a high workload for the measuring laboratory, because of the large number of detectors used. As the ESTRO board requested EQUAL to provide external audits for the largest possible number of centres, the scientific committee had to face the necessity to increase the number of parameters checked without increasing too much the workload. That is why the committee has decided to limit the measurements performed to on-axis points and during the first phase exclude electrons beams.

The present paper reports the first year's experience of EQUAL.

1.1. EQUAL organisation

A formal co-operation between IAEA and ESTRO in radiotherapy dosimetry quality audit programmes has been established during 1998 with the signature of a memorandum of understanding in order to develop common procedures and rules of application.

The access to EQUAL programme can be requested by any individual member of ESTRO. The EQUAL programme involves mainly the European Union, Norway and Switzerland, while IAEA mainly supports developing countries throughout the whole world. If EQUAL receives a request from Central Europe, Eastern Europe, the Mediterranean Basin or another part of the world, the IAEA is informed of the request. Depending on the existing contracts or projects of IAEA, it is agreed if the country concerned is covered by IAEA or by EQUAL to avoid duplication of efforts.

The Physics Department of the Institut Gustave-Roussy (IGR, Villejuif, France) has been elected as the measuring laboratory (ML) in the frame of the EQUAL programme. The work is performed by a staff of three members (I. Ferreira, physicist, C. Dagneaux, technician and A. Méchet, secretary) appointed by ESTRO, under the responsibility of two IGR senior physicists (J. Chavaudra and A, Bridier).

The ESTRO co-ordinating committee of eight members, chaired by H. Svensson with A. Dutreix as the scientific secretary and D.I. Thwaites as the administrator, supervises the work and communicates with the participants in the case of large deviations. To assure a good co-operation with IAEA, P. Andreo, the head of the Dosimetry and Medical Radiation Physics Section is invited to participate in the committee meetings as the IAEA liaison officer.

2. Materials and methods

The EQUAL project started in January 1998. In this TLD audit, a maximum of three photon beams were checked for every participating centre.

2.1. Dosimetry method

For the postal quality assurance network, the measuring laboratory (ML) has chosen lithium fluoride powder (LiF) as the TL material. The LiF dosimeter does not perturb significantly the photon and electron fluences in the high-energy photon beams used [4].

The LiF powder used is DTL 937 (Philitech Company, Buc, France) doped with Na, Mg and Ti and enriched in the ^{7}Li (99.994%). It presents appropriate physical characteristics, including a low fading, less than 5% per year at room temperature, associated with a favourable distribution of the dosimetric information in the glow curve [16]. Before the irradiation, the TLD powder is pre-annealed at 500°C in an oven for 2 h and cooled on a heat conductive surface to the ambient temperature. After the reading, the TLD powder is again annealed. In addition, the powder is encapsulated into opaque polyethylene cylindrical capsules identical to those used by the IAEA measuring laboratory. A glue is used around the capsules, in order to make the container water tight. Each dosimeter contains about 160 mg of powder, allowing five readings per point of measurement.

A PCL 3 automatic reader is used (Fimel, Vélizy, France) [1]. The powder is transferred into containers made of stainless steel with a manual dispenser. Each container receives about 31 mg delivered with a volumetric dispenser. The reader is fast and presents a good reproducibility. The repeatability on the readings for one dosimeter is about 0.3% (one standard deviation).

The method of the TLD calibration and the absorbed dose determination used in IGR has been previously described by Derreumaux et al. [4]. An energy correction factor is applied to the readings when the quality of the investigated photon beam differs from that of the reference beam (^{60}Co). In the radiotherapy range, the energy correction factor varies from 1.00 to 1.03 using ^{60}Co to 25 MV X-rays. A correction for photon beam attenuation in the dosimeter perspex stand (type IAEA holder) is also introduced in the dose calculation. This correction is of significance for the check of depth dose data at 10 and 20 cm depths. The holder correction factors were determined by TLD measurements and Monte Carlo calculations, and are applied to all readings of the TL dosimeters. The value of these factors are in agreement with the experimental results from Izewska et al. [12]. Therefore, the holder correction factors varies from 0.7% for ^{60}Co to 0.2% for 25 MV X-rays at 10 cm depth, and from 2.1% for ^{60}Co to 1.0% for 25 MV X-rays at 20 cm depth. These corrections have been applied to the TLD readings.

The total uncertainty of the TLD system is estimated by the square root of the quadratic sum of individual uncertainties of the TLD calibration with ionisation chamber and of the corrections factors (fading, linearity, energy correction, holder correction). The total uncertainty, at 1 SD, is $s = 1.7\%$ for ^{60}Co γ beams and $s = 2.3\%$ for X-ray beams.

2.2. Traceability of the TLD measurements

The TL postal dosimetric reliability of the ML is regularly checked by internal quality controls and external audits performed by International and National organisms.

The reproducibility of the ^{60}Co reference dose is monitored with the IGR reference ionisation chamber (NE 2571) calibrated at a secondary standard dosimetry laboratory (Laboratoire de Métrologie des Rayonnements Ionisants, Saclay, France, LMRI). The reproducibility of the TL calibration curves (dose, energy response and holder correction) is tested every 6 months by measurements or after TL material annealing.

Intercomparisons were made with the dosimetry laboratory of the IAEA (International Atomic Energy Agency). TL dosimeters from the IAEA were irradiated at the IGR (^{60}Co γ beams, 4, 6, 18, 20 and 25 MV X-ray beams) and measured at the IAEA. The absorbed dose measured at the IAEA to the dose stated by the IGR, derived from their TL measurements, was determined, i.e. $D_{m,IAEA}/D_{s,IGR}$. Similar intercomparisons were also performed with EORTC (European Organisation for Research and Treatment of Cancer) and the measuring centre of the University Hospital in Leuven UHL. The ratio of the absorbed dose to water stated by IGR and the absorbed dose to water measured by the other laboratories is 0.997 ± 0.010 (mean value), for all the photon beam qualities checked.

