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Quality assurance in radiotherapy

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FOREWORD

According to recent studies by the World Health Organization (The World Health Report, WHO, 1995), cancer incidence in the world is increasing rapidly, in both developed and developing countries. About 9 million new cancer cases are recorded each year, about 5 million of these in the developing world. The cancer incidence is projected by WHO to increase to approximately 15 million new cases by the year 2015. Two-thirds of these cases will occur in the developing countries.

About 50% of cancer patients require radiation treatment, either curative or palliative. The urgent need for rapid worldwide expansion of radiation treatment technology demands mobilization of adequate resources, including the creation of new treatment facilities, particularly in the developing countries. Great progress has been made in the field of radiotherapy, in terms of higher levels of expertise and improvements in technology, including the introduction of modern therapy equipment (simulators, CT-scanners, modern tele- and brachytherapy units, computerised treatment planning systems, etc.). The rapid growth in radiation treatment methodology is thus followed by an increasing need for appropriate training of radiation oncologists, medical physicists, radiologists and radiation technologists. Seminars and training courses covering all aspects of radiotherapy are of great value and should be held on a regular basis.

The implementation of modern technology can lead to continuous improvement in the outcome of treatment with respect to a high tumour control probability and a low rate of complications to normal tissue. On the other hand, because of its complexity, radiation treatment is subject to various sources of uncertainties, which may arise during different steps of radiotherapy chain, from dose prescription to dose delivery. In addition to inherent uncertainties in the planning and carrying out of treatment, there is a possibility of errors, including human mistakes and equipment related problems, which can occur during the process of treatment. It is a known fact that many patients receive less than optimal radiation treatments, some being treated inadequately, with the increased probability of a lower cure rate or of severe complications. This problem concerns not only the developing countries without sufficient expertise or resources, but also several cancer centres in developed countries. The risk of inadequate radiation treatment can be minimized through the systematic execution of a comprehensive Quality Assurance (QA) programme, which involves programmes for quality management and includes periodic quality control of equipment.

Major efforts have been made to develop and implement QA methodologies, aimed at reducing various sources of errors to ensure not only a high standard of radiation treatment, but first and foremost to prevent radiation accidents. Institutional QA programmes as well as inter-institutional programmes have to be implemented, together with audits by external reference national or international bodies.

One of the main goals of this seminar was to deal with the design, harmonisation and structures of QA programmes in different countries, as well as with implementation of these programmes at the institutional, national, regional and international levels. These activities can lead to a global QA network having the potential to significantly improve standards of care for millions of cancer patients worldwide.

This meeting was jointly organised by the International Society for Radiation Oncology (ISRO) and the International Atomic Energy Agency (IAEA). The meeting was attended by approximately 120 participants and observers representing national societies for radiation therapy and radiation medical physics in 35 countries and seven international organizations.

The IAEA officer responsible for the meeting was P. Nette of the Division of Human Health. Papers were compiled and edited by J. Izewska, of the same Division.

The organizers are grateful to Varian Associates Inc. for their generous support to this seminar.

EDITORIAL NOTE

CONTENTS

SUMMARY

CONSENSUS STATEMENTS ON MULTI-INSTITUTIONAL QUALITY ASSURANCE PROGRAMMES

PARTICIPANTS: IAEA, ISRO, IOMP, EFOMP, ESTRO, EORTC, EC-Network and representatives of national societies of radiation therapy and radiation physics

1 INTRODUCTION

The aim of the meeting was to summarise the status of quality assurance (QA) in radiotherapy from the experience of research groups, international organisations and national structures involved in QA programmes Thirty-four contributory papers were presented and the achieved results discussed at length. The discussions concerning QA programmes aimed at.

- recognising reference methodologies and transferring the achieved results to standard practice,
- defining priorities for research and development,
- outlining the role of networks in quality assurance programmes

The discussion was focused in the following topics and the consensus statements were drawn from the questions.

- What should be the initial objectives of a quality assurance programme in radiotherapy ?
- What are the reference methodologies available in quality assurance of radiotherapy?
- Who should be responsible for the quality assurance ?
- Is there a role for networks to improve quality assurance in radiotherapy ?

2. WHAT SHOULD BE THE INITIAL OBJECTIVES OF A QUALITY ASSURANCE PROGRAMME IN RADIOTHERAPY ?

Quality assurance of megavoltage beams and equipment is now well documented [1, 2, 6, 12, 16, 17] and applicable to every radiotherapy department Present priorities are

- To implement quality assurance of beams and equipment world-wide on a prospective systematic basis
- To check that once deviations are detected, corrections are made with proper follow-up measurements and audits

Proper implementation of quality assurance in radiation physics constitutes only one sector of the quality assurance programme in radiotherapy Once the beam calibration is under control, the two weakest links of the radiotherapy processes are related to the physician and to the patient

The physician. The physician is responsible for ensuring proper interactions between different members of the radiotherapy team during the planning and delivery of radiotherapy treatment Quality assurance can deal with the risk of errors which

originate from the organisation of the treatment process through a quality management programme. This programme evaluates inaccuracies resulting from the uncertainties of different parameters related to medical decisions (*i.e.* diagnostic procedures, tumour extension, margins of safety, etc.) and those resulting from the differences between prescription and the actual delivered treatment. A number of medical decisions (*e.g.* a definition of the planned target volume) may introduce risk for a larger uncertainty range in the treatment procedure than the uncertainties related to most of the dosimetry parameters.

The patient. The main risk of deviations in dose delivery may be attributed to the individual anatomical variations of different patients, to the reproducibility of patient positioning on the treatment couch, and to the control of patient movements during the treatment sessions.

There is a general agreement that the entire process of radiotherapy, from diagnosis to delivery of treatment, should be subject to the dedicated and comprehensive quality assurance programmes. This conclusion can be actualised by implementing the following recommendations:

- There is a need for every radiotherapy department to develop a programme for quality management of irradiated patients. Such a programme should describe the responsibilities of every member of the radiotherapy team and should list the quality control procedures to be used in the department.

- Once the beam calibration is under control, the most important clinical parameter to measure is the outcome of the whole radiotherapy process (*i.e.* the dose delivered to the irradiated volume in a patient). The detection of a deviation in dose delivery will activate the revision of intermediate steps to locate the origin of the deviation(s). The main advantage of that method is to select cases at risk from a single procedure.

Radiotherapy is not the only discipline requiring the implementation of a quality assurance programme. Other disciplines involved in diagnosis (radiology, laboratories) and therapy (surgery, medical oncology) should develop similar programmes [10].

3. WHAT ARE THE REFERENCE METHODOLOGIES AVAILABLE IN QUALITY ASSURANCE OF RADIOTHERAPY ?

Quality assurance procedures, guidelines and recommendations for medical radiation physics are available internationally : IAEA [11], ICRU [13, 14, 15], ICRP [12], WHO [22], ESTRO [20], EORTC [2, 6, 8, 16, 17], ESO [21], EFOMP [4] and nationally [1, 19, etc.]. National procedures, if available, should not differ significantly from those recommended internationally.

The concept of accreditation of a radiotherapy department was discussed: the consensus reached was to use ISO 9000 standards which are proven to serve as easy use as guidelines for the infrastructure of radiotherapy department, its organisation and equipment.

Two comments were made

- The European Union has just issued QA recommendations (June 95) for the equipment in addition to the ISO recommendations, other essential requirements (CE label) will be applied by EU to each type of equipment An authorised body, specific to each country, will deliver the label « CE »

- The implementation of ISO 9000 recommendations is not sufficient *per se*, since it does not ensure whether equipment is properly used by the radiotherapy staff

Finally, the staff and equipment workloads were discussed Various figures published in North-America and Europe [1, 2, 9, 18] can offer a general idea concerning the subject of the staff and equipment workload which should, however, be interpreted with caution at both the national and institutional level A careful analysis of the responsibilities, tasks and duties of the radiotherapy staff must be performed before the optimal workload for each staff category has been decided upon It seems, however, possible to define a minimum level below which the quality and the safety of the patient treatment can no longer be achieved

The two organising bodies (IAEA and ISRO) in co-operation with national societies of medical radiation physics and radiation therapy, should provide radiotherapy departments with a list of available references.

4 WHO SHOULD BE RESPONSIBLE FOR QUALITY ASSURANCE ?

Two QA levels must be considered individually the internal institutional level and the external independent multi-institutional (regional, national, international) level A consensus has been reached recommending that the implementation of the quality assurance programme be jointly carried out through a close interaction between the above two levels

4 1 The internal institutional level

As aforementioned, quality assurance should investigate every step of the radiotherapy procedure and should involve all categories of the radiotherapy staff The list of procedures, their timing, recording, reporting and corrective processes should exist in a written format and should be available for independent review

4 2 The external independent multi-institutional (regional, national, international) level

The first consensus reached was on the need for minimum flexibility in the organisation and structure of the external independent QA body, which must recognise national differences in competencies and structures in different countries

Metrology institutions can only check beam calibration and will not be able to carry out procedures on quality assurance of patients treated with radiation Hence, it is strongly recommended that quality assurance programmes on the multi-institutional level dealing with beam calibration and/or beam quality checks be jointly co-ordinated by independent experts from both metrology institutions and radiotherapy departments

These external independent structures should naturally comply with the international recommendations and programmes (IAEA, ICRU).

These external independent structures should get a contractual recognition and/or legal administrative organisation to be able to conduct quality assurance programmes on a systematic basis in every radiotherapy department in a given geographical area (region, country...).

National programmes should define several levels of recommendations based on the level of standard practice in the individual countries. It is recommended to try to follow the general model of ICRU concepts (ICRU Report 50 [14]) and its 3 levels:

Level 1. Basic minimum requirements

Level 2. Reference level achieved by most representative institutions (e.g. « the state of art » from expert's consensus)

Level 3. Research level

4.3. Interactions between manufacturers and users of radiotherapy equipment

One of important issues thoroughly discussed was the interaction between manufacturers and users of instrumentation and equipment for radiotherapy. The use of ISO 9000 standards is recommended for acceptance tests, commissioning and quality control of equipment. In addition, interaction between the users and manufacturers should follow written procedures to ensure safe communication of data, especially data related to equipment maintenance, which should always be available for an external review.

5. IS THERE A ROLE FOR NETWORKS TO IMPROVE QUALITY ASSURANCE IN RADIOTHERAPY ?

There are various interpretations of the concept of network. It was agreed that the concept of network should not be restricted to the use of telematics tools linking institutions. A quality assurance network should be defined as a formal quality assurance programme jointly followed by several institutions allowing exchange, intercomparisons and pooling of information according to the same definitions.

An example of a network is, for instance, a mailed TLD dose audit programme, which can be restricted to the check of beam calibration or extended to verification of other dosimetric parameters or dose calculation procedures following well-defined procedures. At a more advanced step, telematics links should allow on-line quality assurance, but this still needs to be investigated.

The important role of networks is to improve the information exchange between industrialised and developing countries in terms of transfer of knowledge, training, etc.. Major investments are required at the national level in different countries. It is, however, essential to define guidelines and standard reference methodologies to ensure easy communication between different regional and national networks in the future, including data transfer, text and image transmission.

6. CONCLUSION

All participants stressed that quality assurance is an excellent short-term investment for nearly all countries in order to achieve improved results in radiotherapy. Better treatment planning and better control of dose delivery improves tumour control, while simultaneously reducing the rate and severity of recurrences and complications. Available methodologies should be more widely used. Major efforts should focus on those steps of the radiotherapy chain which have not yet been fully investigated.

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I. INTRODUCTION TO QUALITY ASSURANCE IN RADIOTHERAPY

RATIONALE FOR QUALITY ASSURANCE

(Abstract)

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Radiotherapy of cancers is a complex multistep process from beam calibration to verifications during treatment. Each step includes measurement uncertainties, risks of systematic and occasional deviations. The final step, the treatment of the patient, incorporates the sum of all deviations added to the potential errors specific to this ultimate event. Hence, quality management must address quality control procedures at each step and at the final product e.g. the treatment of the patient.

Quality management is aiming at prospectively reducing the global risks of deviations through the following methodology :

- To evaluate the multidisciplinary environment for the diagnostic and therapeutic choices.
- To agree upon and to perform the basic radiation physics procedures of megavoltage photon and electron beams, brachytherapy sources and treatment planning systems.
- To check mechanical performances of megavoltage equipment, simulators, remote loading systems for brachytherapy as well as the compliance to maintenance programmes.
- To agree upon rules for prescribing, reporting and recording radiotherapy parameters (including but not exclusively the absorbed dose to the target volume), inside the department and between institutions.
- To determine the quality control procedures performed before and during the treatment delivered to each patient, the respective responsibilities and interactions between radiation oncologists, radiation physicists and radiographers.
- To plan the assessment of the results : time, effort and money spent in a quality assurance programme should produce measurable results over a 5-year period providing the objectives and endpoints are carefully selected and providing that each step of an orderly sequence is adequately covered.

The implementation of this programme should be carried out comprehensively at two independent and interactive levels :

1- Institutional : each department should define a quality system based on ISO 9000 quality standards to fulfil the application of the international recommendations on goals and methodology of quality assurance in radiotherapy.

2- Independent external review by quality assurance experts : this review includes local visits and/or remotely conducted external audits through mailed TL dosimetry protocols, questionnaires, dummy run procedures, phantom and in-vivo measurements.

Last, a control procedure should evaluate the compliance to the quality assurance programme and from the observed results, determine the appropriate follow-up procedures.

The need for all radiotherapy centers to stick to that approach should logically result in regional, national and international networks of quality assurance. Europe provides an interesting model since quality assurance methodology was developed within a clinical research group (EORTC) and later on transferred to standard practice via a network supported by a European community programme (Europe Against Cancer). Hopefully, this historical process should facilitate the emergence of national networks contributing to a consistent and continuous improvement of the quality of the radiotherapy of cancer patients.

ACCIDENTS IN RADIOTHERAPY: LACK OF QUALITY ASSURANCE?

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Abstract

About 150 radiological accidents, involving more than 3000 patients with adverse effects, 15 patient's fatalities and about 5000 staff and public exposures have been collected and analysed. Out of 67 analysed accidents in external beam therapy 22% has been caused by wrong calculation of the exposure time or monitor units, 13% by inadequate review of patient's chart, 12% by mistakes in the anatomical area to be treated. The remaining 35% can be attributed to 17 different causes. The most common mistakes in brachytherapy were wrong activities of sources used for treatment (20%), inadequate procedures fro placement of sources applicators (14%), mistakes in calculating the treatment time (12%), etc. The direct and contributing causes of radiological accidents have been deduced from each event, when it was possible and categorised into 9 categories: mistakes in procedures (30%), professional mistakes (17%), communication mistakes (15%), lack of training (8.5%), interpretation mistakes (7%), lack of supervision (6%), mistakes in judgement (6%), hardware failures (5%), software and other mistakes (5.5%). Three types of direct and contributing causes responsible for almost 62% of all accidents are directly connected to the quality assurance of treatment. The lessons learnt from the accidents are related to frequencies of direct and contributing factors and show that most of the accident are caused by lack, non-application of quality assurance (QA) procedures or by underestimating of QA procedures. The international system for collection of accidents and dissemination of lessons learnt from the different accidents, proposed by IAEA, can contribute to better practice in many radiotherapy departments. Most of the accidents could have been avoided, had a comprehensive QA programme been established and properly applied in all radiotherapy departments, whatever the size.

1. INTRODUCTION

The ultimate overall goal of radiotherapy is to deliver a specified radiation dose to the prescribed target volume with the least dose to healthy tissues. This means a sophisticated balance between the cure of the illness and the possibility of radiation induced complications. The demands for precision and accuracy are high, because very often a small increase in radiation dose will have crucial influence on the probability of a cure but simultaneously the probability of induction of irreversible damage to the patient will increase [1].

An "error" is any deviation between the given numerical value of a quantity, such as the dose at a point or the position of a point, and its "true" value [2]. In radiotherapy, errors may arise from at least four main sources: (i) human mistakes caused by inattention, misunderstanding or misjudgment; (ii) instrumental mistakes caused by mechanical or electrical failure; (iii) random errors due to unknown and/or uncontrolled experimental conditions in the process involved in the planning and delivery of radiation; and (iv) systematic errors, i.e. biases, in the same set of processes. In the following discussion, mistakes will be

considered separately from the random and systematic errors. In principle, mistakes can be eliminated completely by a proper system of cross-checks of both human and instrument performance (by quality assurance system), although, in practice this may prove very difficult and expensive. Random and systematic errors, on the other hand, cannot be eliminated but the magnitude of these uncertainties can be reduced by accumulation of better data and improved techniques of measurements and delivery of radiation
(by improved quality control of all steps of radiotherapy process).

Regarding radiation safety, errors or poor performance in diagnosis can lead to a higher collective dose than necessary, leading to undue radiation detriment to the population. Errors or poor performance in radiotherapy can lead to **severe** consequences to patients, hospital staff and general public which is different from radiological accidents in industrial irradiation facilities where only the last two groups of people can be involved. The full benefit of radiotherapy treatment of cancer can only be achieved if the radiation doses to patients are accurate and reproducible. There are two fundamentally different but equally vital requirements for achieving this.

Firstly, accuracy and precision can be achieved by **high quality** measurements of the treatment beams and careful calculation of doses to target volumes, supported by a good preventive maintenance programme for the equipment, i.e. well implemented quality assurance programme.

Secondly, it is necessary to prevent a wide range of simple **errors, which compromise safety.** This second requirement has not always been acknowledged but its importance may be demonstrated by accidents at busy radiotherapy centres. Failure to recognise and deal with it waste the effort devoted to accuracy and precision of doses.

Even if all recommendations for quality assurance, local rules and practical guidelines are followed the occurrence of misadministration and accidents in radiotherapy departments are still very common. Some recent accidents and errors in radiotherapy have been well reported, others have not been as widely discussed. Different international organisations (IAEA, EFOMP) tried to collect data about the radiological accidents in radiotherapy but with a limited success.

This document gives short analyses of several radiological accidents arising from radiotherapy, considers some lessons which can be learned and which can be introduced in new quality assurance programmes to minimize accidents. It is hopped that better understanding the nature and major causes of misadministration events, users will have better basis for evaluating their quality assurance programmes to determine their effectiveness in preventing various accidents.

2.MATERIALS AND METHODS

2.1 Definition of radiological accident in radiation therapy

The Basic Safety Standards [3] defines the radiological accident as:

ACCIDENT is any severe unintended event, including an operating error, equipment failure or other mishap, the consequences of which cannot be ignored from the protection or safety point of view, and which usually leads to potential overexposure or to abnormal exposure conditions for treated patient, staff or general public.

Any radiological accident in radiation therapy may lead to potential abnormal exposure to all three groups of people covered by the definition, i.e. to patients, staff and

general public. Different categories of people have separate dose limits from radiation protection point of view, and therefore it is difficult to apply this definition uniquely to the different individuals involved in radiological accidents. Patients, staff and general public belong to categories of medical, occupational or public exposures, respectively. Occupational and public exposures are in most countries regulated on the base of the ICRP recommendation [4] and therefore any exposure over well defined limits could be considered as an accident, but medical exposures desire a detail description.

2.2. Medical exposures

Medical exposures are usually intended to provide a direct benefit to the exposed individual. If the practice is justified and the protection and safety optimised, the dose in the patient will be as low as is compatible with medical purpose. Any further application of limits might be to the patient's detriment. The ICRU [4] therefore recommends that dose limits should not be applied to medical exposures.

Medical exposures are also confined to exposures incurred by individuals as a part of their own medical diagnosis or treatments and to exposures (other than occupational) incurred knowingly and willingly by individuals helping in the support and comfort of patients undergoing diagnosis or treatment.

Optimum treatment of the patient in radiation therapy does not mean avoiding exposure to radiation but rather the most judicious application of radiation. The risk for the patient is twofold: first and foremost is the failure to control the initial disease which, when it is malignant, is lethal to the patient; second is the risk to normal tissue from irradiation. While there is always some risk associated with radiation therapy, the risk becomes excessive if, taking into account the dose fractionation, either the cumulative radiation dose is too large or a large volume of normal tissues is irradiated. The acceptable level of normal tissue damage will depend upon the natural course of the disease if untreated, the availability of alternative therapeutic modalities, and upon how well normal structures can be excluded from the target volume. It also depends upon the intent of the treatment; a greater risk of damage may be justified when the intent is the cure of cancer rather than palliation of symptoms or treatment of non-malignant disease. Hence, the risk to patient is manifested in both cases: if the dose to treated volume is less than 10% than the risk of proper tumour control is increased; if the dose to treated volume is 10% high than it is causing complication of the treatment. The value of 10% differing from a prescribed dose is nowadays generally accepted limit for increased complication rate or decreased tumour control for most malignant tumours [2]. Doses applied incidentally outside the proposed treatment volume are always causing complication.

2.3. Criteria for selection of radiological accidents

In order to learn more about selected aspects of radiological accidents the data from reported misadministration and accidents were compiled and analysed. Four basic specific issues were addressed in this analysis. These issues are:

(i) direct causes of misadministrations;

(ii) contributing factors;

(iii) preventability of misadministration and accidents through proper implementation of user quality assurance programme;

(iv) classification of potential hazard.

To facilitate analysis of the issues identified above, a simple database containing information about past misadministration events was developed. The criteria, used in this report, for choice of data to database where following:

a) All radiation therapy misadministration (defined in the Code of Federal Regulation (10 CFR Part 35)[5]):

1) A radiopharmaceutical or radiation from a sealed source other than the one intended;

2) A radiopharmaceutical or radiation to the wrong patient;

3) A radiopharmaceutical or radiation by a route of administration other than intended by the prescribing physician;

4) A therapy dosage of a radiopharmaceutical differing from the prescribed dosage by more than 10 percent;

5) A therapy radiation dose from sealed source such that error in source calibration, time of exposure, treatment geometry, machine failure, etc. results in a calculated total treatment dose differing from the final prescribed dose by more than 10 per cent.

Extending this definition to linear accelerators or other radiation therapy machines and treatment procedures it is possible to establish a basis for separating misadministration from random or systematic errors and uncertainties occurring during radiotherapy treatments.

b) All overexposures of radiation therapy facility staff exceeding annual limits defined by ICRP recommendation [4] originating from the use of radionuclide therapy sources, brachytherapy sources, unsealed sources and radiation therapy machines;

c) All overexposures of general public exceeding annual limits defined by ICRP recommendation [4] as a consequence of radiological accident in radiotherapy;

d) All abnormal occurrence events leading to increased risk to the patient, staff or general public which happened during radiation therapy procedures (mechanical, electrical hazards, etc.).

2.4. Sources of information

Basic source of data consists of Abnormal Occurrence Events reported in the National Regulatory Commission (NRC) [6] quarterly reports to Congress (NUEREG-9000 documents) issued from 1987 through 1992 as well as misadministration events contained in the NRC's Office of Analysis and Evaluation of Operating Data (AEOD) database. Some reports were obtained through different international organisations (IAEA, WHO), national medical physicists organisations (AAPM, HPA, SEFM, and others) and selected from published reports in different scientific journals or publications [7- 20].

A simple database was developed by interpreting and extracting information from the data sources regarding event causes, dose information, treatment modality and other parameters. The database contains up to date 147 records with reasonably described accidents and more than 100 with short records. A few typical accidents will be described elsewhere[21].

3. ANALYSIS OF RADIOLOGICAL ACCIDENTS

3.1 Direct causes and contributing factors

The analysis, based only on data interpretation and extraction from sources regarding event causes, dose information, treatment modality, and other parameters, depends on information provided by these reports. Some of them were reported sufficiently, but unfortunately in many of them the basic data, as a number of patients involved, were expressed by terms like "several patients", etc. Therefore, this analysis could not be regarded as completely exhausting. The main aim of this analysis was to show the extent of radiological accidents, their consequences and to point out a number of common threads that can be identified.

The principle product of analysis of each event should be an identification of the direct cause and the contributing factors that predisposed a direct cause. The ***direct cause*** is defined as a fundamental condition or error that directly results in the occurrence of an accident. A direct cause is absence, inadequacy, or improper implementation of a policy, action or decision that directly initiates or propagates the accident. ***Contributing factors*** are conditions, often environmental or contextual, which did not directly cause an accident. Rather, these conditions serve to increase the likelihood that direct cause will manifest itself, resulting in an accident.
In looking at the direct causes of most accidents analysed for this paper, it is interesting that most of the events involved more than one direct cause. This finding suggests that any steps taken to prevent accidents in future should be systematic in nature and should not address only specific direct causes.

Table 1 to 3 show the main causes of accidents in external beam therapy, brachytherapy and unsealed source therapy according to licensee's reports. In fact they did not express the very direct cause of accident but approximately only what had occurred.

Table 1: CAUSES OF RADIOLOGICAL ACCIDENTS IN EXTERNAL BEAM THERAPY.

Calculational error of the exposure time or dose	15
Inadequate review of the patient's chart	9
Error in the anatomical area to be treated	8
Error in identifying the correct patients	4
Error involving lack of/or misuse of a wedge	4
Error in calibration of Co-60 source	3
Transcription error of the prescribed dose	3
Decommissioning of teletherapy source error	2
Human error during simulation	2
Error in commissioning of TPS	2
Technologist misread the treatment time or MU	2
Malfunction of accelerator	1
Treatment unit mechanical failure	1
Accelerator control software error	1
Wrong repair followed by human error	1

Wrong position of the treatment marks on the body	1
Leakage radiation from accelerator	1
Wrong tattoo mark used to identify the treatment area	1
Miscommunication	1
Error in selecting treatment modality	1
Error in the computer programming entry	1
Human error during the treatment	1
Error in the formula for treatment planning computer	1
total	66

Table 2: CAUSES OF ACCIDENTS IN BRACHYTHERAPY

Wrong activities of brachytherapy sources were used	13
Inadequate procedures for placement of sources in applicator	9
Error in calculating the treatment dose	8
Error entered into the computer data	5
Lack of training of involved personnel	3
Brachytherapy source mishandling	3
Error in defining the treatment area	3
Failure to perform surveys and/or a week radiation safety	3
Lost of brachytherapy source	3
Equipment malfunction	2
Inadequate review of patient's chart	2
Unintended removal of sources by patient	2
Leaking I-125 source used in patient	1
Broken brachytherapy cable left source in patient	1
Incorrect number of brachytherapy sources	1
Inadequate patient restraint	1
Miscommunication among the licensee and staff	1
Misinterpretation of a computer error message	1
Wrong isotope entered into treatment planning system	1
total	63

Table 3: CAUSES OF ACCIDENTS IN UNSEALED SOURCE THERAPY

Error in identifying the correct patient	4
Error in verifying radiopharmaceutical labelling	4
Inadequate assay of the dosage in dose calibration	4
Lack of training of involved personnel	2
No verification of prescribed dose	1
Defective equipment	1
Error in calculation of dosage	1
Miscommunication	1
total	18

In effort to identify the relative impact of various direct causes of radiological accidents, the percentages of events in the database that involved each of the defined direct causes were also evaluated. Although this way of measuring the relative frequencies of specific direct causes of radiological accidents cannot be probably used to draw definite conclusions for true physical common cause. The measures provide valid insight into the degree to which specific causes are common to the sample of radiological accident included in the database. The next Table 4 shows frequencies of primary and secondary direct causes of radiological accidents.

Table 4: ABSOLUTE AND RELATIVE FREQUENCIES OF INITIATING AND CONTRIBUTING CAUSES.

Errors in judgement	***16***	5.7 %
Errors in procedures	***84***	29.8 %
Professional errors	***47***	16.7 %
Communication errors	***44***	15.7 %
Hardware and software errors	***13***	4.6 %
Training	***24***	8.5 %
Supervision	***17***	6.0 %
Error in interpretation	***20***	7.0 %
Other	***17***	6.0 %

The frequencies of direct causes of accidents, presented in Tab.4, reveal that the three most significant direct causes of accidents were inadequate procedures (29.8 %), professional errors (16.7 %) and communication problems (15.7%). These three direct causes were responsible for almost 2/3 (62.2%) of all accidents included in the database. The rest of other direct causes, which contributed to radiological accident, is approximately equally distributed.

Direct cause of inadequate procedures or failure to follow procedure represents procedures that are (a) erroneous, ambiguous, or incomplete; (b) unavailable in the proper place; (c) misunderstood; (d) not used at all. Examples include failures to verify dose information, failure to properly identify the patient or patient chart, failure to verify a treatment site, to verify number and activity of used sources, to verify labels, inadequate procedures to govern administration of radiopharmaceuticals, etc. The lack of procedures or errors in use of procedures for decommissioning of radionuclide sources, lost sources, decontamination actions might have impact on a number of staff and general public to be involved, not only on the patient. The majority of staff and general public involved in the studied events fall into this group.

Direct cause of professional error represents what can be thought of as human errors. Errors in which licensee personnel properly identified the patient, correctly understood the intended treatment procedure, knew how to properly administer the treatment, but still made some kind of mental or physical mistake fall into this category. Almost 17% of events involved professional errors as either primary or secondary direct cause. Typical examples of professional errors are arithmetic errors in calculating doses prior to administration, improper administration of dose, improper positioning of patient during simulation process, source calibration errors, etc. Although it could be argued that more stringent procedures, closer supervision, or more independent verification could have eliminated many of these errors, the events to which these primary direct causes were assigned appeared to be most directly caused by kind of slips and lapses that would likely have occurred regardless of the sophistication of procedures, the degree of training, or amount of oversight that might be present. Thus, they are attributed to simple professional errors. These errors might be easily prevented by incorporating effective human factors design principles into the treatment system. It is not likely, however, that any practical means will ever be found to eliminate all such professional errors.

Communication problems represent the third most common cause of radiological accidents. Communication problems include a lack of communication or the communication of incorrect information, either in written or vocal. More than half of studied events were caused by a lack of written directive, the rest by oral miscommunications, such as relying only on verbal means of identifying a patient, errors in transcribing information, errors in reading the information.

Of the remaining primary and secondary causes, hardware failures accounted only for 4.6%(the lowest value obtained), inadequate training accounted for 8.5 % which is comparatively high value that should be considered as serious problem and proper action must be advocated. An inadequate supervision accounted for 6%, errors for interpretation for 6% and other direct causes and unknown for 6% as well. Most of these direct causes are connected with radiation safety culture in the department.

The subjective nature of the event analysis and data development activities present a relatively large uncertainty in the percentage values presented here. We believe, however, that findings of this analysis provide a very valid indicator regarding the issues addressed. More detail analysis will require more exact data about radiological accidents which have occurred. The system might be useful for the future development of a proper reporting system and for data collection system on which more valuable detail analysis might be produced.

3.2. Observed consequences of accidents

The consequences of investigated radiological accidents range from almost no effect on the patient to the most probable contributing cause of death. The same can be applied to staff and general public involved also in some of the radiological accidents. The actual long-term consequences of accidents were not determined as a part of this study. The detail investigation of consequences is beyond this study.

It is very difficult to define the severity of radiological accidents. Several possible measures of severity can be considered. Perhaps the best measure of severity is reduced life expectancy resulting from the radiological accident. Of course, such measures were not available for most events and simple dedication from dependence of the measure from received absorbed dose is impossible. Likelihood of developing cancers due to the radiological accidents

make little sense for patients because many patients involved were already being treated for cancer. This gives some sense only for staff and general public involved in the radiological accidents. The real effect of radiological accidents represents a complex of different problems and therefore more detail studies will be necessary for finding a suitable measure of the severity of radiological accidents.

The following Tab.5 shows numbers of patients and staff and general public included in the database. As it was mentioned before, the numbers are only part of patients or staff and general public really affected by studied radiological accidents. For example in the famous and excellently reported 'Goiania' accident [7] more than 112 000 persons were monitored, of whom 249 were contaminated either internally or externally. Also, the environment was severely contaminated in this event pointing out another serious consequence of radiological accidents.

Table 5: NUMBER OF PATIENTS AND STAFF OR GENERAL PUBLIC INVOLVED IN RADIOLOGICAL ACCIDENTS.

Category	Involved	Fatal	Adverse effect
Patients	1616	15	around 1000
Staff and general public	4343	4	around 250

4. LESSONS LEARNED

Lessons have been learned from the reported accidents which occurred in radiotherapy departments. The general lesson learned from the analysis of radiological accidents is that licensees who have experienced radiological accidents often lack a comprehensive radiation safety culture, which shapes all aspects of daily operations and which regards patient, staff and public safety as the primary objective of all activities. Some specific lesson learned are briefly summarized as follows:

1. Radiation therapy can generally be performed with high precision and safety only if the equipment which affects the relationship between the prescribed dose and the dose delivered (such as treatment units, lasers, simulators, diagnostic equipment used for localisation and determination of tissue properties, treatment planning computers and devices for blocks and compensator fabrication) fulfill certain minimum requirements, which is done through acceptance tests and commissioning of equipment. Mistakes which happened during the commissioning of equipment and sources, such as:

- calibration of new beams or beams after source replacement,
- determination of beam output for Co-60 machine and dose per monitor units for accelerator,
- preparation of proper decay tables for radionuclide sources,
- proper commissioning of treatment planning systems,
- preparation of proper tables for output factors and wedge factors used for calculation of treatment plans,
- checking of activity of delivered closed and unsealed sources,

affected very large number of patients. When commissioning is complete, the whole system must be tested by comparing the dose planned for a given point in a suitable phantom with the dose measured at that point when the phantom is treated, like a patient, by the person who will routinely operate the machine. Commissioning mistakes can be prevented by:

- human redundancy,
- independent checks performed within institutes,
- independent external audits,
- by in vivo dosimetry performed at least for the first patient's treatment session,
- by well established quality control programme must be ensured that commissioning machine's standards are being maintained during the clinical life time of the equipment (quality control).

However, few events indicate that operators can force equipment to function under conditions which were not explored either by the manufacturer or by the commissioning process. Now therefore, it is also recommended that the equipment operators are given the opportunity to explore the limits to which they will push the equipment in routine use while confirming by measurement that the delivered doses are as expected.

Information for treatment planning, including data on depth doses and dose distributions, as supplied by the manufacturer, should not be used clinically without independent confirmation of the actual values. Back up copies of programmes and data files in use are essential.

2. Most of the radiological accidents analysed in this study involved a lack of procedures, inadequate procedures, or failure to follow procedures. Procedures that require:

- the positive identity of patient through the diagnosis and treatment,
- positive identity of treated tissues,
- clear and unambiguous procedure for tattoos,
- clear and consistent procedure in connection to images from different diagnostic techniques (nuclear medicine, ultrasound, CT, NMR) for simulations,
- radionuclide to be used for treatment,
- isotope source strength,
- location of the source,
- location of patient with radionuclide, etc.

should be carefully prepared and followed.

Although these mistakes affect usually only one patient each time, this type of mistake appears rather often. Failures in patient identification are very critical for all treatments performed only with one fraction (LDR, MDR brachytherapy, radiosurgery).

Prevention of these mistakes can be done by:

- clear identification of patient by photography attached on the patient's chart,
- double check of treatment chart,
- communication with the patient,
- clear assignment of functions,
- clearance by signatures,
- human redundancy, etc.

Effective procedures provide step-by-step instruction in a clear, concise manner for the completion of all tasks. They anticipate potential problems and provide means for detecting, avoiding, or correcting these problems. This means written procedures. Unwritten procedures are never clear and are frequently a feature of accidents. The procedures should not specify only how the work will be done but also when it will be done.

Note that merely developing procedures will not prove effective unless those procedures are fully carried out. Proper implementation means that staff members are aware of the procedures, understand them, have received training regarding the intent and provisions

of the procedures, and that the procedures are unfailingly used and followed. Even the best procedures are useless if they are not understood or used by the staff. A great deal of flexibility can be retained in using effective procedures with the proviso that this flexibility can be exercised or authorised only by staff members who have the knowledge, experience, training and responsibility (both legal and administrative) to deviate from the standard procedure.

3. Mistakes in patients chart:
- wrong dose per fraction or total accumulated dose recorded,
- wrong number of fraction,
- wrong calculation,
- wrong beam quality,
- wrong wedge identification,
- misreading of dose or dosage,
- misreading of the activity units,
- misreading of the patient full name, etc.,

are quite frequent mistakes which affect individual patients. These mistakes can be prevented by:
- two independent revisions per week (i.e. by two persons: physicist, radiotherapist),
- clear written procedures,
- clear definitions of functions and responsibilities,
- clearance by signatures,
- by verification systems.

The manual checking system serves two related distinct purposes: it is immediately effective and remains effective in eliminating most of the results of human fallibility under conditions applying in the centre, and provides a solid basis for the design of an automated system of treatment calculation and dose treatment verification. But even automated verification system has to be check before treatment of patient is started.

4. It is sometimes suggested that brachytherapy procedures involving implantation of sources are simple by comparison with teletherapy and do not need to be written down. However, this is a mistaken view because most of the operations are manual, providing great opportunity for human errors. Mistakes like:
- wrong radionuclide,
- wrong activity of sealed or unsealed sources,
- wrong application time,
- inadequate placement of sources in applicator,
- wrong calculation,
- wrong unit of activity,
- unintended removal of sources by patient,
- incomplete removal of the sources after application,
- wrong handling and storage of sources,
- damage or loss of sources,
- waste disposal,

are examples of mistakes which are as frequent as mistakes in external beam therapy. Most of these mistakes involve one patient, but they are dangerous because the treatment is usually performed in one fraction.

Prevention of these mistake can be achieved by:
- clear procedure for labelling and cross-checking of sources,
- clear allocation of functions for verifying sources,
- records keeping the movement of all sealed sources both inside and outside an establishment,

- checking of sources after application,
- measuring the patient before release,
- storage, use, issue and receipt of sources only by authorized person,
- clearance by signatures,
- quality control of sources and brachytherapy machines, etc.

5. Communication problems represent mistakes which were observed in many of radiological accidents. Communication problems include:

- lack of communication or the communication of incorrect information,
- verbal means of identifying a patient,
- language problems in multiliquinal countries or with large ethnic communities,
- errors in transcribing or reading information,
- oral miscommunications,
- vagaries of handwriting,
- use of unfamiliar, nonstandard or collegial terms,
- labelling of foreign made equipment not in mother language,
- telephone communication,
- interpersonal difficulties,
- use of part-time employees in key positions,
- messy work environment, etc.

Miscommunication mistakes can be reduced by:

- defining safety critical communication,
- preparing procedures for proper communication,
- defining responsibilities and functions for all member staff participating in communication process,
- insisting on written information,
- human redundancy,
- clearance by signatures,
- preparation of check list.

Due to the large number of steps and the number of persons involved in the treatment preparation, the transfer of information from one step to the next is very critical point. Indeed, errors due to inadequate transfer of information will be reflected in every next step and can seriously affect the final results of the treatment.

6. Unique conditions and changes in routine were identified as highly significant contributors to the radiological accidents. These changes or unique conditions might include:

- personnel changes,
- change of the supplier of equipment or radioactive materials,
- change of usual dosage,
- change of units for activity,
- performing a treatment in new location,
- treatment a patient with unusual position for the prescribed site, etc.

These changes or unique conditions serve to introduce unfamiliar and possibly difficult circumstances, which increase the likelihood of errors. The analysis of radiological accidents suggests that it would be beneficial for the licensee to:

- establish mechanism that help anticipates problems associated with changes and unique conditions,
- define formalism of clear, concise, disciplined procedures,
- perform additional training,
- define responsibility for treatments.

7. Based on analysis of the radiological accidents it would appear that the frequency of hardware failures resulting in accidents is low. The consequences of these hardware failures are, however, potentially very severe and have usually effect on many patients. Errors in hardware include such as:

- misinterpretation of displays and conflicting signals,
- safety interlocks failure,
- overriding of safety interlocks,
- improper maintenance,
- software errors having influence on the operation of a machine,
- hardware incompatibilities,
- treatment in non-clinical modes,
- abnormal operation, etc.

It seems likely that the evolution of a more rigorous safety philosophy through the application of disciplined procedures could result in the creation of fault tolerant system in which hardware failures, should they occur, could be quickly detected and, by carrying out systematic mechanisms to detect and mitigate hardware failures, the general impact of these failures might become negligible. Nevertheless, it is necessary to carry out:

- redundancy and independence of safety systems,
- testing of a machine under all possible clinical situations and operating mistakes,
- for treatment use only clinical mode,
- preventive effective maintenance,
- avoiding of bypasses in safety interlocks,
- training of operating staff also in abnormal situations of machine operation,
- redundant, diverse safety systems independent of operating systems.
- better contact with manufactures for obtaining information about all mishaps, accidents which happened with their machines.

8. Lack of responsibility, supervision and training were also observed in most radiological accidents. These include:

- inadequate education and training,
- overestimating responsibility,
- ignorance of written "bureaucratic" procedures,
- unawareness of Local Rules,
- lack of safety culture,
- lack of environmental and personnel monitoring system,
- lack of duties of radiation protection supervisors,
- lack of emergency planning and preparedness, etc.

Protection of the patient can only be assured by :

- specifying entry qualification and training of all staff,
- specifying safety-critical function for each member of staff,
- drawing up a training programme for all staff,
- integration of radiation protection and safety into education and training programme,
- maintenance of a training schedule,
- indication of foreseeable accidents or occurrences and preparedness,
- recommended action for abnormal machine operation,
- provision for adequate communication in an emergency,
- keeping ongoing monitoring the programme.

9. Safe decommissioning of facilities is very important, as it can be documented by two most disastrous radiological accidents [7,8], where hundreds of persons were affected, happened due to the lack of decommissioning procedures. Decommissioning procedures involve:

- removal of sealed sources from a radiotherapy machine,
- disconnection of accelerators from power supply,
- disposal of sealed radionuclides when they are leaking or damaged,
- waste disposal from brachytherapy and nuclear medicine departments, etc.

. Radiation and contamination check must be made of the equipment from which the source(s) has been removed, followed by:

- if necessary, decontamination procedures,
- clear unambiguous labelling of 'empty' and 'clean' containers.

Arrangement must be made for the containment and packing of the sealed source(s) and contaminated items/waste, in preparation for reuse, safe temporary storage or proper disposal, as appropriate.

10. Based on the lesson learned from many radiological accidents apparently human errors are major contributors. Typical examples of human errors are following:

- arithmetic errors in calculation of dose or dosage,
- improper administration of dose or dosage,
- improper positioning of patient during simulation or treatment,
- source calibration errors,
- human-machine interfaces,
- misreading of information,
- misinterpretation of signals, alarms or warnings,
- decision or judgment errors, etc.

When designing a system for protection of the patient, it must be considered what the system requires from a human worker and what the worker can reasonably be expecting to do. This requires:

- proper design of equipment considering human limitations,
- space and time for training activities,
- concentration on work and not to attempt to do more than one thing at a time,
- proper workload of workers,
- proper housekeeping,
- function allocation,
- well-written equipment manuals and procedures,
- professionalism of all staff,
- allocation of additional resources (money, space, personnel support etc.).

Many of other factors which may contribute directly or indirectly to human errors leading to occurrence of incidents or accidents can be identified, like shift practices at facilities which operate twenty-four hours a day, overtime and on-call status, working hours etc. Research aimed at identifying common features in causes of human errors is required in this field [22].

From lessons learned it is oblivious that most of the accidents could have been avoided, had a comprehensive quality assurance programme been established and properly applied in all radiotherapy departments.

5. CONCLUSION

Safety is not to be considered in isolation or as a separate chapter of the radiotherapy syllabus for education of professionals. Rather, safety should be incorporated in all steps of management of radiotherapy, so that an *integrated quality management* system involves both quality and safety [23-25].

In fact, most of the control measures to monitor quality serve to detect any deviation concerning safety as well, since the parameters to be controlled are often the same. The quality control programmes and frequency of the constancy checked can be designed to combine both objectives (quality and safety). Test tools exist nowadays to make more frequent relative measurements as constancy checks, which monitor quality and safety at the same time.

To meet the very high requirements, many of the world's leading radiotherapy centres have implemented or are implementing techniques used in other disciplines, where the prevention of errors and mistakes in order to produce a high quality product over a large number of pieces of product is an everyday issue, and therefore this techniques are very developed. This permeability among different fields (with due care of the differences between industry and medicine) can only render mutual benefits. Elements of this technique (known as *quality management system* and fully defined by ISO standard 9,000/2) can be incorporated as a central framework for planning and delivery of radiotherapy services.

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WOULD ISO 9000 HAVE PREVENTED THE TWO MAJOR RADIOTHERAPY ACCIDENTS IN THE UK?

(Abstract)

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There have been two major radiotherapy accidents in the UK. In Exeter, 207 patients were overdosed by 25%, and, in Stoke-on-Trent, just under 1000 patients were underdosed by about the same amount. The ISO 9000 quality assurance system should create an environment an a culture where the risk of such an accident is minimised. In this presentation, the background to the two accidents is analysed in the light of the question - would these accidents have occurred if ISO 9000 had been in place in the two centres?

II. EXPERIENCES ON CURRENT STATUS. QUALITY CONTROL PROCEDURES FOR EQUIPMENT

PRINCIPLES AND METHODOLOGY

EXTERNAL QUALITY AUDIT PROGRAMMES FOR RADIOTHERAPY DOSIMETRY AND EQUIPMENT

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Abstract

It is widely accepted that individual radiotherapy centres should have in place a comprehensive quality assurance programme on all the necessary steps for the delivery of safe accurate treatment. There are many sets of recommendations on quality assurance and quality control programmes, particularly for megavoltage external beam radiotherapy. Linked to this there are many sets of recommendations on the tolerance required on different parameters and procedures in order to achieve the clinically desirable precision in treatment.

External checking of the achievement of standards has evolved for a number of reasons. One is to provide general quality audit of the implementation and effectiveness of the local institution's quality assurance programme. One particular aspect of this has been to test the consistency of treatment delivery for patients entered into clinical trials and many audits have been associated with particular trials or trial groups. Thus seen from the perspective of the institution an external check is an audit, whereas seen from the perspective of, for example, a clinical trial the external check is a form of quality control.

As regards the performance of radiotherapy equipment and dosimetry, the most widely used process of external checking has been dosimetry intercomparison, comparing independently measured doses to locally stated doses in a variety of conditions. These have been at a number of different levels: from basic beam calibration; up to and including exercises employing anatomic or pseudo-anatomic phantoms and incorporating tests of treatment planning equipment and procedures. Some of these have been one-off exercises, whilst others are continuing, or have given rise to on-going quality audit programmes on a national (or wider) basis. A number of these have evolved, or are evolving, into audits which include external checking of the achievement of standards in performance of treatment equipment, as well as in the dosimetry in each institution involved.

The principles and methodologies of the various types of external checking programmes for treatment equipment and dosimetry are reviewed, covering the experimental approaches and the tolerances applied. What is included in a given programme will, of necessity, depend on the resources available and the purpose of the exercise. Methods and tolerances must be matched to endpoint. Tolerance levels must take into account the experimental uncertainties of the measurement methods employed. Finally, external audit can only be used to complement, and in conjunction with, institutional quality assurance programmes and not as a substitute for them.

1. INTRODUCTION

Quality assurance has always been recognised as vital in order to achieve high quality safe and accurate radiotherapy treatment with optimal outcomes. Historically, formal quality assurance has often been regarded as being linked to those technical and physical aspects which have been easily specified and measurable, and has frequently been limited to what should more correctly be termed quality control. However it has been increasingly acknowledged that quality assurance should be formally implemented at all levels and encompassing all processes relevent to the overall radiotherapy process [1]. This has led to the development of recommendations for comprehensive quality assurance programmes, or quality management systems, to be applied in individual radiation oncology centres [2-4]. Quality audit is an essential part of such a system, to test the effectiveness of its application. The following sections firstly define quality audit, discussing the terminology used and some general principles relating to audit. General methods applied to audit of radiotherapy dosimetry and equipment are then outlined as background to the more specific subsequent papers.

2. QUALITY AUDIT

Quality audit is a systematic independent review of a quality assurance programme or quality management system. It can be used to test both the implementation, or operation, of the system and the effectiveness, or performance, of the system. Thus audit should be both procedural and practical in approach. Independence in this context means that the methods of review must be independent of the procedures and processes under consideration, ie. using evaluation techniques, and equipment where necessary, that are external to the system under test. Total independence implies external personnel. Alternatively, if audit is internal to the institution, independence means at least personnel who are not responsible for the performance of the product or process under review. Quality audit must be conducted against pre-determined quality standards, linked to those which the quality assurance system under review aims to achieve, and should require action if these standards are not met. Quality audit should therefore be regular and should form part of a quality cycle or loop, whereby observations from audit exercises should be fed back into the quality system, leading to improvements. These in turn should be audited at the next exercise. Thus quality audit is not a substitute for local quality assurance, rather the two are complementary. Quality

audit is the last necessary step in a comprehensive quality management system and the system should be responsive to audit findings. The rationale of quality audit is to test the system by testing the overall structure of the quality system as well as a subset of parameters, procedures, records, etc. Just as quality assurance procedures should be applied at all levels and to all processes involved in radiotherapy treatment, so too should audit be developed and implemented at a range of appropriate levels and for a range of appropriate processes.

Quality audit in radiotherapy is not a new phenomenon. For example, there are many types of internal audit, carried out within a given radiotherapy centre using local personnel, procedures and equipment, which are suitably independent of the part or parts of the system being monitored or verified. One increasingly used technique, which can be considered as an internal audit of the quality of treatment delivery and all prior contributing processes, is the routine use of on-line treatment verification devices such as portal imaging systems and in-vivo dosimetry [5]. Similarly, many departments have long-established internal audits of clinical procedures and clinical results. An increasing number of centres have taken part in external quality audits organised in parallel with clinical trials [6-14], as a necessary condition of participating in the trial. However the term 'quality audit' may not necessarily have been applied to these activities. At times there is an unavoidable blurring between the terms quality assurance, quality control and quality audit, depending on the vantage point of the observer. For example, as seen by an individual department, the external testing of procedures regarding patient selection and treatment techniques for clinical trials is an audit, whereas from the point of view of the trial it is quality assurance. A trial associated dosimetry intercomparison is an audit of local dosimetry and equipment, but again from the point of view of the trial it is a quality control process.

Recently there has been a growing emphasis on more formal approaches to audit in radiotherapy and on developing their wider applications to routine practice. In part this has arisen from the impetus given to audit of dosimetry from the many national and international dosimetry intercomparison exercises [15,16]. At the same time much more focussed attention has been given to the need for formal and robust quality management systems for radiotherapy, based on ISO 9000 principles and incorporating a requirement for audit [2-4,17]. These moves are partly linked to regulations and/or recommendations which have appeared following recent specific accidents in radiotherapy and partly to wider requirements for clinical and medical audit being applied generally to health care provision [18,19]. Additional factors include the increasing demands for more detailed audit linked to clinical trial participation and the requirement in some countries for audits to be included in the assessment procedures for departmental accreditation or licensing [20].

For practitioners in the various disciplines involved in radiotherapy, audit is an additional tool to aid in maintaining and demonstrating the provision of consistent and continuing quality, as is required to achieve optimum clinical treatment criteria. Whilst good quality assurance procedures and the implementation of quality audit will assist incidentally in

reducing the occurrence and consequences of radiotherapy accidents and errors, this is not the prime purpose of current moves to encourage all departments to participate in audit exercises. Rather it is to improve the general level of quality of treatment and to provide an evolving mechanism to continue to effect improvement. The overall aim in this is to improve treatment outcome.

3. QUALITY AUDIT OF RADIOTHERAPY DOSIMETRY AND EQUIPMENT AS PART OF A QUALITY ASSURANCE PROGRAMME

There are many sets of national and international recommendations on quality assurance and quality control for radiotherapy dosimetry and equipment [1,21-23]. These include recommendations on the tolerances required on different parameters and procedures in order to provide clinically desirable standards of precision in treatment, as well as recommendations on the appropriate frequencies for quality control tests of different degrees of complexity [24]. These are implemented in individual institutions within the context of the local quality assurance programme which will depend on local structure and resources. Whatever the level of implementation, both internal and external checking of the achievement of the standards then becomes desirable to close the quality loop. External checking of dosimetry and equipment performance has been one of the most widely applied forms of external quality audit in radiotherapy. This is partly because it is relatively straightforward to implement systematic checks in these areas, quality standards being well defined. In addition it is important as a first step to ensure that quality is being achieved in each institution in the provision of this basic 'dosimetric infrastructure', because of the potential for such things to affect the treatment of significant numbers of patients.

4. DOSIMETRY INTERCOMPARISON

The most widely used process in the audit of radiotherapy dosimetry has been dosimetry intercomparison, in which doses are measured in individual departments using external independent equipment and methods and the measured values are compared to the locally stated or calculated values. Most of these exercises have been for external beam megavoltage photons and electrons, although a few have considered kV x-rays and brachytherapy sources. The methodology has been based on visits, using ion chambers, or on mailed dosimeters, usually TLD. Intercomparison types and their design criteria have been discussed recently by Thwaites and Williams [16], whilst intercomparison methods and results have been reviewed in a number of publications [13-16, 25,26]. Dosimetry intercomparisons have been carried out at various levels in the clinical dosimetry chain. A relatively large number have used conditions duplicating or approximating treatment beam calibration reference conditions and these have been summarised recently by Thwaites [27]. A smaller number of exercises have simulated multi-beam treatment delivery to an anatomic or semi-anatomic phantom which has gone through a full treatment planning process [7-10,15,26,28,29].

The typical aim of an intercomparison exercise has not necessarily been to provide an audit as such, but rather to establish the accuracy and precision of dosimetry at critical points in the chain within a given country or region, or for groups of centres participating in clinical trials. However intercomparisons have by default also provided an audit of the dosimetry of the centres involved, in that usually discrepancies outwith some pre-determined value have been followed up, for example in the UK photon intercomparison each deviation greater than 5% resulted in further investigation [15]. Intercomparisons have thus introduced and promoted the development and acceptance of audit. In addition, they have provided the basis of practical dosimetry audit methodology and have resulted in a baseline dataset useful as a reference point for subsequent audits.

As an example of a dosimetry intercomparison which has provided the basis for an on going audit system, the UK megavoltage photon dosimetry intercomparison [15] was carried out under the auspices of the IPSM and selected two major dosimetry levels to be investigated. These were (i) up to and including treatment beam calibration and (ii) up to and including the basic physical aspects of planned multi-beam irradiation. The aim was to separate out the underlying dosimetric aspects of treatment from the specifically clinical and patient-related aspects as a first step to be tested. A geometric phantom was designed to be relatively simple in shape (trapezoidal) and set up, but to enable the contribution of a number of relevant factors to be tested. It was constructed from water-equivalent epoxy-resin plastic with interchangeable inserts to take an ionisation chamber in pre-determined positions. An 8 cm diameter lung-equivalent plastic insert could replace the standard plastic to introduce an inhomogeneity (Figure 1).

The phantom and measuring equipment were taken to all UK centres. Reference point measurements were made in all (161) cobalt-60 and megavoltage x-ray beams. The mean ratio (measured-to-stated dose) was found to be 1.003, with a standard deviation of 1.5%. All the ratios lay within ±4% of unity, with the exception of two results. One of these moved within 4% when account was taken of the daily output calibration factor. The second involved a large error in a Co-60 calibration which led to an official investigation [30] and has been widely publicised due to this. 97% of measured ratios lay within ±3% of unity, which has often been taken as a suitable tolerance level for clinical trial audit compliance. In addition two three-field planned irradiations were carried out, one with no inhomogeneity and one with the lung-equivalent insert included, on one beam only in each centre in order to test beam data acquisition and some basic aspects of treatment plannning systems and algorithms. The mean ratios (measured-to-stated doses) were found to be close to 1.01, with standard deviations of approximately 3%. 89% of measured doses lay within 5% of stated values. A subsequent UK-wide intercomparison of clinical electron beam dosimetry is currently underway funded by the Department of Health (NHS Management Executive), to be completed in 1996 [31].

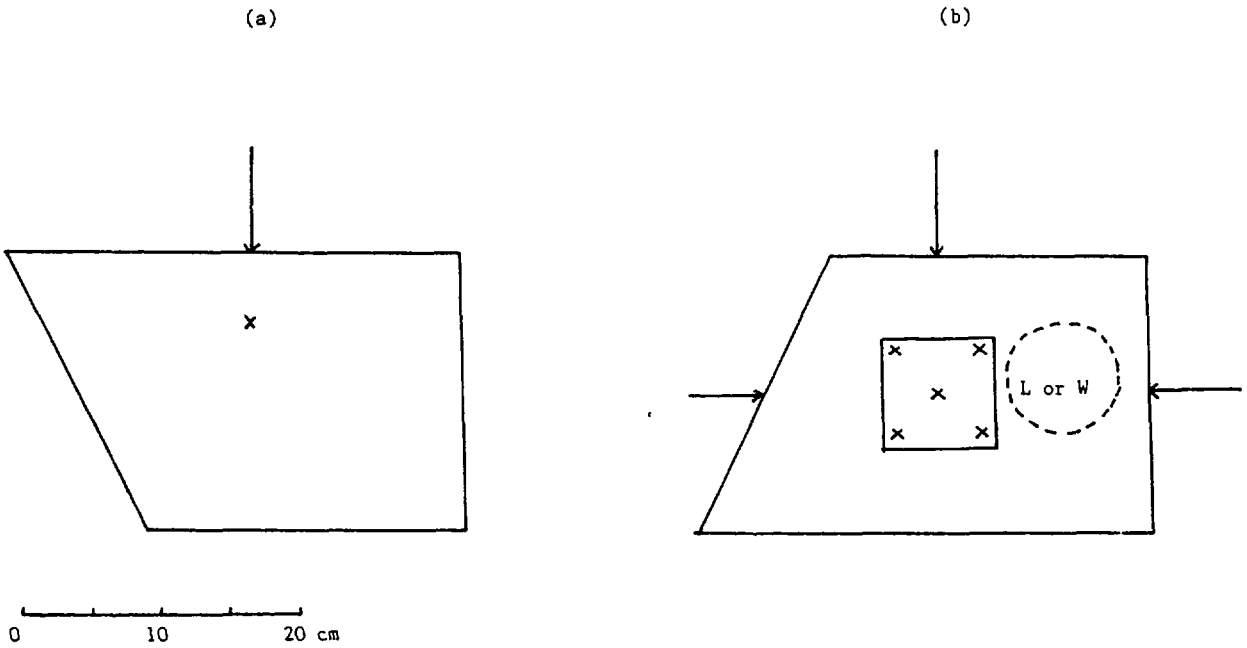

FIGURE 1. SCHEMATIC DIAGRAM OF THE SOLID WATER-EQUIVALENT PLASTIC PHANTOM USED IN THE IPSM PHOTON DOSIMETRY INTERCOMPARISON. The dimension perpendicular to this plane is 25 cm. x represents a measurement point, the dashed line represents an interchangeable insert of either water-equivalent or lung-equivalent plastic, the solid line represents the 'target volume': (a) shows the arrangement for reference point measurements, (b) shows that for the three-field planned irradiations.

TABLE 1. SUMMARY OF TESTS AND TOLERANCES APPLIED IN THE SCOTTISH+ GROUP.

Geometric/alignment tests	± 2 mm
Field size	± 3 mm
Pressure measurement	± 0.5%
Chamber calibration	± 1%
Beam quality	± 2%
Beam calibration (photon and electron)	± 3%
Specific single field data:	
eg field size factors, tray, wedge factors, depth dose values, etc.	± 2%
Planned multi-field irradiations:	
- geometric phantom and semi-anatomic phantom, dose values	± 5%
Procedural audit	UK recommendations

5. FROM DOSIMETRY INTERCOMPARISON TO DOSIMETRY QUALITY AUDIT

Whilst a Dosimetry Intercomparison is essentially a one-off scientific exercise to ascertain accuracy and precision, nevertheless the term 'dosimetry intercomparison' can also be used to describe the essential practical approach used as part of wider dosimetry quality audit. Some of the characteristics that a dosimetry quality audit should have which may distinguish it from a Dosimetry Intercomparison are: an audit would typically have a wider scope than an intercomparison, in terms of what was being checked and tested; quality standards would be necessarily pre-defined, in terms of tolerance levels and possibly also action levels (or alternatively minor and major deviations); feedback from the auditors to the centre would be necessary, with any points for action identified, and a response from the centre would be required where appropriate; some level of procedural audit should be incorporated, which may include inspection of relevant methods, instructions and records and discussion with local personnel if the audit is based on a visit, or on a questionaire if by mail; and audit should be regularly repeated at an appropriate frequency.

Clinical trial associated exercises have generally been designed as audits from the outset, having most or all of the above characteristics [eg.6-11,13,14]. Most of these include audit of a wide variety of dosimetry and equipment performance parameters, including mechanical and geometric treatment unit and simulator characteristics, dosemeter and treatment beam calibration, radiation beam data for both reference and non-reference single fields and the performance of treatment planning systems and procedures in multi-beam irradiation siuations. In addition many other relevant procedural and practical parameters are audited in connection with selection, treatment, dosimetry and reporting of patients entered into a particular trial. Some simpler intercomparison systems, not associated with clinical trials, are really also audits, such as the long-established IAEA/WHO mailed TLD service for checking Co-60 beam calibrations [32,33].

The concept of a more widely available and regular quality audit of radiotherapy dosimetry and equipment has gradually developed out of the experience from these specific trial audits and from the growing number of isolated intercomparison exercises. Here the aim is to provide the opportunity of audit for any institution. Whilst the underlying philosophy and principles are the same, the practical approach needs to be assessed carefully in the light of the potential extension from a relatively limited number of centres to all centres and to open-ended continuing audit.

