Dosimetry

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TOPICS OF THIS LESSON

1) Introduction
   - Definition of ’’Radiation Dose’’
   - Requirements on accuracy in radiotherapy

2) Radiation Dosimeters

3) Relative and Absolute Dosimetry

4) Metrologic Traceability
   - Calorimetry

INTRODUCTION

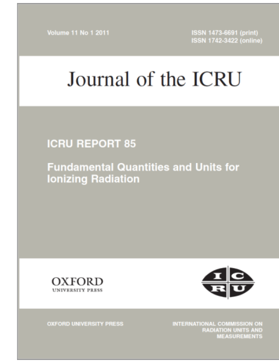
Definition of absorbed dose

What do we mean with radiation dose?

- *Dose* is a sloppy formulation for radiation dose and should only be used if the opposite really knows what is meant.
- Radiation dose is correctly denoted by the physical quantity of absorbed dose, *D.*
- The most fundamental definition of absorbed dose is given in ICRU Report 85

INTRODUCTION

Definition of absorbed dose



- According to ICRU 85 the absorbed dose is defined by:

5.2.5 Absorbed Dose

The *absorbed dose*, D, is the quotient of $\mathrm{d}\bar{\varepsilon}$ by $\mathrm{d}m$, where $\mathrm{d}\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to matter of mass $\mathrm{d}m$, thus

$$D = \frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}.$$

Unit: $\mathrm{J\ kg^{-1}}$

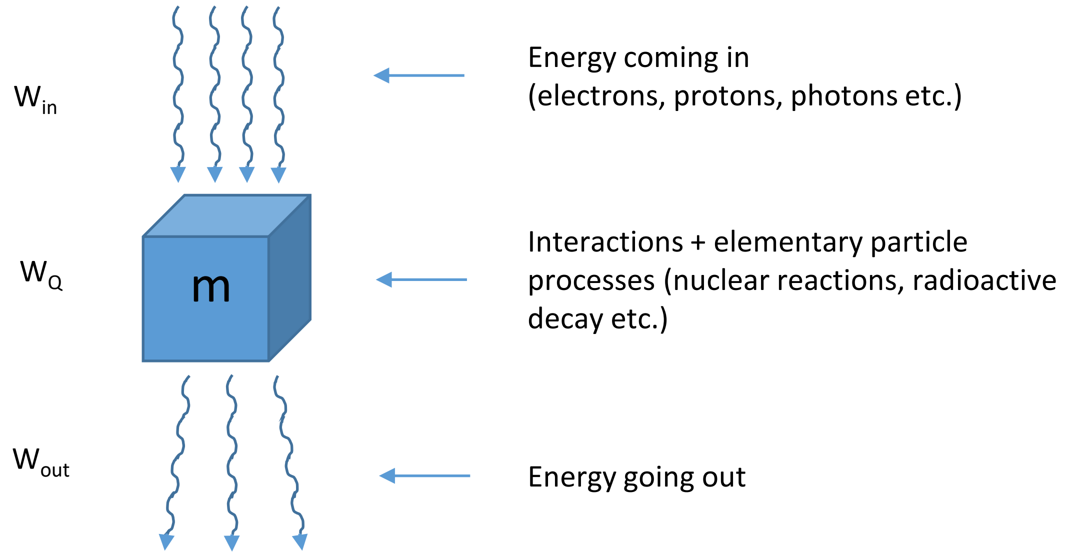
The special name for the unit of absorbed dose is gray (Gy).

ICRU Report 85, p. 27

INTRODUCTION

Definition of absorbed dose

The term "energy imparted" can be considered to be the radiation energy absorbed in a volume with a mass m:

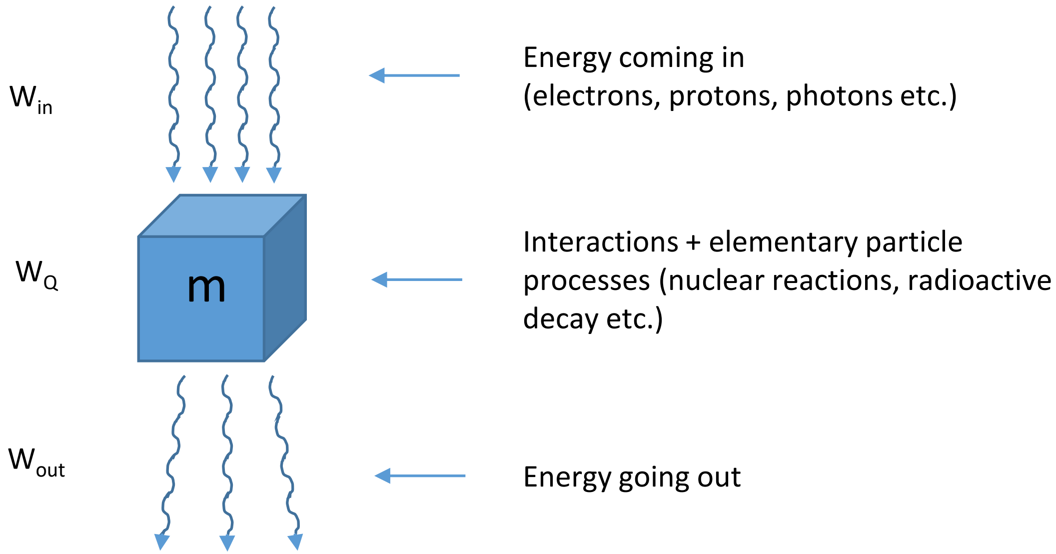


Energy absorbed = $W_{in} - W_{out} + W_Q$ (W_Q: <0 , >0)

INTRODUCTION

Definition of absorbed dose

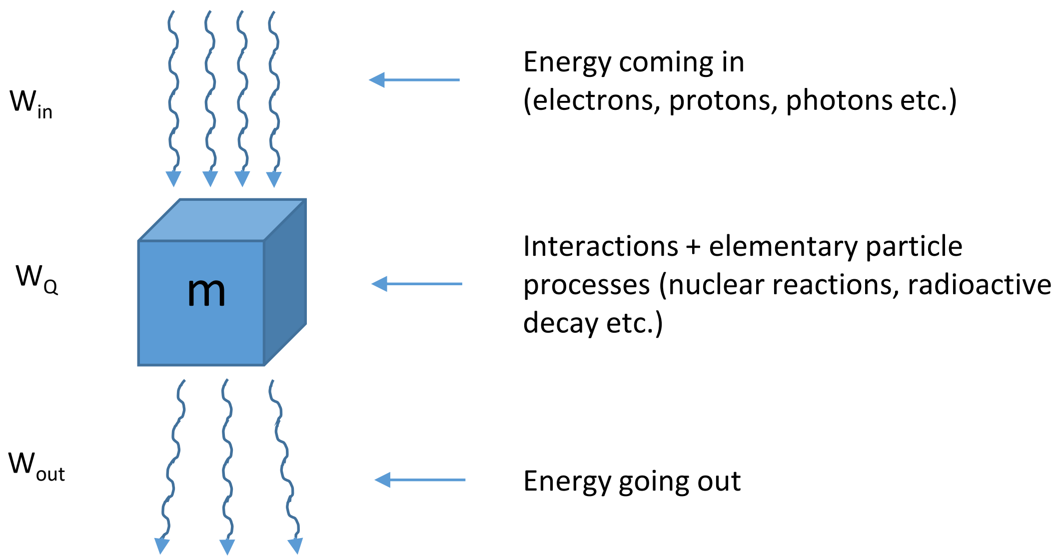
The term “absorbed dose” refers to an exactly defined volume:

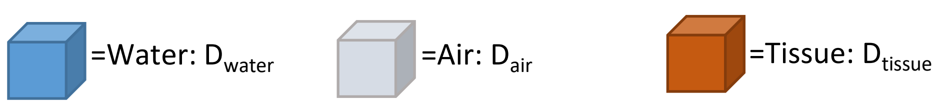


INTRODUCTION

Definition of absorbed dose

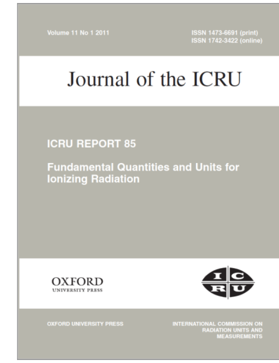
The term "absorbed dose" refers to the Material of the volume:





INTRODUCTION

Definition of absorbed dose



Energy imparted: the ICRU 85 formulation

5.2.2 Energy Imparted

The *energy imparted*, ε , to the matter in a given volume is the sum of all energy deposits in the volume, thus

$$\varepsilon = \sum_i \varepsilon_i ,$$

where the summation is performed over all energy deposits, ε_i, in that volume.