2.3. Practical organisation of the external audits

The TLDs are mailed to the participant together with a TLD holder (the IAEA holder type) to be irradiated in a water phantom at a fixed source-skin-distance (SSD) or at a fixed source-detector-distance (SDD) depending of the local practice. The number of monitor units or irradiation time required, should be calculated by the participant according to the procedure in use in clinical practice.

The EQUAL TLD audit includes checks on: reference beam output, beam output variation with collimator opening, depth dose data and wedge transmission factor. A total of 15 dosimeters are used, 12 are mailed including 10 dosimeters to be irradiated (Table 1) and two for monitoring and control; and three dosimeters for reference following the protocol described previously [4].

Strict confidentiality is maintained throughout the EQUAL procedure and only general statistics and analysis of the causes of deviations are given in this paper.

2.4. Dosimetric parameters checked

2.4.1. The reference beam output

The beam output is checked in the conditions used as reference conditions by the participant. Two dosimeters (TLDs Nos. 1 and 2, see Table 1) are irradiated at 2 Gy: one TLD at the user reference depth and one TLD at 10 cm depth, the reference depth recommended by ESTRO (booklet No. 3, [5]). The irradiation should be performed at the usual reference SDD or SSD with a vertical beam of 10 × 10 cm at the reference distance (Table 1).

2.4.2. The depth dose data

The depth dose data are checked by irradiating simultaneously two TLDs at 10 and 20 cm depths at the SSD normally used in the centre. Depth dose data are checked for two field sizes: 10 × 10 cm (TLDs 3a,b) and 20 × 20 cm (TLDs 4a,b). The dose delivered at 10 cm depth to TLDs 3a and 4a should be equal to 2 Gy (Table 1). If the participating centre uses SSD for the reference beam output set-up, the TLD No. 3a confirms the measured dose in the TLD No. 2.

2.4.3. Beam output variation with field size

The variation of the beam output with collimator opening is checked at 10 cm in water for field sizes 7 × 7 cm and 7 × 20 cm (TLDs 5 and 6) at the usual SDD or SSD, in addition to the 10 × 10 cm and the 20 × 20 cm field size irradiated previously. A dose of 2 Gy should be delivered at 10 cm depth to TLDs five and six (Table 1).

2.4.4. Wedge transmission factor

To check the wedge transmission factor, two additional dosimeters are irradiated with the wedge filter most often

Table 1
Irradiation conditions and TLD number used in the EQUAL network

TLD No.	Depth in water (cm)	Geometry set-up	Field size (cm × cm)	Accessory in the beam	Dose (Gy)
1	10, 5 or max	SDD or SSD	10 × 10	No	2
2	10	SDD or SSD	10 × 10	No	2
3a	10	SDD	10 × 10	No	2
3b	20				
4a	10	SDD	20 × 20	No	2
4b	20	SDD or SSD			
5	10	SDD or SSD	7 × 7	No	2
6	10	SDD or SSD	7 × 20	No	2
7	10	SDD or SSD	10 × 10	Wedge	2
8	10	SDD or SSD	7 × 20	Wedge	2

used in clinical practice. The TLDs seven and eight are irradiated in the 10×10 cm and 7×20 cm wedged beams respectively, at 10 cm depth in water. For minimizing the uncertainty on the transmission factor due to the dose gradient, the irradiation of TLD No. 7 and 8 are performed two times: half the dose (1 Gy) with a 0° (or 90°) collimator rotation and half the dose (1 Gy) with a 180° (or 270°) collimator rotation. The TLDs are placed so that their axes are perpendicular to the slope of the wedge in order to obtain an homogeneous irradiation of the entire volume of the TLD powder contained in each capsule. The SSD or SDD used should be adapted to the conditions used for the previous irradiations to facilitate the calculation of the transmission factor.

TLD ratios are used to estimate different physical parameters to be checked: percentage depth dose, beam output variation for open and wedged beams, and wedge transmission factors as shown in Table 3.

2.5. Levels of deviation

The levels of deviation between measured and stated quantities (Qm/Qs) and the corresponding EQUAL actions are specified as follows: optimal level when the deviation Qm/Qs is $\leq \pm 3\%$, a level outside optimal and within tolerance level when the deviation is $> \pm 3\%$ and $\leq \pm 5\%$, a level outside tolerance level when the deviation is $> \pm 5\%$ and $\leq \pm 10\%$, and emergency level when the deviation is $> \pm 10\%$. If the level of deviation of a participating centre is optimal, the full detailed results are mailed to the physicist and to the radiation oncologist who have requested the EQUAL audit, with a certificate of compliance signed by the EQUAL physicists and the physicists responsible of the measuring laboratory. If the results present deviations outside optimal level and within tolerance level, the full detailed results are mailed to the physicist of the participating centre who is asked to check the treatment planning system (TPS) and the dose calibration.

If some deviations are outside tolerance level or at the emergency level, the participating physicist is contacted by phone by an EQUAL physicist, who indicates the deviation level, but neither the sign nor the exact value. A second check is highly recommended and a new set of dosimeters is mailed within the next few days. Recommendations are given to the physicist to look carefully at the possible causes of deviation and to send any comments. In addition, the participating physicist is requested to inform the radiation oncologists of the possibility of a dose deviation. An on site visit may be suggested for any instance where a large deviation is confirmed in the second check.

3. Results

3.1. The network

Between January 1998 and December 1998, 168 centres volunteered to be tested, 18 centres have been referred to IAEA following the memorandum of understanding; out of the total of 150 accepted centres, 102 have been audited in 1998 in the EQUAL project 86.2% (group 1) of the tested centres belong to the European Union including Norway and Switzerland; 6.9% (group 2) belong to Central Europe and 6.9% (group 3) to the Mediterranean Basin (Fig. 1).

Only 76 centres have filled in the questionnaire on radiotherapy structure sent with the TLD. In these centres, there are 218 radiotherapy units including 180 linacs and 37 ^{60}Co units, with a large majority of radiotherapy departments having one to three treatment units (88%). The number of radiotherapy centres audited compared to the estimated total number of radiotherapy centres is shown in Fig. 2.