6. ROUTINE EXTERNAL QUALITY AUDIT OF DOSIMETRY AND EQUIPMENT PERFORMANCE

A number of general questions can be raised in considering the possible structure of a routine on-going external quality audit system for radiotherapy dosimetry and equipment performance. There is no unique set of answers applicable for all countries or regions, as account must be taken of local circumstances and in

particular of any already existing audit programmes. The resources available for audit may determine both the audit structure and the design of practical audit methods. This is turn influences the scope of audit in terms of the content, frequencies and tolerances involved. Systems need to be cost-effective, leading to considerations of how the exercise is costed and paid for and also of ensuring effectiveness of audit in relation to the development and structure of local radiotherapy centres and quality assurance programmes. This makes flexibility of design necessary to allow different levels of audit to be applied to suit the local situation, such that the audit can be matched to the resources available and also so that audit is at an acceptable level to local personnel and not seen either as too simplistic by some centres or on the other hand too advanced by others. Audit methods should be structured to use a step-by-step approach to test simpler levels first, but to allow the development of more complex levels, moving nearer to the point of patient treatment and involving more complex parameter testing, as the situation allows. An individual centre, or a local organisation, could then select the appropriate level of audit to suit their circumstances. Both resources and effectiveness have a bearing on choice of the interval between successive audits. It is generally accepted that this should ideally be one year, but no more than five years [34].

Mailed audit systems may be cheapest to operate in many circumstances. However they reduce the scope of both the practical and the procedural audit; they may typically have larger associated measurement uncertainties; ambiguities in local interpretation of mailed instructions may affect the results; and there are inevitable delays in feedback and response. Nevertheless this will often be the preferred organisational basis of audit systems with a wide geographical spread. Thus the IAEA [35], the US RPC [13,14] and the European developmental systems [36-38] all employ this approach, using TLD as the practical measurement method. The EORTC audit has also recently developed mailed TLD methods of a very similar nature [39]. Whilst the RPC and the EORTC intend the use of mailed dosemeters as a first-line approach, they also supplement this with selected site visits. Audits based on site visits, using ion chambers as the measurement method, can be more flexible, responding immediately to information gathered; can include more parameters can vary parameters as required; should typically have better precision; and can include a much more comprehensive procedural audit. However they will be more expensive in audit personnel time for both travel and audit. These systems are appropriate for centres which prefer and can support detailed audit of a more complex nature and which are within acceptably close distances for site visits to be manageable.

Different models have been proposed, or actually set up, for the administration and direction of audit systems and again this necessitates flexibility to allow for local circumstances. Developing audit systems should take account of existing exercises, to utilise these in the optimum way, maximising linkage between structures and minimising overlap and duplication. Thus in at least one country, Finland [20,40], audit of dosimetric infrastructure is statutory and is carried out centrally by a national centre. There are other national centres

set up to carry out audit activities, such as that in the US [13,14], but with no regulatory requirement that centres participate in audit. On the other hand the IAEA/WHO audit programme was set up originally with one global centre [32,33], but with a developing network of local national or regional link centres to assist in the operation of the system. In some countries, such as the UK, interdepartmental audit has been piloted [41,42] in a developing network system [43], which grew out of the national dosimetry intercomparison experience. Most clinical trial audits and national and regional dosimetry intercomparison exercises were established with a single measuring centre or a small team of auditors. Increasingly, as audit is extended to more and more centres and as it is established as a regular on-going programme, a more flexible approach is required and this has encouraged the further development of networks as a solution to the problem.

7. AUDIT NETWORKS

The concept of an audit network is to provide a flexible system which can link in to - or incorporate - existing audit programmes and which can attempt to alleviate some of the problems associated with wider participation in audit. A network is set up to have a number of nodes which act as regional - or possibly national - centres. These may simply provide co-ordination and linkage between other parts of the audit programme, for example measurement and reporting centres, and individual hospitals, if part of a larger-scale system. Alternatively these centres may organise and carry out audit and provide an interface between that particular audit group and other groups or other audit programmes in other areas, if that particular audit system is a stand-alone one. Audit networks can be developed to have variable sized groups to suit local circumstances, although each group needs to be of manageable size, taking the audit methods and scope into account. Different approaches can be employed in different groups without problem, as long as there are at least some common minimum standards and points of contact. By utilising existing audit systems, networks can minimise overlap and ensure there are no audits carried out which are not appropriate to the centres involved. In this way cost-effectiveness is also optimised regardless of the local situation, by tailoring the audit to suit that situation.

The IAEA/WHO mailed TLD audit system was implemented essentially as a network from the outset, with one central measuring centre. The UK photon dosimetry intercomparison was carried out with some elements of a network incorporated into its organisational structure. Both of these have been extended recently and can be contrasted as examples of possible audit network development.

8. THE IAEA AND EUROPEAN PILOT QUALITY AUDIT NETWORKS

The IAEA/WHO system was originally set up in 1966 for Co-60 beam calibration checks only. This has very recently been extended via a development programme to checks on beam quality and beam calibration for megavoltage x-rays, using a modification of the well-established simple IAEA TLD holders to be irradiated in a

water phantom [35]. A 'multi-purpose phantom', with a shape based on similar principles to that of the UK intercomparison phantom (Figure 1), has been designed by an advisory group [44] to test a wider set of megavoltage photon parameters and simple planning performance. It is a rigid trapezoidal container made from PVC, to be filled with water, in which 11 TLDs can be inserted at different depths on and off axis to be irradiated simultaneously. It has been evaluated at Villejuif and has been pilot tested in a number of reference centres [36,45]. In addition a system is under development for use in electron beams [46,47]. Exactly the same designs are being used in a parallel European Commission funded project, being developed in conjunction with the IAEA work, with members of advisory and development groups being common to both systems [36- 38,48]. This is aimed at extending the possibility of audit to any centre not already involved in existing audits in both Western and Eastern Europe. These programmes have actively developed the idea of networks to cope with the potentially large numbers of institutions involved. This has been achieved by having, at least in these initial stages, one measuring centre preparing, sending out, receiving back and reading out the TLDs and one co-ordinating centre to administer the system. As the link between these and individual hospitals, national or regional reference centres have been designated which have carried out some initial procedural audit by mailed questionnaire and which have acted as the two-way channel for information and dosemeters [48]. These centres would also act as an initial point of contact, where appropriate, to attempt to solve any problems which arise. In any of these steps, confidentiality of results is necessary. The intention of the development is to pass the responsibility for the audit system to national bodies as soon as procedures are established, with an international co-ordinating and advisory role retained [48].

9. THE UK QUALITY AUDIT NETWORK

By contrast the UK national audit network is based on site visits and ion chambers as the measurement method, but many of the network principles are similar. The network arose out of the photon dosimetry intercomparison exercise and its findings [15] and began to develop in 1991/2. It utilises the same methodology as the intercomparison for the basic practical approach, but extends the scope and allows for development of the system. It is coordinated by IPSM and has a Steering Group, chaired by S Powley (Lincoln) and made up of a representative of each of the seven geographically organised regional network groups in the UK. Each of these groups contains around 9 radiotherapy centres, serving populations of 8×10^6 on the average, and to a certain extent each group is developing its own approach to what is audited and to audit methods. The Steering Group meets to review experience and to make recommendations on what might be considered a minimum common or standard content to the audit, to allow a basic uniformity of inter-group comparison at occasional intervals to ensure that the whole system is linked across the country. Currently the recommended minimum standard audit includes similar measurements to those in the original dosimetry intercomparison, including dosimetry checks to encompass ion chamber calibration, treatment beam calibration, beam quality

checks, beam modifier checks and computer plan accuracy. As a minimum, one machine and one modality should be audited in each centre and the recommended frequency of audit is yearly. Procedures and records for dosimetry and quality control should be included in the audit. The aim of a standard audit is to demonstrate that radiation doses admininistered to patients are within 5% of those prescribed, in accordance with ICRU 49]. The general approach has been to use varying degrees of inter-departmental audit [42], whereby centres are audited by peer professionals from other centres within the group. In some groups this has been organised from one central co-ordinating hospital, whilst other groups have used mutual audit, in which centre 1 audits centre 2, which in turn audits centre 3 and so on. Inter-departmental audit is cost-effective, but requires co-operation and trust between departments. In any of these structures it is again imperative that confidentiality of results be maintained between auditor and audited department. Occasional linkage between the groups, at least at the level of absolute dose calibration, can be made by visits during other exercises. For example the current national electron dosimetry intercomparison will include at least one photon beam test in each centre visited. Other linkages occur through clinical trial audit visits such as that set up for CHART [8-10]. Alternatively occasional special visits can be made to one centre of each group, for example the NPL is currently completing such an exercise to test absolute dosimetry methods, organised in conjunction with the IPSM Steering Group. Links to other audit systems can be made through the participation of centres in international trial audit programmes or via interfacing to other routine programmes. In this context the Edinburgh centre has been involved in the development and pilot testing of the IAEA and European systems.

In practice almost all the UK network groups have developed their systems to include more parameters than the minimum standard audit, in some cases much more [42,50]. This was one intention of setting up a flexible system, to attempt to ensure that audit content could be developed and would not simply become entrenched at a basic level. It is important in this context that audit development be directed by relevant professional groups, so that the audit scope can evolve in appropriate ways, to reflect the changing requirements, techniques and standards in the speciality. A number of the groups have already implemented regular electron beam audit and some groups are already actively considering piloting kV beam and brachytherapy audit. At least some of the groups have developed external beam treatment planning and treatment delivery audit using more complex semi-anatomical phantoms to be used as a next step after the geometric phantom. Figure 2 illustrates the semi-anatomical phantom developed for use in the 'Scottish+' group (Scottish centres, plus Newcastle, Carlisle and Belfast). This allows tests of a number of planned irradiations simulating different clinical situations.

This latter group is implementing a hierarchical audit, in the sense that annual audit visits are to be carried out, but different levels of the dosimetry chain are to be tested in different years, over a five year cycle. The first step in this hierarchy is to carry out some simple tests of mechanical

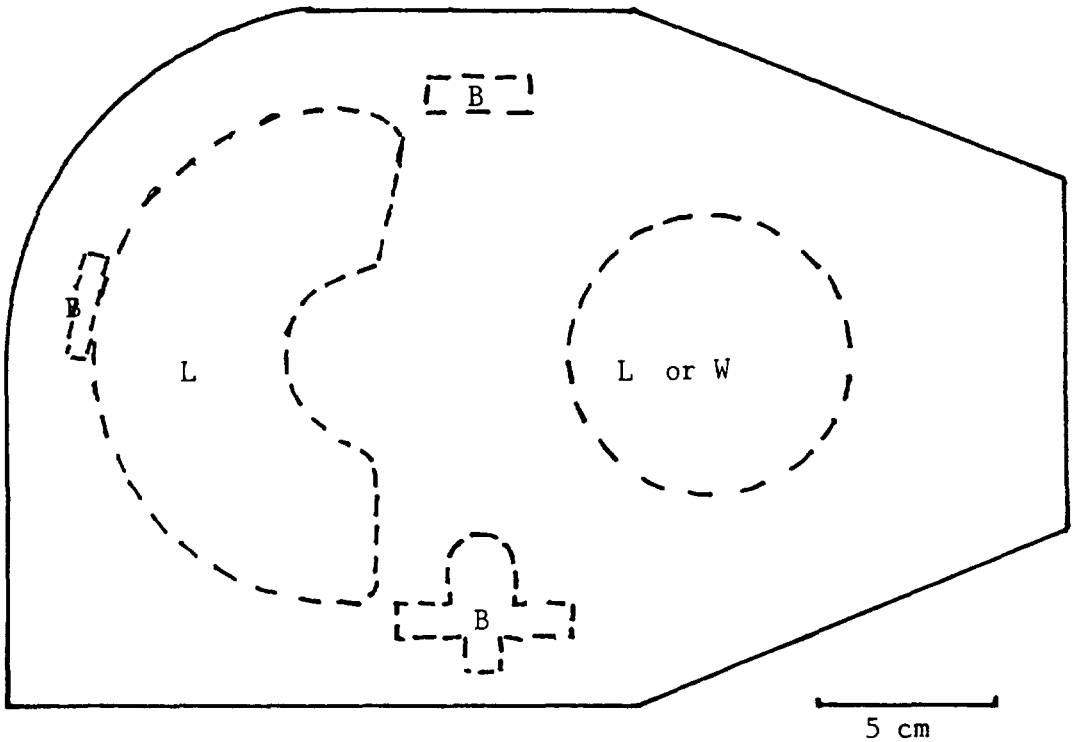

FIGURE 2. SCHEMATIC DIAGRAM OF THE SEMI-ANATOMICAL PHANTOM DEVELOPED FOR INRERMEDIATE STAGE AUDIT IN THE SCOTTISH+ AUDIT NETWORK GROUP. The phantom is constructed from solid water-equivalent plastic and has inhomogeneities of bone-equivalent and lung-equivalent plastic. One inhomogeneity is interchangeable and accepts the cylindrical inserts from the geometric phantom. the phantom has dimensions and shapes to simulate breast, thorax, head and neck, etc. situations.

and geometric parameters of treatment equipment, to audit dosemeter and beam calibration and beam quality, to test a sub-set of single field data and to audit the procedures, tolerances, frequencies and records for dosimetry and quality control in the centre. The second step is to test a more complex sub-set of single field data and to utilise the geometric phantom (Figure 1) to audit the basic practical planning methods and data. Allied to this, procedural audit of treatment planning can be developed. Subsequent levels utilise different areas of the semi-anatomic phantom at different visits. The aim is to move along the dosimetry chain making the audit more complex, and incorporating previous levels into subsequent audit tests. The end-point of this evolution is the development of audits using anatomic phantoms and audit at the level of treatment delivery to the patient. Of course, at these more involved levels, the participation of other professions, such as radiographers and radiotherapists, becomes necessary and the dosimetric and equipment audit begins to interface to medical and clinical audit. Using a five year cycle means that the basic (level 1 - 2) audit is repeated approximately twice throughout the lifetime of a machine. However problems observed on a subsequent audit could

trigger investigations using a lower level audit if necessary. In addition the availability of the audit equipment and structure could be used to provide independent verification of definitive calibrations of new treatment machines, replacement cobalt sources or following major repairs as appropriate and as recommended by IPSM [51] and others [34].

To implement such systems requires sufficient pump-priming resources, at least to cover the development stages. The Scottish+ group were funded initially by the Scottish Home and Health Department's Clinical Resource and Audit Group to develop the methodology. This funding provided equipment, phantoms and some funding towards the personnel time involved. The funding was provided though on the understanding that ways would be identified to transfer the costs for the routine on-going audit onto the individual radiotherapy centres.

As an example of the outcome of this type of audit programme, the Scottish+ results are typical of the overall UK network results. Representatives of each centre in the Scottish group, as it was originally, initially met to agree the content and methodology of the system and to discuss audit tolerances. As a starting point, tolerances were set to be generally compatible with UK [52] quality control recommendations, but with beam calibration and planned irradiation audit tolerances set at twice the standard deviations observed in the national dosimetry intercomparison. Table I summarises some of the tolerances used. Procedural audit 'tolerances' were taken to be the UK recommendations given in dosimetry protocols and quality control guidance. To date approximately 35 photon beams and 35 electron beams have been audited at levels 1 and 2, involving approximately 500 separate parameters. Of these, five have been found out of tolerance; two wedge factors (at 3% deviation), one electron beam calibration (at 4.6% deviation), one photon beam quality (at 3.8% deviation) and one geometric performance parameter (at ±4 mm on an older machine). The procedural audit has not observed any major problems, but the initial experience of this leads to the conclusion that it needs to be more tightly defined. The overall good agreement means that there is probably scope to reduce the tolerances for subsequent tests at the same levels. The next audit round, involving the semi-anatomic phantom is to begin shortly (summer 1995).

10. CONCLUSIONS

Quality audit generally in radiotherapy, as well as specifically in the area of radiotherapy dosimetry and equipment performance, is now a well-proven tool. It improves overall quality, focusses attention on problem areas and provides confidence that the required quality standards are being met. It can identify systematic problems in the quality assurance programme of a particular centre and thereby help to minimise the occurrence or consequences of accidents and errors. Quality audit should be available as a routine on-going programme to all centres and current moves to develop quality audit networks are designed to do this. These systems require careful organisation to be cost-effective, to minimise overlap, to link existing studies where they are already established, to ensure confidentiality of audit

results and reports and to provide flexible approaches which can be tailored to the requirements of the radiotherapy centres involved locally. Audit scope and content, as well as the inherant quality standards, should be evolving to encompass more and more areas of the radiotherapy process, as resources and structure allow. Involvement of the relevant professional groups is necessary in managing and developing audit in an appropriate way. Participation in external audit for radiotherapy is strongly recommended.

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A GLOBAL PROGRAMME FOR ESTABLISHING DOSIMETRIC QUALITY AUDIT NETWORKS

(Abstract)

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The IAEA and WHO are jointly taking steps to improve dosimetric quality assurance for radiotherapy centres for developing countries. Three components are already in place.

The IAEA/WHO of Secondary Standard Dosimetry Laboratories (SSDLs) provides calibration of dosimetric equipment and establishes calibration traceability for hospitals.

The IAEA/WHO TLD Postal Dose Intercomparison Service checks dose calibration of radiation beams of teletherapy units in more than 300 hospitals yearly. This service is also used to check on calibration performance of SSDLs.

The TLD service has reached about 1000 hospitals. The results show that many treatment beams have an unacceptable calibration. Until 1991 all results were from Co-60 irradiations. Since then the service has been expanded to include X-ray beams from medical accelerators. Also since 1991 the IAEA has sent a follow-up TLD set to all hospitals and to all SSDLs having poor results. Up to now all follow-up measurements with SSDLs have shown improvement, providing results within established acceptance limit. Follow-up measurements with hospitals, however, have not been satisfactory in many cases, even after a second follow-up. Consequently, more attention is required, as well as on-site measurements and discussions with the hospital's physicist.

Today about 2000 Co-60 units and medical accelerators are in routine use in developing countries, based on responses to a survey being done by IAEA. In addition more and more accelerators are being installed that also produce electron beams. The TLD service, therefore needs to expand accordingly.

Furthermore, an effective quality control system for dosimetry, involving patient treatment must look at more than just the calibration of the radiation beam. It also has to examine all dosimetric steps from dose prescription to dose delivery to the patient. Such a system, using TLDs in human shaped phantoms presently is developed in European centres with the IAEA's co-operation. To include all European hospitals, the participation of several reference centres is required to operate a TLD service and to follow-up detected discrepancies.

As a consequence of all these experiences, the IAEA/WHO is moving to decentralise its quality control programme. It is now planned to merge the IAEA/WHO TLD Postal

Dose Service with the IAEA/WHO Network of SSDLs and establish an SSDL/Hospital Quality Audit Network. Several SSDLs, each in connection with a well established Radiotherapy Department will form National Reference Centres operating a TLD dose intercomparison service, eventually also covering neighbouring countries.

In this new scheme the IAEA/WHO will take over the co-ordination and will design and implement a measuring programme to control the quality of work of the Reference Centres.

The IAEA already has started to establish Reference Centres in Argentina, India and Thailand. Still this year, additional SSDLs will join supported through an IAEA initiated Co-ordinated Research Programme on this matter. The US and the EU operate already Quality Audit Networks in close contacts with the IAEA, the Australian Radiation Laboratory might join these efforts.

This all could lead to a global programme "Quality Audit Network" having a potential to significantly improve patient care for millions inflicted with cancer.

QUALITY CONTROL PROCEDURES FOR EQUIPMENT: THE EORTC RADIOTHERAPY GROUP EXPERIENCE

(Abstract)

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The QA program of the Radiotherapy Co-operative Group of the EORTC (European Organisation for Research and Treatment of Cancer) has included quality control procedures for equipment from its starting date in 1982. During on-site visits carried out by a team of radiotherapists and physicists the following equipment checks and measurements were performed :

- mechanical and beam alignment checks of simulator and therapy units
- measurements of the dose homogeneity for X-ray and electron beams
- intercomparison of ionization chambers
- measurements of the depth dose distribution at several depths
- absorbed dose determination in specific points in water for several combinations of field sizes and accessories, for photon and electron beams

In addition calculations of treatment time and monitor units were carried out for reference cases and the relevant beam data from all machines in use were collected

In order to provide a follow-up of the on-site visits, a mailed TLD program was then established in 1986. The program has been very successful, the centers are eager to participate since it constitutes an independent check of the measurements performed by the local physicists. It also allows to detect dosimetric problems in centers not yet included in the site visit program. To date, all participating centers have been monitored by mailed TLD, several more than once This has led to the decision of stopping the site visits unless large deviations cannot be resolved by a second TLD mailing

The Radiation Physics Department of the Goteborg University Hospital has been the main partner in this QA effort. Since 1993 the mailed TLD program continues in co-operation with the Institut Gustave Roussy in Villejuif Besides water phantom measurements on the beam axis, the IGR, in collaboration with the Radiation Physics Center in Houston, is planning a procedure to check off-axis doses by means of a TLD-loaded multi-purpose phantom.

1. Introduction

The Radiotherapy Cooperative Group of the EORTC (European Organization for Research and Treatment of Cancer) was formed in 1975 with the goal of improving long-term results of curative radiotherapy by carrying out clinical research studies based on new developments in radiation physics and radiation biology. Today, more than 80 institutions are participating in the 11 currently active protocols, accruing more than 1000 patients per year.
Already in 1982, a Quality Assurance program was initiated and, from its start, it also included quality control procedures for equipment. Detailed results and analysis have been published (see reference list). In this presentation, the dosimetric intercomparisons carried out during the early site visits will be reviewed; mechanical checks and beam alignment of the units will also covered as well as results of the follow-up mailed TL dosimetry campaign.
The motor behind the program was K.-A. Johansson from the Sahlgren Hospital in Göteborg, Sweden. Since 1993, the mailed TLD procedure is organized together with the Institut Gustave Roussy in Villejuif, France.

2. Dosimetric intercomparison

During the site visits of participating institutions, one team consisting of radiation oncologists evaluated the clinical aspects of treatment, while a second team, consisting of physicists, reviewed the dosimetry aspects. Between 1982 and 1985 seventeen European radiotherapy centers were audited.
A Farmer-type and an NACP plane-parallel chamber, both calibrated with the associated electrometer, were used for water phantom measurements in photon and electron beams, respectively. For each unit, measurements were carried out for a combination of field sizes (6x6, 10x10 with and without wedge filter/shadow tray, 20x20 and 12x20 cm^2 for photon beams and 10x10 and 20x20 cm^2 for electron beams) and depths along the beam axis.
The mean, standard deviation and range (difference between highest and lowest value) of the ratios of the absorbed dose to water determined by the visiting team and the absorbed dose stated for patient treatment by the institution are given in Table I:

TABLE I - RATIOS OF MEASURED TO STATED ABSORBED DOSE TO WATER

Radiation Beams	Mean	1 S.D.	Range
59 Co-60 beams, 5 cm depth	1.001	0.019	0.10
140 x-ray beams, 5 cm depth, 4 - 25 MV	1.013	0.032	0.13
electron beams, d_{max}, 4 - 25 MeV			
- 59 beams with scattering foils	0.995	0.017	0.09
- 58 with scanning beam system (sbs)	1.001	0.027	0.11
- 31 sbs with no recombination loss correction	1.088	0.044	0.16

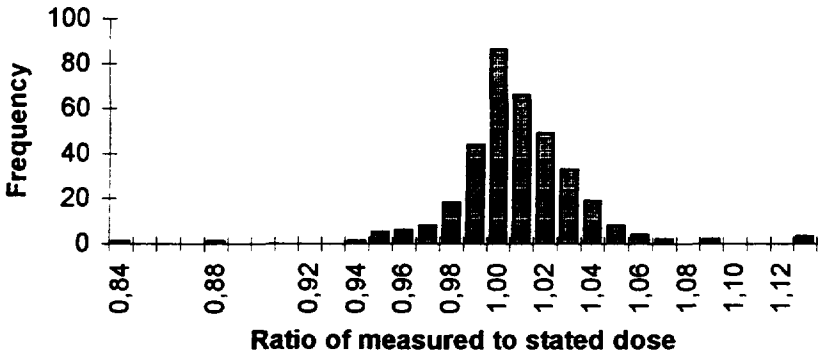

Fig. 1. Frequency distribution of the ratios between measured and stated dose (1987-1992).

The adopted acceptable levels of variation, including the measuring uncertainties, were ±3.1 % for Co-60 photons, ±3.2 % for x-rays and ±3.4 % for electrons. Major deviations were defined as greater than twice the acceptable level, minor deviations being between these two levels. For Co-60, 85 % of all beams were within the acceptable limits and there were no major deviations. The spread was larger for small field sizes and for fields with beam modifiers. For x-ray beams from 26 accelerators, the average measured value is 1.3% higher than the value stated by the institutions, 70 % of all photon beams were within the acceptable levels of variation and 5 % were major deviations; the largest deviation was 9 %. The main reason for the significant deviation of the mean ratio from unity is the fact that most of the institutions were not yet using a modern dosimetry protocol. The relatively large spread in the results is also caused by the fact that some centers having monitor chambers of the accelerator sensitive to atmospheric conditions did not correct for daily changes in air pressure and temperature. When the dose value stated by the center was corrected by means of a check measurement of the reference field before and after the review, the resulting spread was reduced: for 16 beams the σ and the Δ values were reduced from 0.033 and 0.14 to 0.022 and 0.09, respectively. For electron beams, 80 % of the beams from scattering foil units and 63 % of those from scanning beam units were within the acceptable levels of variation. The absorbed dose was underestimated by up to 18% for some accelerators with scanning electron beam-flattening systems due the fact that the dose stated by the center had been determined without correcting for the relatively higher recombination losses typical for these units. In addition, as for photon beams, the use of unsealed accelerator monitor chambers contributed to the large spread in the results.

The off-axis dose distribution at one depth (5 cm for photons and d_{max} for electrons) for a 20x20 cm^2 field was also evaluated by means of a film irradiated in a polystyrene phantom. The results were satisfactory for most of the photon beams, the low energy accelerators with only photon beams having a significantly more uniform dose distribution. For electron beams, only 60 % of the 20x20 cm^2 field size beams had both flatness and symmetry within the acceptable levels of variation and major deviations were detected in 8 % of the beams. The reason for this large deviation, observed especially in electron beams with energies lower than 10 MeV, is that for several accelerators there is a distance of 5 - 10 cm between the end of the applicator and the patient surface resulting in a broader penumbra.

3. Mechanical checks and beam alignment

During the site visits mentioned above, it was observed that some of the problems were caused by unsatisfactory mechanical adjustment of the units. Beginning in 1987, both for treatment

units and for simulators, mechanical checks were included in the physics part of the EORTC site visit program and were carried out before starting the dose measurements
The results presented here cover 16 centers representing a total of 23 accelerators, 14 cobalt units and 14 simulators for a grand total of 1299 irradiation parameters A complete check list for one unit covers 32 parameters subdivided into

1 Isocenter indication, collimator rotation, room lasers and optical distance indicator (2 mm)
2 Angular scales of gantry and collimator (0 5°)
3 Field size indication and coincidence between light and radiation field (2 and 3 mm)
4 Stability of gantry and collimator using lateral opposed beams (3 mm)
5 Table movements to test the vertical and lateral treatment couch displacements (2 mm)

The values in parentheses represent the acceptability limit ε for the parameter checked. It takes into account the accuracy aimed at, as well as the experimental uncertainties

Observed deviations were considered as acceptable (A), minor (m) or major (M) when their absolute value Δ met the following respective criteria.

- $\Delta \leq \varepsilon$ acceptable (A)
- $\varepsilon < \Delta \leq 2\varepsilon$ minor deviation (m)
- $2\varepsilon < \Delta$ major deviation (M)

Table II below summarizes the results: for the three types of units, it gives their distribution in % for each of the five groups of checks subdivided according to the acceptability level of the observed deviations

TABLE II - DISRIBUTION (%) OF MECHANICAL AND BEAM ALIGNMENT CHECKS

Check	Isocenter			Angles			Fields			Stability			Table		
Deviations	A	m	M	A	m	M	A	m	M	A	m	M	A	m	M
Accelerators	83	9	9	82	12	6	70	22	9	96	0	4	67	19	14
Cobalt units	36	21	43	78	11	11	57	36	7	69	31	0	67	25	8
Simulators	64	29	7	90	0	10	71	21	7	85	15	0	58	33	8

The majority of observed deviations are acceptable Among the major deviations, 3 cobalt units showed an 8 mm maladjustment of a laser and a 10 and 20 mm maladjustment of the optical distance indicator, for each unit type there was one occurrence of maladjustment of the field size indicator (9 mm, 9 mm and 10 mm, respectively) The best scores are obtained for the angular indications Cobalt units scores are inferior to those of accelerators and simulators, especially for isocenter indication with 43 % of major deviations and only 36 % of acceptable deviations This is certainly due to the advanced age (up to 20 years) of some of these units.

4. Mailed TL dosimetry

The aim of the EORTC-RT group mailed TLD program is to serve as an independent check as well as a complement to the on-site visits described above During the period from 1987 to 1992, the various beams of 55 different institutions were monitored, several more than once, for a total of 127 mailings (Table III), covering 357 photon beams

TABLE III - REPEATED INSTITUTION PARTICIPATION

# of participations	1	2	3	4	5	Total
# of institutions	18	16	11	6	4	55
# of mailings	18	32	33	24	20	127

The centers received a special PMMA holder consisting of a flat and of a long tube with a hole at 5 cm from one end to accomodate the TL dosimeter The two parts are easy to mount before use The complete set-up consisting of the holder and the inserted TLD capsule was to be placed in a container filled with water up to the top of the tube and a dose of 2 Gy was to be delivered at the position of the dosimeter The ratio between the absorbed dose to water determined by the measurement and that stated by the institution for a total of 357 beams is shown in figure 1 The mean and the standard deviation are 1 007 ± 4 % and include two values of 0 50 and 0 51 not shown in the figure for better clarity 243 beams or 68 % showed an acceptable deviation (within ± 4 %), 9 beams or 2 5 % showed major deviations (larger than ± 7 %)

In order to follow the development of the dosimetry for some of the institutions that have participated more than once, the results of three consecutive mailings were analyzed for 13 centers with both cobalt units and linear accelerators The mean and standard deviation of the ratios of measured to stated dose are shown in Table IV

TABLE IV - TLD RESULTS OF THREE CONSECUTIVE MAILINGS

# of participations	1	2	3
Cobalt units	1 036 ± 0.069	1 009 ± 0 013	1 004 ± 0 012
Linear accelerators	1 030 ± 0 036	1 015 ± 0 018	1 009 ± 0 021

The large standard deviation for cobalt units at the first participation is partly due to the inclusion of a major deviation It can be seen that the mean ratio is approaching unity with a decreasing standard deviation with increasing number of consecutive mailings For linear accelerators, the mean is slightly above unity probably due to the use of different dosimetry protocols and to the lack of correction by some institutions for ion recombination losses

Since October 1993, the mailed TLD program is run in cooperation with the Institut Gustave Roussy 26 institutions, most of them already checked in the past, have been monitored for a total of 71 beams No major and 7 minor deviations were found Figure 2 shows the frequency distribution of the measured to stated dose ratios The peak is at unity with a mean value of 1 015 and a standard deviation of 0 021 The reason for this shift of the mean is currently being investigated by requesting from the institutions details about their dosimetry procedure

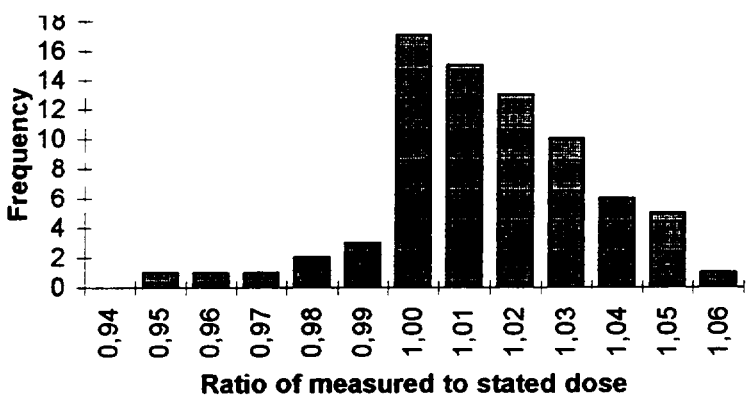

Fig 2 Frequency distribution of the ratios between measured and stated dose (1993-1994)

5. Conclusions

The strong point of the quality control procedures for equipment of the EORTC Radiotherapy Group has been the organization of the site visits of participating centers. Important dosimetric shortcomings, such as use of outdated dosimetry protocols or non-correction for ion recombination losses for scanned electron beams, have been discovered, discussed with the local physicists and corrected. The beam alignment and mechanical checks carried out at the same time have been as a whole quite satisfactory and have allowed the visited centers to focus their attention on problem areas and motivated the the local responsibles to implement modern QA procedures.
The mailed TLD program is now deemed sufficient to monitor beam calibration. Site visits will be limited to centers with repeated major deviations of the TLD check and/or where other QA procedures of the group (dummy runs, individual case reviews) reveal serious problems.

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RADIATION ONCOLOGY QUALITY ASSURANCE IN RTOG PROTOCOL STUDIES - PHYSICAL ASPECTS

(Abstract)

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All multi-institutional protocol studies do require quality assurance monitoring programme to assure validity of collected patient treatment and outcome data. The RTOG, over the past two decades, has developed an integrated clinical quality control programme for radiation oncology to assure that the treatment is delivered in compliance with requirements of the protocol. The different components of the programme and their specific aims are:

- Participation during protocol development - to assure unambiguous statements on radiation treatment specification.
- Initial radiation treatment review - to minimise variations from protocol requirements while patients are in early phase of treatment.
- Retrospective final review - to confirm the delivered treatment and score each case according to pre-established compliance groups.
- Compilation and reporting of QA results - to provide feedback to participating institutions and relevant RTOG committees.

The RTOG Headquarters dosimetry staff is actively involved in both the initial and final review. A computerised data monitoring and reminder system is in place to ensure the timely submission of all required information. During initial review the dose description, field placement and calculated dose are reviewed by a dosimetrist and radiation oncologist for protocol compliance. The final review is an overall evaluation of protocol compliance, primary emphasis on primary tumour, regional nodes and critical structures with respect to field border placement, total dose delivered, applied fractionation and total elapsed days of treatment. Copies of localisation/simulation radiographs and beam portal verification films of all fields treated, isodose distribution on the central plane of the tumour, dose/monitor unit set calculations and daily radiation treatment records are submitted to RTOG Headquarters to complete the final review. The dosimetrists perform a recalculation of dose delivered from all fields treated on those cases selected by a random sampling program, which has been in effect since 1991. Machine calibration data used in the dose calculation are forwarded to the RTOG Quality Assurance office from the national Radiological Physics Centre (RPC). Agreement in dose delivery must be maintained at 5%.

The compliance observed during initial review is better than 98%. However, there is still a continuing concern about delinquent data and/or data received too late for review. The compliance score for final review shows some variation between the different protocols, but it is in the range of 80-95%. The variations are primarily due to protocol ineligibility or incomplete treatment delivery and not due to any significant dose and/or treatment deviations from protocol.

THE EUROPEAN PILOT NETWORK FOR QUALITY ASSURANCE IN RADIOTHERAPY

(Abstract)

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Based on the IAEA/WHO experience in mailed dosimetry, a Quality Assurance Network, sponsored by the EC Committee "Europe against Cancer", has been set-up in 1991. For all European Centres not involved in clinical research, besides a survey of radiotherapy facilities, the project includes three measurement steps: a check of beam output and quality in reference conditions with a mailed TLD procedure, the mailed verification of other beam data and dose calculation procedures with a multipurpose phantom, and in vivo dosimetry at the individual patient level with mailed dosimeters.

The results concerning 228 beams from 105 Centres have been analysed (75 Co-60 beams and 153 X-ray beams). 33 beams present minor deviations (3 to 6%) and 12 beams (4/75 Co-60 beams and 8/153 X-ray beams) from 11 centres present major deviations (≥6%). The analysis shows that 13/33 minor deviations and all major deviations have been detected in centres which have not benefited from an external check during the last 5 years; in 10 out of 12 large deviations, the measured dose is smaller than the stated dose. This makes the clinical detection of such deviations more difficult. In most centres with major deviations, the physicists did not have the necessary experience and did not calibrate regularly the beams. In 5 Centres out of 11 there was no dosimeter or the dosimeter available had not been calibrated recently. In 4 Centres the physicist did not give any explanation. The conclusions concerning the second step (multipurpose phantom) outline the larger magnitude of the deviations for off-axis points, oblique beam incidence, and the use of wedge filters.

EROPAQ QUALITY ASSURANCE NETWORK: RADIOTHERAPY INFRASTRUCTURE AND TLD INTERCOMPARISON

(Abstract)

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The first steps of the EROPAQ project are: assessment of the radiotherapy infrastructure, equipment and staffing, and mailed TLD dosimetry intercomparison of beam output and quality of radiation beams. The infrastructure questionnaires were received through the Reference Centres (Budapest, Prague, Warsaw) from all Polish (18), all Hungarian (11) from 19 out of 22 radiotherapy centres in the Czech Republic. There are only 19% of linacs, but 35% of Co-60 units, 7% of Cs-137 units, 4% of betatrons and 35% of conventional X-ray units. About 47% of teletherapy units is older than 12 years and about 20% of machines is older than 21 years. Only 30% centres in Czech Republic and 40% centres in Hungary are equipped with simulators, while in Poland all, but one centre have simulators. Average number of patients treated per radiation oncologist, physicist and radiographer are comparable with West European countries.

The TLD project started with the set-up of the TLD system: calibration, reader and evaluation procedures. In the TLD intercomparisons with the EC Measuring Centre (IGR, Villejuif) and with the IAEA, agreement in system calibration within 1% has been obtained. Intercomparisons with the Reference Centres verified the precision of EROPAQ procedures: the distribution of deviations of measured and stated dose had a mean of 0.6% and SD = 1.4%. The acceptance level of ±3% (2 SD of the system uncertainty) was set for EROPAQ TLD audits. From 104 beams checked before February 95, 80 results (77%) were found within ±3% limit. The remaining 24 (23%) beams were incorrectly calibrated. Nine beams showed deviations larger than ±6% (4 SD of the system uncertainty), and the immediate corrective action was undertaken. More than half (22/43) audited centres did not participate in any external dosimetry check in the last 5 years. In these centres, 66% of a total number of photon beams checked but only 55% of gamma beams were within acceptance limit, while in the other 21 centres, checked before, these figures were 84% and 91%, respectively. The sources of errors were thoroughly investigated, discussed with the participants and corrected.

DOSIMETRIC ITERCOMPARISON PROGRAMME FOR Co-60 THERAPY UNITS IN ARGENTINA

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Abstract

Thermoluminescence dosimeters (TLD) are widely used to verify absorbed dose delivered from radiation therapy beams. The Regional Reference Center (RRC) for Dosimetry of Argentina uses TLD for its mailed dose intercomparison programme for cobalt 60 radiation therapy units. Results obtained since 1978 as well as causes of dose discrepancies greater than 5% are analyzed.

Results of the external quality control performed by the IAEA for this programme indicate that the dose evaluated by the RRC TLD service for the participating centers is about 1% lower than that evaluated by the IAEA TLD service. This deviation is accepted taking into account that a ± 2% dose uncertainty for TLD dosimetry is reasonable.

1. INTRODUCTION

The Regional Reference Center (RRC) for Dosimetry of Argentina was established in 1968 by agreement between the World Health Organization (WHO) and the National Atomic Energy Commission (Comisión Nacional de Energía Atómica CNEA) of Argentina in cooperation with the International Atomic Energy Agency (IAEA).

This RRC is a Secondary Standard Dosimetry Laboratory (SSDL) belonging to the IAEA-WHO-SSDLs Network. As similar secondary laboratories existing in other countries the RRC was established due to the necessity of improving the dosimetry and treatment plannings in radiation therapy centers and to increase the participation of specially trained physicists within the staff of these centers.

The most relevant activities performed by this SSDL in the field of radiation therapy are calibration service for dosimeters used in radiation therapy; calibration programme for cobalt therapy units in the country; dose intercomparison programme for cobalt therapy units using mailed TLD dosimeters; clinical dosimetry at hospital; advisory about clinical dosimetry to radiation therapy centers; organization of post-grade courses for physicians, for physicists to be specialized in physics in radiation therapy and for technicians to be trained in radiation therapy dosimetry

In Argentina radiation therapy is carried out in a large number of medical centers using external beams from different types of machines and using brachitherapy. With a population of about 32 million inhabitants there are at present 84 cobalt units and about 30 linear accelerators in operation.

To obtain satisfactory cancer cure rates in radiation therapy it is essential to ensure a dosimetry accuracy better than ± 5% . This requires not only internal checks performed by the radiotherapy department itself, but also external checks made by intercomparisons with other centers or external audits made by national or international reference organizations [1].

Since 1966 the IAEA offers a postal dosimetry service to developing countries all over the world in order to check the beam output of cobalt 60 machines, and more recently for high energy X ray beams From 1974 to 1977 the RRC contributed to the IAEA/WHO TLD service by sending the set of capsules to the therapy centers and giving them technical assistance in the experimental procedure for the intercomparison. Only few centers benefited with this programme: from about 80 cobalt therapy machines operating in Argentina at that time only 15 completed the intercomparison during the mentioned period.

In 1977 through the IAEA Research Contract RC 1791/RB the RRC started to develope a national postal dose intercomparison programme, following the same procedure as IAEA, in order to check regularly the beam output of all cobalt 60 units in Argentina (there were no linear accelerators opertaing in the country at that time)

Equipment and methodology employed by the RRC for the TLD intercomparison programme is briefly described and the results of the quality controls performed through this programme are presented and analyzed in the following paragraphs

2 EQUIPMENT

The RRC calibration service facilities are located in the Atomic Center Ezeiza, about 45 km far from the capital city Buenos Aires Calibration beams are provided by two X-ray machines (10 to 100 kV and 50 to 300 kV) and a Picker C4M60 cobalt 60 therapy unit

The secondary standard dosimeter is a Nuclear Enterprises 2560 with two ionization chambers N E 2561 The primary calibration was certified by the U.K National Physics Laboratory in 1979 Traceability to the international dosimetry system is maintained through periodic external quality control provided by the IAEA Quality Control Programme for the SSDLs, which includes traceability to the Bureau International des Poids et Measures (BIPM)

Traceability of radiation measurements in Argentina is accomplished by the RRC This is the unique laboratory in the country where metrological activities in the field of ionizing radiation are made The National Commission for Metrology recognized this RRC as the national laboratory for metrology of ionizing radiation

The dosimeter calibration service has been carried on by the RRC since 1970 Nowadays about 15 radiotherapy level dosimeters including about 30 ionization chambers are calibrated per year

TLD measurements are made at RRC with a Teledyne Isotope 7300 C TLD Reader Recently, a Harshaw 3500 TLD Reader has been set up for TLD measurements Through an IAEA Technical Assistance Project ARG/1/024 for the period 1993-1994 the RRC has modernized the equipment and procedures for calibrations and TLD measurements

3 METHOD

The method and technique employed by the RRC for the postal dose intercomparison programme were described in previous papers [2], [3], [4]. Briefly, the dosimeters consist of LiF powder contained in plastic capsules. A batch of capsules containing annealed powder TLD-700 is prepared by the RRC and sent by post to radiation therapy centers Each center receives 3 capsules for irradiation and one control capsule irradiated to 2 Gy at the RRC

The participating center is requested to irradiate each of the three capsules separately to a dose of 2 Gy to water, in a water phantom, at the central axis of a vertical irradiation beam,

at 5 cm depth. The field size to be used is 10 cm x 10 cm at either the source to surface distance (SSD) or the source to capsule distance, depending upon the usual technique employed at the center. The irradiation is coordinated so that all participants and the RRC irradiate during the same week in order to avoid any fading correction. The participants have to fill in a data sheet giving the method used for the absorbed dose determination. This helps to find the reasons of dose discrepancies between the dose quoted by the participant and the dose evaluated at RRC.

For the calibration of TL-dosimeters the RRC uses the IAEA International Code of Practice, [5], for absorbed dose determination. The measurements at RRC are made in a water phantom at the central axis of a vertical cobalt 60 beam, with the ionization chamber centered at 5 cm depth and correcting for effective point of measurement. A 10 cm x 10 cm field size at surface is used.

Once the TL-dosimeters return to RRC all measurements corresponding to a batch are made. From each capsule 3 TL-readings are obtained. The mean value is determined for each capsule being the standard deviation of these readings better than 1.5 % . The TL-readings are normalized to reference powder readings. The calibration line is obtained and the dose delivered by the participant is determined by interpolation in this straight line. The total uncertainty of the RRC TLD-system is ±2% .

After the dose delivered by the participant is evaluated at RRC, the percent deviation, Dev(%), between the dose quoted by the particiant, QD, and the dose evaluated by the RRC, ED, is calculated for each participating center:

$$Dev(\%) = (QD - ED) \times 100/ED$$

Dose deviations within the interval ±5% are considered acceptable . When great dose discrepancy occurs the center is contacted immediately and the cause of such a discrepancy is investigated.

When the cause of dose discrepancy is detected the participant is requested to make the necessary correction and to participate in the next intercomparison. When the cause of unacceptable discrepancy is not detected but the dose deviation is lower than 10% the participant is included in the next intercomparison without making any change in the beam calibration. If the cause of discrepancy is not detected and the dose deviation is greater than 10% the participant is requested to check the unit and to recalibrate it (if necessary) before being included in the next intercomparison. Strict confidentiality is maintained and the results are sent to participants with a code number in order to avoid identification.

According to national regulations approved in 1980, the participation in the RRC dosimetric intercomparison programme is compulsory in Argentina. Private and state radiation therapy centers have to take part in this programme at least once a year.

4.TEST OF THE METHOD

During 1992 and 1993 the RRC participated in the IAEA Quality Control Programme for the RRC TLD postal dose intercomparison service in order to check it. The QC programme included: a) reference irradiation at IAEA of TL-dosimeters from RRC; b) participation of IAEA as a radiation therapy center; c) run of IAEA TLD service in paralell with RRC TLD service. Distribution of capsules was coordinated in such a way that participating centers, IAEA and RRC irradiated during the same week.

In May 1992, previous to the irradiation window established for TL-capsules, the RRC received the IAEA CARE system consisting in two electrometers and two ionization therapy level chambers to be calibrated at RRC. These dosimeters were calibrated in a horizontal cobalt 60 beam, in air, using the Secondary Standard NE 2560 . The calibration factor in terms of air kerma, N_K, was obtained for each CARE system. The CARE dosimeters were calibrated in a water phantom too, in a horizontal cobalt 60 beam at 5 cm depth on the central axis. The calibration factor in terms of absorbed dose to water $N_{D,w}$ for each CARE dosimeter was determined.

Results obtained in the IAEA CARE Programme participation are summarized in Table I. The maximum difference between the N_K factors obtained by the RRC and those reported by IAEA was -0.63 % . For the $N_{D,w}$ factors the maximum deviation of RRC values with regard to those reported by IAEA was + 0.31% .

The results of participation in the IAEA QC Programme for TLD postal dose intercomparison service of the RRC are summarized in Table II. The ratios of the dose evaluated by the RRC, ED_{RRC} , for the participating centers and the dose evaluated by IAEA, ED_{IAEA} , for the same centers are shown there. According to these results the dose evaluated by RRC TLD-system is about 1% lower than that evaluated by IAEA TLD-system, being the standard deviation 1.1% .

5. RESULTS

Two groups of 18 cobalt 60 units with physicists within the staff and 19 cobalt units without assistance of physicists were considered. Taking 137 results over the first group it can be seen that 82.5% of dose deviation were within the interval ±5% . For the other group from 148 results only 58.1% were within the accepted deviation interval. This figures show clearly that the presence of a medical physicist makes possible a marked improvement of dose discrepancies.

Results for the 84 cobalt 60 therapy units operating at present in Argentina are summarized in Figures 1 to 3. Considering the first participation of a center in the RRC intercomparison programme (Figure 1) it was found that only 45/84 units delivered the dose within the interval ±5% . Only a group, G1, of 37/84 machines had a medical physicist working at the center and the rest, group G2, had no physicist within the staff of the radiation therapy department. For the group G1 the results showed that 27/37 units obtained an acceptable deviation and for the group G2 only 19/47 machines delivered the those within the acceptable level.

Dose discrepancies greater than 20% were obtained by 5 centers of group G2. These centers were immediately contacted and it was found that the instruction sheet had not been understood at all. The follow up of these centers showed that 2 of them obtained dose deviation within ±5% in the second intercomparison, the others improved their results but only obtained acceptable deviations after a medical physicist joined the center.

Dose deviations greater than 10% but lower than 20% were obtained by 15/84 units. From them, 11 machines obtained accepted deviations in the second intercomparison, 3 improved the result but the deviation remained between 10% and 20%, and 1 center enlarged its deviation to values greater than 20% . In this last case the physicist made a lot of mistakes during capsule irradiation.

Dose deviations between 5.1 and 10% were found in 18/84 units. From them, 12 machines improved their results in the second run obtaining acceptable deviations, 4 units did not improve their results in the second participation and 2 units delivered the dose with deviations greater than 10% during the second run.

TABLE I

RESULTS OF PARTICIPATION IN IAEA CARE PROGRAMME

	CAD 104 Ion.chamber TK02 s/n 104	CAD 105 Ion.chamber TK02 s/n 105
Mean Air Kerma cal. factor N_K det. by IAEA [Gy/V]	1.599±0.8%	1.598±0.8%
Mean Air Kerma cal. factor N_K det. by SSDL [Gy/V]	1.589±0.9%	1.590±0.9%
Deviation (%)	-0.63	-0.50
Abs. Dose to Water cal. factor N_D det. by IAEA [Gy/V]	1.721±1.0%	1.722±1.0%
Abs. Dose to Water cal. factor N_D det. by SSDL [Gy/V]	1.726±1.1%	1.722±1.1%
Deviation (%)	+0.31	+0.17

Deviation (%) = (RRC-IAEA)x100/IAEA

TABLE II

RATIO BETWEEN ED_{RRC} AND ED_{IAEA}

Participant TLD set	ED_{RRC} / ED_{IAEA}
R002	0.9961
R003	0.9926
R004	1.0073
R005	0.9891
R007	0.9963
R008	0.9735
R009	0.9975
EL/1-93023	1.0055
EL/1-93024	0.9824
EL/1-93025	0.9931
EL/1-93026	1.0000
EL/1-93028	0.9664
EL/1-93029	0.9867
EL/1-93030	0.9888
EL/1-93031	0.9827
EL/1-93032	1.0054
	Mean = 0.9915 s.d.= 1.1%

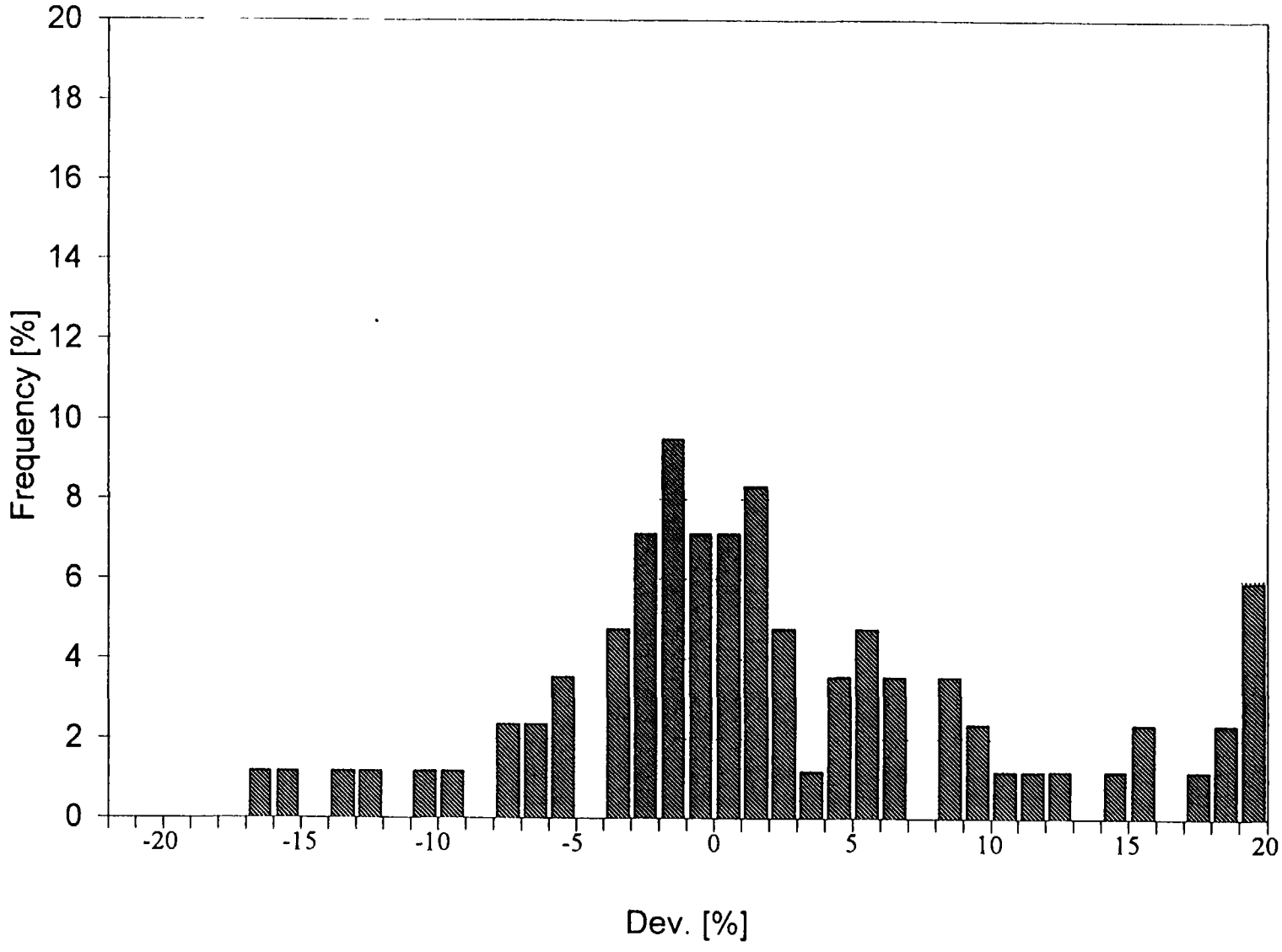

Figure 1. Results of RRC TLD service for cobalt 60 therapy units. First participation .

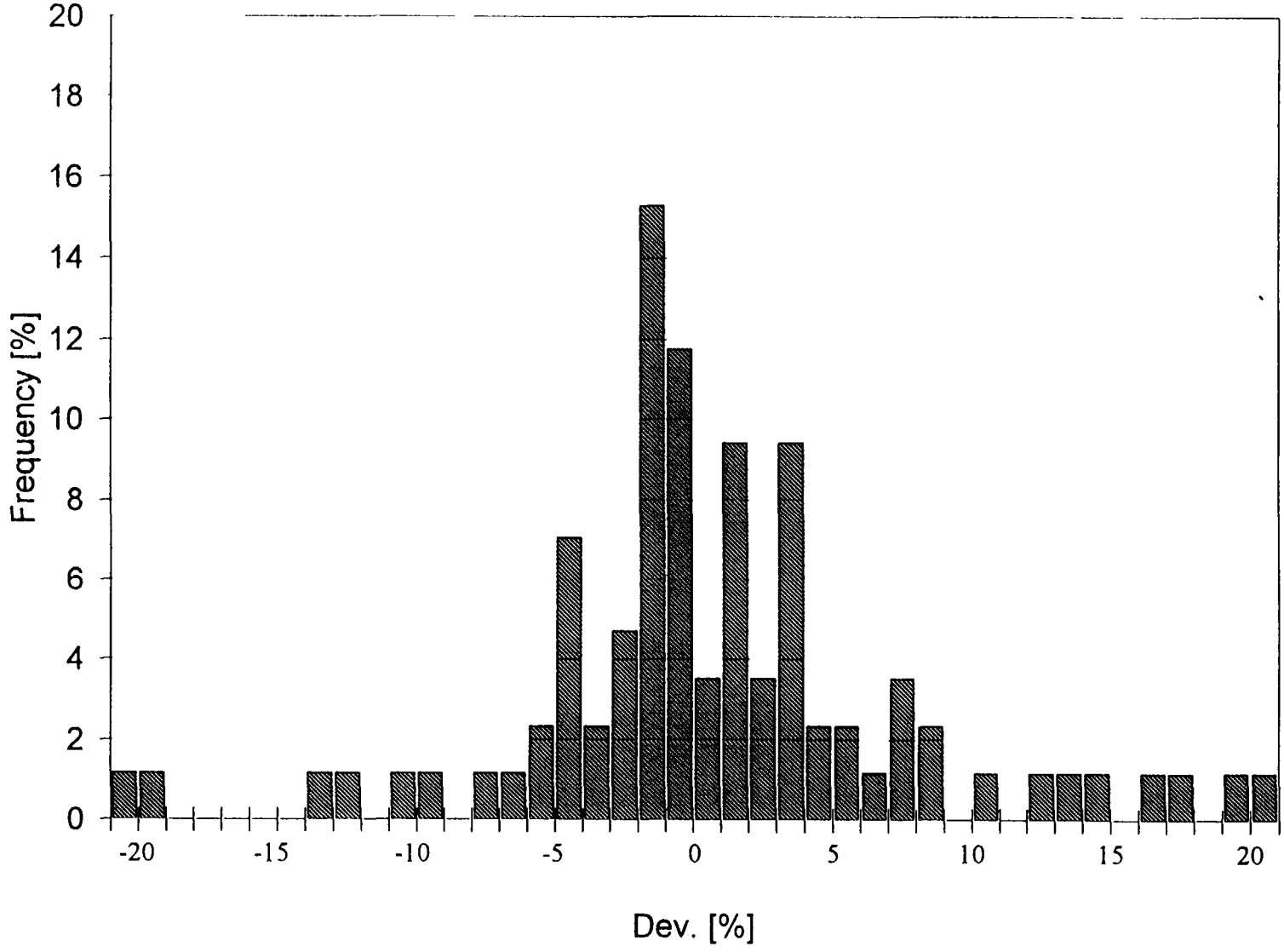

Figure 2 Results of RRC TLD service for cobalt 60 therapy units Second participation

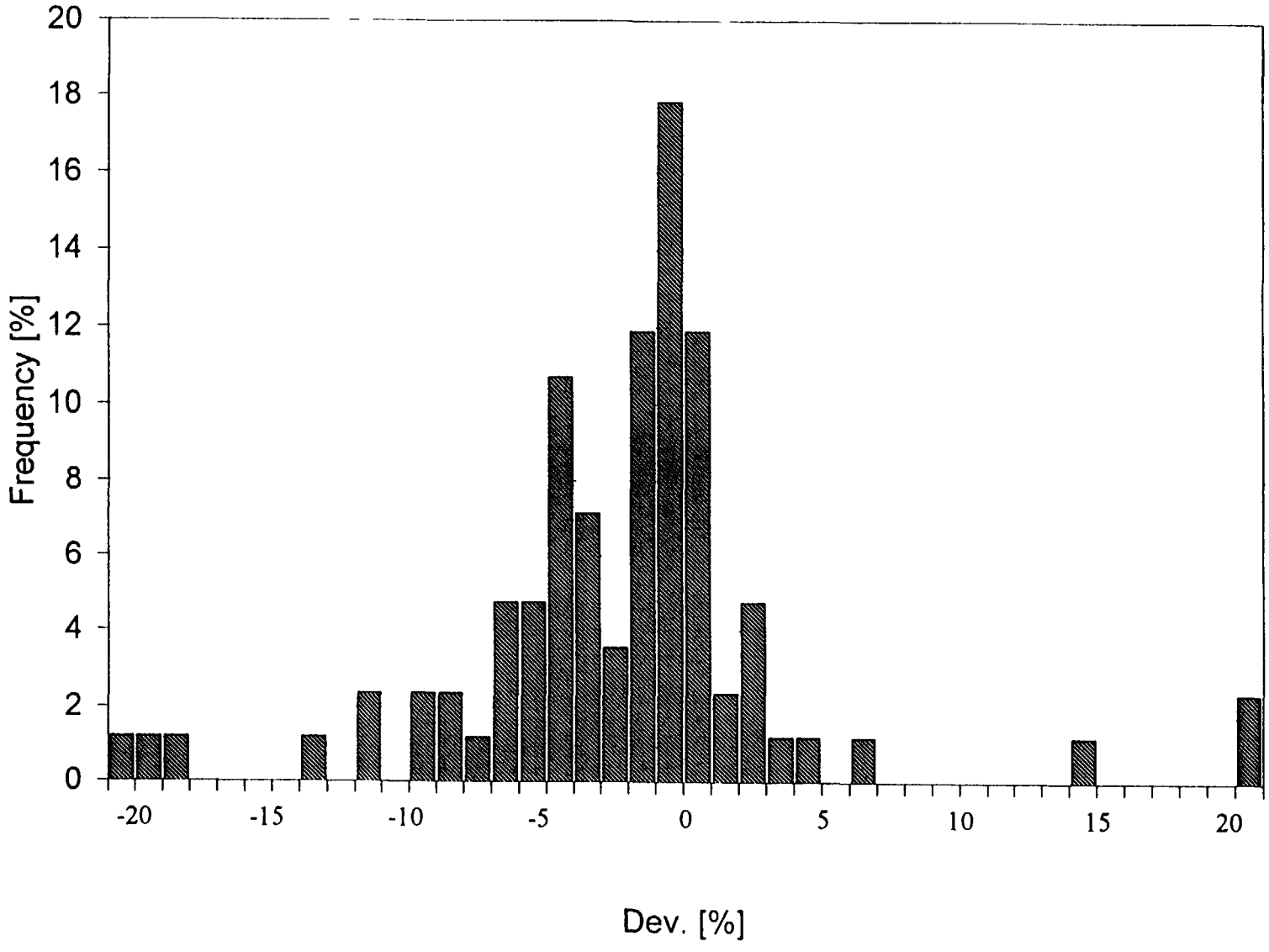

Figure 3 Results of RRC TLD service for cobalt 60 therapy units Last participation

Considering the results of centers whose dose deviations were within the interval ±10%, the mean dose was calculated for their first participation: D= 1.981 Gy (st.dv.= 4.2%) .

