Chapter 12
Quality Assurance of External Beam Radiotherapy

This set of 146 slides is based on Chapter 12 authored by D. I. Thwaites, B. J. Mijnheer, J. A. Mills of the IAEA publication (ISBN 92-0-107304-6):

Radiation Oncology Physics: A Handbook for Teachers and Students

Objective:

To familiarize students with the need for and concept of a quality system in radiotherapy as well as with recommended quality procedures and tests.

IAEA
International Atomic Energy Agency

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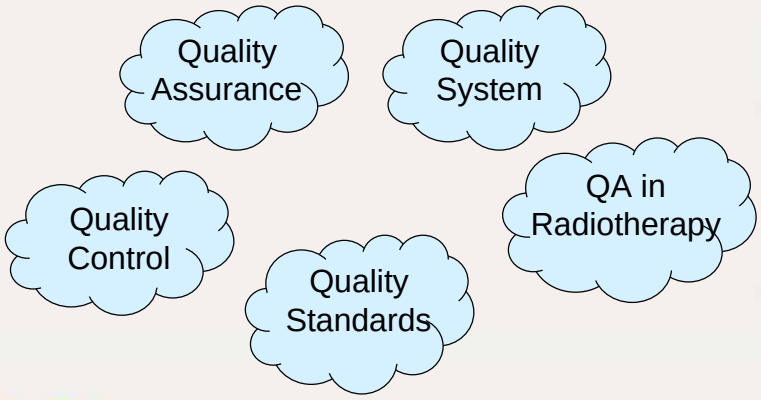
CHAPTER 12. TABLE OF CONTENTS

12.1 INTRODUCTION
12.1.1 Definitions

- Commitment to Quality Assurance (QA) needs a sound familiarity with some relevant terms, such as:



12.1 INTRODUCTION
12.1.1 Definitions

- Quality Assurance
  - Quality Assurance is all those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy the given requirements for quality.
  - As such, QA is wide ranging and covering:
    - Procedures
    - Activities
    - Actions
    - Groups of staff.
  - Management of QA program is called Quality System Management.

12.1 INTRODUCTION
12.1.1 Definitions

- Quality Control
  - Quality Control is the regulatory process through which the actual quality performance is measured, compared with existing standards, and the actions necessary to keep or regain conformance with the standards.
  - Quality control forms part of quality system management.
  - Quality Control is concerned with operational techniques and activities used:
    - To check that quality requirements are met.
    - To adjust and correct performance if requirements are found not to have been met.

12.1 INTRODUCTION
12.1.1 Definitions

- Quality Standards
  - Quality standards is the set of accepted criteria against which the quality of the activity in question can be assessed.
  - In other words: Without quality standards, quality cannot be assessed.

12.1 INTRODUCTION
12.1.1 Definitions

Quality System

- Quality System is a system consisting of:
  - Organizational structure
  - Responsibilities
  - Procedures
  - Processes
  - Resources

  required to implement a quality assurance program.

12.1 INTRODUCTION
12.1.1 Definitions

Quality assurance in radiotherapy

- Quality Assurance in Radiotherapy is all procedures that ensure consistency of the medical prescription, and safe fulfillment of that radiotherapy related prescription.
- Examples of prescriptions:
  - Dose to the tumour (to the target volume).
  - Minimal dose to normal tissue.
  - Adequate patient monitoring aimed at determining the optimum end result of the treatment.
  - Minimal exposure of personnel.

12.1 INTRODUCTION
12.1.1 Definitions

Quality standards in radiotherapy

- Various national or international organizations have issued recommendations for standards in radiotherapy:
  - World Health Organization (WHO) in 1988.
  - American Association of Physicists in Medicine (AAPM) in 1994.
  - European Society for Therapeutic Radiology and Oncology (ESTRO) in 1995.
  - Clinical Oncology Information Network (COIN) in 1999.

12.1 INTRODUCTION
12.1.1 Definitions

Quality standards in radiotherapy

- Other organizations have issued recommendations for certain parts of the radiotherapy process:
  - International Electrotechnical Commission (IEC) in 1989.
  - Institute of Physics and Engineering in Medicine (IPEM) in 1999.
- Where recommended standards are not available, local standards need to be developed, based on a local assessment of requirements.

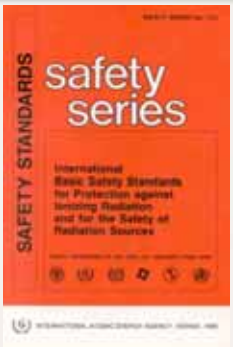
12.1 INTRODUCTION
12.1.2 The need for QA in radiotherapy

Why does a radiotherapy center need a quality system?

- The following slides provide arguments in favour of the need to initiate a quality project in a radiotherapy department.

12.1 INTRODUCTION
12.1.2 The need for QA in radiotherapy

1) You must establish a QA programme



- This follows directly from the Basic Safety Series (BSS) of the IAEA.
- Appendix II.22 of the BSS states: "Registrants and licensees, in addition to applying the relevant requirements for quality assurance specified elsewhere in the Standards, shall establish a comprehensive quality assurance program for medical exposures with the participation of appropriate qualified experts in the relevant fields, such as radiophysics or radiopharmacy, taking into account the principles established by the WHO and the PAHO."

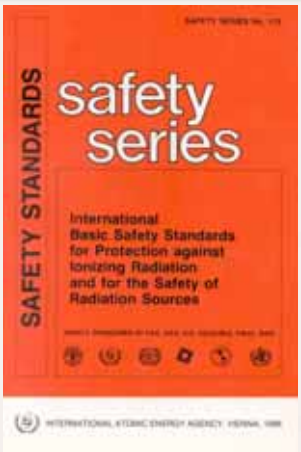
12.1 INTRODUCTION
12.1.2 The need for QA in radiotherapy

1) You must establish a QA programme

- Appendix II.23 of the BSS states: Quality assurance programs for medical exposures shall include:

  (a) Measurements of the physical parameters of the radiation generators, imaging devices and irradiation installations at the time of commissioning and periodically thereafter.

  (b) Verification of the appropriate physical and clinical factors used in patient diagnosis or treatment …"



12.1 INTRODUCTION
12.1.2 The need for QA in radiotherapy

2) QA programme helps to provide "the best treatment":

- It is a characteristic feature of the modern radiotherapy process that this process is a multi-disciplinary process.
- Therefore, it is extremely important that:
  - Radiation oncologist cooperates with specialists in the various disciplines in a close and effective manner.
  - Various procedures (related to patient and the technical aspects of radio-therapy) will be subjected to careful quality control.
- The establishment and use of a comprehensive quality system is an adequate measure to meet these requirements.

12.1 INTRODUCTION
12.1.2 The need for QA in radiotherapy

3) QA programme provides measures to achieve the following:

- Reduction of uncertainties and errors (in dosimetry, treatment planning, equipment performance, treatment delivery, etc.)
- Reduction of the likelihood of accidents and errors occurring as well as increase of the probability that they will be recognized and rectified sooner
- Providing reliable inter-comparison of results among different radiotherapy centers
- Full exploitation of improved technology and more complex treatments in modern radiotherapy

12.1 INTRODUCTION
12.1.2 The need for QA in radiotherapy

Reduction of uncertainties and errors.....

Human errors in data transfer during the preparation and delivery of radiation treatment affecting the final result: "garbage in, garbage out"

Leunens, G; Verstraete, J; Van den Bogaert, W; Van Dam, J; Dutreix, A; van der Schueren, E
Department of Radiotherapy, University Hospital, St. Rafaël, Leuven, Belgium

Abstract

Due to the large number of steps and the number of persons involved in the preparation of a radiation treatment, the transfer of information from one step to the next is a very critical point. Errors due to inadequate transfer of information will be reflected in every next step and can seriously affect the final result of the
l number of
464 new trea
roneous data
transfer has
ffected 26%
(119/464) of
geographical
miss or impo
volume, thus
increasing the complications or decreasing the tumour control probability, if not corrected. Such major

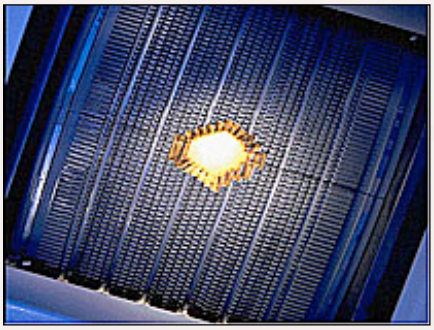
Radiother. Oncol. 1992: > 50 occasions of data transfer from one point to another for each patient.
If one of them is wrong - the overall outcome is affected.

12.1 INTRODUCTION
12.1.2 The need for QA in radiotherapy

Full exploitation of improved technology.....