A total of 235 beams have been checked, including 28 ^{60}Co beams, 20 X-ray beams from 3 to 5 MV, 96 X-ray beams from 6 to 8 MV, 42 X-ray beams from 10 to 15 MV and 49 X-ray beams greater than 15 MV. The beam qualities more often checked are 6 MV (89 beams) and 18 MV (35 beams). In 1999, 108 beams are already scheduled to be checked.

The delay between the TLD irradiation by the participating centres and the receipt of their results is on average 1 month. The total delay between the mailing of the TLD by the ML and the receipt of the results by the participating centre is about 1–2 months. In the whole TLD mailing programme no TLD have been damaged or lost.

3.2. Observed deviations

In order to measure the agreement between the quantity measured Qm determined in the ML and that stated by the participating centre Qs, the ratios of these two values Qm/Qs are calculated for the reference beam output, beam output variation, depth dose data and wedge transmission factors.

3.2.1. Reference beam output

The results of the reference beam output checks are reported in Fig. 3 and Table 3 for the reference conditions used by the participating centres. TLD No. 1 is considered alone when the participating centre uses a reference depth of 5, 7 cm or dose max, and the mean of TLD Nos. 1 and 2 when the reference depth is 10 cm. The deviation larger than $\pm 10\%$ have been excluded from the plot. For the total number of beams, the standard deviation s is 2.1%, the mean is 0.994 and the spread is 0.17 (Fig. 3).

The centres are divided in two groups, i.e. those which have benefited of an external audit in the previous 5 years (A) and on the other hand, those which have not (B). The first group represents 37% of the checked centres and the second one 63%. The external audits reported by centres A have been performed by 12 different organisations, national or international. The standard deviations on the distributions of the ratios Qm/Qs, for both ^{60}Co and X-ray beams, are 2.2% for centres A and 2.0% for centres B. In centres A 89%

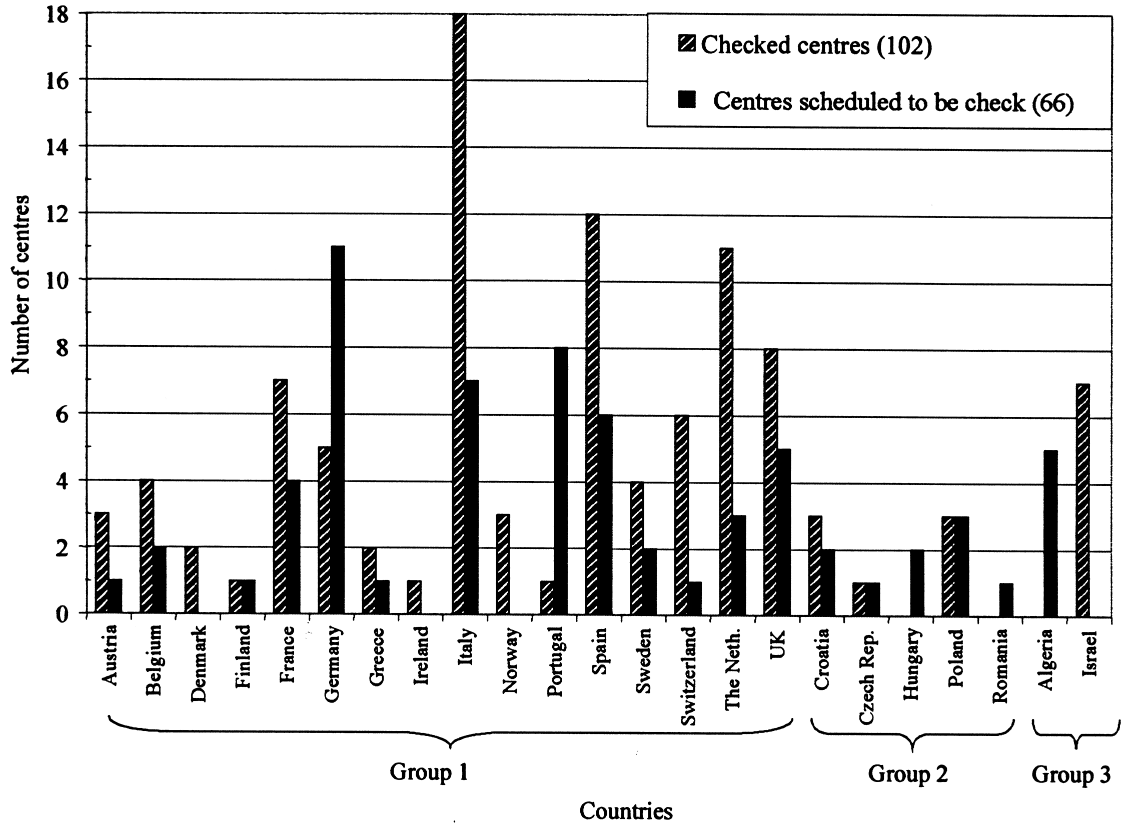

Fig. 1. Countries participating in the EQUAL project and distribution of the number of centres checked (102) and scheduled to be checked in 1999 (66) by countries. Group 1 includes European Union plus Norway and Switzerland, group 2 includes central and Eastern Europe and group 3 the Mediterranean Basin.