The principal causes of great dose discrepancy detected through the data sheet information have been related to: a) source-surface distance (either for lack of light indicator calibration or because of mistakes); b) the decay factor employed; c) wrong correction factors employed for irradiation time calculation; d) time irradiation calculated at surface instead of at 5 cm depth. In order to correct calculation errors the RRC sent to each center the corresponding information, the method for dose calculation and a list with the last recommended factors for dose evaluation.

The general improvement on the beam output check can be seen in Figure 2 where the results of the second participation shows that 60/84 machines delivered the dose within the accepted level. The mean dose was D = 1.996 Gy (st.dv.= 3.8%)

Results obtained during the last participation of centers in this programme are shown in Figure 3 It can be seen that 61/84 machines delivered the dose within the accepted deviation level ±5%. The mean dose was D = 2.044 Gy (st.dv = 3.3%) .

Dose deviations for 3/84 machines were greater than 20% . Nevertheless dose deviations were within the interval ±5% in all previous participation of these centers From data sheet information it was not possible to detect the cause of such discrepancies. One physicist reported that found an error in time calculation of capsules but the error did not affect the treatment plannings. For the other 2 machines no explanation has been offered yet.

Dose deviations between 10% and 20% were obtained by 6/84 units. There are no physicist in 4/6 centers and the results of previous intercomparisons were out of the interval
± 5% One center has closed, other is out of work at present and two of them require urgently the help of a medical physicist. From the other 2/6 centers with physicists, one of them made a calculation error and the other was not able of explain the cause of such unacceptable dose discrepancy

Dose deviations between 5.1% and 10% were obtained by 14/84 centers It was found that 9/14 machines had had acceptable deviations in previous runs of the intercomparison programme. The other 5/14 centers obtained dose deviations near 10% . From the data sheet it has been impossible to detect the cause of such deviations Only one physicist reported to the RRC the mistakes made during irradiation of TLD capsules.

Considering the number of cobalt 60 machines operating in different geographical zones it can be seen (Figure 4) that centers located near the capital city obtain better results than those far from this city, as was expected due to the possibility of centers to get assistance from other radiation therapy departments or from the RRC

6 CONCLUSIONS

The RRC of Argentina has gained great experience in the TLD intercomparison programme for cobalt 60 therapy units. The RRC mailed thermoluminescense dosimetry method, based on the IAEA experience, has a precision of 2% and is traceable to the IAEA

The large number of great deviations detected in reference conditions demonstrates the importance for a center to participate in national or international intercomparisons and the usefulness of the RRC programme that provides a service accesible to all radiotherapy centers and ensures the required confidentiality.

The principal causes of unacceptable dose deviations have been related to positioning of capsules and calculation mistakes. Output of machines generally was well determined.

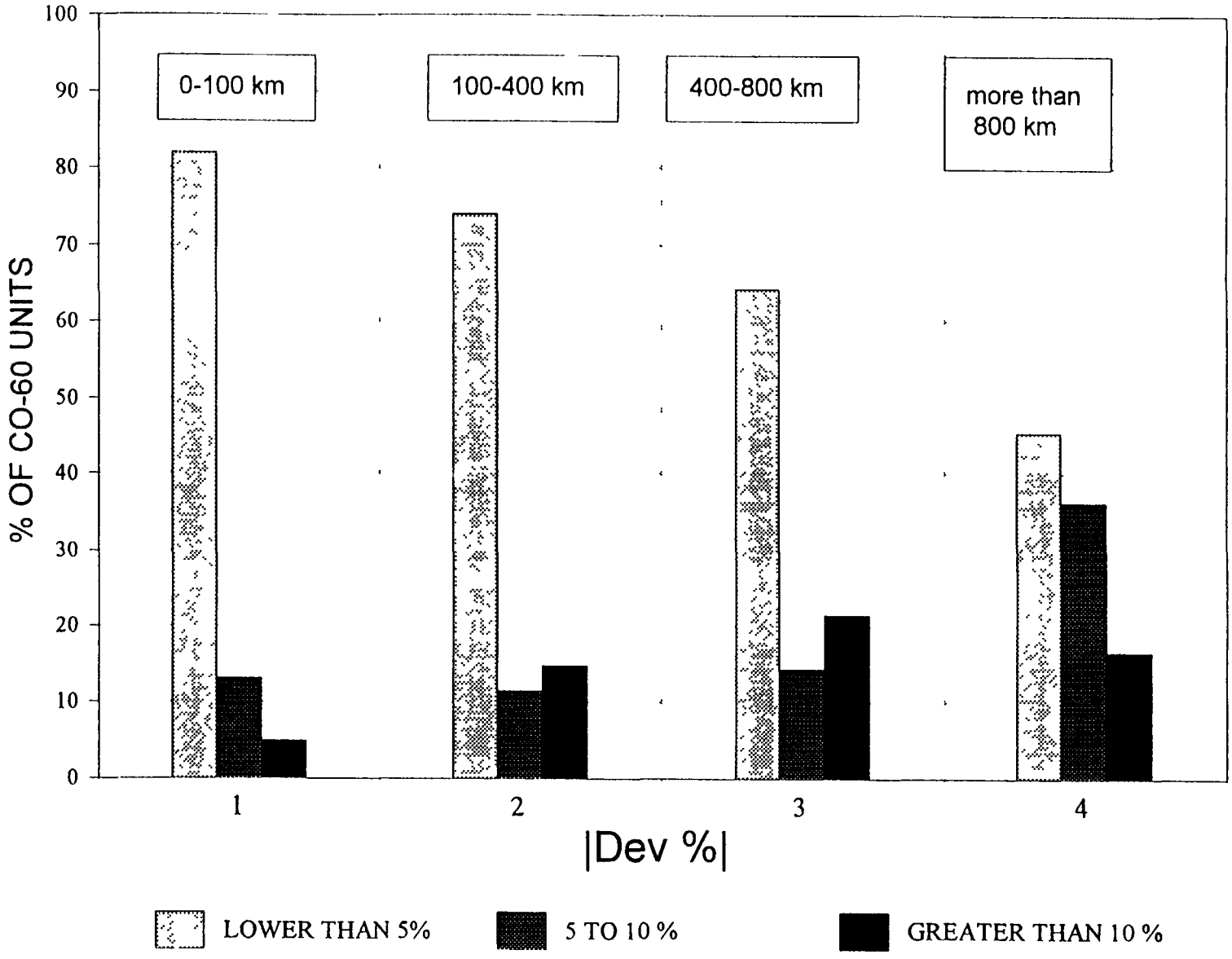

Figure 4. Results of RRC TLD service for cobalt 60 therapy units considering 4 geographical regions

The RRC should increase the number of on-site visits to radiation therapy centers, specially to those centers without assistance of a medical physicist . An effort from the RRC clinical dosimetry section will be necessary in order to strength the follow-up of centers.

The presence of medical physicists in radiation therapy centers helps to improve the dosimetry in radiotherapy. Training courses should be organized in order to up grade the staff of these centers.

National regulations for operation of radiation therapy centers have given the necessary sustain for application of the RRC dose intercomparison programme.

7. FUTURE PLANS

Owing to an increase in the use of medical accelerators in the country the RRC intends to expand its TLD service to include initially high energy X ray beams and later on electron beams. For X ray beams the necessary correction factors to account for the energy dependence of TLDs are going to be determined through two experimental intercomparison runs during this year, with the help of IAEA for reference irradiations of TLD capsules in terms of dose absorbed to water. A first national dosimetric intercomparison for high X ray beams is scheduled for november 1995.

The RRC is participating in the IAEA Pilot Study to transfer the IAEA/WHO TLD service to regional SSDLs. Other SSDLs from the IAEA/WHO Network are participating in this Pilot Study too.

The RRC intends to become part of the International Quality Assurance Network , [6], which has been experimentally introduced by the IAEA. This programme covers three dosimetric steps from single field water phantom to multiple field organ phantom measurements.

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III. EXPERIENCES ON CURRENT STATUS. QUALITY ASSURANCE OF THE IRRADIATED PATIENT

PRINCIPLES

QUALITY ASSURANCE IN RADIOTHERAPY: FROM THE PHANTOM TO THE PATIENT

(Abstract)

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When considering Quality Assurance in radiotherapy it is important to pay heed to whole chain, from the infrastructure to the treatment process and to the outcome The first requirement is to quantify the precision achieved in the present situation at every level of the chain. The first step in dosimetry is a photon beam calibration in a water phantom, in reference conditions. Under the sponsorship of the programme "Europe Against Cancer", in collaboration with the IAEA and EORTC, pilot studies have been performed in the last years on a relatively large scale through quality assurance networks involving 122 centres from 15 countries External audits using mailed thermoluminescent dosimeters, performed on 194 X-ray beams and gamma ray beams, have shown that deviations larger than 6% have been detected in 17% of the beams from centres who did not participated in an external audit during the last 5 years, and that such deviations have not been detected in the other centres These studies have already been extended to 3 countries from Central and Eastern Europe (49 centres, 49 X-ray beams and 62 γ-ray beams) with the support of the Flemish government and should be extended to 4 more during the next year with a Copernicus contract from the EC

Some measurements have been carried out with a multipurpose phantom to check the dose in non reference conditions A large number of dosimeters were necessary for each beam and the results were rather difficult to analyse as several factors were simultaneously influencing the outcome A simpler phantom to be used with a small number of TLD dosimeters has recently been designed and should be used in a feasibility check in the near future

Other programs have been carried out by on-site visits, including the check of mechanical parameters The advantages and disadvantages of mailed dosimetry versus on-site visits have to be carefully investigated, including costs, and taking into account the size of the country

External audits with mailed dosimeters will be soon extended to electron beams Special phantoms have been designed in collaboration between the IAEA and the European group After the feasibility has been checked with the participation of 11 reference centres in Europe and 1 in USA, the intercomparisons will be extended to other centres through a new EC contract

It is time to further extend these audits to other levels of the treatment process, from the calculation of the treatment time (or of the number of monitor units) to the dose effectively delivered to the patient in clinical practice This last step could be checked by mailed in vivo dosimetry It has been shown that in vivo dosimetry is a very efficient

tool to verify the whole chain from the beam output calibration to the daily dose delivery to the patient. The feasibility of mailed in vivo dosimetry has still to be assessed. An external audit with mailed in vivo dosimetry could constitute an actual help to radiation oncologists and physicists to improve their techniques. It would certainly facilitate the intercomparisons of clinical results between different radiotherapy centres. It would reinforce the leader role of radiotherapy in Quality Assurance in the medical field.

VOLUME AND DOSE SPECIFICATION FOR REPORTING EXTERNAL BEAM THERAPY (THE ICRU RECOMMENDATIONS)

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Abstract

The International Commission on Radiation Units and Measurements (ICRU) has published the Report 50 "Prescribing, Recording, and Reporting Photon Beam Therapy" (1993). The aim of the Report is to promote the use of a common set of definitions and concepts for specifying and reporting the doses in radiation therapy, as well as the volumes in which they are prescribed and delivered.

Different volumes need to be identified prior to treatment planning: the gross tumour volume (GTV) and the clinical target volume (CTV). The planning target volume (PTV) is defined for treatment planning. The treated volume and the irradiated volume are identified when the treatment techniques and irradiation plan have been decided upon.

As a general recommendation, the dose at, or near, the centre of the PTV, as well as the maximum and the minimum dose, shall be reported. Additional information when clinically relevant and available, should also be reported.

The system of recommendations for reporting dose is based on the selection of a point within the PTV, which is referred to as the ICRU Reference Point. The ICRU Reference Point is selected firstly at the centre, or in the central part, of the PTV, and secondly on, or near, the central axes of the beams.

A certain degree of inhomogeneity of the absorbed dose throughout the PTV cannot be avoided. Therefore, as a basic requirement, the best estimate of the maximum dose and the minimum dose to the PTV shall be reported together with the dose at the ICRU Reference Point. These 3 dose values then indicate the dose profile within the PTV.

ICRU Report 50 allows for reporting basic data for all treatments at any level of complexity for absorbed dose computation. It also allows for reporting additional clinical and relevant data obtained by sophisticated methods. The recommendations are thus applicable to all external radiotherapy procedures.

INTRODUCTION

If the irradiation techniques would be so perfect that it would be possible to irradiate the full "volume to be treated", in a homogeneous way (e.g. 60 Gy), and with (quasi) no dose to the surrounding normal tissues, the situation would be very simple. In this ideal situation, the prescribed dose would be 60 Gy, the recorded dose (in the patient treatment chart) would also be 60 Gy, and the reported dose (e.g. for publication, or multicentre studies) would be 60 Gy.

Unfortunately, it is not the case and within the "volume to be treated", one can identify a maximum and a minimum dose and, from the dose distribution, one can derive a mean or (several) weighted mean doses. In addition, some normal tissues receive dose levels which are high, often similar to the prescribed dose and which sometimes exceed their tolerance limit.

Actually, due to the limitations of the available irradiation techniques, the differences between the maximum and the minimum doses often reach 10, 15 and even 20%. Therefore, one can introduce large discrepancies depending on the criteria (thus the dose levels) used for prescribing, recording and reporting the treatment.

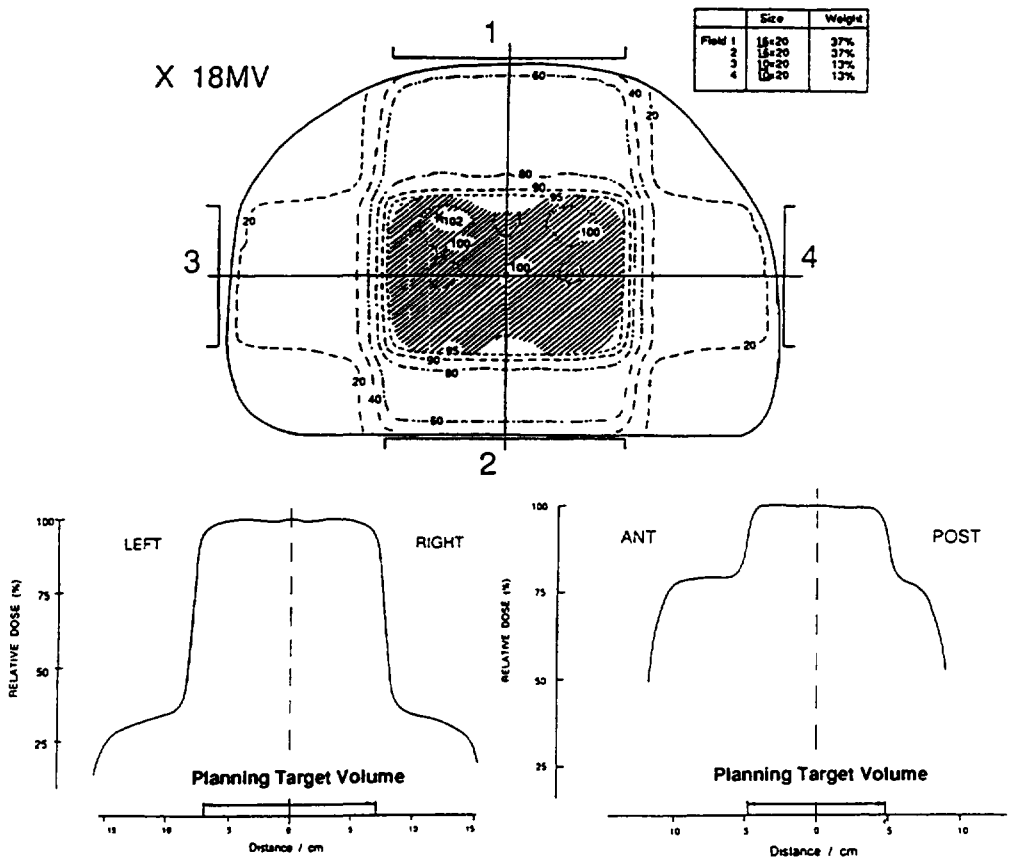

Figure 1: "Box technique" using 4 photon beams of 18 MV which converge toward one point. The dose distribution in the plane containing the beam axes (central plane) is displayed, as well as the dose profiles along the AP and left-right beam axes. The PTV (Planning Target Volume) is represented by the hatched area. According to ICRU Report 50, the dose should be specified at the centre of the PTV, at the intersection point of the 4 beams (indicated as 100%). The maximum and minimum doses within the PTV are 103% and 95% respectively. As can be seen from the dose distribution in the central plane and from the two dose profiles, the point at the intersection of the beams fulfils the criteria recommended in Table I. This would obviously not be the case if the specification point would have been selected at the periphery of the PTV.

The International Commission on Radiation Units and Measurements (ICRU) has recognized the importance of the problem many years ago and, in 1978, published Report 29 "*Dose specification for reporting external beam therapy with photons and electrons*".

Since then, it became clear that further interpretation of the concepts have become necessary, as well as more guidelines in order to apply the recommendations more widely. In addition, the rapidly expanding use of computers in radiotherapy, allowing for a better 3-D dose distribution, is changing clinical practice. In 1993, the ICRU published Report 50 "*Prescribing, recording and reporting photon beam therapy*", which superseded Report 29.

For other radiotherapy techniques, the problem of dose specification has also been studied by the ICRU, who in 1985 published Report 38 "*Dose and volume specification for reporting intracavitary therapy in gynaecology*". The Report "*Dose and volume specification for reporting interstitial therapy*" is now in press. Other ICRU Reports dealing with dose specification for special techniques, such as electron-, proton-, and neutron-beam therapy and BNCT (Boron Neutron Capture Therapy), are in preparation.

Before discussing the specification of the doses, it is necessary to define the volumes in which the doses are delivered.

DEFINITION OF VOLUMES

The process of determining volumes for the treatment of a malignant disease consists of several distinct steps during which different volumes may be defined.

The two first ones are defined prior to treatment planning: the Gross Tumour Volume and the Clinical Target Volume.

During the treatment planning process, other volumes have to be defined: the Planning Target Volume and the Organs at Risk.

As a result of treatment planning, further volumes can be described: the Treated Volume and the Irradiated Volume.

Gross tumour volume (GTV)

From the origin of medical terminology the word tumour was used to designate a swelling which could be of different natures.

The Gross Tumour Volume (GTV) is the gross palpable or visible/demonstrable extent and location of malignant growth.

The GTV may consist of the primary tumour, metastatic lymphadenopathy(ies), or other metastases.

The shape, size and location of the GTV may be determined by means of different diagnostic methods such as clinical examination (e.g. inspection, palpation, endoscopy), and various imaging techniques (e.g. x-ray, CT, ultrasound, magnetic resonance imaging and radioisotope methods).

The GTV may seemingly be different in size and shape, sometimes significantly, depending on what examination technique is used for evaluation (e.g. palpations vs mammography for breast). Therefore the therapist should, in each case, indicate which methods have been used for evaluation and delineation of the GTV.

The Gross Tumour Volume should be described in standard topographical or anatomical terms, e.g. "*tumour of the roof of nasopharynx with metastatic nodes in the sternomastoid chain bilaterally in the neck*". In many situations, a verbal description might be too cumbersome and also, for the purpose of data recording and analysis, a classification system is needed. Several systems are proposed for coding the anatomical description; some of them are mentioned in ICRU Report 50.

There are at least 3 reasons to identify the GTV. Firstly, accurate description of the GTV is needed for staging (e.g. TNM). Secondly, identification of the GTV is necessary to allow for recording of tumour response in relation to the dose and other relevant factors. It can be used (carefully ?) as a prognostic factor. Thirdly, an adequate dose must be delivered to all parts of the GTV in order to obtain local tumour control in radical treatments.

Clinical Target Volume (CTV)

Clinical experience indicates that around the GTV there is in general subclinical involvement, i.e. individual malignant cells, small cell clusters, or microextensions which cannot be detected by the staging procedures. The GTV together with this safety margin consisting of tissues with presumed or proved subclinical involvement is defined as a Clinical Target Volume (CTV). The tissues immediately surrounding the GTV have usually a high malignant cell density close to the edge of the GTV; the cell density decreases towards the periphery of the CTV.

Additional volumes (CTVs) with presumed or proved subclinical spread (e.g. regional lymph nodes) may also be considered for therapy.

The Clinical Target Volume (CTV) is a tissue volume that contains a demonstrable GTV and/or subclinical microscopic malignant disease. This volume has to be treated at an adequate dose level (and time-dose pattern) in order to achieve the aim of therapy, cure or palliation.

If different doses are prescribed, different CTVs have to be defined. Thus, for any given situation, there is often more than one CTV. One situation can be illustrated by considering

a primary tumour and its regional lymphatics separately (e.g. in breast saving procedures where the breast and regional lymphatics are separated anatomically). In other situations, the aim is to treat two CTVs at different dose levels ("boost" therapy), where the "high-dose" volume (often containing the GTV) is located inside the "low-dose" volume.

Delineation of a CTV will require consideration of factors such as the local invasive capacity of the tumour and its potential to spread to, e.g. regional lymph nodes.

One has to stress that definitions of the GTV and CTV are based only on general oncological principles, and are not specific to the field of radiation therapy. For example, in surgery, a safety margin is taken around the gross tumour volume according to clinical judgement, and this implies the use of the same Clinical Target Volume concept as in external beam therapy. Also, in brachytherapy, volumes to be irradiated are defined, and thus the concept of CTV is applied. Furthermore, the concept can be applied to other modalities, e.g. hyperthermia or photocoagulation.

Planning Target Volume (PTV)

To ensure that all tissues included in the Clinical Target Volume (CTV) receive the prescribed dose, one has, in principle, to plan to irradiate a volume geometrically larger than the CTV. It is the Planning Target Volume or PTV.

The additional safety margin, included in the PTV, results from a number of factors:

- movements of the tissues which contain the CTV (e.g. with respiration), as well as movements of the patient.

- variations in size and shape of the tissues that contain the CTV (e.g. different fillings of the bladder, rectum, stomach).

- all variations and uncertainties in beam geometry and patient-beam geometry. There are some uncertainties in the beam sizes, shapes and directions, as well as in the relative position of the beam with respect to the patient, the CTV and the normal tissues.

- all uncertainties in dose distribution, especially in or close to the penumbra region (see below), or where inhomogeneities have to be taken into account (e.g. beam penetration for electron beams).

The above uncertainties in dose distribution and geometry depend also on the quality of anatomical data acquisition. They may vary from centre to centre, and within a given centre from machine to machine. The use of patient immobilization devices and the skill and experience of the radiographer's team are important factors which have also to be taken into account.

Finally, the safety margin depends on the beam arrangement that the radiation oncologist will select.

When delineating the PTV, consideration may also be given to the presence of any radiosensitive normal tissue (organs at risk) as well as to other factors such as the general condition of the patient.

The Planning Target Volume is a geometrical concept, used for treatment planning, and it is defined to select appropriate beam sizes and beam arrangements, taking into consideration the net effect of all the possible geometrical variations, in order to ensure that the prescribed dose is actually absorbed in the CTV.

The dose distribution to the PTV has to be considered to be representative of the dose to the CTV. The PTV has thus to be clearly indicated on the different sections used for treatment planning.

Delineation of the PTV is a matter of compromise implying the judgement and thus the responsibility of the radiation oncologist and radiation physicist . In particular, it is not recommended that all uncertainties be added linearly because this would probably lead to too large margins, resulting in unnecessary side effects.

The penumbra is not included in the PTV margin. Penumbra has to be taken into account separately considering dose distribution.

Treated Volume

Due to the limitations of the irradiation techniques and in some specific clinical situations, the volume receiving the prescribed dose may not match accurately the PTV; it may be larger (sometimes much larger) and in general of a simpler shape. This leads to the concept of treated volume. It is defined when the treatment planning procedure is completed and the beam arrangement approved as well as all the other irradiation parameters.

The treated volume is the tissue volume which (according to the approved treatment plan) is planned to receive at least a dose selected and specified by the radiation-oncologist as being appropriate to achieve the purpose of the treatment, e.g. tumour eradication or palliation.

The treated volume is thus the volume enclosed by the isodose surface corresponding to that dose level. For example, if the prescribed dose is 60 Gy, with an accepted variation of ± 5%, the treated volume is enclosed by the 57 Gy isodose surface.

Normally, in the patient, the tissue volume which actually receives that dose level (i.e. "actual" treated volume) should match the "planned" treated volume. It is the goal of the quality assurance procedures.

Irradiated Volume

The irradiated volume is the tissue volume which receives a dose that is considered significant in relation to normal tissue tolerance.

If the irradiated volume is reported, the significant dose must be expressed either in absolute values (in Gy) or relative to the specified dose to the PTV. The irradiated volume depends on the treatment technique used.

DOSE SPECIFICATION FOR REPORTING

General recommendations for reporting doses

The dose at or near the centre of the Planning Target Volume as well as the maximum and the minimum dose to the PTV shall be reported.

Additional information, when available and clinically relevant, should also be reported, i.e. average dose (and its standard deviation) in different volumes, biologically weighted average doses in different volumes, dose/volume histograms, etc.

The ICRU reference point

The present system of recommendations for reporting is based on the selection of a point within the PTV, which is referred to as the ICRU reference point. The dose at the ICRU reference point shall always be reported. The ICRU reference point shall be selected according to the 4 general criteria listed in Table I.

The criteria listed in Table I will be met if the ICRU reference point is located firstly at the centre, or in the central part, of the PTV, and secondly on the central axes of the beams.

In some situations, the conditions do not allow for the ICRU reference point to be localized both at (or near) the centre of the PTV, and also on the beam axes. In these cases, the first criterion, i.e. localization at (or near) the centre of the PTV should be given preference.

In some situations, it will be found that the centre of the PTV will not be a meaningful concept, if it is taken to imply the purely geometrical centre or the centre of gravity. Such a definition could result in the centre being outside the tissues

TABLE I

Criteria for selecting the ICRU reference point

(a) the dose at that point should be clinically relevant and representative of the dose throughout the PTV;

(b) the point should be easy to define in a clear and unambiguous way;

(c) the point should be selected where the dose can be accurately determined (physical accuracy);

(d) the point should be selected in a region where there is no steep dose gradient.

represented by the PTV (e.g. when treating the chest wall, where the centre of gravity of the PTV may be in healthy lung tissue, or, in the case of treatment of the regional lymph nodes of a pelvic tumour, where the PTV may be ring-shaped, and its centre of gravity is not in the tissue concerned).

In these cases, one has to select the ICRU reference point inside the tissues represented by the PTV, and in a place where dose specification is considered to be meaningful. Such a place could be in the GTV (Gross Tumour Volume).

The dose variation throughout the PTV

A certain degree of inhomogeneity of the absorbed dose throughout the PTV cannot be avoided.

As a minimum requirement, the maximum dose and the minimum dose to the PTV shall be reported, together with the dose at the ICRU reference point. The three dose values then indicate the dose to the CTV and the dose variation.

Other dose values considered to be relevant, when available, should also be reported, as indicated above.

The three levels of dose evaluation for reporting

The level of completeness and accuracy of reporting a therapeutic irradiation depends to a large extent on the situation in the department and on the aim of the treatment. For different clinical and practical considerations, different levels of ambition for dose evaluation can be identified. Three levels have been selected for reasons given below, but it is recognized that intermediate levels could also be identified.

Level 1: Basic techniques

The minimum requirements for reporting, as indicated above, can be followed in all centres, including those with restricted therapy equipment, dosimetric, computer, and staff facilities. This minimum level may sometimes be sufficient, in any centre, when simple treatments are performed (e.g. some palliative treatments).

At this level, it is assumed that the dose at the ICRU reference point and an estimate of the maximum and minimum doses to the PTV can be determined using, e.g. central axis depth dose tables. Some information about the dose outside the beam axis could also be obtained by means of standard isodose charts.

Level 2: advanced techniques

At this level, it is assumed that the GTV, CTV and PTV can be defined in one or more planes, using reliable patient data acquisition tools, and/or modern imaging techniques under reliable conditions (e.g. a series of CT and/or MRI sections).

It is also assumed that complete dose distributions are computed in the central plane and in other planes using central plane dose data, and with inhomogeneity corrections, when appropriate.

The standards of dose planning at this level allow the exchange between different centres of more complete and relevant information.

Level 3: developmental techniques

The performance of dose planning at level 3 provides for the development of new techniques and clinical research in radiotherapy.

At this level, 3-D dose computation of any beam arrangement and dose-volume histograms are available. It is only when 3-D dose computation is available that the "true" maximum and minimum dose levels in the PTV (volume) can be obtained.

Complex treatments with more than one PTV

With the increasing complexity of radiotherapy treatments, more than one PTV is frequently identified. In practice, the two most common situations are adjacent PTVs and overlapping PTVs.

Adjacent PTVs

In this situation, the PTVs are adjacent to each other; they do not overlap. A typical example may be the postoperative treatment of breast cancer including the breast and chest wall, and the regional lymphatics. When the PTVs are adjacent to each

other, as a minimum requirement, the dose to each PTV (at its ICRU reference point, as well as the maximum and the minimum dose to each PTV) should be reported. Note that since treatment of one PTV may give a dose contribution to the other PTV, reporting at level 1 may give information that does not take this into consideration.

Overlapping PTVs

In this situation, one PTV is totally contained within the confines of the other. A typical example is the boost technique. In this case, again, two situations may occur:
- the beam axes of the two PTVs are identical and the centres coincide
- the centres of the two PTVs and the beam axes differ

When the PTVs are overlapping the following procedures are recommended:

At level 1:
The dose to the ICRU reference point and the maximum and minimum dose to each PTV for each part of the treatment are calculated along the central beam axes and should be reported accordingly. At level 1, the report is confined to a simple description of technique.

At levels 2 and 3:
The dose distribution for each PTV are calculated and added and the dose to each ICRU reference point, as well as the maximum and minimum dose for each PTV, are reported, taking into account the cumulative contribution to each PTV. For the smaller PTV, the criteria of central position of the ICRU reference point in the PTV can usually be met. For the larger PTV, an ICRU reference point has to be selected at a specially selected position considered to be significant for tumour control in this PTV.

Organs at risk and hot spots

When reporting at level 3 is possible, dose-volume histograms for organs at risk, average doses, biologically weighted quantities, etc. could also be reported.

A Hot Spot represents a volume outside the PTV which receives the dose larger than 100% of the specified PTV dose. If a hot spot occurs, its size and position should be reported.

DISCUSSION

THE DEFINITION OF VOLUMES

In principle, the number of volumes to be defined (and on which one should agree) has to be kept as small as reasonably possible.

Gross Tumour Volume and Clinical Target Volume

They are pure oncological concepts and should be part of the medical record. Ideally, the GTV and CTV should be defined "collegially" by all clinical teams involved in the patient treatment, or at least the information should be made available to them. These two volumes are independent from any treatment method.

Planning Target Volume

The PTV is a geometrical concept used for treatment planning. When going from the CTV to the PTV, the additional safety margin depends on the technique and indeed may vary to a large extent with the selected technique.

For example, depending whether the patient is heavily suffering, restless or not, there are considerable differences in the inaccuracies or sources of mistakes and, as a result, this influence the thickness of the accepted safety margin.

If during the course of the treatment planning procedure, several plans are considered successively and compared (e.g. use of electron boost or not, change of machine, etc.), different PTVs may have to be delineated.

As mentioned above, one can identify different causes of uncertainties and for each of them propose a corresponding safety margin. It is not realistic to add (linearly) all these safety margins, since it could lead to too large PTVs which are probably useless for local cure and would certainly increase the risk of complications. The thickness of the final safety margin should thus be decided based on clinical judgement and experience. Of course, systematic analysis of some of the uncertainties may help to select the safety margin on more objective basis.

The use of the concept of PTV is needed during treatment planning and also for dose specification (for reporting).

Depending on the clinical situation, and on the selectivity of the irradiation technique, the PTV could be very similar to the CTV (e.g. small skin tumours, pituitary tumours) or in contrast much larger (e.g. bronchus carcinoma).

In most of the situations, the dose at the ICRU reference point (centre of the PTV) is close to the dose at the centre of the CTV. The maximum dose in the PTV is often the maximum dose in the CTV. In contrast, the minimum dose to the PTV is probably often lower than the minimum dose to the CTV (it is in principle its lowest limit). This is one of the reasons why the minimum dose to the PTV is probably not always relevant clinically.

Treated Volume, Irradiated Volume

The treated volume is fixed as soon as the treatment technique has been decided upon ("planned" treated volume). Determination of the "actual" treated volume in the patient implies quality control procedures. The same is true for the irradiated volume.

Differences between CTV, PTV, Treated Volume and Irradiated Volume reflect both the complexity of the clinical situation and the limitations of the radiotherapy techniques. They are important optimization parameters.

A recurrence within the treated volume is a true "in-field" recurrence due to inadequate dose (or inadequate time-dose pattern) or treatment delivery.

A recurrence adjacent to the treated volume is a "marginal" recurrence due to inadequate volume delineation (wrong evaluation of the CTV and/or PTV) or a mistake in treatment delivery.

DOSE SPECIFICATION FOR REPORTING

The ICRU reference point

ICRU report 50 recommends that a point in the centre, or in the central part, of the PTV be selected as the ICRU reference point and that the dose at that point be defined as the ICRU reference dose.

It is mandatory to report the ICRU reference dose and to describe the dose variation by reporting also the maximum and the minimum dose to the PTV.

The dose at the ICRU reference point is clinically relevant and can be considered as representative of the dose distribution throughout the PTV (Fig. 1). The point is easy to describe in an unambiguous way and it is located in a region where there is little dose gradient. Lastly, as far as dosimetry is concerned, the dose on the beam axes can be determined most accurately.

The isodose envelope

Some centres, traditionally, select the isodose surface encompassing at best the PTV and the corresponding dose level is used for reporting the dose to the PTV. The objective with this approach is to ensure that all tissues containing malignant cells will receive at least the prescribed dose. This practice is equivalent to report only the minimum dose to the PTV; it has several shortcomings.

The minimum dose is certainly not representative of the dose distribution to the PTV; most parts of it receive significantly larger doses (+15%, +20%,...). Tumour regression and tumour control can thus not be correlated with this minimum dose. In general the minimum dose will be received by only a few cells or

often by no cell at all, depending on the distributions of the malignant cells in the safety margin. Of course we are not dealing here with a "geographical miss" of e.g. a part of the GTV! Lastly, the envelope isodose is generally located in an area where there is a high dose gradient and where in addition if is difficult to determine the dose accurately. The true minimum and maximum doses in the PTV can be reported only if 3-D dose computation is available.

For a given treatment the minimum dose in the PTV depends on the delineation of the PTV itself and thus on the safety margins which were selected to define the CTV and the PTV. For a given clinical situation, the safety margins may largely differ from a therapist to another one.

As recommended above, the best estimate of the minimum dose to the PTV has to be reported, but together with the dose at the ICRU reference point and the maximum dose to the PTV.

Average doses and biologically weighted average doses

According to biological models, the average dose to the cancer cell population is the parameter which should be best correlated with the treatment outcome (provided the dose heterogeneity is not too large).

However there may be several cancer cell populations with various radiosensitivities (e.g. hypoxic, quiescent, etc.) and in addition the cancer cell density varies to a large extent within the PTV. It is difficult today to take these variations into account in a clinically relevant way and the average dose to the PTV is thus probably not the average dose to the relevant cancer cell population.

This strongly weakens the value of the average dose to the PTV as the most relevant parameters to describe the treatment.

In addition, determination of average doses and biologically weighted average doses for reporting requires sophisticated computing facilities (e.g. at least 3-D treatment planning). Today only part of the centres in the world can perform these complex computations, and this approach can thus not be recommended as the only one for reporting a treatment.

However the need for collecting all possible relevant information is fully recognized and, as stressed before, the average doses, when clinically relevant, should be reported when available, but in addition to the set of the three values already recommended: i.e. the dose at the ICRU reference point and the maximum and minimum dose to the PTV.

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SPECIFICATION OF VOLUME AND DOSE IN RADIOTHERAPY

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Abstract

As a result of a questionnaire about dose and volume specifications in radiotherapy in the Nordic countries, a group has been set up to propose common recommendations for these countries. The proposal is partly based on ICRU 50, but with major extensions. These extensions fall into three areas: patient geometry, treatment geometry, and dose specifications. For patient geometry and set-up one need alignment markings and anatomical reference points, the latter can be divided into internal and external reference points. These points are necessary to get relationships between coordinate systems related to patient and to treatment unit. For treatment geometry the main volume will be an anatomical target volume which just encompass the clinical target volume with all its variations and movements. This anatomical volume are the most suitable volume for prescription, optimization and reporting dose. A set-up margin should be added to the beam periphery in beams-eye-view to get the minimum size and shape of the beam. For dose specification the most important parameter for homogenious dose distributions is the arithmetic mean of dose to the anatomical target volume together with its standard deviation. In addition the dose to the ICRU reference point should be reported for intercomparison, together with minimum and maximum doses or dose volume histograms for the anatomical target volume.

1. INTRODUCTION

A questionnaire to all Nordic radiotherapy centres in 1991 about volume and dose specification [1] revealed several problem areas for specification of volumes and doses. The investigation resulted in setting up a group of radiotherapists and physicists under Nordic Association of Clinical Physics (NACP) to make consistent recommendations for volume/dose definitions and specifications.

The recommendations treat the situation at clinics with state of the art equipment and procedures, having the fairly uniform situation in the Nordic countries in mind. The proposals have evolved in discussions among radiotherapists and physicists in the Nordic countries during the last five years. They have also been considerably influenced by discussions with, and work of the international radiotherapy community (e.g. ICRU 50 [2]).

2. AIM

The recommendations should describe the fundamental concepts and quantities used during the whole radiotherapy chain to avoid misunderstandings between different personnel groups sharing the responsibility during the therapy process, but also between different

therapy centers reporting results. Ideally one should have a complete 3D description of patient and treatment volumes for every patient and a perfect fixation of the patient relative to the beam. In practice this is not the situation, but one should be aware of consequences for the limitations, simplifications and assumptions of the procedures used. Definitions and specifications have to fit the ideal situation as well as simpler cases, but if necessary special assumptions may be done for the 0simpler cases.

3. PATIENT GEOMETRY AND SET-UP

Since no rigid connection exists between different tissues and organs of the patient and the radiation beam, local coordinate systems have to be used. These systems are related to either patient or treatment unit. To get a connection between these systems two sets (internal and external) of Anatomical Reference Points have to be used. In addition Aligment Markings have to be used for correct set-up of the patient.

Internal Reference Points are local points inside the body and used for beam set-up at the simulator and portal verification at treatment unit. External Reference Points are palpable or visible points located on the surface of the body or on fixation devices that fit closely to the exterior of the body, and used for beam set-up both at simulator and treatment unit. A special case of External Reference Points are External Reference Systems, which are fixation systems like stereotactic frames in which the target volume is described and defined.

The Anatomical Reference Points should be as rigid as possible relative to patient and target tissues and located as close as possible to target tissues. Different means are developed to minimize set-up errors, and combined with the use of Anatomical Reference Points these will minimize errors between local coordinate systems and margins for volumes to be delineated. The use of Anatomical Reference points makes it possible to distinguish between variations inside the patient and external variations and errors for set-up of patient and beam.

4. TREATMENT GEOMETRY AND BEAM SET-UP

It is in many situations practical to distinguish between tumors/tissues as medical specifications and volumes as geometrical specifications, hence nomenclature should make this possible. Margins have to be added for different volumes to take into account variations inside the patient and variations/errors during set-up using the Anatomical Reference Points. In addition one should have just one type of target volume to avoid ambiguity. ICRU 50 [2] are using two different target volumes (Clinical and Planning Target Volumes (CTV, PTV)). We recommend to use an Anatomical Target Volume that just encompass the target tissues (CTV) with presumed variations and movements. This volume should be used for optimization and portal verification. A Set-up Margin should be added to the beam periphery in beams-eye-view to account for errors and variations of patient and beam set-up. Using this concept of splitting the margins into two part, one related to internal variations and one related to external variations, there will be no need for the Planning Target Volume. Due to this the nomenclature should be slightly different from ICRU50, se table I.

TABLE I. RELATIONSHIPS BETWEEN DIFFERENT TISSUES AND VOLUMES FOR TREATMENT GEOMETRY AND BEAM SET-UP

Tissue / Volume	Coord. system	Concept
Gross Tumor (ICRU 50 [2])	tumor coord. system	medical
+Microscopic Disease (verified/presumed)	tumor coord. system	medical
=Target Tissues (Clinical Target Volume)	tumor coord. system	medical
+Target Margin (3D)	patient coord. system	geometrical
=Anatomical Target Volume	patient coord. system	geometrical
+Set-up Margin (2D in beams-eye-view)	beam coord. system	geometrical

Target Tissues contains all Gross Tumor and verified or presumed Microscopic Disease to be treated, and are similar to Clinical Target Volume (ICRU50). Target Margin accounts for uncertainty in anatomic information, expected movements and/or variations of shape and size of Target Tissues relative to Anatomical Reference Points. Anatomical Target Volume is then a geometrically volume fixed to Anatomic Reference Points. The Target Tissues are expected to move just inside this volume, and therefore it should be used for prescription, optimization and reporting of doses. When there is no ambiguity between Anatomical Target Volume and other definitions of target volumes (e.g. CTV, PTV), Anatomical Target Volume can simply be called Target Volume. The radiation oncologist is responsible for delineating Target Volume.

The Set-up Margin (including uncertainties of positioning, movements during irradiation, dose planning, treatment technique and treatment unit performance charisteristics) have to be added to the periphery of the beam to give the final size and shape of beam. This should to be done in beams-eye-view projection and related to Anatomical Reference Points. No volume delineation (like ICRU Planning Target Volume) is then necessary for beam set-up.

The components of Anatomical Target Volume defined above will vary considerably. For postoperative treatment the Gross Tumor will normally be removed, and for brachytherapy the Target Margin will not be needed. In many cases Gross Tumor will be given a larger dose than Microscopic Disease, and Gross Tumor have to be delineated as a separate Target Volume with its own Target Margin. Organs at risk should similarly to Target Tissues have margins to delineate Organ at Risk Volumes.

5. DOSE SPECIFICATIONS

For homogenious dose distributions, as for most external radiotherapy situations, the arithmetic mean dose to Anatimcal Target Volume is the most important dose concept together with its standard deviation. Hence the arithmetic mean dose should be used for both prescription and reporting. For simpler cases, e.g. palliative treatments and single beam technique, the mean dose can be approximated by the dose around a representative point selected to be close to the average dose value. The arithmetic mean dose (or its approximated point dose) will normally be slightly different from the ICRU reference point dose, and for intercomparison purposes both should be reported.

For situations where dose distribution to Target Volume have large variations, e.g. brachytherapy and external therapy to very small volumes, a dose close to the minimum dose inside the volume will be the most important value and should be used for prescribing and reporting.

Minimum and maximum doses to Anatomical Target Volume should be specified if variations are larger than allowed tolerance range, together with dose to eventually hot spots outside Anatomical Target Volume. As a general rule all information available and used for dose specification (e.g. radiation and beam set-up parameters, dose plans, dose volume histograms) should be stored together with already mentioned dose values.

6. CONCLUSIONS

These recommendations will be discussed September 1995 at a Nordic Concensus Meeting in Umeå, Sweden.

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MARGINS IN RADIOTHERAPY

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Abstract

As part of the treatment prescription procedure, one has to prescribe in anatomical terms any GTV (Gross Tumor Volume) according to the general TNM-rules as well as any other tissues that are to be treated for presumed subclinical disease. These prescriptions of one or several Clinical Target Volumes (CTVs) are based on general oncological principles, and are not related to the treatment modality. If external beam radiotherapy is being used, one

has to consider special problems related to different geometric inaccuracies and uncertainties, which can be both intrafractional and interfractional. Such inaccuracies and uncertainties are due to either the position, shape and size of the patient/tissues in relation to a fix point, or to variations in beam geometry. The two different types of variations may or may not co-variate. A margin or margins for these uncertainties has to be included in the dose planning procedure, which then will evaluate a static situation, representing the CTV(s) plus geometric "safety" margin(s) (= Planning Target Volume, PTV) and in fact not the true clinical situation. The dose distribution arrived at for this static representation will however have to be considered as representative for the CTV. This presents of course a dilemma, but one has to accept a reasonable compromize. There is no general rule on the size of the different geometric uncertainties or how they should be added up. Individual evaluations are needed.

The reasons for selecting different volumes in radiotherapy as well as the definitions recommended for these volumes for the purposes of prescribing, recording, and reporting external beam therapy are given in other communications in this report. The purpose here is to point to some special problems that are encountered during the process of prescription and planning.

DEFINITION OF THE GTV(s) AND PRESCRIPTION OF THE CTV(s).

As part of the treatment prescription procedure, one has firstly to define in anatomical terms any GTV (Gross Tumor Volume) according to the general TNM-rules, and secondly to prescribe also treatment of other tissues for presumed subclinical disease. This prescription of one or several Clinical Target Volume(s) (CTVs) (= GTV [if present] and presumed subclinical disease) is based on general oncological principles, and it is not related to the treatment modality.

There are often problems to delineate the GTV unambiguosly, and this constitutes at present one of the important uncertainties in radiotherapy. The problem varies with the tumour site as well as with the diagnostic methods and also with the observer's experience. Thus in breast cancer, one may with some histologic types (notably tubuloductal carcinomas) arrive at different sizes depending on which method that is used for evaluation (palpation, or mammography, or histology), and this points to the importance of stating, when the treatment is reported, which method that was used. Similarly, in bronchogenic carcinoma (Fig. 1) it is noto-

riously difficult to distinguish between the GTV proper and its secondary changes in the lung parenchyma. New techniques such as MRI have up to now not eliminated this problem, but future improvements are expected.

Even in seemingly simple situations, different observers may arrive at different sizes, shapes and position of the GTV (Fig. 2).

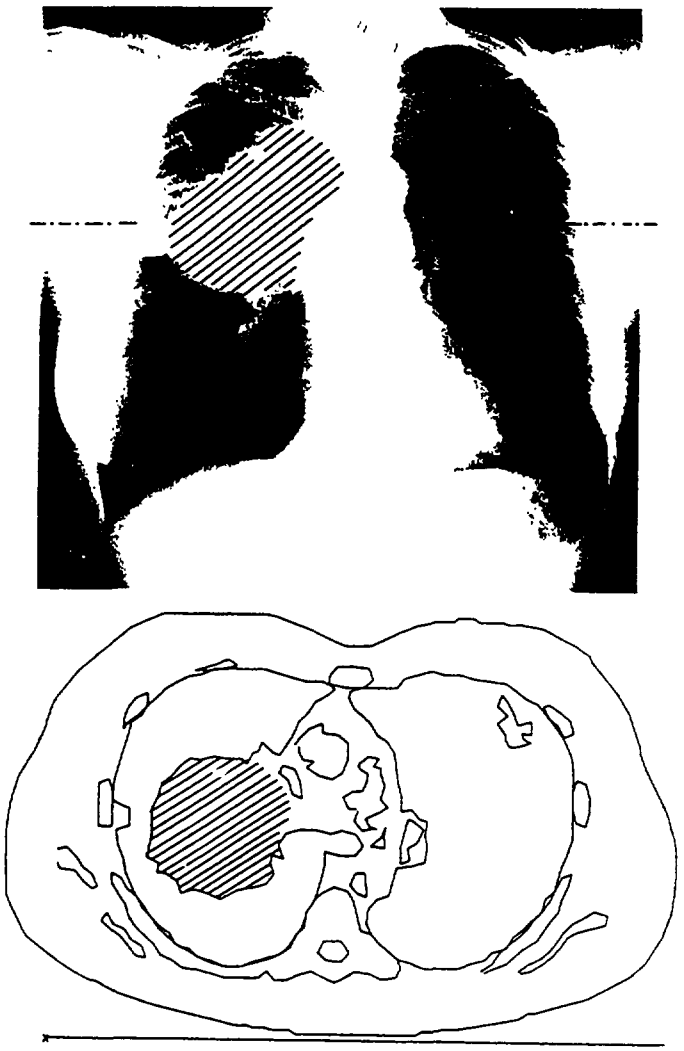


Fig. 1. Case of bronchogenic carcinoma. There is a problem to distinguishe on X-ray between the GTV and its secondary changes in the lung parenchyma.
From ICRU Report # 50 (1993). (By kind permission from ICRU).
NB: all figures show only a two-dimensional representation, but of course all prescriptions and plannings have to be made for the real three-dimensional situation.

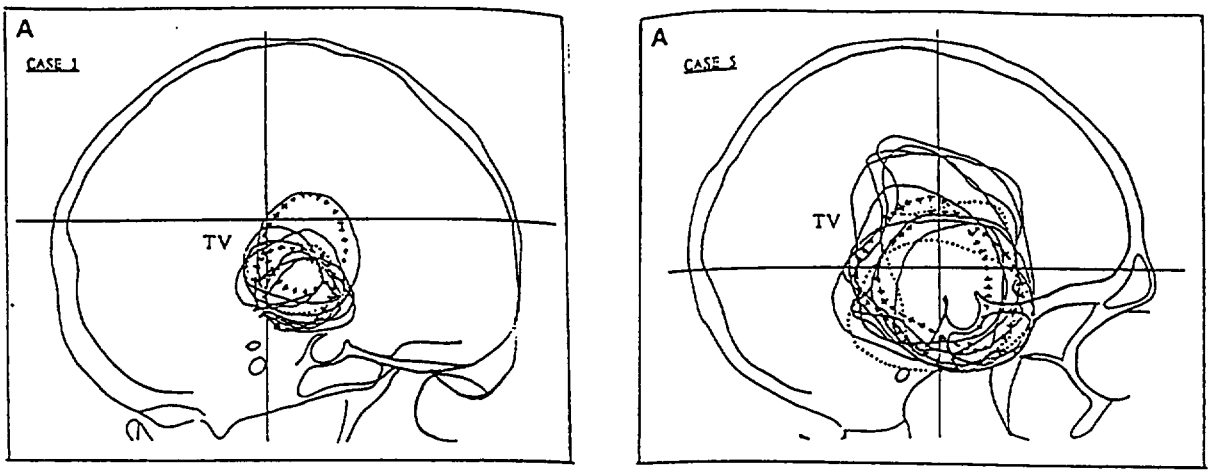


Fig. 2. Schematic drawings on lateral orthogonal radiographs for two patients with brain tumours, where the gross tumour was delineated by:
- 8 radiation oncologists (full drawn lines),
- 2 radiodiagnosticians (dotted lines), and
- 2 neurosurgeons (cross-lines).
From: Leunens et al., Radiotherapy and Oncology 29 (1993), 169-175. (By kind permission from the editors).

For subclinical (microscopical) loco-regional and distant extensions of the GTV, additional volumes have to be prescribed for treatment. Such volumes may be:
- locally around a GTV,
- regional lymph nodes,
- well defined anatomical space in continuity (*e.g.* subdural space, peritoneum),
- distant sites (*e.g.* brain, lungs).

Thus, clinical experience as well as histopathological examinations indicate that (except for some situations where there is a definite anatomical border like the pleural surface with lymphoma), it is not adequate to treat (*e.g.* excise or irradiate) only the GTV, but one has also to include a margin for local subclinical extensions around the GTV. The tumour cell density in the margin is usually largest close to the GTV, and the decreases centripetally from the GTV, but this may occur in an uneven fashion, and there may be distinct strands of subclinical extensions in some directions, and even local small deposits (Fig. 3). It will to-day have to be the clinical experience that governs the decision on the size in different directions of the margin for local subclinical disease around a GTV. If this margin is well described, then it should be possible during follow-up to identify cases where the margin was inadequate, since these should show a higher frequency of a marginal relapse. Over-evaluation however can not be judged by this method. The situation is the same with regional and distant subclinical disease (see below).

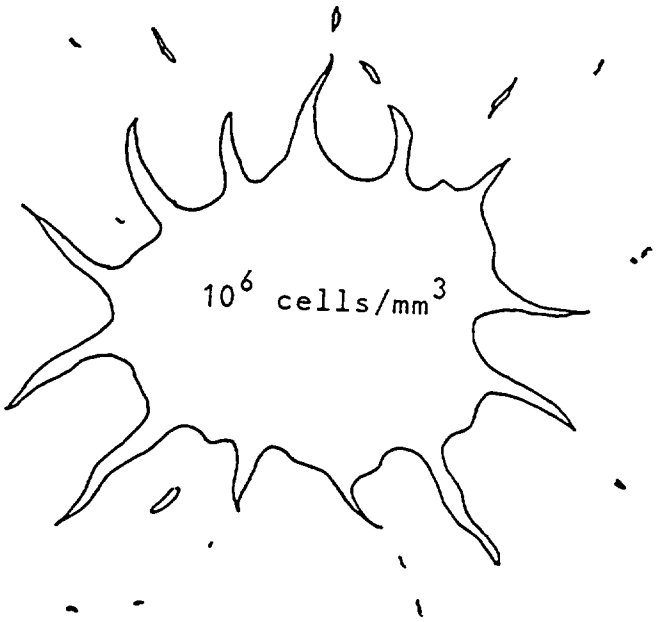


Fig. 3. A tumour with high tumour cell density and its surrounding microextensions with lower tumour cell density. The extensions may be different in different directions, and the possibility of separate small local deposits may also have to be considered.

The other most frequent volumes selected for treatment of subclinical disease are the regional lymph nodes (in node negative patients). There should be no problems to identify the normal position of the nodes that are prescribed for treatment (Fig. 4). Unfortunately this is not always done, resulting in both undertreatment and overtreatment.

In some situations the anatomical borders of the tissues that are prescribed for treatment of subclinical disease are quite well definable, *e.g.* the subdural space in the spinal or cranial regions (Fig. 5), or the lungs.

For the patient illustrated in Fig. 1, one may then prescribe treatment of not only the GTV and its margin for local subclinical extensions (Fig. 6) but also (maybe to an other prescribed dose) of presumed subclinical spread to the regional lymph nodes in the mediastinum (Fig. 7).

DEFINITION OF THE PTV DURING THE PLANNING PROCESS.

For some treatment modalities (*e.g.* surgery and hyperthermia) there are no (or should be no) problems with geometrical uncertainties once the CTV(s) has been prescribed before treatment.

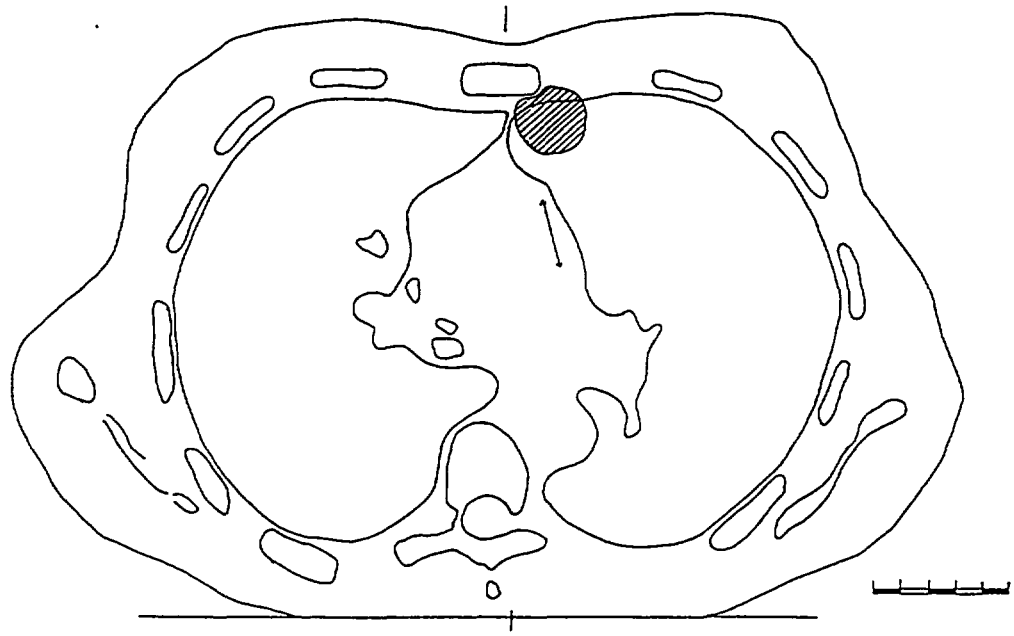
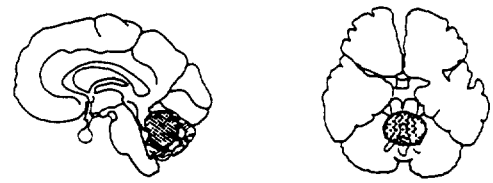


Fig. 4. Typical CTV for the treatment of subclinical metastases to the regional lymph nodes, in this case the internal mammary nodes in breast cancer.



Medulloblastoma of 4th ventricle

Anatomical structure	ICD-O(9)	ICD-O(10)	Laterality	T-SNOMED
Gross tumor volume				
Roof of the 4th ventricle	191.5	C71.7	3	T-X1820
Clinical target volume				
Cerebellum	191.6	C71.6	3	T-X6000
Intracranial meninges	192.1	C70 0	–	T-X1410
Spinal meninges	192 3	C70 1	–	T-X1115

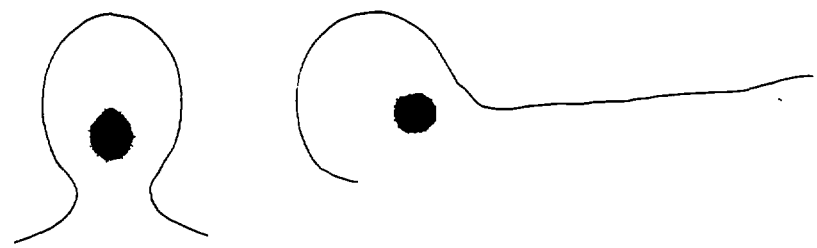


Fig. 5. Case of prescription of a CTV for treatment of subclinical disease in the subdural space in medulloblastoma. In this case, the anatomical borders of the CTV can be defined unambiguously.
From ICRU Report # 50 (1993). (By kind permission from ICRU).

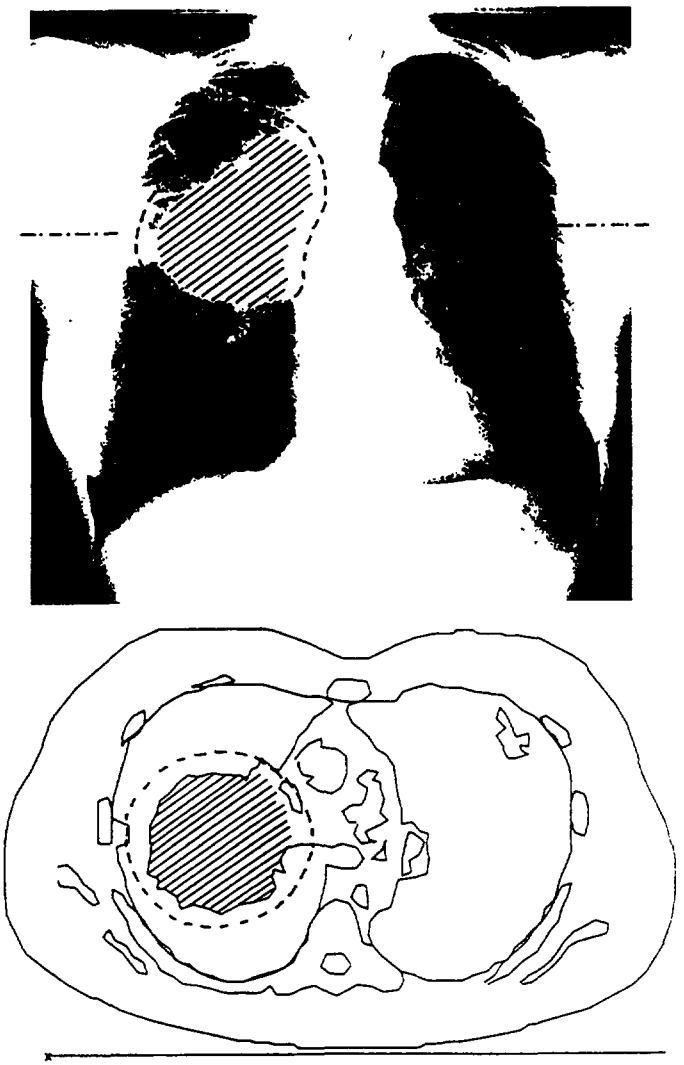


Fig. 6. Case of bronchogenic carcinoma (same case as in Fig. 1). Treatment prescription for the GTV and local subclinical extensions (CTV 1) (indicated by the dashed line). From ICRU Report # 50 (1993). (By kind permission from ICRU).