- Example of improved technology:

  Use of a multileaf collimator (MLC)



12.1 INTRODUCTION
12.1.3 Requirements on accuracy in radiotherapy

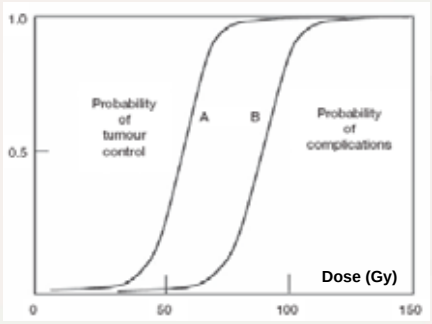
- Many QA procedures and tests in a QA programme for equipment are directly related to clinical requirements on accuracy in radiotherapy:
  - What accuracy is required on the absolute absorbed dose?
  - What accuracy is required on the spatial distribution of dose (geometrical accuracy of treatment unit, patient positioning etc.)?

12.1 INTRODUCTION

12.1.3 Requirements on accuracy in radiotherapy

- Such requirements can be based on evidence from dose response curves for the tumour control probability (TCP) and normal tissue complication probability (NTCP).

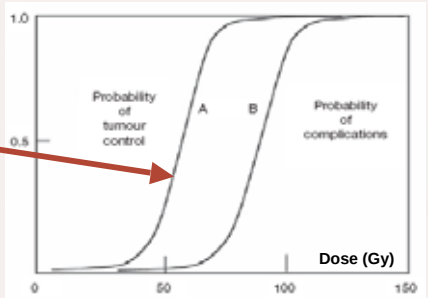
TCP and NTCP are usually illustrated by plotting two sigmoid curves, one for the TCP (curve A) and the other for NTCP (curve B).



12.1 INTRODUCTION

12.1.3 Requirements on accuracy in radiotherapy

- The steepness of a given TCP or NTCP curve defines the change in response expected for a given change in delivered dose.



- Thus, uncertainties in delivered dose translate into either reductions in the TCP or increases in the NTCP, both of which worsen the clinical outcome.

12.1 INTRODUCTION

12.1.3 Requirements on accuracy in radiotherapy

- The ICRU Report No. 24 (1976) concludes that:
  An uncertainty of 5% is tolerable in the delivery of dose to the target volume
- The value of 5% is generally interpreted to represent a confidence level of 1.5 - 2 times the standard deviation.
- Currently, the recommended accuracy of dose delivery is generally 5–7% at the 95% confidence level.

12.1 INTRODUCTION

12.1.3 Requirements on accuracy in radiotherapy

- Geometric uncertainty, for example systematic errors on the field position, block position, etc., relative to target volumes or organs at risk, also leads to dose problems:
  - Either underdosing of the required volume (decreasing the TCP).
  - Or overdosing of nearby structures (increasing the NTCP).
- Figures of 5–10 mm (95% confidence level) are usually given on the tolerable geometric uncertainty.

12.1 INTRODUCTION
12.1.4 Accidents in radiotherapy

- Generally speaking, treatment of a disease with radiotherapy represents a twofold risk for the patient:
  - Firstly, and primarily, there is the potential failure to control the initial disease, which, when it is malignant, is eventually lethal to the patient;
  - Secondly, there is the risk to normal tissue from increased exposure to radiation.
- Thus, in radiotherapy an accident or a misadministration is significant if it results in either an underdose or an overdose, whereas in conventional radiation protection only overdoses are generally of concern.

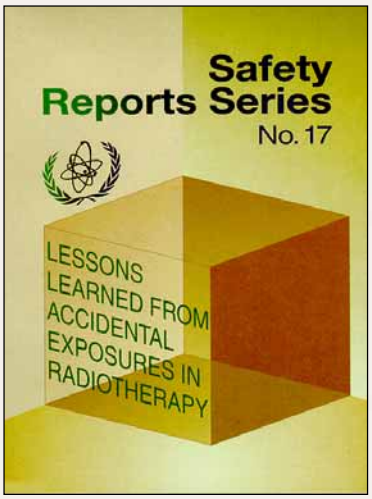
12.1 INTRODUCTION
12.1.4 Accidents in radiotherapy

- From the general aim of an accuracy approaching 5% (95% confidence level), a definition for an accidental exposure can be derived:

  A generally accepted limit is about twice the accuracy requirement, i.e. a 10% difference should be taken as an accidental exposure
- In addition, from clinical observations of outcome and of normal tissue reactions, there is good evidence that differences of 10% in dose are detectable in normal clinical practice.

12.1 INTRODUCTION
12.1.4 Accidents in radiotherapy

- IAEA has analyzed a series of accidental exposures in radiotherapy to draw lessons in methods for prevention of such occurrences.
- Criteria for classifying:
  - Direct causes of mis-administrations
  - Contributing factors
  - Preventability of misadministration
  - Classification of potential hazard.



12.1 INTRODUCTION
12.1.4 Accidents in radiotherapy

Examples of direct causes of misadministrations

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

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME

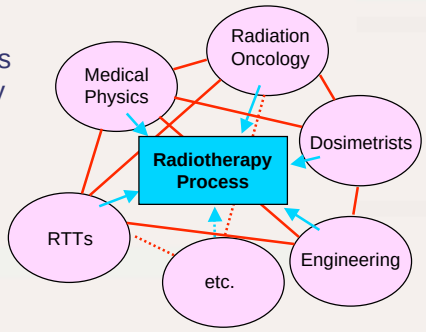
- It must be understood that the required quality system is essentially a total management system:
  - For the total organization
  - For the total radiation therapy process
- The total radiation therapy process includes:
  - Clinical radiation oncology service
  - Supportive care services (nursing, dietetic, social, etc.)
  - All issues related to radiation treatment
    - Radiation therapists
    - Physical quality assurance (QA) by physicists
    - Engineering maintenance
    - Management

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME

- A number of organizations and publications have given background discussion and recommendations on the structure and management of a quality assurance programme in radiotherapy or radiotherapy physics:
  - WHO in 1988
  - AAPM in 1994
  - ESTRO in 1995 and 1998
  - IPEM in 1999
  - Van Dyk and Purdy in 1999
  - McKenzie et al. in 2000

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME
12.2.1 Multidisciplinary radiotherapy team

- One of the reasons to implement a Quality System is that radiotherapy is a multidisciplinary process.
  - Responsibilities are shared between the different disciplines and must be clearly defined.
  - Each group has an important part in the output of the entire process, and their overall roles as well as their specific quality assurance roles, are inter-dependent requiring close cooperation.



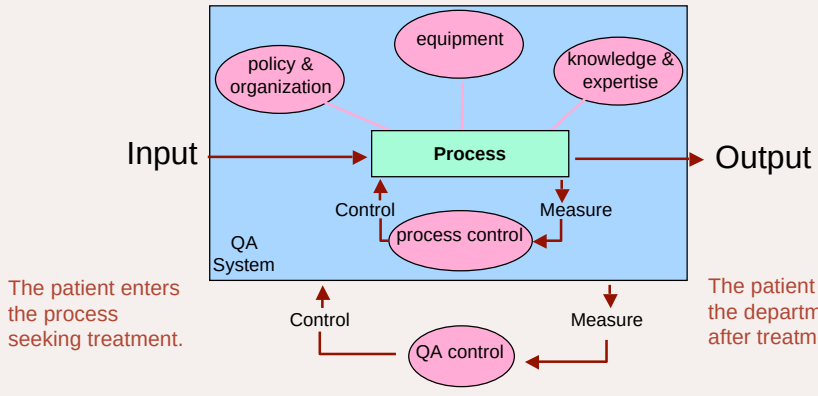
12.2 MANAGING A QUALITY ASSURANCE PROGRAMME
12.2.1 Multidisciplinary radiotherapy team

- The multidisciplinary radiotherapy team consists of:
  - Radiation oncologists
  - Medical physicists
  - Radiotherapy technologists
    - Sometimes referred to as radiation therapists (RTT), therapy radiographers, radiation therapy technologists.
  - Dosimetrists
    - In many systems there is no separate group of dosimetrists; these functions are carried out variously by physicists, medical physics technicians or technologists, radiation dosimetry technicians or technologists, radiotherapy technologists, or therapy radiographers.
  - Engineering technologists
    - In some systems medical physics technicians or technologists, clinical technologists, service technicians, electronic engineers or electronic technicians.

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME
12.2.2 Quality system/comprehensive QA programme

- It is now widely appreciated that the concept of a Quality System in Radiotherapy is broader than a restricted definition of technical maintenance and quality control of equipment and treatment delivery.
- Instead it should encompass a comprehensive approach to all activities in the radiotherapy department:
  - Starting from the moment a patient enters the department.
  - Until the moment he or she leaves the department.
  - Continuing into the follow-up period.

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME
12.2.2 Quality system/comprehensive QA programme



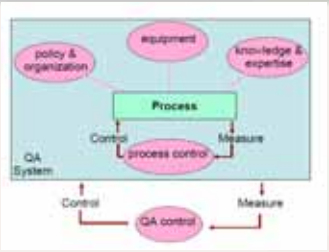
Outcome can be considered of good quality when the handling of the quality system organizes well the five aspects shown in the illustration above.

