# Chapter 10: Acceptance Tests and Commissioning Measurements

**Set of 189 slides based on the chapter authored by**
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**of the IAEA publication:**
***Review of Radiation Oncology Physics:***
***A Handbook for Teachers and Students***

**Objective:**

To familiarize the student with the series of tasks and measurements required to place a radiation therapy machine into clinical operation.

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## CHAPTER 10. TABLE OF CONTENTS

## 10.1 INTRODUCTION

- In many areas of radiotherapy, particularly in the more readily defined physical and technical aspects of a radiotherapy unit, the term "**Quality Assurance**" (QA) is frequently used to summarize a variety of actions
  - to place the unit into clinical operation, and
  - to maintain its reliable performance.
- Typically, the entire chain of a QA program for a radiotherapy unit consists of subsequent actions as shown in the following slide.



## 10.1 INTRODUCTION

| Subsequent QA actions | Purpose |
|---|---|
| • Clinical needs assessment | Basis for specification |
| • Initial specification and purchase process | Specification of data in units of measure, design of a tender |
| • Acceptance testing | Compliance with specifications |
| • Commissioning for clinical use, (including calibration) | Establishment of baseline performance values |
| • Periodic QA tests | Monitoring the reference performance values |
| • Additional quality control tests after any significant repair, intervention, or adjustment | Monitoring possibly changed reference performance values |
| • Planned preventive maintenance program | Be prepared in case of malfunctions etc. |

## 10.1 INTRODUCTION

- **Acceptance tests** and **commissioning** constitute a major part in this QA program for radiotherapy.
- This chapter is focusing on the duties of *acceptance testing* and *commissioning*.
- Although calibrations of the treatment beams are a part of the acceptance tests and commissioning, calibration will not be discussed in this chapter as it is fully covered in Chapter 9.



## 10.2 MEASUREMENT EQUIPMENT

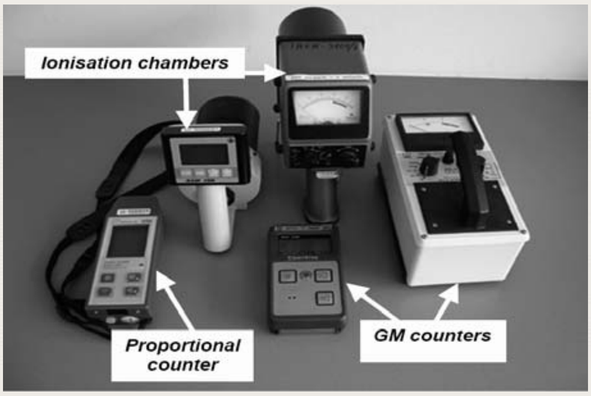
Acceptance tests and commissioning can performed only if adequate measurement equipment is at disposal:

- **Radiation survey equipment:**
  - Geiger counter
  - Large volume ionization chamber survey meter
  - Neutron survey meter (if the unit operates above 10 MeV)
- **Ionometric dosimetry equipment**
- **Other dosimetric detectors (Film, Diodes)**
- **Phantoms**
  - *Radiation field analyzer and water phantom*
  - *Plastic phantoms*

## 10.2 MEASUREMENT EQUIPMENT

### 10.2.1 Radiation survey equipment

- A Geiger-Mueller (GM) counter and a large volume ionization chamber survey meter are required for radiation survey for all treatment rooms.




Typical survey meters of different shapes and sizes



## 10.2 MEASUREMENT EQUIPMENT

### 10.2.1 Radiation survey equipment

- For facilities with a treatment unit operated above 10 MeV, neutron survey equipment are necessary.

- Example of neutron survey meters:
  - Bonner spheres
  - long counters
  - BF3 counters

## 10.2 MEASUREMENT EQUIPMENT
### 10.2.1 Radiation survey equipment

- However, for neutron measurements specialized skills and knowledge are required.
- Therefore, it may be appropriate to contract neutron measurements to a medical physics consulting service.
- This may be a less expensive option than developing the skills and knowledge and acquiring the expensive neutron detection equipment that is typically required only during the acceptance tests.



## 10.2 MEASUREMENT EQUIPMENT
### 10.2.2 Ionometric dosimetry equipment

- During acceptance testing and commissioning of a radiation treatment unit, a variety of radiation beam properties must be measured.
- Good quality **ionometric dosimetry equipment** is essential for this purpose.

Main components of **ionometric dosimetry equipment** are:

- several ionization chambers (of thimble or plane-parallel type)
- a versatile electrometer
- cable and connectors fitting to the electrometer and all chambers
- thermometer, barometer (for absolute dose measurements!)







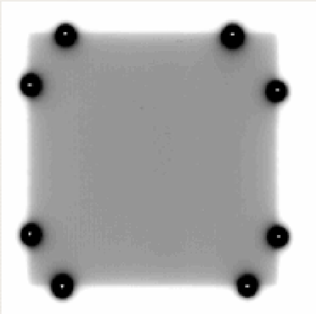
## 10.2 MEASUREMENT EQUIPMENT
### 10.2.2 Ionometric dosimetry equipment


| Typical measurements and/or characteristics | Adequate type of ionization chamber |
|---|---|
| central axis depth dose curves | thimble ionization chambers with volumes on the order of 0.1 - 0.2 $cm^3$ |
| profiles | |
| output factors | |
| measurements in rapidly changing gradients | small volume ionization chambers, parallel plane chambers |
| calibration measurements | calibrated thimble ionization chamber with a volume on the order of 0.5 $cm^3$ |

## 10.2 MEASUREMENT EQUIPMENT
### 10.2.3 Film

- Radiographic film has a long history of use for quality control measurements in **radiotherapy physics**.

- Example:
  Congruence of radiation and light field (as marked by pinholes)





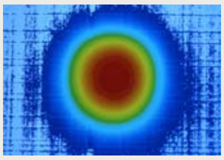
## 10.2 MEASUREMENT EQUIPMENT
### 10.2.3 Film

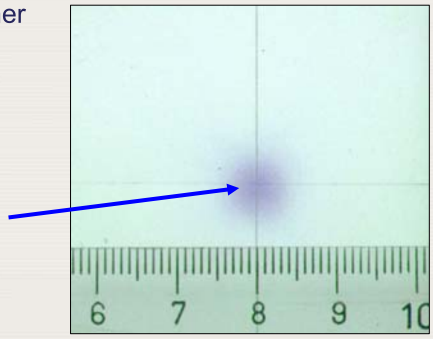
- Important additional required equipment for film measurements:
  - a well controlled film **developing unit**;
  - **densitometer** to evaluate the darkening of the film (= optical density) and to relate the darkening to the radiation received.

- Note:
  Since the composition of radiographic film is different from that of water or tissue, the response of films must always be checked against ionometric measurements before use.

## 10.2 MEASUREMENT EQUIPMENT
### 10.2.3 Film

- In the past decade **radiochromic film** has been introduced into radiotherapy physics practice.
- This film type is **self-developing**, requiring neither developer nor fixer.
- Principle:
  Radiochromic film contains a special dye that is polymerized and develops a blue color upon exposure to radiation.





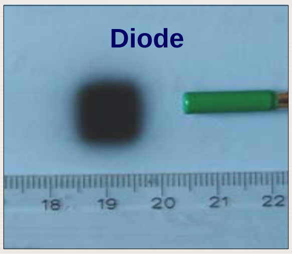



## 10.2 MEASUREMENT EQUIPMENT
### 10.2.3 Film

- Radiochromic film may become more widely used for photon beam dosimetry because of its independence from film developing units.
  (There is a tendency in diagnostics to replace film imaging by digital imaging systems.)
- **Important:**
  Since the absorption peaks occur at wavelengths different from conventional radiographic film, the adequacy of the densitometer must be checked before use.

## 10.2 MEASUREMENT EQUIPMENT
### 10.2.4 Diodes

- Because of their small size silicon diodes are convenient for measurements in small photon radiation fields. Example: Measurements in a 1 x 1 $cm^2$ field


- Note:
  The response of diodes must always be checked against ionometric measurements before use.

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## 10.2 MEASUREMENT EQUIPMENT
### 10.2.5 Phantoms

***Water phantom (or Radiation field analyzer)***

- A water phantom that scans ionization chambers or diodes in the radiation field is almost mandatory for acceptance testing and commissioning.

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## 10.2 MEASUREMENT EQUIPMENT

### 10.2.5 Phantoms

- This type of water phantom is frequently also referred to as a **radiation field analyzer** (RFA) or an isodose plotter.
- Although a two dimensional RFA is adequate, a three dimensional RFA is preferable, as it allows the scanning of the radiation field in orthogonal directions without changing the phantom setup.
- The scanner of the RFA should be able to scan 50 cm in both horizontal dimensions and 40 cm in the vertical dimension.
- The water tank should be at least 10 cm larger than the scan in each dimension.



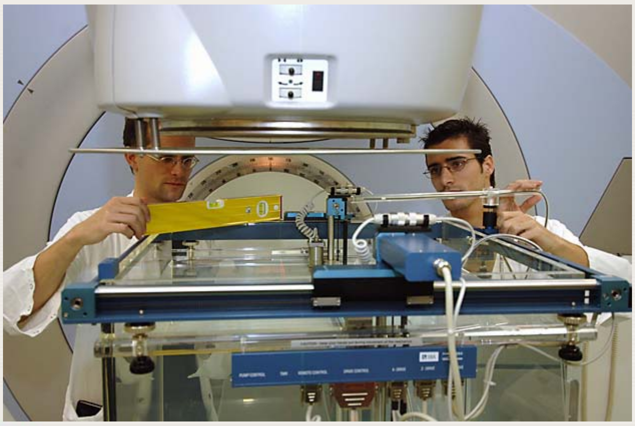
## 10.2 MEASUREMENT EQUIPMENT

### 10.2.5 Phantoms

**Practical notes on the use of an RFA:**

- The RFA should be positioned with the radiation detector centered on the central axis of the radiation beam.
- The traversing mechanism should move the radiation detector along the principal axes of the radiation beam.
- After the gantry has been leveled with the beam directed vertically downward, leveling of the traversing mechanism can be accomplished by scanning the radiation detector along the central axis of the radiation beam indicated by the image of the cross-hair.
- The traversing mechanism should have an accuracy of movement of 1 mm and a precision of 0.5 mm.

## Set up of RFA

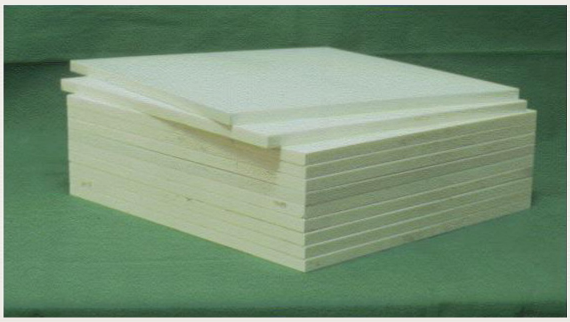






***Plastic phantoms***

- For ionometric measurements a polystyrene or water equivalent plastic phantom is convenient.