For radiotherapy, and particularly with external beams, the situation is different, and different geometrical uncertainties have to be considered and taken into account when planning the treatment. One thus has to add margin(s) to the CTV(s) for dose planning purposes. This is not restricted to fractionated external beam therapy, albeith the problems are then most obvious. The process requires a close cooperation between the radiation oncologist and the radiophysicist.

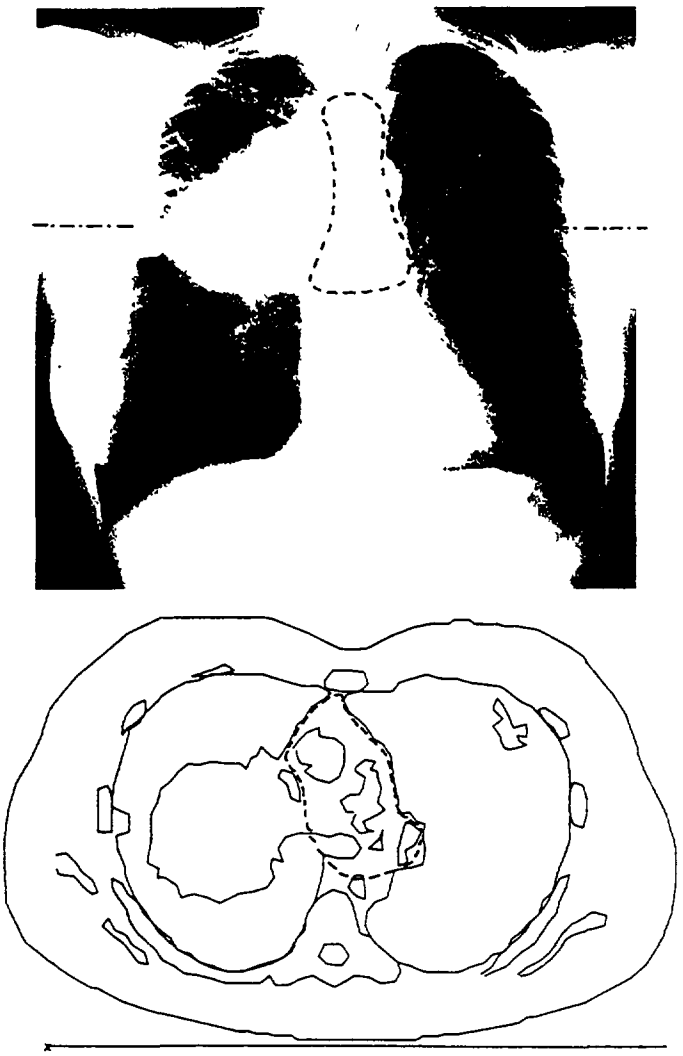


Fig. 7. Case of bronchogenic carcinoma (same case as in Fig. 1). Treatment presription for the mediastinal lymph nodes (CTV 2) (indicated by the dashed line).
From ICRU Report # 50 (1993). (By kind permission from ICRU).

The different geometrical uncertainties can be described as follows:

- movements of the patient as well as movements of the tissues which contain the CTV (*e.g.* with respiration),
- variations in size, shape and position of the tissues that contain the CTV (*e.g.* different fillings of the bladder, respiration),
- variations in beam geometry characteristics (*e.g.* beam sizes, beam directions).

The uncertainties may be both intrafractional and interfractional.

Thus, when once the CTV has been defined, then one has to consider special problems related to different geometric inaccuracies and uncertainties. A margin or margins for these uncertainties has to be included in the dose planning procedure, which then will evaluate a static situation, representing the CTV(s) plus geometrical "safety" margin(s) (= Planning Target Volume, PTV) and in fact not the true non-static clinical situation. The dose distribution arrived at for this static representation will, however, have to be considered as representative for the CTV. This presents of course a dilemma, since the CTV (and Organs at Risk) may during real treatment move in an uneven fashion across a dose gradient in a way that is not demonstrated by the static dose plan. If this occurs in a steep dose gradient (note special case: scanning beam), then the effect may be significant. It is, however, necessary to accept a reasonable compromise. There are no general rules on the size of the different geometric uncertainties or how they should be added up. Individual evaluations are needed.

The following points to some of the problems that are encountered when defining these geometrical margins.

The starting point is the definition of the CTV(s), examplified in Fig. 8 in a transversal plane for a patient with a mediastinal tumour (full drawn line).

There are different possibilities for movements of the patient and the tissues that contain the CTV in relation to a fix point (*e.g.* suprasternal notch).

Thus the patient may move linearly in any direction (lateral directions shown in Fig. 9 upper), and there may also be a rotation along any axis (shown for a sagittal axis in Fig. 9 lower). Most of the variations can be diminished by adequate patient immobilization devices.

The tissues that contain the CTV may vary in size, shape, and position in relation to the fix point. Thus there may *e.g.* be different fillings of the bladder and the esophagus (Fig. 10 upper), and there may be displacements due to *e.g.* respiration and variations of atelectasis and pleural effusion (Fig. 10 lower).

All these potential variations may or may not co-variate. Futhermore they may be systematic and/or random in their freqency, magnitude, and direction. Some of these variations can be studied, *e.g.* by means of repeat chest x-ray in treatment position, or by fluoroscopy, but usually it is not possible to predict exactly their total effect in a patient. Assumptions have to be made (see below). As a first step in the dose-planning procedure one can then add a combined margin to the CTV for the total effect of these patient/tissue movements (Fig. 11). As shown in the figure, the size of this integrated margin may differ in different directions.

It is thus obvious that, even with reproducible beam geometry, the beams' sizes will have to be adjusted to cover the margin that is needed for patient and tissues movements. Such an adjustement may be different for different beam directions (Figs. 12 & 13). If the beam geometry that will be used is known already at this stage

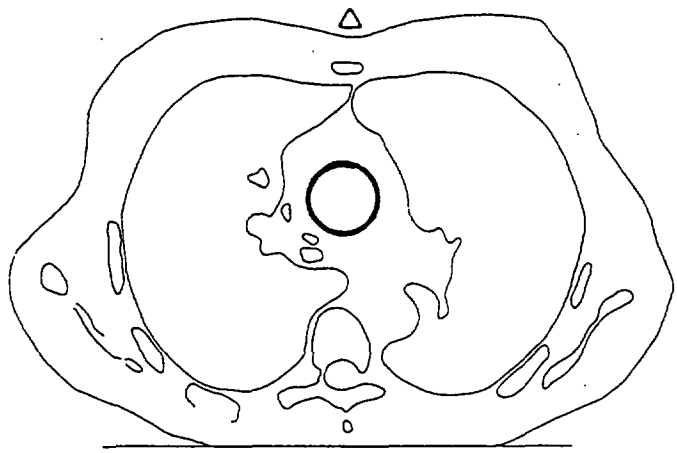


Fig. 8. CTV (related to a fix point, *e.g.* sternal notch) represented as a prescription for an assumed static situation, for a patient with a tumuor in the mediastinum.

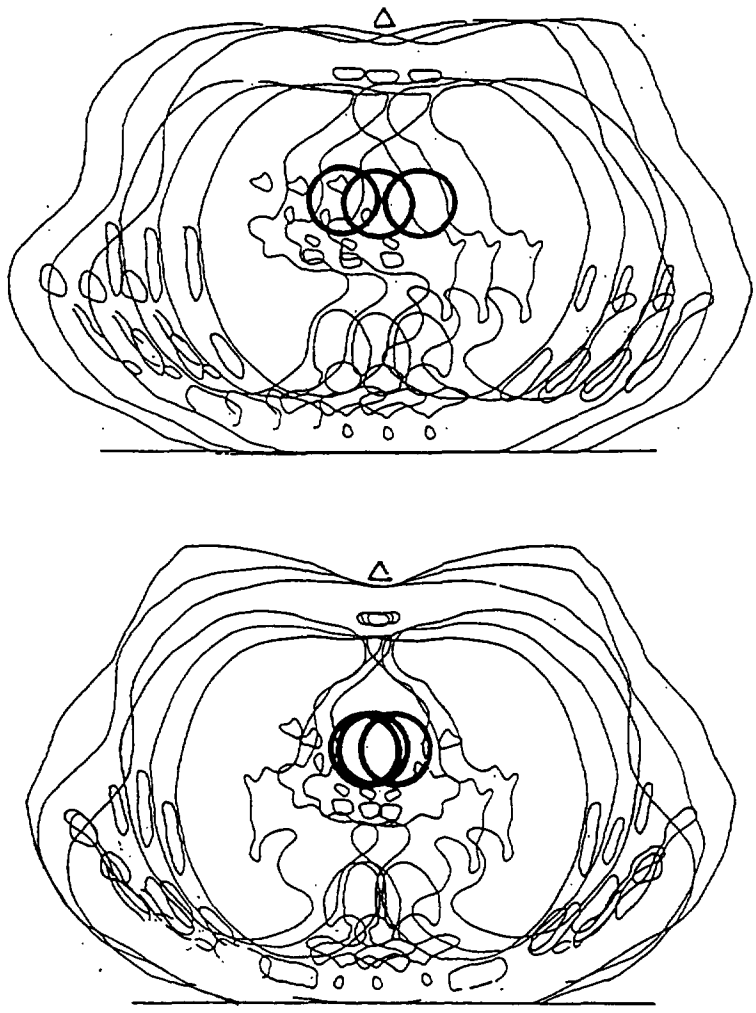


Fig. 9. Different types of patient's movements in relation to the fix point have to be evaluated, and are shown here as demonstrated by a limited number of transverse section for two possibilities, viz. lateral displacement (above) and rotation (below) of the whole patient.

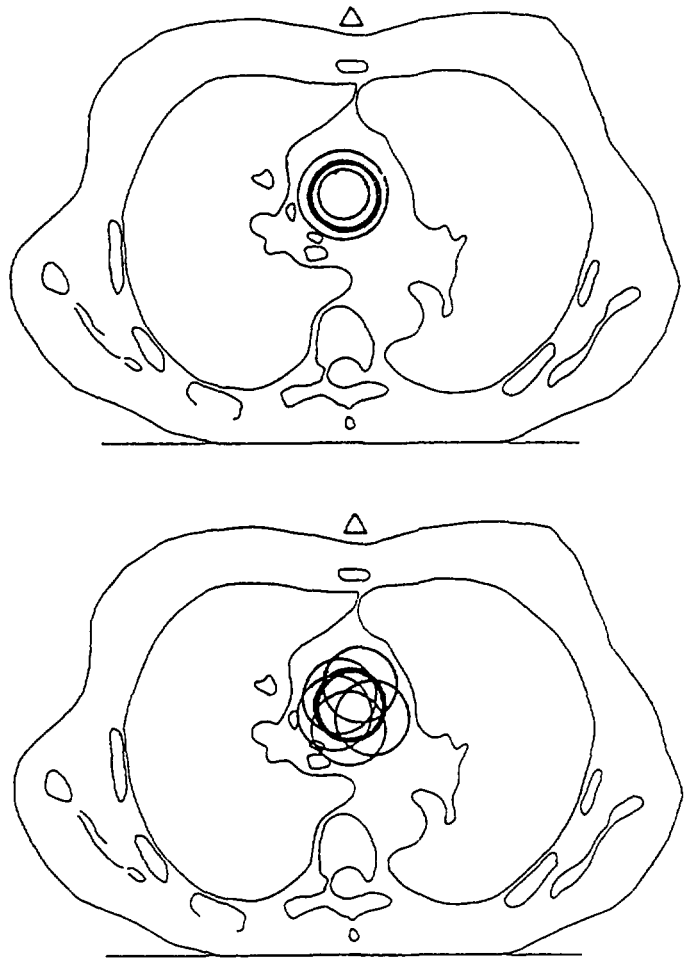


Fig. 10. The tissues that contain the CTV may vary in size due to e.g. different fillings of a hollow viscus (above) and it may vary in position in relation to the fix point e.g. due to effects of respiration (lower).

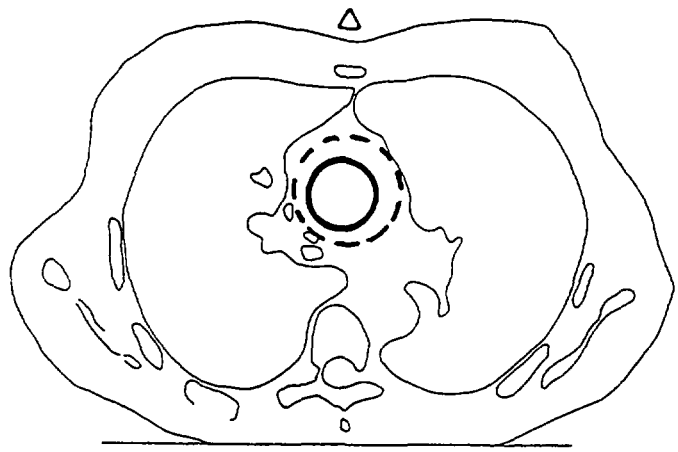


Fig. 11. The variations shown in Figs. 9 & 10 may or may not co-variate. The may also be of different size in different directions. There combined effect can be estimated taking into account normal variations as well as extreme deviations. One then arrives at an accepted limit (broken) line for these patient/tissue variations.

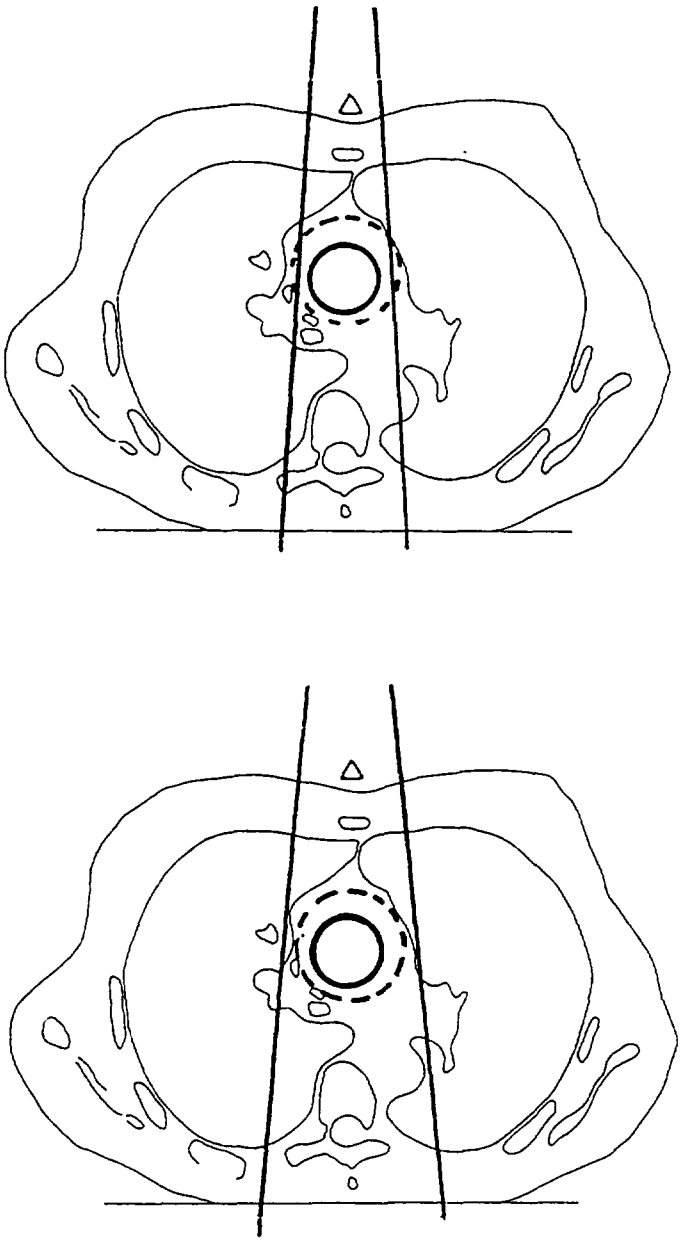


Fig. 12. If the beams' sizes are choosen only according to he CTV (fulldrawn line), then parts of the CTV will be missed due to variations described in Figs. 9 & 10, and it will be necessary to use (as a first step) larger beams to cover the CTV and its geometric variations due to patient/tissue movements (broken line) with reasonable safety. The figure shows the situation for an anterior beam, where the anatomical uncertainties for this particular beam will have to be considered.

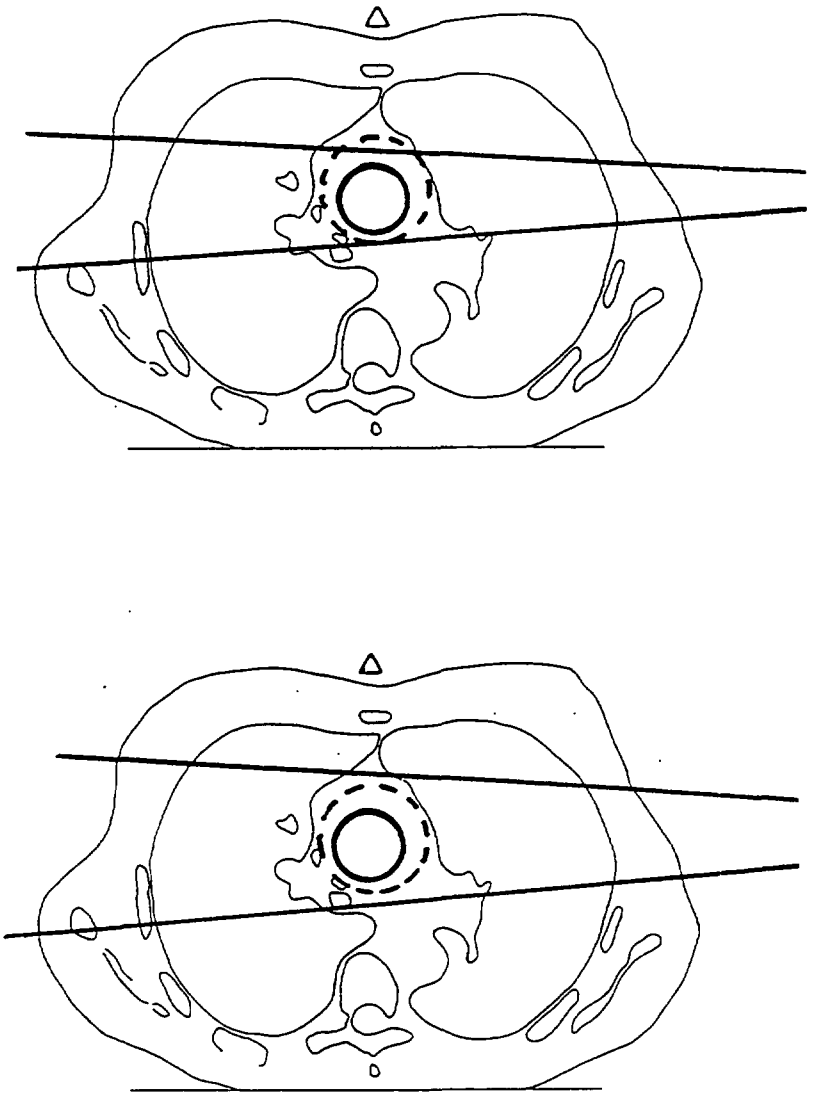


Fig. 13 For the same situation as in Fig. 11, but with a lateral beam, the situation will have to be handled similarly.

It is obvious from Figs. 12 & 13, that if only one beam is used, one has consider margins for beam geometry reasons in a plane only in two directions (lateral directions for situation in Fig. 11, and AP-PA directions for situation in Fig. 12). The need to define these margins is therefore in fact related to the beam geometry that will be used. As a compromise it is probably useful in the routine work to accept that any beam geometry will be tested, and add margins according to this, as shown in Fig. 11.

(*e.g.* according to a treatment protocol), then it is only necessary to define the margin for beam size in some directions, and then only the influence of dose variation in the beam direction to the CTV due to possible movements have also to be considered. In other situations, as a useful compromise, it is usually feasible to define the margin for patient/tissue movements in relation to the fix point in all directions, as indicated in Fig. 11. Otherwise the margin would have to re-defined in an iterative way as different beam directions are tested during the dose-planning procedure.

Next problem is related to variations in beam sizes and directions during treatment. These uncertainties may also be both systematic (*e.g.* sagging jaws) and random. The beams' sizes may vary, as well as the rotation and gantry angle. Blocking can also be considered to be part of this problem. Examples of lateral dislocation of the beam as well as variation in beam angle are shown in Fig. 14 (upper). In order to compensate for this, it is obviously necessary to apply a larger beam (Fig. 14 lower). These variations can to some extent be studied by means of portal imaging. If this is rapid enough and on line, corrections during treatment can be performed. Other parameters can be controlled by means of different types of Check and Confirm Systems.

In analogy with the situation with margins for patient/tissue variations, one could for dose-planning purposes add up the margins needed for the different types of beam geometry uncertainties (Fig. 15). Note that these may have a different shape and position than the one needed for patient/tissue movements.

It is usually not reasonable to add up all uncertainties linearly. This would probably in most cases lead to too large volumes being treated and thus unnecessary toxicity. Instead, one may assume that the random uncertainties are normally distributed (Hess et al., 1994) and the systematic uncertainties can be estimated by their standard deviations, and then the combined effect can be estimated. The total standard deviation is then the root of the square sum of random and systematic uncertainties (ICRU Report 50, 1993).

If such a method is accepted, then the different kinds of uncertainties may be amalgamated into one margin (Fig. 16 bottom), that will be used for dose planning, and, with all its limitations, also for recording and reporting the dose to the CTV. Fig. 17 shows this principle applied to the patient previously demonstrated in Figs. 1, 6, and 7.

During recent years, several studies on the problem of margins in external beam radiotherapy have been reported (*e.g.* Blanco S. et al [1987], Brenner D. [1989], Gildersleve J. et al [1994], Goitein M. [1985], Goitein M. & Busse J. [1975], Graham M. et al [1994], Hess C. et al [1994], Holmberg O. et al [1994], Huizenga H. et al [1988], Leunens G. et al [1993], Moerland V. et al [1994], Rudat V. et al [1994], and Wambersie A. et al. [1994]). Often they focus mainly on beam positioning errors. Even though several of different the types of margins are largely influenced by patient and tumor characteristics, and thus individual, a search for typical patterns is highly needed. It is hoped that future research and technical developments will help to clarify the issue.

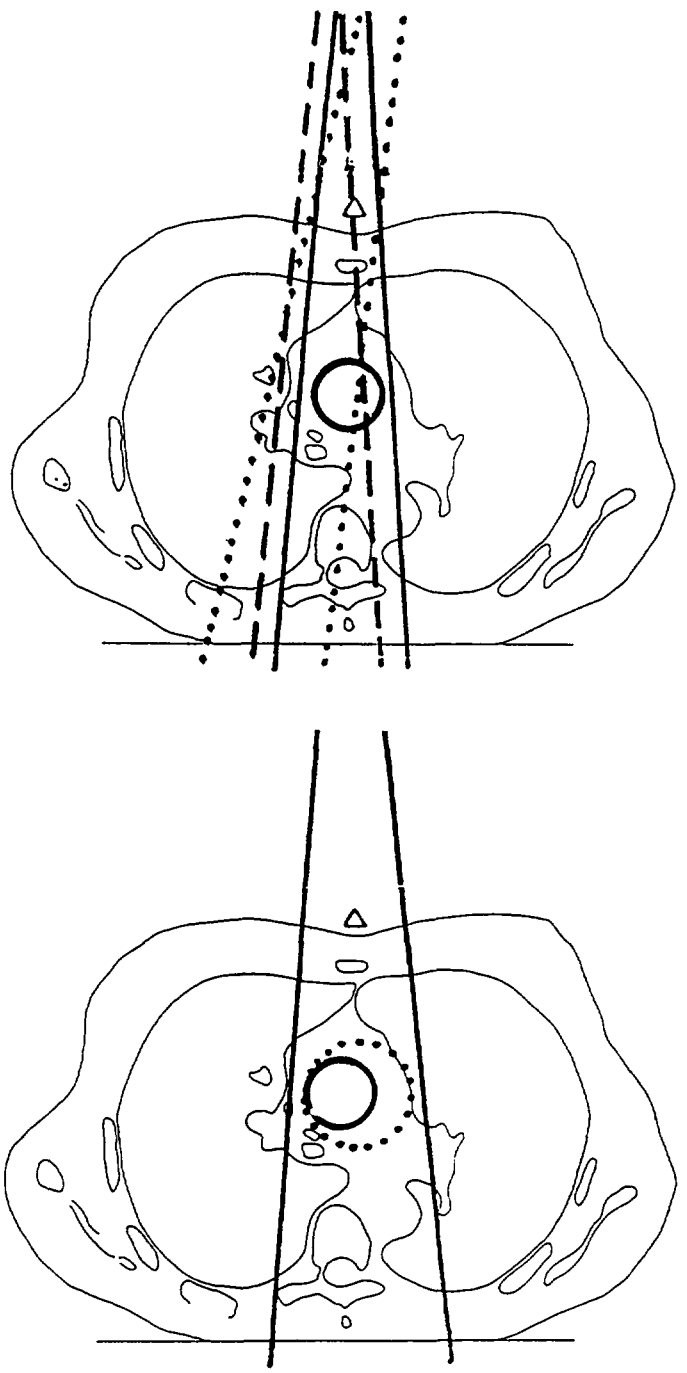


Fig. 14 An other problem that needs to be handled is geometric uncertainties of the positioning of the beams in relation to the fix point. These uncertainties may well be both systematic (e.g. sagging jaws) and random. Shown here are positioning variations in lateral direction as well as directional variations (above), and the margin needed to select proper beam sizes to compensate for these variations (below).

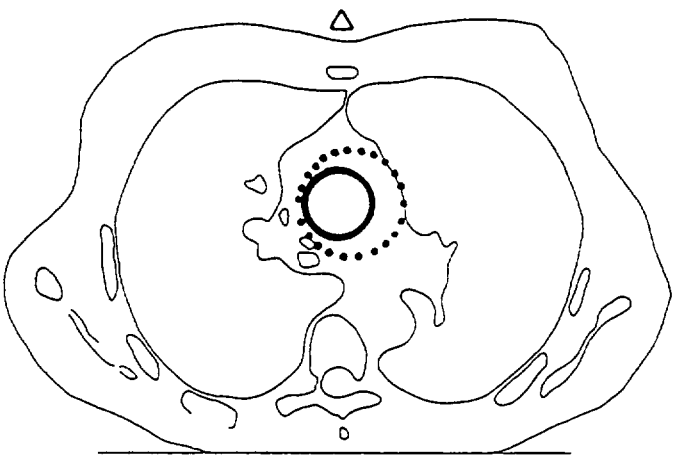


Fig. 15 Thus in analogy to the situation described in Fig. 11, for dose planning purposes it is useful to add a margin (dotted line) for these beam geometry uncertainties. the CTV (full drawn line).

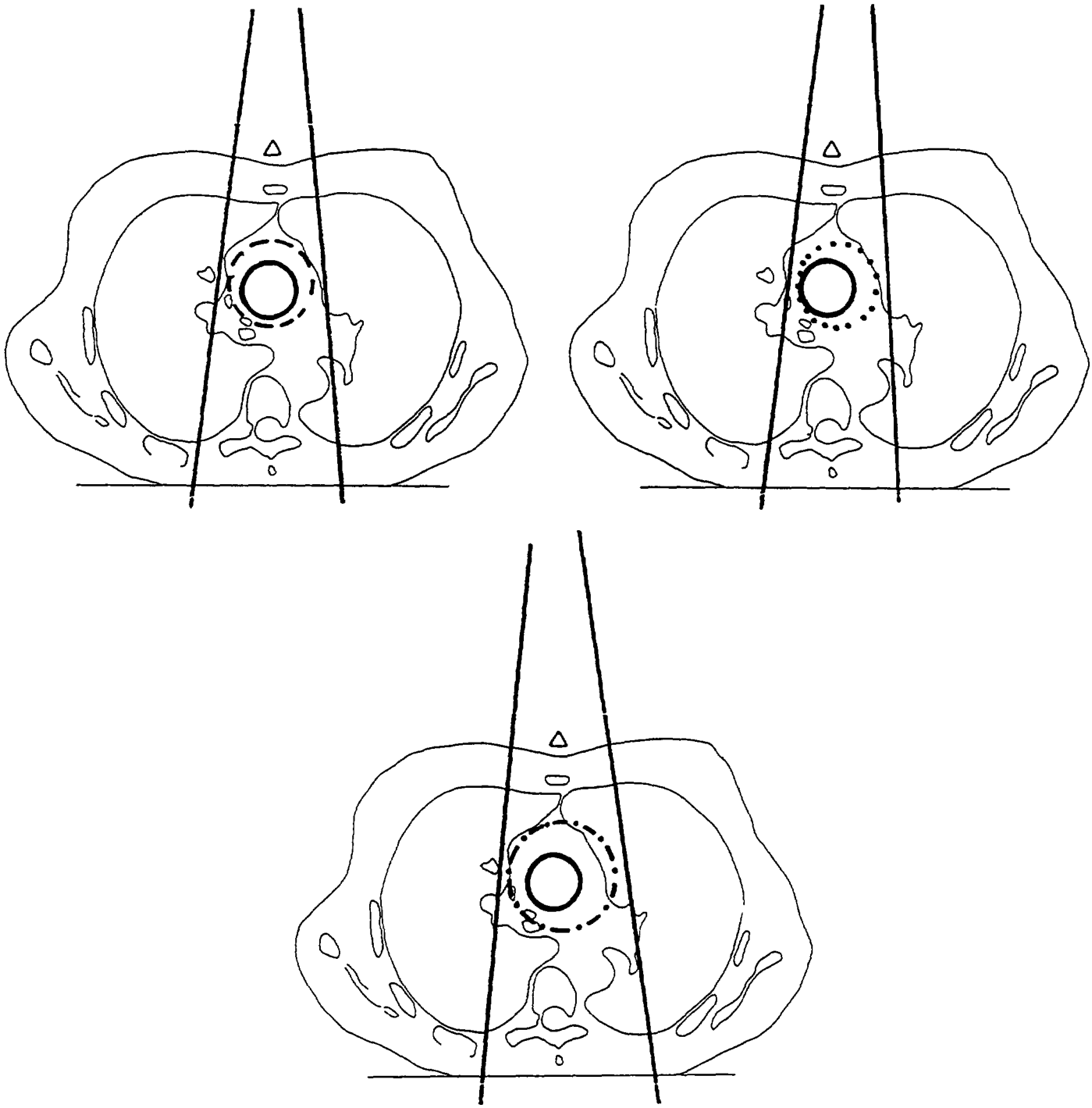


Fig. 16 All the uncertanties demonstrated in Figs. 9, 10, and 14 have to be considered together, since dose-planning at present is made assuming static conditions. In this example, beam margins needed because of patient/tissue variations (upper left) have been considered separately from margins needed due to beam geometry variations (Fig. 14) (upper right). It is by no means clear a priori how the different margins should be added up for the purpose of dose planning, since they may or may not co-variate, and furthermore they may be both systematic and random. The lower figure shows a compromize where the addition has been made as described in the text. This is the static representation (PTV) that is used for treatment planning for the CTV shown in Fig. 8, and for recording and reporting dose to the CTV.

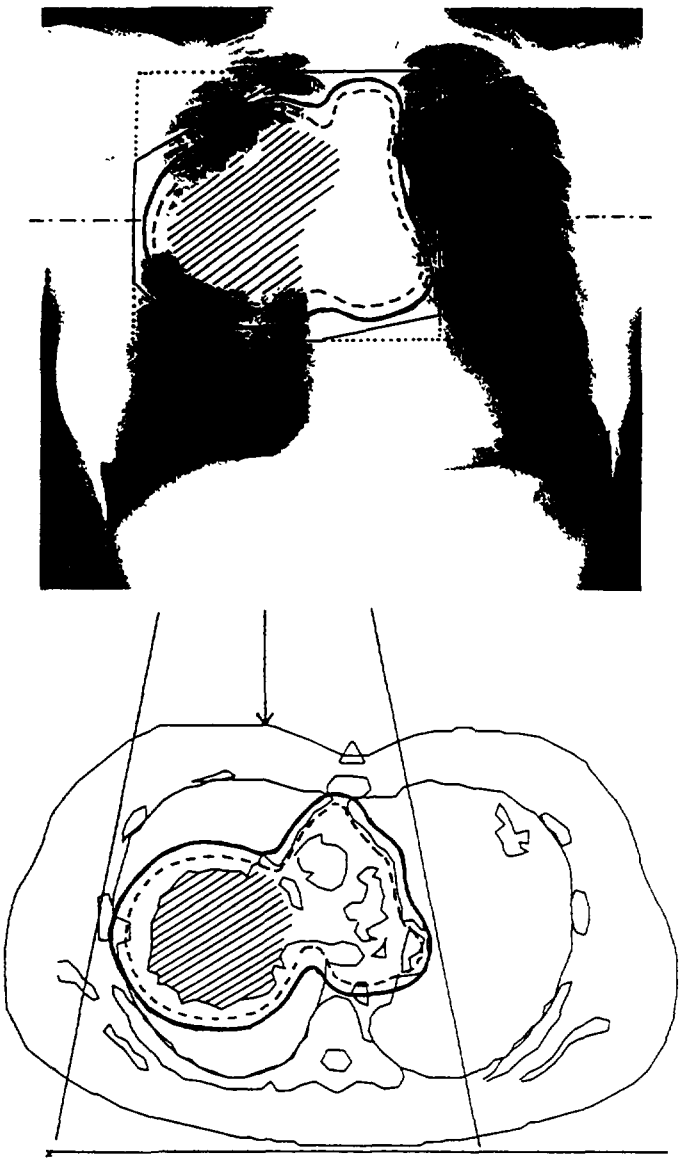


Fig. 17 For the patient with a bronchogenic carcinoma shown above (Figs. 1, 6 & 7) the PTV was defined as shown in this figure by the thick full-drawn line (same dose prescribed for both CTV 1 and CTV 2).
From ICRU Report # 50 (1993). (By kind permission from ICRU).

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RESULTS

CURRENT STATUS OF QUALITY ASSURANCE OF TREATMENT PLANNING SYSTEMS

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Abstract

A review is given of the current status of quality assurance of treatment planning systems. At this moment only one comprehensive report is available. In order to review national activities a questionnaire has been distributed amongst national societies of medical physicists. From the 23 responding countries, 8 indicated that only limited efforts are underway, 8 answered that a working group is evaluating their specific national requirements while in 5 countries a document is drafted. The highlights of these reports have been summarized.

1. INTRODUCTION

In contrast with the information available on quality assurance, QA, programmes of treatment machines, there is relatively little guidance related tot QA of a Treatment Planning System, TPS. Acceptance testing, commissioning and quality control of accelerators are well developed procedures and many documents exist giving recommended procedures. For treatment planning systems these recommendations are scarce or still have to be developed. Although the need for QA of a TPS is generally recognized and each physicist is performing a set of (routine) tests of his/her planning system, different approaches are possible. It is the purpose of this presentation to review the current status of QA of TPS, mainly for external photon beams.

In order to start a QA programme of a TPS, accuracy requirements have to be formulated. As an example for good clinical practice, the following data, given as one standard deviation, have been proposed [1, 2]:

- absorbed dose at the dose specification point (average dose) : 3.5%
- absorbed dose at other points in the target volume : 5 %
- position of field edge : 4 mm

Knowledge of the dose delivered to a point in a patient is usually the result of three distinct steps:
(1) determination of the absolute dose at the reference point in a water phantom under reference circumstances;
(2) calculation of the dose at points in the patient relative to the dose at the reference point in the water phantom;
(3) deviations between actual and intended set-up and treatment of the patient.

The uncertainty in step (1) is about 2.5% and in step (3) may be estimated to be 1.5% along the central axis of the beam and about 3% at other places in the field. This leaves an uncertainty in the determination of the relative dose distribution varying between about 2% and 3% (excluding the effect of heterogeneities). This is in agreement with the requirement given in some documents as summarized in Table I.

TABLE I. CRITERIA OF ACCEPTABILITY IN COMPARING CALCULATED TO MEASURED RELATIVE ABSORBED DOSE DISTRIBUTIONS OF EXTERNAL PHOTON BEAMS.

Reference		Small dose gradient (%) (mm)	Large dose gradient
McCullough and Krueger	[3]	3	4
Dahlin et al.	[4]	3	3
ICRU Report 42	[5]	2	2
Brahme et al.	[6]	3	3
Van Dyk et al.	[7]	2-3*	4
Kutcher et al.	[8]	2	2

* The lower value is valid for central-ray data; the higher one for the high-dose region

The actual position of the field edges with respect to the target volume is also the result of several steps, including the uncertainty introduced by the treatment planning system. Compared with the other uncertainties, e.g. patient movement, the geometric uncertainty resulting from the planning system can be made quite small, e.g. of the order of 2 mm or less. Although this requirement can generally be achieved for 2D-treatment planning systems, the increased number of possibilities of 3D-planning systems requires a much more extensive QA programme to check if such a requirement is achieved in all directions, as will be discussed in section 5.

2. TESTING TREATMENT PLANNING SYSTEMS

The main error sources in computerized treatment planning are related to·

(1) hardware components;
(2) beam data acquisition and reconstruction;
(3) patient data acquisition and representation;
(4) algorithms used for the dose computation and representation.

In principle the manufacturer of a TPS should provide the user with detailed information about the performance of the system. It is, however, extremely difficult, both for the vendor and the user, to assure the quality of the system under all clinical conditions. For that reason only recently guidelines have been formulated for acceptance testing, commissioning and QA of a TPS.

Before placing a computer planning system into clinical use, it must be carefully checked with respect to its diverse functions and accuracy. Basically there are two different approaches of testing computer planning systems:
(1) a comprehensive test using a *standard set of beam data* [9, 10, 11];
(2) a user oriented test based on *local beam data* and local computer facilities [12, 13].

Method (1) is more general and avoids the necessity of making measurements by the user of the test programmes. It does require, however, the introduction by the physicist of basic beam data in the system which are generally not directly of relevance for his own clinic. The second method has the advantage that the results are directly applicable to his own situation. A comparison with other institutions is, however, more difficult because the treatment planning system and/or the treatment beam will differ.

Most of these systematic tests or intercomparisons of treatment planning systems concerned comparisons of measured and predicted dose distributions Differences could generally be attributed to limitations in the accuracy of dose calculations algorithms, particularly in the scattered component of the dose Some intercomparisons also revealed discrepancies between the actual beam data and those applied in the TPS [9, 13] Although most information deals with external beam treatment planning, systematic tests of treatment planning systems for brachytherapy have also been performed [e g , 14]

It should be noted that these tests are not specifically addressing the problem of program correctness For this purpose a number of techniques for preventing, discovering and repairing programming errors have been discussed by Jacky and Kalet [15]

It is important that the manufacturer provides a description of the dose calculation models and their limitations to the users The manufacturer should, in addition, make available documentation of the use of the system, for instance of the beam weighting procedures and of wedge factors Finally the manufacturer should make available to all users information concerning software "bugs" and other relevant information, for instance during users' meetings and in release notes

3. REPORTS ON QA OF TREATMENT PLANNING SYSTEMS

The first report that describes systematically a series of tests to be performed by a TPS user in order to evaluate the accuracy of dose calculations, has been presented by McCullough and Krueger [3] Their publication does not, however, provide information on a routine QA programme At this moment the only comprehensive report that deals with commissioning and QA of a TPS, is the report by a group of physicists from Ontario, Canada [7] The contents of that report is given in Table II

TABLE II CONTENTS OF THE ONTARIO REPORT ON THE COMMISSIONING AND QA OF TREATMENT PLANNING COMPUTERS [7]

1	Computer programs and system documentation and user training
2	Sources of uncertainties and suggested tolerances
3	Initial system checks
4	Reported system checks
5	Quality assurance through manual procedures and in vivo dosimetry
6	Additional considerations, including administration and manpower requirements

Detailed information, including a large number of examples of initial and reproducibility tests can be found in this report

QA of TPSs is also part of a more general report on QA for radiation oncology as published by the AAPM Radiation Therapy Committee Task Group 40 [8] This report does not provide detailed tests, as given in the Van Dyk et al manuscript, but gives recommendations on the frequency and tolerance limits of these tests

4. QUESTIONNAIRE ON NATIONAL ACTIVITIES IN THE FIELD OF QA OF TREATMENT PLANNING SYSTEMS

In order to review national activities in the field of QA of TPS, a questionnaire was sent to representatives of national societies of medical physicists active in this field The questions were "Do national recommendations on QA of TPS exist in your country? If not yet available, is there a group working on a such a national report and are there other activities going on in your country such as users' meetings of a particular TPS?"

TABLE III. CONTENTS OF THE DRAFT IPSM REPORT ON QA OF TREATMENT PLANNING SYSTEMS

1. Introduction
2. Description of the computerized planning system
3. Testing of general hardware
4. CT interface
5. External photon beam algorithms
6. Evaluation of electron beam algorithm
7. External beam-patient planning checks
8. Brachytherapy algorithms

TABLE IV. CONTENTS OF THE PROPOSED NORWEGIAN PROTOCOL ON QA OF TREATMENT PLANNING SYSTEMS

1. Introduction
2. Competence levels
3. Acceptance tests for system
4. Acceptance tests for treatment unit data
5. Constancy tests for system
6. Constancy tests for treatment unit data

App. A. Test geometries
App. B. Forms

TABLE V. SUGGESTED AUSTRALIAN PROTOCOL FOR COMMISSIONING AND QA OF TREATMENT PLANNING SYSTEMS AND MONITOR UNIT CALCULATIONS [16]

Frequency	Test	Tolerance
Commissioning and following software update	Identify algorithms used and their limitations	Appropriate for application
	Single field or source isodose distribution	2% or 2 mm
	MU calculations	2%
	Test cases	2% or 2 mm
	I/O system	1 mm
Weekly	I/O devices	1 mm
Monthly	Checksum	No change
	Subset of reference QA test (when checksums not available)	No change
	I/O system	1 mm
Annual	MU calculations	2%
	Reference QA test set	2% or 2 mm
	I/O system	1 mm

TARLE VI. OUTLINE OF THE REPORT ON QA OF TREATMENT PLANNING SYSTEMS IN THE CZECH REPUBLIC / SLOVAK REPUBLIC.

1. Recommendation for documentation
   a) Documentation provided by the producer
   b) Documentation of basic beam data of TPS
   c) Log-book of TPS (for recording all modifications of data, software, hardware and all failures and repairs of TPS)
   d) Documentation of the information obtained from TPS
   e) Documentation of patient treatment
2. User training
3. Sources of uncertainties in treatment
4. Suggested tests and checks of TPS (with tolerance and action levels and frequency of tests)
   a) Commissioning tests
   b) Tests after repair or new software release or modification of data
   c) Regular tests of TPS

Appendices:

I. Short description of algorithms for photon beam calculation
II. Short description of algorithms for electron beam calculation
III. Short description of inhomogeneity corrections and corrections for patient outline.

TABLE VII. NATIONAL REPORTS IN PREPARATION ON QA OF TREATMENT PLANNING SYSTEMS.

Country	Contact person
Great Britain	Dr Jim Shaw, Clatterbridge Centre for Oncology, Clatterbridge Hospital, Bebington Wirral L63 4JY, Great Britain
Australia	Dr Jim Cramb, Peter MacCallum Cancer Institute, Locked Bag 1, A' Beckett Street, Victoria, Australia, 3000
Norway	Dr Sverre Leverness, Dept. of Medical Physics, The Norwegian Radium Hospital, N-0310 Oslo, Norway
Czech Republic/ Slovak Republic	Dr Anna Kindlova, Dept. of Radiotherapy and Oncology, Faculty Hospital Královské Vinohrady, Šrobárova 50, 100 34 Prague, 10, Czech Republic.

From the 23 responding countries, 8 indicated that only limited efforts are underway, 8 answered that a working group is evaluating their specific national requirements while in 5 countries a document is drafted or tested in various clinics (Table VII) The outline of the British, Norwegian, Australian, Czech Republic and Slovak Republic protocols are presented in Tables III - VI, respectively. The Norwegian protocol is currently tested in some radiotherapy centres in Norway. The Australian protocol is part of a more extensive QA document [16]. The activities in Great Britain are described in a report of the Institute of Physical Sciences in Medicine, IPSM [17]. A special feature of this report is the extensive testing of hardware. These tests concern the functioning of individual system elements and comparisons with existing information. In the Czech Republic and the Slovak Republic a common set of recommendations for QA in radiotherapy is under preparation. It will include an extensive list of tests, as well as tolerance limits, action limits and frequencies of these tests.

A number of replies to the questionnaire mentioned that participation in users' meetings of a particular TPS and having close contacts with the manufacturer is an important aspect of a QA programme of a TPS. In some countries national or regional TPS users' meetings have been reported (Table VIII). In Finland all 9 radiotherapy centres nowadays have the same TPS (Varian - Dosetek CADPLAN). The QA in radiotherapy in Finland is performed by the Finnish Centre for Radiation and Nuclear Safety (STUK). Besides quality audits of equipment STUK is starting now also a programme of QA of TPS. For this purpose a special phantom [18] will be used.

5. QA OF 3-D TREATMENT PLANNING SYSTEMS

QA of a 3-D TPS is a time consuming process, particularly if wedges, blocks and asymmetric collimators are involved. The problems related to gathering the optimum amount of data, designing models to describe the 3-D dose distribution and to verify the results of these calculations, are still under investigation. At this moment it is recommended to apply a pragmatic approach instead of an extensive QA programme, i.e., to test only those geometries in 3-dimensions that are applied clinically. For instance, a comparison of measured and calculated dose values at relevant points for specific treatment techniques (e.g., breast treatment [13]) is a good approach. These tests provide, however, an overall result and do not discriminate between errors in beam data, dose calculation algorithm or other sources. A more fundamental approach of testing special aspects of a 3-D TPS can be performed in some institutions. Their experience should then be reported to the vendor and other users of the system.

Use of image information is extremely important in 3-D treatment planning. Not only CT information but also MR images, digitized radiographs and digitally reconstructed radiographs are currently incorporated in the planning process. All these imaging tools should be checked using specific geometrical tests. Also other geometrical locations of, for instance, Beam's-Eye-View and Region-of-Interest (ROI) should be tested. The use of dose volume histograms (DVHs) is one of the advantages of 3-D treatment planning systems over conventional systems. The proper functioning of the integration over specific ROIs should be checked. This is of particular importance if the DVH is sensitive to grid size and contour directions (e.g., if the DVH of the rectum wall is calculated for pelvic treatments [19]).

Most of the tests described in QA protocols concerns 2-D planning systems, i.e. mainly checks of treatment plans in the central plane. In principle these tests can also be extended to other planes if target volume, normal tissue contours and beam configuration are indicated in these planes as well. In addition 3-D image information concerning anatomy, beam set-up and dose distribution should be verified. Finally tools for analysis of dose distributions should be tested. This subject is still in its early stage of development and has been discussed by McShan [20].

TABLE VIII. REPORTED USERS' MEETING

Country	Treatment planning system
Finland	Varian - Dosetek - CADPLAN
Nordic countries	HELAX TMS
Poland	Alfard*
The Netherlands, Australia	Nucletron - PLATO

* 2D PC-based Polish system

6. CONCLUSIONS

At this moment there is only one comprehensive report available that deals with QA of treatment planning systems while no national or international recommendations are currently available. In a number of countries, however, working groups are drafting documents with sets of recommendations. It can be expected that in the near future a more uniform approach of QA of treatment planning systems will be adopted in radiotherapy institutions. For 3-D treatment planning systems systematic checks are still under development. Close cooperation between manufacturers and users of treatment planning systems remains an important aspect of the quality of the use of these systems.

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QUALITY ASSURANCE BY IN VIVO DOSIMETRY

(Abstract)

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By measuring the dose actually given to the patients, in vivo dosimetry is a key procedure in quality assurance. Verifying the final product has the advantage to cover all preceding steps This includes basic dosimetry and acquisition of all machine and patient related data as well as the accuracy of the daily execution of treatment.

One of the difficult problems one is faced with is the integration of the procedure of in vivo dosimetry in the daily procedure of radiotherapy. This is influenced, among other things, by the modality of measurement. "Off-line" measurements will detect all deviations and errors post factum, meaning that only the systematic errors, which will be repeatedly reproduced will be traceable. "On-line" measurements will also enable the identification of the cause of random errors as the patient set-up can be checked at the end of the session during which a deviation is traced.

Taking a representative sample of measurements one can first of all, assess the global performance of the department. The value of the core procedures can be expressed by the mean precision of all measurements, the dispersion and finally by the incidence of "large errors". While the mean value of all measurements gives an indication on the accuracy of the core procedures, the dispersion is the expression of the reproducibility, while the frequency with which "large errors" does occur is the measure of the reliability or of the incidence of human errors. Next to the core procedures of the whole department, it is possible to assess the same values for individual treatment machines or specific treatment techniques.

Besides information on the functioning of the whole department, in vivo dosimetry gives valuable information on an individual irradiation session or treatment of a patient. The implementation of this information is slightly more complex than the assessment of the functioning of the department. Indeed, while in the assessment of global accuracy, actions always retrospective and based on global analysis, for the individual treatment, immediate decisions always have to be taken. For this, it is important to know what degree of accuracy can be expected in a specific situation. Indeed, the level set for necessary correction is determined by the spread that is occurring in daily practice. This means that implementation on the individual patient level and decisions on corrective action can only be taken after the first step on the value of core procedures has been carried out.

A similar situation does exist when assessing the representativity of single measurements for a whole treatment. This representativity will be determined by the reproducibility of specific treatment techniques. For set ups which give very high reproducibility, a singly measurement will give reliable information. When more scatter is expected in the repeated set-ups, several measurements will be necessary to give reliable information.

Finally, decisions will have to be taken on what can be measured. The simplest approach is to measure only the entrance dosis on the axis of the beam. In subsequent steps, off-axis measurements and exit dose measurements can be used. While the entrance dose measurements give information on all the preparatory steps and on the accuracy of positioning the patient, the exit dose also gives

additional information on the calculation of dose absorption where deviations can occur, mainly related to the inhomogeneities in irradiated volume and density.

In vivo dosimetry is a very powerful tool to audit the performance of a radiotherapy department. As it only looks at an "endpoint", any deviations found will require an evaluation of the different preceding steps to identify the reason of the deviation.

QUALITY ASSURANCE FOR ELECTRONIC PORTAL IMAGING DEVICES

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Abstract

Electronic portal imaging devices (EPIDs) are assuming an ever-increasing role in the verification of radiation treatment accuracy. They are used both in a passive capacity, for the determination of field displacement distributions ("setup errors"), and also in an active role whereby the patient setup is corrected on the basis of electronic portal images. In spite of their potential impact on the precision of patient treatment, there are few quality assurance procedures available, and most of the EPIDS in clinical use are subject, at best, to only perfunctory quality assurance. The goals of this work are (a) to develop an objective and reproducible test for EPID image quality on the factory floor and during installation of the EPID on site; (b) to provide the user with a simple and accurate tool for acceptance, commissioning, and routine quality control; and (c) to initiate regional, national and international collaboration in the implementation of standardized, objective, and automated quality assurance procedures. To this end we have developed an automated test in which a simple test object is imaged daily, and the spatial and contrast resolution of the EPID are automatically evaluated in terms of "acceptable", "warning" and "stop" criteria. Our experience over two years shows the test to be highly sensitive, reproducible, and inexpensive in time and effort. Inter-institutional trials are under way in Canada, US and Europe which indicate large variations in EPID image quality from one EPID to another, and from one center to another. We expect the new standardized quality assurance procedure to lead to improved and consistent image quality, increased operator acceptance of the technology, and agreement on uniform standards by equipment suppliers and health care agencies.

1. INTRODUCTION

Electronic portal imaging devices (EPIDs) are assuming an ever-increasing role in the verification of radiation treatment accuracy. They are used both in a passive capacity, for the determination of field displacement distributions ("setup errors"), and also in an active role whereby the patient setup is corrected on the basis of electronic portal images. In spite of their potential impact on the precision of patient treatment, there are few quality assurance procedures available, and most of the EPIDS in clinical use are subject, at best, to only perfunctory quality assurance. The goals of this work are (a) to develop an objective and reproducible test for EPID image quality on the factory floor and during installation of the EPID on site; (b) to provide the user with a simple and accurate tool for acceptance, commissioning, and routine quality control; and (c) to initiate regional, national and international collaboration in the implementation of standardized, objective, and automated quality assurance procedures. To this end we have developed an automated test in which a simple test object is imaged daily, and the spatial and contrast resolution of the EPID are automatically evaluated in terms of "acceptable", "warning" and "stop" criteria.

2. MATERIALS AND METHODS

It is not easy to determine the quality of an image in an objective and reproducible manner. If a test object is imaged and viewed by an observer, the final decision regarding its acceptability or otherwise will depend not only on the performance of the imaging system, but also on the display modality and on the experience, capability and subjective decision criteria of the observer. On the other hand, a totally computerized analysis of the image does not verify the adequacy of the display modality, nor the suitability of the image for succesful observer evaluation. Since our goal in this study is to determine the performance level of an electronic portal imaging device, we have chosen to acquire a megavoltage portal image of a specially developed test phantom, and to use a computer program to determine the intrinsic spatial and contrast resolution in the digital image. Additional tests are required to ensure that the display monitor used under clinical conditions is performing well, and that the observers are well trained and motivated for the tasks required of them when viewing the images.

Our intention was to develop an objective and reproducible test of EPID image quality for use during installation, acceptance, commissioning, and routine quality control. The test is performed by acquiring two portal images of a specially designed test phantom under normal treatment conditions. A computer program then automatically analyzes the images and determines the frequency dependant square wave modulation transfer function (SWMTF), from which the frequency at 50% modulation (f_{50}) is derived. The phantom consists of a rectangular aluminium frame, with length about 130 mm and width 110 mm, in which a set of test objects are located, as shown in Fig. 1. The central row of objects is a series of high contrast bar patterns, made from alternate sheets of lead and plastic, with spatial frequencies of 0.1, 0.2, 0.25, 0.4 and 0.7 lp/mm and presenting a depth of 15 mm to the radiation beam. The other test objects consist of lead and plastic blocks with different thicknesses up to 15 mm. The phantom is placed either on the surface of the EPID, or on the treatment couch at isocentre, and rotated by 45° to the saggittal plane. Two megavoltage images are acquired, and transferred to an IBM compatible PC for analysis. Pairs of images may be acquired for

different gantry angles and beam energies. They are then transferred to an off-line personal computer for analysis.

3. IMAGE ANALYSIS

Figure 1 shows an image of the test phantom acquired at an energy of 6 MV. The computer program searches for the outer edge of the phantom, determines the positions of the four corners, and then superimposes on the image 6 regions of interest (ROIs). The variance of the pixel values in each ROI is determined and the method suggested by Droege [1,2] is used to obtain the SWMTF in which each ROI corresponds to a point on the modulation curve. The values are normalized to the first (lowest frequency) bar pattern, giving a relative modulation transfer function (RMTF). The modulation curve is then interpolated to find f_{50} as shown in Fig. 2. The Contrast to Noise ratio (CNR) is also determined from the ratio of signal to noise in ROIs 1 and 6 in the two images [3].

4. CLINICAL TESTS

Quality control tests were performed on a daily basis over an extended period on a Siemens KD2 dual energy linac equipped with a BEAMVIEW^{PLUS} electronic portal imaging system[1]. Two images of the phantom were acquired on each test day and subsequently analyzed automatically. Figure 3 shows a plot of f_{50} over the extended test period. Of interest in this plot is the sharp increase in f_{50} at day 129 of the test period at which time a preventative maintenance was performed on the portal imaging system. The maintenance consisted of lens and mirror cleaning, and adjusting the camera f-stop and focus. The f_{50} gradually decreased to the values recorded prior to maintenance. A second preventative maintenance was performed and once again there was a sharp increase in the f_{50} . The f_{50} then stayed relatively constant for the remaining days of the test period. This test demonstrated that f_{50} is a sensitive indicator of the spatial resolution of the EPID, and can be used to warn the operator when the system is performing at less than optimal image quality. It can also be used to optimize the system's performance during acceptance testing, preventative maintenance, and periodic quality assurance surveys.

5. EFFECT OF ENHANCEMENT

In order to evaluate the sensitivity of the test to small changes in image quality, we processed portal images of the phantom using standard blurring and sharpening filters, and determined the subsequent change Δf_{50} in spatial resolution. We applied Gaussian smoothing filters to images of the quality control phantom acquired at beam energies of 6 and 23 MV to simulate an EPID which is out of focus, and we applied a sharpening filter to simulate improved images due to optimal adjustment and calibration. In Fig. 4 the RMTF curves are plotted as a function of frequency for the original and processed images. As expected, smoothing increases the slope and reduces

[1] Siemens Medical Systems, Concord, Ca.

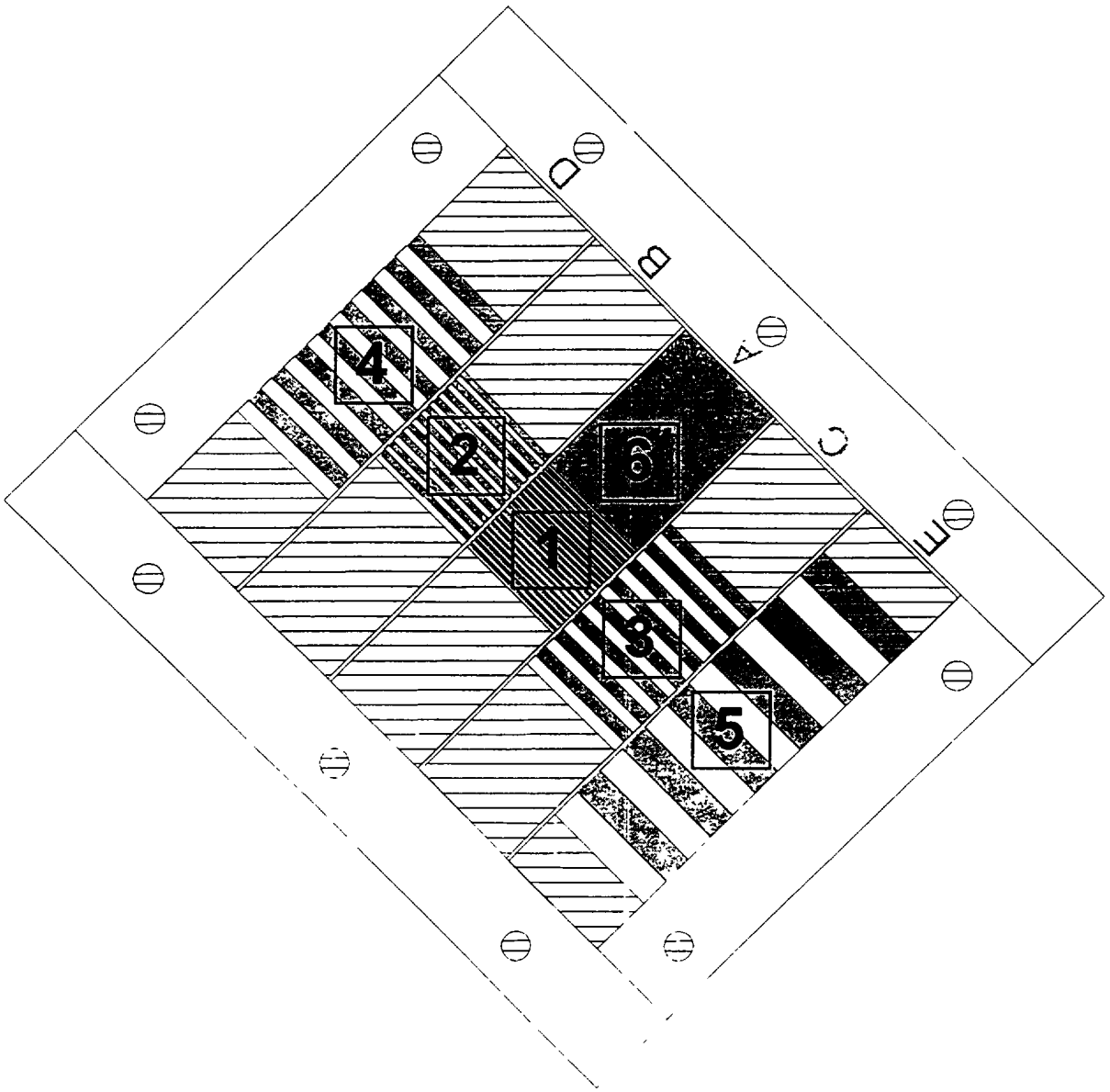

Figure 1. A schematic diagram of the test phantom used to monitor performance of an EPID in terms of spatial resolution and contrast to noise ratio.