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME

12.2.2 Quality system/comprehensive QA programme

- A comprehensive quality system in radiotherapy is a management system that:

Policy & organization



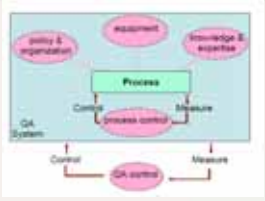
- Should be supported by the department management in order to work effectively.
- Must have a clear definition of its scope and of all the quality standards to be met.
- Must be regularly reviewed as to operation and improvement. To this end a quality assurance committee is required, which should represent all the different disciplines within radiation oncology.
- Must be consistent in standards for different areas of the program.

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME

12.2.2 Quality system/comprehensive QA programme

- A comprehensive quality system in radiotherapy is a management system that:

Equipment

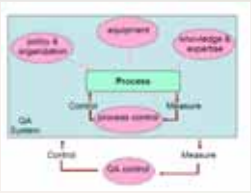


- Requires availability of adequate test equipment.

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME

12.2.2 Quality system/comprehensive QA programme

- A comprehensive quality system in radiotherapy is a management system that:



Knowledge & expertise

- Requires every staff member to have qualifications (education, training and experience) appropriate to his or her role and responsibility.
- Requires every staff member to have access to appropriate opportunities for continuing education and development.

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME

12.2.2 Quality system/comprehensive QA programme

- A comprehensive quality system in radiotherapy is a management system that:

process control

- Requires the development of a formal written quality assurance programme that details the quality assurance policies and procedures, quality control tests, frequencies, tolerances, action criteria, required records and personnel.
- Must be consistent in standards for different areas of the programme.
- Must incorporate compliance with all the requirements of national legislation, accreditation, etc.

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME
12.2.2 Quality system/comprehensive QA programme

- Formal written quality assurance programme is also called referred to as the Quality Manual.
  - The quality manual has a double purpose:
    - External
    - Internal.
  - Externally to collaborators in other departments, in management and in other institutions, it helps to indicate that the department is strongly concerned with quality.
  - Internally, it provides the department with a framework for further development of quality and for improvements of existing or new procedures.

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME
12.2.2 Quality system/comprehensive QA programme

Practical guidelines for writing a quality manual:

ESTRO EUROPEAN SOCIETY FOR THERAPEUTIC RADIOLOGY AND ONCOLOGY

ESTRO Booklet 4:

PRACTICAL GUIDELINES FOR THE IMPLEMENTATION OF A QUALITY SYSTEM IN RADIOTHERAPY

A project of the ESTRO Quality Assurance Committee sponsored by 'Europe against Cancer'

Writing party: J W H Leer, A L McKenzie, P Scalliet, D I Thwaites

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME
12.2.2 Quality system/comprehensive QA programme

- A comprehensive quality system in radiotherapy is a management system that:

QA control

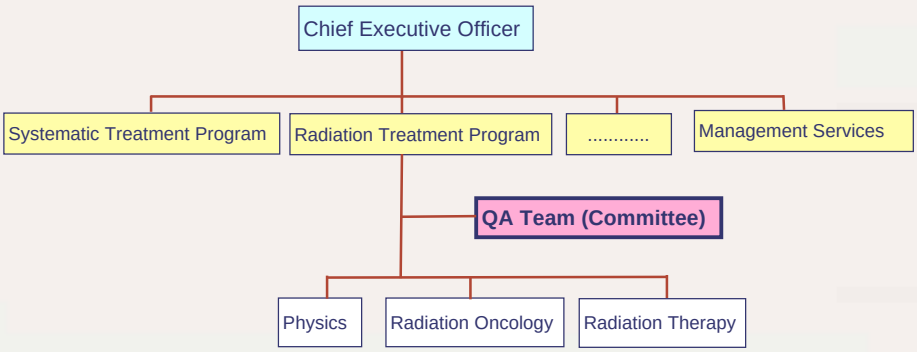
  - Requires control of the system itself, including:
    - Responsibility for quality assurance and the quality system: quality management representatives.
    - Document control.
    - Procedures to ensure that the quality system is followed.
    - Ensuring that the status of all parts of the service is clear.
    - Reporting all non-conforming parts and taking corrective action.
    - Recording all quality activities.
    - Establishing regular review and audits of both the implementation of the quality system (quality system audit) and its effectiveness (quality audit).

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME
12.2.2 Quality system/comprehensive QA program

- When starting a quality assurance (QA) program, the setup of a QA team or a QA committee is the most important first step.
  - The QA team should reflect composition of the multi-disciplinary radiotherapy team.
  - The quality assurance committee must be appointed by the department management/head of department with the authority to manage quality assurance.

12.2 MANAGING A QUALITY ASSURANCE PROGRAMME
12.2.2 Quality system/comprehensive QA program

Example for the organizational structure of a radiotherapy department and the integration of a QA team



12.2 MANAGING A QUALITY ASSURANCE PROGRAMME
12.2.2 Quality system/comprehensive QA program

Membership and Responsibilities of the QA team (QA Committee)

QA Team (Committee)

Membership:
Radiation Oncologist(s)
Medical Physicist(s)
Radiation Therapist(s)
.....
Chair:
Physicist or
Radiation Oncologist

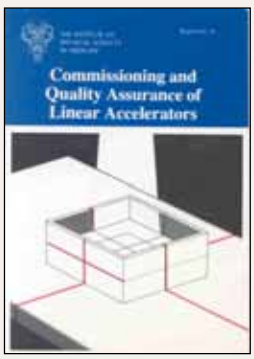
Responsibilities:
Patient safety
Personnel safety
Dosimetry instrumentation
Teletherapy equipment
Treatment planning
Treatment delivery
Treatment outcome
Quality audit

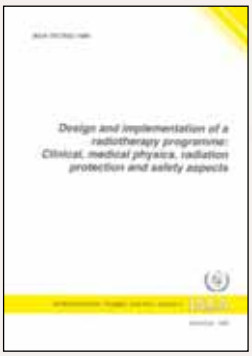
12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

- The following slides are focusing on the equipment related QA programme.
  - They concentrate on the general items and systems of a QA program.
  - Therefore, they should be "digested" in conjunction with Chapter 10 and other appropriate material concerned with each of the different categories of equipment.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

- Appropriate material: Many documents are available:





12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

- Examples of useful published material:
  - AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE (AAPM), "Comprehensive QA for radiation oncology: Report of AAPM Radiation Therapy Committee Task Group 40", Med. Phys. **21**, 581-618 (1994)
  - INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC), "Medical electrical equipment - Medical electron accelerators-Functional performance characteristics", IEC 976, IEC, Geneva, Switzerland (1989)
  - INSTITUTE OF PHYSICS AND ENGINEERING IN MEDICINE (IPEM), "Physics aspects of quality control in radiotherapy", IPEM Report 81, edited by Mayles, W.P.M., Lake, R., McKenzie, A., Macaulay, E.M., Morgan, H.M., Jordan, T.J. and Powley, S.K, IPEM, York, United Kingdom (1999)
  - VAN DYK, J., (editor), "The Modern Technology for Radiation Oncology: A Compendium for Medical Physicists and Radiation Oncologists", Medical Physics Publishing, Madison, Wisconsin, U.S.A. (1999)
  - WILLIAMS, J.R., and THWAITES, D.I., (editors), "Radiotherapy Physics in Practice", Oxford University Press, Oxford, United Kingdom (2000)

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.1 The structure of an equipment QA programme

General structure of a quality assurance program for equipment

(1) Initial specification, acceptance testing and commissioning for clinical use, including calibration where applicable	(2) Quality control tests before the equipment is put into clinical use, quality control tests should be established and a formal QC program initiated
(3) Additional quality control tests after any significant repair, intervention or adjustment or when there is any indication of a change in performance	(4) Planned preventive maintenance programme in accordance with the manufacturer's recommendations

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.1 The structure of an equipment QA programme

- Step 1: Equipment specification and assessment of clinical needs:
  - In preparation for procurement of equipment, a detailed specification document must be prepared.
  - A multidisciplinary team from the department should be involved in the decision process.
  - This should set out the essential aspects of the equipment operation, facilities, performance, service, etc., as required by the customer.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.1 The structure of an equipment QA programme

- Questions to be answered in assessment of clinical needs:
  - Which patients will be affected by this technology?
  - What is the likely number of patients per year?
  - Number of procedures or fractions per year?
  - Will the new procedure provide cost savings over old techniques?
  - Would it be better to refer patients to a specialist institution?
  - Is the infrastructure available to handle the technology?
  - Will the technology enhance the academic program?
  - What is the organizational risk in implementing this technology?
  - What is the cost impact?
  - What maintenance is required?