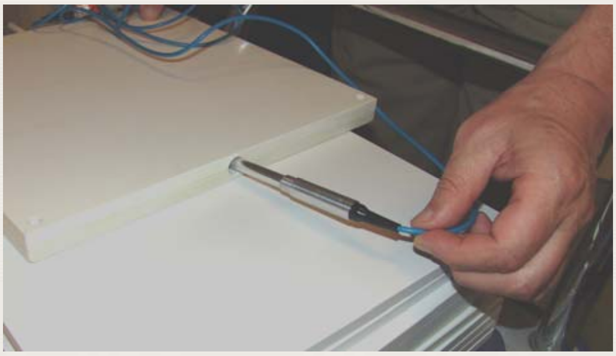


## 10.2 MEASUREMENT EQUIPMENT

### 10.2.5 Phantoms

***Plastic phantoms for ionization chambers***

- One block should be drilled to accommodate a Farmer-type ionization chamber with the center of the hole, 1 cm from one surface.





## 10.2 MEASUREMENT EQUIPMENT

### 10.2.5 Phantoms

***Plastic phantoms for ionization chambers***

- A second block should be machined to place the entrance window of a parallel plate chamber at the level of one surface of the block. This arrangement allows measurements with the parallel plate chamber with no material between the window and the radiation beam.

## 10.2 MEASUREMENT EQUIPMENT
### 10.2.5 Phantoms

***Plastic phantoms for ionization chambers***

- An additional seven blocks of the same material as the rest of the phantom should be 0.5, 1, 2, 4, 8, 16 and 32 mm thick.
- These seven blocks combined with the 5 cm thick blocks allow measurement of depth ionization curves in 0.5 mm increments to any depth from the surface to 40 cm with the parallel plate chamber and from 1 cm to 40 cm with the Farmer chamber.



## 10.2 MEASUREMENT EQUIPMENT
### 10.2.5 Phantoms

**Note:**

In spite of the popularity of plastic phantoms, for **calibration measurements** (except for low-energy x-rays) their use of is strongly discouraged, as in general they are responsible for the largest discrepancies in the determination of absorbed dose for most beam types.

***Plastic phantoms for films***

- A plastic phantom is also useful for film dosimetry.
- It is convenient to design one section of the phantom to serve as a film cassette. Other phantom sections can be placed adjacent to the cassette holder to provide full scattering conditions.



10.2 MEASUREMENT EQUIPMENT

10.2.5 Phantoms

**Practical notes on the use of plastic phantoms for film dosimetry:**

- Use of ready pack film irradiated parallel to the central axis of the beam requires that the edge of the film be placed at the surface of the phantom and that the excess paper be folded down and secured to the entrance surface of the phantom.
- Pinholes should be placed in a corner of the downstream edge of the paper package so that air can be squeezed out before placing the ready pack in the phantom. Otherwise air bubbles will be trapped between the film and the paper. Radiation will be transmitted un-attenuated through these air bubbles producing incorrect data.

## 10.3 ACCEPTANCE TESTS

### Acceptance Tests of Radiotherapy Equipment: Characteristics

- Acceptance tests assure that
  - the specifications contained in the purchase order are fulfilled;
  - the environment is free of radiation;
  - the radiotherapy equipment is free of electrical hazards to staff and patients.
- The tests are performed in the presence of a manufacturer's representative.



## 10.3 ACCEPTANCE TESTS

### Characteristics (continued)

- Upon satisfactory completion of the acceptance tests, the physicist signs a document certifying these conditions are met.
- When the physicist accepts the unit, the final payment is made for the unit, owner-ship of the unit is transferred to the institution, and the warranty period begins.
- These conditions place a heavy responsibility on the physicist in correct performance of these tests.

## 10.3 ACCEPTANCE TESTS

Acceptance tests may be divided into three groups:

**(1) safety checks;**
**(2) mechanical checks;**
**(3) dosimetry measurements.**

- A number of national and international protocols exist to guide the physicist in the performance of acceptance tests.

Example:

- Comprehensive QA for Radiation Oncology, AAPM Task Group 40

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## 10.3 ACCEPTANCE TESTS

### 10.3.1 Safety Checks

***Safety checks include those of:***

- Interlocks
- Warning lights
- Patient monitoring equipment
- Radiation survey
- Collimator and head leakage

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## 10.3 ACCEPTANCE TESTS

### 10.3.1 Safety Checks: Interlocks

***Interlocks***

- The initial safety checks should verify that **all interlocks** are functioning properly and reliable.

- **"All interlocks"** means the following four types of interlocks:



## 10.3 ACCEPTANCE TESTS

### 10.3.1 Safety Checks: Interlocks

**(1) Door interlocks:**
The door interlock prevents irradiation from occurring when the door to the treatment room is open.

**(2) Radiation beam-off interlocks:**
The radiation beam-off interlocks halt irradiation but they do not halt the motion of the treatment unit or patient treatment couch.

## 10.3 ACCEPTANCE TESTS
### 10.3.1 Safety Checks: Interlocks

**(3) Motion-disable interlocks:**
The motion-disable interlocks halt motion of the treatment unit and patient treatment couch but they do not stop machine irradiation.

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## 10.3 ACCEPTANCE TESTS
### 10.3.1 Safety Checks: Interlocks

**(4) Emergency-off interlocks:**
Emergency-off interlocks typically disable power to the motors that drive treatment unit and treatment couch motions and power to some of the radiation producing elements of the treatment unit. The idea is to prevent both collisions between the treatment unit and personnel, patients or other equipment and to halt undesirable irradiation

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## 10.3 ACCEPTANCE TESTS

### 10.3.1 Safety Checks: Warning lights

***Warning lights***

- ❑ After verifying that all interlocks and emergency off switches are operational, all warning lights should be checked.




## 10.3 ACCEPTANCE TESTS

### 10.3.1 Safety Checks: Patient monitoring equipment

***Patient monitoring equipment***

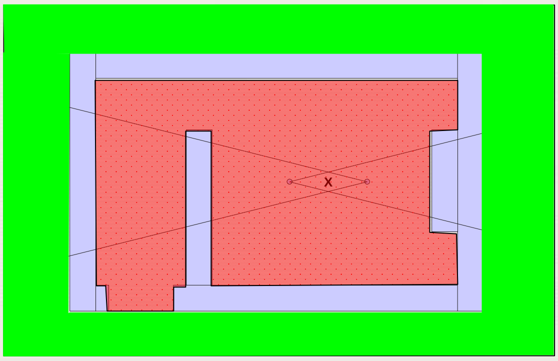
- ❑ Next the proper functioning of the patient monitoring audio-video equipment can be verified. The audio-video equipment is often useful for monitoring equipment or gauges during the acceptance testing and commissioning involving radiation measurements.

## 10.3 ACCEPTANCE TESTS
### 10.3.1 Safety Checks: Radiation survey

**_Radiation survey_**

- In all areas outside the treatment room a radiation survey must be performed.

*Typical floor plan for an isocentric high-energy linac bunker.*



***Green*** *means:*
*A*ll areas outside the treatment room must be "free" of radiation



## 10.3 ACCEPTANCE TESTS
### 10.3.1 Safety Checks: Radiation survey

- For cobalt units and linear accelerators operated below 10 MeV a **photon survey** is required.
- For linear accelerators operated above 10 MeV the physicist must survey for **neutrons** in addition to photons.
- The survey should be conducted using the **highest energy photon beam**.
- To assure meaningful results the physicist should perform a preliminary calibration of the highest energy photon beam before conducting the radiation survey.

## 10.3 ACCEPTANCE TESTS

### 10.3.1 Safety Checks : Radiation survey

**Practical notes on performing a radiation survey:**

- The fast response of the Geiger counter is advantageous in performing a **quick initial survey** to locate areas of highest radiation leakage through the walls.
- After location of these "hot-spots" the ionization chamber-type survey meter may be used to quantify the leakage values.

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## 10.3 ACCEPTANCE TESTS

### 10.3.1 Safety Checks : Radiation survey

**Practical notes on performing a radiation survey:**

- The first area surveyed should be the control console area where an operator will be located to operate the unit for all subsequent measurements.
- All primary barriers should be surveyed with the largest field size, with the collimator rotated to 45º, and with no phantom in the beam.
- All secondary barriers should be surveyed with the largest field size with a phantom in the beam.

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## 10.3 ACCEPTANCE TESTS
### 10.3.1 Safety Checks: Collimator and head leakage

- The source on a cobalt-60 unit or the target on a linear accelerator is surrounded by a shielding.
- Most regulations require this shielding to limit the leakage radiation to a 0.1% of the useful beam at one meter from the source.
- The adequacy of this shielding must be verified during acceptance testing.

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## 10.3 ACCEPTANCE TESTS
### 10.3.1 Safety Checks: Collimator and head leakage

**Practical notes on performing a leakage test:**
**Use of a film – ionization chamber combination**

- The leakage test may be accomplished by closing the collimator jaws and covering the head of the treatment unit with film.
- The films should be marked to permit the determination of their position on the machine after they are exposed and processed.
- The exposure must be long enough to yield an optical density of one on the films.
- Any hot spots revealed by the film should be quantified by using an ionization chamber-style survey meter.

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## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks

**The mechanical checks include:**

(1) Collimator axis of rotation
(2) Photon collimator jaw motion
(3) Congruence of light and radiation field
(4) Gantry axis of rotation
(5) Patient treatment table axis of rotation
(6) Radiation isocenter
(7) Optical distance indicator
(8) Gantry angle indicators
(9) Collimator field size indicators
(10) Patient treatment table motions



## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks

The following mechanical test descriptions are structured such that for each test four characteristics (if appropriate) are given:

**(1)** **aim** of the test;

**(2)** **method** used;

**(3)** **practical suggestions**;

**(4)** **expected results**.

## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Collimator axis of rotation

**Aim**

- The photon collimator jaws rotate on a circular bearing attached to the gantry.
- The axis of rotation is an important aspect of any treatment unit and must be carefully determined.
- The central axis of the photon, electron, and light fields should be aligned with the axis of rotation of this bearing and the photon collimator jaws should open symmetrically about this axis.

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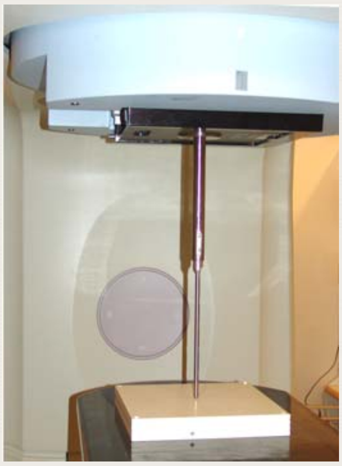
## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Collimator axis of rotation

**Method**

- The collimator rotation axis can be found with a rigid rod attached to the collimator.
- This rod should terminate in a sharp point and be long enough to reach from where it will be attached to the approximate position of isocenter.