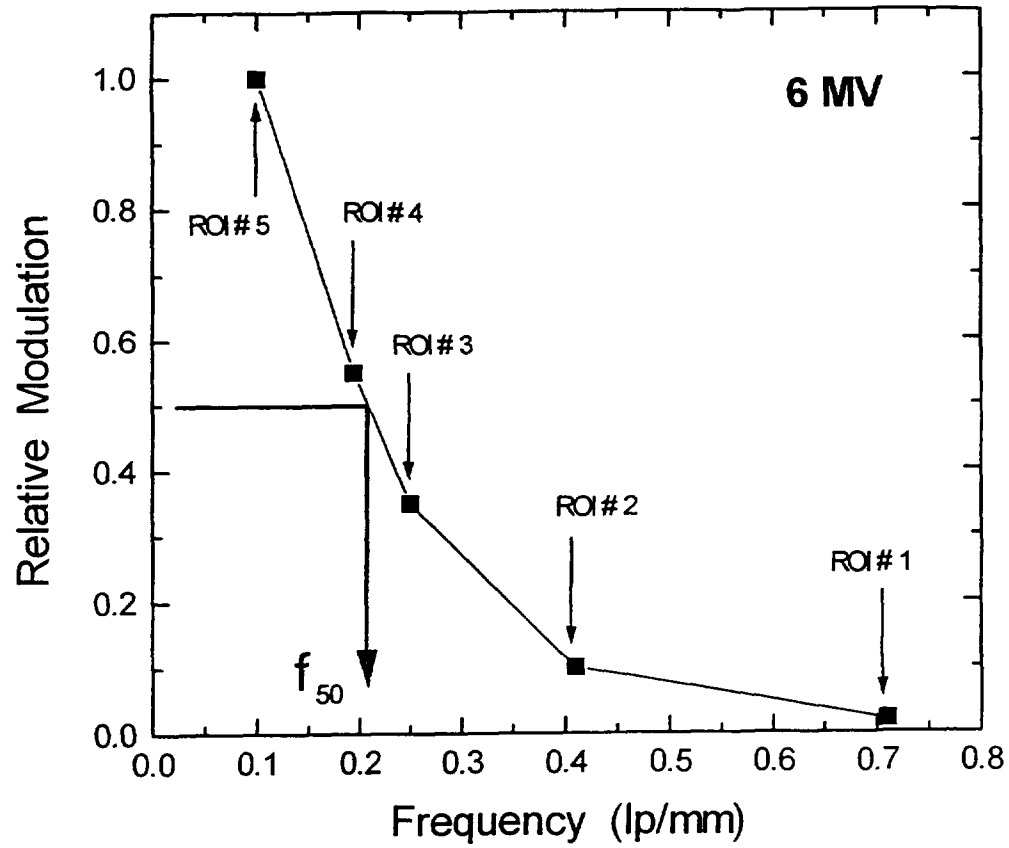

Figure 2. Derivation of f_{50} from the relative modulation curve.

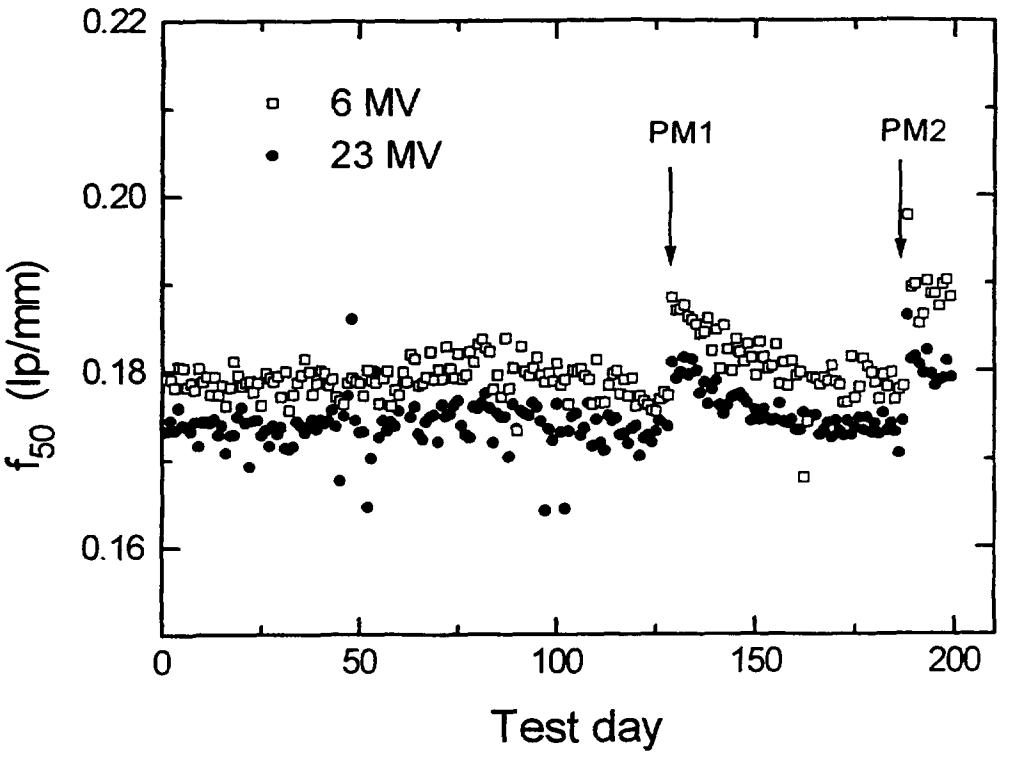

Figure 3. A plot of f_{50} over an extended test period showing the effect of two preventative maintenances on the spatial resolution of an EPID.

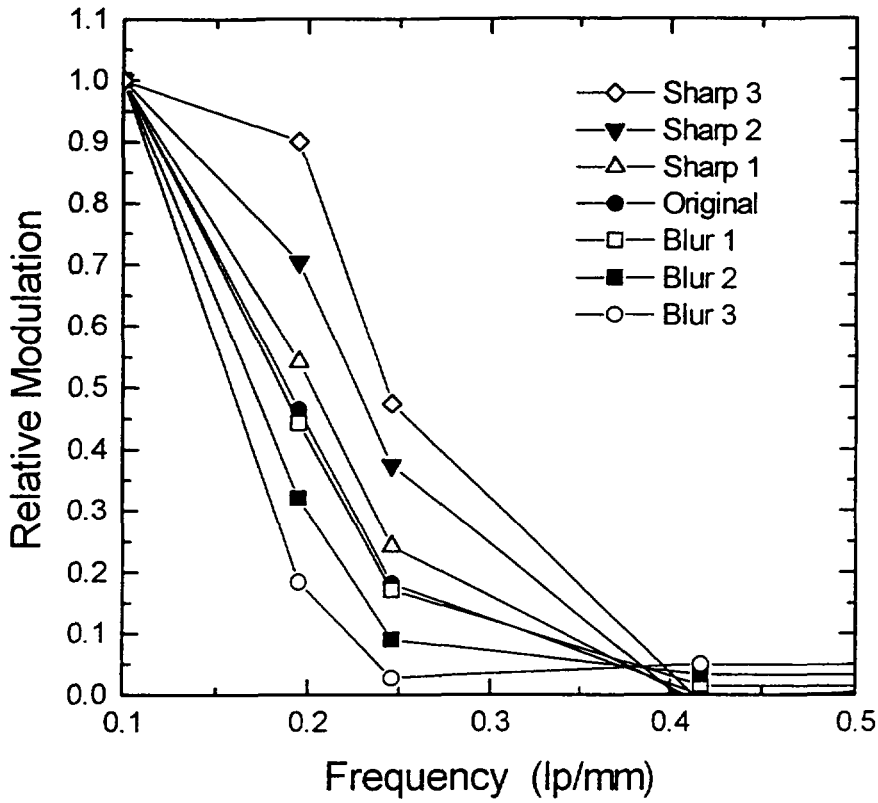

Figure 4. The relative modulation plotted as a function of frequency for an original image acquired at 6 MV and for images processed by sharpening and smoothing filters.

the value of f_{50}, while sharpening raises the curves and the value of f_{50}. Figure 5 plots the difference in f_{50} between a processed and an original phantom image. Blurring with a 9x9 Gaussian filter (σ=3 pixels) reduced f_{50} by up to 0.03 lp/mm, while edge sharpening could improve resolution by about 0.05 lp/mm, compared to typical day-to-day variations of less than 0.001 lp/mm. Clinically significant changes in image quality are readily detected, and maintenance can be initiated before patient management is compromised. Indeed, the high sensitivity of the test permits its use for optimising the operating conditions of the EPID, such as selecting the optimal image processing technique for routine clinical use.

6. COMPARISON OF EPIDS

The test is primarily intended to serve as a routine measure of image quality in a single EPID, and to warn the operator when a deterioration has occurred. However, it can also be used to compare image qualty from one EPID to another, so that manufacturing standards can be verified, acceptance tests can be based on quantitative specifications, and different EPIDs compared before a purchase decision is made. The test is presently being used for a multi-center comparison of EPIDs and initial results indicate that there is a wide range in image quality between different vendors, and even between EPIDs supplied by the same vendor. Fig. 6 shows RMTF curves for EPIDs from four vendors and for film. Since these preliminary results are from a small sample of EPIDs, they should not be interpreted as typical of all EPIDs from these vendors.

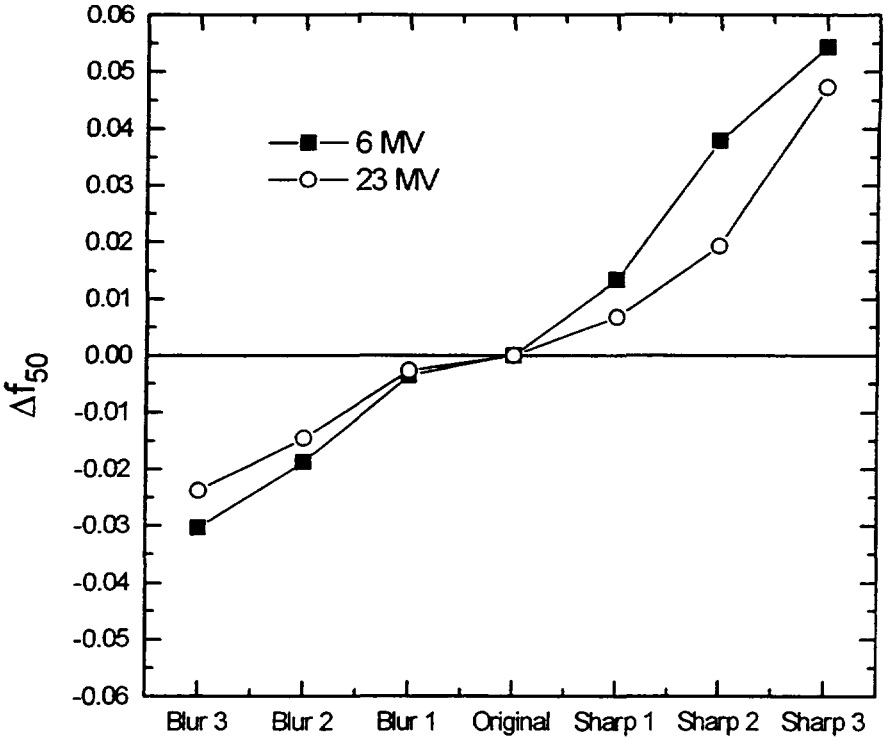

Figure 5. The change in 50% modulation between a processed and an original image. Sharpening simulates focussing, and smoothing simulates defocussing an optical system.

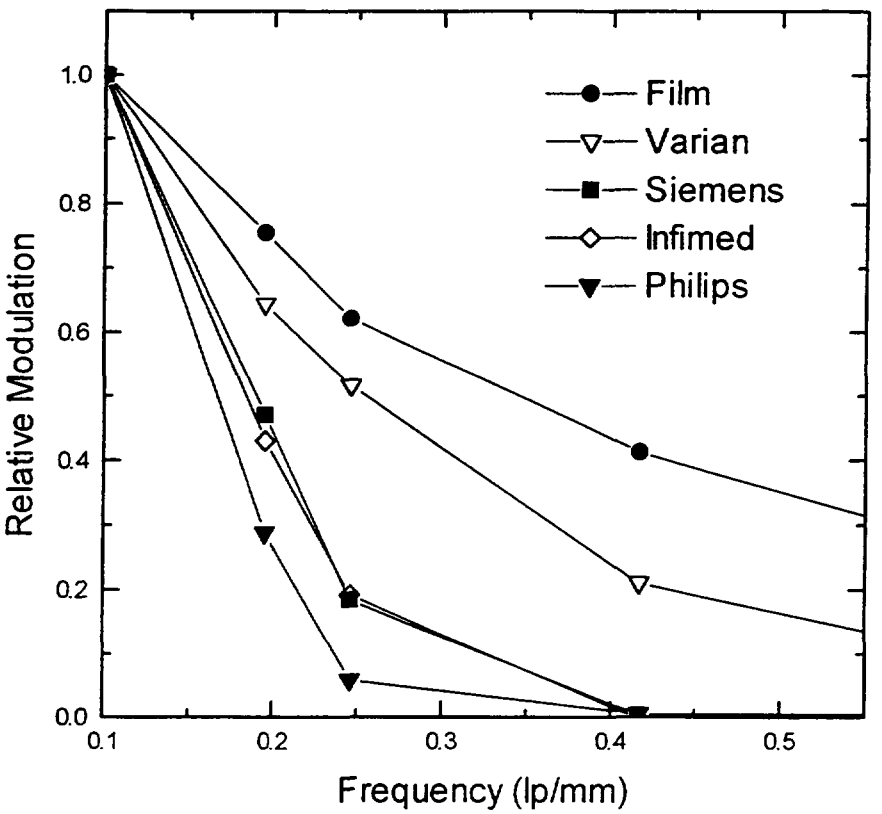

Figure 6. An inter-center comparison shows a wide range of image quality between EPIDs from different vendors.

7. CONCLUSIONS

We have developed an objective, reproducible and rapid test for the performance evaluation of EPIDs which is useful during installation, acceptance, commissioning and quality control. The test consists of acquiring images of a specially designed phantom which are automatically evaluated by software written for a personal computer. The procedure has proven itself to be a useful tool in the performance monitoring of the EPIDs at our center as well as for evaluating the performance of EPIDs from different vendors. Our experience over two years shows the test to be highly sensitive, reproducible, and inexpensive in time and effort. Inter-institutional trials are under way which indicate large variations in EPID image quality from one EPID to another, and from one center to another. We expect this new standardized quality assurance procedure to lead to improved and consistent image quality, increased operator acceptance of the technology, and agreement on uniform standards by equipment suppliers and health care agencies.

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QUALITY ASSURANCE IN CANCER MANAGEMENT. IMPACT OF QUALITY STANDARDS ON TREATMENT ACCURACY: THE EXPERIENCE OF THE EORTC

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Abstract

There is thus a need to ensure that the same quality of treatment is offered to all cancer patients in Europe A research of this kind must be aimed at identifying which steps in the complex treatment processes are more error prove, which of those can most effectively be corrected, and which procedures could be taken over by countries, or individual centers to monitor themselves the quality of their treatment procedures. To achieve this goals, the EORTC Radiotherapy Co-operative Group has put a major effort in the development of two Quality Assurance programs: the Physics Audit program (*PAQ*) and in the Assurance of Protocol Compliance Program (*APCP*).

In the *PAQ*, a first survey conducted in 1986, on the radiotherapy infrastructure in European Centers participating in clinical trials showed that 20% of the centers encountered difficulties to comply with the EORTC requirements due to imbalance in staff or equipment. Besides radiotherapy infrastructure, the beam output was checked in 50 centers: a major problem was detected in 30% of the checked electron beams. Dosimetric recommendations were sent out to all radio-oncology departments active in the EORTC (Johansson et al, 1986) and a mailed measurement procedure was developed for the verification of the beam output in photon beams (Hansson et al, 1991).

The *APCP*, which was activated in 1987, can be divided as follows
- phantom dosimetry studies (Johansson et al, 1987)
- dummy run procedures for breast, prostate, and head and neck cancers (van Thienhoven, 1991)
- check of case report forms for prostate, breast and rectal cancers (Vantongelen et al, 1990)
- individual case reviews for prostate, breast and rectal cancer (van Thievenhoven et al, 1992)
- QA procedures at patient level for breast cancer (Hamers et al, 1991)
- outcome evaluation after irradiation of rectal cancer (Letschert et al, 1994)

The EORTC Radiotherapy Group has demonstrated that multicenter QA programs permit, through the pooling of a large number of data, auditing by specialists of implemented Quality Standards both in radiation physics and in clinical oncology, contributing to the basis for the development of harmonized quality procedures and standards in the therapeutic management of cancer. This type of QA program should also foster the interaction between several medical disciplines and promote the application of Quality Standards in community level hospitals Current efforts are also put forth to develop common research instruments, such as the processing of database and MRI or CT-scan images through teleconferencing and the set up of electronic radiotherapy files, as well as to the introduction of new health care technologies such as three-dimensional treatment planning and conformal, high dose/high precision radiotherapy

1. GENERAL CONSIDERATIONS

In oncology, the first discipline to embark on Quality Assurance programmes was Radiotherapy In the fifties many radiation therapy institutes had already implemented their own programmes of beam controls, and in the seventies, the creation of cooperative groups triggered the activation of Quality Assurance programmes In most groups, the accent was put on a better documentation of the causes of inter-center discrepancies with respect to disease staging, treatment parameters and irradiation beam qualities

That was the reason why, since 1982, year of the project activation, the Radiotherapy Group of the European Organization for Research and Therapy of Cancer (EORTC) progressively extended its original project of Quality Assurance into pilot studies in an attempt to promote a systematic check of individual patients and to improve the reliability of treatment procedures Once general requirements needed to warrant a valid cooperation were identified, the group directed its efforts to the clinical ground and in particular to the set up of reliable control procedures to improve the quality of protocols of phase III clinical studies This general philosophy led to considerable improvements in the writing of protocols, in data management and in detection and correction of dosimetric parameters as well

The Quality Assurance Program of the Radiotherapy Group consisted so far of three main phases articulated around the development of two Quality Assurance (QA) programs the Physics Audit Quality program (*PAQ*) and in the Assurance of Protocol Compliance Program (*APCP*)

In the *first phase*, that roughly lasted five years (1982-1987), various centers were visited by a team of radiotherapists and radiation physicists In 1987 a vast program of mailed dosimetry was activated to document, through a large number of beam calibrations and measurements, the profile of the dose deviations between the values determined by the team of radiophysicists of the EORTC and those reported by institutions

In 1987 the Radiotherapy Group activated a *second phase* of the Quality Assurance programme, and set up a series of procedures (dummy-runs) to document systematic errors made in single institutions and control the accuracy of the design and the application of phase III study protocols

Finally, in 1989, a *third phase*, more patient-oriented, was activated to tackle random errors individual case reviews directed to patient data and treatment parameters were aimed at improving the compliance of the participating centers to study protocols and at detecting obscurities in protocol guidelines

2. MATERIAL AND METHODS

The issues addressed by the EORTC Quality Assurance Programme in Radiotherapy may be summarized as follows

2.1 Baseline investigations on structures, human resources and methodology

2.1.1 On-Site visits

Aims: One of the goals of the visiting teams of radiotherapists and radiophysicists was to know the medical and radiotherapeutic environment of each participating center Secondly, since numerous centers were involved in the cooperative trials, it was absolutely necessary to check the radiation physics performances of the megavoltage equipment of the participating radiotherapy departments

Methods: The radiation physics QA program of the EORTC started in 1982 with the site visits of the participating institutions, during which both the mechanical and radiation parameters of the equipment in use were being tested The control procedures performed at the visited Institutions included the following radiation physics measurements and data retrieval processes

- intercomparison of ionization chambers
- absorbed dose determination in specific points in water for several combinations of field sizes and accessories, for photon and electron beams

- measurements of the dose homogeneity for X-ray and electron beams
- mechanical and beam alignment checks of simulator and therapy units
- measurements of the depth dose distribution at several depths
- calculation of treatment time and monitor setting for reference cases
- collection of beam data from all machines in use

2.1.2 Mailed in water dosimetry

Aim: This program which started in 1987, aims at performing mailed dosimetric audits and to periodically monitor absorbed doses at reference points for photon beams

Methods: Briefly, the given design criteria of this dosimetry system were ability to identify errors in values of absorbed dose larger than 3 %, malleability, applicability to photon beams of interest (60-Co - 30 MV), simplicity of use and reasonable cost The dosimeters used were circular ships made of LiF The mailing procedure started with a questionnaire to the participating institutes, which were asked to provide the radiation physics reference center, with information on beam qualities in use Later on, they received a mailing containing instructions for irradiation in water, data sheets, holders for in-water irradiation and a set of dosimeters They were also instructed on how to perform irradiations After irradiation, all the material was returned to the reference center for read-out and absorbed doses determinations

To date, all participating centers have been monitored by mailed TLD, several more than once This has led to the decision of stopping the site-visits unless large deviations cannot be resolved by a second TLD mailing The Radiation Physics Department of the Goteborg University Hospital has been the main partner in this QA effort till 1992 In 1993 the mailed TLD program has been taken over by the Institut Gustave Roussy in Villejuif

2.1.3 Questionnaire

Aim: This questionnaire was activated in 1990 and since then, it has undergone a constant updating The aim of this questionnaire was to complete and update the information collected during on-site visits on the equipment and human environment of all radiotherapy departments participating to the activities of the EORTC Radiotherapy Group Indeed some items had not been registered before, especially in the field of treatment techniques, biomedical and radiobiological environment Thus the purpose of this questionnaire was

- to collect "on time" data by sending a questionnaire to all centers entering patients in current protocols of the Group
- to specify the definitions of some items which had led in the past to difficulties of interpretation (for instance, workload and staff unbalance)
- to extend the questionnaire to items that had not been investigated before brachytherapy, radiobiology, institutional quality control procedures, etc

Methods: This questionnaire consisted of a survey on the status of the Institution, on its infrastructure in terms of equipment, on workload and staff structure Centers were also asked to provide the coordinators with data on treatment planning and delivery both for external radiotherapy and brachytherapy

2.1.4 Mailed TL-dosimetry for brachytherapy

Aim: Till 1991, the programme of Quality Assurance in Radiotherapy essentially consisted of control procedures for external radiation therapy Four years ago, the programme was for the first time extended to brachytherapy dosimetry checks for 192-Ir wires The aim of this pilot study was to compare the dose computation for 192-Ir at some selected Institutes

Methods: The centers received a holder and a set of T L D strings, each with 5 dosimeters, for in-water irradiation The radiation physics team of each center was asked to compute the dose delivered to each dosimeter and to irradiate the TLD strings before returning them to Goteborg for read-out and evaluation Values of absorbed doses were then compared to the doses stated by the Institute

2.1.5 Three-dimensional dose distribution in tangential irradiation of breast after conservative treatment

Aim: This Q A programme of dosimetry intercomparison was designed to investigate whether the procedures used in several institutions, based on various dosimetry protocols and dose calculations by planning systems, result in an acceptable accuracy in delivered doses

Methods: The phantom used for this quality control procedure was a breast-shaped mould model made of polyethylene and filled with water Investigators were sent a set of CT scan of this breast-lung phantom, with precise contours as input in the planning systems, in three cranio-caudal plans Each participating institution was asked to calculate the absolute dose in the planned points of measurement, using the parameters of the prescribed irradiation and computational algorithms of their planning system Later on, in each of the centers that participated to this study, the breast phantom was irradiated according to the prescribed protocol and dose measurements were carried out in the phantom using a small irradiation chamber, previously calibrated In every point, the dose measured in the phantom was compared with the dose calculated by the institution After a preliminary study carried out in 21 Dutch radiotherapy centers, three institutions active in the EORTC Radiotherapy Group were visited

2.1.6 Master Protocol for phase III studies

Aim: Most studies activated by the EORTC Radiotherapy Group are phase III clinical trials It was thus felt that it should be necessary to provide study coordinators with practical guidelines on how radiotherapy protocols have to be written to reduce protocol obscurities and subsequent risks of low compliance to the study guidelines

Methods: These guidelines are the subject of a publication (24) Emphasis was put on minimal requirements regarding pretherapeutic clinical staging criteria Particular attention is also paid to a clear description of treatment-related parameters

In this master protocol, it is pointed out that patient data acquisition throughout the various phases of the treatment planning has to be reproducible Moreover, since one of the weakest points in most protocols is the definition of the volumes encompassed by the irradiation, a clear delineation of these volume has to be carried out according to the recommendation of the ICRU report 50 gross tumor volume (G T V), clinical target volume (C T V), planning target volume (P T V) and organs at risk must now always be delineated independently of the dose distribution

2.2 Quality Control Procedures specific to trials and patients

2.2.1 Dummy-runs

Aim: Originally, the dummy-runs were initiated to get impression of the planning facilities at the participating institutions It was soon evident that the objectives of these procedures were not only to evaluate differences in treatment techniques and dose calculations but also to detect, within a few months after a clinical activation the potential causes of poor compliance to the protocol and sources of heterogeneity in irradiations A particular attention was also paid to the potential impact of treatment technique differences on heterogeneity of dose distribution In the breast, heterogeneity that might prevent investigators to identify clear-cut dose-control relationships More specifically, in radiation physics, the main purpose of a dummy-run is to evaluate differences in (a) treatment volume, (b) irradiation technique, (c) dose specification, (d) dose homogeneity and (e) the uniformity of the dose to the specification point

Methods: In a dummy-run, transversal slices of the relevant anatomic region are sent to the centers participating to the investigated clinical trial Radiation oncologists and physicists are asked to design a target volume and to provide a treatment plan with dose distribution in each of these plans They are also asked, as is was the case for the dummy run for the prostate irradiation, to compute the absorbed doses in the points of interest indicated on the slices both for dose prescription points and for those located in surrounding normal tissues Finally, they were requested to complete a questionnaire on treatment technique and beam data These dummy-runs were carried out in the frame of three EORTC trials trial 22881/10882 for breast cancer, trial 22862 for prostate carcinoma and trial 22931 for head and neck cancers

2.2.2 Individual case reviews

Aims: This quality control procedure aims at improving the compliance of the centers to study protocols, with special attention to the minimal requirements of radiation physics experts and to the medical profiles and biomedical environments of radiotherapy departments As in the dummy-run procedure, another objective was to detect obscurities in the protocol of treatment, in the very early phase of the trial

Methods: These reviews, carried out by a team of physicians and physicists, analyzed the clinical and technical parameters contained in the charts of randomly selected cases Since 1990, they took place before each Group meeting Each time, four to five centers were asked to bring their clinical and technical charts to the expert team, to discuss the several radiation physics and clinical parameters listed in the questionnaire More specifically, the clinical data were reviewed with respect to eligibility criteria, documentation of tumour stage and staging procedures Radiotherapy data were analyzed for treatment technique factors, calculated dose levels and dose heterogeneity Data were also compared to those forwarded to the Brussels Data Center Finally, simulator films and gammagraphies were compared

2.2.3 The boost evaluation in the breast trial 22881/10882

Aim: The aim of this project is to evaluate the practice of boost irradiation in breast conserving therapy within and outside EORTC trial 22881/10882, for institutions that actively participate to this trial

Methods: To assess the reliability and comparability of the data on booster irradiation, particular emphasis was put on treatment technique, treatment dose, fractionation and

treatment volume Participating institutions were asked to provide the Q A study coordinators with a plan of the booster irradiation and technical data on the beams used for the booster irradiation and to complete a questionnaire on their general practice of booster irradiation, and more specifically on (a) irradiation dose, (b) choice of the boost target volume, (c) choice of technique, (d) differences between general practice and that used for this trial and (e) usefulness of the previous Q A projects

2.2.4 Mailed entrance-exit measurements in breast irradiation (protocol 22881/10882)

Aim: The mailed dosimetry of entrance/exit measurements carried out for breast cancer In the framework of the in vivo audit program was started in 1989 The aim of this study performed in 1989-1990 was to check the accuracy and quality of the dose delivered to the breast for patients entered into the trial 22881/10882 Its purpose was to compare in vivo measurements performed during the treatment of breast cancer with the planned isodose distribution as well in external irradiation as in interstitial radiotherapy

Methods: Measurements with mailed TL-dosimetry were carried out both inside the breast for external and interstitial radiotherapy This project was first developed in cooperation with Verbeeten Institute, Tilburg In 1989, the mailing was extended to 19 institutions that were actively participating to the breast trial Fifteen centers have sent back their irradiated dosimetry set to the radiation physics reference center Three of these centers have been investigated at least twice since 1989

2.2.5 Late small bowel and volume factor for pelvic postoperative radioterapy

Aim: The aim of this study was to quantify the correlation between irradiated small bowel volume and late complications for pelvic external irradiation in postoperative setting for high-risk rectal and rectosigmoid cancers

Methods: Small bowel volumes were measured using orthogonal films in treatment position The treatment fields were outlined on these films and a grid was superimposed By adding the products of the segmental bowel loops an estimation of the small bowel volume encompassed by irradiation portals was obtained

3. RESULTS

3.1 Baseline investigations on structures, human resources and methodology

3.1.1 On-Site visits

Throughout the 1982-1987 period , 37 visits have been paid to 32 centers Whereas the number of centers visited represents 50 % of the total number of the active radiotherapy departments, it is to be pointed out that these visits have been paid to all the most active centers For the last years, budget reductions prevented the EORTC teams to maintain the rythm of visits which often require long-distance trips and prolonged stays for the visiting teams

These local audits first demonstrated marked inter-center variations large number of beam calibrations and measurements allowed the documentation of dose deviations, sometimes significant, between the values determined by the team of radiophysicists of the EORTC and those reported by some hospitals Major deviations were found in the dose calibration of some electron beams with scanning system and also mechanical instabilities were reported for some 60Co machines

Moreover, whilst the radiation physics measurements performed in a phantom irradiated in various institutions substantiated no major differences in prescribed dose at the center of the tumor, significant deviations in doses were found both inside and outside the target volume, resulting in a significant risk of decreased tumor control or increased probability of late damage in normal tissues

There was thus a clear need to instruct local teams to apply common protocols for measurements This first measure that eliminated a large number of systematic deviations, was followed by others that all aimed at tackling the causes of deviations

This detailed inter-center comparison of technical and staff environment also demonstrated large inter-center variations in workload it was indeed reported that 25 - 30 % of the radiotherapy centers faced major problems of compliance to the requirements of the EORTC protocols, mostly because of a shortage or unbalance of staff categories It was also shown that, in some departments, the number of simulators was suboptimal and interactions between CT scan and dosimetry treatment planning had to be improved (16,18)

3.1.2 Mailed in water dosimetry

The ratio between absorbed dose to water and that stated by the Institute was used as a measure of agreement These ratios were then divided into three categories acceptable level of deviation (less or equal to 4 %), minor deviation (5-7 %) and major deviation (> 7 %) Whereas in the early eighties, the general conclusion of the TLD program was that less than 80 % of the beams measured were within acceptable levels of variation for the absorbed dose stated, i e with deviations lower or equal to 4 % (2, 15), the main message of this investigation is now that, with sequential mailings, an improvement of the basic dosimetry was seen, as the mean ratio between EORTC determined versus institute stated doses progressively approached unity and standard deviations were decreasing as shown in Tables 1 and 2 Of interest, it should be noted that, in some centers, the reasons for major deviations observed in radiation physics could be identified, corrected and checked by mailed dosimetry and through straight forward oral and written exchanges between visiting experts and either local radiotherapists or radiophysicists (19)

3.1.3 Questionnaire

Fifty centers have answered the questionnaire Equipment, human resources and workload are characterised by a very wide range of answers Comparisons between data collected in the early eighties and during a recent update show no difference in workload per megavoltage equipment and per simulator The number of cancer patients treated per year, per radiotherapist and per member of the radiation physics team seems to diminish, especially for this latter staff The radiographer's workload showed an opposite trend (Table 3) This survey also indicates that efforts have to be put forth in some institutions to reduce the workload at simulators Moreover, in comparison with a previous report published in 1986, the present analysis undoubtedly emphasises an increasing use of CT-SCAN investigations in the treatment planning

TABLE I

DOSIMETRIC AUDITS

Observation period (1982 - 1989)	Acceptable level of deviation (≤ 4 %)	Minor deviation (5-7 %)	Major deviation (> 7 %)
On-site visits			
(1982 - 1986)			
379 Photon beams	78 %	16 %	6 %
37 Institutions			
Mailed TLD			
(1987 - 1989)			
178 Measurements	89 %	10 %	1 %
29 Institutions			
(1989 - 1992)			
358 Beams	92 %	6 %	2 %
55 Institutions			
(1992 - 1995)			
75 Beams	96 %	4 %	0 %
26 Institutions			

TABLE 2

BASIC DOSIMETRY MONITORING WITH SEQUENTIAL TLD MAILING

	photon beams (linac)	60-Cobalt
first mailing	1.022 +/- 0.024	1.025 +/- 0.027
second mailing	1.013 +/- 0.017	1.006 +/- 0.014
third mailing	1.007 +/- 0.013	0.994 +/- 0.004

TABLE 3

WORKLOAD COMPARATIVE ANALYSIS: 1982-84/1990-92*

	1982-1984	1990-1992
EQUIPMENT		
simulator	1185	1192
treatment unit	501	506
STAFF		
radiotherapist	328	316
radiographer	117	131
physics team member**	482	464

* = expressed as mean number of cases per year and per equipment unit or staff member
** = including radiation physicists and dosimetrists

Our database provide participating centres with strong comparative arguments to correct staff and equipment unbalances and to convince administrative authorities of priorities in decision making (20)

3.1.4 Mailed TL-dosimetry for brachytherapy

A work of TLD calibration including the determination of energy dependence and sensitivity for 192-Ir as well as calibration against ionisation chamber measurements, was successfully completed at the radiation physics reference center of Goteborg The sensitivity for 192-Ir, in the Goteborg irradiation set-up, was found 7 % larger than that previously observed for 60-Co beams (11)

3.1.5 Three dimensional dose distribution in tangential irradiation of breast after conservative treatment

The dosimetry intercomparison yielded, among the three centers, large variations in measured dose values Moreover, after normalization of measurements at the isocenter, the ratio of calculated and measured doses was found to vary markedly among the various measurement points with deviations between -8 and +12 % The Q A study coordinators pointed out that such variations are probably explained by errors in output or errors in beam data implemented in the planning system The spread in the points of measurements is also partly due to the limited accuracy of some computational algorithms, e g the lung correction The material used for this quality control procedure has been shown to be reliable and the dosimetry intercomparison has underlined that large differences exist between prescribed, calculated and delivered doses in patients receiving tangential treatment to their breast The unexpected, large range of deviations observed in this study demonstrates the need for adequate quality control of the beam characteristics, particularly of the beam data present in the treatment planning system (4,5)

3.2 Quality Control Procedures specific to trials and patients

3.2.1 Dummy-runs (Table 4)

In the dummy-run carried out for the trial 22862, 11 of the 15 centers that received the dummy-run material answered the study coordinator Some major deviations were identified In three centers, the treatment technique was not isocentric as required now by the protocol In one center, all fields were not treated each day In one center, the stated dose was not adequate In two centers, the technique was not a four field box arrangement In five centers, the booster field size was too small and in one center, there was two reductions of field size for the boost

In the dummy-run of trial 22881/10882, the dose at the isocenter using the beam data and the treatment chart showed a remarkable agreement since the deviations remained within 2 % of the stated dose The dose reported in the tumour excision area varied between 93 and 100 %, with a mean of 96 % It was found that the use of extremely low or extremely high wedge angles resulted in an increase of dose heterogeneity from 16 to 24 %, expressing the difference between stated minimum and maximum doses within the target volume

The dummy-run of trial 22931 is under way preliminary investigations indicate that there are marked inter-center variations in planned target volume outline

TABLE 4

IDENTIFICATION OF SYSTEMATIC ERRORS : THE DUMMY-RUN

TARGETS

- Breast cancers (trial 22881/10882)
- Head and neck cancers (trial 22931)
- Prostate cancers (trial 22863)

RESULTS

MAJOR DEVIATIONS WERE FOUND WITH RESPECT TO

- Target volume accuracy
- Irradiation techniques
- Dose specification

3.2.2 Individual case reviews (Table 5)

In trial 10882/22881 , the data of 75 patients treated in 15 institutions were reviewed It was found that excellent documentation of clinical and radiation data was provided In 5 institutions, dose specification was deviating from protocol prescriptions There appeared reluctances to indicate target volumes on treatment plan in 7 institutions The estimated dose heterogeneity ranged from 15 to 33 % Boost irradiation prescriptions also appeared to be unclear, leading to various fractionation schemes (21)

After the first review of 5 centers, it was felt that some aspects of the protocol had to be clarified, especially concerning the interpretation of some guidelines It essentially concerned pre-operative staging, post-operative status, dose prescription for tangential beams, dose prescription for the boost dose fractionation for the boost, definition and delineation of target volumes, especially that of the boost

Based on these findings, a list of recommendations was circulated among the departments participating to the trial In subsequent reviews, this list showed to have clarified most ambiguities This control procedure was thus found to be very helpful in detecting possible obscurities in the breast carcinoma study protocol and in pointing out, early in the course of the trial, misinterpretations due to insufficient and/or ambiguous descriptions of therapeutic guidelines

In trial 22862, two types of deviations were discovered during the case review Firstly, difficulties in measuring tumour volume, both by rectal examination and with ultrasound, were observed in most centers Secondly, variations in PSA measurements and toxicity scoring were commonly found among the institutions invited to participate to this individual case review

TABLE 5

RANDOM ERROR TACKLING:
THE INDIVIDUAL CASE REVIEW

TARGETS

- Breast cancers (trial 22881/10882)
- Rectal cancers (trial 22921)
- Prostate cancers (trial 22863)

RESULTS

MAJOR DEVIATIONS WERE FOUND WITH RESPECT TO

- Target volume outline
- Heterogeneity of dose distribution
- Deviations in dose specification from protocol guidelines
- Protocol obscurities

3.2.3 The boost evaluation in the breast trial 22881/10882

The EORTC trial 22881/10882 is a multicentric study with 26 participating centers from all over Europe and about 5000 cases will be evaluable It is likely that the degree of heterogeneity in the actually administered treatment parameters (total dose, dose homogeneity, irradiated volumes) could be closely linked to differences in treatment outcome, both for tumor control and cosmetic results (3)

In this trial, patients with stage I-II breast carcinoma are treated with postoperative radiotherapy Depending upon the completeness of the tumor excision, randomized treatment arms foresee to deliver, after the whole breast irradiation, a booster dose to the surgical bed Whereas the dummy-run and in-vivo dosimetry study did not emphasize major problems regarding the whole breast irradiation, both the quality control of forms at the Data Center and the individual case review demonstrated

that the boost treatment was in reality the main source of ambiguities. Large variations in treatment volume, fractionation schemes and boost techniques were indeed observed among participants: Figures 1-2 demonstrate indeed that, in an earlier phase of the trial, delivered doses could, in some institutions, significantly differ from the prescribed doses, both at point A (on-axis) and point B (off-axis). Monitoring the evolution of dose delivery indicate nevertheless that the spread of doses progressively diminished both in single institutions (Fig. 3) and for the whole population entered in the trial (Fig 4) (22).

3.2.4 Mailed entrance-exit measurements in breast irradiation (protocol 22881/10882)

In the breast protocol, the criteria for dose homogeneity state that the magnitude of the dose delivered should be within -5 and +10 % of the prescribed doses. This criteria was fulfilled for 14 of the 16 patients. Doses were also quantified on the skin (entrance-exit) and a good correlation was found between internal and external measurements. The measurements extended to institutes participating to the breast trial indicated that, for external beams, the delivered doses were within 2 % from the computed dose. For interstitial treatments the delivered doses were within about 5 % from the computed doses (1,13).

3.2.5 Late small bowel and volume factor for pelvic postoperative radiotherapy

For 183 out of 203 patients with available follow-up data on small bowel complications, a significant correlation was found between volume and non surgical small bowel complications such as late occurring diarrhoea, ileal dysfunction and malabsorption (Fig. 5). No volume-effect was demonstrated on the incidence of small bowel complications requiring surgery (12).

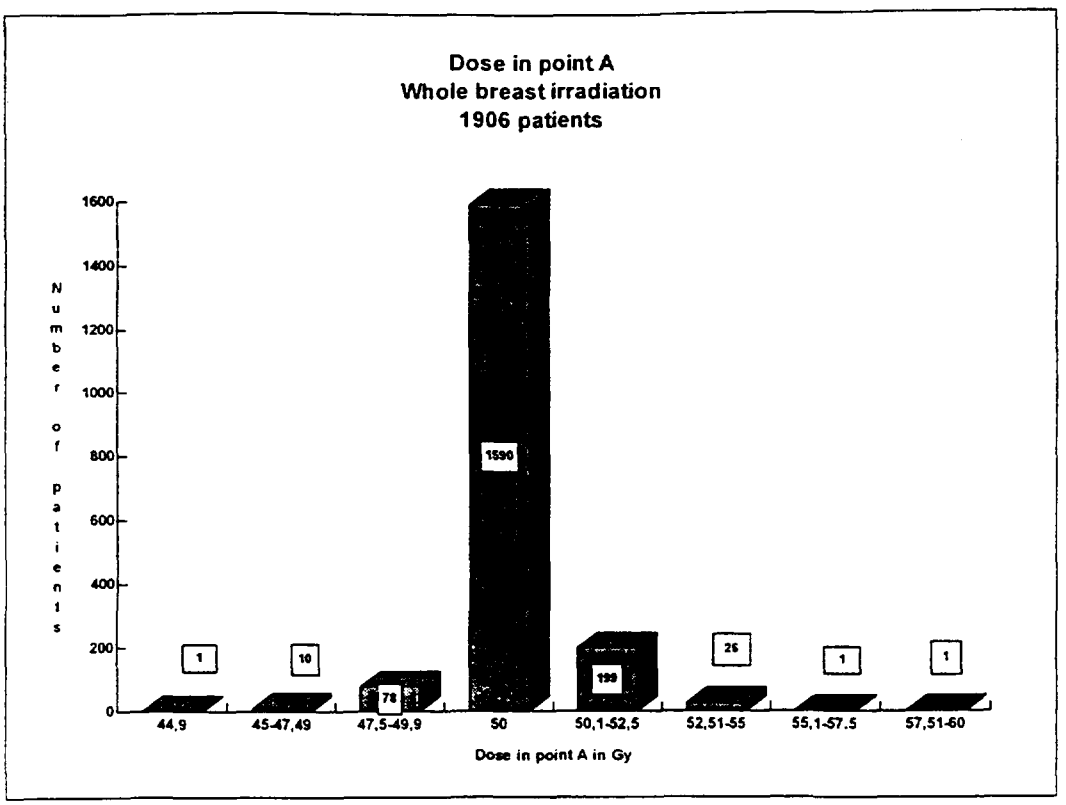

Fig. 1. EORTC Trial 22881/10882: Distribution of delivered doses at reference point A.

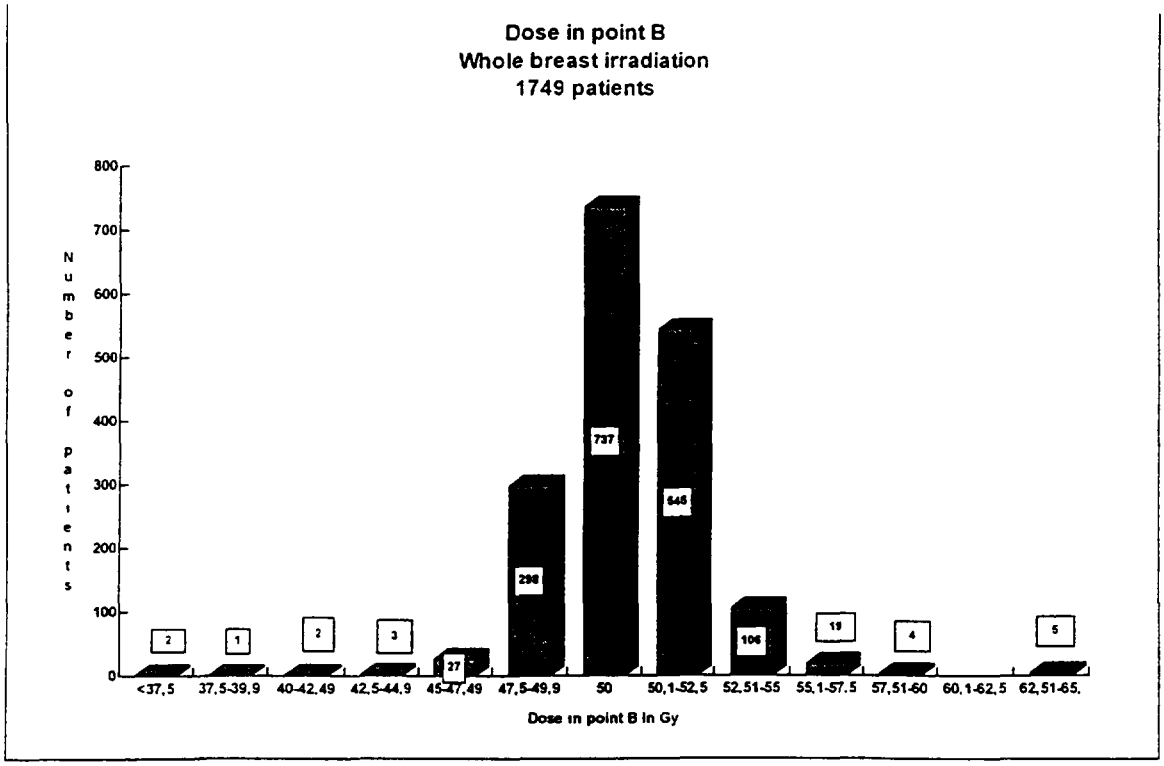

Fig.2. EORTC Trial 22881/10882: Distribution of delivered doses at reference point B

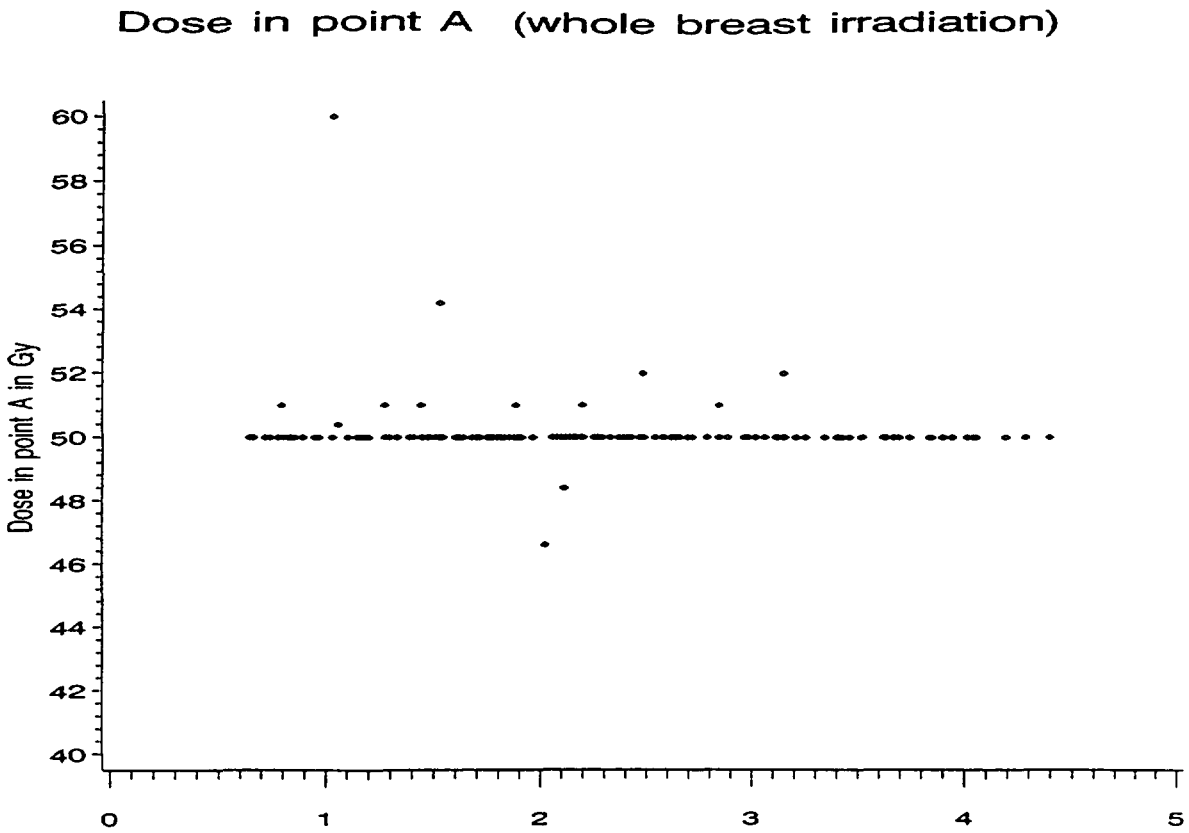

Fig.3. EORTC Trial 22881/10882: Distribution of delivered doses at reference point A throughout the whole period of trial activation (single institution).

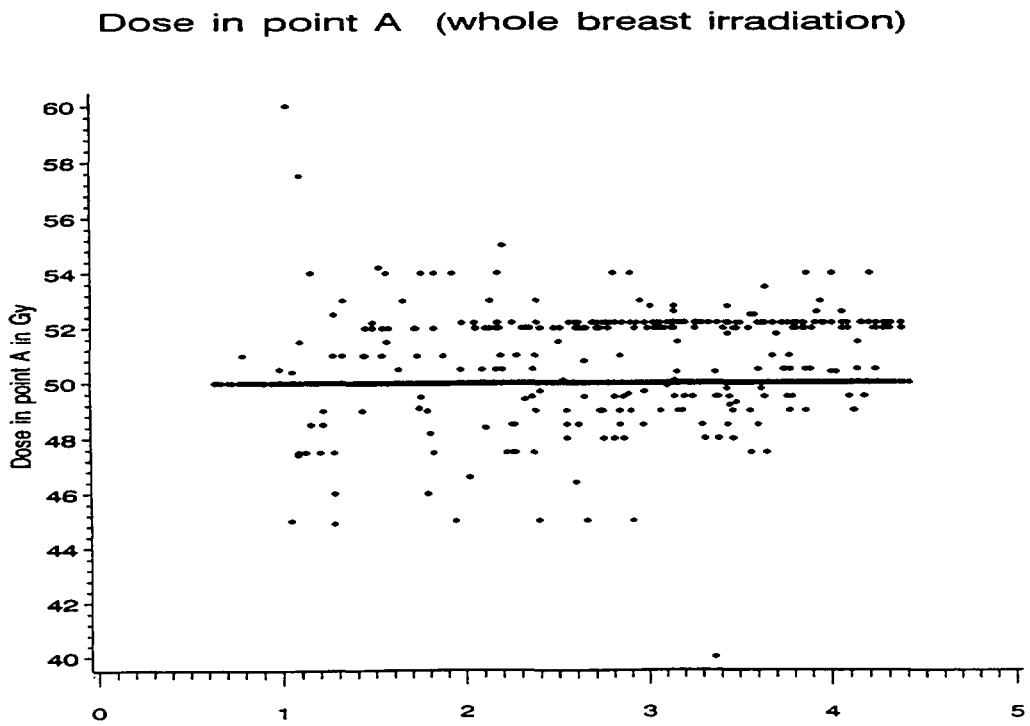

Fig.4. EORTC Trial 22881/10882: Distribution of delivered doses at reference point A throughout the whole period of trial activation (all institutions).

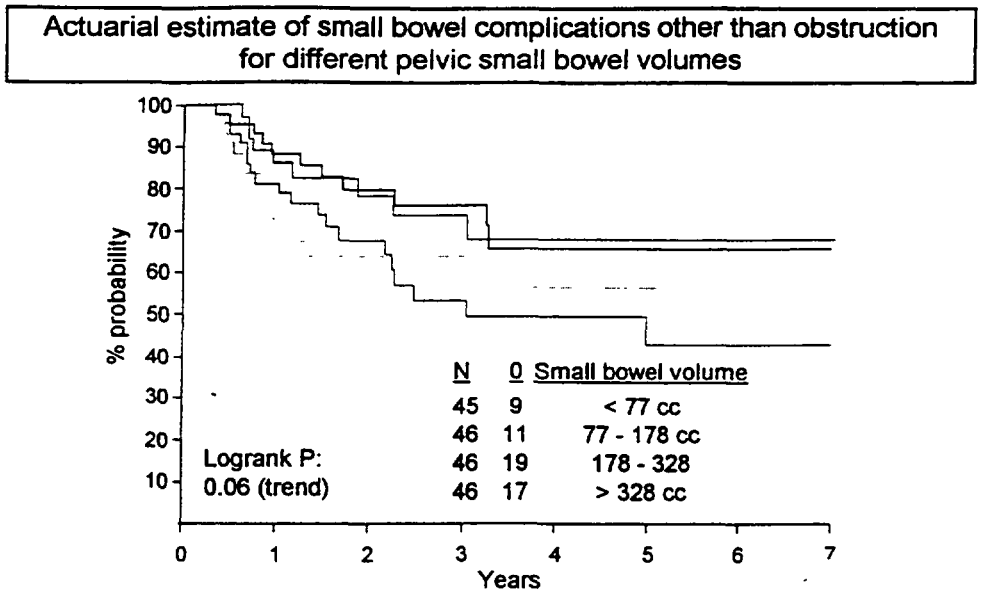

Fig.5. Correlation between irradiation volume and non surgical bowel complications (ref. [12]).

4. DISCUSSION

Overhaul of costly health care systems is currently at the center of looming budget battles in most industrialized countries. Undoubtedly a point of agreement among health authorities is the necessity of promoting Quality Assurance (QA) as a means to develop cost-efficient medical practice. Quality of treatments provided to patients varies indeed among institutions and the consequences of these variations are deleterious: beyond the fact that they affect the effectiveness of therapeutic management for a given disease, poor quality treatments often lead to severe complications which significantly reduce the quality of life and contribute to the rise of health costs. With respect to cancer management, it has now been repeatedly substantiated that large national differences in survival rates are found among patients with similar diagnostic backgrounds.

Interestingly enough, in oncology, the major efforts of Quality Systems have been invested in procedures directed to screening programs like mammography: it is emblematic that major influences on sensitivity and selectivity have been shown to generate a ten-fold difference in the number of biopsies for breast lesions. It is striking to see that, so far, less effort has been made to implement similar criteria for a "symptomatic" population in spite of the problems recently documented by various pattern of care studies. For instance, in radiotherapy centers which do not participate in QA programs, up to a quarter shows unacceptable deviations in given doses. In contrast, our last update shows that the percentage of major deviations in dose delivery drops to less than 1 % in institutions involved in QA programs such as beam verification (Table 1).

Likewise, given the potential toxicity of chemotherapy, it is surprising that too few guidelines or requirements for cytostatic treatment documentation exist. A similar situation exists for surgical procedures. Developing research in QA is thus a priority of cancer management more especially as all oncological treatment modalities have now narrow therapeutic margins requiring very critical calibration.

In oncology, quantitative analyses of the impact of QA programs on treatment delivery and on disease outcome - both for increases in cure rates and decreases in complications - still pertain to clinical research: a recent analysis conducted by the Patterns of Care Study in patients with stage I-II Hodgkin's disease and treated with radiation therapy alone, demonstrated that between the mid-seventies and the mid-eighties, improvement in radiotherapy technique and control procedures during treatment planning and delivery have roughly halved the number of relapses (23).

There is thus a need to ensure that the same quality of treatment is offered to all cancer patients in Europe. A research of this kind must be aimed at identifying which steps in the complex treatment processes are more error-prove, which of those can most effectively be corrected, and which procedures could be taken over by countries, or individual centers to monitor themselves the quality of their treatment procedures. To achieve this goals, the EORTC Radiotherapy Cooperative Group has put a major effort in the development of two Quality Assurance programs: the Physics Audit Quality program (*PAQ*) and in the Assurance of Protocol Compliance Program (*APCP*).

In the *PAQ*, a first survey conducted in 1986, on the radiotherapy infrastructure in European Centers participating in clinical trials showed that 20 % of the centers encountered difficulties to comply with the EORTC requirements due to imbalance in staff or equipment. Besides radiotherapy infrastructure, the beam output was checked in 50 centers: a major problem was detected in 30 % of the checked electron beams. Dosimetric recommendations were sent out to all radio-oncology departments active in the EORTC and a mailed measurement procedure was developed for the verification of the beam output in photon beams.

The *APCP* , which was activated in 1987, can be divided as follows:

- phantom dosimetry studies
- dummy run procedures for breast, prostate, and head and neck cancers

- check of case report forms for prostate, breast and rectal cancers
- individual case reviews for prostate, breast and rectal
- QA procedures at patient level for breast cancer
- outcome evaluation after irradiation of rectal cancer

With respect to the *PAQ*, our research is designed to expand these investigations to the newly affiliated radiotherapy centers and to carry out further sequential beam checks in those institutions which were already monitored in the early eighties, so that it can provide radiation physicists with minimum requirements and contribute to the basis of an improvement in accuracy for dose delivery in all radio-oncology centers

The activities realised so far in the *APCP* were pilot feasibility studies Guidelines and Quality Systems for the Assurance of Protocol Compliance Program (Table 6) are currently developed to ensure in the most cost-effective way, uniformity in radiation treatment delivery in multi-center clinical trials, and subsequently in daily practice in community level centers

TABLE 6

DISTRIBUTION OF GUIDELINES

- EORTC DATA CENTER PROCEDURES MANUAL
- EORTC MANUAL FOR CLINICAL RESEARCH IN BREAST CANCER
- EORTC CLINICAL INVESTIGATORS MANUAL
- DATA MANAGEMENT AND CLINICAL TRIALS
- RADIOTHERAPY MASTER PROTOCOL - PHASE III STUDIES

The main axes of research for the period 1995-1998 are

- Cost-benefit analysis of the dummy-runs, case report forms and individual case review procedures, in specific randomized trial of the Cooperative Radiotherapy Group of the EORTC
- Development of a standardized method for QA at patient level (in vivo dosimetry in a multicentric setting) and testing the method in a specific treatment protocol
- Update of information on required radiotherapy infrastructure in EORTC institutions based on mailed questionnaires and development of a tentative European radiotherapy department profile
- Development of a Quality Assurance Manual that will provide a practical document to the physicians to improve the quality of the technical and medical charts for research and routine therapy

Through the use of telematic services, the EORTC Radiotherapy group will also investigate the feasibility of teleconferencing QA audits by physicists and medical specialists for new radiotherapy techniques such as high dose/high precision therapy planning In patients with prostate cancer, determination of the anatomical pattern of variations in dose distribution between three-dimensional and conventional planning algorithms, will be carried out for tumors and normal tissues In a second phase, optimization of the dose distribution will be worked out, using all available tools of conformal radiotherapy Research activities of this task will aim at determining the impact of the electronic QA program on high precision radiotherapy of prostate cancer, in the framework of the QUACON project (QUality Assurance and Control through Oncological Network), which is being developed by the Radiotherapy Cooperative Group of the EORTC (Fig 6)

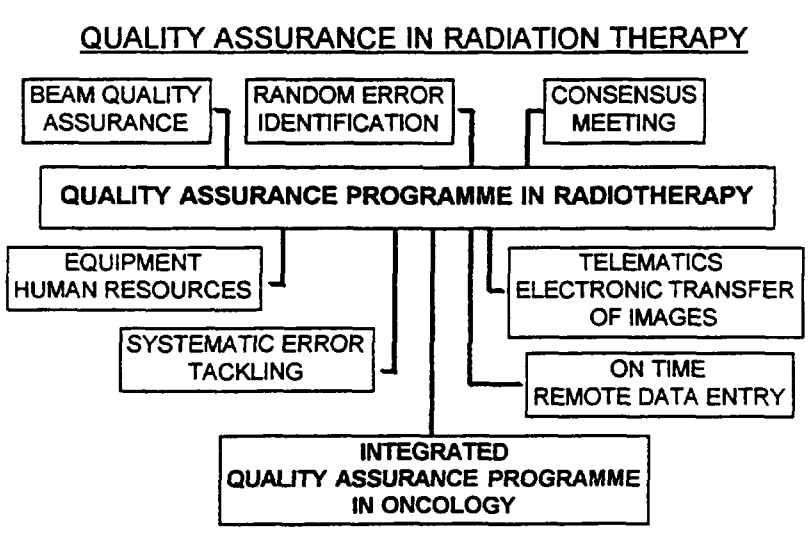

Fig 6 Current programmes and future directions of the EORTC Quality System in Radiotherapy

5. CONCLUSIONS

In radiotherapy, the goals of quality control procedures are twofold Firstly, through an improved quality of irradiation, to provide the highest possible accuracy of protocols studied on a multicentric scale Secondly, to provide all other radiation therapy centers with a methodology that has already been checked and confined through the "test-bench" of trials conducted by cooperative groups

Throughout the last decade, the Cooperative Group for Radiotherapy has been able to extend its basic quality controls of equipments and dosimetry into prospective investigations consisting of pilot studies for systematic checkings of individual treatment and treatment reliability, resulting in a large body of data on treatment precision level, systematic deviations and individual errors the tackling of systematic and random errors has been extremely successful since the set up of control procedures such as the dummy-runs and individual case reviews enabled the identification of the major sources of ambiguities as well as all causes of poor compliance to the protocols, resulting in the release of helpful recommendations for all participating centers

This type of QA program should also foster the interaction between several medical disciplines and promote the application of Quality Standards in community level hospitals Current efforts are also put forth to develop common research instruments, such as the processing of database and MRI or CT-scan images through teleconferencing and the set up of electronic radiotherapy files, as well as to the introduction of new health care technologies such as three-dimensional treatment planning and conformal, high dose/high precision radiotherapy

Quality assurance programmes are not only well accepted by all participants but also felt by everyone as a mandatory condition for the validity of a cooperative work between several centers This project is provoking within the group lively and very constructive discussions, especially during the last five years where individual contacts among investigators and local teams were promoted

The EORTC Radiotherapy Group has demonstrated that multicenter QA programs permit, through the pooling of a large number of data, auditing by specialists of implemented Quality Standards both in radiation physics and in clinical oncology, contributing to the basis for the development of harmonized quality procedures and standards in the therapeutic management of cancer

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IV. IMPLEMENTATION OF THE QA PROGRAMMES AT THE INSTITUTIONAL, NATIONAL, REGIONAL AND INTERNATIONAL LEVELS

COMPLEMENTARITY OF INDEPENDENT REVIEWS AND INSTITUTIONAL QUALITY ASSURANCE PROGRAMMES

(Abstract)

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The emergence of quality assurance led many institutions to either participate to an existing programme and/or to initiate a quality assurance programme in the department of radiotherapy. Although the two processes are fully interactive, they represent two different aspects of quality assurance and should be clearly individualised.