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.1 The structure of an equipment QA programme

- Equipment specification and assessment of clinical needs:
  - Once this information is compiled, the purchaser is in a good position to develop clearly his own specifications.
  - The specification can also be based on:
    - Manufacturers specification (brochures)
    - Published information
    - Discussions with other users of similar products
  - All specification data must be expressed clearly in well defined and measurable units.
  - Decisions on procurement should again be made by a multi-disciplinary team.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.1 The structure of an equipment QA programme

- Acceptance of equipment
  - Acceptance of equipment is the process in which the supplier demonstrates the baseline performance of the equipment to the satisfaction of the customer.
  - After new equipment is installed, it must be tested in order to ensure that it meets the specifications and that the environment is free of radiation and electrical hazards to staff and patients.
  - The essential performance required and expected from the machine should be agreed upon before acceptance of the equipment begins.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.1 The structure of an equipment QA programme

- Acceptance of equipment
  - It is a matter of professional judgment of the responsible medical physicist to decide whether or not any aspect of the agreed acceptance criteria is to be waived.
  - This waiver should be recorded along with an agreement from the supplier, for example to correct the equipment should performance deteriorate further.
  - The equipment can only be formally accepted to be transferred from the supplier to the customer when the responsible medical physicist either is satisfied that the performance of the machine fulfils all specifications as listed in the contract document or formally accepts any waivers.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.1 The structure of an equipment QA program

- Commissioning of equipment
  - Commissioning is the process of preparing the equipment for clinical service.
  - Expressed in a more quantitative way:
    A full characterization of its performance over the whole range of possible operation must be undertaken.
  - In this way the baseline standards of performance are established to which all future performance and quality control tests will be referred.
  - Commissioning includes the preparation of procedures, protocols, instructions, data, etc., on the clinical use of the equipment.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.1 The structure of an equipment QA programme

- Quality control
  - It is essential that the performance of treatment equip-ment remain consistent within accepted tolerances throughout its clinical life.
  - An ongoing quality control programme of regular perfor-mance checks must begin immediately after commissioning to test this.
  - If these quality control measurements identify departures from expected performance, corrective actions are required.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.1 The structure of an equipment QA program

- Quality control (continued)
  - Equipment quality control programme should specify the following:
    - Parameters to be tested and the tests to be performed.
    - Specific equipment to be used for the tests.
    - Geometry of the tests.
    - Frequency of the tests.
    - Staff group or individual performing the tests, as well as the individual supervising and responsible for the standards of the tests and for actions that may be necessary if problems are identified.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.1 The structure of an equipment QA programme

- Quality control (continued)
  - An equipment quality control program should specify the following:
    - Expected results.
    - Tolerance and action levels.
    - Actions required when the tolerance levels are exceeded.
  - The actions required must be based on a systematic analysis of the uncertainties involved and on well defined tolerance and action levels.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.1 The structure of an equipment QA programme

- If corrective actions are required: Role of Uncertainty
  - When reporting the result of a measurement, it is obliga-tory that some quantitative indication of the quality of the result be given. Otherwise the receiver of this information cannot adequately asses its reliability.
  - The "Concept of Uncertainty" is used for this purpose.
  - In 1993, the International Standards Organisation (ISO) published a "Guide to the expression of uncertainty in measurement", in order to ensure that the method for evaluating and expressing uncertainty is uniform all over the world.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.1 The structure of an equipment QA programme

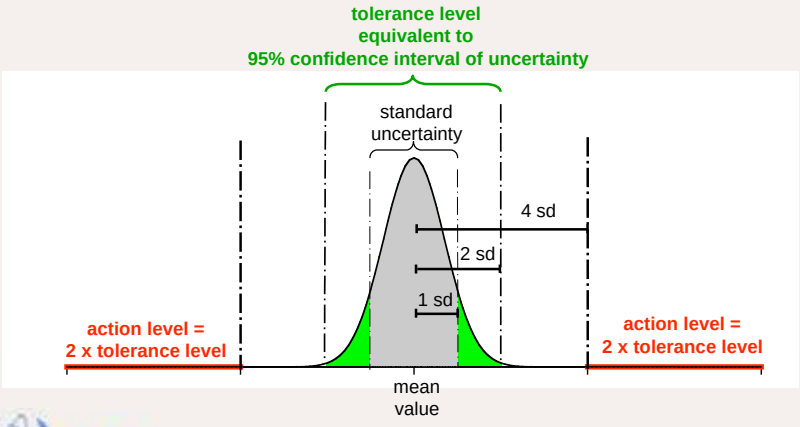
- If corrective actions are required: Role of Tolerance Level
  - Within the tolerance level, the performance of equipment gives acceptable accuracy in any situation.
  - Tolerance values should be set with the aim of achieving the overall uncertainties desired.
  - However, if the measurement uncertainty is greater than the tolerance level set, then random variations in the measurement will lead to unnecessary intervention.
  - Thus, it is practical to set a tolerance level at the measurement uncertainty at the 95% confidence level.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.2 Uncertainties, tolerances and action levels

- If corrective actions are required: Role of Action Level
  - The performance outside the action level is unacceptable and demands action to remedy the situation.
  - It is useful to set action levels higher than tolerance levels thus providing flexibility in monitoring and adjustment.
  - Action levels are often set at approximately twice the tolerance level.
  - However, some critical parameters may require tolerance and action levels to be set much closer to each other or even at the same value.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.2 Uncertainties, tolerances and action levels

Illustration of a possible relation between uncertainty, tolerance level and action level



12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.2 Uncertainties, tolerances and action levels

- The system of actions:
  - If the measurement result is within tolerance level, no action is required.
  - If the measurement result exceeds the action level, immediate action is necessary and the equipment must not be clinically used until the problem is corrected.
  - If the measurement falls between tolerance and action levels, this may be considered as currently acceptable.
  - Inspection and repair can be performed later, for example, after patient irradiations.
  - If repeated measurements remain consistently between the tolerance and action level, adjustment is required.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.3 QA programme for cobalt-60 teletherapy machines

- A sample quality assurance programme (quality control tests) for a cobalt-60 teletherapy machine with recommended test procedures, test frequencies and action levels is given in the following tables.
- They are structured according to daily, weekly, monthly, and annual test schedules.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.3 QA programme for cobalt-60 teletherapy machines

Daily Tests

Procedure or item to be tested	Action level
Door interlock	functional
Radiation room monitor	functional
Audiovisual monitor	functional
Lasers	2 mm
Distance indicator	2 mm

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.3 QA programme for cobalt-60 teletherapy machines

Daily Tests

Procedure or item to be tested	Action level
Door interlock	functional

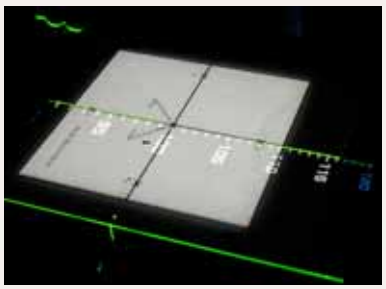
IAEA

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.3 QA programme for cobalt-60 teletherapy machines

Daily Tests

Procedure or item to be tested	Action level
Lasers	2 mm
Optical distance indicator	2 mm



IAEA

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.3 QA programme for cobalt-60 teletherapy machines

Weekly Tests

Procedure or item to be tested	Action level
Check of source position	3 mm

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.3 QA programme for cobalt-60 teletherapy machines

Monthly Tests

Procedure or item to be tested	Action level
Output constancy	2%
Light/radiation field coincidence	3 mm
Field size indicator	2 mm
Gantry and collimator angle indicator	1º
Cross-hair centering	1 mm
Latching of wedges and trays	functional
Emergency off	functional
Wedge interlocks	functional

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.3 QA programme for cobalt-60 teletherapy machines

Annual Tests

Procedure or item to be tested	Action level
Output constancy	2%
Field size dependence of output constancy	2%
Central axis dosimetry parameter constancy	2%
Transmission factor constancy for all standard accessories	2%
Wedge transmission factor constancy	2%
Timer linearity and error	1%
Output constancy versus gantry angle	2%

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.3 QA programme for cobalt-60 teletherapy machines

Annual tests (continued)

Procedure or item to be tested	Action level
Beam uniformity with gantry angle	3%
Safety interlocks: Follow procedures of manufacturer	functional
Collimator rotation isocenter	2 mm diameter
Gantry rotation isocenter	2 mm diameter
Table rotation isocenter	2 mm diameter
Coincidence of collimator, gantry and table axis with the isocenter	2 mm diameter

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.3 QA programme for cobalt-60 teletherapy machines

Annual Tests (continued)

Procedure or item to be tested	Action level
Coincidence of the radiation and mechanical isocenter	2 mm diameter
Table top sag	2 mm
Vertical travel of table	2 mm
Field light intensity	functional

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

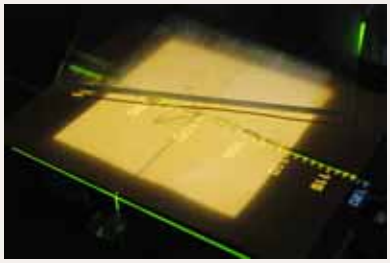
12.3.4 QA programme for linear accelerators

- Typical quality assurance procedures (quality control tests) for a dual mode linac with frequencies and action levels are given in the following tables.
- They are again structured according to daily, weekly, monthly, and annual tests.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.4 QA programme for linear accelerators

Daily Tests

Procedure or item to be tested	Action level
Lasers	2 mm
Optical distance indicator	2 mm



12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.4 QA programme for linear accelerators

Daily Tests

Procedure or item to be tested	Action level
Audiovisual monitor	functional

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.4 QA programme for linear accelerators