Unit: J

ICRU Report 85, p. 26

INTRODUCTION

Definition of absorbed dose

The ‘energy deposit’: the ICRU 85 formulation

5.2.1 Energy Deposit

The *energy deposit*, ε_i, is the energy deposited in a single interaction, i thus

stochastic nature!

$$\varepsilon_i = \varepsilon_{\text{in}} - \varepsilon_{\text{out}} + Q,$$

where ε_{in} is the energy of the incident ionizing particle (excluding rest energy), ε_{out} is the sum of the energies of all charged and uncharged ionizing particles leaving the interaction (excluding rest energy), Q is the change in the rest energies of the nucleus and of all elementary particles involved in the interaction ($Q > 0$: decrease of rest energy; $Q < 0$: increase of rest energy).

Unit: J

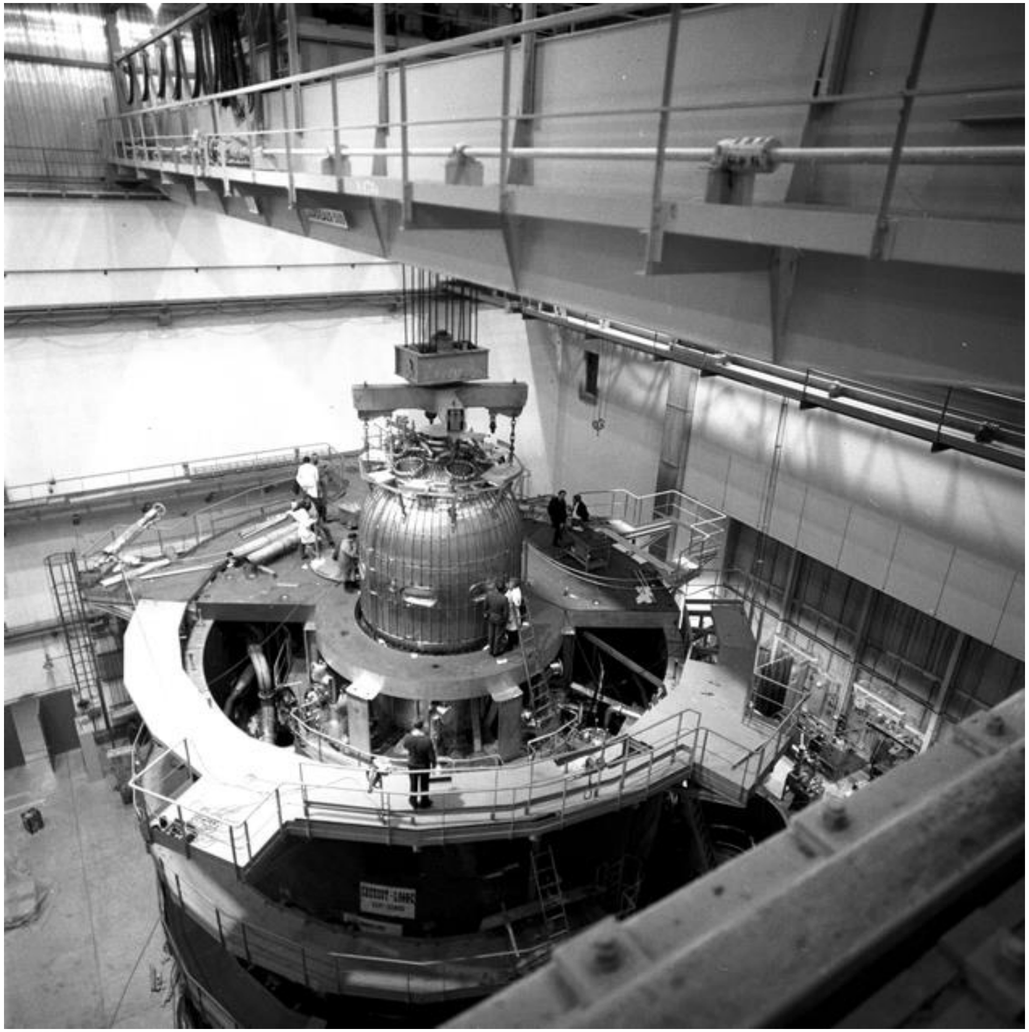
ICRU Report 85, p. 26

INTRODUCTION