The goals of quality assurance cannot be achieved in the absence of one of the two components.

By definition, the independent review is part of the quality assurance process. In practical terms, it means that at regular intervals, quality assurance programme must be checked by an observer who is not part of the radiotherapy department staff under evaluation. This can be achieved in every discipline involved (radiation oncology, radiation physics, data management, etc...) by the intervention of external reviewers following a previously validated audit methodology (either a site-visit or a mailed procedure).

Deviations observed in comprehensive quality assurance programmes can be identified as systematic errors or occasional errors. A systematic error results from a reproducible coherent fault. It is a « well performed » inadequate procedure e.g. an accurate reading using a wrong calibration method resulting in an inaccurate measurement. Such a problem is immediately detected by a independent review while it can last for years inspite of an internal quality assurance programme. Conversely, occasional errors are those occuring randomly. Severe accidents usually result from a cascade of such undetected deviations. Fortunately, most systematic deviations are of a small magnitude.

The development of quality assurance in clinical research trials first put the emphasis on tracking systematic deviations to ensure the reliability of technical data gathered in multi-institutional studies.

The experience of the EORTC Radiotherapy Group was helpful to identify the most frequent reasons for systematic deviations in radiation physics dosimetry, treatment planning and tumor sites. Usually the independent review immediately spots systematic errors which may otherwise remain undetected for years by an institutional review.

The detection of occasional errors is both difficult and time consuming. The incidence and range of severity of occasional deviations provides a fair estimate of the safety and reliability of the procedures undertaken in the radiotherapy department. Their demonstration demands action, preferably preventive, with careful thought as to how best correct the weak links in planning and treatment. Important consequences include a need for improvement in equipment, staff number and competence, last for a better interaction between staff members.

Institutional quality assurance programme should be developed according to ISO 9000 quality standards and to methodological guidelines provided by international and national societies of radiotherapy and radiation physics. This should enable local responsibles to justify the need for correcting staff and equipment unbalances to comply with minimum requirements and/or to progress to the higher standards needed to comply with the level 2 and 3 requirements defined in the ICRU report 50.

The role of networks of quality assurance is essential to provide a fruitful interactivity between the independent quality assurance review process and the institutional programme. Besides tracking systematic deviations, the independent review should validate the contents of the institutional quality assurance programme and whenever needed, point out weaknesses or missing aspects. It should also convey new methodologies developed in research programmes once they have produced evidence of technical maturity and usefulness.

Last, the interactions between reference bodies (international and national primary and secondary standard laboratories) and radiotherapy departments should be facilitated by the existence of formal structures responsible for external independent review on quality assurance. This point is of utmost importance to promote most existing quality assurance attempts into truly systematic national programmes.

RADIATION ONCOLOGY QUALITY ASSURANCE FROM THE NEW WORLD: THE MEMORIAL SLOAN-KETTERING CANCER CENTER EXPERIENCE

(Abstract)

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The aim of this presentation will be to highlight our experience in radiation oncology quality assurance We will first discuss our overall philosophy in developing and implementing QA programme This discussion will include a description of the central place of the QA committee and it's role in setting policy and monitoring procedures We will also indicate the increasing role of "quality management" in shaping our evolving QA strategies Examples of the co-ordination between the radiation oncologist, radiation therapists and medical radiation physicists will be presented However, to keep the discussion within bounds we will describe only those procedures related to external beam radiation therapy

In addition to describing the overall QA programme, we will present some details on specific QA procedures in 2 areas of radiation physics, namely, treatment machine QA and treatment planning QA procedures We will illustrate this discussion with examples of the type of tests performed, their frequency and associated action limits These procedures will be presented in the framework of the new QA protocol of the AAPM[1]

A third area, 3D treatment planning, presents new and more complex problems in quality assurance We will concentrate on special methods we have developed to assure accurate implementation of conformal therapy Examples of the accuracy of positioning patients prior to treatment and evolving methods to control and/or correct organ motion will be discussed We will also describe procedures we have been developing for acceptance testing, commissioning and ongoing QA and 3D treatment planning system Some examples, which are being used to acceptance test and commission a new 3D system will be presented

QA procedures in the United States are overlaid, and in part driven by, conflicting societal expectations on the one hand, there is a high rate of malpractice suits and growing demands by managed care systems for more personal and mistake free treatment, and on the other hand, medical care is being driven by economic forces to provide less costly care Quality assurance is trapped between these opposing forces and mus refashion itself to maintain high quality at lower costs A discussion of this dilemma and our preliminary plans to confront it (in part through new technology) will conclude the presentation

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DEVELOPMENT OF A QUALITY ASSURANCE SYSTEM FOR RADIOTHERAPY

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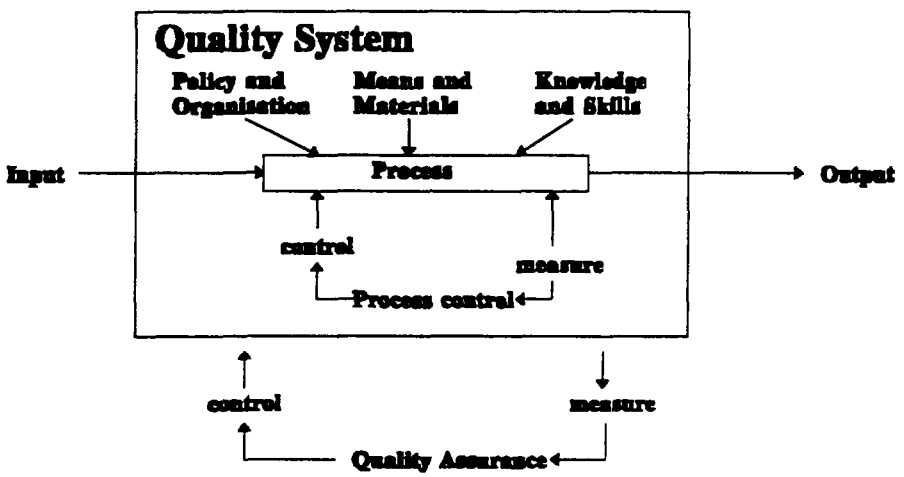
Abstract

Due to 1996 legislation in the Netherlands, every heath care facility should have a quality assurance program. Because it is difficult to measure the quality of the product of care, a choice is made to focus on the process of care. For this purpose PACE was founded. (PACE is a Dutch acronym for *P*roject *A*Ccreditation) with as founding members:
Public Health Insurance Council, TNO health research, 4 university hospitals and 4 large general hospitals.
For in total 19 services and disciplines quality assurance standards where developed by groups in six of the hospitals.

The quality system

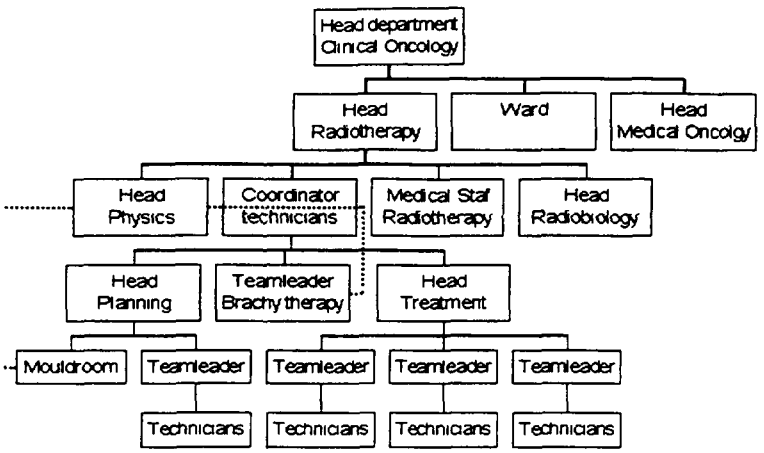
The idea's followed are according to the ISO 9000 series of standards originally developed for industrial production and services. In this system there is a primary process in our case patient care with patients as input, and treated patients as output. During the process different parameters can be measured and used as a feedback to control the care process.



The elements that influence the process are the policy and the organisation structure of the department, available means and materials, and the knowledge and skills.
Implementation of a quality system is only successful when it is clear what the position of the department is and what the aims are. For instance what type of patients do we want to treat, what types treatments do we want to perform. The institute can be a centre for bone marrow transplantation and so the department has to perform total body irradiations. It can be better to refer some patients, with retinoblastoma, to an other institute with more expertise in that field.
It is possible that for research reasons certain groups of patients are recruited in special, and others referred to other centres. Training doctors asks for special rules in the procedures.

The structure of the department can be described by the *hierarchical*, the *functional* and the *operational* relations of staff and management. The structure of the department can be described by the *hierarchical*, the *functional* and the *operational* relations of staff and management. Who is responsible for what task and what are the competencies. How are communication between different disciplines organized. Who is responsible for what task and what are the competencies. How are communication between different disciplines organized.

Hierarchical relations can be mapped in an organisation chart.



From an operational point of view there can be project groups that have links through and outside the department independent of hierarchical structures.

After the organisation charts are made all the responsibilities, tasks and competencies of each staff member must be determined. For every task one and only one should be responsible, bet several people can have an advisory task. The physician is responsible for the medical decisions, but technicians and physicists have an advisory function. The secretary is responsible for ordering stock and the others have advisory functions here. It must be clear how the responsibilities and competencies are regulated, who can start or stop a treatment, who take a treatment machine out of service.

Means and materials include the technical infrastructure, such as housing and transportation, the machinery e.g. treatment machines and instruments. The maintenance schedules and the schedules for replacement must be documented

There must a guaranty that exploitation goods such as films, disposables, are available in the department on the right moment.

Knowledge and Skills have to be kept up-to-date for all staff also in non-training departments. Educational entrance criteria must be determined, there must be training programs, excess to literature and access to congresses and post graduate courses also for non-research workers.

Important is to define a system for exchange of knowledge between the different groups in and outside the department.

The process control is the most intriguing part of setting up a Quality system. All activities concerning the patient, from the moment he or she enters the department until the end of treatment should be described. For this reason we need protocols, procedures, guide lines and check lists for diagnostic and therapeutic procedures, for information to the patient, reporting, privacy protection, waiting list management, referral of patient to and from the department, for safety and protection of patient and personnel. Every step of the patient through the process can be described in flow charts, where for every step the documentation to be filed, and the protocols that must be used are indicated.

The last step in maintaining a Quality System is, the control of the System. On a regular time basis all protocols and handbooks must be updated. The system must be evaluated by internal audit and if necessary corrected.

And last but not least the important thing in building a Quality system is that every one in the organisation is motivated to act along the lines of the Quality System, without that the system will fail.

ON THE SAFE USE OF VERIFY-AND-RECORD SYSTEMS IN EXTERNAL BEAM RADIATION THERAPY

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Abstract

Verify-and-record (V&R) systems are being used increasingly, not only for verification, but also for computer aided setup and chart printing. The close intercorrelation between V&R system and treatment routine requires new ideas for quality assurance (QA) : pure "machine checking" as with treatment units is not sufficient anymore. The level of QA obviously depends on the tasks of the V&R system : the most advanced case of the system being used for computer aided setup and for chart printing is discussed - both are indispensable for an efficient use of V&R systems. Seven propositions are defined to make this not only efficient but safe.

1. INTRODUCTION

Early versions of verify-and-record (V&R) systems were mere checking systems : they did not indicate discrepancies during the set-up procedure, but check at the time of attempted beam-on whether all parameters had been set correctly; if not, beam-on would be prevented, and the fact recorded. This made statistics on prevented mistakes possible : there is a wide variety of definitions of "significant" mistakes, influencing the rate of mistakes detected, but on average these statistics show mistakes for some 1 % of all fields treated; if independent errors are assumed (and these are the main errors prevented by such a system) Poisson statistics apply; further assuming a standard treatment course of 25 sessions with 2 fields each, i.e. 50 fields treated, some 40 % of all patients had a significant mistake prevented by the passive checking systems; 0.2 % of all patients would have been irradiated wrongly four times !

Active verify-and-record systems are now increasingly becoming the state-of-the-art with modern linear accelerators for external beam radiotherapy. They are not only an effective means of verifying patient set-up, thus reducing the likelihood of set-up errors; they may and increasingly will be relied upon for treatment chart printing instead of handwritten charts, and/or controlling patient set-up (auto set-up). Unlike the old, passive systems, certain human actions are replaced by computer actions. As no computer system is 100 % reliable and foolproof, it is important to use the computer facility to aid efficiency, but continue to rely on common sense, experience and quality assurance (QA). For the safe use of V&R systems, widely different QA measures are necessary - both, in the design of the system (by the manufacturer), and in its use (by the hospital).

For external beam treatment machines several QA measures are necessary and can be defined irrespective of machine type or manufacturer. To compile general recommendations on QA for just

the V&R system in a similar manner, is impossible - the checks necessary will very much depend on the type of system. This paper therefore defines seven more general propositions : On the one hand design features influencing the "inherent safety" of the system (this is aimed at the manufacturers) are described, and on the other, guidelines for the use of the system within a department are given. The latter will include a few functional checks, and for the larger part recommend departmental procedures, not only concerned with the V&R system.

2. TASKS FOR VERIFY-AND-RECORD SYSTEMS

a. Verification : the system verifies that all parameters set by the radiographer are correct within specified tolerances; discrepancies will usually be indicated during the set-up procedure.
b. Recording and chart printing :
   α. Recording on computer media, e.g. hard disk : recording of all parameters (patient related and machine related data); applications include :
      - availability of patient related data, independent of patient notes (especially in large institutions with network)
      - identification of circumstances that have led to an error/failure
      - statistical evaluation of both, patient related (e.g. doses) and machine related (e.g. workload, error conditions) data.
   β. Chart printing : must fulfil the legal requirements if handwritten charts are to be replaced; legislation in several European countries requires a machine log in addition to the obvious patient chart. In order to get manageable and readable charts, only the necessary minimum of data is to be printed. (The term "chart printing" has been used here instead of the more familiar term "reporting" to avoid confusion with the definition of "reporting" as used in ICRU Report 50.)
c. Auto Set-up : in order to free the radiographer from machine oriented tasks and thus dedicate more time to the patient, auto set-up is a desirable function. Auto set-up may also help to regain some of the time spent entering data into the V&R system.

3. LEVELS OF QUALITY ASSURANCE

Quality assurance is mandatory for all above mentioned tasks; its level will depend on the type of task.

a. The level will be the lowest required if the system is used for verification only : all parameters are typed in first, but this is not used during patient set-up; instead the patient is set by a radiographer according to the patient chart; in case of deviation, both the patient set-up and the parameters given by the system are checked. QA has only to reduce the likelihood of errors going undetected.
bα. It needs to be checked that all treatment parameters and error conditions are recorded reliably: the record is only used in case of an error, in addition to or in comparison with handwritten notes. Additional QA procedures may be required if a statistical evaluation of these parameters is considered important.
bβ. If patient chart and/or machine log are printed by the system, it should be used to replace hand-written records after a thorough check has been carried out to ensure the proper functioning of the print-out sequence. As the printed record is therefore the only record of a given treatment, a much more sophisticated QA is required : this includes both QA of the system itself, and checking of the resulting print-out.
c. An effective auto set-up feature has very high merits; on the other hand, it compromises the verification feature : if stored paramaters are corrupted an auto set-up with wrong parameters will not be detected if the same corrupted data are used for verification. Additional QA measures are needed to guarantee data integrity; careful checking of the auto set-up by the radiographer is mandatory - the rôles have changed : the radiographer verifies that the V&R system has set-up correctly !

4. BASIC PRINCIPLES

There are three basic principles underlying the following propositions, valid not only for V&R systems :

a. It is generally accepted that every crucial step in the treatment procedure (from patient data acquisition to treatment recording) be done by two independent procedures or independently performed and checked by two different persons; either, a step-by-step check by the second person, or an independent check of the complete chain, is acceptable.
b. Relevant are checks for malfunctions which may go undetected for extended periods of time, unless the check is performed, or checks to detect trends in adjustments/calibrations. Less meaningful are checks of functions which could fail at any time suddenly, but would be detected immediately. Examples : it is not meaningful to do extra checks on the linac beam off when the set MU are reached - if it fails it will fail the first time on any beam during the day, but should be detected immediately by the radiographer responsible. It is, however, meaningful to check monitor calibration - a change would not be detected during patient treatments, and a trend may indicate possible sources of error, e.g. a leaking sealed monitor chamber.
c. For accidents (treatment errors) to occur, it is usually necessary that two separate and unrelated factors coincide : a weak point in a procedure or system, and usually several "unfortunate circumstances". The probability of unfortunate circumstances coinciding cannot be reduced to zero by any means - this will always happen and cannot be predicted. The weak points, on the other hand, are inherent in the system, and should be eliminated by careful consideration. Statements like "it will work properly if used properly" are not acceptable : "inherent safety" implies that the probability of possible improper use or it going undetected is reduced to a minimum - this applies to both the design of the V&R system, and its integration into the departmental routine.

The consequence of these basic considerations is that there are (almost) no meaningful measures checking just the machine function of the V&R system. Much more important are organisational measures to

- prevent handling errors (incl. errors during data transfer and inadvertent changes of stored parameters),
- detect immediately any erroneous behaviour of the V&R system, like any effects due to data corruption, or software bugs resulting in errors under unusual conditions only.

If this is to work efficiently, the entire organisation of the radiotherapy procedure (and therefore the clinic) has to be adapted when a V&R system is introduced. The extent of adaptation necessary depends on the "inherent safety" of the system : both, the design (manufacturer) and the handling (user) of the system have to be guided by this relation.

5. PROPOSITIONS

All parameters are entered into the V&R system before the first treatment session. For keying in these parameters it is useful to compile all data on a single form, designed with the screen layout as template - this speeds up data entry, and reduces the likelihood of transfer errors. If parameters are transferred on-line, e.g. from the planning system or simulator, appropriate QA measures have to be taken. These steps of data transfer are most critical for two reasons : usually several people from different staff groups are involved, and due to error propagation, transfer errors will become systematic errors - once the V&R system has stored wrong parameters (e.g. a missing wedge) it will ensure that these wrong parameters are used for each session ! Therefore irrespective of the method of data entry set-up parameters should be printed out and checked by another person; the print-out should be done automatically by the system each time data are entered or edited. Only then the first set-up at the treatment machine, supervised by the radiotherapist, forms a final and comprehensive QA measure. Portal imaging and in-vivo dosimetry during the first treatment session are additional safeguards against transfer errors.

"Auto-acquire" of parameters of manual set-ups is to be avoided whenever possible. If done at all, only parameters displayed in the treatment room should be acquired : never acquire monitor units. Additional checking should be introduced before subsequent treatment sessions. If the parameters to be acquired cannot be selected by the user the preferred procedure would be to type in the relevant parameters manually during first set-up, rather than relying on auto-acquire.

If "Auto set-up" is used, data integrity is of utmost importance. Checks against data corruption due to computer malfunction (e.g. check sums) should be incorporated by the manufacturer. The "inherent safety" may further reduce the probability of inadvertent data modifications due to handling errors. This includes a screen dialogue in the native language, editing procedures that differ from normal treatment procedures (e.g. an additional key switch, not just another point on the menu or a password, see "basic principle c"), and automatic printing of a new set-up protocol.

"Override" treatments are to be avoided. Instead several suitably defined tolerance tables should be used for different treatment techniques, as for immobilized patients (e.g. by a head mask), photon treatments without patient immobilisation, electron treatments, or for palliative treatment of bedridden patients (see table I). Only with this attitude will override treatments be the exceptional situation urging everyone involved to pay special attention.

Table I : SET OF TYPICAL TOLERANCE VALUES FOR DIFFERENT TREATMENT CONDITIONS

Parameter		1	2	3	4
Gantry angle	(°)	0.5	0.5	2	5
Collimator angle	(°)	0.5	0.5	5	10
Field size X,Y (also asymmetrical)	(cm)	0.2	0.2	0.2	0.2
Table vertical	(cm)	2	5	5	*
Table lateral	(cm)	2	10	10	*
Table longitudinal	(cm)	2	*	*	*
Table rotation[a]	(°)	1	1	1	*

1 = immobilised patient (e.g. head mask)
2 = photon treatment without patient immobilisation
3 = electron treatment
4 = treatment in bed
* = not checked or maximum tolerance possible with V&R system
[a] = isocentric and table-top (if applicable)

Duplicate patient charts (hand-written and computer-printed) are to be avoided. Instead the computer-printed patient chart is to be checked carefully after each session and signed or initialled: if both records are to be kept, there is a tendency to rely on a later comparison if a discrepancy is suspected - if this takes place several days (or even more) later and a dicrepancy is detected, the exact circumstances that may have led to an error will not be remembered in such detail as to enable a sound decision to be taken; either record may be wrong. The abolishment of hand-written charts is only possible if the printed charts fulfil the legal requirements, both for the patient chart, and the machine log requirements. Furthermore, all computer-printed charts must be restricted to meaningful data and should be arranged in such a way that they are readily accessible.

Continued staff training : Especially in the case of frequent staff changes the transfer of information within the team needs to be scrutinised; a combination of several minor changes from the original sequence of procedures may result in unsafe practice. This may be prevented by regular refresher courses.

All responsibilty is carried by humans. The computer may help to improve efficiency and safety of radiotherapy applications, but will never take responsibility - the computer has to be checked by the radiographer, and not vice versa. This point needs to be stressed especially in connection with the introduction of the V&R system, to avoid detrimental effects on staff motivation.

6. CONCLUSION

Quality assurance measures should be balanced and adapted to the risks they are meant to minimise : it does not make sense to reduce certain risks (machine malfunction) even further at high cost, whilst other, much larger risks (procedural errors) remain untackled - and human errors are the more likely ones with modern computers.

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QUALITY CONTROL OF THE TRANSLATION OF THE LABORATORY RESEARCH INTO CLINICAL PRACTICE

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Abstract

This paper discusses the biological basis of new treatment strategies that are being introduced into the clinic in the form of controlled clinical trials. There is an increasing awareness of the need for quality assurance in the design, execution and analysis of these trials. However there is little awareness of the need to critically assess the biological basis of the trial design, to ensure that no other biological principles have been contravened in the attempt to optimise just one of the many parameters that determine the differential in sensitivity between tumours and normal tissues. Some examples are given of the changes that have recently occurred in the laboratory interpretation of both the mechanism of action and the therapeutic gain of several novel approaches. If these are not considered, the carefully controlled clinical trials may be wasted, because of being based on an incomplete consideration of all the interconnected biological factors.

1. INTRODUCTION

Cancer research and cancer therapy can be compared to industry in terms of the Research and Development (R and D) and marketing sections which are aimed to produce a better product for the customer, in this case the patient suffering from cancer. There are two categories of cancer patients; those in whom the tumour is still localised, for whom complete eradication of the disease is a possibility, and those in whom it is already widespread, in which case the disease may be kept under control, but complete cure is unlikely. The localised disease group currently have at least a 50% likelihood of cure, with surgery and/or radiotherapy being the most important approaches, and it is this very success rate that makes it so difficult to introduce radically new therapies, for fear of losing existing benefits. Most of the research funded by industry is aimed at the group with disseminated disease. It aims to increase the sale of drugs which rarely cure, but give useful remissions. Little commercial funding goes into the improvement of the curative treatments with surgery or radiotherapy.

Oncology is a massive global international enterprise, both in terms of the thousands of researchers, tens of thousands of practitioners and the millions of cancer sufferers, (40% of the population develop cancer in western countries). There is an admirable degree of academic freedom and sharing of information across national and scientific boundaries. It is impossible to imagine an overall strategic plan, because of the multi-faceted nature of the research and its funding, and the relatively loose international network in which researchers interact rapidly via scientific publications and conference presentations. Of course the rapid exchange of information is desirable to allow the field as a whole to progress efficiently. Research activities are carried out in both academic and commercial settings. On the pharmaceutical side there are stringent regulations imposed by national government drug licensing authorities before a new product can be marketed. However, if an existing drug, or an agent like radiation is to be used in a new schedule, based on biological data from the laboratory, the constraint is only at the level of the ethical committees within individual hospitals. These do not have the resources for a detailed examination of the data base underlying each new proposal, and certainly not the time or the expertise to look for logical inconsistencies or for technical flaws.

As the research approaches clinical implementation, a quality control framework is needed to ensure that the expenditure of the vast amounts of time, effort and talent needed to carry out a controlled clinical trial are focused only on novel treatments that offer real benefit over those already in existence With the increasing diversification of scientific specialities there is an ever-increasing difficulty in communications between the scientists and clinicians and the different oncology disciplines Indeed no scientist within oncology can be completely familiar with all the technical details and the potential artefacts of all aspects of the diverse fields of cancer research, and so communication barriers are developing within the laboratory sphere, as well as between full time clinicians and full time researchers The clinicians who divide their time between laboratory and clinical research are, of course an important ingredient in the bridging process, but they suffer the dual problem of staying abreast of both clinical and laboratory developments

National and international voluntary co-operative groups have been set up to co-ordinate multicentre clinical trials and provide quality assurance, in order to ensure that they are performed according to established scientific principles They work with defined methods of collecting the information about the response of the tumour and any side effects, so that an impartial assessment can be made of whether a new treatment gives any benefit compared to conventional therapy However, the method by which the small fraction of the possible new approaches is selected to go forward into clinical trials is at present haphazard There is an increasing emphasis on quality assurance in the execution and analysis of the trials, but there is little or no corresponding quality assurance on the method of implementing the biological concepts and principles which underpin the new approaches. It is this aspect that the present paper addresses, with particular emphasis on the treatment of potentially curative tumours, using X or gamma radiation as the tool The following questions need to be posed At present it would be difficult to give reassuring answers to them

- How can the full benefit be gained from the thousands of man-years of research and the enormous body of information already published from laboratory studies?
- Are we any closer to the elusive 'breakthrough', or will progress only come from small incremental steps?
- Is there a failure to carry through good concepts to clinical evaluation?
- Are any good ideas being discarded because of inappropriate implementation?
- What determines which concepts are adopted, and in which tumours they are evaluated?
- Are they being tried in the right tumour type, using the right dose or combination of agents?
- Could there be an incomplete understanding of their mode of action, and therefore an inappropriate extrapolation from experimental systems to man?

Will a new approach be suitable for all the patients in a particular disease site or should it be used only for a selected subset with defined parameters?

2. RADIOBIOLOGY AND RADIATION THERAPY

The implementation of laboratory research into routine clinical practice takes a long time The basic research of the thirties and forties in radiation physics has led to dramatic advances in the methods of delivering radiation to the desired target, and of accurately measuring that dose delivery Supervoltage therapy machines were introduced in the sixties and these provided part of the impetus to develop the more sophisticated imaging devices in the seventies and eighties These have all been brought together with the aid of computer assisted dose planning to enable people now to contemplate conformal therapy as a practical possibility Thus nowadays the practice of radiotherapy in a department that does not employ basic scientists, in the form of hospital physicists and engineers, would be difficult to imagine

The situation is however quite different for radiation biology It is widely recognised that the damaging effect of radiation is not identical on all normal tissues tumours, both in terms of the extent of cell kill that is achieved with a particular dose, and the timescale over which the cell death is observed The differences in response form the basis of the common clinical practice of fractionation Although the existing schedules have evolved with clinical experience over decades, there is no certainty that they are yet optimised

Radiobiology, the study of the biological effects of radiation, is a long established field, yet there are no radiobiologists employed in a support role like hospital physicists Indeed most respected radiotherapy departments in Europe have no access to a radiobiologist on site, even within academic departments In spite of this apparent lack of integration of radiobiology within radiotherapy departments, there is an acknowledged impact of radiobiology research in the practice and training of conventional radiotherapy, and even more in the developments of new initiatives

The early studies of radiation effects in biological systems revealed the complexities of the response and the way it could be influenced by such factors as the age of the cell in the cell cycle, the intracellular concentrations of oxygen and the sulphydryls that protect against oxidative damage Much effort was needed to distinguish between radioresponsiveness, i e the speed of reaction to the toxic insult, and radiosensitivity, i e the fraction of cells succumbing to the toxic agent Assays of cellular survival, both in culture and in situ in the animal were painstakingly developed, so that the response of whole tissues and/or solid tumours could be understood in terms of the constituent cells It has been recognised that all multicellular organs have heterogeneous cell populations within them, and may show a variety of responses according to the fraction of the organ that is irradiated, and the method of administering the radiation, i e it's distribution both in time and space This research has led to the diverging fields of

preclinical radiobiology, with its emphasis on the influence of microenvironmental factors and the compensatory responses of whole tissues when they are damaged,

cellular and subcellular radiobiology, concerned with the study of DNA repair and the chemical, physical, biochemical and genetic factors that influence the response of individual cells to radiation and other toxic insults

There is now a perceived need for a new breed of researchers, whose special interest will be in the translation of the increasingly complex laboratory studies into practical concepts that can be considered for improving clinical outcome Their involvement in the evolution of new treatment strategies is particularly important when there are existing treatments with a significant probability of curing the patient, and with known probabilities of morbidity In this situation any new proposal must be viewed with extreme caution since there is the double risk of failure, either by losing some of the existing success rate in eradicating the tumour, or by increasing the morbidity

The role of the translational researcher is crucial in ensuring the optimal trial design to take new biological concepts forward into clinical trial There must be an exceptional degree of communication and of dialogue to ensure the greatest probability of benefit to the patient, and the least waste of energy and resources in trials which are unlikely to show a real benefit, because they have failed to take account of all the interconnected biological aspects The assessment of new curative regimes in cancer therapy require many years, often exceeding a decade to demonstrate either a long term benefit or a long term hazard Surprisingly with such an investment at risk, few of the trial co-ordinating groups regard it as essential to involve the translational scientists in the details of their trial design, although none of them would buy a new radiotherapy machine without the detailed advice of their radiation physics colleagues

3. CLINICAL APPLICATION OF RADIOBIOLOGICAL PRINCIPLES

As quality assurance in clinical trials becomes increasingly common, it seems an appropriate time to review the progress that has been made in the biological understanding of the cytotoxic action of radiation, and particularly the way the preclinical field has changed its interpretation of data in the last decade or so

Over the years there have been waves of enthusiasm, disappointment and disillusion before a realistic appreciation was gained of the potential benefit from a series of different biological principles These have included altered fractionation, low doserate, hyperbaric oxygen, fast neutrons, negative pi mesons and other unconventional radiations, chemical radiosensitisers and chemical radioprotectors At present the clinical interest is focused on accelerated schedules, the use of more and smaller doses (hyperfractionation), the use of several fractions per day, high dose rates for brachytherapy, and the use of gaseous or chemical radiosensitisers which affect either the delivery of oxygen to deprived cells, or act as a substitute for it Many of these areas have now progressed into rational clinical evaluation, and no longer have the unrealistic expectations that often accompany the initial adoption of a concept into the clinic Each of these topics is backed by a large body of data obtained in a variety of biological systems, ranging from chemical and biochemical assays in test tubes, through viruses, bacteria and mammalian cells in dishes, to organised tumours and normal tissues in animals The preclinical studies in rodents are an essential last step to determine whether there is a differential in the increased damage between tumours and normal tissues

The biggest changes have been the development of quantitative assays that permit non lethal endpoints to be used for acute and late reactions, novel experimental designs that allow low dose levels to be studied e.g. the top-up technique, and the use of these with schedules close to those that are likely to be used in the clinic.. Such studies have shown that all normal tissues are not alike in their response to altered fractionation schedules or to physical and chemical modifiers, and that the gain predicted from single dose experiments is grossly in error when compared with the gains for multiple fractions of 2-3Gy.

Many of the biological concepts were taken forward for clinical evaluation long before completion of the full spectrum of preclinical studies, which were necessary to show how the new approach should be used to give the maximum chance of success Initially the preclinical studies were limited to large single doses, or a few large doses, but not using clinically relevant 2-4 Gy fractions The pathophysiology of tumours determines the response, particularly the gradients of oxygen and other nutrients These gradients change as soon as therapy commences, and so the results with single doses or a few large fractions are usually totally misleading for fractionated therapy Therefore, it sometimes seemed that radiobiology was trailing the clinic, explaining why something failed, rather than pointing the way to new successes! Since there are no magic differences in the radiosensitivity of tumour cells versus normal cells, the benefits are likely to come from 'fine tuning', which requires a careful consideration of *all* aspects, especially those relating to the dynamics of the tumour microenvironment Rushing in with a partial data base is inevitably going to lead to failure This was clearly demonstrated with hypofractionation and with neutron therapy

4. BIOLOGICAL EFFECTIVENESS AND THERAPEUTIC GAIN

The oxygen effect was for many years the main preoccupation of both radiobiologists and radiotherapists because it indicated a difference between solid tumours and *all* normal tissues that could be limiting treatment success Recently the emphasis has shifted to consider differences ***between*** different types of normal tissue as being at least as important as the oxygen effect, particularly in relation to the overall treatment time and the dose per fraction(6) Two of the most fundamental changes that have been proposed to the clinicians (hyperfractionation and acceleration) involve altering the total dose in such a way that the acute reactions (occurring shortly after treatment) will become more severe and dose limiting, but with a concomitant sparing of damage to the deeper tissues, which have delayed 'late' reactions after irradiation It has been realised that ***the tumour responds more like the acute than the late reactions when radiotherapy schedules are altered***, presumably because of their cell kinetic characteristics (3, 22, 23) Thus to inflict more tumour injury it may be necessary to inflict more acute normal tissue injury, but of course it would be unacceptable to do this if there were a corresponding risk of an increase in the more life-threatening late damage This is a very fundamental change from the sixties and seventies when skin and gut, both acutely responding tissues, were the standard normal tissues against which all therapeutic gain comparisons were made To explain this

shift in emphasis it is necessary to understand the underlying biology and the predictability of responses in the different tissues at risk The following sections are provided as a summary of the relevant areas of research for the clinical trials at present in progress, or about to be initiated

In the seventies and eighties a great deal of effort was put into studies of the aetiology of injury in tissues with different patterns of cell turnover and cell renewal potential, with a distinction being drawn between the epithelial tissues with high turnover rates and the more structured deep organs in which cell turnover is normally minimal (3) A distinction was made between hierarchical and flexible tissues, in which the fundamental difference is that in one the proliferating and differentiated cells are visibly and functionally distinct, whereas in the other individual cells can either function as proliferating or as differentiated elements, as the occasion demands This distinction separates most of the epithelial tissues, which are hierarchical from the structural and connective tissues which are flexible, but it does not separate acute and late responding tissues completely since some epithelia have very slow turnover of their structured cell layers e g bladder The cell kinetic characteristics influence the homeostatic response to any injury, including radiation, and particularly to fractionation, both in terms of overall time and the size of individual dose fractions (3, 24)

Hyperfractionation, using more than the usual 30-35 fractions, with an appropriate reduction of fraction size below 2 Gy is associated with a lower protection of tumour cells by hypoxia (14) and also gives a disproportionate sparing of damage as the dose is subdivided in late reacting tissues(24). It must be administered as more than one fraction per day unless the overall time is to be considerably prolonged This introduces the need to know whether prolongation of time is a good or bad thing, and the necessary time for complete repair of sublethal lesions in order to decide the interfraction interval if using more than one fraction a day At one stage it was assumed that an interval of 3-4 hours was adequate, but it is now accepted that the interval should be at least 6 hours This makes it easy to use two fractions per day, but logistically harder to use three or four With hyperfractionation higher total doses can be given, e g 80 Gy without exceeding the tolerance for late damage (8,11,15)

A contrasting approach, based on a different aspect of the radiobiological difference between acute and late responses, is to give accelerated treatments, so that the entire course of radiotherapy is given over 2-3 weeks, instead of the conventional 6-8 weeks (7) This is based on the recently acquired knowledge that only acute reactions and tumour damage are spared by protracted treatments, and that overall time has little influence on late reacting tissues, which are often the life threatening organs at risk (3)

The next phase, which is just beginning, is to combine some of these strategies into multifactorial approaches to overcome several aspects of radioresistance simultaneously, as with accelerated hyperfractionation or with the addition to this of several types of hypoxic cell sensitiser as in ARCON (4, 17) In implementing this approach ***the total dose may need to be significantly reduced***, as in the extreme case of CHART, where 54 Gy is given in 12 days instead of the usual 64-66 Gy in 6½ weeks (18) Of course it takes courage, good communication and a solid body of data from the laboratory for clinicians to sacrifice physical dose, which they can measure, for the potential benefits of increased biological effect with a different schedule

5. HYPOXIC RADIORESISTANCE

It has been known for several decades that the concentration of oxygen surrounding cells has a profound influence on their radiosensitivity (9, 21) The number of cells that are killed is, of course, the main determinant of the success of therapy, but since hypoxic cells require three times as much dose to kill them, the oxygen effect can dominate the overall effect Hypoxic cells are common in untreated solid tumours. but rarely if ever exist in normal tissues This means that the radiotherapist is starting at a disadvantage, treating radioresistant tumours, embedded in radiosensitive, normal structures Hypoxic stains have recently been developed that allow the demonstration and quantitation of these cells (10) The important question now is not whether hypoxic cells exist, (they do), but whether they ***persist*** throughout a course of therapy

Many studies have shown that there are two separate mechanisms that can lead to hypoxic resistance The first type results from cells being pushed so far away from the capillaries that they are beyond the

diffusion range for oxygen in a respiring tissue (21) These cells will die of their hypoxia if they are not rescued However the process of initiating therapy can anomalously rescue these cells e g by x-rays killing some of those closest to the vessel and hence allowing the oxygen to diffuse to more distant cells The new vessel network in tumours is inadequate, and the inter-capillary distances are large enough for this form of hypoxia to be common in many solid tumours, in contrast to all normal tissues The structure of a central vessel, surrounded by a cuff of tumour cells, 6-9 cells wide (about 150μm), and bounded by necrotic (dead) tissue is a common microscopic pattern repeated throughout the tumour mass The central capillary in each cord is the only source of oxygen and other nutrients, and there is no reserve or collateral circulation , which is a common feature of normal tissues This corded micro-architecture is not to be confused with the cruder and less accurate concept of a dead 'centre' to a tumour, surrounded by a rim of 1-2 cm of viable tumour That macro-architecture may eventually develop, superimposed on the microscopic arrangement, as individual vessels looping into the tumour structure become so long that they are completely depleted of all nutrient, and then all the dependent cells die

A second mechanism of hypoxia has more recently been highlighted, resulting from transient closure of individual vessels, which renders all the cells around such a vessel temporarily hypoxic The reasons and the timescale of this intermittent opening and closing is at present poorly understood The periods of obstruction may last minutes, or an hour or two It may be caused by intermittent oedema resulting from small changes in the intravascular pressure, because the intravascular to extravascular pressure differential that exists in normal tissues is lost in tumours due to the lack of lymphatic drainage Alternatively, it may be the result of abnormal stickiness of the endothelial cells leading to blockage of the narrow vessels by aggregates of leukocytes which subsequently break loose and are flushed through (4) Tumour cells can only tolerate a few hours of complete oxygen deprivation (5-12 hours in mice) before they die an ischaemic death Thus no single cell is likely to exist in the state of hypoxia that confers radioresistance from the start to the end of a course of fractionated radiotherapy Therefore it is important to gain an understanding of the dynamic processes that determine how the fraction of resistant hypoxic cells changes as treatment progresses, i e their loss and replacement

6. OVERCOMING THE TUMOUR RADIORESISTANCE.

The first form of 'diffusion-limited' hypoxia can be overcome by increasing the oxygen transported in the blood, or by providing non-metabolisable substitutes for oxygen that mimic its electron affinic characteristic Nimorazole (a nitro-imidazole) and gaseous mixtures with increased oxygen tensions (e g Carbogen containing 95% oxygen and 5% CO2)are currently being tested in the clinic For the perfusion limited hypoxia it is necessary to use something that reduces the cyclic closing of vessels Large doses of the vitamin supplement Nicotinamide have been shown to achieve radiosensitisation in mice by this means (12, 16, 17), When two approaches are combined. in the form of nicotinamide and carbogen, overcoming both forms of hypoxia at the same time, a very large benefit is seen even with the small repeated doses of radiation simulating a course of radiotherapy (17)

New techniques, some of which can already be used in the clinic, are available to monitor the flow of blood through tissue, either at the gross level of arterial and venous flow, or at the microvessel level These include isotope tracer techniques and physical measures e g with laser Doppler flow There are also microelectrode methods of monitoring the levels of oxygenation in tumours. and novel compounds that are metabolised into bound products only in low oxygen tensions, which can be used to determine the fraction of cells in a tumour that are below the critical oxygen tensions (10) Some of these techniques have already been adopted in certain experimental studies in patients. whereas others are still too invasive or have not yet been proven to be sufficiently non-toxic

The initial excitement with both hyperbaric oxygen and the chemical sensitisers like misonidazole, was based on the false premise that the large dose modifying factors seen in culture or in single dose studies in mouse tumours, corresponding to an effective dose increase of 100-200% would be achieved in the clinic The animal data had already shown in the early to mid seventies that much of this effect was lost with fractionation, because of reoxygenation, and the likely gain in the clinic was only 2-20% in dose equivalents, depending on the characteristics of the individual tumours (5).

7. UTILISING TUMOUR HYPOXIA TO ADVANTAGE

When the radiosensiters like Flagyl and Misonidazole were originally developed, their mechanism of action was postulated to be as chemical substitutes for oxygen, which could diffuse through tumours because they were not metabolised, and act as electron acceptors at the site and at the time of the ionisations produced by X or gamma rays They were believed to have a purely chemical function with no biochemical or physiological involvement However they were then shown to have two other mechanisms by which the cytotoxic effect of the combined therapy might be influenced, bio-reduction to a toxic metabolite and vasoactivity causing the tumour blood vessels to shut down Each of these activities could cause extensive cell kill within tumours, which could have been confused with, and interpreted as, chemical sensitisation in the initial studies These effects only occur at high dose levels, e g 500-1000 mg/kg and are therefore unlikely to give the same effect in man where 10-fold lower doses were used in the disappointing clinical trials

This illustrates again how great care must be taken in translating from the laboratory to the clinic It is worth noting, in passing, that these findings have contributed to two completely new approaches to tumour therapy The first, bioreductive drug development has already led to the synthesis of analogues of Misonidazole that have a much greater potential for conversion from an inactive prodrug to a toxic product, only at extremely low oxygen tensions If oxygen is present the process is reversible and a futile cycle results Thus the toxin is only produced in the radioresistant hypoxic cells within tumours, and it does not diffuse to adjacent well oxygenated tissues (20). The second field, vascular targeting, develops the concept of specifically occluding tumour capillaries for a period of several hours, by which time the dependent cells will have succumbed to an anoxic death (4) It is now known that a very large number of the novel agents being considered for cancer therapy, e g hyperthermia, cytokines, and photodynamic therapy, have this action in mice at the doses used in the preclinical evaluation on which the current trials are based This activity is markedly influenced by the scheduling of the agent and the present clinical trials may be disappointing because this supplementary mode of action has not been considered in the trial designs (4). Both of these fields seek to capitalise on the intrinsic poor blood vessels in tumours and to use the existing, or an enhanced level of hypoxia as a weapon against the tumour

8. CELL PROLIFERATION PATTERNS

Proliferation characteristics of tumours and normal tissues have been measured for decades, using techniques developed by radiobiologists (13) The original techniques were very labour intensive and slow, involving labelling the animal with the radio-isotope tritiated thymidine and then making autoradiographs by exposing sections of tissue for several weeks to photographic emulsion and scoring the results under a microscope They could not be used in man because of the slow timescale and the risk of administering DNA seeking radio-isotopes The animal studies showed that in most solid tumours the cells were dividing rapidly, often every 12-24 hours Often there were many cells not actively engaged in proliferation, either because of residual characteristic differentiation, or more commonly because of inadequate nutrition The overall rate of expansion of the cell population was slower than the cell cycle time, and could be expressed as the potential doubling time, Tpot The overall growth rate of the tumour, determined as a volume doubling time, was usually 5-10 times slower than Tpot because many cells were lost, presumably due to starvation as a result of the inadequate blood vessels (3, 4, 19)

In normal tissues there is also extensive cell loss, with one cell being lost for every new cell that is born Indeed it is the precise balance between cell production and loss that is a characteristic of normal tissues and which distinguishes them from tumours, rather than the actual rate of cell production itself The reason for the cell loss in normal tissues has to do with the functional 'wear and tear' on that tissue Cell turnover is very rapid in the epithelial tissues which act as a barrier in relation to the environment In the intestine, the epithelial cells have a cell cycle time of about 8-12 hours, i e as short as any tumour cells In stark contrast the rate of cell replacement in some of the deep organs and

epithelial structures, such as bladder, heart, lung or liver is exceedingly slow and it is extremely difficult to detect any cells in these tissues that are actively dividing (in mitosis) or even in the act of preparing to divide (in the DNA synthesis phase)

9. LATENCY OF NORMAL TISSUE INJURY

Radiobiologists have long been aware that the damage inflicted by ionising radiation is expressed at the time the cell attempts to divide At first it was thought that non-dividing cells were unresponsive to radiation But now it is recognised that it is simply a question of the timescale over which the response is expressed Rapidly proliferating tissues can express their radiation injury within hours or days They can also attempt to compensate for cell depletion with equal rapidity, and certainly within the duration of a normal course of radiotherapy (3)

As the normal wear and tear processes lead to cell loss and the irradiated cells cannot undergo successful divisions to replace them, the tissue becomes depleted of cells Thus depletion is more dependent on the failure of irradiated cells to provide offspring at a later division than it is on cell destruction caused directly by the radiation and for this reason the damage is expressed at different rates in different organs, according to their normal rate of cell turnover This ranges from less than a day in the intestine to more than a year in many of the deep tissues Each tissue is capable of a compensatory acceleration of cell production to repair such a deficit, and if the depletion has not been too severe it may not even be possible to detect the injury because the cells are replaced before tissue dysfunction occurs Skin seems to be capable of functioning quite normally even if 99 9% of the cells are destroyed, whereas other tissues show detectable malfunction after lower levels of depletion If the cell kill is excessive, or introduced too quickly (depending on the rate of dose delivery) there may be a permanent failure of tissue function, leading to long term ulceration or necrosis The importance of this will vary from one tissue to another, but of course it is always undesirable

In slowly proliferating tissues the damage can be latent for many months, or even years, since the constituent cells rarely attempt division, and radiation damage does little to influence the differentiated function of cells It will however be expressed when normal wear and tear occurs, or if any additional injury or trauma to the tissue makes a demand for cell replacement which the irradiated cells cannot fulfil This latent injury in tissues means that these slow turnover tissues do not attempt to accelerate cell production **during** a course of radiotherapy, unlike the intestinal or buccal mucosa and skin (3) They also appear to have a different pattern of recognising and repairing DNA lesions, which leads to a greater sparing effect of subdividing the radiotherapy into smaller and smaller fractions This is now expressed in terms of the linear quadratic equation as the α/β ratio, and is the main rationale for the use of hyperfractionation (8, 23) Smaller doses spare the late reactions, but do not spare the acute reactions or the tumour damage However the effect of unhealed acute reactions leading to consequential and permanent late effects if the acute reactions are too severe must always be borne in mind as a possible complication

10. TECHNIQUES IN CELL KINETICS

In the last decades revolutionary new techniques have been developed which makes it possible at last to rapidly measure the cell kinetic characteristics of human tumours They depended upon the development of sophisticated machines to measure the level of fluorescence in individual cells (flow cytometers) and the technology of monoclonal antibodies Precursors of DNA which contain halogens such as Bromine or Iodine as substitutes for methyl groups have been developed, which the cell will incorporate as if they were thymidine e g Bromo-deoxyuridine. BUdR and Iodo-deoxyuridine, IUdR They are not radioactive, can be used at very low tracer doses of 250-500 mg, which do not interfere with cellular functions and are not mutagenic The DNA that has the incorporated halogen can be detected with a monoclonal antibody, and the labelled cells can either be viewed directly under the microscope to determine the architectural arrangement of proliferation, or their frequency can be quantified with the laser beam of a flow cytometer If necessary, an answer could now be provided on an individual biopsy within 24 hours, and the limitation now is simply of manpower, not of technology

A significant step forward in the clinical application of cell kinetic techniques in man came with the development by Begg et al of the 'relative movement assay' in 1985 (1) This allows the simultaneous measurement of the fraction of cells engaged in synthesising new DNA ***and*** the duration of the DNA synthetic phase These two parameters together allow the calculation of the potential doubling time, i e the rate of cell production, taking into account both those cells actively engaged in cell proliferation and those that are quiescent The difference between this potential doubling time and the observed volume doubling time is a measure of the extent of natural cell loss in the microenvironmental conditions within an untreated tumour It is easy now to study the proliferation characteristics of a tumour before treatment It is however much harder to interpret the results from this technique for tumours during the course of therapy, because at present there are no methods available to distinguish between the cells which are doomed to die but still look viable and those that are potential clonogenic survivors

This technique has already been used for the measurement of cell production and loss for several thousand human tumours over the last decade These measurements have shown that human tumours have cell production rates very similar to those in mice, in spite of having volume doubling times 10-100 times longer The median Tpot values for all the cells (both tumour and stroma) in a solid tumour are 4-6 days for most tumour types, if measured with the flow cytometer (23) The much slower volume doubling times of months is due to extensive cell loss, amounting to 90-99% of the cells that are born

The data are startling and have led to an increased interest in methods of accelerating the delivery of the whole of a course of therapy However, even these very short potential doubling times may be underestimates, because of the contaminating effect of the non-dividing normal cells within the tumour biopsy If the flow cytometer measurements are combined with a second antibody to distinguish tumour cells from stromal cells, e g cytokeratin stains, or immunohistochemistry to visually scan histological preparations, the tumour cells can now be separated from the normal cell components within the tumour mass The Tpot measurement for the tumour cells alone are even shorter, averaging 2-3 days for many tumour types, with highly labelled 'hot spots' in many tumours in which the Tpot is only 1-1 5 days (6, 23) At this point it is not clear which of these Tpot values is the relevant one, but they are all much shorter than most therapists had believed

Since cell production within tumours is now shown to be so very rapid, it becomes important to question how many additional cells are being produced during the 6-7 weeks of a conventional course of therapy The conventional regimes, involving slow treatment over many weeks, were based on the external observations that tumour doubling times were months, and without the modern knowledge of the underlying explosive cell turnover Would radiotherapy be more effective if it was given in a much shorter timescale, and would all tumours benefit from such an accelerated regime, or only those with pre-treatment Tpot values that are below the median? This depends on whether the rate of cell regeneration after treatment is initiated is determined by the ***cell*** production rate, or by the pre-treatment ***volume*** doubling rate

To answer this question, one must consider whether, and how quickly, the pre-treatment balance between cell production and cell loss is altered If the cell loss is the result of starvation as cells are pushed away from blood vessels, the reversal of that process may be rapid, occurring within hours to days as cells close to the blood vessels die, allowing oxygen to diffuse to more distant cells If, however, it results from residual differentiation it is unlikely to be altered by the initiation of radiotherapy This is a topic that is hotly debated at all sessions on accelerated fractionation at the moment and requires new techniques to distinguish the mode of cell death before it can be resolved

11. ACCELERATED REGIMES

A number of radically different radiotherapy schedules are currently being tested in clinical trials, with the aim of shortening the overall treatment time These are summarised in the papers by Fowler (8) and by Saunders and Dische (7, 18) Most of these trials were initiated before the large body of data on the cell kinetics of human tumours were available Sometimes an acceleration of just a week or two is achieved by giving two fractions only on some treatment days, as in the concomitant boost trial In

others, 2 or 3 fractions are given each day, thereby achieving an even greater shortening of the schedule It is difficult to administer the same total dose in these twice or thrice daily regimes, and some trials have therefore incorporated a short break or rest period, as in the EORTC trial (11), even though this is anathema to any 'mouse radiotherapist'! Others have considerably reduced the total dose in the belief that the biological gain outweighs the loss in physical dose (18) The most extreme example of this approach is CHART, pioneered at Mt Vernon Hospital in collaboration with the Gray Laboratory In this regime of Continuous Hyperfractionated Accelerated Radiation Therapy, 36 fractions, each of 1 5 Gy, are given three times a day, with a minimum interval of 6 hours The whole treatment is complete in one third of the normal time (54 Gy in 12 days instead of 66 Gy in 6½ weeks) In spite of the reduction of the total dose by 20% the results from the initial non-randomised trials in head and neck tumours, and in lung cancer were very promising Two large randomised, multi-centre trials are still in progress (7) The trials have now closed to accrual (April 1995) and the results of the first evaluation will be presented at the BOA Meeting in York in July 1995 These data show a highly significant increase in both local control and survival in bronchial carcinoma, and a significant increase in local control of a subset of head and neck tumours, which does not, however,translate into an increase in survival (Saunders personal communication)

Within the CHART studies and the other accelerated regimes currently being studied in many centres world-wide, it is hoped that the tumour Tpot values can be analysed, in order to see whether accelerated regimes might benefit all patients or only the subset with the fastest growing tumours At this point it is impossible to predict whether all patients would benefit That depends upon the changes that occur in the cell kinetics once treatment has commenced and the nutrient supply has improved to the cells that were initially starving to death, and to those that are prevented from cycling by their nutrient deprivation The pre-treatment Tpot values have highlighted the potential for extremely rapid tumour cell regeneration, but have not yet proven that such proliferation is limiting treatment success with conventional 6-7 week schedules The randomised CHART trial data take us closer to confirming that the detriment of prolongation shown in the analyses by Fowler (10-15% loss in local control per week if treatments are prolonged beyond 7 weeks) may also translate into a corresponding gain if treatments are shortened below 7 weeks Certainly the 20% reduction in dose with the CHART regime could only lead to a benefit if this dose, (at least), is normally wasted in counteracting the detrimental tumour proliferation that is possible during the conventional longer schedules

12. MULTIFACTORIAL APPROACHES

The most recent interactions at the interface between the radiobiology lab and the clinic have been in an attempt to combine the concepts of acceleration, hyperfractionation to spare late normal tissue damage, and sensitisers of both diffusion- and perfusion- limited hypoxic cells (17) These concepts have been brought together under the acronym ARCON, which stands for Accelerated Radiotherapy with Carbon dioxide, Oxygen and Nicotinamide Two workshops have recently been held on this concept at the Gray Laboratory Many individual centres are investigating the clinical potential and four multicentre EORTC trials have been initiated A variety of accelerated regimes are being used, usually with multiple fractions per day Large daily doses of about 6 grams of Nicotinamide are given and the patients breathe 95% oxygen and 5% CO2 for a few minutes before and during each treatment These protocols are based on the experimental studies using clinically relevant fractionation schedules in mice of Rojas and her co-workers at the Gray Laboratory, including studies of 30 fractions in 6 weeks (conventional) and 36 fractions in 12 days (CHART)(17) These followed on the extensive single dose studies of Horsman et al(12) Rojas et al have shown a much larger and more consistent therapeutic gain from this ARCON combination at clinically relevant dose levels than anything else that has ever been studied as an adjunct to radiotherapy

However caution is again appropriate The more recent approaches try to take advantage of the sparing of late reactions with hyperfractionation and avoid tumour cell proliferation with shorter schedules. and overcome the two different versions of hypoxia Somewhat surprisingly, the combination of carbogen and nicotinamide does not show the loss of therapeutic effectiveness with fractionation that is predicted for reoxygenating tumours (5) This means that it is necessary to question whether the observed

benefits are simply due to overcoming the hypoxic radioresistance, or whether there is also a contribution from another, as yet unidentified mechanism e g oxygen toxicity as in reperfusion injury

The animal studies have mostly been performed with very large doses of Nicotinamide, 500-100 mg/kg and the maximum tolerated dose with repeated fractions in man is 80 mg/kg This gives a serum level that produces some sensitisation in mouse tumours, but is below the optimum dose in mice It is always a problem to know if doses in mice should be extrapolated to man on a weight basis or on a surface area basis because of the difference in the metabolic rates If it is simply the drug level at the time of irradiation that is important for influencing the transient hypoxia, the plasma levels should be predictive However the very large effect with fractionated treatments cannot be explained by this alone, and we do not know whether the extra benefit results from prolonged exposure (AUC) or from the peak concentrations Thus further laboratory studies on mechanism are needed to explain the unexpectedly high gains in the fractionated schedules This is a perfect example of the need for continuous dialogue between clinicians, preclinical and basic scientists

13. DOSE AT THE TARGET

Radiobiologists have for years focused on the concept of dose, both in gross terms and at the subcellular chromosomal level They have always been concerned to know the dose that is delivered to the target volume and the micro-environmental factors within each cell that influence that doses' effectiveness It is, however, at the gross level of dose delivered to the whole target, the tumour and the surrounding normal tissue, that radiobiology most obviously interacts at present with radiation physics and the quality assurance programmes in dose delivery Clearly every time a margin is added to the tumour boundary, to diminish the possibility of a geographic miss, the amount of normal tissue exposed to the full dose is increased in a way that is not obvious from the simple statement of a 10 or 20 mm addition margin to the field This apparently small change could correspond to a 30 fold increase in the volume of normal tissue irradiated with small tumours or the addition of litres of additional normal tissue with larger fields (A 2 cm diameter tumour corresponds to a sphere of 5 4 ml but with a 20 mm margin the sphere expands to 144 ml For a 6 cm or a 10 cm tumour the corresponding figures are 144 and 670 ml and 670 and 1840 ml) The added volume of normal tissue is larger in absolute terms for the larger tumours, but a smaller increase in relative terms

The consequence of this increase in the fraction of an organ that is irradiated is generally believed to be very serious, though it is very hard to quantify from studies in small rodents There is a clear need to find techniques that minimise movement and positioning artefacts in order to keep the normal tissue involvement to a minimum while guaranteeing no geographic misses The many physics quality assurance programmes that are now developing in academic centres which are involved in randomised trials will undoubtedly lead to optimisation, and will ultimately contribute to better general practice throughout Oncology departments in the future

However, we should consider the tolerance levels that are being set as the targets in these 'best studies', in the light of the biological gains that can be expected from the new schedules that are being tested in these clinical trials The predicted benefits from moderate hyperfractionation, a 1-3 week shortening in radiotherapy schedules or from the use of an hypoxic cell sensitiser with fractionated radiotherapy are in the range of 5-15% in dose equivalents, and a great deal of effort is being expended to achieve these gains A variation in dose of ±5% is currently regarded as ***a minor deviation*** in a trial protocol and such patients will be analysed as if they had all received the prescribed dose Because of the sigmoid shape of the dose response curves a 10% increase in dose effectiveness could translate into a much larger increase in local control The logical conclusion then must be that a ±5% deviation is not minor! Furthermore one could gain far more information from trial data if the data are analysed according to the dose each individual tumour actually received, rather than pooling the data to the arbitrary original prescribed value, especially when there is known to be a wide (at least 10%) spread in the dose delivered

In almost every trial designed over the last 20 years there has been great resistance from the oncologists to deliberately build in a dose variation of ± 3% or 5% in order to bracket the likely dose in the new (unknown) treatment arm that should give equal tumour and normal tissue damage It transpires that at least that dose variation is present in any well controlled and documented trial, even with good quality assurance I would urge the trial co-ordinators and analysts to recognise this as a potential golden of information Disregarding the spread may ensure that the small but important biological gains that are being sought will be missed because they are of the same order as the error spread in dose delivery that is considered as acceptable quality control Thus the data from any such studies should be analysed according to the treatment actually received by each patient, and not according to the prescription dose, or even more irrationally according to the arm to which they were randomly allocated, regardless of what treatment they actually received!

14. SUMMARY

This manuscript discusses the biological basis of new treatment strategies that are being introduced into the clinic in the form of controlled clinical trials There is an increasing awareness of the need for quality assurance in the design, execution and analysis of these trials However there is little awareness of the need to critically assess the biological basis of the trial design, to ensure that no other biological principles have been contravened in the attempt to optimise just one of the many parameters that determine the differential in sensitivity between tumours and normal tissues Some examples are given of the changes that have recently occurred in the laboratory interpretation of both the mechanism of action and the therapeutic gain of several novel approaches If these are not considered, the carefully controlled clinical trials may be wasted, because of being based on an incomplete consideration of all the interconnected biological factors

The challenge, as always, is to find ways of crossing the communication boundaries between fields, and of moving forward in a spirit of co-operation and collaboration, rather than the competitive spirit that decreasing resource pools can engender Only in that way is the current generation of cancer sufferers likely to get the benefit from the billions of pounds that have already been invested in basic and applied cancer research, and in the sophisticated technologies now available to identify the tumour margins and to deliver the dose with great accuracy to the chosen volumes The fractionation schedule over which that dose will be administered, or the associated combinations of therapy must also be reassessed with vigour to ensure that great care is not being taken to ensure good quality control of trials which are ill conceived in the first instance Good quality control of the details of the implementation of new concepts is every bit as important as the accurate delivery of treatment, but this is almost never discussed openly

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IMPLEMENTATION OF THE QA PROGRAMMES AT THE NATIONAL LEVEL

XA9846646

RADIOTHERAPY PHYSICS QUALITY AUDIT NETWORKS IN THE USA

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Abstract

Two programs within the Section of Outreach Physics, Department of Radiation Physics, The University of Texas M.D. Anderson Cancer Center, provide quality assurance and quality audit to 1240 radiotherapy facilities, 80% of all facilities in the USA and Canada. These programs have been in existence since 1968. The backbone of both programs is a routine postal TLD program for both photon and electron beams. Discrepancies identified by the TLD are resolved by phone conversations with the participating physicists, follow-up TLD and, if necessary, an on-site review of the facility by one of our physicists with a portable dosimetry system.