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## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Collimator axis of rotation

**Practical suggestions**

- The gantry should be positioned to point the collimator axis vertically downward and then the rod is attached to the collimator housing. Millimeter graph paper is attached to the patient treatment couch and the treatment couch is raised to contact the point of the rod. With the rod rigidly mounted, the collimator is rotated through its range of motion. The point of the rod will trace out an arc as the collimator is rotated. The point of the rod is adjusted to be near the center of this arc. This point should be the collimator axis of rotation. This process is continued until the minimum radius of the arc is obtained.

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## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Collimator axis of rotation

**Expected result**

- The minimum radius is the precision of the collimator axis of rotation.
- In most cases this arc will reduce to a point but should not exceed 1 mm in radius in any event.

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# 10.3 ACCEPTANCE TESTS
## 10.3.2 Mechanical Checks: Photon collimator jaw motion

**Aim**

- The photon collimator jaws should open symmetrically about the collimator axis of rotation.

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# 10.3 ACCEPTANCE TESTS
## 10.3.2 Mechanical Checks: Photon collimator jaw motion

**Method**

- A machinist dial indicator can be used to verify this. The indicator is attached to a point on the collimator housing that remains stationary during rotation of the collimator jaws.

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## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Photon collimator jaw motion

**Practical suggestions**

- The feeler of the indicator is brought into contact with one set of jaws and the reading is recorded. The collimator is then rotated through 180º and again the indicator is brought into contact with the jaws and the reading is recorded. The collimator jaw symmetry about the rotation axis is one half of the difference in the two readings. This value projected to the isocenter should be less than 1 mm. This procedure is repeated for the other set of collimator jaws.

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## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Photon collimator jaw motion

**Expected result**

- This value projected to the isocenter should be less than 1 mm. This procedure is repeated for the other set of collimator jaws.

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## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Photon collimator jaw motion

**Aim**

- The two sets of collimator jaws should be perpendicular to each other.

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## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Photon collimator jaw motion

**Method**

- To check this, the gantry is rotated to orient the collimator axis of rotation horizontally.
- Then the collimator is rotated to place one set of jaws horizontally.
- A spirit level is placed on the jaws to verify they are horizontal.
- Then the spirit level is used to verify that the vertically positioned jaws are vertical.

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## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Collimator angle indicator

**Method**

- The accuracy of the collimator angle indicator can be determined by using a spirit level.
- With the jaws in the position of the jaw motion test the collimator angle indicators are verified. These indicators should be reading a cardinal angle at this point, either 0, 90, 180, or 270º depending on the collimator position. This test is repeated with the spirit level at all cardinal angles by rotating the collimator to verify the collimator angle indicators.

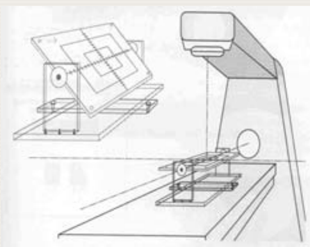


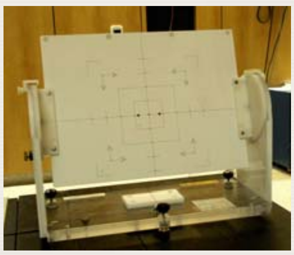
## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Congruence of light and radiation field

**Aim**

- Correct alignment of the radiation field is always checked by the light field. Congruence of light and radiation field must therefore be verified. Additional tools can be used.





## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Congruence of light and radiation field

**Method: Adjustment**

- With millimeter graph paper attached to the patient treatment couch, the couch is raised to nominal isocenter distance.
- The gantry is oriented to point the collimator axis of rotation vertically downward. The position of the collimator axis of rotation is indicated on this graph paper. The projected image of the cross-hair should be coincident with the collimator axis of rotation and should not deviate more than 1 mm from this point as the collimator is rotated through its full range of motion.



## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Congruence of light and radiation field

**Method (continued)**

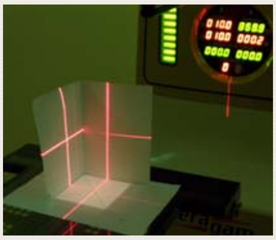
- The congruence of the light and radiation field can now be verified. A radiographic film is placed perpendicularly to the collimator axis of rotation.
- The edges of the light field are marked with radio-opaque objects or by pricking holes with a pin through the ready pack film in the corners of the light field.
- Plastic slabs are placed on top of the film such, that the film is positioned near $z_{max}$
- The film is irradiated to yield an optical density between 1 and 2.

## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Congruence of light and radiation field

**Expected result**

- The light field edge should correspond to the radiation field edge within 2 mm.
- Any larger misalignment between the light and radiation field may indicate that the central axis of the radiation field is not aligned to the collimator axis of rotation.



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## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Gantry axis of rotation

**Aim**

- As well as the collimator rotation axis, the gantry axis of rotation is an important aspect of any treatment unit and must be carefully determined.
- Two requirement on the gantry axis of rotation must be fulfilled:
  - good stability
  - accurate identification of the position (by cross hair image and/or laser system)

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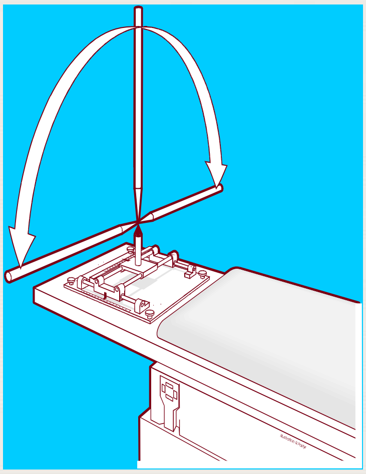
# 10.3 ACCEPTANCE TESTS
## 10.3.2 Mechanical Checks: Gantry axis of rotation

### Method

- The gantry axis of rotation can be found with a rigid rod aligned along the collimator axis of rotation; its tip is adjusted at nominal isocenter distance.
  A second rigid rod with a small diameter tip is attached at the couch serving to identify the preliminary isocenter point .



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# 10.3 ACCEPTANCE TESTS
## 10.3.2 Mechanical Checks: Gantry axis of rotation

### Practical suggestions

- The gantry is positioned to point the central axis of the beam vertically downward. Then the treatment table with the second rigid rod is shifted along its longitudinal axis to move the point of the rod out of contact with the rod affixed to the gantry.
- The gantry is rotated 180º and the treatment couch is moved back to a position where the two rods contact. If the front pointer correctly indicates the isocenter distance, the points on the two rods should contact in the same relative position at both angles.

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## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Gantry axis of rotation

**Practical suggestions**

- If not, the treatment couch height and length of the front pointer are adjusted until this condition is achieved as closely as possible.
- Because of flexing of the gantry, it may not be possible to achieve the same position at both gantry angles.
- If so, the treatment couch height is positioned to minimize the overlap at both gantry angles. This overlap is a “zone of uncertainty” of the gantry axis of rotation.
- This procedure is repeated with the gantry at parallel-opposed horizontal angles to establish the right/left position of the gantry axis of rotation.



## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Gantry axis of rotation

**Expected result**

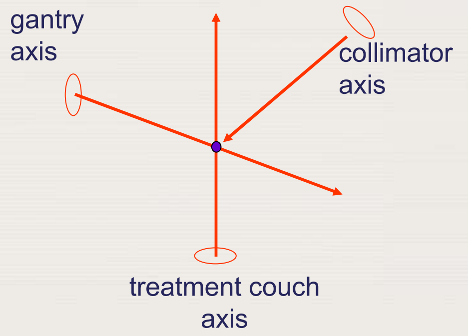
- The tip of the rod affixed to the treatment table indicates the position of the gantry axis of rotation.
- The zone of uncertainty should not be more than 1 mm in radius.
- The cross-hair image is aligned such that it passes through the point indicated by the tip of the rod.
- Patient positioning lasers are aligned to pass through this point.

## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Couch axis of rotation

**Aim**

- The collimator axis of rotation, the gantry axis of rotation, and the treatment couch axis of rotation ideally should all intersect in a point.

- Note:
  Whereas the collimator and gantry rotation axis can hardly be changed by a user, the position of the couch rotation axis can indeed be adjusted.






## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Couch axis of rotation

**Method**

- The patient treatment couch axis of rotation can be found by observing and noting the movement of the cross-hair image on a graph paper while the gantry with the collimator axis of rotation is pointing vertically downward.

## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Couch axis of rotation

**Expected result**

- The cross-hair image should trace an arc with a radius of less than 1mm.



## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Radiation isocenter

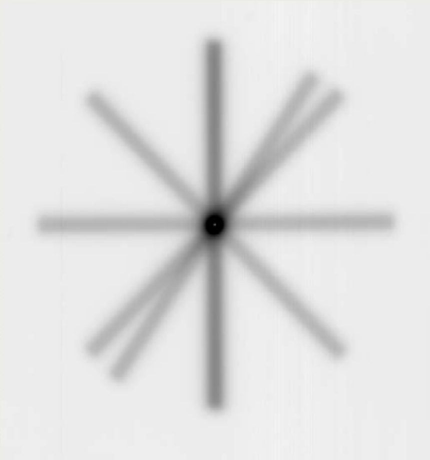
**Aim**

- The radiation isocenter is primarily determined by the intersection of the three rotation axes: the collimator axis of rotation, the gantry axis of rotation, and the treatment couch axis of rotation.
- In practice, they are not all intersecting at a point, but within a **sphere**.
- The radius of this sphere determines the isocenter uncertainty.
- Radiation isocenter should be determined for all photon energies.

## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Radiation isocenter

**Method**

- The location and the dimension of the radiation isocenter sphere can be determined by a film using the "star-shot" method.





## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Radiation isocenter

**Practical suggestions**

- A ready-pack film is taped to one of the plastic blocks that comprise a plastic phantom.
- The film should be perpendicular to and approximately centered on the gantry axis of rotation.
- A pin prick is made in the film to indicate the gantry axis of rotation.
- Then a second block is placed against the film sandwiching it between the two blocks and the collimator jaws are closed to approximately 1 mm × 1 mm.

## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Radiation isocenter

**Practical suggestions**

- Without touching the film, the film is exposed at a number of different gantry angles in all four quadrants.
- In addition, the film can be exposed at a number of different couch angles.
- The processed film should show a multi-armed cross, referred to as a “star shot.”
- The point where all central axes intersect is the radiation isocenter.

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## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Radiation isocenter

**Expected result**

- Because of gantry flex, it may be a few millimeters wide but should not exceed 4 mm. This point should be within 1 mm to 2 mm of the mechanical isocenter indicated by the pin-prick on the film.
- The collimator axis of rotation, the gantry axis of rotation and the treatment table axis of rotation should all intersect in a sphere. The radius of this sphere determines the isocentre uncertainty. This radius should be no greater than 1 mm, and for machines used in radiosurgery should not exceed 0.5 mm.