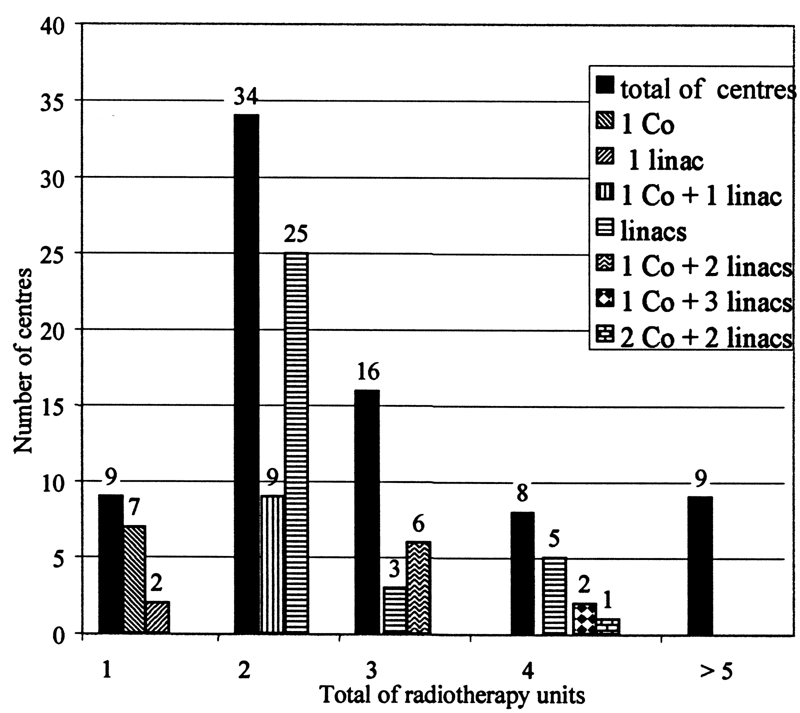

Fig. 2. Number of centres participating in the EQUAL network with 1, 2, 3, 4 and 5 machines or more. For each group, the total number of ^{60}Co and linac units is shown separately. Only 76 of 102 centres have filled in the questionnaire on radiotherapy structure sent with the TLD and could be included in the figure.

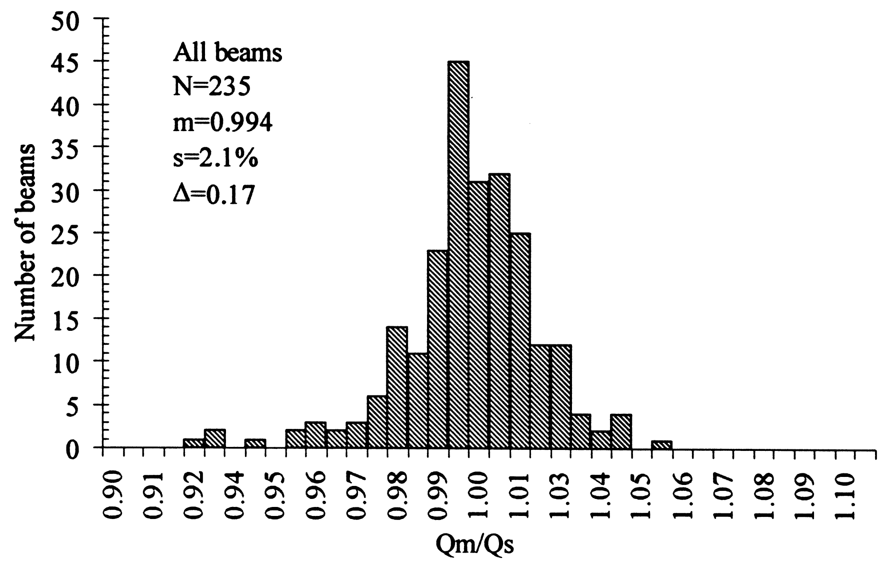

Fig. 3. Results of the reference beam output check for ^{60}Co and X-rays beams expressed as the ratio of absorbed dose in water Qm measured by the ML and the absorbed dose in water Qs stated by the participating centre (Qm/Qs). *N* is the number of beams, *n* is the number of dosimeters, m is the mean of the distribution, s is the standard deviation and Δ is the spread of the results (difference between the highest and the lowest values of the ratio Qm/Qs. The deviations larger than 10% are not shown on the figure: 0.885.

of X-ray and ^{60}Co beams checked are within the optimal level (deviation in Qm/Qs $\leq \pm 3\%$), and 90% in the centres B. A total of 8 deviations larger than ±5% have been observed, 4 deviations in the centres A and 4 in centres B.

For the 37 ^{60}Co beams, the mean of the distribution of Qm/Qs is 1.001 ($s = 2.0\%$) and the spread is 0.09, while for the 180 X-ray beams the mean of the distribution of Qm/Qs is 0.994 ($s = 2.0\%$) and the spread is 0.17. One large deviation corresponding to the emergency level, has been observed in an X-ray beam, with a ratio Qm/Qs equal to 0.885.

Table 2 shows the results of the reference beam output checked at 10 cm depth, the reference depth recommended by ESTRO [5] and at a reference depth differing from 10 cm (i.e. 5, 7 cm or dose max). 94 dosimeters (TLD No. 1) were irradiated at 10 cm depth, with a mean of 0.996, a standard deviation *s* of 1.5%, and a spread of the results of 0.08, whereas, in the beams (141) irradiated at a reference depth differing from 10 cm, the mean is 0.992, $s = 2.4\%$, and the spread of the results is 0.17. The number of deviations larger than ± 5% for these different reference depths are 1 and 6, respectively.

3.2.2. Depth dose data

The results of the depth dose data checks for the X-ray and ^{60}Co beams are reported in Figs. 4a,b for the 10 × 10 cm and 20 × 20 cm field sizes, respectively. They are expressed as the ratio of the depth dose data measured with TLD to the depth dose data stated by the participant $[D_{20}/D_{10}]_m/[D_{20}/D_{10}]_s = $ Qm/Qs. The mean values m of the distributions are 0.996 and 0.994 with standard deviations of 1.5 and 1.8% for 10 × 10 cm and 20 × 20 cm field sizes, respectively. For the 10 × 10 cm field size, 95% (206/217) of the beam checks are within the optimal level and only one beam is outside the tolerance level (Fig. 4a and Table 3); the spread of the results is 0.10. Corresponding data, for the 20 × 20 cm field size are: 90% (197/217) are within the optimal level, three beams are outside the tolerance level, and the spread is 0.16 (Fig. 4b).

3.2.3. Beam output variation

Fig. 5 and Table 3 presents the beam output variation for all checked field sizes, for open beams. The total number of checks is 642 including checks for field sizes 7 × 7 cm, 20 × 20 cm, and 7 × 20 cm as compared with 10 × 10 cm. The beam output variation checks are expressed as the ratios $[(Qm/Qs)_{Xcm \times Xcm}/(Qm/Qs)_{10cm \times 10cm}]$, where the (Qm/Qs) are the ratios of the measured to the stated dose for the Xcm × Xcm and 10 × 10 cm field sizes. The mean *m* of the distribution is 1.003 with a standard deviation *s* of 1.8% and a spread of the results of 0.17 (Fig. 5).