The Radiological Physics Center (RPC) program has additional quality audit activities including periodic on-site review of the participating facilities, regardless of the postal TLD results, to verify the quality of the dosimetry data used clinically. The on-site visit includes a review of basic data such as output factors, depth dose data, off-axis factors, etc., to verify the institution's data and its consistency with other machines of the same make and model. To assess the quality of treatment planning, the local physicist is asked to plan the treatment for typical "benchmark" test cases, with data and methods which are used clinically. At each step of the dosimetry process, the reviewing physicist and the local physicist work together to resolve any results which seem to be discrepant.

One program, Radiation Dosimetry Services (RDS), is a voluntary service-for-a-fee program dealing with highly motivated and cooperative physicists. The cost is reasonable and the user chooses the frequency of the TLD, usually monthly, quarterly or semi-annually. The other program, The Radiological Physics Center (RPC), is sponsored by the USA National Cancer Institute to monitor all institutions providing megavoltage therapy to patients on cooperative clinical trials, so participation is mandatory. The results of these two programs will be presented, and the implications of the different motivations for participation in the two programs will be discussed.

2. INTRODUCTION

The Section of Outreach Physics, Radiation Physics Department, The University of Texas M.D. Anderson Cancer Center (UTMDACC) has been involved in remote monitoring of radiation dosimetry since the late 1960s. There are presently two programs active in remote quality monitoring: Radiation Dosimetry Services (RDS) with Marilyn Stovall, Director, and the Radiological Physics Center (RPC) with W. F. Hanson, Director. RDS is a fee-for-service program in which institutions participate voluntarily. Their major service is a mailed TLD program to which users subscribe on a monthly, quarterly, semiannual, or

irregular basis The RPC is a program funded by the U S. National Cancer Institute (NCI) Participation is compulsory for all megavoltage radiation therapy facilities that participate in cooperative clinical trials funded by the NCI The RPC services are more comprehensive, involving mailed TLD, on-site measurements by physicists, review of treatment planning techniques, and educational efforts The two programs provide some service to 1240 radiotherapy facilities, 80% of all megavoltage facilities in the U S A and Canada

The American College of Radiology also has a program which reviews the entire radiotherapy department or reviews only radiotherapy physics These programs also could be considered part of a service network In the USA we also have several programs that are regulatory rather than service in nature; including the Nuclear Regulatory Commission (NRC) and the Joint Commission for Accreditation of Hospital Organizations (JCAHO) I am qualified to discuss only the RPC and RDS programs However, I will begin this presentation with a discussion of philosophy, drawing a clear line between the regulatory agencies and service programs I will then discuss the RPC and RDS networks in some detail

3 PHILOSOPHY

The quality of patient care should be, first and foremost, the interest and concern of the individual institution Positive motivation for quality care can come from humanitarian or ethical considerations to provide quality care or to meet some community standard Participation in a quality network may be to verify that one meets this standard The desire to participate in cooperative trials is a motivation that has been used effectively in the U S A., Canada, Europe, and in Latin America to a limited extent Outreach Physics finds that many physicists like our programs because of the supportive nature of our activities, particularly when a problem develops We are always accessible by phone, if we don't know the answer, we can usually direct people to someone who does know Negative motivation can be provided by regulations, accreditation, codes of practice, and concern over litigation I consider these later motivations to be grossly inferior to the former The ruling philosophy of the UTMDACC Outreach Physics Network is positive motivation

Various steps in the quality process have been defined I would like to define them as I understand them, again to emphasize my philosophy **Quality control** procedures are established by the institution to ensure that the patient treatment is correct, these includes activities such as preventive maintenance, in-service training, etc **Quality assurance** measurements are taken by the institution to verify that the controls in place are in fact working, these include output checks on machines, etc **Quality audit** independent evaluation is done by the institution itself or by an outside entity to verify that the total treatment meets a local, national, or global standard

I would also like to discuss a "Network" that goes beyond mere quality audit This network should provide a **resource** to individual institutions to assist them in the implementation of their quality assurance In order to optimize the benefits, personnel in the network should be involved in the practice of radiotherapy The network should include some remote monitoring and professionals from the network might even visit the institution to assess how it implements its quality assurance and quality audit programs The network should provide follow-up which includes recommendations based on the visit, resolution of perceived or real discrepancies identified by the remote monitoring, and closing the loop by repeat remote monitoring to verify that changes actually improve the situation Most

important, all of the activities of the network should have a strong component of education and training. It is the expressed intent of the UTMDACC Outreach Physics Section to help every institution find solutions to any problems so that they can meet or exceed the criteria for acceptable performance.

4. THE NETWORK(S)

Radiation Dosimetry Services (RDS) is a limited network, providing postal dosimeters with feedback to resolve discrepancies. The service is voluntary and the motivation of most participants is to assure themselves that they are providing quality calibrations. The Radiological Physics Center is a more comprehensive network. The activities include on-site measurements at the participating institutions, mailed TLD as a periodic monitor of the machine output, and review of reference cases and individual patient treatment records to verify patient dosimetry practices. During all of these activities, we pursue any discovered discrepancies, helping the institution to identify the origin of the problem, and helping the institution to develop a solution that meets the needs and procedures of the institution. Our physicists are also available, by phone, to respond to any questions on machine calibration, quality assurance procedures, or patient dose calculations. The motivating force for institutions monitored by the RPC is their desire to participate in cooperative clinical trials.

4.1 Dosimetry Review Visits

Over the 25 years that the RPC has been in existence, nearly 1150 dosimetry review visits have been made to 560 radiotherapy facilities. Table 1 lists the activities during a dosimetry review visit. The RPC physicist interviews the radiation oncologist and physicist to determine treatment and dosimetry techniques. After patient treatment is completed for the day, physical measurements on the therapy units are made, and brachytherapy sources are measured at a convenient time. We evaluate the treatment planning process through the use of benchmark cases and by reviewing the records of patients under treatment. Our physicist conducts an exit interview with the physicist and the radiation oncologist to discuss the findings of the visit and proposed modifications in their dosimetry and/or quality assurance program. At every step during this process, we make every effort to educate and train physics and dosimetry personnel

Table 1. Activities During a Dosimetry Review Visit

- Discuss practices with the radiation oncologist and physicist
- Measure radiation parameters on therapy units
- Calibrate brachytherapy sources
- Review benchmark cases and actual patient treatments
- Conduct exit interview with oncologist and physicist

The measurements made are listed in Table 2 All measurements are made in the presence of the institution's physicist and results are determined on the spot This approach allows any discrepancies with the institution to be investigated and resolved immediately

Table 2: Measurements Made During a Dosimetry Review Visit

Ionization measurements
- verification of chamber factor
- calibration as a function of field size
- relative depth dose
- wedge and tray transmission
- off-axis factors
- verification of inverse square law
- calibration of brachytherapy sources

Mechanical Measurements
- light and radiation field alignment
- distance indicator
- field size
- isocenter

Today, the mean ratio of the calibration absorbed dose determined by the RPC to that measured by the institution, is very near 1.00 with a standard deviation of about 2% (see Figure 1). The distribution is essentially Gaussian. Figure 2 shows the number of beams within our calibration criteria as a function of time. We see that in 1970 about 70% of all beams were inside our criteria while today nearly 98% of photons and 95% of electron beams are within our criteria. Also plotted in Figure 2 are the results of our chamber factor intercomparisons. The increase in reliability of beam calibration correlates well with the increase in reliability of chamber factors (increased from 70% in compliance in the mid 1970s to more than 95% today). The increase in reliability of chamber factors correlates well with increased usage of secondary standards laboratories, known in the U.S.A. as Accredited Dosimetry Calibration Laboratories (ADCL). In the 1970s, approximately 100 dosimeters were calibrated per year by the ADCLs while today in excess of 1,000 dosimeters are calibrated annually.

Since the RPC review is comprehensive, for more than 90% of institutions, we have at least one recommendation for the institution to improve its procedures. It also is possible to combine discrepancies in various parameters to yield a worst case scenario. For more than 25% of the institutions visited, we find at least one worst case which represents a clinical situation in which the patient could receive a dose different than intended by more than 5%. So although calibration results are very good, our on-site review does improve the quality of dosimetry at the majority of the institutions visited.

The postal TLD program is the mainstay of both the RPC and RDS networks. The RPC provides TLD approximately twice per year while the RDS customers purchase service on a monthly, quarterly, or semiannual basis. The two programs presently monitor in excess of 3000 therapy units, evaluating approximately 5950 photon beams and 5800 electron beams in 1994. For photons, the TLD verifies only output for the standard field; for electrons, the TLD verifies both output near d_{max} and depth dose at one depth between d_{80} and d_{20}. We consider the efforts we make to resolve discrepancies to be a crucial component of the postal TLD system. If the dose measured by the TLD differs from that reported by the institution by more than 5%, this is considered an apparent discrepancy and we pursue the cause. We review the institution's submitted data and compare it with previous TLD from the institution. Next, a phone call is made to the institution's physicist to discuss dosimetry practice, TLD set-up, and protocol calculations. Repeat TLD are sent to verify changes in dosimetry or to verify

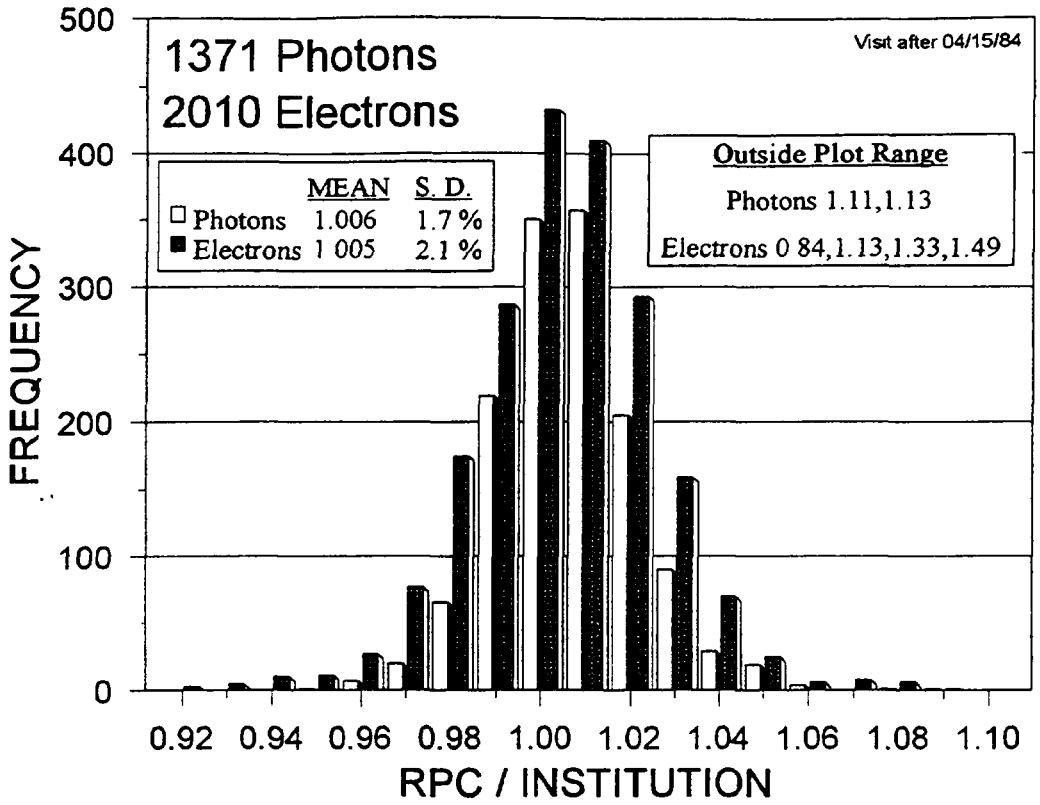

Figure 1: Histogram of the absorbed dose measured by the RPC, for the reference geometry, versus that used clinically by the institution. Results are presented from all on-site dosimetry reviews for both electrons and photons since April 1984.

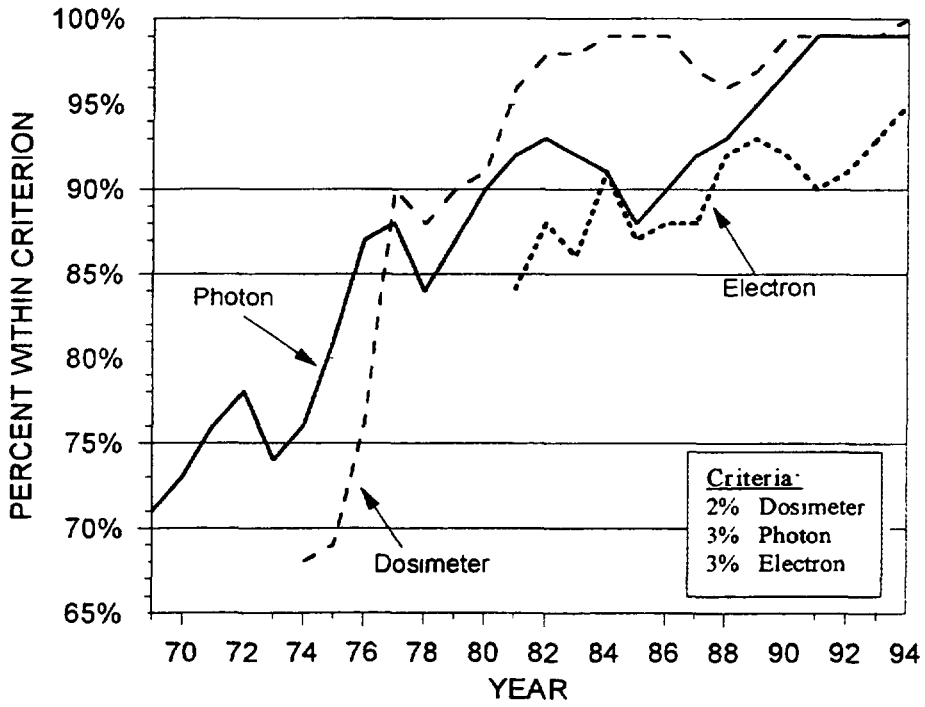

Figure 2: The results of dosimeter intercomparisons and beam calibration, performed during on-site dosimetry visits, expressed as the percent within the RPC criteria, as a function of time.

4.2 Mailed TLD

the TLD results. If the repeat TLD also are outside the criteria and still no explanation can be found, a physicist makes an on-site dosimetry review to identify the discrepancy using ion chamber measurements. Approximately 5% of all TLD checks are outside the ±5% criterion, however, most discrepancies are resolved by phone, FAX, or mail. Four to six institutions per year require a visit by a physicist because of discrepancies which cannot be resolved by phone or FAX.

The TLD programs are designed to identify problems at the 5% level. However, particularly with the voluntary RDS program, when output checks by TLD are done on a monthly or quarterly basis, changes in the institution's dosimetry of 3% have been flagged by the TLD program and a discrepancy uncovered. Again, the primary rule is that our program (network - if you wish) is intended to not only discover problems at an institution, but to help the institution discover the origin of the problem and then help them solve the problem Although the bulk of our physical effort is in routine activities, the bulk of the mental effort. and certainly the most enjoyable effort, is spent identifying and helping institutions resolve dosimetry discrepancies

4 3 Standard Dosimetry Data

One of the spin-offs of our on-site dosimetry review visits is the vast amount of dosimetry data accumulated We have data measured in a consistent fashion on many similar units For more than 30 different models of therapy units, the RPC has measurements on 5 or more machines and for 20 models we have data on 10 machines or more We do not routinely search out dmax for photon beams, so our presentation of depth dose data is normalized to measurements at 5 or 7 cm depth Tables of all RPC depth dose data were generated for all units for which we had 5 or more sets of measurements The minimum, maximum, mean, standard deviation, and number of machines differing from the mean by more than 1% and 2% were generated Table 3 shows the results for the Clinac 18 for which we have more than 50 sets of data For this unit the standard deviation of the relative depth dose for all units at the 9 measurement points is less than 1%, and no beam deviated from the mean by more than 2% The Clinac 18 is one of 19 machines for which the data all show spreads of this magnitude No machine/energy combination has a standard deviation exceeding 2% In general, the relative depth dose data used clinically by multiple institutions, for a given make and model of accelerator, have a standard deviation 1 5 to 2 0 times larger than the RPC measured data Similarly, RPC measured output factors show a standard deviation which varies from less than 1 0% to a maximum of 1.5% Data for field size dependence, off-axis factors, and wedge factors have a larger spread, but we are able to identify trends

There are two benefits we derive from these data We recommend that an institution compare its measured dosimetry parameters with standard data for that make and model of therapy unit; these standard data typically are available in the literature If the measured data disagree with the standard data by more than 2%, we believe that the institution has a problem. The first suspect, in our experience, is the institution's measurement technique. The second suspect is that the therapy unit is not operating properly. The second benefit is that we can review an institution's dosimetry data, compare it with standard data, and identify potential discrepancies with the institution's clinical dosimetry data In the past 2 years, we have visited 3 institutions because of questionable dosimetry data and have verified a discrepancy in the depth dose data used clinically.

Table 3: RPC-Measured Depth Dose Characteristics for a 10 MV X-Ray Beam from the Varian Clinac 18. For each field size, the depth dose values are normalized to unity for the calibration depth (5 cm). Presented for each of the nine field size and depth combinations are the number of machines, minimum value, maximum value, mean value, standard deviation of the mean, number of machines varying by more than 2% from the mean, and number of machines varying by more than 1% from the mean

Field size (cm x cm) Depth (cm)	n	MIN	MAX	Mean	Std Dev (%)	#>2%(%)	#>1% (%)
6 X 6							
@ 10	52	0 7766	0 7916	0 7855	0 0031 (0 4)	0 (0 0)	1 (1 9)
@ 15	49	0 6031	0.6204	0.6116	0.0038 (0 6)	0 (0 0)	5 (10.2)
@ 20	38	0 4684	0.4852	0.4761	0 0038 (0 8)	0 (0 0)	8 (21 1)
10 X 10							
@ 10	69	0 7914	0 8056	0 7999	0 0027 (0 3)	0 (0 0)	1 (1 4)
@ 15	67	0 6235	0.6401	0 6326	0.0034 (0 5)	0 (0 0)	7 (9 0)
@ 20	53	0 4907	0 5082	0 4989	0 0036 (0 7)	0 (0 0)	7 (13 2)
20 X 20							
@ 10	61	0 8026	0 8248	0 8164	0 0033 (0 4)	0 (0 0)	3 (4 9)
@ 15	59	0 6517	0 6678	0 6604	0 0030 (0 5)	0 (0 0)	3 (5 1)
@ 20	43	0 5234	0 5377	0 5314	0 0029 (0 5)	0 (0 0)	4 (9 3)

4.4 Benchmark Cases and Review of Patient Dosimetry

Since the beginning, the RPC has been reviewing the radiotherapy treatment records of patients entered onto the clinical trial protocols that we monitor The dose delivered to the protocol prescription point is calculated and compared with the dose reported by the institution on the protocol reporting forms. Agreement within ±5% is considered acceptable If our calculation disagrees with the institution by more than 5%, the records are reviewed in detail to discover the origin of the discrepancy The institution is then contacted by letter or phone to discuss and correct the discrepancy.

I would like to make two observations concerning these reviews 1) We recently began a data base of dosimetry problems encountered We have identified 60 problems which resulted in dose discrepancies exceeding 5%. Half of these we identified as systematic discrepancies that impact on more than one protocol patient and probably adversely affect non-protocol patients at the institution. Thus our review has a positive effect on more than just protocol patients. 2) Our patient review efforts improve cooperative group data Table 4 is an analysis of the discrepancies noted during this treatment record review Results cover approximately 6 years of experience and include the review of, on average, 2 points of calculation on 13,500 patients Note that for 99% of the patients, the RPC and institution are able to agree, within ±5%, on the dose at the prescription point However, for about 2% of the patients, the institution changes its dose prescription as a result of our review Also note that we observe reporting errors on the prescription dose for about 7% of the patients The majority of these errors are made because the institution prescribes dose to an isodose line while the protocol calls for a point dose calculation Thus our review results in an institution's revising their calculations for perhaps 2 to 3% of the patients, however, the data available to the study groups is improved for approximately 15% of the patients (see the bottom right hand number in Table 4)

Table 4: Analysis of Discrepancies Noted During Patient Calculations for External Beam
27,562 Points of calculation, 13,552 Patients

	PER CALCULATION POINT		PER PATIENT (13,552)
	(27,562) All Sites	(21,372) Prescription Sites	
Dose revised by institution	515 1.9%	319 1.5%	363 2.7%
Reporting error in dose, corrected by RPC	1919 7.0%	1490 7.0%	1415 10.4%
Disagreement in dose >5% unresolved	420 1.5%	**154** **0.7%**	320 2.4%
Any of above	2747 10.0%	1902 8.9%	**1968** **14.5%**

More recently, the RPC has been asking institutions to calculate the monitor setting necessary to deliver a given dose to 4 "typical treatments" or benchmark cases. These include a parallel opposed total brain treatment, a wedged pair (head tumor), a tangential breast treatment and an AP-PA lung treatment, including the supraclavicular nodes. For the lung case, we ask for calculations on the central axis and at 2 off-axis points, the lower mediastinum and the supraclavicular node point. In our review of the benchmark cases, we use the hard-copy dosimetry data that the institution has for its therapy beam. We use our own measured off-axis data for that unit and our own estimate of off-axis energy changes.

Our review therefore verifies principally that the institution is consistent in the use of their own data. The results are listed in Table 5. We see from the table that for all central axis calculations, discrepancies exceeding 5% occur only 1% of the time; if we tighten the criteria to 3% agreement, discrepancies occur about 5% of the time. The off-axis calculations, however, show a much different picture. In this case, nearly 30% disagree with the RPC at the 3% level and more than 10% disagree at the 5% level. Our experience is that these discrepancies are due to the fact that the physicist does not understand the dose computation algorithm in the treatment planning computer, and is using it incorrectly. Frequently, inappropriate input data are used.

Table 5: Results of RPC Review of Benchmark Radiation Treatment Calculations

Treatment	Calculation Point	Number of Cases	Number of Discrepancies > 5%	> 3%
Parallel-opposed whole brain	Midplane, central axis	458	4 (0.9%)	21 (4.6%)
Wedged head	Intersection of axes	454	7 (1.5%)	15 (3.3%)
Tangential breast	NSABP*	115	2 (1.7%)	6 (5.2%)
AP-PA lung	Central axis	434	4 (0.9%)	21 (4.8%)
	Off-axis points	884	95 (10.7%)	255 (28.8%)

*The NSABP point is defined to be two-thirds the distance from the apex of the breast to the baseline, at the center of the baseline which connects the edges of the two fields.

The next step is to combine the knowledge that we have gained about standard data for machines and about benchmark cases We plan to begin sending benchmark cases to institutions when they first enter onto our program We will perform our calculations using our standard data and compare that to the institutions calculations This will evaluate both the dosimetry data used and the treatment planning algorithm used by the institution We believe that this will be a beneficial addition to our program

5. CONCLUSIONS

The Outreach Physics Section of M D Anderson Cancer Center has two radiotherapy physics quality assessment networks providing service to more than 1200 radiotherapy facilities in North America One network relies principally on postal TLD with follow-up to resolve discrepancies The other network is more comprehensive and adds on-site measurements by a physicist and review of treatment planning practices to the postal TLD program Again, comprehensive follow-up and education are important factors in the success of the program We offer the following as a suggestion for an effective and cost efficient network

Table 6 Suggested Network

- Mail dosimeters (TLD) to verify the basic calibration of the therapy unit
- Review dosimetry data used clinically to verify that it complies with standard data for the specific make and model of therapy unit
- Evaluate benchmark cases to verify the validity of the treatment planning algorithms
- Provide workshops and educational efforts, including laboratories of routine quality assurance measurements, as needed
- Conduct on-site measurements by a physicist to resolve intractable discrepancies

***All of these components must contain mechanisms to resolve discrepancies

I would like to leave one strong take-home message Motivation for proper quality therapy and quality assurance of therapy should arise from within the institution from a higher human plane than regulation or fear of legal action We, at this meeting, can make it our job to find this motivation In a major program in the U S A and Canada and in a much smaller program in Latin America, the Radiological Physics Center has found participation in cooperative clinical trials to be an excellent motivating force

IMPLEMENTATION OF THE QUALITY ASSURANCE PROGRAMMES FOR RADIOTHERAPY AT THE NATIONAL LEVEL

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Abstract

Whilst it has long been recognised that Quality Assurance (QA) in radiotherapy is vital to ensure the achievement of safe effective treatment, it has been increasingly acknowledged that a systematic approach to QA is necessary. The implementation of such systems in details depends on the local special needs and resources, and should become in harmony with the infrastructure already available in the given country or region. While some common principles should be followed, the approach to the QA system in a small country may be somewhat different from that adopted in a large country. This paper presents the implementation of the QA programmes in Finland, in a small developed country, reflecting the possible advantages of the situation with relatively small-scale needs.

The efficient implementation of QA principles and practices in radiotherapy could be achieved through the following main elements : (1) the suitable education and training system for the qualification of the radiotherapy professionals, (2) the appropriate legislation for radiation protection and sufficient measures for supervision, and (3) the provisions of standards to ensure traceable measurements with calibrated dosimeters.

In Finland, the general principles and objectives of the QA are being more and more incorporated in the basic curricula of radiotherapy professionals: radiotherapists, radiation technologists (nurses), and the physicists, in particular. The medical physicists are identified as an independent specialty which, after the general studies in physics requires a special examination and five years practising in various aspects of radiotherapy clinical work. Specific meetings organized both occasionally and regularly by national societies, hospitals and the authorities collect together different specialists in the field, thus providing opportunities for continuous up-keeping of knowledge and the exchange of experiences in QA.

The Finnish Centre for Radiation and Nuclear Safety (STUK), operating under the Ministry of Social Affairs and Health, is the national authority for radiation protection covering all fields of the application of radiation. Besides its supervisory role, i.e. to control that the safety of various applications meets the requirements et by legislation, considerable amount of the resources are devoted to research in support of the supervisory activities. For radiotherapy, the leading principle is to ensure the safety of patients, personnel and the public, the good accuracy of the dose to the patient being one of the main objectives. In essence, this leading principle manifests itself through the maintenance of standards, measurement techniques and calibration services traceable to the international measurement system. and through the legal inspections as well as independent reviews and measurements to assess the QA systems of hospitals (i.e. through Dosimetry Audits or Quality Audits).

1. INTRODUCTION

Whilst it has long been recognised that Quality Assurance (QA) in radiotherapy is vital to ensure the achievement of safe effective treatment, it has been increasingly acknowledged that a systematic approach to QA is necessary. There is no suspense that it is the responsibility of the

radiotherapy departments to establish and implement QA programmes, and that the best benefits of QA are achievable only if the importance of the QA is recognized and the objectives for quality clearly defined at the institutional level. However, *the coordination and control of the local efforts at the national and international level are important* to ensure the correctness of methods applied, the most efficient use of the available knowledge and resources, and in order to avoid duplication of effort. The implementation of the national or regional QA systems in details depends on the local or regional needs and resources, and should become in harmony with the infrastructure already available in the given country or region. While some common principles should be followed, the approach to the QA system in a small country may be somewhat different from that adopted in a large country.

This paper presents *the implementation of the QA programmes in Finland*, in a relatively small developed country, reflecting the possible advantages of the situation in the region with relatively small-scale needs. The emphasis will be on *physical and technical aspects of the QA*, where the national guidance or control could more easily play an important role in establishing efficient and generally acceptable QA procedures. The efficient implementation of the principles and practices of such QA programmes could be achieved through the following main elements: (1) the suitable education and training system for the qualification of the radiotherapy professionals, (2) the appropriate legislation to cover all aspects of radiation protection, and sufficient means for supervision, and (3) the provisions of standards and metrological services to ensure traceable measurements with calibrated dosimeters. While the first element is the necessary basis for the creation of proper attitudes and knowledge for the practical work on QA, the QA arrangements are actually manifested in the two other elements and they will be the main concern of this paper.

A few distinctive numbers from Finland are needed to scale the systems with other countries. In Finland there are 9 radiotherapy centres (mainly belonging to the university hospitals), with 25 accelerators (alltogether providing 76 electron beams and 33 photon beams), 1 ^{60}Co gamma beam equipment, 10 afterloading units, 11 treatment simulators and 11 conventional X-ray units. The population of Finland is about 5 million and the number of new cancer patients per year is about 16000. About 70 % of the cancer patients are treated with radiotherapy, roughly half of this as the primary method of treatment.

2. QUALIFICATION FOR QA

The "seeds" for QA should be sown in the basic curricula of the different groups of staff in the radiotherapy department. This is important as the experience has shown that a lot of extra efforts in the local training may sometimes be needed to work on the attitudes for proper understanding the importance of QA. The basic requirements on the level of qualification of different groups should then be supplemented by adequate knowledge on the principles of QA. In Finland, the general principles and objectives of the QA are being more and more incorporated in the basic education of the radiotherapy professionals: radiotherapists, radiation technologists (the nursing staff), and the physicists, in particular. The medical physicists are identified as an independent speciality which, after the general studies in physics requires a special examination and five years practicing in various aspects of radiotherapy clinical work.

Specific meetings organized both occasionally and regularly by the national societies, a few hospitals and the authorities collect together different specialists in the field, thus providing important opportunities for continuous up-keeping of knowledge and the exchange of experiences in QA. Examples of such meetings are the two days meeting on "Radiotherapy methods and equipment", organized every two years by the Radiological Society of Finland and the Finnish Society for Medical Physics and Medical Engineering, the two days meeting "Radiotherapy in practice" organized every two years by Kuopio University Hospital, and another two days meeting "Radiation Protection Days", organized annually by the Radiological Society of Finland and STUK. All these meetings collect radiotherapists, nurses, physicists, technical staff and also the representatives of authorities to present and discuss the various questions of QA, among the other topics. A special two days meeting solely

for radiotherapy physicists is annually organized by STUK, dealing with radiotherapy dosimetry and the problems of QA in radiotherapy.

3. COORDINATED EFFORTS FOR QA BY THE CENTRAL AUTHORITY

3.1. General

The Finnish Centre for Radiation and Nuclear Safety (STUK), operating under the Ministry of Social Affairs and Health, is the national authority for radiation protection covering all fields of the application of radiation. The main objective of the Centre is to ensure that the safety of the various applications meets the requirements set by the legislation. In radiotherapy, the supervisory role of the Centre covers the safety of patient, staff and general public. *For the safety of the patient, the leading principle is to prevent any large misdosage and to ensure the good accuracy of the dose.* In essence, this leading principle manifests itself through the maintenance of standards, measurement techniques and calibration services traceable to the international measurement system, and through the legal inspections as well as independent reviews and measurements to assess the Quality Control (QC) systems of hospitals (i.e. through Dosimetry Audits or Quality Audits). According to the stated objectives, all aspects of the radiotherapy process which affect the accuracy of dose to the patient should be covered by these procedures.

It has been the policy of the small country to combine the supervisory actions (on all applications of radiation), radiation metrology (the national standards laboratory activities) as well as the supporting research activities in the same institute. This has ensured very effectively the maintenance of high competence of the staff besides conserving the small resources available for such a special work. Because the traceability and accuracy of measurements and the availability of metrological services are of highest importance for radiotherapy, and to maximize the the benefits of synergy in combining small resources, the standard dosimetry activities at STUK are practically organized in the same organizational unit with the supervision of radiotherapy safety. The personnel of this unit (5 physicists) are experienced both in the calibration work and in the practical dosimetry and QA procedures for radiotherapy equipment, thus providing maximum flexibility and availability of competent personnel for the different tasks.

3.2. Safety licence, inspections and audits

According to the Finnish Radiation Act, a special ***safety licence*** is needed for radiotherapy, for the use of each radiotherapy apparatus [1]. New equipment may not be taken into use before an *inspection* by STUK (see below) has been carried out, unless otherwise specified in the licence. A condition of the licence requires that *the organization for safety* in the radiotherapy department has to be specified. In particular, the persons responsible for the dose measurements, for the QC of radiotherapy equipment and for the arrangements for radiation safety shall be specified. On request, STUK will make an advance statement on the radiation shielding plan for the radiotherapy rooms, and if needed, carries out an advance inspection for radiation shielding. Information on the radiotherapy department and its equipment is entered into a computerized *equipment register* maintained by STUK. Also recorded in the register are the important data on inspections, machine faults, radiation accidents and abnormal incidences.

A new radiotherapy apparatus (or a simulator), the rooms where it will be used and the compliance of the operation with the safety licence are ***inspected*** by STUK before the equipment is taken into use. The inspection is carried out also after significant repairs of the equipment and if its accepted location in the department is changed. Thereafter *the inspections are repeated regularly* as follows:

At the minimum every two years:	high-energy treatment equipment, conventional X-ray therapy equipment and radiotherapy simulators
At the minimum every five years:	afterloading equipment

Sometimes the information received from the radiotherapy department gives rise to an extra inspection.

Table I specifies the contents of the inspection for different radiotherapy equipment. Table II gives an extract of the suggested details of the inspection for a high-energy treatment equipment [1].

An essential role in the inspection play *the comparative measurements* (Table II), where the high-quality equipment of STUK is used. The extent of measurements by STUK is dependent on the results of the QC program of the radiotherapy department and is decided on-site after the review of the QC documentation. The dose at the reference point in water per monitor unit for each high-energy photon and electron beam is always measured, while e.g. the wedge factor and the dependence of the results on the field size are checked only to a certain extent. The results of measurements are compared with that obtained by the local staff using the local equipment at the time of the inspection. In the comparison, the following action levels are applied:

Consistency of dose per monitor unit at the reference field size:	
photons	1 %
electrons	2 %
Consistency of the wedge factor	1 %
Consistency of field size dependence	1 %

TABLE I. OBJECTS OF THE INSPECTION BY STUK FOR DIFFERENT RADIOTHERAPY EQUIPMENT (I: first inspection, R: regular inspection).

Object of inspection	High-energy treatment equipment	Conventional X-ray therapy equipment*	Afterloading equipment*	Treatment simulator
Compliance with the licence	I,R	I,R	I,R	I,R
Structural radiation shielding	I	I	I	I
Radiation safety arrangements	I,R	I,R	I,R	I,R
Dose per monitor unit at reference point (incl. wedge factor, field size dependence)	I,R	I,R	I,R	
Radiation beam characteristics	I,R	I,R	I,R	
Dose monitoring characteristics	I,R	I,R	I,R	
Mechanical characteristics	I,R	I,R		I,R
Imaging and fluoroscopic characteristics				I,R
Results of QC	R	R	R	R
Treatment Planning System	I,R	I	I,R	

* when applicable

TABLE II. SUGGESTED DETAILS FOR THE INSPECTION OF HIGH-ENERGY TREATMENT EQUIPMENT (Extract from the complete table).
Gantry angle (GA) and collimator angle (CA) are 0° unless otherwise stated.

Object of inspection	**A. First inspection before taking into use**		**B. Regular inspection**	
	1. Total procedure	2. Measurements by STUK	1. Total procedure	2. Measurements by STUK
Dose per monitor unit at the reference point	All radiation qualities, dose rates, wedges and field sizes.	All radiation qualities, dose ratesand wedges. Selected field sizes.	As A2.	As A2.
Radiation beam characteristics Uniformity Symmetry Penumbra	All radiation qualities. Field sizes 10 cm x 10 cm, ref. size, max and one field size between the two last ones. Minimum: GA 0° and 90°. Minimum: CA 0° and 90°, when GA 90°. Measuring depths: ref. depth (all GA and CA) and another depth (only GA 0°, CA 0°).	Minimum: one setting for each radiation quality (i.e. field size, GA, CA, measuring depth).	All radiation quallities. Minimum: field sizes ref. and max. Minimum: GA 0° and 90°. Minimum: CA 0° and 90°. Minimum: one measuring depth.	Minimum: one photon and one electron quality. For each quality, minimum: one setting (field size, GA, CA, measuring depth).
...				
Mechanical characteristics Accuracy of radiation field indicators	All radiation qualities. Minimum: four field sizes for photons and all field applicators for electrons.	Minimum: one photon and one electron energy. Minimum: two field sizes for photons and one field size for electrons.	Minimum: one photon and one electron energy. Minimum: four field sizes for photons and all field applicators for electrons.	Minimum: one photon energy. Minimum: two field sizes.
...				

If the action level is exeeded, the reason will be carefully examined. In the rare and unfavourable case that the discrepancy above the accepted level remains unsolved, the most reliable result of measurements to be used as the basis of treatments, or further actions and possible limitations of the use of the equipment are agreed on-site.

For the afterloading equipment, the inspection by STUK includes the check of the reference air kerma rate. For the conventional X-ray therapy equipment, the absorbed dose rate produced by the equipment is determined solely by STUK, for one tubus (deep therapy) or separately for each tubus (superficial therapy). The measured dose rate for each tubus or the calculated dose rate as the function of the field size is then reported to the radiotherapy department.

The purpose of the above procedures with comparative measurements are to review the quality control system of the radiotherapy department in order to verify the correctness of methods and the acceptable functioning of the system. As this is carried out by an independent body which is not responsible for the process under review, the procedures can be considered to represent ***dosimetry audit*** or, in its most comprehensive form, ***quality audit*** [2], carried out by site visit. They correspond to the most efficient form of the audits as, on the basis of the results, immediate further studies or corrective actions can be initiated. However, they differ from the general principles of audit in the aspect that the results can also be used by STUK to set up requirements for the operation.

The quality audit should cover all aspects which affect the accuracy of the dose to the patient. In this sense, the current procedures by STUK are not yet fully comprehensive and are being further developed. For example, a special phantom with simulated anatomical structures is being developed [3] in order *to spot check the whole radiotherapy process*, from CT-scanning of the target region to the dose delivery, thus including a check of the treatment planning system (TPS). The phantom with suitable dosimeters would be CT-scanned and irradiated according to the plan produced by the local TPS, and the results of dose measurements at several selected points would be compared by the values calculated by the TPS.

3.3. Quality Control programmes for equipment

An important requirement by the Finnish legislation is *a documented Quality Control program* for each radiotherapy apparatus, which the radiotherapy departments have to prepare for approval by STUK within one year from starting to use the equipment. The criteria for the approval of the programs are based on a review of several international recommendations and on discussions with radiotherapy physicists in the annual meetings. In the approved programs, the QC tests to be performed, their objectives, methods and equipment to be used, test frequencies, performing staff, action levels and proposed actions are described. The QC procedures shall be started from the beginning of the use of the radiotherapy equipment, while the period of one year is considered acceptable to establish the most suitable program for the individual equipment. However, as the QC programs are (and should be) dynamic by nature, the essential modifications to them are discussed and accepted in connection with the regular inspections.

3.4. Responsibilities for giving information

In the Radiation Degree a number of matters are pointed out where the radiotherapy department is responsible *for informing STUK*. The changes of the licence or the given conditions, as well as the important machine faults and repairs, radiation accidents or incidents affecting the radiation safety must be reported to STUK. STUK must also be informed, if the result of the local dose measurement for a high-energy equipment, taking into account all possible adjustments of the calibration, differs by more than 5 % from the value agreed on during the latest inspection by STUK.

3.3. Calibration and testing of dosimeters

The position of STUK as the National Standards Laboratory is based on the metrological needs by the supervisory activities and on the aim at conserving resources, as described earlier. This position is confirmed by the Finnish Radiation Protection legislation. For practical and economical reasons in the small country, *secondary standards* have been adopted as national standards. The therapy level secondary standards have been calibrated by the International Bureau of Weights and Measures (BIPM). To ensure acceptable accuracy in the operation, the SSDL of STUK (SSDL-Helsinki in the IAEA/WHO network of SSDLs) participates in international intercomparisons and calibration audits organized by the IAEA, EUROMET and other organizations. Comparisons of standards between the Nordic Standard Dosimetry Laboratories (Finland, Sweden, Denmark, Norway and Iceland) have also been carried out. To improve the QA of radiotherapy through the first link of dosimetry at the national level, i.e. in the standard dosimetry activities, the Quality System of the SSDL is currently being re-evaluated and documented according to the requirements of the international quality standards.

The local dosimeters used by the radiotherapy centres shall be re-calibrated every three years in a recognized Standards Dosimetry Laboratory, which has the traceability of its standards to the international measurement system. While there is no obligation then, in principle, for the radiotherapy centres to make use of the calibration services offered by STUK, it is of course the most practical and natural choice to use the national (local) laboratory. Since the relatively expensive calibration rooms and facilities are primarily established for the needs of the supervisory activities, and would exist for that purpose anyway, it is considered most sensible to use these facilities to provide calibrations and testing services on request of various other customers, such as the radiotherapy hospitals. The actual costs of the services are charged from the customers, while in practice only a small part of the basic investments and their up-keeping can be financed through the calibration fees.

3.4. Research, standardization and international cooperation

The efficient implementation of QA programmes at national level requires continuous efforts of *research and standardization* and participation in *the international cooperation*. STUK is performing continuous follow-up on the problems of calibration, dose measurements, quality control of equipment and other aspects which affect the overall accuracy of the dose to the patient. Research is undertaken in order to solve the problems, to improve the methods and to maintain the competence of the personnel on all aspects of QA work. Close contacts and co-operation with international organizations are considered important.

As an important example of QA research and standardization undertaken by STUK, the methods of dose specification in the Finnish radiotherapy centres have been reviewed and an initiative taken to improve the inconsistent use of various concepts. This work has later been extented to the Nordic level, and an investigation among the Nordic radiotherapy centres in 1991 confirmed that inconsistent use of dose and volume concepts is seriously jeopardizing the high standard of radiation therapy. A Nordic Working group was set up by the Nordic Association of Clinical Physics (NACP) to standardize the concepts and quantities used throughout the whole radiotherapy process. The group is now finalizing its report "Specification of Dose Delivery in Radiation Therapy".

3.5. Training

Training of the users of radiation in dosimetry and QA is obviously an important addition to the national efforts of QA implementation. Regular meetings with radiotherapy physicists are organized by STUK, and lectures are given in various other meetings and occasions (see Chapter 2). The general guidance given by STUK is usually discussed with the radiotherapy physicists at these meetings before final issue.

TABLE III. EXAMPLES OF DISCREPANCIES OBSERVED AT QUALITY AUDITS BY STUK

Observation and comments	Actions or remarks
Dose per monitor unit at the reference point was wrong by 10-13 % for photons and by 13-15 % for electrons. QC measurements were performed but the results were not properly observed.	The dose per monitor unit values were corrected. The hospital was requested to evaluate the possible effects on the treatment of patients.
Wedge factor was 52 % in error because of a measuring error by the local physicist. Two patients received overdose.	The wedge factor was corrected. The patients were subjected to special follow-up.
Dose per monitor unit for one photon energy was 9 % in error. The reason was the change of the daily control instrument without due change of the reference value.	The dose per monitor unit was corrected. The reference value for the daily controls was up-dated.
Dose measurement for electrons resulted in 5 % discrepancy between STUK and hospital. The reason turned out to be inadequate (erroneous) collecting voltage of the hospital chamber, which affected the recombination correction during beam measurements byt not at calibration.	The measuring instrument of hospital was repaired.
The penumbra values for 6 MV photons exceeded 12 mm. The reason turned out to be the inadequate energy compensation of the diode detector used by the hospital which lead to erroneously high values of penumbra.	The detector was replaced by a new one.

4. EXAMPLES OF COSTS AND BENEFITS

The benefits of the QA programmes are quite evident based on the experience and follow-up through site visits and comparative measurements over 15 years. A few examples of the discrepancies observed during the site visits by STUK are collected in Table III. In a number of cases the observations would not have been possible or would have been less probable if only postal procedures had been applied. It can be claimed that the uncertainty of dose has decreased and the accuracy in dose delivery improved by several per cent since the introduction of systematic programmes for QA.

The total costs of the supervisory and audit activities by STUK (including all costs "rolled" e.g. from administration, library etc, but not including the costs for the maintenance of standards) are about US $ 250 000 per year, most of which is due to the salaries. The operation is mainly financed by annual charge collected from the hospitals.

An exact measurement of the benefits of the QA programmes in terms of improved outcome of the treatment is not possible. However, starting from the knowledge on the dose-effect curves, both for tumour control and for normal tissue damage probabilities, it is possible to postulate that the implementation of the QA would have a significant impact on radiotherapy results. A simple calculation, where the value of the normalized dose response gradient (γ) [2] was taken as 4 and the improvement in accuracy was assumed to be at least 3 %, lead to the annual saving of several millions of US $ per year through the decreased treatment costs by improved results (less recurrencesor re-treatments) and through the savings of work years with more patients cured. Against such estimates, even the most effective control and audit procedures would be well justified.

5. LINKS TO THE INTERNATIONAL QA NETWORKS

In the framework of the international QA networks, STUK provides through the SSDL operation the metrological link for traceable calibrations on one hand, and the position of the *national reference centre* (Quality Audit centre for Finland) on the other hand. In this scheme, the competence of STUK for *both* the calibrations of dosimeters at the SSDL *and* the dose measurements for audits in radiotherapy is subjected to external audits through the regular dose intercomparisons and calibration comparisons organized by the IAEA, and also by other international organizations (e.g. EUROMET). In the future, the full implementation of the European QA network would mean that the dose measurements by STUK in the hospitals would be audited by the "European co-ordinating centre" instead of the IAEA.

6. SUMMARY

The implementation of the physical and technical QA procedures for radiotherapy in a systematic way, at the national level in Finland, has been accomplished by the support of, and parallel to the development of the Finnish radiation protection legislation. The practical arrangements have mostly been carried out under the auspieces and by the coordination of the central authority for radiation protection (STUK). The various meetings organized by the national societies, hospitals and the authorities have provided opportunities to discuss the desirable developments. The programmes to-day involve efficient systems for the qualification of the QA organization, for the QC of equipment and for the verification of the accuracy and traceability of dosimetry. The future developments concentrate on supplementing the QA programmes to cover all aspects affecting the accuracy of the dose to patient, including unified conceps in dose specification and the checking of dose planning calculations. The links of the systems to the international QA networks have been identified and remain to be enforced.

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THE ROLE OF EFOMP IN THE EUROPEAN STRUCTURES FOR IMPLEMENTATION AND HARMONISATION OF QA PROGRAMMES IN RADIOTHERAPY

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Abstract

The increased complexity of technical innovations in the planning and delivery of therapeutic radiation in the last two decades requires a corresponding increase in the demand for quality assurance procedures. The European Federation of Organisations for Medical Physics (EFOMP) has sought to harmonise and promote the best practice of medical physics in Europe over nearly the same period. The initiatives of EFOMP in definition of roles and responsabilities for medical physicists and recommendations for education and training and other professional matters are presented as an important basis for a common European initiative for implementation of quality assurance programmes in radiotherapy.

Introduction.

The European Federation of Organisations for Medical Physics (EFOMP) was inaugurated in London in 1980. The aim and purposes of the Federation are given in Article 4 of the Constitution and include:

> "Fostering and co-ordinating the activities of the Member Organisations in the field of Medical Physics and collaborating where appropriate with national and international organisations. Encouraging exchanges between the Member Organisations and desseminating professional and scientific information through publications and meetings. Proposing guidelines for education, training and accrediation programmes. Making recommandations, on the appropriate general responsibilities, organisational relationship and roles of workers in the field of Medical Physics".

At the time of the original constitution there were fourteen founder members. Today there are a total of 26 member organisations and all together there are about 5100 medical physicists within the Federation. Between 30 and 80% of the medical physicists in the individual national organisations are working in relation to radiotherapy. The administration of EFOMP is held by the Council and by the Officers. The Council is formed by two delegates from each member organisation and meets once a year. The Officers are nominated for a 3-year term by the EFOMP Council.

There has been a pressing need to harmonise the differences between countries in Europe especially within the European Union (EU), where freedom of movement and employment has been in effect since 1992. It is obvious that the European region should take advantage of the results obtained by the must developed organisations in order to accelerate a harmonization of the differences and in this way to promote the best practice of medical physics in the whole region including the physics support to quality assurance programmes in radiotherapy.

Qualified Expert. The Qualified Expert in radiophysics QE(r) was introduced by article 5 of EEC Directive 84/466 Euratom of September 1984 [1]: "A Qualified Expert in radiophysics shall be available to sophisticated departments of radiotherapy and nuclear medicine". The expression "*Sophisticated department*" is to be interpreted as a department "in which complex radiological methods and procedures requiring special protection of the patient are undertaken". According to EFOMP [2] the QE(r) is defined as "an experienced Medical Physicist working in a hospital or in a recognised analogous institution, whose knowledge and training in radiation physics are required in services where the quality of the diagnostic image or the precision of treatment is important and the doses delivered to the patients undergoing these medical examinations or treatments must be strictly controlled". The Qualified Expert should normally be a suitably experienced physical scientist who would be responsible for the safe application of radiological techniques in respect of the protection of the patient. This description has been accepted by the representatives of the national authorities of EU Member States [3].

In the policy statement of 1988 [2] the formal part of the training required for a QE(r) is also indicated: "The Qualified Expert should firstly have an education in physical sciences that provides an adequate scientific basis in radiation physics of a masters degree or its equivalent". Then a curriculum of basic courses and special courses must be followed. The special courses are differentiated to the fields of application, e.g., radiation therapy, radiodiagnosis and nuclear medicine.

The role of the QE(r) in relation to radiation therapy has been formulated by the EFOMP Education, Training and Professional Committee as follows:

a) to have a thorough understanding of the physical principles and technical features of irradiation facilities used for radiotherapy treatment in accordance with statutory legislation.

b) to carry out physical measurements on external beam and brachytherapy equipment which are necessary and sufficient to provide information on patient dose in all possible treatment circumstances. To undertake calculations of change of source activity due to radioactive decay in both external beam and brachytherapy.

c) to establish protocols for quality assurance testing of radiotherapy treatment apparatus, simulators and treatment planning computers and to ensure that routine and regular quality assurance procedures are carried out.

d) to assist in the choice of new radiotherapy equipment and in the planning of new installations - with particular regard to radiation protection matters.

e) to undertake commissioning measurements on new or modified radiotherapy equipment.

f) to ensure that those working in areas where radiation hazards might exist work safely and effectively

g) to take part in the training of medical and other staff in the physical aspects of radiotherapy and in radiation protection

Competence levels. EFOMP has recognised that the most appropiate way to achieve harmonization of standards across the whole Europe is to express the duties and competencies expected of the QE(r) in very practical terms. A framework of five levels of competency that covers the whole career structure of the medical physicist has therefore been proposed[4]:

Competence level	*Training/Experience*
1	Relevant first degree or equivalent
2	As 1, plus two years directed training
3	As 2, plus two years subseguent practical experience
4	As 3, plus 4-5 years subsequent experience
5	As 4, plus greater responsibility and a mature overview

Recognition as a qualified medical physicist, a trained medical physicist, should follow completion of level 3. Because of the very advisory nature of the work of the QE(r), often requiring judgement in new or non-standard situations a further period of experience is required, to competency level 4, before becoming a QE(r). Competency level 5 would be appropriate for a head of department who is managing a range of routine services.

Registation. As for the assessment and recognition of training, EFOMP proposes that "appropriate arrangements should be made for assessment and certification of Qualified Expert either by the competent national authorities or by the national professional organisations for medical physics. The certificate awarded on successful completion of the designate training should be formally recognised by the competent national authority as indicating a Qualified Expert in radiophysics".

It is worth noting that the EFOMP strategy is toward a recognition of the European Medical Physicist. For this purpose the EFOMP proposal is to encourage a registration scheme (on voluntary basis) as apposed to a regulation scheme (as imposed by law). Recommendations for guidelines on national registration schemes for medical physicists have been given by EFOMP and the national organisations have been invited to submit details of their schemes to the EFOMP Registrar for approval.

Staffing levels. In the 1991 Policy Statement [5] EFOMP analyses the needs for the number of physicist in a Medical Physis Department. In 1993 EFOMP made a survey on the number of trained medical radiation physicists working in radiation therapy, diagnostic radiology and nuclear medicine. Answers were received from 18 countries, giving a broad overview of the European situation.

Table I. Trained Medical Radiation Physicists per 10^6 population in Europe (1993)

	Radiation therapy	Diagnostic radiology	Nuclear medicine
Highest	6,5	4,3	4,9
Lowest	1,0	0,1	0,3
Median	3,0	0,8	1,6
Upper quartile	4,4	1,9	3,0

The number of medical physicists per million inhabitants shows wide variations in different European countries, from less than 2 in Portugal to 15 in Sweden. The survey covered both trained medical radiation physicists with at least five years of relevant experience since completion of training. In radiotherapy where we have the lowest spread only around two thirds of the trained physicists had more than five years of relevant experience and half of the countries have less than three radiotherapy physicists per million of the population. Figures can be used in comparisons between countries only if they are covering the same areas of physics related activities and related to the number and qualifications of the supporting staff. The figures depend to some extend on the amount of equipment available and the complexity of examinations and treatments together with possible responsibilities in research, development and teaching. The minimum staffing of the medical physics support of radiotherapy is reconsidered at the moment, but if standards in health care in Europe are to be harmonised by levelling up rather than down, it is reasonable to consider the staffing leves in those countries that are relatively well equipped.

Departments of Medical Physics. In the 1993 document [6] the advantages, organisation and management of Departments of Medical Physics are described. The organization of medical physics services in health care varies widely througout Europe. The higest standards and most cost effective provision of services are usually obtained if the services is organized by an independent Department of Medical Physics. That means that the head of the department is an experienced medical physicist with responsibilities for professional standards, provision of scientific services and the department's budget. Because the medical physicist must have in depth understanding of techniques used for examinations or treatments there must be close daily relationship between the medical physicist and the patient environment especially the medical staff. The medical physics department should therefore be close to relevant clinical areas but an integrated Department of Medical Physics give advantages of links with many clinical specialities, a multidisciplinary approach to problems, cost-effective use of time and equipment, peer review of work, a broad training base and realistic career development prospects.

EFOMP and Quality Assurance in Radiotherapy.

The quality assurance in radiotherapy must be multi-disciplinary and cooperative based on a clearly defined structure and areas of responsibility. The radiotherapy medical physicists are primarily and professionally engaged in the evaluation, delivery, and optimization of radiation therapy and their role has clinical, research and educational components. Already at the World Congress of Medical Physics and Bioengineering in Helsinki in 1985 a symposia on "Quality Assurance in Radiation Therapy" was organised by EFOMP and a survey of European protocols was presented. Several symposia in related topics have been held since in relation to scientific meetings and often in cooperation with other organisations. The accident reporting scheme was launched in 1991 by the Scientific Committee to assist the national organisations to share information about accidents, and cases involving nearly 1500 patients have been recorded. The Committee has recently begun to look into desirable characteristics of verify-and-record systems as reported in another paper at this meeting [7].

Conclusion.

Because all medical physicists working in radiotherapy in Europe are organized within EFOMP, where a well structured network for educational and scientifical matters exist, the Federation has a vital role to play for implementation and harmonization of Q.A. programmes in radiotherapy in Europe.

The role of EFOMP in this field can be summerized as follow:

- to define the roles and responsibilities for the radiation therapy physicist which are general accepted by the national medical physics professions in the European region.

- to promote standards of qualification, competency based training and conduct of scientists practising as qualified medical physicists and as Qualified Experts in radiophysics.

- to establish recommended guidelines on national registrations schemes for medical physicists and promote official recognised certifications.

- to negotiate professional matters in medical physics on a Eropean scale and provide authoritative responses to the administrators of the Commission of the European Union.

- to revise currently the EFOMP activities in response to the technological developments and to new demands in quality assurance from the radiation oncology community.

- to take advantage of the existing structured network, which can be used for surveys, harmonizing protocols and quality assurance programmes, staffing needs, auditing etc.

- to respond to other organisations and international bodies with shared responsibilities.

Because EFOMP is aiming a recognition of the Eropean Medical Physicist with a well defined scheme of qualifications it will secure a high and comparable standard of the medical physicists practicing clinical physics service and supervision to radiotherapy.

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The EFOMP Policy Statements can be obtained from the General Office of EFOMP, 4 Campleshon Road, York, Y02 1PE, U.K.

V. EXPERIENCES ON CURRENT STATUS FROM NATIONAL NETWORKS

QUALITY ASSURANCE NETWORK IN RADIOTHERAPY IN DENMARK

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Abstract

Quality Assurance in radiotherapy has in the past mainly been concerned with control of the physical dosimetry since this, as demonstrated recently may affect the outcome of the treatment for a large number of patients.

In Denmark control of physical dose in radiotherapy centres have been carried out in 1972 and in 1980 as part of a comparison between centres in Scandinavia. These comparisons have played a major role in removing important dosimetry differences. In a recent dosimetry comparison carried out in 1992 no deviation between stated and measured dose above 3% have been discovered.

The majority of radiotherapy with curative intent is carried out according to national protocols. DBCG (breast) and DAHANCA (head and neck) are two well known examples. Following the encouraging results quality control groups for the physical dosimetry have been created.

A head and neck phantom in solid water has been designed for dosimetry control of the physical dose, i.e. check of the dose-planning system and fabrication of compensators. The phantom contains low and high density volumes simulating air and bone.

An ionisation chamber can be placed in six different positions in the phantom. The phantom is used both as a check of dose planning and as a control of appropriate drawing of treatment portals in various clinical situations.

Radiotherapy with electronaccelerators is in Denmark carried out at six centers of Oncology. Traditionally there has been close cooperation between the radiotherapy centers and most cancers at least all the common types are treated according to national protocols and have been so for many years.

This cooperation have necessitated and accentuated the need for standardized physical as well as clinical dosimetry to get maximal information out of the clinical trials.

A network for the physical dosimetry has existed for almost 20 years.A dosimetry group consisting of one physicist from each center and a physicist from the Danish Secondary Dosimetry Standard laboratory has had the responsibility for creating standardized dosimetry.

The need for standardized physical dosimetry has been demonstrated in Scandinavian dosimetry intercomparisons in 1971 and in 1980.These intercomparisons showed major differences in physical dosimetry between centers due to use of different dosimetry protocols.

When the IAEA TRS 277 protocol was introduced in Denmark the dosimetry group was very active in ensuring that it was introduced in a uniform way in the six centers and plans were proposed for a new dosimetry comparison shortly after the introduction of the IAEA protocol.

Such a intercomparison may either be carried out using mailed dosimeters e.g.TLD or by a small group of physicists visiting the centers.Mailed dosimetry using alanine dosimeters were tested in a small scale and found to have suitable accuracy for the purpose whereas TLD dosimetry was deemed not to have the accuracy and reproducibility necessary for the purpose.

It was decided to start with site visits using ionization chambers since this had the advantage of immediate discussions with the local physicists about problems discovered during the intercomparison.

Financial support for the intercomparison was obtained both from the National Institute of Radiation Hygiene and from a reseach foundation.During 1991 and 1992 a group of two physicists visited all centers and measured the dosimetry under standard conditions for almost all beam qualities.

The results for photons and electrons are shown in figs.1 and 2.The data clearly show that after the introduction of the IAEA protocol a very good agreement exists between the centers regarding the physical dosimetry under standard conditions.