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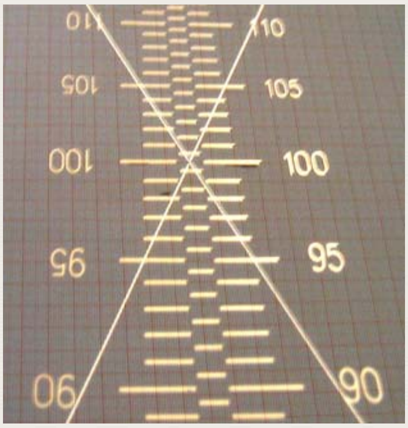
## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Optical distance indicator

**Method**

- A convenient method to verify the accuracy of the optical distance indicator over the range of its read-out consists of projecting the indicator on top of a plastic phantom with different heights.

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## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Optical distance indicator

**Practical suggestions**

- With the gantry positioned with the collimator axis of rotation pointing vertically downward five of the 5 cm thick blocks are placed on the treatment couch with the top of the top block at isocenter.
- The optical distance indicator should read isocenter distance.
- By adding and removing 5 cm blocks the optical distance indicator can be easily verified at other distances in 5 cm increments.

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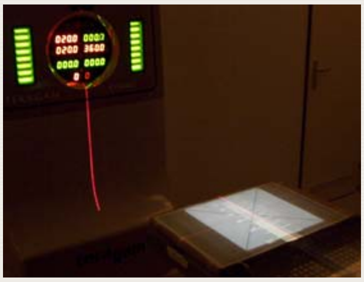
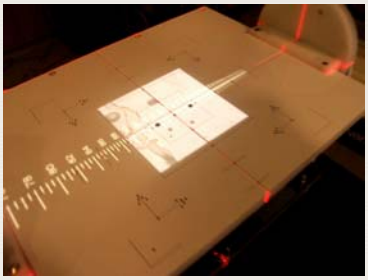
## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Optical distance indicator

**Expected results**

- The deviation of the actual height from that indicted by the optical distance indicator must comply with the specification.





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## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Gantry angle indicators

**Method**

- The accuracy of the gantry angle indicators can be determined by using a spirit level.

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### 10.3.2 Mechanical Checks: Gantry angle indicators

**Practical suggestions**

- At each of the nominal cardinal angles the spirit level should indicate correct level.
- Some spirit levels also have an indicator for 45° angles that can be used to check angles of 45°, 135°, 225°, and 315°.



10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Gantry angle indicators

**Expected results**

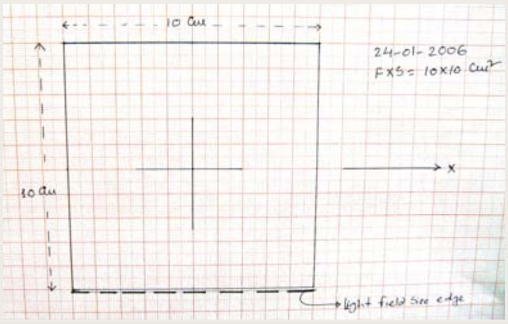
- The gantry angle indicators should be accurate to within 0.5°.

# 10.3 ACCEPTANCE TESTS

## 10.3.2 Mechanical Checks: Collimator field size indicators

### Method

- The collimator field size indicators can be checked by comparing the indicated field sizes to values measured on a piece of graph paper.






# 10.3 ACCEPTANCE TESTS

## 10.3.2 Mechanical Checks: Collimator field size indicators

### Practical suggestions

- The graph paper is fixed to the treatment couch with the top of the couch raised to isocenter height.
- The range of field size should be checked for both symmetric and asymmetric field settings.

## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Collimator field size indicators

**Expected results**

- The field size indicators should be accurate to within 2 mm.

  (Suggested in: Comprehensive QA for Radiation Oncology, AAPM Task Group 40)



## 10.3 ACCEPTANCE TESTS

### 10.3.2 Mechanical Checks: Couch motions

**Aim**

- The patient treatment couch should exactly move in vertical and horizontal planes.

**Method**

- The vertical motion can be checked by attaching a piece of millimeter graph paper to the treatment couch and with the gantry positioned with the collimator axis of rotation pointing vertically downward.





**Practical suggestions**

- Mark the position of the image of the cross-hair on the paper.
- As the treatment couch is moved through its vertical range, the cross-hair image should not deviate from this mark.
- The horizontal motions can be checked in a similar fashion with the gantry positioned with the collimator axis in a horizontal plane.
- By rotating the treatment couch 90 degrees from its “neutral” position, the longitudinal motion can be verified.

## 10.3 ACCEPTANCE TESTS
### 10.3.2 Mechanical Checks: Couch motions

**Expected results**

- The deviation of the movement from vertical and horizontal planes must comply with the specification.



## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements

- After completion of the mechanical checks, dosimetry measurements must be performed.

- Dosimetry measurements establish that
  - the central axis percentage depth doses, and
  - off axis characteristics of clinical beams meet the specifications.
  - The characteristics of the monitor ionization chamber of a linear accelerator or a timer of a cobalt-60 unit are also determined.

## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements

**The dosimetry measurements include:**

(1) Photon energy
(2) Photon beam uniformity
(3) Photon penumbra
(4) Electron energy
(5) Electron beam bremsstrahlung contamination
(6) Electron beam uniformity
(7) Electron penumbra
(8) Monitor characteristics
(9) Arc therapy



## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements

The following dosimetry measurement descriptions are structured such that for each test two characteristics are given:

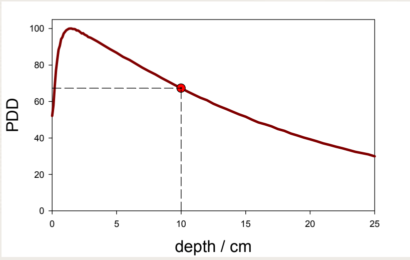
(1) the parameter used to specify the dosimetrical property;

(2) the method used;

## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Photon energy

**Specification**

- The "energy" specification of an x-ray beam is usually stated in terms of the central axis percentage depth dose.
- Typically used:
  the central axis percentage depth dose value in a water phantom for:
  - *SSD* = 100 cm
  - field = 10×10 $cm^2$
  - at a depth of 10 cm.






## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Photon energy

**Method**

- During acceptance testing the central axis percentage depth dose value will be determined with a small volume ionization chamber in a water phantom according to the acceptance test protocol.
- This value is compared to values given in the British Journal of Radiology, Supplement 25 to determine a nominal energy for the photon beam.

## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Photon beam uniformity

**Specification**

- The uniformity of a photon beam can be specified in terms of the
  - **flatness** and **symmetry** measured in **transverse beam profiles**, or
  - the **uniformity index**.

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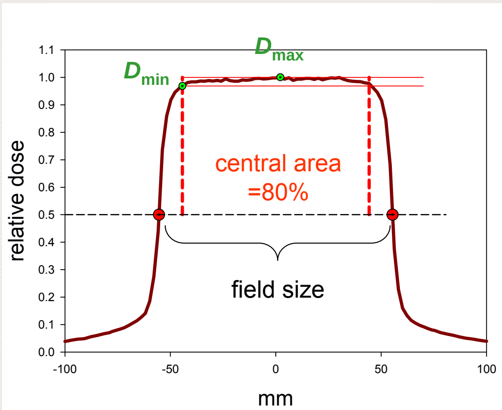
## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Photon beam uniformity

**Methods using transverse beam profiles**

- **Beam flatness *F***, obtained from the profile in 10 cm depth:

$$F = 100 \cdot \frac{D_{max} - D_{min}}{D_{max} + D_{min}}$$

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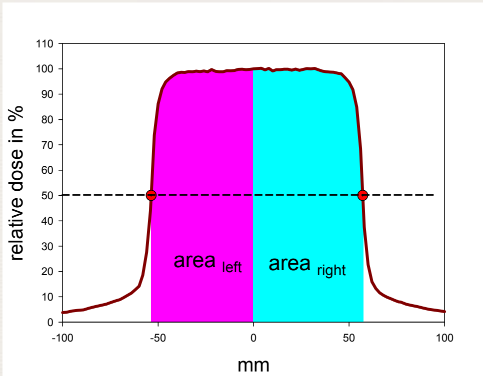
## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Photon beam uniformity

**Methods using transverse beam profiles**

- **Beam symmetry *S***, obtained from the profile in the depth of dose maximum:

$$S = 100 \cdot \frac{area_{left} - area_{right}}{area_{left} + area_{right}}$$

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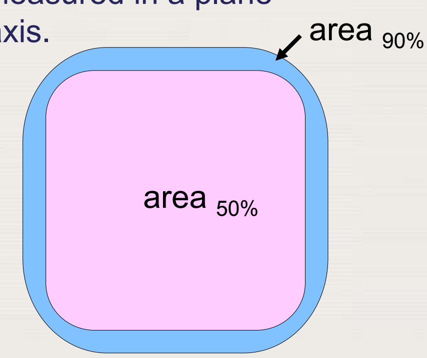
## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Photon beam uniformity

**Methods using the uniformity index**

- The **uniformity index *UI*** is measured in a plane perpendicular to the central axis.
- It is defined using the areas enclosed by the 90% and 50% isodose by the relationship:

$$UI = \frac{area_{90\%}}{area_{50\%}}$$

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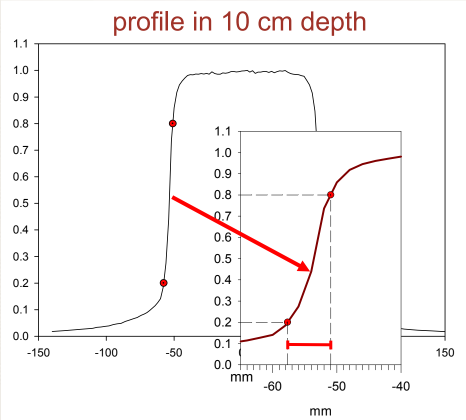
## Specification

- The photon penumbra is typically defined as the distance between the 80% and 20% dose points on a transverse beam profile measured 10 cm deep in a water phantom.








## Method

- During acceptance testing the profile dose value will be determined with a small volume ionization chamber in a water phantom according to the acceptance test protocol.
- Whenever penumbra values are quoted, the depth of profile should be stated.

- Note:
There are also other definitions of the penumbra, such as the distance between the 90% and 10% dose points on the beam profile at a given depth in phantom.

## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Electron energy

**Specification**

- The electron energy can be specified as the most **probable electron energy** $E_{p,0}$ at the surface of a water phantom.

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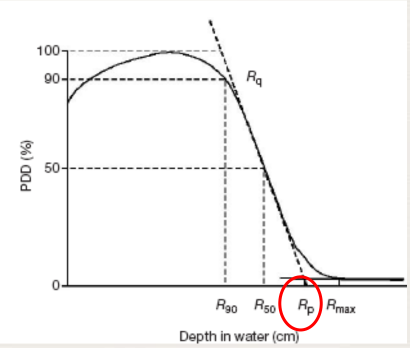
## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Electron energy

**Method**

- $E_{p,0}$ is based on the measurement of the practical range $R_p$ in a water phantom.