Eighty nine percent (570/642) of the results beam output

Table 2
Results of the TLD irradiation in the ^{60}Co beams and X-rays beams for the reference beam output checked at the different reference depths used in the participating centres

Reference depth	Reference beam output (^{60}Co and X-rays)				
	N	*m*	*s*	Δ	nb of Qm/Qs >±5%
5 cm or max	141	0.992	2.4%	0.17	6
10 cm	94	0.996	1.5%	0.08	1

Table 3
Number of beams checked within the different levels of deviation for reference beam output, beam output variation, depth dose data and wedge transmission factor

Parameters checked	TLD used to calculate the Parameters	Deviation Levels (Qm/Qs)				Total of Beams
		≤3%	>3 to ≤5%	>5 to ≤10%	>10%	
Reference beam output	1 and 2	191	38	5	1	235
Percentage depth dose	3b/3a, 4b/4a	190	27	4		220
Beam output variation						
Open beams	5/3a, 6/2, 5/2, 4a/4b	174	41	11	1	227
Wedged beams	8/7	188	15	2	6	208
Wedge transmission factor	7/2, 7/3a, 8/6	164	33	5	7	209

variation for open beams are within the optimal level (Qm/Qs ≤ ±3%), and 8% show deviations in Qm/Qs between ±3 and ±5%. In addition, 2% (16/642) show deviations outside tolerance level, including two beams in the emergency level (Fig. 5).

3.2.4. Beam output variation for wedged beams

The results of beam output variations in X-ray and ^{60}Co for wedged beams are shown in Fig. 6 and Table 3 as the ratio of Qm/Qs for the field size 7 × 20 cm compared to the field size 10 × 10 cm. The mean *m* of the distribution without the largest deviations is 0.999 with a standard deviation *s* is 1.9% and a spread of 0.13. Six deviations larger than ±10% are observed. When these deviations are included in the distribution, the mean is 1.006, the standard deviation is 14% and the spread is 2.02.

3.2.5. Wedge transmission factor

Fig. 7 shows the wedge transmission factors checked in the X-ray and ^{60}Co beams for 10 × 10 cm and 7 × 20 cm field sizes. Excluding the larger deviations, the mean *m* of the distribution is 1.002 and the standard deviation *s* is 2.0% with a spread of 0.16. When including the 10 deviations larger than ±10%, the mean of the distribution is 1.007, the standard deviation is 10% and the spread of the results is 2.02. Seven of the 10 deviations in the emergency level are observed for the 10 × 10 cm wedged field size. The means are 1.03 and 1.002 with standard deviations of 14 and 3.3% for the 10 × 10 cm and the 7 × 20 cm field sizes, respectively.

3.2.6. Global results

Table 3 shows the results concerning all the dosimetric data checked, reference beam output, beam output variation (open and wedged beams), depth dose data and wedge transmission factor. The table gives the number of beams as a function of the deviation level. The wedged beams are responsible for the largest number of deviations observed at the emergency level. All participating centres in which one or several beams present deviations in Qm/Qs exceeding ±5%, a second check has been suggested. All centres concerned have accepted to participate in the new TLD check. A total of 24 centres have been scheduled to be rechecked, 17, five and two of theses centres have one, two and three beams to be rechecked, respectively. Eleven of the 24 centres are type A centres and 13 are type B centres. To date, 14 centres have already been rechecked, and the results for the first, second and third checks are shown in Table 4.

4. Discussion

In the EQUAL network, the results on the reference beam

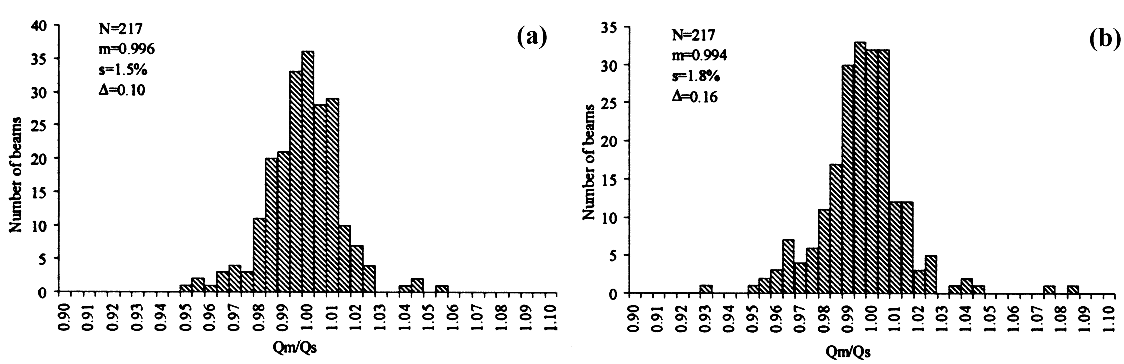

Fig. 4. Results of the depth dose data checks for ^{60}Co and X-rays beams expressed as the ratio of depth doses $[D_{20}/D_{10}]_m$ = Qm measured by TLD, and depth doses $[D_{20}/D_{10}]_s$ = Qs stated by the participating centres: (Qm/Qs). *N* is the number of beams, *m* the mean of the distribution, *s* the standard deviation and Δ the spread of the results. (a) Field size 10 × 10 cm and (b) field size 20 × 20 cm.