Definition of absorbed dose

Bubble chamber

https://en.wikipedia.org/wiki/Bubble_chamber

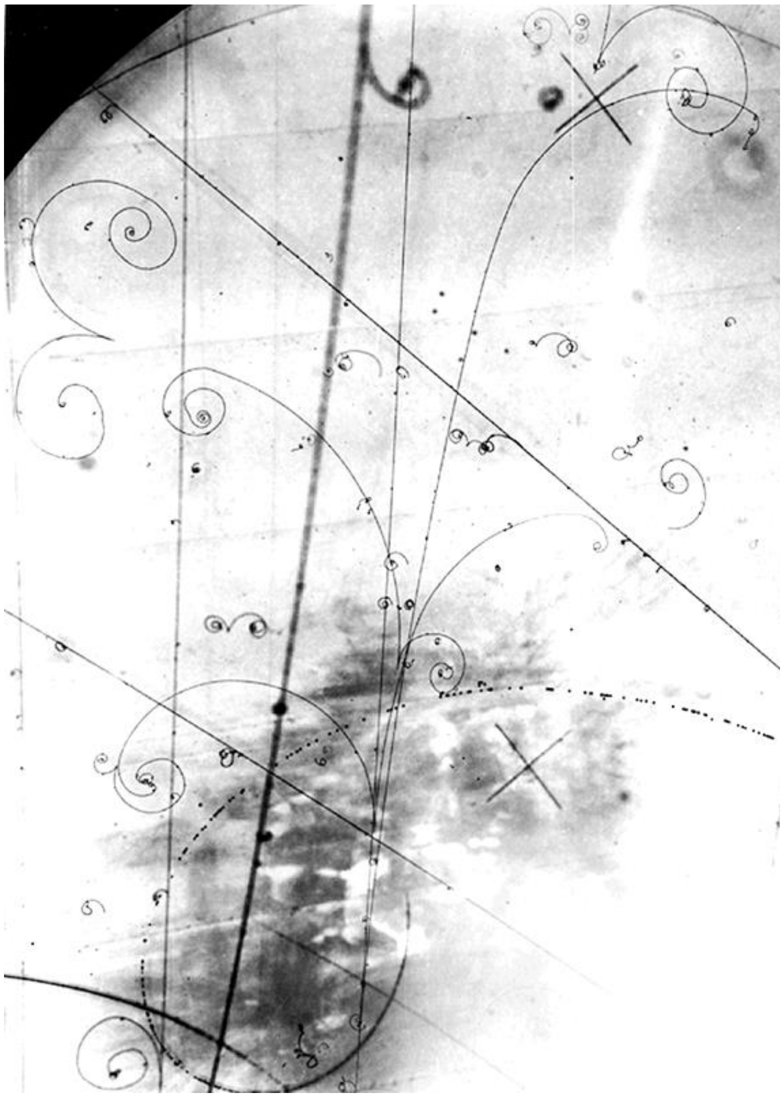


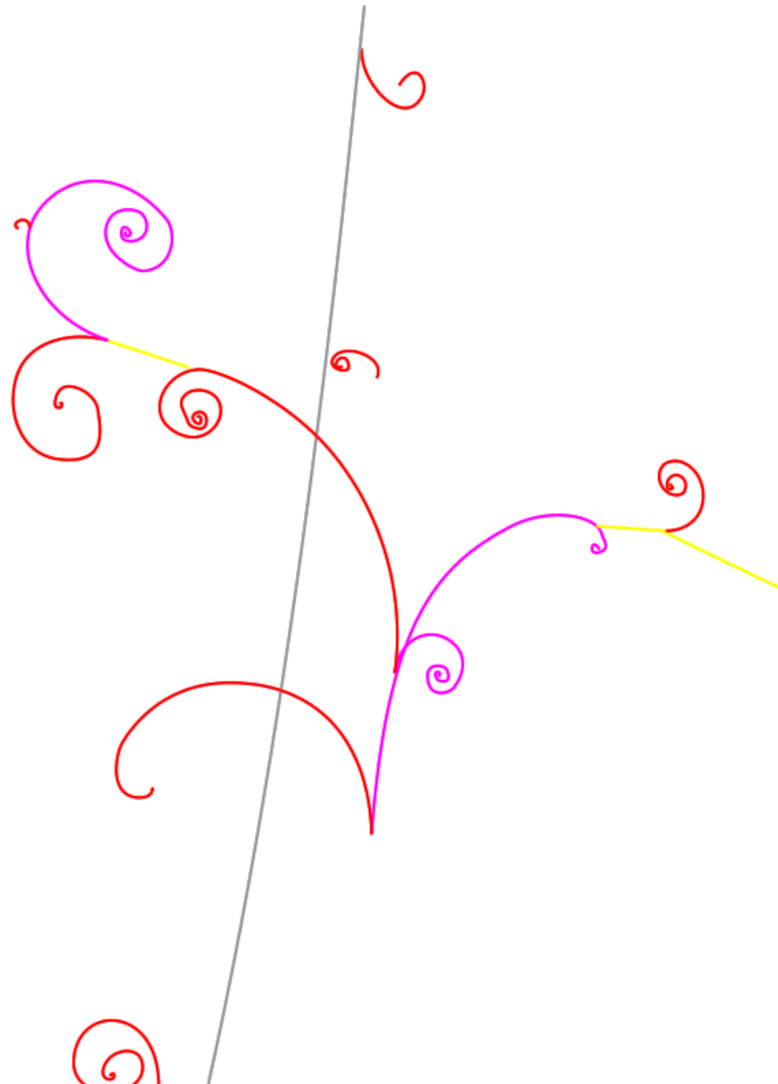
https://cds.cern.ch

INTRODUCTION

Definition of absorbed dose

Bubble chamber (2)



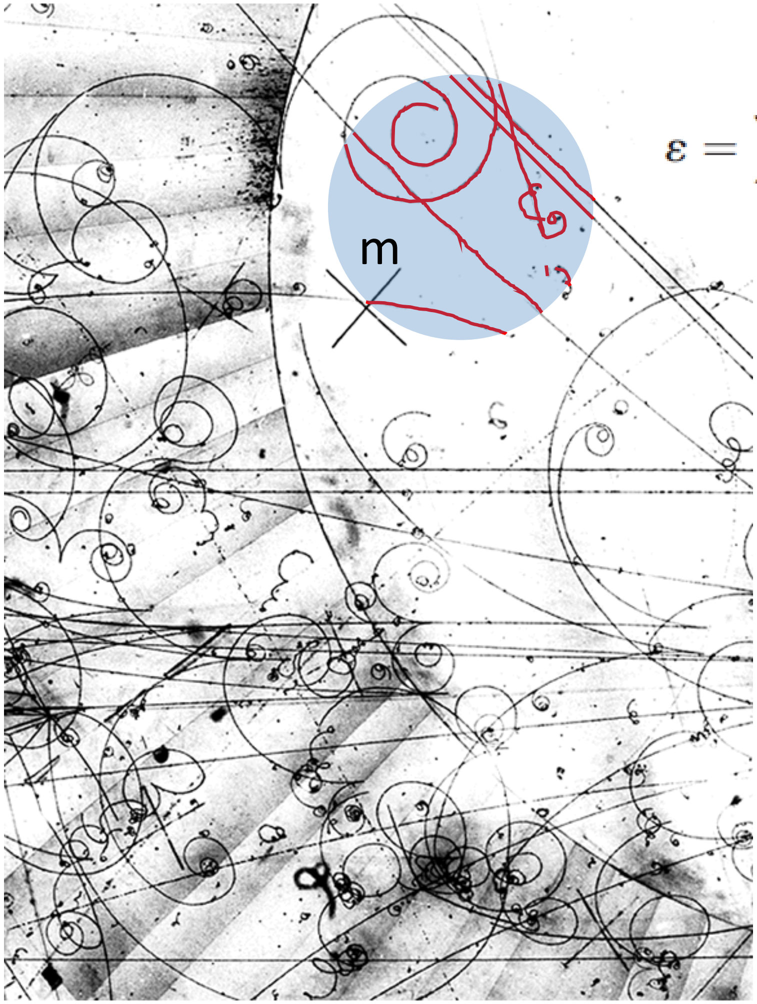


From the discontinued Cern website: “A step by step tutorial on how to read bubble chamber pictures.”