- $E_{p,0}$ is determined from the practical range with the following equation:




$$E_{p,0} = 0.0025 \cdot R_p^2 + 1.98 \cdot R_p + 0.22$$

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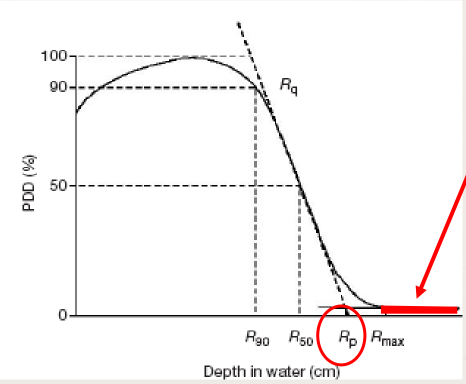
# 10.3 ACCEPTANCE TESTS
## 10.3.3 Dosimetry Measurements: Bremsstrahlung contamination

### Specification




The bremsstrahlung contamination of the electron beam is the radiation measured beyond the practical range of the electrons in percent of the maximum dose.



# 10.3 ACCEPTANCE TESTS
## 10.3.3 Dosimetry Measurements: Bremsstrahlung contamination

### Method

- The bremsstrahlung contamination of the electron beam is determined directly from PDD curves measured in electron beams.
- For this purpose, the central axis PDD must be measured to depths large enough to determine this component.

## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Electron beam uniformity

**Specification**

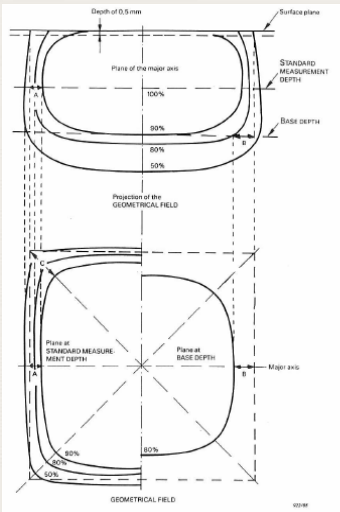
- The uniformity of an electron beam can be specified similar to that of photon beams in terms of the
  - **flatness** and **symmetry** measured in **transverse beam profiles**, or
  - the **uniformity index**



## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Electron beam uniformity

**Note**

- The IEC definition of electron field uniformity includes measuring beam profiles at depths of 1 mm, the depth of the 90% dose, and at one half the depth of the 80% dose.



## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Monitor characteristics

**Specifications**

- The monitor unit device consists of
  - a timer in case of a cobalt unit
  - an ionization chamber that intercepts the entire treatment beam in case of a linear accelerator.
- The following characteristics of the monitor unit device must be checked:
  - Linearity
  - Independence from temperature-pressure fluctuations
  - Independence from dose rate and gantry angle.



## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Monitor characteristics

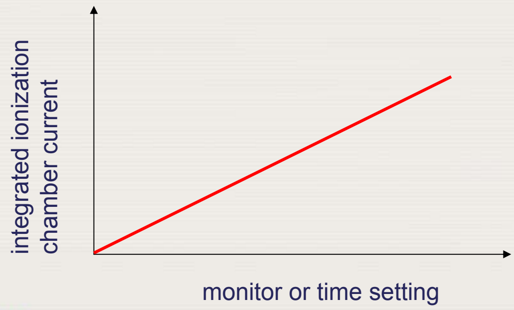
**Methods: Linearity**

- The *linearity* of the monitor unit device should be verified by placing an ionization chamber at a fixed depth in a phantom and recording the ionization collected during irradiations with different time or monitor unit settings over the range of the monitor.
- The collected ionization can be plotted on the y-axis and the monitor or time setting on the x-axis. These data should produce a straight line indicating a linear response of the monitor unit device or timer.

## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Monitor characteristics

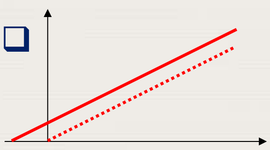
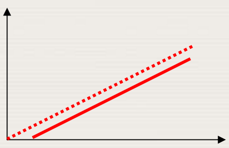
**Methods: Linearity**

- ❑ These data should produce a straight line indicating a linear response of the monitor unit device or timer.






## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Monitor characteristics

- ❑ 
  A **negative x-intercept**:
  more radiation is delivered than indicated by the monitor unit setting.
- ❑ 
  A **positive x-intercept**:
  less radiation is delivered than indicated by the monitor unit setting.
- ❑ This end effect should be determined for each energy and modality on the treatment unit.
- ❑ For teletherapy units and orthovoltage x-ray units this effect is referred to as the **shutter error**.

## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Monitor characteristics

**Methods: Independence from temperature-pressure fluctuations**

- Most linear accelerator manufacturers design the monitor chamber to be either sealed so that the monitor chamber calibration is independent of *temperature-pressure fluctuations* or the monitor chamber has a temperature-pressure compensation circuit. The effectiveness of either method should be evaluated by determining the long-term stability of the monitor chamber calibration. This evaluation can be performed during commissioning by measuring the output each morning in a plastic phantom in a set up designed to reduce set up variations and increase precision of the measurement.

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## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Monitor characteristics

**Methods: Independence from dose rate and gantry angle**

- Linear accelerators usually provide the capability of irradiating at several different *dose rates*. Different dose rates may change the collection efficiency of the monitor ionization chamber, which would change the calibration (cGy/MU) of the monitor ionization chamber. The calibration of the monitor ionization chamber should be determined at all available dose rates of the treatment unit. The constancy of output with gantry angle should also be verified.

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## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Arc therapy

**Specification**

- The rotation of arc or rotational therapy must exactly terminate when the **monitor or time setting** and at the same time the **number of degrees** for the desired arc is reached.
- Proper function is specified by a difference as small as possible in monitor units (or time) as well as in degrees from the setting.

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## 10.3 ACCEPTANCE TESTS
### 10.3.3 Dosimetry Measurements: Arc therapy

**Method**

- A check is accomplished by setting a number of monitor units on a linear accelerator or time on a cobalt-60 unit and a number of degrees for the desired arc.
- Termination of radiation and treatment unit motion should agree with the specification.
- This test should be performed for all energies and modalities of treatment and over the range of arc therapy geometry for which arc therapy will be used.

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## 10.4 COMMISSIONING

**Characteristics**

- Following acceptance, a characterization of the equipment's performance over **the whole range of possible operation** must be undertaken.
- This is generally referred to as **commissioning**.
- Another definition is that commissioning is the process of preparing procedures, protocols, instructions, data, etc. for **clinical service**.
- Clinical use can only begin when the physicist responsible for commissioning is satisfied that all aspects have been completed and that the equipment and any necessary data, etc., are safe to use on patients.



## 10.4 COMMISSIONING

Commissioning of an external beam therapy device includes a **series of tasks**:

(1) acquiring all radiation beam data required for treatment;
(2) organizing this data into a dosimetry data book;
(3) entering this data into a computerized treatment planning system;
(4) developing all dosimetry, treatment planning, and treatment procedures;
(5) verifying the accuracy of these procedures;
(6) establishing quality control tests and procedures; and
(7) training all personnel.

## 10.4 COMMISSIONING

The following slides are dealing with commissioning procedures of the most important first item:

**acquiring of all photon and electron beam data required for treatment planning**



## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements

**Photon beam data to be acquired include:**

(1) Central axis percentage depth doses (PDD)
(2) Output factors
(3) Blocking tray factors
(4) Characteristics of Multileaf collimators
(5) Central axis wedge transmission factors
(6) Dynamic wedge data
(7) Transverse beam profiles/off-axis energy changes
(8) Entrance dose and interface dosimetry data
(9) Virtual source position

## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements: PDD

**Method**

- Central axis percentage depth doses are preferable measured in a water phantom.
- For measurements, **plane-parallel ionization chambers** with the effective point of measurement placed at nominal depth are recommended.

Note:
The effective point of measurement of a plane-parallel chamber is on the **inner surface of the entrance window**, at the center of the window for all beam qualities and depths.



## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements: PDD

**Note:**

Ionization chambers always provide **depth-ionization** curves.

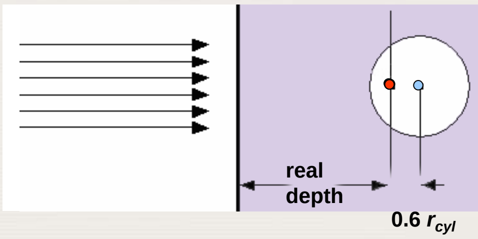
Since stopping-power ratios and perturbation effects for photon beams the are almost independent of depth, **relative ionization distributions** can be used in a very good approximation as **relative distributions of absorbed dose**.

## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements: PDD

**Method (continued)**

- If a cylindrical ionization chamber is used instead, then the **effective point** of measurement (●) of the chamber must be taken into account.




- This may require that the complete depth-ionization distribution be shifted towards the surface a distance equal to 0.6 $r_{cyl}$ where $r_{cyl}$ is the cavity radius of the cylindrical ionization chamber.



## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements: PDD

**Practical suggestions**

- PDD values should be measured over the range of field sizes from 4×4 $cm^2$ to 40×40 $cm^2$.
- Increments between field sizes should be no greater than 5 cm but are typically 2 cm.
- Measurements should be made to a depth of 35 cm or 40 cm.
- Field sizes smaller than 4×4 $cm^2$ require special attention. Detectors of small dimensions are required for these measurements.
- A 0.1 $cm^3$ chamber oriented with its central electrode parallel to the central axis of the beam or a diode may be used in a water phantom.

## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: PDD

**Note:**

- Many photon central axis percentage depth doses reveal a shift in the depth of maximum dose toward the surface as the field size increases.
- This shift results from an increasing number of secondary electrons in the beam generated from the increasing surface area of the collimators as well as flattening filter viewed by the detector.



## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Output factors

- The radiation output specified, for example, in
  - cGy/MU for a linear accelerator
  - cGy/min for a cobalt unit,

  depends on collimator opening or field shape:

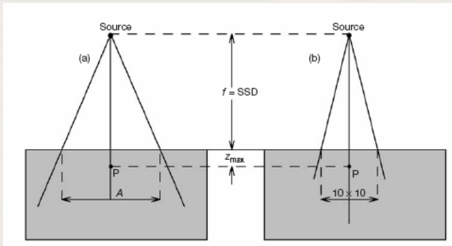
  **the larger the field size, the larger the radiation output**

- The change in output must be known in particular for
  - square fields
  - rectangular fields
  - asymmetric fields (if clinically applied).

## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Output factors

- The radiation output is frequently given as a relative factor, referred to as:
  - (machine) output factor *OF*,
  - relative dose factor (*RDF*), or
  - total scatter factor
- It is defined as:

$$OF = \frac{D_P(z_{max}, A, SSD, E)}{D_P(z_{max}, 10, SSD, E)}$$






## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Output factors

**Method**

- Output factors should be measured with an ionization chamber. Water phantom and plastic phantom is equally appropriate.