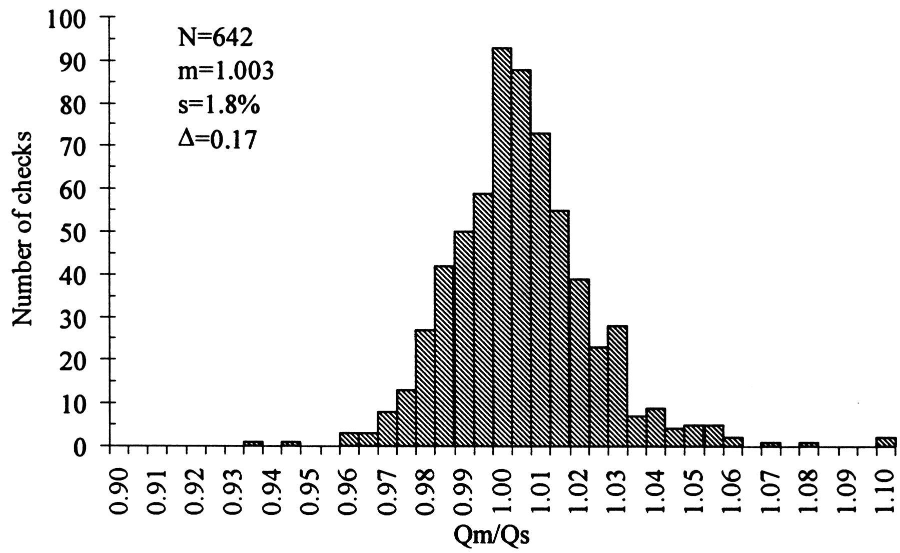

Fig. 5. Results of beam output variations with collimator opening for ^{60}Co and X-rays beams expressed as the ratio $(Dm/Ds)_{Xcm \times Xcm}/(Dm/Ds)_{10cm \times 10cm} = (Qm/Qs)_{Xcm \times Xcm:10cm \times 10cm}$. *N* is the number of beam output variations for open beams checked.

output check are relatively good with only 3% of deviations in Qm/Qs larger than ±5%. Similar investigation of reference beam output has been performed by other organisations leading to much larger rates of deviation. The number of deviations larger than ±5% reported by the organisations is: 32% of 3307 beams checked by the IAEA/WHO between 1969 and 1998 [10] and 11% of the 178 beams checked for the EORTC audit [9]. Deviations larger than ±6% concern 12% of the 125 beams checked in the EC network [6], and 9% of 129 beams in the EROPAQ, Central Europe network [11].

In the EQUAL programme, the local physicist is asked to calculate the absorbed dose in reference conditions with the method used in the clinical routine, whereas in the previous programmes on quality assurance the local physicist was asked to measure carefully the output in reference conditions [6] before the TLD irradiation. The EQUAL method allows to check the beam calibration as it is used routinely for patient treatments. Surprisingly enough, in the previous method, in some centres where the physicist might not have an adequate training, the measurements have resulted in large deviation, whereas the calibration data used in routine

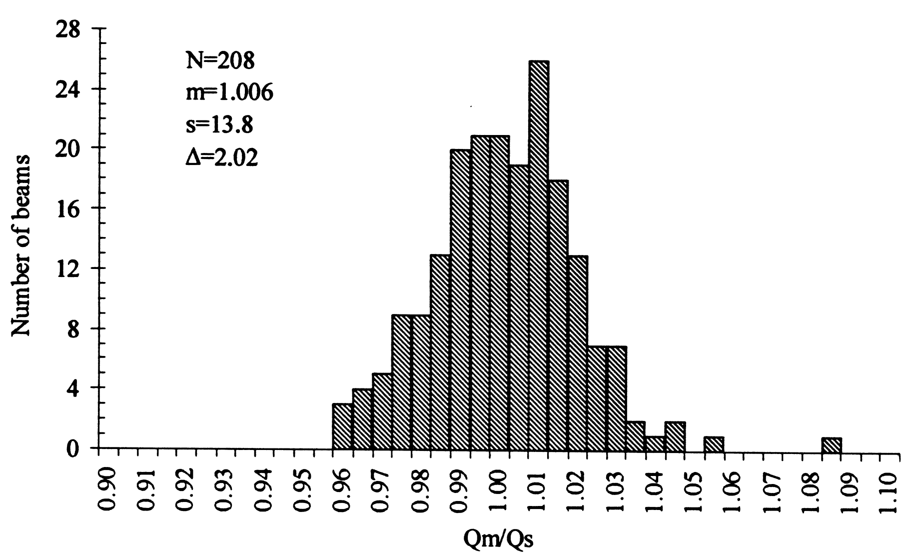

Fig. 6. Beam output variation for ^{60}Co and X-rays wedged beams expressed as the ratio of Qm/Qs for the field size 7×20 cm compared to 10 × 10 cm. *N* is the number of beam output variations for wedged beams checked. The deviations larger than 10% are not shown on the figure: 0.58, 0.62, 0.70, 1.19, 2.11, 2.44.

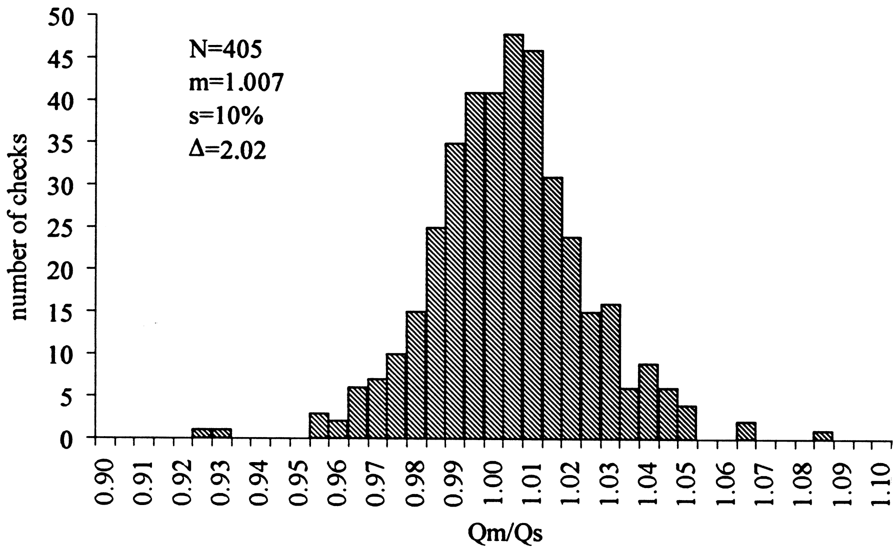

Fig. 7. Checks of the wedge transmission factors for ^{60}Co and X-rays beams expressed as the ratios of Qm/Qs with and without a wedge. *N* is the number of wedge transmission factors checked. The deviations larger than 10% are not shown on the figure: 0.41, 0.47, 0.74, 0.76, 1.20, 1.21, 1.65, 1.68, 1.73, 2.4.

have been determined correctly at the origin by the manufacturer or by a qualified physicist. It can explain the significant difference in the number of large deviations observed between the programmes having different protocols.