Daily Tests

Procedure or item to be tested	Action level
X ray output constancy	3%
Electron output constancy	3%

Daily output checks and verification of flatness and symmetry can be done using different multi-detector devices.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.4 QA programme for linear accelerators

Daily Tests

Procedure or item to be tested	Action level
X ray output constancy	3%
Electron output constancy	3%

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.4 QA programme for linear accelerators

Monthly Tests

Procedure or item to be tested	Action level
X ray output constancy	2%
Electron output constancy	2%
Backup monitor constancy	2%
X ray central axis dosimetry parameter constancy (PDD, TAR, TPR)	2%
Electron central axis dosimetry parameter constancy (PDD)	2 mm at therapeutic depth
X-ray beam flatness constancy	2%

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.4 QA programme for linear accelerators

Monthly Tests (continued)

Procedure or item to be tested	Action level
Electron beam flatness constancy	3%
X ray and electron symmetry	3%
Emergency off switches	functional
Wedge and electron cone interlocks	functional
Light/radiation field coincidence	2 mm or 1% on a side
Gantry/collimator angle indicators	1º
Wedge position	2 mm or 2% change in transmission

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.4 QA programme for linear accelerators

Monthly Tests (continued)

Procedure or item to be tested	Action level
Tray position and applicator position	2 mm
Field size indicators	2 mm
Cross-hair centering	2 mm diameter
Treatment table position indicators	2 mm / 1º
Latching of wedges and blocking tray	functional
Jaw symmetry	2 mm
Field light intensity	functional

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.4 QA programme for linear accelerators

Annual Tests

Procedure or item to be tested	Action level
X ray/electron output calibration constancy	2%
Field size dependence of X ray output constancy	2%
Output factor constancy for electron applicators	2%
Central axis parameter constancy (PDD, TAR, TPR)	2%
Off-axis factor constancy	2%
Transmission factor constancy for all treatment accessories	2%

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.4 QA programme for linear accelerators

Annual Tests (continued)

Procedure or item to be tested	Action level
Wedge transmission factor constancy	2%
Monitor chamber linearity	1%
X ray output constancy with the gantry angle	2%
Electron output constancy with the gantry angle	2%
Off-axis factor constancy with the gantry angle	2%
Arc mode	Manufacturer's specifications

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.4 QA program for linear accelerators

Annual Tests (continued)

Procedure or item to be tested	Action level
Safety interlocks	functional
Collimator rotation isocenter	2 mm diameter
Gantry rotation isocenter	2 mm diameter
Table rotation isocenter	2 mm diameter
Coincidence of collimator, gantry and table axes with the isocenter	2 mm diameter
Coincidence of the radiation and mechanical isocenter	2 mm diameter

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.4 QA programme for linear accelerators

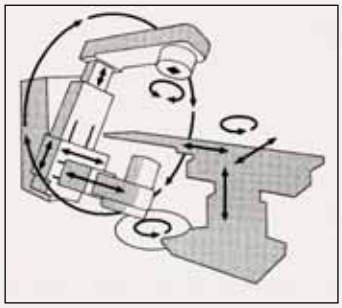
Annual Tests (continued)

Procedure or item to be tested	Action level
Table top sag	2 mm
Vertical travel of the table	2 mm

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.5 QA programme for treatment simulators

- Treatment simulators replicate the movements of isocentric ^{60}Co and linac treatment machines and are fitted with identical beam and distance indicators. Hence all measurements that concern these aspects also apply to the simulator.
  - During 'verification session' the treatment is set-up on the simulator exactly like it would be on the treatment unit.
  - A verification film is taken in 'treatment' geometry



12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.5 QA programme for treatment simulators

- If mechanical/geometric parameters are out of tolerance on the simulator, this is likely to affect adversely the treatment of all patients.
- Performance of the imaging components on the simulator is of equal importance to its satisfactory operation.
- Therefore, critical measurements of the imaging system are also required.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.5 QA programme for treatment simulators

- A sample quality assurance programme (quality control tests) for treatment simulators with recommended test procedures, test frequencies and action levels is given in the following tables.
- They are again structured according to daily, monthly, and annual tests.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.5 QA programme for treatment simulators

Daily Tests

Procedure or item to be tested	Action level
Safety switches	functional
Door interlock	functional
Lasers	2 mm
Distance indicator	2 mm

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.5 QA programme for treatment simulators

Monthly Tests

Procedure or item to be tested	Action level
Field size indicator	2 mm
Gantry/collimator angle indicators	1°
Cross-hair centering	2 mm diameter
Focal spot-axis indicator	2 mm
Fluoroscopic image quality	baseline
Emergency/collision avoidance	functional
Light/radiation field coincidence	2 mm or 1%
Film processor sensitometry	baseline

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.5 QA programme for treatment simulators

Annual Tests

Procedure or item to be tested	Action level
Collimator rotation isocenter	2 mm diameter
Gantry rotation isocenter	2 mm diameter
Couch rotation isocenter	2 mm diameter
Coincidence of collimator, gantry, couch axes with isocenter	2 mm diameter
Table top sag	2 mm
Vertical travel of couch	2 mm

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.5 QA programme for treatment simulators

Annual Tests (continued)

Procedure or item to be tested	Action level
Exposure rate	baseline
Table top exposure with fluoroscopy	baseline
kVp and mAs calibration	baseline
High and low contrast resolution	baseline

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.6 QA programme for CT scanners and CT-simulators

- For dose prediction as part of the treatment planning process there is an increasing reliance upon CT image data with the patient in a treatment position.
- CT data is used for:
  - Indication and/or data acquisition of the patient's anatomy.
  - Acquisition of tissue density information which is essential for accurate dose prediction.


Gammex RMI CT test tool

- Therefore, it is essential that the geometry and the CT densities are accurate. CT test tools are available.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.6 QA programme for CT scanners and CT-simulators

- A sample quality assurance programme (quality control tests) for CT scanners and CT-simulation with recommended test procedures, test frequencies and action levels is given in the following tables.
- They are again structured according to daily, monthly, and annual tests.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.6 QA programme for CT scanners and CT-simulators

Daily Tests

Procedure or item to be tested	Action level
Safety switches	functional
Door interlock	functional
Lasers	2 mm
Distance indicator	2 mm

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.6 QA programme for CT scanners and CT-simulators

Monthly Tests

Procedure or item to be tested	Action level
Field size indicator	2 mm
Gantry/collimator angle indicators	1°
Cross-hair centering	2 mm diameter
Focal spot-axis indicator	2 mm
Fluoroscopic image quality	baseline
Emergency/collision avoidance	functional
Light/radiation field coincidence	2 mm or 1%
Film processor sensitometry	baseline

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.6 QA programme for CT scanners and CT-simulators

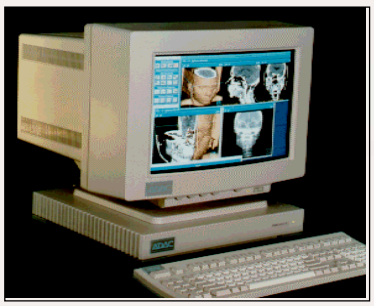
Annual Tests

Procedure or item to be tested	Action level
Collimator rotation isocenter	2 mm diameter
Gantry rotation isocenter	2 mm diameter
Couch rotation isocenter	2 mm diameter
Coincidence of collimator, gantry, couch axes with isocenter	2 mm diameter
Table top sag	2 mm
Vertical travel of couch	2 mm

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

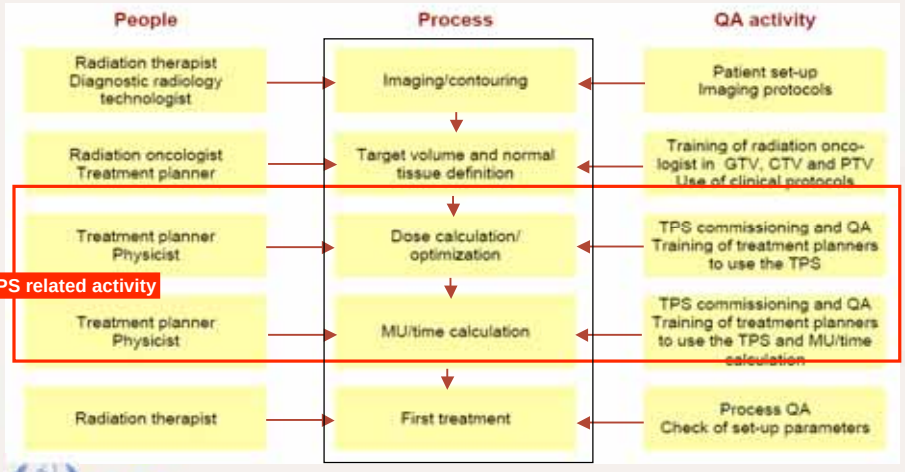
12.3.7 QA programme for treatment planning systems

- In the 1970s and 1980s treatment planning computers became readily available to individual radiation therapy centers.
- As computer technology evolved and became more compact, so did Treatment Planning Systems (TPS).
  - Simultaneously, dose calculation algorithms and image display capabilities became more sophisticated.
  - Treatment planning computers have become readily available to virtually all radiation treatment centers.