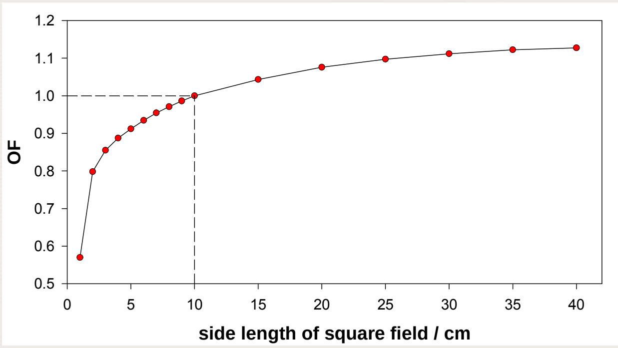
**Note:**

The determination of output factors in the small fields is not easy. Other detectors than ionization chambers may be appropriate. Their response must always be checked against ionometric measurements in larger fields.

## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Output factors

**Square fields**

- Output factors ***OF*** are usually presented graphically as a function of the side length of square fields.






## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Output factors

**Rectangular fields**

- In a good approximation, the output for rectangular fields is equal to the output of its **equivalent square field**.

$$a_{eq} = 2ab/(a+b)$$

- This assumption must be verified by measuring the output for a number of rectangular fields with high and low aspect ratios.
- If the outputs of rectangular fields vary from the output of their equivalent square field by more than 2%, it may be necessary to have a table or graph of output factors for each rectangular field.

# 10.4 COMMISSIONING

## 10.4.1 Photon Beam Measurements: Output factors

### Rectangular fields (cont.)

- This matter can be further complicated as linear accelerators may exhibit a dependence on jaw orientation.
- For example, the output of a rectangular field may depend on whether the upper or lower jaw forms the long side of the field.
- This effect is sometimes referred to as the **collimator exchange effect** and should be investigated as part of the commissioning process.

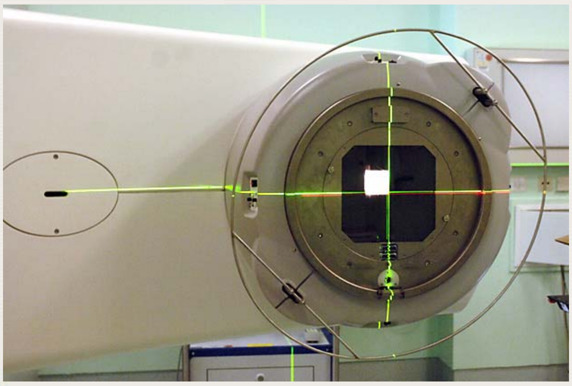


# 10.4 COMMISSIONING

## 10.4.1 Photon Beam Measurements: Output factors

### Asymmetric fields

- Treatment with asymmetric fields requires knowledge of the change of output factors of these fields.



## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Output factors

**Asymmetric fields**

- The output factors for asymmetric fields can be approximated by:

$$OF_{a,y} = OF_s \cdot OAR(z_{max}, y)$$

| | | |
|---|---|---|
| $OF_{a,y}$ | = | output factor with asymmetric collimator opening |
| $OF_s$ | = | output factor with symmetric collimator opening |
| y | = | displacement of the central ray of the asymmetric field from that of the symmetric field |
| $OAR(z_{max},y)$ | = | off axis ratio measured at $z_{max}$ and $y$ centimeters from the central axis of the symmetric field |

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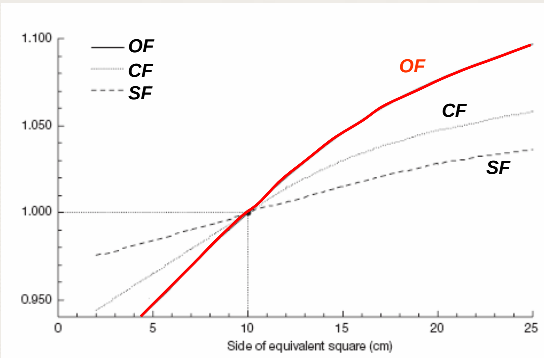
## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Output factors

**Collimator scatter factor**

- The output factor *OF* is the product of the collimator scatter factor *CF* and the phantom scatter factor *SF* .

(for details see Chapter 6).

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# 10.4 COMMISSIONING
## 10.4.1 Photon Beam Measurements: Output factors

### Collimator scatter factor

- The collimator scatter factor is measured “in air” with a build-up cap large enough to provide electronic equilibrium.
- Use of a build-up cap made of higher density material (aluminum or copper) may be appropriate.
- Alternatively, the collimator scatter factor may be determined by placing the ionization chamber at an extended *SSD*.

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# 10.4 COMMISSIONING
## 10.4.1 Photon Beam Measurements: Output factors

### Phantom scatter factor

- Since output factor ***OF*** and collimator scatter factor ***CF*** can be measured, and:

$$OF = CF \cdot SF$$

the phantom scatter factor ***SF*** may be simply found by dividing the output factor by the collimator scatter factor.

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## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements: Blocking tray factors

**Purpose**

- Shielding blocks are frequently used to protect normal critical structures within the irradiated area. These blocks are supported on a plastic tray to correctly position them within the radiation field.
- Since this tray attenuates the radiation beam, the amount of beam attenuation denoted as **Blocking Tray Factors** must be known to calculate the dose received by the patient.

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## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements: Blocking tray factors

**Method**

- The attenuation for solid trays is measured by placing an ionization chamber on the central axis of the beam at 5 cm depth in phantom in a 10×10 $cm^2$ field.
- The ratio of the ionization chamber signal with the tray in the beam to the signal without the tray is the blocking tray transmission factor.
- Although the tray transmission factor should be measured for several depths and field sizes this factor usually has only a weak dependence on these variables and typically one may use one value for all depths and field sizes.

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## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Multileaf collimators

**Purpose**

- On most current treatment machines multileaf collimators (MLC) are finding widespread application for conventional field shaping as a replacement for shielding blocks.

- A series of additional data on MLC fields is required such as:
  - central axis percentage depth doses;
  - penumbra of the MLC fields;
  - output factors;
  - the leakage through and between the leaves.



## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Multileaf collimators

**Central axis percentage depth doses values**

- They should again be measured in a water phantom. Typically these values are not significantly different from fields defined with the collimator jaws.

**Penumbra**

- The penumbra should be measured for both the leaf ends and edges.
- Generally, the MLC penumbra is within 2 mm of the penumbra of fields defined with the collimator jaws, with the greatest difference being for singly focused MLC fields not centered on the collimator axis of rotation.

## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Multileaf collimators

**Output factor**

- The output factor for MLC fields is generally given by:

$$OF_{\text{MLC}} = CF_{\text{MLC setting}} \cdot SF_{\text{irradiated area}}$$

with ***CF*** = collimator scatter factor
***SF*** = phantom scatter factor

- This relationship must be verified on each machine.

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## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Multileaf collimators

**Leakage**

- Leakage through the MLC consists of
  - transmission through the leaves
  - leakage between the leaves.

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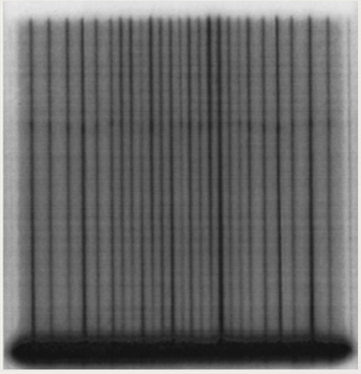
## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements: Multileaf collimators

**Leakage**

- Leakage can be determined using film dosimetry.
- The method consists of comparing a film obtained with totally closed MLC leaves (and hence must be exposed with a large number of MU) with that of an open reference field.
- Typical values of MLC leakage through the leaves are in the range of 3% to 5% of the isocenter dose.



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## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements: Wedge transmission factors

**Specification**

- The central axis wedge transmission factor is the ratio of the dose at a specified depth on the central axis of a specified field size with the wedge in the beam to the dose for the same conditions without the wedge in the beam.
- Frequently, the factor determined for one field size at one depth is used for all wedged fields and depths.
- This simplification must be verified for a number of depths and field sizes.

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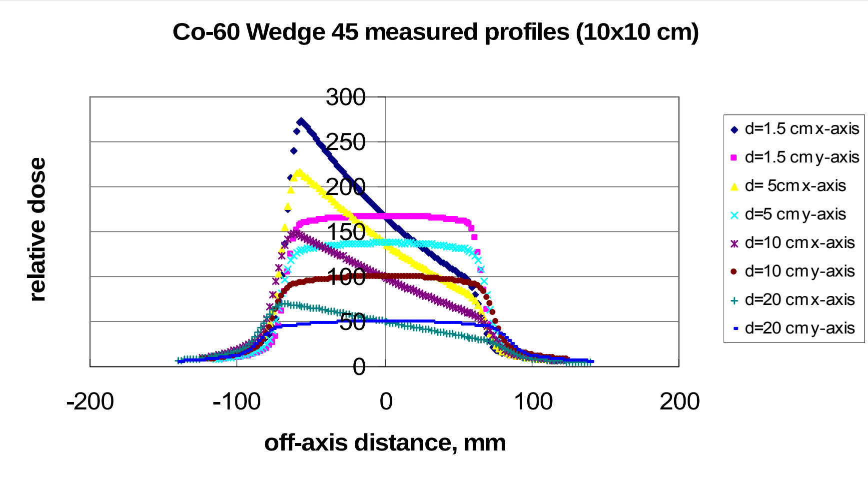
## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Wedge transmission factors






## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Wedge transmission factors

**Method**

- Wedge transmission factors ***WF*** are measured by placing a ionization chamber on the central axis with its axis aligned **parallel** to the **constant thickness of the wedge**.
- Measurements should be performed with the wedge in its original position and with a rotation of 180° by
  - rotation of the wedge itself which reveals whether or not the side rails are symmetrically positioned about the collimator axis of rotation;
  - rotation of the collimator which verifies that the ionization chamber is positioned on the collimator axis of rotation.

## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Wedge transmission factors

**Note on the result of *WF* after wedge rotation:**

- If
  ($WF_{0°}$ - $WF_{180°}$ ) > 5% for a 60° wedge
  ($WF_{0°}$ - $WF_{180°}$ ) > 2% for a 30° wedge
  the wedge or the ionization chamber is **not** positioned correctly and the situation should be corrected.

- Otherwise:

$$WF = \frac{WF_{0°} + WF_{180°}}{2}$$

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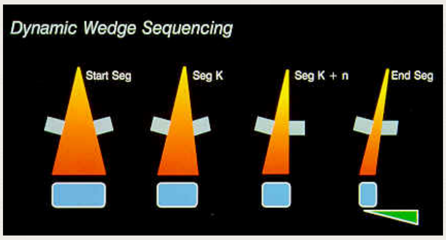
## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Dynamic wedges

- Dynamic wedges are generated by the modu-lation of the photon fluence during the delivery of the radiation field.




- Clinical implementation of dynamic wedges requires not only measurement of central axis wedge transmission factors but additionally measurements of:
  - central axis percentage depth doses,
  - transverse beam profiles of the dynamic wedges.