The majority of the beams checked (147 out of 235) are from the centres which have not benefited from an external audit during the previous 5 years. No significant difference is observed between A and B centres for the deviation level and the standard deviation of the reference beam output (Fig. 3). This conclusion differs from those given for the EC network [6] and the EROPAQ network [11] and can be partially explained by the small number of large deviations observed.

The results of the reference beam output checks show that, for linac photon beams the number of large deviations is higher than for ^{60}Co beams. For the 17 deviations shown in Fig. 3 outside optimal level and within tolerance level (Qm/Qs is $> \pm 3\%$ and $\leq \pm 5\%$), 10 are from Linacs, and the 7 deviations larger than $\pm 5\%$ are all from linacs. This difference between X-ray beams and ^{60}Co beams can be explained probably by the instability of the output of some accelerators [2,11]. It is important to note that of 6 out of the 7 deviations larger than $\pm 5\%$ observed in the reference beam output refer to centres using as the reference depth, depths other than 10 cm (Table 2). The results for the beams using a calibration depth of 10 cm are more accurate than for other reference depths. This result confirms the usefulness of the recommendation presented in the ESTRO booklet No. 3 [5].

As far as the depth doses are concerned, the number of deviations observed is larger for the 20×20 cm field size than for the 10×10 cm, showing that most probably reference conditions are checked more carefully than others.

Regarding the beam output variation, out of the 16 deviations outside the tolerance level, eight concern the 20×20 cm field size and six the 7×20 cm field size. It is not clear from the data sheets, if the participant's TPS include an algorithm for the calculation of the beam output variation, and if so, what kind of algorithm is used. A more acute problem is seen for the output variation of the wedged beams, since as much as six values (out of 208) are at the emergency level. The results concerning the wedge transmission factors of the X-ray and ^{60}Co beams confirm the high rate of errors observed for the output variation of the wedged beams, since 15 deviations are outside tolerance level including 10 deviations at the emergency level.

4.1. Analysis of deviations outside tolerance level

Approximately 20% of all checked centres present a minimum of one point in Qm/Qs where the deviation is outside tolerance level; however, most discrepancies observed in the ratio Qm/Qs have been resolved by phone or mail between the EQUAL physicists and the participating physicist. Up to the present time, it has not been considered to be necessary to organise any on-site visit although it has been offered several times to the centres with large deviations.

In the second check (centres 1, 2, 3, 4, 7a,b, and 12) there is often a good agreement between the measured and stated doses: according to the participating physicist, the errors observed in the first check are probably due to an error on one of the geometric parameters during TLD irradiation (Table 4). The agreement observed in the Qm/Qs ratios in the second check suggest that patients have probably been irradiated correctly. However, it is surprising to observe a large number of deviations during a verification procedure which is expected to be performed with a special care. It is not very easy to determine if these errors which seem to be random errors, could affect the patient treatments or have occurred only during the TLD irradiation.

When there are deviations outside tolerance level, the EQUAL physicist recommends to the participant centre to compare the dosimetric parameters measured with TLD with the data from the TPS and with standard data available in the literature for a similar treatment unit. This method helps to identify any discrepancy between measured dosimetric parameters and the dosimetric data used in the TPS. For instance, in centre No. 6, the participating physicist has re-measured the dosimetric data and found discrepancies with the initial value used in TPS (Table 4). In this centre, the physicist did not indicate which kind of TPS error was involved, therefore the impact of this error on the patient treatment is not easy to evaluate.

Table 4
Ratio of the measured and stated quantities, Qm/Qs, in the successive checks, for the 14 centres with deviations larger than 5% in the first check[a]

A	Beam quality	TLD to recheck	Qm/Qs (check number)			Explanation given by the participating centre
			First	Second	Third	
1	20 MV	7	1.663	0.988		The TLD No. 7 was probably irradiated three times instead of two
2	10 MV	7	0.402	1.009		The irradiation of TLD No. 7 started without wedge filter, and the irradiation was stopped
3	23 MV	8	1.080	1.039		Instability of the linac during the irradiation of the TLD No. 8
4	25 MV	7	2.401	1.021		No clear explanation, probably the TLD No. 7 was irradiated twice
5	18 MV	5	1.068	1.004		No explanation
		7	1.057	1.008		
6	6 MV	3b	0.947	1.002		Depth dose data and wedge attenuation factor measured initially with a diode and re-measured with an ionisation chamber before the second check
		7	0.921	0.926		
		8	0.929	–		
7a	Co-60	4b	0.942	0.989		The irradiation was performed with a 45° wedge and the dose was stated for a 30° wedge
		7	0.726	1.012		
		8	0.733	0.981		
7b	10 MV	7	0.926	0.993		The irradiation was performed with a 45° wedge and the dose was stated for a 30° wedge
8	Co-60	3b	0.946	1.000		The depth dose data were re-measured with an ionisation chamber, and the deviations with the TPS data were within 2%
9	4 MV	1	0.929	0.922	0.953	For the error in first and second check: The depth dose data for the field size 10 × 10 cm were used to calculate the number of MU for the field size 20 × 20 cm. The reference depth used for dose calculations, and TLD irradiations of TLD No. 1 was 1.3 cm in water. In addition, in first check the irradiation performed with an additional perspex cylinder (a distance plug of the TLD holder)
		2	0.986	0.98	0.982	
		3a	0.937	0.987	0.991	
		3b	0.940	0.98	0.987	
		4b	1.073	1.072	1.028	
		5	0.936	0.977	–	
		6	0.919	0.975	–	
10	6 MV	1	0.916	1.007		Irradiation performed with an additional perspex cylinder (plug). This plug is responsible only for an underdosage of about 2.2%. No other explanation given.
11	6 MV	3a	0.950	0.988		No explanation
12	15 MV	2	0.969	0.981		The TLD No. 5 was erroneously irradiated with a 10 × 10 cm field size instead of 7 × 7 cm
13	10 MV	1	0.882	0.995		The number of monitor units differs only by 1% between the two checks. Most probably phantom set-up error
		2	0.912	0.963		
		3a	0.895	0.973		
		3b	0.901	0.979		
		4a	0.919	0.995		
		4b	0.885	0.961		
		5	0.920	0.997		
		6	0.919	0.989		
		7	0.899	0.978		
		8	0.905	0.976		
14	Co-60	2	1.032	1.044		The large deviation on TLD No. 8 is partly explained by a an incorrect wedge transmission factor
		7	1.040	1.047		
		8	1.236	1.039		

[a] The explanations given by the participating centre are also listed.