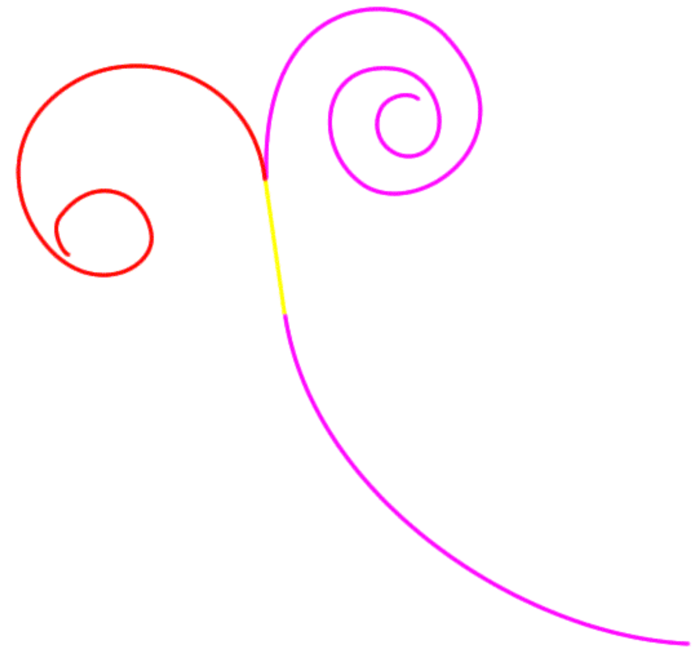
INTRODUCTION

Definition of absorbed dose

Bubble chamber (3)