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## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements: Dynamic wedges

**Method**

- The central axis percentage depth dose and transverse profiles must be measured at each point during the entire irradiation of the dynamic wedge field.
- Dynamic wedge transverse beam profiles can be measured with a detector array or an integrating dosimeter such as radiochromic film. When a detector array is used, the sensitivity of each detector must be determined.



## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements: Dynamic wedges

**Note:**

- The central axis wedge transmission factors for dynamic wedges may have much larger field size dependence than physical wedges and the field size dependence for dynamic wedges may not be asymptotic.
- During commissioning, this characteristic should be carefully investigated on each machine.

## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Transverse beam profiles

**Purpose**

- For the calculation of 2-D and 3-D dose distributions, off-axis dose profiles are required in conjunction with central axis data.
- The number of profiles and the depths at which these profiles are measured will depend on the requirements of the treatment planning system.
- Frequently off-axis data are normalized to the dose on the central axis at the same depth.
- These data are referred to as **off-axis ratios** (*OAR*).



## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Transverse beam profiles

**Method**

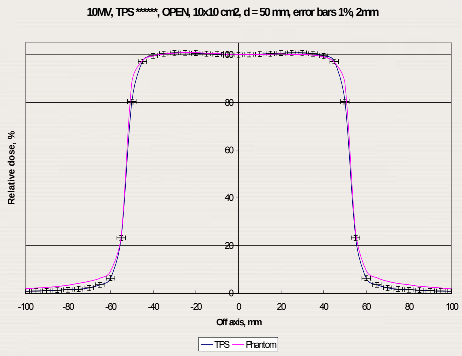
- A water phantom (or radiation field analyzer) that scans a small ionization chamber or diode in the radiation field is ideal for the measurement of such data.

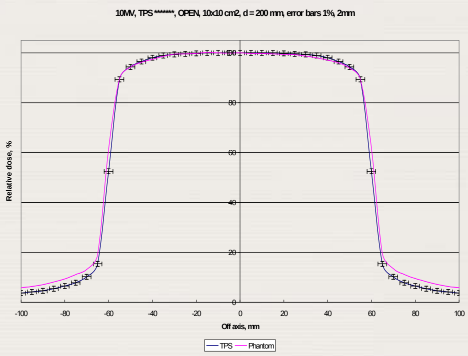
**Note:**

- In addition to those transverse beam profiles on which the beam model is determined, further profiles (including such of wedge fields) should be measured to verify the accuracy of the treatment planning system algorithms.

# 10.4 COMMISSIONING

## 10.4.1 Photon Beam Measurements: Transverse beam profiles






# 10.4 COMMISSIONING

## 10.4.1 Photon Beam Measurements: Entrance/interface dose

### Purpose

- ❑ Knowledge of dose values at interfaces is important in a variety of clinical situations.
- ❑ Examples:
  - entrance dose between the patient surface and $z_{max}$,
  - interfaces at small air cavities such as the nasopharynx,
  - at the exit surface of the patient,
  - at bone–tissue interfaces
  - interfaces between a metallic prosthesis and tissue.

## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Entrance/interface dose

**Method**

- Rapidly changing dose gradients are typical in interface situations.
- Under such conditions, a thin window parallel plate chamber is adequate to perform measurements.

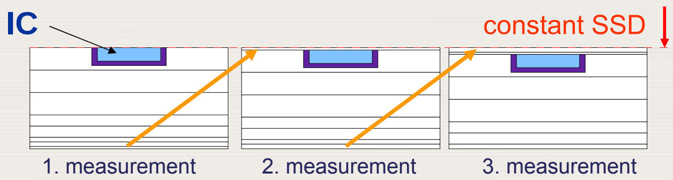
- **Note:**
  Measurements with a thin window parallel plate chamber may be difficult to perform in a water phantom because of the need to waterproof the chamber and to avoid deformation of the window by hydrostatic pressure.



## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Entrance/interface dose

**Method (continued)**

- Interface measurements are typically carried out in a plastic phantom in a **constant SSD** geometry.




- The first measurement is made with no buildup material.
- The next depth is measured by moving the appropriate sheet of buildup material from the bottom to the top of the phantom, etc.
- This scheme maintains a constant SSD as buildup material is added.

## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements: Entrance/interface dose

**Method (continued)**

- Interface dosimetry measurements should always be performed with both polarities on the entrance window of the ionization chamber.
- Large differences in the signal at the interface will be observed when the polarity is reversed. Measurements farther from the interface exhibit decreasingly smaller differences than measurements nearer the interface.
- The true value of the measured ionization is the average from both polarities.

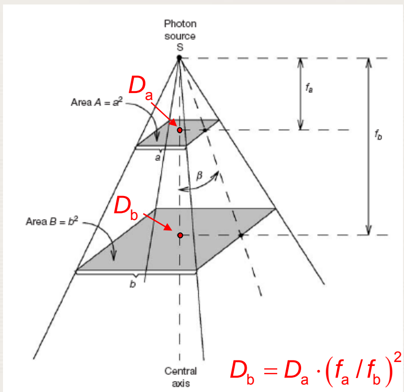


## 10.4 COMMISSIONING

### 10.4.1 Photon Beam Measurements: Virtual source position

**Purpose**

- Inverse square law behavior is assumed to be exactly valid for the virtual source position.
- Knowledge of the virtual source position is required for treatment at extended *SSD*.

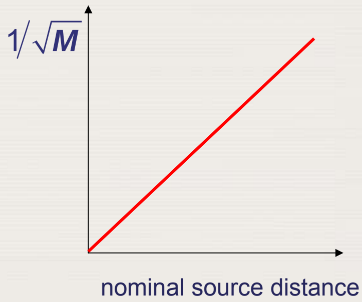


## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements: Virtual source position

**Method**

- ❑ A common technique is to make “in-air” ionization measurements at several distances from the nominal source position to the chamber.

- ❑ The data are plotted with the distance to the nominal source position on the x-axis and the reciprocal of the square root of the ionization ***M*** on the y-axis.

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## 10.4 COMMISSIONING
### 10.4.1 Photon Beam Measurements

**Method (continued)**

- ❑ This data should follow a straight line.
If not the radiation output does not follow inverse square.

- ❑ If the straight line passes through the origin the virtual and nominal source positions are the same.

- ❑ If the straight line has a positive x-intercept, the virtual source position is downstream from the nominal source position while a negative x-intercept indicates an upstream virtual source position.

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## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements

- Commissioning procedures for acquiring **electron beam data** are similar (but not identical) to those of photon beams.

**Data to be acquired include:**

(1) Central axis percentage depth doses (*PDD*)
(2) Output factors
(3) Transverse beam profiles
(4) Corrections for extended *SSD* applications



## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements: PDD

**Method**

- Central axis percentage depth doses are preferable measured in a water phantom.
- For measurements, **plane-parallel ionization chambers** with the effective point of measurement placed at nominal depth are **highly** recommended.

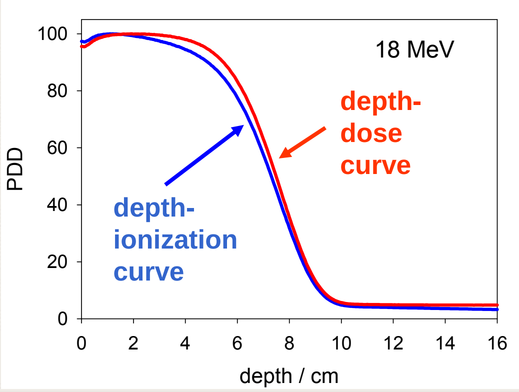
**Note:**
The effective point of measurement of a plane-parallel chamber is on the **inner surface of the entrance window**, at the center of the window for all beam qualities and depths.

## 10.4 COMMISSIONING

### 10.4.2 Electron Beam Measurements: PDD

**Note:**

- Ionization chambers always provide **depth-ionization** curves.
- The depth-ionization curve of electrons **differs** from the depth-dose curve by the water-to-air stopping power ratio.






## 10.4 COMMISSIONING

### 10.4.2 Electron Beam Measurements: PDD

**Note (cont.)**

- Since the stopping-power ratios water to air are indeed **dependent on electron energy** and hence on the depth, relative ionization distributions **must be converted** to relative distributions of absorbed dose.
- This is achieved by multiplying the ionization current or charge at each measurement depth by the stopping-power ratio at that depth.
- Appropriate values are given, for example in IAEA TRS 398.

### Measurement of $R_{50}$

- In modern calibration protocols, the quality of electron beams is specified by the so-called beam quality index which is the **half-value depth in water $R_{50}$** .
- This is the depth in water (in g cm$^{-2}$) at which the absorbed dose is 50% of its value at the absorbed-dose maximum, measured with a constant SSD of 100 cm and a field size at the phantom surface of at least
  - 10 cm x 10 cm for $R_{50} \leq 7$ g cm$^{-2}$ ($E_0 \leq 16$ MeV)
  - 20 cm x 20 cm for $R_{50} > 7$ g cm$^{-2}$ ($E_0 > 16$ MeV).

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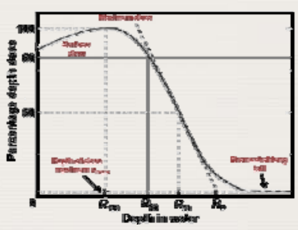
### Practical suggestions

- For all beam qualities, the preferred choice of detector for the measurement of $R_{50}$ is a plane-parallel chamber.
- A water phantom is the preferred choice.
- In a vertical beam the direction of scan should be towards the surface to reduce the effect of meniscus formation.



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## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements: PDD

**Practical suggestions (continued)**

- When using an ionization chamber, the measured quantity is the half-value of the **depth-ionization** distribution in water, $R_{50,ion}$. This is the depth in water (in g cm$^{-2}$) at which the ionization current is 50% of its maximum value.
- The half-value of the **depth-dose** distribution in water $R_{50}$ is obtained using:

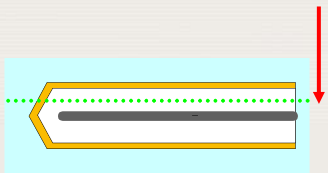
$R_{50}$ = 1.029 $R_{50,ion}$ - 0.06 g cm$^{-2}$ ($R_{50,ion} \leq 10$ g cm$^{-2}$)
$R_{50}$ = 1.059 $R_{50,ion}$ - 0.37 g cm$^{-2}$ ($R_{50,ion} > 10$ g cm$^{-2}$)



## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements: PDD

**Use of cylindrical chambers**

- For electron beam qualities with $R_{50} \geq 4$ g cm$^{-2}$ (i.e. for electron energies larger than 10 MeV) a cylindrical chamber may be used.
- In this case, the reference point at the chamber axis must be positioned half of the inner radius $r_{cyl}$ deeper than the nominal depth in the phantom.



### Use of plastic phantoms

- For beam qualities $R_{50} < 4$ g cm$^{-2}$ (i.e. for electron energies smaller than 10 MeV) a plastic phantom may be used.
- In this case, each measurement depth in plastic must be scaled using

$$z_w = z_{pl}\, c_{pl} \quad \text{g cm}^{-2} \quad (z_{pl} \text{ in g cm}^{-2})$$

to give the appropriate depth in water.