12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

Steps of the treatment planning process, the professionals involved in each step, and the QA activities associated with these steps (IAEA TRS 430).



12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

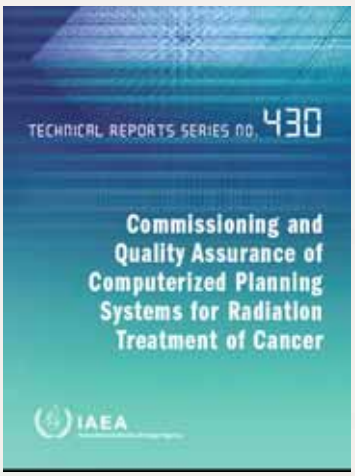
- The middle column of the previous slide summarizes the steps in the process flow of the radiation treatment planning process of cancer patients.
- The computerized treatment planning system (TPS) is an essential tool in this process.
- As an integral part of the radiotherapy process, the TPS provides a computer based:
  - Simulation of the beam delivery set-up
  - Optimization and prediction of the dose distributions that can be achieved both in the target volume and also in normal tissue.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

- Treatment planning quality management is a sub-component of the total quality management process.
- Organizationally, it involves physicists, dosimetrists, RTTs, and radiation oncologists, each at their level of participation in the radiation treatment process.
- Treatment planning quality management involves the development of a clear QA plan of the TPS and its use.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

- Acceptance, commissioning and QC recommendations for TPSs are given, for example, in:
  - AAPM Reports (TG-40 and TG-43)
  - IPEM Reports 68 (1996) and 81 (1999),
  - Van Dyk et al. (1993)
  - Most recently: IAEA TRS 430 (2004)
- The following slides are mostly following the TRS 430 Report.



12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

- Purchase
  - Purchase of a TPS is a major step for most radiation oncology departments.
  - Particular attention must therefore be given to the process by which the purchasing decision is made.
  - The specific needs of the department must be taken into consideration, as well as budget limits, during a careful search for the most cost effective TPS.
  - The following slide contains some issues on the clinical need assessment to consider in the purchase and clinical implementation process.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

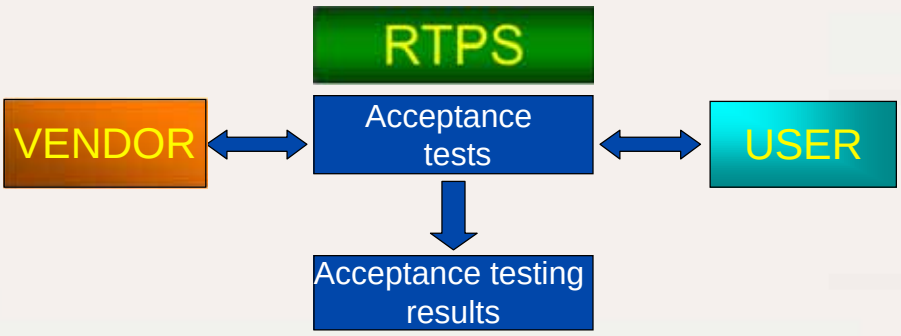
Clinical need assessment: Issues	Questions and/or comments
Status of the existing TPS	Can it be upgraded? Hardware? Software?
Projected number of cases to be planned over the next 2–5 years	Include types and complexity, for example number of 2-D plans without image data, number of 3-D plans with image data, complex plans, etc
Special techniques	Stereotactic radiosurgery? Mantle? Total body irradiation (TBI)? Electron arcs? HDR brachytherapy? Other?
Number of workstations required	Depends on caseload, average time per case, research and development time, number of special procedures, number of treatment planners and whether the system is also used for MU/time calculations
Level of sophistication of treatment planning	3-D CRT? Participation in clinical trials? Networking capabilities?
Imaging availability	CT? MR? SPECT? PET? Ultrasound?
CT simulation availability	Network considerations
Multileaf collimation available now or in the future	Transfer of MLC data to therapy machines?
3-D CRT capabilities on the treatment machines	Can the TPS handle the therapy machine capabilities?
IMRT capabilities	Available now or in the near future?
Treatment trends over the next3–5 years	Will there be more need for IMRT or electrons?
Case load and throughput	Will treatment planning become the bottleneck?

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

- Acceptance
  - Acceptance testing is the process to verify that the TPS behaves according to specifications (user's tender document, manufacturer' specifications).
  - Acceptance testing must be carried out before the system is used clinically and must test both the basic hardware and the system software functionality.
  - Since during the normally short acceptance period the user can test only the basic functionality, he or she may choose a conditional acceptance and indicate in the acceptance document that the final acceptance testing will be completed as part of the commissioning process.

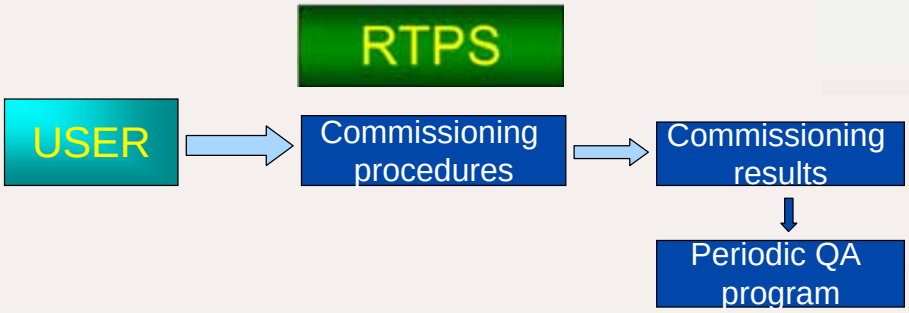
12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

- Acceptance testing of the TPS



12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

- Commissioning of the TPS



12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA program for treatment planning systems

- Acceptance and Commissioning
  - The following slides summarizes the various components of the acceptance and commissioning testing of a TPS.
  - The intent of this information is not to provide a complete list of items that should be verified but rather to suggest the types of issue that should be considered.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

Main component	Issues
Hardware	• CPUs, memory and disk operation. • Input devices: Digitizer tablet, Film digitizer, Imaging data (CT, MRI, ultrasound, etc.), Simulator control systems or virtual simulation workstation, Keyboard and mouse entry • Output: Hard copy output (plotter and/or printer), Graphical display units that produce DRRs and treatment aids, Unit for archiving (magnetic media, optical disk, etc.)

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

Main component	Issues
Network integration and data transfer	• Network traffic and the transfer of CT, MRI or ultrasound image data to the TPS. • Positioning and dosimetric parameters communicated to the treatment machine or to its record and verify system. • Transfer of MLC parameter to the leaf position. • Transfer of DRR information. • Data transfer from the TPS to auxiliary devices (i.e. computer controlled block cutters and compensator machining devices). • Data transfer between the TPS and the simulator • Data transfer to the radiation oncology management system. • Data transfer of measured data from a 3-D water phantom system

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

Main component	Issues
Software	• CT input • Anatomical description • 3-D objects and display. • Beam description • Photon beam dose calculations various open fields, different SSDs, blocked fields, MLC shaped fields, inhomogeneity test cases, multibeam plans, asymmetric jaw fields, wedged fields and others. • Electron beam dose calculations open fields, different SSDs, shaped fields, • Dose display, DVHs • Hard copy output

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

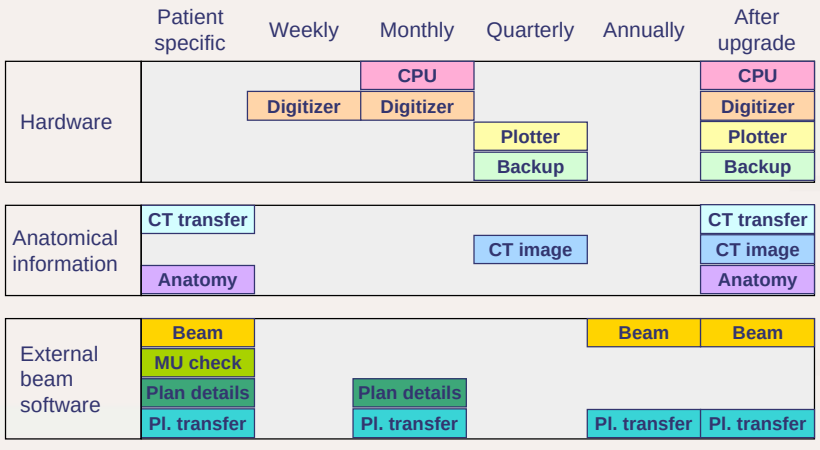
- Periodic quality control
  - QA does not end once the TPS has been commissioned.
  - It is essential that an ongoing QA program be maintained, i.e., a periodic quality control must be established.
  - The program must be practical, but not so elaborate that it imposes an unrealistic commitment on resources and time.
  - Two examples of a routine regular QC program (quality control tests) for a TPS are given in the next slides.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

Frequency	Procedure	Tolerance level
Daily	Input and Output devices	1 mm
Monthly	Check sum Reference subset of data Reference prediction subset Processor tests CT transfer	No change 2% or 2 mm 2% or 2 mm pass 1 mm
Annually	Monitor Unit calculations Reference QA test set	2% 2% or 2 mm

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT
12.3.7 QA programme for treatment planning systems

Example of a periodic quality assurance program (TRS 430)



12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.8 QA programme for test equipment

- Test equipment in radiotherapy concerns all the required additional equipment such as:
  - Measurements of radiation doses,
  - Measurements of electrical machine signals
  - Mechanical measurements of machine devices.
- Some examples of test and measuring equipment which should be considered for a quality control programme are given in the next slide.