In centre eight deviations in Qm/Qs outside the tolerance level (between 5 and 6%) are observed on the doses at 20 cm depth for the two field sizes (point 3b and 4b) (Table 4). The participating physicist explained that he re-measured the dosimetric data with an ionisation chamber, and that the results were in agreement within 2% with the values calculated with the TPS. If this deviation of 2% is taken into account, the deviation of Qm/Qs falls within tolerance level. Moreover, the second check gives for Qm/Qs results differing from the first ones by 5% and therefore within optimal level of deviation. On the other hand, this ^{60}Co beam has been checked in another postal dosimetric program, including the water Multipurpose Phantom (EC network, [3]), and deviations of about 5% had already been observed on some points at depth.

In centre nine deviations outside the tolerance level have been observed in two of three checks. The participating physicist has given the same explanation for observed deviations in the two checks. The depth dose data for the field size 10×10 cm were used to calculate the number of monitor units for the field size 20×20 cm. Moreover, the second check gives for Qm/Qs results outside the tolerance level again. The reference depth used for dose calculations, and TLD irradiations of TLD No. 1 was 1.3 cm in water. An agreement is observed in the Qm/Qs ratios in the third check excepted for the TLD No. 1, the deviation from this point is explained by the fact that the holder used to irradiate the TLD was not adapted to irradiate at a depth different of 5, 10 or 20 cm. This error is obviously due to the method used for the TLD irradiation, and has a large probability not to occur during other measurements or to have an impact on patient treatment.

In centre 10, the only explanation given by the physicist to the deviations was the presence of the additional perspex cylinder during irradiation. This could, however not explain the deviations observed for all points. It appears that the number of monitor units used in the second check differs from the first one. As all the results are optimal in the second check, one can assume that, although it was not noted by the physicist, some systematic error has been made during the first irradiation and that the linac has been re-calibrated before the second check.

This might also the case for centre No. 13 (Table 4), where deviations were at the emergency level for all points, and where, according to the local physicist, there has probably been an error in the phantom set-up during the irradiation, since the results of the second check show a good agreement in Qm/Qs for all points rechecked, when the number of monitor units used was identical. Moreover, in this centre two different beams have been also checked at the same time with very good results. We can assume that this error had no effect on patients.

In centre 14 an incorrect wedge transmission factor was used to calculate the dose to TLD No. 8 (Table 4). According to the participating physicist this factor is correctly used in clinical routine, in contrary to the calculation made for the TLD irradiation. One can assume that the deviation observed in this beam had no consequence on the patient treatments if the wedge transmission factor in the TPS was correctly used.

Centres five and 11 did not give any explanation concerning the deviations observed in the first TLD check (Table 4). However, according to the data sheet completed by the participating centres, several comments can be made. For centre five, although the number of monitor units used to irradiate the reference dosimeter (TLD Nos. 1 and 2) are identical for the first and second checks, the number of monitor units MU used to irradiate TLD No. 5 and 7 increases from 249 MU to 265 UM, and from 598 to 636 MU, respectively, from the first to the second check. The difference between the two checks (0.940) correspond to the observed deviation in the first check. The difference in the number of monitor units for the TLDs Nos. 5 and 7 between the two checks is probably due to an error on the TPS data or to a wrong MU calculation. The agreement observed in the Qm/Qs ratios in the second check for centre five suggests that patients have probably been irradiated correctly only after the second check. Concerning centre 11, the number of monitor units used to irradiate the reference dosimeter and the TLD Nos. 3a,b are identical from the first and second check. As the Qm/Qs ratios are at optimal level in the second check, one can assume that the deviations observed in the first check are accidental. They can be due to some mistake in the irradiation parameters or to water leakage in the TLDs.

5. Conclusion

The first results of the ESTRO QUALity Assurance network (EQUAL) shows the importance of external audits in radiotherapy centres in order to check the dose, in non reference conditions, in addition to reference conditions, in order to check physical parameters used in clinical practice.

During the first year, EQUAL has received a total of 168 applications showing the great interest of radiotherapy centres for the service offered by ESTRO. The results show a low percentage (3%) of large deviations (Qm/Qs $> \pm 5\%$) on the beam output in reference conditions, among the 102 centres checked. However, in 24 centres out of 102, deviations outside tolerance level have been observed at one point or more, affecting mainly the large and rectangular field sizes and the wedged beams.

Only nine among the 102 centres checked have one single treatment unity. The ESTRO-EQUAL co-ordinating committee wishes to encourage the small radiotherapy departments to participate in this external audit.

The participating physicists have been very co-operative. However, the determination of the cause of errors and of their impact on the patient treatment it is not easy. One does not know if a random error observed at the time of the audit, means or not that the probability of random errors in patient treatment is higher in the concerned centres than in others.

These 1 year results show clearly the importance for the radiotherapy community that a quality assurance network could be organised by ESTRO for the European radiotherapy centres.

Considering the EQUAL experience, the programme will be extended in September 1999 to include electron beam checks.

Acknowledgements

The present work would not have been possible without the strong support of the ESTRO Committee for Quality Assurance and the financial help of the EC Committee 'Europe Against Cancer'. The authors thank the physicists who participated in the network for their co-operation. They appreciated deeply the excellent relations they maintained with the EQUAL team. They are very grateful to the IAEA for their co-operation to the project, and more especially to P. Andreo and J. Izewska for the useful discussions on the organisation of the network.

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