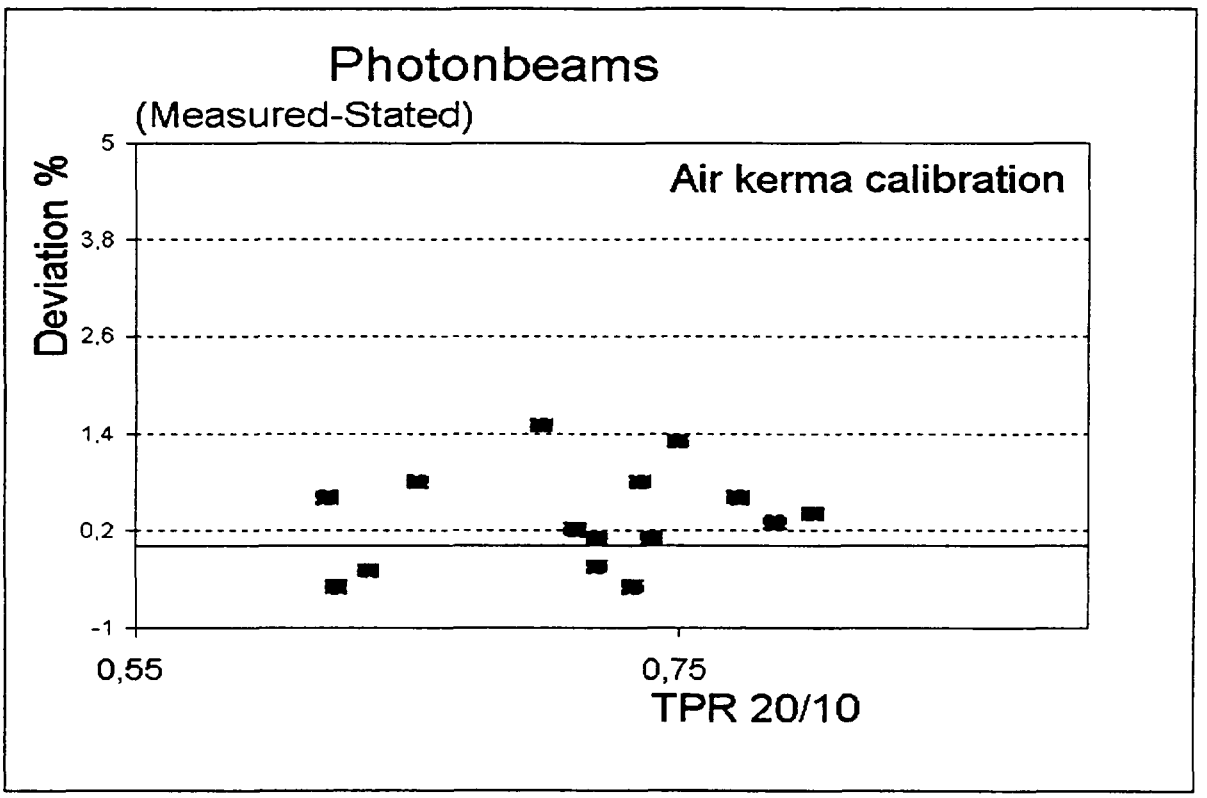

Figure 1

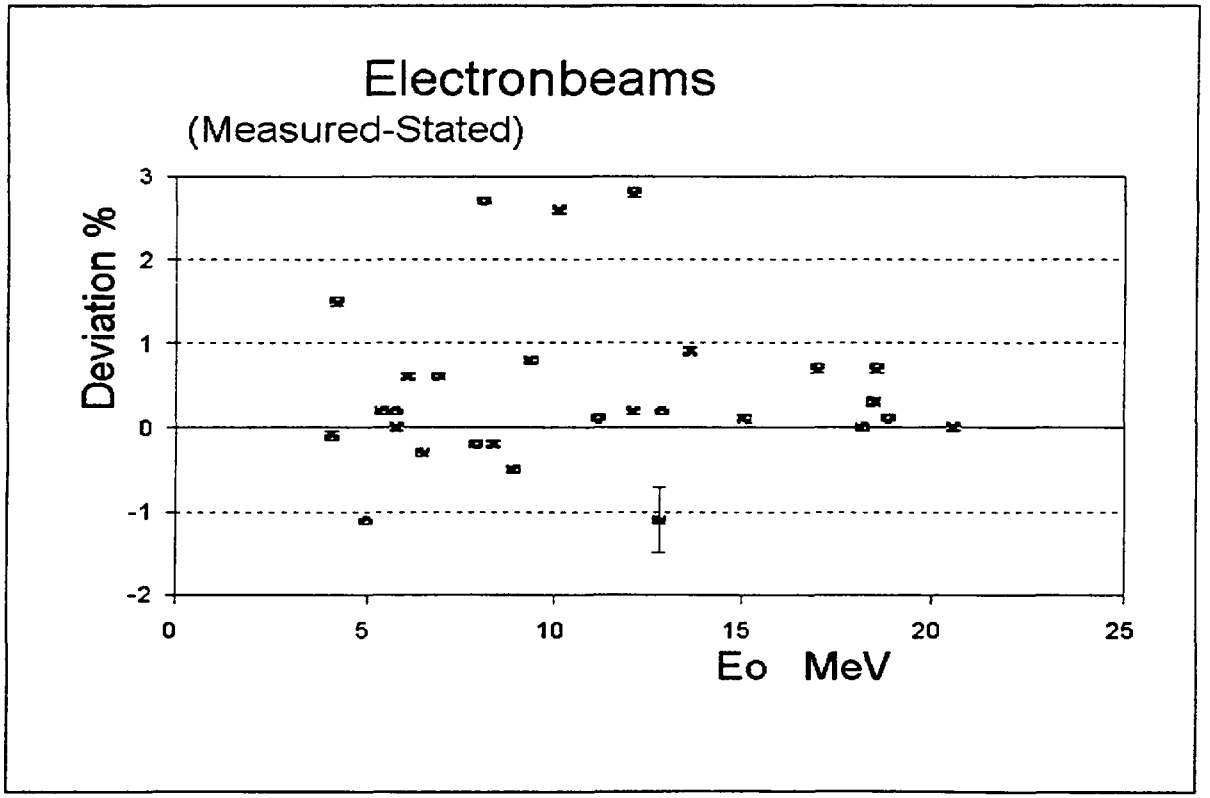

Figure 2

The next step will encompass clinical dosimetry i.e.corrections for shielding blocks,doseplanning systems,compensators and design of treatment portals.This will focus on breast cancer and head-and-neck cancer.

For head-and-neck cancers treated according to the DAHANCA protocol a dosimetric phantom has been constructed in solid water material simulating both the neck and the chin area.Ionisation chambers may be placed in the phantom which also contains irregularities with air and bone.The phantom will allow a test of the compensation methods used as well as the accuracy of the doseplanning system for this treatment.With the high doses used for head and neck cancers even small systematic differences between centers may be important.

Regarding the design of treatment portals for head-and-neck cancers regular meetings where radiotherapists from the participating centers present cases and corresponding treatment portals have decreased the differences between centers considerably.

Breast cancer is treated according to the DBCG protocol.A group of two physicians and two physicists will visit each center and review treatment techniques,dosimetry ,documentation and follow-up.

INTERCOMPARISON OF QUALITY CONTROL PROCEDURES IN RADIOTHERAPY IN THE NETHERLANDS

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Abstract

A grant was received from the Dutch government to accomplish the development and implementation of guidelines for quality control (QC) of radiotherapy equipment in The Netherlands. QC of electron accelerators, simulators, CT scanners, mould room equipment, dosimetry equipment and treatment planning systems will be considered in this project. The project started in September 1994 with an investigation of QC of medical electron accelerators as performed in all 21 radiotherapy institutions in The Netherlands. An extensive questionnaire on QC procedures of electron accelerators was sent to all centres with items related to safety systems, mechanical aspects, radiation leakage, beam data and dosimetry equipment (in total about 60 questions). From the answers the following conclusions can be drawn:

- There is a large variation in time spent on QC;
- This QC time strongly depends on the complexity of the linear accelerator;
- There is a large variation in frequency and tolerance levels of the various tests;
- The way QC of an item is performed differs considerably (extensive-comprehensive).

From these data recommendations specific for the situation in The Netherlands are being prepared and compared with other existing national and international reports. Similar procedures are underway for CT scanners and simulators while for the other equipment minimum guidelines still have to be developed.

1. INTRODUCTION

In The Netherlands there are 21 radiotherapy institutions. All these institutions have a quality assurance programme to ensure the safe and efficacious application of radiation for treatment of cancer. Up to now each institution applies its own criteria for such a QC-programme, guided by the many directives published about this subject. Because of the various guidelines employed and the differences in individual interpretation, a large variety of QC protocols is currently applied in The Netherlands.

This report describes the first results of the project 'Development and implementation of guidelines for quality control in radiotherapy in The Netherlands', initiated by the Netherlands Society on Clinical Physics, the Netherlands Society on Radiotherapy, the Dutch Society for Radiographers, the Netherlands Commission on Radiation Dosimetry (NCS) and financed by the ministry of Health, Welfare and Sports of the Dutch government. The principal aim of this project is to achieve a consensus on the different QC programmes and to recommend national minimum guidelines concerning QC procedures in radiotherapy for:

- *phase 1* : medical electron accelerators
- *phase 2* : simulators, CT scanners, dosimetry equipment
- *phase 3* : treatment planning systems

In order to realize this aim a physicist has been recruited for two years (G.J. Meijer). The set of minimum guidelines will be deduced from the currently employed protocols concerning QC in radiotherapy in The Netherlands together with recommendations found in various national and international reports. This report will discuss some of the results of the first phase of the project concerning the QC of medical linear accelerators.

2. INTER-INSTITUTIONAL SURVEY

To achieve insight in the currently employed QC protocols for medical electron accelerators in The Netherlands, an extensive questionnaire, with about 60 questions, has been sent to all radiotherapy institutions. The questionnaire covered many topics such as:

- safety systems
- mechanical parameters
- radiation leakage
- light field - photon field coincidence
- field flatness and symmetry
- beam energy
- absolute dosimetry
- wedge filters
- dose monitoring system
- arc therapy

Questions were asked concerning methods, frequencies, time required for the tests, tolerance levels (wherever relevant) as well as the training of the personnel performing these measurements. The institutions were also asked to return QC protocols and checklists when available, in order to obtain a better insight in the different methods used in the various institutions. Besides topics refering to different physical parameters, questions were asked concerning the overall time spent on QC per accelerator, the size of the institution (expressed as the total number of new patients) and available resources. All 21 radiotherapy institutions answered the questionnaire.

3. RESULTS OF PHASE I

3.1. OVERALL TIME SPENT ON QC

The institutions were asked how much time they monthly spent on QC of their accelerators. When different accelerators within a single institution required a different amount of time spent on QC, each accelerator had to be specified to the modalities available. The accelerators were subdivided into three different classes:

class I : accelerators with one photon beam and no electron beams
class II : accelerators with one photon beam and several electron beams
class III : accelerators with two (or more) photon beams and several electron beams

As expected the time spent on QC increases with the complexity of the accelerator and amounts on average 13.5, 15.5 and 22 hours per month for class I, II and III accelerators, respectively. It is also interesting to note that there exists a lot of variation in time spent on QC within each category, especially for dual (or triple) energy photon accelerators with several electron beam applications. In this category differences occurred from 8 hours up to over 30 hours monthly spent on QC of a single accelerator. Although it was specifically asked to give the time monthly spent on QC without the time spent on preventive maintenance, it might be that different interpretations may have contributed to the spread in the stated times spent on QC. Nevertheless the differences are striking and are probably due to differences in philosophy with regard to QC and the differences in resources and machine time available.

3.2. TEST FREQUENCIES

The test frequencies depend mainly on criteria such as the seriousness of the possible consequences of a malfunction and the likelihood of this malfunction. A number of reports has been published concerning QC of medical accelerators. Due to different interpretations, experience and available resources, a wide variety exists in the applied test frequencies of the various parameters. The smallest spread in test frequencies is found for the absolute dosimetry for photon

beams. About 60% of the institutions verifies the photon dose calibration on a weekly basis, four institutions have a(n) (additional) daily check procedure, often performed by the radiographers. Three institutions determine the absorbed dose only once every two weeks. An extreme large variation can be found in the beam quality check for photon beams as can be seen in Figure 1. One way to explain the wide spread of test frequencies is that the photon beam energy is implicitly checked by a symmetry interlock system. Consequently, different conceptions may occur concerning the need for additional tests.

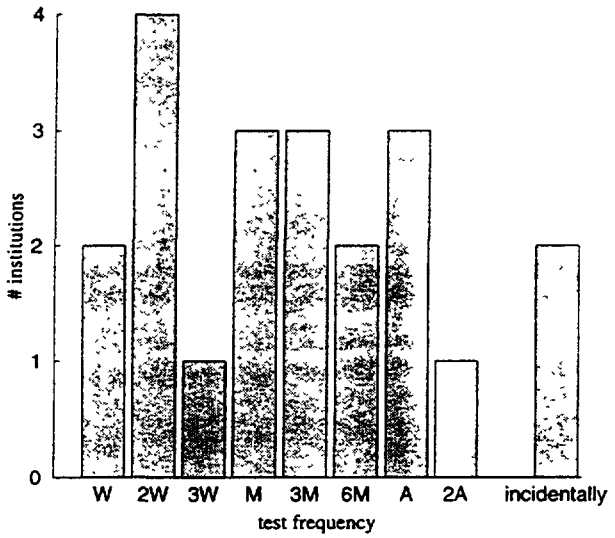

Figure 1: *Frequency distribution of the beam quality check of photon beams*

3.3. TOLERANCE LEVELS

A tolerance level can be defined in such a way that, whenever the equipment is tested and found in the range below the tolerance level, the equipment is suitable for high quality radiation therapy. The tolerance levels for dosimetric, geometric and mechanical parameters are limited by technical boundaries. The allowed uncertainties though have to be perceived as clinically acceptable. Because the technical boundaries are more or less the same within all institutions no extreme differences were found. When a parameter exceeds the tolerance level suitable actions should be taken. However, in special cases it might be very difficult to adjust a parameter or to repair a part of the accelerator easily and quickly. For this reason some institutions define an action level in addition to a tolerance level for some parameters. Whenever this action level is reached, it is essential that appropriate corrective action *immediately* is taken and no treatments will be given until suitable corrections have been performed.

3.4. TEST METHODS

A detailed description of the test procedures is essential when evaluating different QC-programmes, since a particular physical parameter can be tested in various ways, e.g. beam symmetry and field flatness. Many devices are nowadays commercially available for this purpose, such as linear detector arrays and quick check devices which easily check the dose rate in two orthogonal directions in a limited number of points. It should be noted that a check with such a device cannot directly be compared with a more time consuming test with a water phantom with a scanning mechanism, although both tests do provide valuable information.

4. NATIONAL RECOMMENDATIONS

The Netherlands Commission on Radiation Dosimetry (NCS) has recently drafted a comprehensive report on methods for QC of medical linear accelerators[7]. This NCS report covers a large number of QC aspects, including extensive descriptions of test methods, test frequencies and tolerance levels and is meant to serve as a model for good clinical practice. The results from the questionnaire were compared with this NCS report and with national and international recommendations [1, 2, 4, 5, 6, 8] and subsequently a minimum set of guidelines specific for the situation in The Netherlands was deduced.

5. CONCLUSIONS

The results of the questionnaire show a large variation in test frequencies, test methods and overall time spent on QC of electron accelerators and a somewhat smaller variation in tolerance levels. No correlation could be found between test frequency and tolerance level of a certain parameter and the type or make of the accelerator since the number of institutions was too small compared with the number and distribution of accelerators. From these data, together with national and international recommendations, a set of minimum requirements has been formulated specific for the situation in The Netherlands containing more than 30 test procedures including test frequencies and tolerance levels. These guidelines will be elucidated at various meetings and be compared with current practice in each situation. As a consequence the current large dispersal in test frequencies and test parameters might decrease. Phase 1 of the project has now been completed and phase 2 and 3 have been started to accomplish minimum guidelines for QC procedures for simulators, CT-scanners, dosimetry equipment and treatment planning systems.

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CURRENT STATUS OF QUALITY ASSURANCE IN FRANCE

(Abstract)

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1. Legal obligations: A full time qualified radiation physicist is compulsory whenever an X-ray beam (E>1 Mev) is used for medical purpose for any X-ray generator (E>12 keV), a dosimeter, regularly calibrated in national standard laboratory has to be available. In January 1995, periodic safety and quality control of high energy beams became a legal obligation.

2. Notional recommendations: In 1991, both radiotherapists and physicists communities strongly pointed out the need of routine quality assurance programme and established recommendations. *Special attention was given to the need of independent quality control through intercomparisons.*

3. National Intercomparisons available: A) The national standards laboratory **LPRI** provides users with a yearly programme enabling them either to calibrate their own dosimetric equipment in standard beams or to irradiate alanine probes in their own beam; (20 centres first run). So far, high energy photons or electrons beams are not included in these intercomparison. **B)** Local physicists associations organized their own intercomparison with independent equipment and team performing on site visits (>30 centres).

4. International Intercomparisons: A) 10 centres entered **IAEA TLD** postal intercomparison **B)** Since 1982, 14 centres including patients in **EORTC** trials benefit from several calibration checks through mailed dosimetry. At the end of 1993, Gustave Roussy Institute (Villejuif) became EORTC measuring centre. **C)** Within the framework of a clinical trial, 9 other centres were included in a quality assurance programme (Elanidazole Quality Assurance Group). **D)** Within the **EC,** an experimental Quality Assurance Network has been implemented. (Coordinating centre: University Hospital Saint Rafael (Leuven - Belgium)- Measuring centre: Gustave Roussy Institute (Villejuif)- National reference centre: G.F. Leclerc Cancer Centre (Dijon). In 1993, 9 French centres participated in the first runs.

5. Conclusion: Overall, 25% at least of the 194 French radiotherapy centres participated in an intercomparison and/or benefited from an external audit in the last 10 years. ***An application has been made to the French authorities for setting up a complete national quality assurance programme.***

CONTRIBUTION OF THE BELGIAN HOSPITAL PHYSICISTS ASSOCIATION TO QUALITY ASSURANCE IN RADIOTHERAPY

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Abstract

In 1987, the Belgian Hospital Physicists Association (BHPA) has started a program in order to uniformize the dosimetry in the Belgian radiotherapy centres Several initiatives were taken

a) dosimetry of photon beams

Endorsement of the Dutch dosimetry code of practice (NCS) (1), calibration of ionisation chambers in a common laboratory (Laboratory for standard dosimetry,RUG), on site visits where. besides mechanical checks of simulators and radiation units. absorbed dose was measured at different locations in a water phantom Since 1987, a total of 23 centres were visited involving 18 simulators. 17 cobalt units and 22 linear accelerators with 33 photon beams The energy of those photon beams ranged from 4 to 25 MV (2)

b) dosimetry of electron beams

Endorsement of the Dutch dosimetry code of practice(3) calibration of several parallel plate chambers following the recommendations of the IAEA (4)and the NCS . on site visits for local measurements in electron beams This program started last year. three centres were visited with a total of 23 energies ranging from 4 5 to 21 MeV

c) elaboration of procedures and common reporting form for daily quality control will be published

1. Introduction

The Belgian Hospital Physicists Association (BHPA) has contributed since 1987 to quality assurance in the radiotherapy centres. Her goal was to initialize a standardisation process of the dosimetry in Belgian radiotherapy centres. Indeed, at that time the calibration factors of the local standard ionisation chambers were obtained in different standard laboratories and a number of dosimetric protocols were in common use.
In order to present this contribution, a short description of the situation of radiotherapy

and radiophysics in Belgium is necessary. Legal requirements on equipment and staffing levels play an important role and have imposed a good level for radiotherapy departments.

2. The situation in Belgium

2.1. The current status of radiotherapy in Belgium

In Belgium, 27 radiotherapy centres with 40 linear accelerators and 21 Cobalt machines are available for a population of 9 millions inhabitants.

The state financing of a radiotherapy department is regulated by law. In 1991, the Royal decree (Arrêté Royal) of the 5th of April prescribed the requirements for a radiotherapy department to be approved as a « heavy » medico-technical department, in the meaning of the sophisticated department of the 84/466 European patient directive. Documentation, staffing levels and material requirements are included.

-Equipment. Beside the necessary radiation treatment units, treatment planning systems, localisation and immobilisation devices should be available as well as radiophysics equipment for dosimetry and quality control: electrometers, different ionisation chambers, water phantom, film dosimetry system, in-vivo dosimetry equipment....Unfortunately, no requirement was made for regular calibration of the dosimeters used for absolute dose measurements.

- Staffing levels concern each team working in the radiotherapy department : medical doctors, physicists, technologists, nurses, social and administration workers.

2.2. Legal requirements regarding clinical medical physicists

Two Royal Decrees have been published concerning medical physicists.

- A.R. 05/04/1991. There should be a full time physicist in the radiotherapy department per 750 patients. He is the responsible person for the physical dosimetry, the quality of the beam, the functioning of the different machines and the security of the radiation department. He shares the responsibility with medical doctors for the elaboration of treatment plans.

- A.R. 15/10/1993 in partial application of the article 5 of the EC 84/466 patient directive.

A qualified expert in radiophysics shall be available in radiotherapy , nuclear medicine and radiodiagnostics to organize and survey the necessary actions to ensure radiation protection of the patient and quality control of the installations.

Unfortunately, none of these texts define clearly who is the qualified expert, his education, role and responsibilities.

3. The contribution of the BHPA to quality assurance in radiotherapy

Long before the legislation has given us an important role for quality control, the BHPA has considered that is was the duty of medical physicists to set up programs to check the quality of the dosimetry of the beams and all the parameters for which they are responsible.

Our program started in 1987 with the aim of uniformizing the dosimetry in Belgian radiotherapy centres.

3.1. The dosimetry of photon beams

This program included three steps:

- calibration of the ionisation chambers in air Kerma in a Cobalt beam (N_K) in a standard laboratory (SSDL), the standard Dosimetry Laboratory of the University of Gent.
- endorsement of the Dutch code of practice for the dosimetry of high energy photon beams published by the Netherlands Commission on Radiation Dosimetry (1).

- on site visits organised on a voluntary base by a team of physicists of the BHPA. There are no legal requirements on external audit in radiotherapy in Belgium. Mechanical checks of simulators and treatment units were performed, following the EORTC methodology, as well as absorbed dose measurements.

Twenty three centres, representing 85% of Belgian centres were visited. Measurements were performed on 18 simulators, 17 Cobalt units and 22 linear accelerators delivering 33 photon beams whose energy were ranging from 4 to 25 MV.
The first results of this intercomparison have been published in 1993 (2).
Table 1 summarizes the results of mechanical and beam alignment checks of this study : digital display of angular scales appear to be the weakest point for every unit, even for recent one, as well as the isocenter indications of Cobalt units , some of them being rather old.
Quality index of the beams as well as percentage depth dose were checked, before performing absorbed dose measurements under reference conditions according to NCS code of practice and under non reference conditions. As an example, fig. 1 of the publication presents the distribution of the ratio of measured to stated absorbed dose under reference conditions.
Our results have been compared to those obtained in similar intercomparisons in different countries (Table 2). The distribution of values corrected for beam output variation reflects the reliability of the application of a common protocol, with a somewhat smaller range (5.5%) than in the other studies.

3.2 The dosimetry of electron beams.

Encouraged by the results obtained for photon beams, the BHPA extends her study to the dosimetry of electron beams, following a similar pattern.

The physicists are encouraged to adopt for their absolute dose measurements, the Dutch code of practice for high energy electron beams (3). The results of measurements using this protocol have been compared with those obtained using the technical report 277 (4) published by the International Atomic Energy Agency (IAEA) and were found to be consistent.

A quality audit program has been started in 1994. Three centres were visited and 23 energies ranging from 4.5 to 12 MeV have been measured. No conclusions can obviously be given today for such a small number of results.

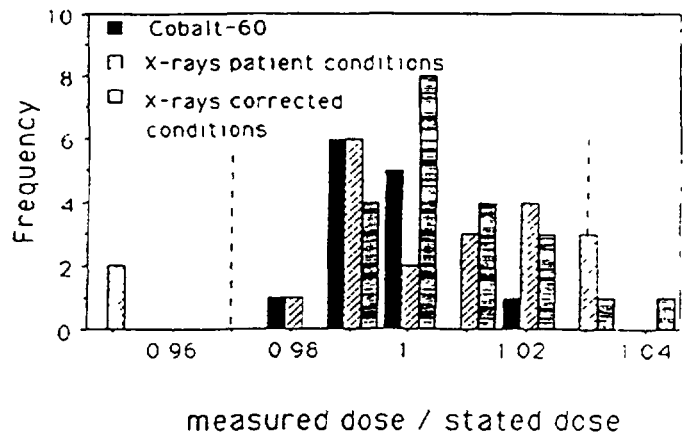

Figure 1. Distribution of the ratio of the measured to stated absorbed dose under reference conditions. The total number of beams is 13 and 21, the mean value is 0.999 and 1.006 (patient values) and the standard deviation is 0.010 and 0.023 for the cobalt-60 beams and the X-ray beams respectively. (from reference 2)

3.3. Periodical quality controls

For the commissioning of therapy machines, the BHPA has endorsed the protocol published by the Société Farnçaise des Physiciens des Hôpitaux (SFPH) for cobalt (5) and linear accelerators (6).
On this base, a document recommending test frequencies, tolerances and common reporting procedures is under development for periodical quality control checks.

4. Conclusion

Quality assurance in radiotherapy is a reality in Belgium, but mainly under voluntary base and without financial support and legal structure.

The Belgian Hospital Physicists Association contributes actively to the physical and dosimetrical part of it. The standardization process started in 1987 has given encouraging results for photon beams and helped to improve the quality and uniformity of dosimetry. This encourages the BHPA to continue this program, which is part of a larger one developed in collaboration with the Belgian Association for Radiotherapy and Oncology to cover all aspects of quality assurance in radiotherapy.

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MEDICAL ASPECTS OF QUALITY ASSURANCE IN THE UNITED STATES

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Abstract

Cancer management by radiation oncologists in the United States of America occurs in about 1500 separate facilities throughout the 50 states. These Radiation Oncologists have been concerned about assessing and improving the quality of care delivered in the United States to the 97% of all patients who are not on prospective clinical trials.

This national concern has been addressed by the American College of Radiology, along with other national societies, through various committees that have addressed the medical and physical sides of the issue. This presentation will concern itself with the medical side of quality assurance as developed in the United States over the last 10-15 years. The patterns of Care Study was at the heart of these developments in that it provided accurate national baseline data on structure of facilities, processes of care and outcome of care for comparisons.

Three powerful national programs have been developed, and their acceptance and utilization in the United States have been accelerated by the recent development of managed competition.

The first program was a model quality assurance program for day to day use in an individual radiation oncology facility. In addition to maintaining the physical aspects of the department, the medical side includes indicator items in patient evaluation and treatment and other measures that are periodically monitored. The entire process is comprehensive and is accepted by the Joint Commission on Hospital Accreditation as being satisfactory evidence of ongoing quality assurance and quality improvement.

The second program was the development of a set of standards for radiation oncology in the United States. These standards were developed in the past and have recently been expanded into a more comprehensive document that describes the appropriate performance by this specialty.

The third program was a Practice Accreditation program. The Practice Accreditation program is an on-site review of structure and processes of patient care by a radiation oncologist and data manager. This intense on-site review generates data that is then compared to similar facilities and to national averages to judge the adequacy of patient management in the facility. We have observed recently that various managed care programs require this practice accreditation before their patients can be treated in contracting facilities.

Lastly, the Council of the American College of Radiology has made some extremely positive statements in support of improving radiation oncology practice, and the positive effects of these council resolutions can be clearly shown on the practice.

1. *INTRODUCTION*

Cancer management by the 2,871 practicing radiation oncologists in the United States of America occurs in 1,545 separate facilities throughout the 50 states. More than 556,000 new patients are treated each year.[1] These radiation oncologists have been concerned about assessing and improving the quality of care delivered in the United States to the 97% of all patients who are not on prospective clinical trials. Most clinical trials groups maintain an ongoing separate quality assurance process.

This national concern has been addressed by the American College of Radiology (ACR), along with other national societies and, through various committees, the ACR has addressed the medical and physical sides of the issue. This presentation will concern itself with the medical aspects of quality assurance as developed in the United States over the last 10-15 years. Others will address the physics programs. The Patterns of Care Study (PCS)[a] was at the heart of these developments in that it provided accurate national baseline data on structure of facilities, processes of care and outcome of care for comparisons.[2, 3, 4, 5]

2. *QUALITY ASSURANCE PROGRAMS*

Table 1 lists eight separate programs developed by the ACR and directed to improving patient treatment. Four of these programs will be developed in more detail.

The first program was a model quality assurance program for day to day use in an individual radiation oncology facility. This program covers the structure, processes and outcomes of care. In addition to defining mechanisms for maintaining the physical aspects of the department, the medical side includes the periodic assessment of items in patient evaluation and treatment and periodic outcome assessments. The entire process is comprehensive and is accepted by the Joint Commission on Hospital Accreditation as being satisfactory evidence of ongoing quality assurance and quality improvement.

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[a] Gerald E. Hanks, M.D., Principal Investigator

The second program was the development of a set of standards for radiation oncology in the United States. These standards were developed in the past and have recently been expanded into a more comprehensive document that describes the appropriate performance by this specialty. The endorsement of these standards by the Council of the ACR has established them as peer accepted national standards. A portion of the standards includes the staffing and work load described in the "Blue Book"[b] .

The third program was a Practice Accreditation program. The Practice Accreditation Program is an on-site review of structure and processes of patient care in an individual facility by a radiation oncologist and data manager (Table 2). This intense on-site review generates data that is then compared to averages for facilities of similar size and composition and to national averages to judge the adequacy of patient evaluation and management in the examined facility. We have observed recently that various managed care programs require this practice accreditation before their patients can be treated in contracting facilities.

Lastly, the Council of the American College of Radiology has made some extremely positive statements in support of improving radiation oncology practice, and the positive effects of these council resolutions can be clearly shown on the practice (Table 3). In the first, the council of the College passed a resolution eliminating the use of short SSD cobalt units as the only treatment units in a facility. At the time this action was taken there were more than 100 such equipped facilities. In four years there were none. A

TABLE 1
QUALITY ASSURANCE PROGRAMS
PATTERNS OF CARE - AMERICAN COLLEGE OF RADIOLOGY

- Individual Facility Accreditation Program
- Problem Resolution Consultation Program
- Model QA Program - Medical
- Model QA Program - Physics
- Standards for Radiation Oncology
- Model QA Program - Nursing in Radiation Oncology
- Resolutions of the Council of the ACR
- Inter-Society Activities

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[b] "Radiation Oncology in Integrated Cancer Management." Report of the Inter-Society Council for Radiation Oncology, November, 1991.

TABLE 2
INDIVIDUAL FACILITY ACCREDITATION PROGRAM

- Voluntary(managed care)
- Outside Record Review 25 Curative in 5 sites, 20 Palliative
- Workup and Treatment Scores compared to similar facility & national averages
- Committee Judgement on Accreditation 3 years
- Recommend Corrective Action & Resurvey

TABLE 3
RESOLUTIONS OF THE COUNCIL OF THE ACR

- Short SSD Cobalt
- Treatment Simulation
- Physician Availability

second resolution required that all patients have access to treatment simulation. This resolution effectively stopped the construction of faciities without a treatment simulator. The third resolution required the immediate availability of a qualified physician to the treatment facility. This reduction contributed to eliminating the treatment of patients without physician supervision.

All of their activities were aided by data accumulated in the sequentional PCS surveys. The remarkable acceptance of these mechanisms of improvement by the practicing radiation oncologists in the United States is a credit to their desire and committment to help their patients.

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IMPLEMENTATION OF QA PROGRAMMES AT THE INSTITUTIONAL, NATIONAL, REGIONAL AND INTERNATIONAL LEVELS. ROLE OF NETWORKS. AN AUSTRALIAN PERSPECTIVE

(Abstract)

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Measurement standards for physical quantities in Australia are the responsibility of the National measurement Laboratory (NML), which is part of commonwealth Scientific Industrial Research Organization (CSIRO) Division of Applied Physics. In the medical field the QA programme in Australia is one where all hospitals have traceability to the relevant Australian measurement standard. The national standard of air kerma/exposure is maintained by the Australian Radiation Laboratory as an agent of NML. The national standard of absorbed dose is maintained under a similar arrangement by the Australian Nuclear Science and Technology Organization (Ansto). Both Ansto and ARL maintain working standards of the other quantity. Instruments used by hospitals involved in radiotherapy or the measurement of patients doses arising form X-ray diagnosis are calibrated on a voluntary three yearly cycle, the vast majority by the ARL. Most matters relating to medical and protection related use of radiation are handled by ARL which is part of the Commonwealth Department of Human Services and Health. Matters of an industrial nature are mostly handled by Ansto.

ARL regularly intercompares its standards with those maintained by the International Bureau of Weights and Measures (BIPM) and with those of other primary standards laboratories as the occasion arises. The reliability of the ARL and Ansto standards is also maintained by regular supervisory meetings between NML, ARL and Anso, and intercalibrations between ARL and Ansto. The physical measurements themselves are performed in accordance with Australian Standard AS 3902-1987, which is identical with ISO 9002:1987.

As an independent QA measure of dose delivery in hospitals ARL distributes TLDs obtained from the IAEA for exposure in water phantoms and subsequent evaluation by the IAEA. In the longer term ARL hopes to institute a similar system on a cost recovery basis. The major advantage of such a check of a hospital's performance is that it serves to promote user confidence in the adequacy of dose measurements made in a hospital in a manner which is completely independent of the Australian measurement system.

Professional matters in relating to the training and qualifications of persons working in physical QA in Australia as it relates to dose in radiotherapy are overseen by the Australian college of Physical Scientists and Engineers in Medicine and its various working parties.

A QUALITY ASSURANCE NETWORK FOR RADIOTHERAPY CENTRES IN ITALY

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Abstract

Since 1993 a dosimetry intercomparison of Co60 photon, high energy photon and electron beams has been carried out in 17 centres in Italy on 43 beams for the Associazione Italiana di Fisica Biomedica (AIFB). The network structure is described and the results of the intercomparison are presented. The Italian primary laboratory of the Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti (INMRI) has partecipated providing the calibrated transfer dosimeter and acting as measuring centre. The ratio of the absorbed dose to water measured by the partecipating centre to that stated by the INMRI has been determined with the Fricke chemical dosimeter. The mean value of the frequency distribution of the ratios is 1.009 and the standard deviation 0.025. Data are disregarded according the type and energy of the beams. The electron beams show the greatest deviations. The results are compared to those from other intercomparisons performed in Italy.

1. INTRODUCTION

Since 1971 clinical evidence of the necessity of keeping the accuracy of ±5% in the delivery of absorbed dose was pointed out [1] and in 1976 ICRU believed this level to be achievable [2]. Some authors [3,4] have proposed even lower tollerance level, of the order of 3%, in dose delivery to the patient. All the numerous processes involved in radiotherapy contribute to the overall uncertainty which is a suitable combination of random (type A) and systematic (type B) uncertainties. Recently substantial improvements have been made in patient data acquisition, dosimetry, treatment planning and simulation, however it has been realized that only a concerted interdisciplinary action ensures the propter delivery of the prescribed dose to the patients Therefore Quality Assurance procedures has started to be introduced to ensure consistenty, initially for inter-institutional clinical trials and later for individual radiotherapy centre. An independent review of the whole radiotherapy process has been found to be very effective to assess sources of the discrepancies eventually observed. One of the major source of uncertainty in the assessment of the absorbed dose in the target volume and surrounding structures is the determination of the absorbed dose at the reference point in clinical beams. The overall uncertainty in the determination of absorbed dose to water, given as one standard deviation in the

combined uncertainty, has been estimated as 2.7% for Co60 beams, 3.4% for megavoltage x ray and 3.8% for electron beams [5]. The uncertainty in the calibration chain has been evaluated from the determination of air kerma at a standard laboratory to the measurements of absorbed dose in the reference point at the user's beam at the hospital. A dosimetric intercomparison performed by an external body is very effective to point out any sources of deviations, permitting to improve the overall uncertainty in this specific step [6, 7, 8]. It is difficult only for an internal action to reach the same results.

2. THE ITALIAN INTERCOMPARISON

In 1991, in the frame of "Europe against Cancer" of the EC Committee, a European Quality Assurance Network (EQAN) has been set up for the European centres. One of the aim of the programme was to check with mailed dosimeters the beam output in radiotherapy centres in several European countries. Another aim of the programme was to encourage the transfer of technical knowledge and the guidelines to national level, if possible, keeping the core procedure identical in every country. The EQAN action promoted to establish a very similar structure of organization for Italy.

In 1993 the Associazione Italiana di Fisica Biomedica (AIFB) created a working group, in which the University of Florence acts as Co-ordinating Centre (CC), to organize and perform dosimetry intercomparisons in reference conditions. The University of Florence has also acted as national reference centre in the European Quality Assurance Network and in a previous national intercomparison, granted by the Italian National Council of Researches (CNR) [9]. This latter was performed in 1982-84 with the partecipation of all the public radiotherapy centres having Co60 units installed. The output of 72 Co60 beams was tested in reference condition with mailed TLD dosemeter.

3. THE NETWORK STRUCTURE

Actually there are 93 public radiotherapy centres in Italy [10], using 72 linacs, 46 with electron beams, 83 Co60 and 6 Cs137 units. Until now 17 centres with a total amount of 43 beams have partecipated to the AIFB intercomparison. The network structure is shown in fig.1. The Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti (INMRI), which is the Italian national primary standard laboratory, acts as Measuring Centre (MC). The IMNRI has prepared and calibrated the dosimeter utilized in the intercomparison. The transfer dosimeter is sent to the CC that distributes it to the Partecipating Centres (PC). Time schedule is established by the CC in order to have the dosimeter irradiated in the same week. The CC receives the irradiated dosemeter and the data sheets filled by the PC, describing the procedures followed for the dose determination. The MC measures doses, sending the results to the CC which makes an analysis of the possible causes of discrepancies between dose quoted by the PC and dose measured by the MC. In case of difficulties a standing

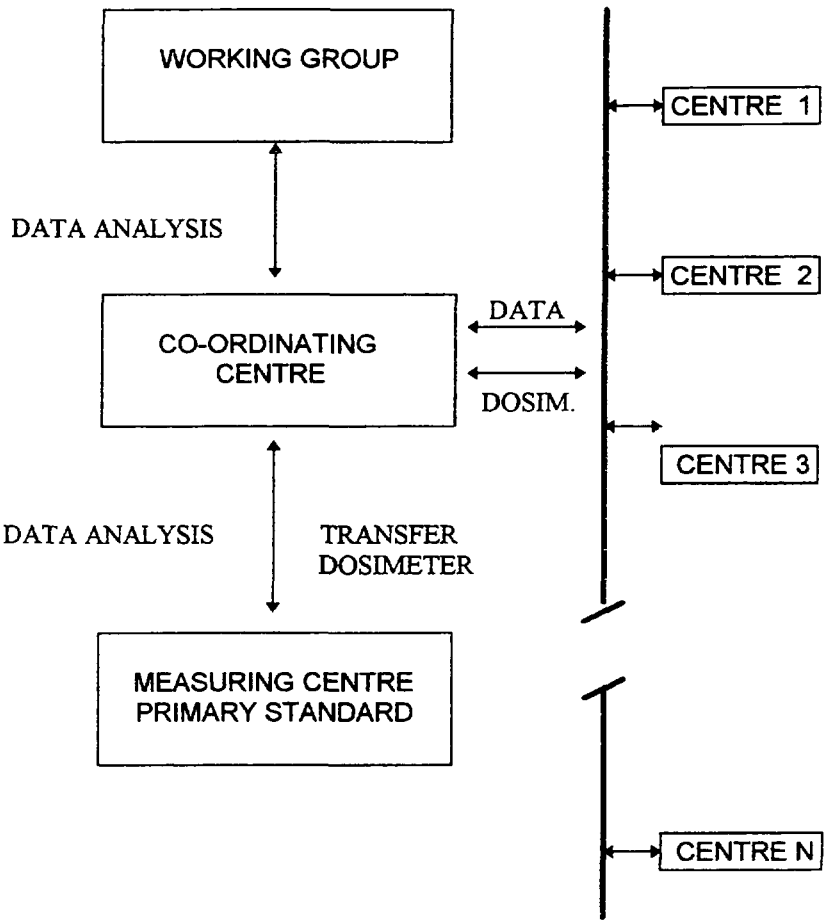


FIG. 1. The network structure.

working group, composed by expert from Universities and Hospitals, makes a further analysis. The CC send confidencially the results and comments to the PC. Measurements made during the intercomparison are intended to verify the calibration of beams and the procedures used in dose determination. The main goal of the programme is to ensure by review that the output of the units are within ±2% of that stated.

4. DOSIMETER USED IN THE INTERCOMPARISON

For the determination of absorbed dose to water the Fricke dosimeter is used. The transfer dosemeter consists in a flame sealed ampoule of Pyrex glass, 3 cm^3 in volume, lenght 36 mm., outer diameter 11 mm. wall thickness 0.5 mm, filled with the Fricke solution (ferrous sulphate). The Fe^{3+} solution is prepared following the Italian Protocol for Photon and Electron Dosimetry in Radiotherapy [11].

The Fricke ferrous sulphate dosimeter has been chosen with respect to its accuracy, reproducibility and linearity of response. The presence of the wall introduce a small beam quality dependence as the perturbation factor varies from nothing in a Co60 beam up to 2% in a 24 MV beam [12].

The dosimeter is calibrated, at INMRI, against the Italian primary absorbed dose to water standard [13] for Co60 gamma rays. The transfer dosimeter can be used for Co60, MVRX and for electron of mean energy at the phantom surface less than 14 MeV.

The calibration factor $N_{w,F}$ of the transfer dosimeter at the Co60 beam is given by

$$N_{w,F} = D_w / \Delta A$$

where D_w is the absorbed dose to water for Co60 gamma ray without dosimeter and ΔA is the increase of absorbance due to irradiation during the calibration. Corrections for the irradiation and measuring temperature are applied.

The absorbed dose at the radiotherapy centre is evaluated by

$$D_w = \Delta A \quad N_{w,F} \quad (f\, p_{wall}\, p_{air})_Q \,/\, (f\, p_{wall}\, p_{air})_{Co60}$$

where f is the factor which corrects the non equivalence between water and Fricke solution, p_{wall} is the the correction factor which takes into account the perturbation introduced by the wall of the ampoule, p_{air} is the correction factor for the presence of residual air in the ampoule. The subscripts Q and Co60 are refer, respectively, to the partecipating centre beam quality and Co60 photon radiation. The factor f and p_{wall} are taken from Ma and Nahum (1993a) [14] for photon beams and from Ma and Nahum (1993b) [15] for electron beam, p_{air} has been taken from Ma et al. [12].

In the Table I the uncertainties (1 σ) in the experimental determination of the absorbed dose to water with the use of the transfer dosimeter are reported. The overall uncertainty of the transfer dosimeter is 0.8% for Co60 photons, 0.95% for high energy photons and 1.1% for electrons with mean energy at the phantom surface less than 14 MeV. The perturbation effect corrections increase with decreasing electron energy and so the dosimeter cannot be used with electron beams with a mean energy lower than 15 MeV as large corrections are needed, different from the applied ones, to mantain the 1.1% overall uncertaintiy.

5. INTERCOMPARISON PROCEDURES

The partecipating centre receives three ampoules to be irradiated for each beam quality and two supplementary ampoules for control purpose. The centre is requested to irradiate the three ampoules separately at a minimum dose of 30 Gy in reference conditions.

The dosimeter is irradiated in a water tank using a perspex support send to the centre together with the dosimeter batch. The holder is represented in fig.2. A graduated spacer and a disk with a marker in the centre permit the precise and reproducible positioning of the dosimeter at the reference depth on the beam axix. The spacers and the disk are taken off during the irradiations. The radiotherapy centre is also asked to describe the procedures adopted to determine the absorbed dose to water and to give information on the dosimeter in use and its calibration.

TABLE I UNCERTAINTIES (1σ) IN THE EXPERIMENTAL DETERMINATION OF THE ABSORBED DOSE-TO-WATER BY THE TRANSFER DOSIMETERS (Adapted from[16])

	Uncertainty (%)		
	Co 60	MV photons	Electrons
Dosimeter calibration at INMRI			
Primary Standard D_w [13]	0 5	0 5	0 5
Absorbance A	0 3	0 3	0 3
Calibration Factor D_w/A	0 6	0 6	0 6
Dosimeter irradiation at the centre			
Absorbance	0 5	0 5	0 5
p_{wall}	0 3	0 3	0 3
$(\varepsilon G)_Q/(\varepsilon G)_c$ (1)		0 5	0 5
D_w (2)	0 8	0 95	1 10

(1) $(\varepsilon G)_Q/(\varepsilon G)_c$ = 1 000±0 005 (Shortt et al Phys Med Biol (1993), 1937-1955)

(2) Absorbed dose to water as determined at INMRI for the dosimeters irradiated at the radiotherapy centres

6. RESULTS OF THE INTERCOMPARISON

The ratio D_m / D_s has been determined, where D_m is the absorbed dose-to-water measured at INMRI and D_s is the absorbed dose-to-water stated by the partecipating radiotherapy centre. Fig.3 shows a histogram including a total of 43 beams, independently of the type and quality of the beams. Results can be disregarded according the type and energy of the beams. Fig.4 shows the three histograms obtained respectively for Co60 photons, high energy photons and electrons.

The 17 radiotherapy centres, which have partecipated until now to the AIFB intercomparison, represent the 18.3% of the Italian centres.

In Table II a summary of the dosimetry intercomparison performed in Italy in reference condition is reported. Fig.5 and Fig. 6 show the histograms reporting data obtained in the CNR and EQAN intercomparisons to permit a comparison with the AIFB one. Table III reports a summary of the results.

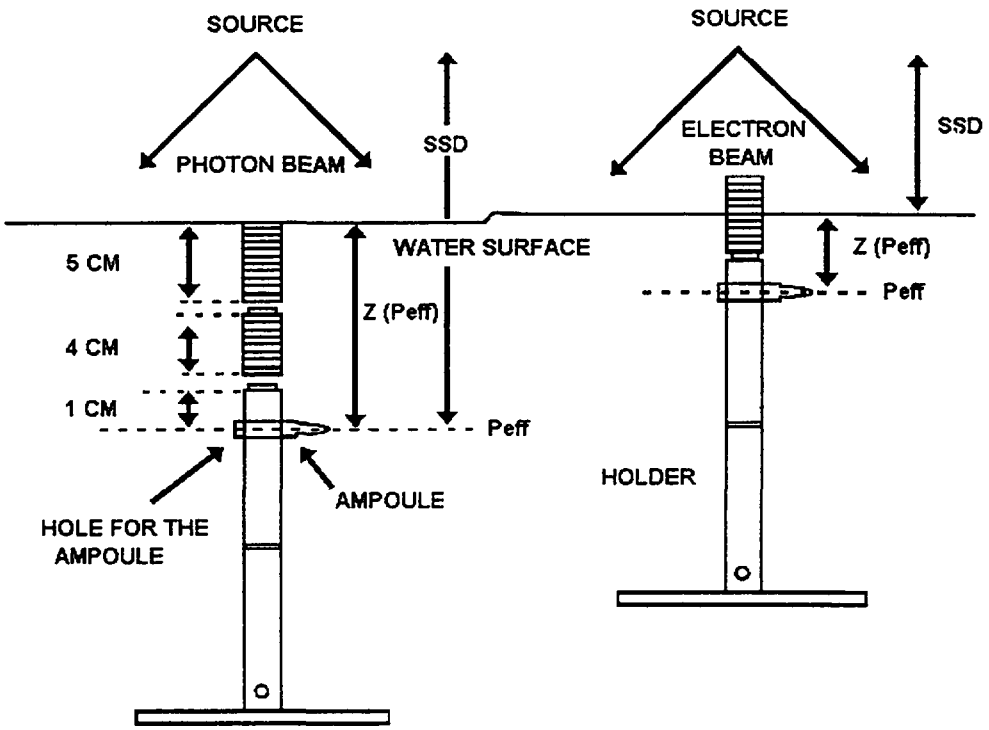


FIG 2 The PMMA transfer dosimeter holder

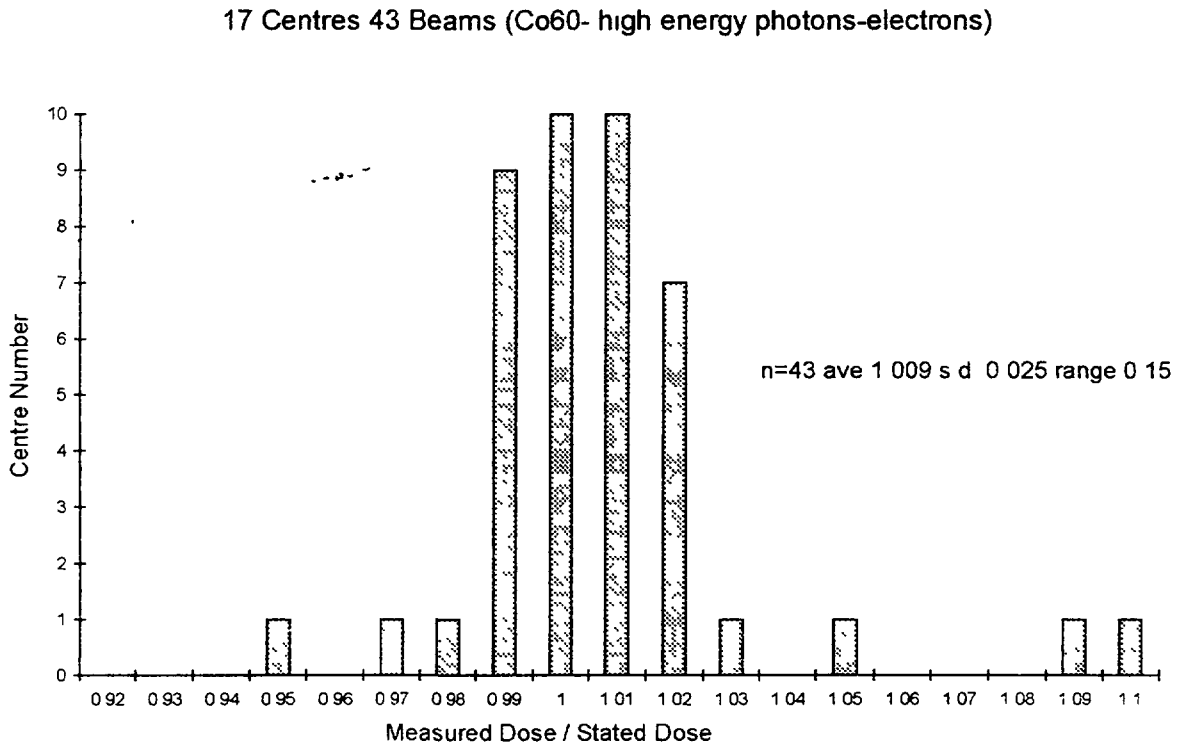
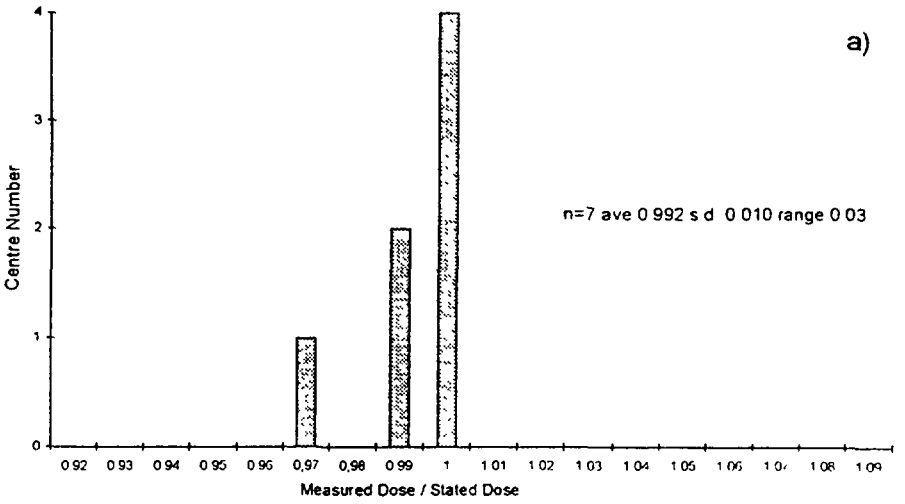
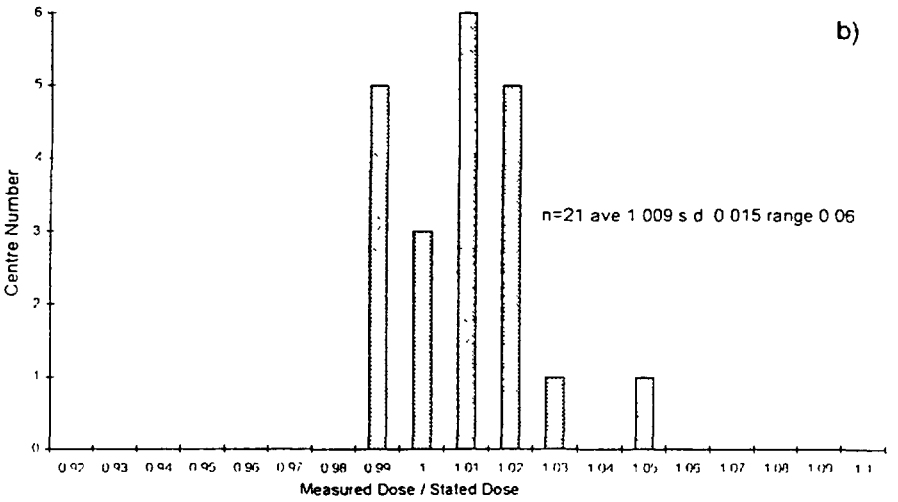


FIG 3 Results of the AIFB intercomparison





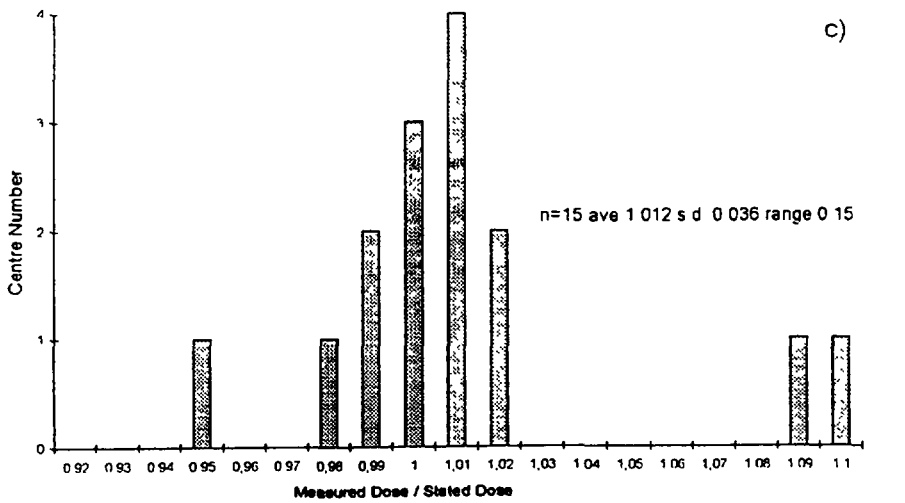


FIG. 4. Results of AIFB intercomparison for (a) Co60 photon, (b) high energy photons and (c) electrons.

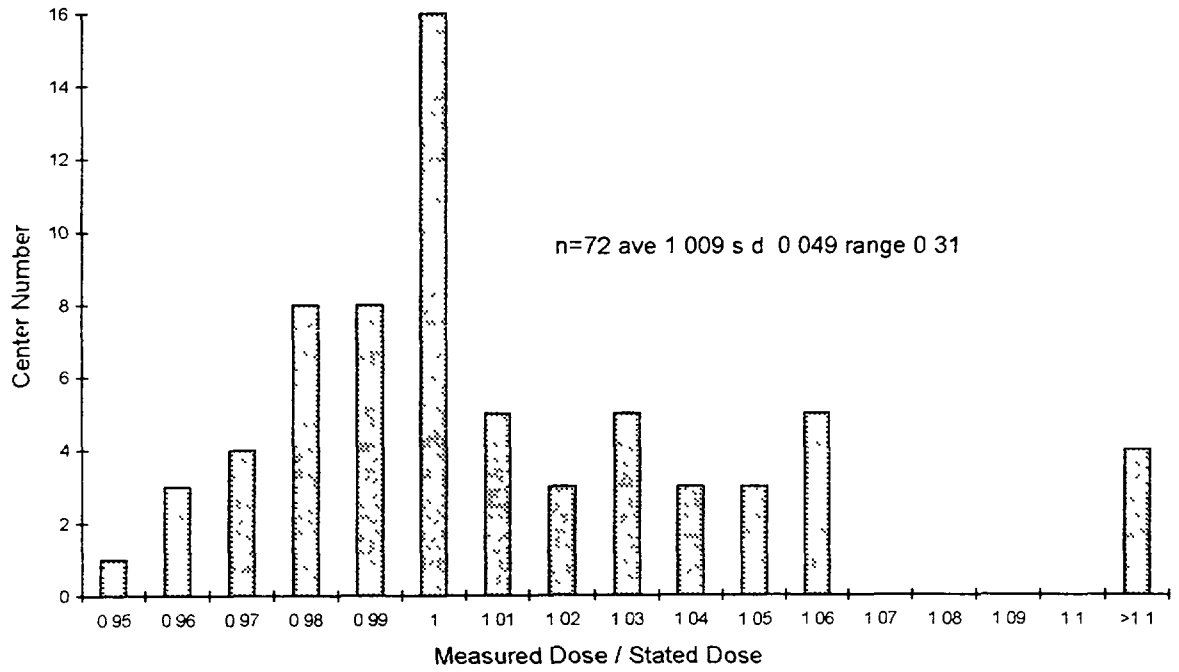


FIG 5 Results of the 1982-84 CNR intercomparison

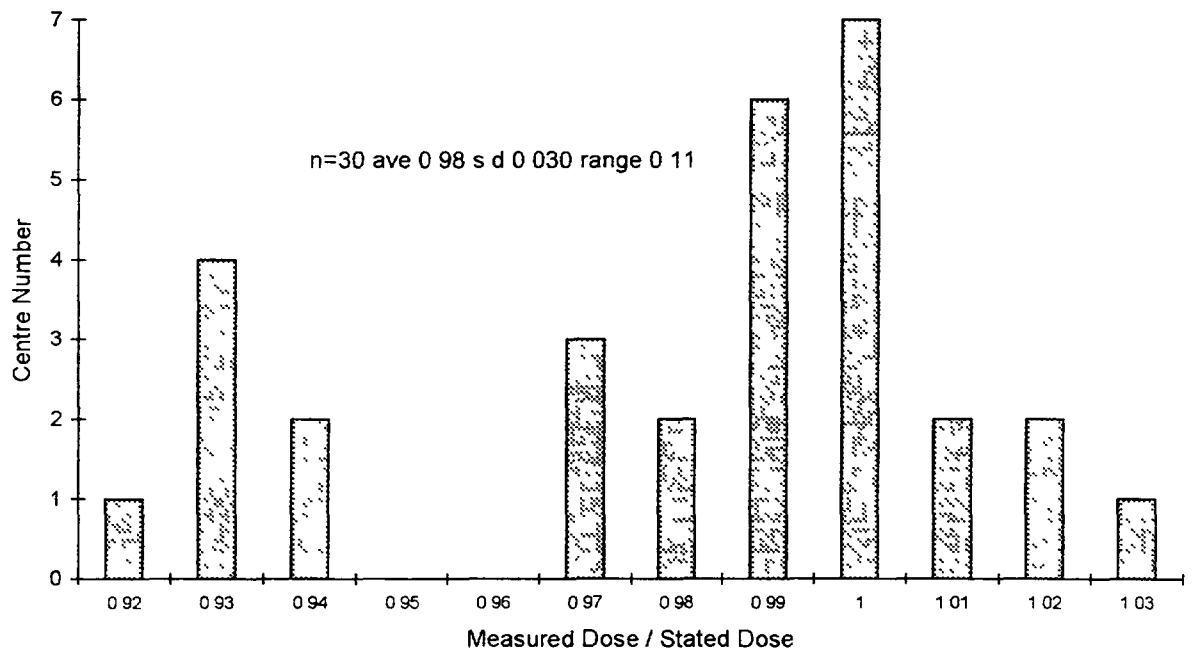


FIG 6 Results of the EQAN intercomparison in Italy

TABLE II DOSIMETRIC INTERCOMPARISONS IN THE REFERENCE POINT CARRIED OUT IN ITALY

Intercomparison	Beams	Number	Mean	σ	Range
CNR 1982-84	Co 60	72	1 009	0 049	0 31
EQAN Italy	Co 60 MV photons	30	0 980	0 030	0 11
AIFB	Co60, MV photons, electrons	43	1 009	0 025	0 15
	Co 60	7	0 992	0 010	0 03
	MV photons	21	1 009	0 015	0 06
	Electrons	15	1 012	0 036	0 15

The percentage of deviation on the ratios of the measured dose and the stated dose is shown in TableIII. Three different levels of deviation are considered: an acceptable level according a $<2\%$ deviation, a level according a 2-5% deviation and an action level according a $>5\%$ deviation. The overall uncertainty of the Fricke transfer dosimeter was used to establish the acceptance level. A further level 2-5% was indicated as related to minor deviations. In case of deviations larger than 5% it would be possible to point out and to remove the causes of errors.

For the CNR and EQAN intercomparisons data are similarly reported without considering the uncertainties associated to the utilized transfer dosimeters in order to compare the data.

7. CONCLUSION

The distribution of the ratio measured dose over stated dose is rather asymmetrical and shows a tail up to 1.1. If disregarded data are considered the form of distribution is almost entirely due to electron beam results, confirming the greater difficulties in electron dosimetry. The results indicate better distributions with high energy and Co60 photon beam even if some improvements are possible.

TABLE III PERCENTAGE OF DEVIATION ON THE RATIOS OF THE MEASURED DOSE AND THE STATED DOSE

	Deviation (%)			
Beams	<2%	2-5%	>5%	
Co 60	55	26 3	18 7	CNR
	71	22	7	EQAN
	85 7	14 3	-	AIFB
MV photons	44	19	37	EQAN
	90 5	9 5	-	AIFB
Electrons	80	6 7	13 3	AIFB

Compared with results of EQAN intercomparison, partially performed in the same period, the AIFB results indicate a general better agreement between measured and stated dose. This is essentially due to relative low number of partecipating radiotherapy centres. In the EQAN intercomparison a higher number of small radiotherapy centre was involved and so the possible explanation of the differences can be the reduced availability of accurate dosimetric equipment and the reduced possibility in regular cultural exchange with major centre. The difference with CNR intercomparison, far in time, are due to the introduction of new dosimetric protocols and reveals the improvement in the dosimetric chain obtained recently.

All data underline the utility of intercomparisons as valuable tool to be included in local Quality Assurance programme to assure that the physical dose to tumor and normal tissue surrounding tumor may be delivered in accordance with the recommended and advisable accuracy.

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