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.8 QA programme for test equipment

- Test equipment for radiotherapy equipment support
  - Local standard and field ionization chambers and electrometer.
  - Thermometer.
  - Barometer.
  - Linear rulers.
  - Phantoms.
  - Automated beam scanning systems.
  - Other dosimetry systems: e.g., systems for relative dosimetry (e.g., TLD, diodes, diamonds, film, etc.), in-vivo dosimetry (e.g., TLD, diodes, etc.) and for radiation protection measurements.
  - Any other electrical equipment used for testing the running parameters of treatment equipment.

12.4 TREATMENT DELIVERY
12.4.1 Patient charts

- Patient chart (paper or electronic) is accompanying the patient during the entire process of radiotherapy.
  - Any errors made at the data entry into the patient chart are likely to be carried through the whole treatment.
  - QA of the patient chart is therefore essential.
- Basic components of a patient treatment chart are:
  - Patient name and ID
  - Photograph
  - Initial physical evaluation of the patient
  - Treatment planning data
  - Treatment execution data
  - Clinical assessment during treatment
  - Treatment summary and follow up
  - QA checklist.

12.4 TREATMENT DELIVERY
12.4.1 Patient charts

- AAPM Radiation Therapy Committee, Task Group 40 recommends that:
  - Charts be reviewed:
    - At least weekly.
    - Before the third fraction following the start or a field modification.
    - At the completion of treatment.
  - Review be signed and dated by the reviewer.
  - QA team oversee implementation of a program which defines:
    - Which items are to be reviewed.
    - Who is to review them.
    - When are they to be reviewed.
    - Definition of minor and major errors.
    - What actions are to be taken, and by whom, in event of errors.
  - A random sample of charts be audited at intervals prescribed by the QA team.

12.4 TREATMENT DELIVERY

12.4.1 Patient charts

- In particular, all planning data and all data entered as the interface between the planning process and the treatment delivery process should be independently checked.
- Examples for this requirement are:
  - Plan integrity
  - Monitor unit calculations
  - Irradiation parameters.
- Data transferred automatically, e.g., from the treatment planning system, should also be verified to check that no data corruption occurred.

12.4 TREATMENT DELIVERY

12.4.1 Patient charts

- All errors that are traced during chart checking must be thoroughly investigated and evaluated by the QA team.
- The causes of these errors should be eradicated and may result in (written) changes in various procedures of the treatment process.

12.4 TREATMENT DELIVERY
12.4.2 Portal imaging

- As an accuracy requirement in radiotherapy, it has been stated that figures of 5–10 mm (95% confidence level) are used as the tolerance level for the geometric uncertainty.
- The geometric accuracy is limited by:
  - Uncertainties in a particular patient set-up.
  - Uncertainties in the beam set-up.
  - Movement of the patient or the target volume during treatment.
- Portal imaging is frequently applied in order to check geometric accuracy of the patient set-up with respect to the position of the radiation beam

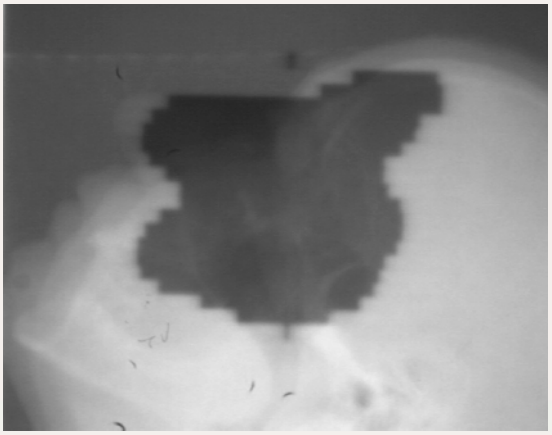
12.4 TREATMENT DELIVERY
12.4.2 Portal imaging

- The purpose of portal imaging is in particular:
  - To verify the field placement, characterized by the isocenter or another reference point, relative to anatomical structures of the patient, during the actual treatment.
  - To verify that the beam aperture (blocks or MLC) has been properly produced and registered.

Portal film device

12.4 TREATMENT DELIVERY
12.4.2 Portal imaging

- Example for portal imaging: Port film



Port film for a lateral irregular MLC field used in a treatment of the maxillary sinus.

This method allows to visualization of both the treatment field and the surrounding anatomy.

12.4 TREATMENT DELIVERY
12.4.2 Portal imaging

- Disadvantage of the film technique is its off-line character, which requires a certain amount of time before the result can be applied clinically.
- For this reason on-line electronic portal imaging devices (EPIDs) have been developed.
- Three methods are currently in clinically use:
  1. Metal plate–phosphor screen combination is used to convert the photon beam intensity into a light image. The screen is viewed by a sensitive video camera.
  2. Matrix of liquid filled ionization chambers.
  3. Amorphous silicon flat panel systems.

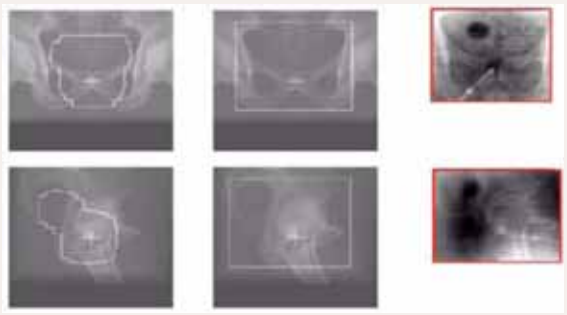
12.4 TREATMENT DELIVERY
12.4.2 Portal imaging

Amorphous silicon type of EPID installed on the gantry of a linac.

12.4 TREATMENT DELIVERY
12.4.2 Portal imaging

- Comparison between digitally reconstructed radiograph (DRR) and image obtained with EPID

DRR treatment fields | DRR EPID fields | EPID images



DRRs from treatment fields and large fields to verify the position of isocentre and the corresponding EPID fields.

12.4 TREATMENT DELIVERY
12.4.2 Portal imaging

- As part of the QA process, portal imaging may lead to various strategies for improvement of positioning accuracy, such as:
  - Improvement of patient immobilization.
  - Introduction of correction rules.
  - Adjustment of margins in combination with dose escalation.
  - Incorporation of set-up uncertainties in treatment planning.

12.4 TREATMENT DELIVERY
12.4.2 Portal imaging

- QA in portal imaging
  - Process control requires that local protocols must be established to specify:
    - Who has the responsibility for verification of portal images (generally a clinician), and
    - What criteria are used as the basis to judge the acceptability of information conveyed by portal images.

12.4 TREATMENT DELIVERY

12.4.3 In-*vivo* dose measurements

- There are many steps in the chain of processes which determine the dose delivery to a patient undergoing radiotherapy and each of these steps may introduce an uncertainty.
- It is therefore worthwhile, and maybe even necessary for specific patient groups or for unusual treatment conditions to use in-vivo dosimetry as an ultimate check of the actual treatment dose.

12.4 TREATMENT DELIVERY

12.4.3 In-*vivo* dose measurements

- In-vivo dose measurements can be divided into
  - Intracavitary dose measurements (frequently used).
  - Entrance dose measurements (less frequently used).
  - Exit dose measurements (still under investigation).

Diodes applied for intracavitary in vivo dosimetry.

12.4 TREATMENT DELIVERY
12.4.3 In-*vivo* dose measurements

- In-vivo dose measurements

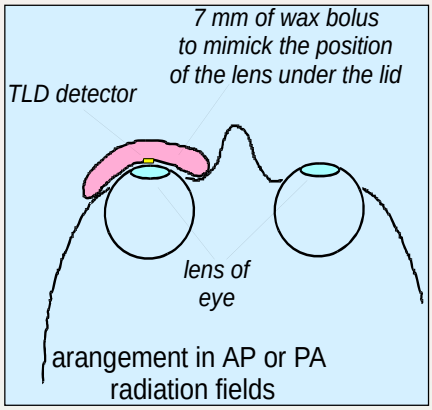
12.4 TREATMENT DELIVERY
12.4.3 In-*vivo* dose measurements

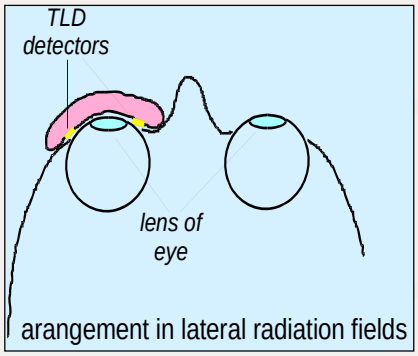
- Examples of typical application of in-vivo dosimetry:
  - To check the MU calculation independently from the programme used for routine dose calculations.
  - To trace any error related to patient set-up, human errors in the data transfer during the consecutive steps of the treatment preparation, unstable accelerator performance and inaccuracies in dose calculation, e.g., of the treatment planning system.
  - To determine the intracavitary dose in readily accessible body cavities, such as the oral cavity, oesophagus, vagina, bladder, and rectum.
  - To assess the dose to organs at risk (e.g., eye lens, gonads and lungs during TBI) or situations where the dose is difficult to predict (e.g., non-standard SSD or using bolus).