$$\varepsilon = \sum_i \varepsilon_i$$

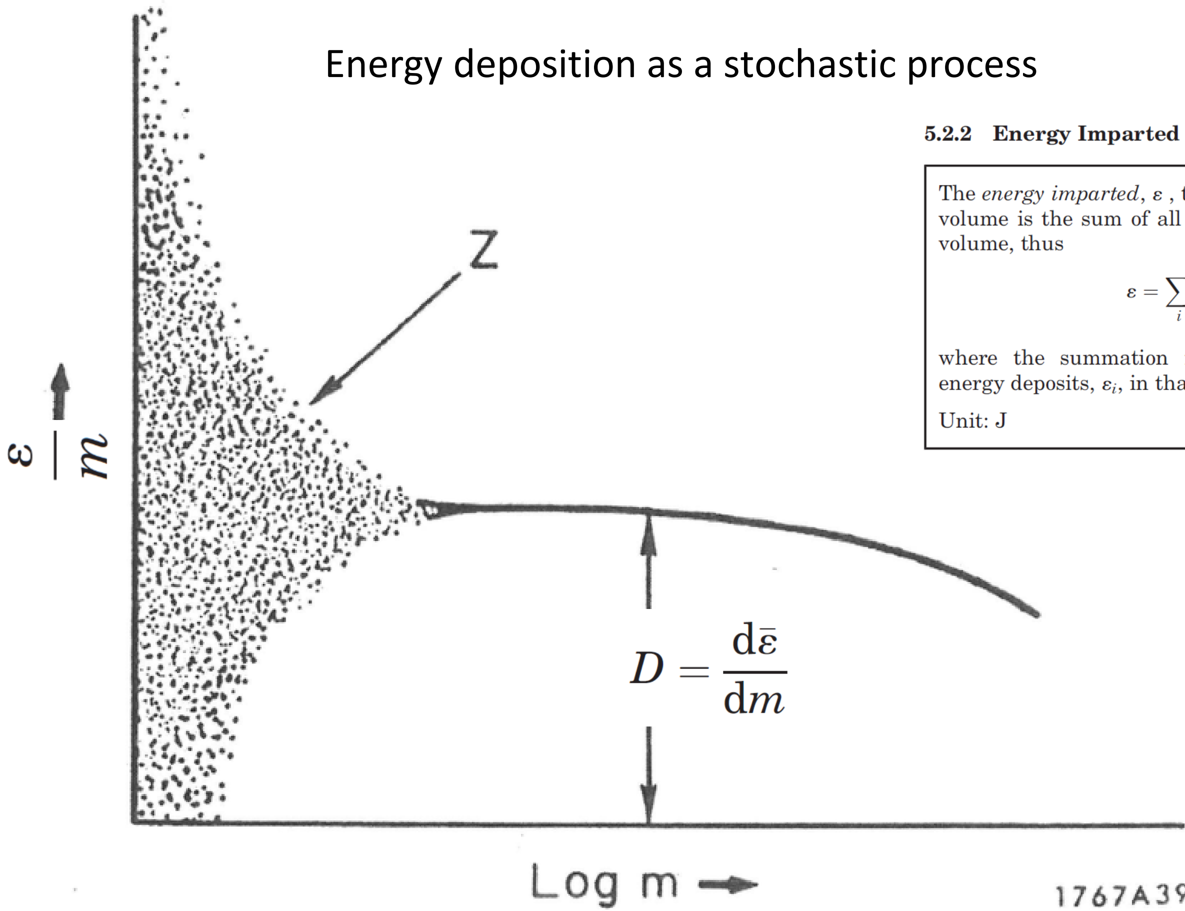


From the discontinued Cern website: “A step by step tutorial on how to read bubble chamber pictures.”

INTRODUCTION

Definition of absorbed dose

Energy deposition as a stochastic process



5.2.2 Energy Imparted

The *energy imparted*, ε , to the matter in a given volume is the sum of all energy deposits in the volume, thus

$$\varepsilon = \sum_i \varepsilon_i,$$

where the summation is performed over all energy deposits, ε_i, in that volume.

Unit: J

Energy deposited per unit mass, plotted against the mass, m, of the scoring volume, as this volume is gradually changed in size for a given incident radiation fluence. The shaded portion represents the range where statistical fluctuations become important as the volume (i.e. m) is getting smaller. (From Rossi, H. H., Radiation Dosimetry, Vol. 1, Academic Press, New York, 1968.)

INTRODUCTION

Requirements on accuracy in radiotherapy

- What accuracy is required on the absolute absorbed dose ?

- What accuracy is required on spatial distribution of dose ?
  (geometric accuracy of treatment unit, Patient positioning etc.)

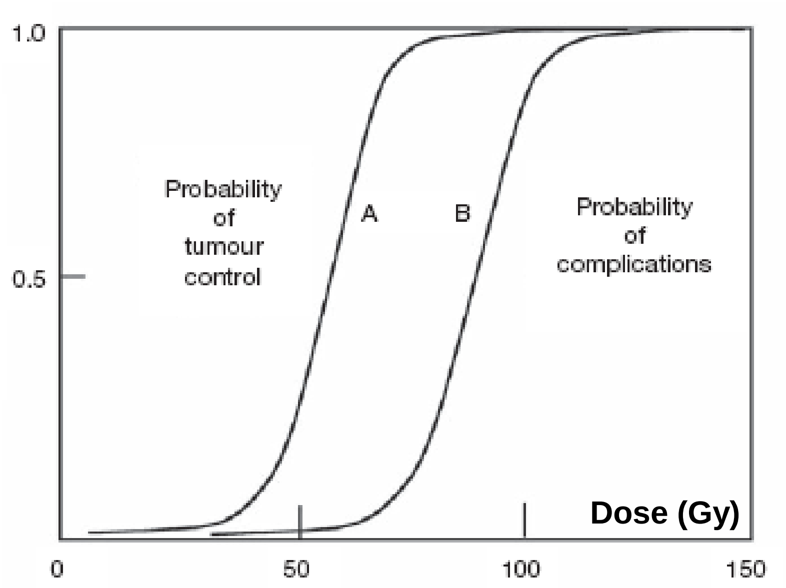
INTRODUCTION

Requirements on accuracy in radiotherapy

- Such requirements can be based on evidence from dose response curves (TCP and NTCP)