(Table from IAEA TRS 398)

| plastic phantom | $c_{pl}$ |
|---|---|
| solid water (RMI-457) | 0.949 |
| PMMA | 0.941 |
| white polystyrene | 0.922 |





### Use of plastic phantoms (cont.)

- In addition, the dosimeter reading $M$ at each depth must also be scaled using

$$M = M_{pl}\, h_{pl}$$

- For depths beyond $z_{ref,pl}$ it is acceptable to use the value for $h_{pl}$ at $z_{ref,pl}$ derived from the Table below.
- At shallower depths, this value should be decreased linearly to a value of unity at zero depth.

(Table from IAEA TRS 398)

| plastic phantom | $h_{pl}$ |
|---|---|
| solid water (RMI-457) | 1.008 |
| PMMA | 1.009 |
| white polystyrene | 1.019 |

## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements: PDD

**Practical suggestion**

- Electron percentage depth dose should be measured in field size increments small enough to permit accurate interpolation to intermediate field sizes.
- Central axis percentage depth dose should be measured to depths large enough to determine the bremsstrahlung contamination in the beam.

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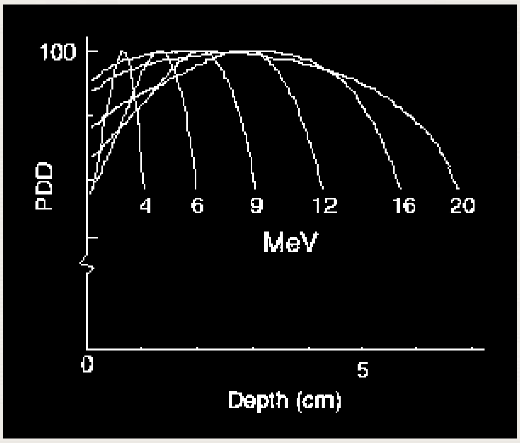
## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements: PDD

**Practical suggestion**

- Although skin sparing is much less than for photon beams, skin dose remains an important consideration in many electron treatments. Surface dose is best measured with a thin-window parallel-plate ion chamber.

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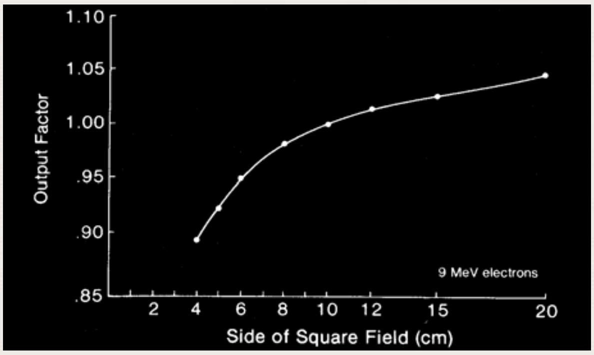
**Specification and measurement**

- The radiation output is a function of field size.

Example:

9 MeV electrons








**Specification and measurement**

- The radiation output is a function of field size.
- The output is measured at the standard *SSD* with a small volume ionization chamber at $z_{max}$ on the central axis of the field.
- Output factors are typically defined as the ratios to the 10×10 $cm^2$ field at $z_{max}$.

## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements: Output factors

**Radiation output for specific collimation**

- Three specific types of collimation are used to define an electron field:
  (1) secondary collimators (cones) in combination with the x-ray jaws,
  (2) irregularly shaped lead or low melting point alloy metal cutouts placed in the secondary collimators, and
  (3) skin collimation.

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## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements: Output factors

**(1) Radiation output for secondary collimators**

- Cones, or electron collimators, are available in a limited number of square fields typically $5 \times 5$ cm$^2$ to $25 \times 25$ cm$^2$ in 5 cm increments.

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## 10.4 COMMISSIONING

### 10.4.2 Electron Beam Measurements: Output factors

**(1) Radiation output for secondary collimators**

- Cones, or electron collimators, are available in a limited number of square fields typically 5×5 cm$^2$ to 25×25 cm$^2$ in 5 cm increments.
- The purpose of the cone depends on the manufacturer. Some use cones only to reduce the penumbra, others use the cone to scatter electrons off the side of the cone to improve field flatness.
- The output for each cone must be determined for all electron energies. These values are frequently referred to as **cone ratios** rather than output factors.



## 10.4 COMMISSIONING

### 10.4.2 Electron Beam Measurements: Output factors

**(1) Radiation output for secondary collimators**

- For rectangular fields formed by placing inserts in cones the equivalent square can be approximated with a square root method.
- The validity of this method should be checked on each machine for which the approximation is used.

## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements: Output factors

**(2) Radiation output for metal cutouts**

- Irregularly shaped electron fields are formed by placing metal cutouts of lead or low melting point alloy in the end of the cone nearest the patient.



## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements: Output factors

**(2) Radiation output for metal cutouts**

- The output factors for fields defined with these cutouts depend on the electron energy, the cone and the area of the cutout.
- The dependence of output should be determined for square field inserts down to 4×4 $cm^2$ for all energies and cones

**Note:**
To obtain output factors down to 4×4 $cm^2$ is again a challenge of small beam dosimetry!

## 10.4 COMMISSIONING

### 10.4.2 Electron Beam Measurements: Output factors

**(2) Radiation output for small fields**

- The output factor is the ratio of dose **at $z_{max}$** for the small field to dose **at $z_{max}$** for the 10×10 $cm^2$ field.
- Since $z_{max}$ shifts toward the surface for electron fields with dimensions smaller than the range of the electrons, it must be determined for **each small field size** when measuring output factors.
- For ionometric data this requires converting the ionization to dose at each $z_{max}$ before determining the output factor, rather than simply taking the ratio of the ionizations.



## 10.4 COMMISSIONING

### 10.4.2 Electron Beam Measurements: Output factors

- Film is an alternate solution. It can be exposed in a polystyrene or water equivalent plastic phantom in a parallel orientation to the central axis of the beam.
  - one film should be exposed to a 10×10 $cm^2$ field;
  - the other film to the smaller field.
- The films should be scanned to find the central axis $z_{max}$ for each field.

## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements: Output factors

**(3) Radiation output for skin collimation**

- Skin collimation is accomplished by using a special insert in a larger electron cone. The skin collimation then collimates this larger field to the treatment area.
- Skin collimation is used
  - to minimize penumbra for very small electron fields,
  - to protect critical structures near the treatment area,
  - to restore the penumbra when treatment at extended distance is required.



## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements: Output factors

**(3) Radiation output for skin collimation**

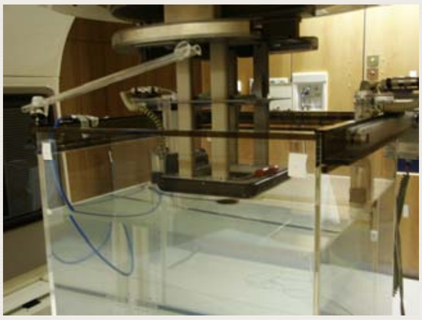
- If skin collimation is clinically applied, particular commissioning tests may be required.
- As for any small field, skin collimation may affect the percent depth dose as well as the penumbra, if the dimensions of the treatment field are smaller than the electron range.
- In this case, PDD values and output factors must be measured.

## 10.4 COMMISSIONING

### 10.4.2 Electron Beam Measurements: Transverse beam profiles

**Method using a water phantom**

- The same methods used for the commissioning of transverse photon beam profiles are also applied in electron beams.
- A water phantom (or radiation field analyzer) that scans a small ionization chamber or diode in the radiation field is ideal for the measurement of such data.





## 10.4 COMMISSIONING

### 10.4.2 Electron Beam Measurements: Transverse beam profiles

**Method using film dosimetry**

- An alternate technique is to measure directly isodose curves rather than beam profiles
- A film is ideal for this technique.
- The film is exposed parallel to the central axis of the beam. Optical isodensity is converted to isodose.
- However, the percent depth dose determined with film is typically 1 mm shallower than ionometric determination for depths greater than 10 mm, and for depths shallower than 10 mm the differences may be as great as 5 mm.

**Virtual source position**

- Frequently electron fields must be treated at **extended distances** because the surface of the patient prevents positioning the electron applicator at the normal treatment distance.
- In this case, additional scattering in the extended air path increases the penumbral width and decreases the output.
- Knowledge of the virtual electron source is therefore required to predict these changes.
- Determination of the virtual source position is similar to the verification of inverse square law for photons.





**Air gap correction factor**

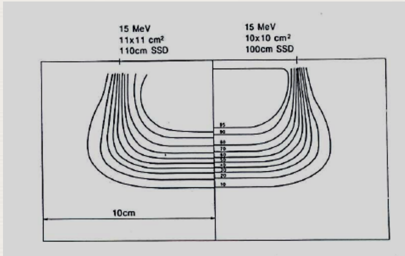
- The radiation output as predicted by the treatment planning computers use the virtual source position to calculate the divergence of the electron beams at extended *SSD*s.
- In addition to the inverse square factor, an air gap correction factor is required to account for the additional scattering in the extended air path.
- The air gap factor must be measured.
- Air gap correction factors depend on collimator design, electron energy, field size and air gap. They are typically less than 2%.

## 10.4 COMMISSIONING

### 10.4.2 Electron Beam Measurements: Extended SSD applications

#### PDD changes

- There can be significant changes in the percent depth dose at extended *SSD* if the electron cone scatters electrons to improve the field flatness.
- For these machines it may be necessary to measure isodose curves over a range of *SSDs*.






## 10.4 COMMISSIONING

### 10.4.2 Electron Beam Measurements: Extended SSD applications

#### Penumbra changes

- Treatment at an extended *SSD* will also increase the penumbra width.
- At lower energies the width of the penumbra (80%-20%) increases approximately proportionally with air gap.
- As electron energy increases the increase in the penumbra width is less dramatic at depth than for lower energies but at the surface the increase in penumbra remains approximately proportional to the air gap.

## 10.4 COMMISSIONING
### 10.4.2 Electron Beam Measurements: Extended SSD applications

**Penumbra changes**

- In order to evaluate the algorithms in the treatment planning system in use, it is recommended to include a sample of isodose curves measurements at extended *SSD*s during commissioning.

**Note:**
The penumbra can be restored when treating at extended distances by use of skin collimation as discussed before.



## 10.5 TIME REQUIRED FOR COMMISSIONING

- Following completion of the acceptance tests, the completion of all the commissioning tasks, i.e. the tasks associated with placing a treatment unit into clinical service, can be estimated to require:

**1.5 - 3 weeks per energy**

## 10.5 TIME REQUIRED FOR COMMISSIONING

- The time will depend on machine reliability, amount of data measurement, sophistication of treatments planned and experience of the physicist.

- Highly specialized techniques, such as, stereotactic radiosurgery, intraoperative treatment, intensity modulated radiotherapy, total skin electron treatment, etc. have not been discussed and are **not included in these time estimates**.