12.4 TREATMENT DELIVERY

12.4.3 In-*vivo* dose measurements

Example for TLD in vivo dosimetry: Lens dose measurements





12.4 TREATMENT DELIVERY

12.4.4 Record-and-verify systems

- A computer-aided record-and-verify system aims to compare the set-up parameters with the prescribed values.

12.4 TREATMENT DELIVERY
12.4.4 Record-and-verify systems

- Patient identification data, machine parameters and dose prescription data are entered into the computer beforehand.
- At time of treatment, these parameters are identified at the treatment machine and, if there is no difference, the treatment can start.
- If discrepancies are present, this is indicated, the parameters concerned are highlighted, and the treatment cannot start until the discrepancies are corrected or overridden.

12.4 TREATMENT DELIVERY
12.4.4 Record-and-verify systems

- Discrepancies can be indicated only when tolerance values are exceeded.
- Tolerance values must be therefore established before.
  - Tolerances for verification of machine parameters should be provided by the manufacturer.
  - Clinical tolerance tables must also be defined locally in the department for each set of techniques to allow for patient/set-up variations day-to-day.
  - Record-and-verify systems must have the flexibility to be overridden. This feature must be used with care and only when reasons are clear and properly documented.

12.4 TREATMENT DELIVERY
12.4.4 Record-and-verify systems

- QA of Record-and-verify systems
  - Treatment delivered, if relying on record-and-verify system setting or verifying the parameters, is only as good as the information input to the system.
  - Therefore, it is vital that the data in the record-and-verify system is quality-controlled, using independent (redundant) checking to verify the input and to sanction its clinical use.
  - Performance of the record-and-verify system should be included in an appropriate QA program.
  - Details of such QA tests will be specific to the system in question.

12.5 QUALITY AUDIT
12.5.1 Definition

- Definition of Quality Audit
  - Quality audit is a systematic and independent examination to determine whether or not:
  - Quality activities and results comply with planned arrangements.
  - Arrangements are implemented effectively and are suitable to achieve the stated objectives

12.5 QUALITY AUDIT

12.5.1 Definition: Parameters of quality audits

- Quality audits:
  - Can be conducted for internal or external purposes.
  - Can be applied at any level of a QA program.
  - Are performed by personnel not directly responsible for the areas being audited, however in cooperative discussion with the responsible personnel.
  - Must be against pre-determined standards, linked to those that the QA program is trying to achieve.
  - Evaluate the need for improvement or corrective action if those standards are not met.

12.5 QUALITY AUDIT

12.5.1 Definition: Parameters of quality audits

- Quality audits:
  - Should be regular and form part of a quality feedback loop to improve quality.
  - Can be mainly procedural, looking at QA procedures, protocols, QC programs, QC and QA results and records, etc.
  - Can be mainly practical to verify the effectiveness or performance of a quality system.
  - May be voluntary and co-operative, or may be regulatory (e.g., for accreditation of the department or hospital, for QS certification, etc.).

12.5 QUALITY AUDIT

12.5.2 Practical quality audit modalities

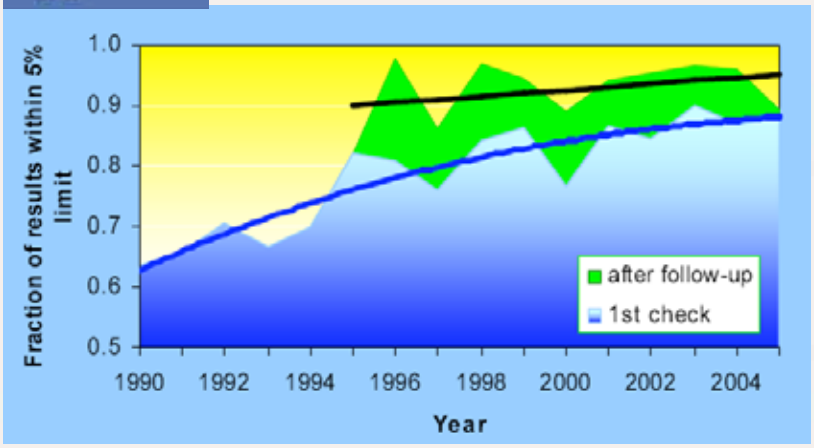
- A good example for an external audit is the simple but very effective dosimetry audit organized as postal audit with mailed dosimeters (usually TLD).
- These are generally organized by SSDLs or agencies, such as the IAEA, Radiological Physics Center (RPC) in the U.S., ESTRO (EQUAL), national societies, national quality networks, etc.

Material used in IAEA/WHO TLD audits

12.5 QUALITY AUDIT

12.5.2 Practical quality audit modalities

TLD results within the 5% limit



12.5 QUALITY AUDIT

12.5.3 What should be reviewed in a quality audit visit?

- The content of a quality audit visit must be pre-defined.
- It will depend on the purpose of the visit:
  - Is it a routine regular visit within a national or regional quality audit network?
  - Is it regulatory or co-operative between peer professionals?
  - Is it a visit following a possible misadministration?
  - Is it a visit following an observed higher-than-expected deviation in a mailed TLD audit program that the centre cannot explain?

12.5 QUALITY AUDIT

12.5.3 What should be reviewed in a quality audit visit?

- Example of content of a comprehensive quality audit visit:

  Check infrastructure
  - Equipment.
  - Personnel.
  - Patient load.
  - Existence of policies and procedures.
  - Quality assurance program in place.
  - Quality improvement program in place.
  - Radiation protection program in place.
  - Data and records, etc.

12.5 QUALITY AUDIT

12.5.3 What should be reviewed in a quality audit visit?

- Example of content of a comprehensive quality audit visit:

Check documentation

- Content of policies and procedures
- QA program structure and management
- Patient dosimetry procedures
- Simulation procedures
- Patient positioning, immobilization and treatment delivery procedures
- Equipment acceptance and commissioning records
- Dosimetry system records
- Machine and treatment planning data
- QC program content
- Tolerances and frequencies, QC and QA records of results and actions
- Preventive maintenance program records and actions
- Patient data records
- Follow-up and outcome analysis etc.

12.5 QUALITY AUDIT

12.5.3 What should be reviewed in a quality audit visit?

- Example of content of a comprehensive quality audit visit:

Carry out check measurements of

- Beam calibration
- Depth dose
- Field size dependence
- Wedge transmissions (with field size), tray, etc. factors
- Electron cone factors
- Electron gap corrections
- Mechanical characteristics
- Patient dosimetry
- Dosimetry equipment comparison
- Temperature and pressure measurement comparison, etc.

12.5 QUALITY AUDIT

12.5.3 What should be reviewed in a quality audit visit?

- Example of content of a comprehensive quality audit visit:

  Carry out check of training programs
  - Academic program.
  - Clinical program.
  - Research.
  - Professional accreditation.
  - Continuing Professional Education.

12.5 QUALITY AUDIT

12.5.3 What should be reviewed in a quality audit visit?

- Example of content of a comprehensive quality audit visit:

  Carry out check measurements on other equipment
  - Simulator
  - CT scanner, etc.

  Assess treatment planning data and procedures.

  Measure some planned distributions in phantoms.

12.5 QUALITY AUDIT

12.5.3 What should be reviewed in a quality audit visit?

Example of a comprehensive international external audit: The QATRO (Quality Assurance Team for Radiation Oncology) project developed by the IAEA.

- Based on:
  - Long history of providing assistance for dosimetry audits in radiotherapy to its Member States.
  - Development of a set of procedures for experts undertaking missions to radiotherapy hospitals in Member States for the on-site review of the dosimetry equipment, data and techniques, and measurements, and training of local staff.
  - Numerous requests from developing countries to perform also comprehensive audits of radiotherapy programs.

12.5 QUALITY AUDIT

12.5.3 What should be reviewed in a quality audit visit?

- In response to requests from member states, the IAEA convened an expert group, comprising of radiation oncologists and medical physicists, who have developed guidelines for the IAEA audit teams to initiate and perform such audits and report on them.
  - The guidelines have been field-tested by IAEA teams performing audits in radiotherapy programs in hospitals in Africa, Asia, Latin America and Europe.
  - QUATRO procedures are endorsed by the European Society for Therapeutic Radiology and Oncology (ESTRO), the European Federation of Organizations for Medical Physics (EFOMP) and the International Organization for Medical Physics (IOMP).