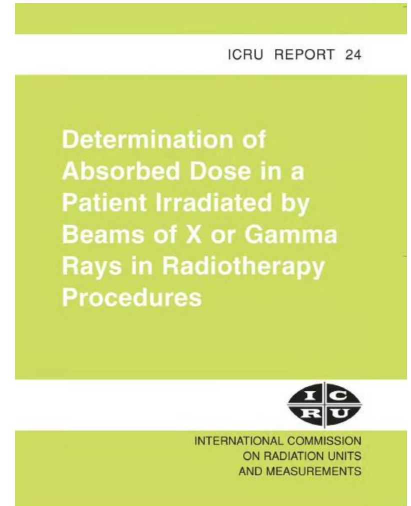
- Steepness of a given TCP or NTCP curve defines the change in response expected for a given change in delivered dose.

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



INTRODUCTION

Requirements on accuracy in radiotherapy



- ICRU Report No. 24 (1976) concludes:

  An uncertainty of 5 % is tolerable in the delivery of absorbed dose to the target volume.

- 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.

INTRODUCTION

Requirements on accuracy in radiotherapy

Example of accidental exposure

Report* on an incident from “Institute Gustave Roussy”, Villejuif, South Paris

- Patients with squamous cell carcinoma of the tonsil were randomized in an internal study.
- The study was intended to demonstrate that HE-Electrons and HE-Photons give the same effect on tumors.
- Nominally identical doses were given (18 x 2.5Gy in 40days).
- Tumor regression during the treatment was recorded.

* Flamant, R., Malaise, E., Dutreix, J., Hayem, M., Pierquin, B., Tubiana, M. and Dutreix, A. Un essai thérapeutique clinique sur l’irradiation des cancers amygdaliens par faisceaux de photons ou d’électrons de 20 MeV. Eur. J. Cancer 3: 169–181, 1967.

Andrée Dutreix, Radiotherapy and oncology, 2 (1984) 275-292

INTRODUCTION

Requirements on accuracy in radiotherapy

Report on an incident from “Institute Gustave Roussy” (2)

- A smaller efficiency for the electron treatment was observed.

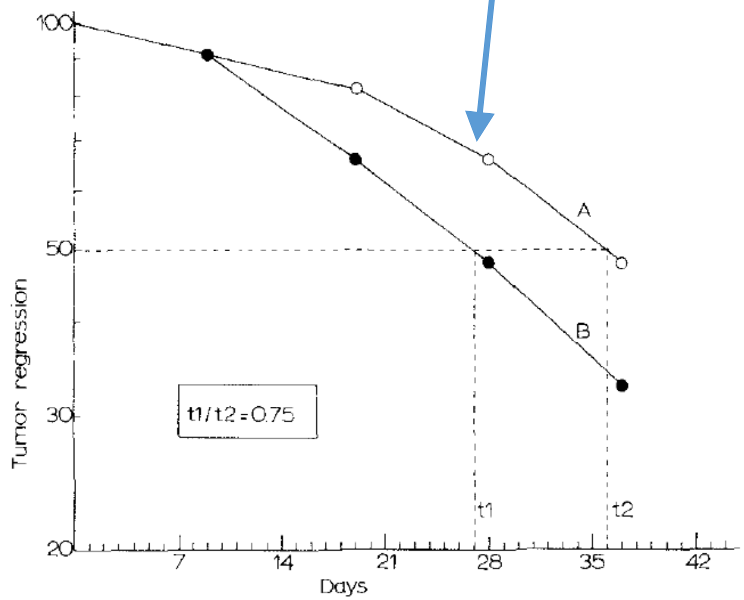


Fig. 1. Average regression of tonsil tumours for patients randomised into two groups A and B treated with dose fractions of 2.23 and 2.46 grays, respectively, 3 times a week as a function of the number of days. The difference is statistically significant although the number of patients treated is small (19 and 22 respectively).

from: Andrée Dutreix, Radiotherapy and Oncology, 2 (1984) 275-292

INTRODUCTION

Requirements on accuracy in radiotherapy

Report on an incident from “Institute Gustave Roussy” [3]

- This observation lead to the immediate discontinuation of the trial.
- A new calibration for the dosimeters was achieved.
- The new calibration lead to a >7% dose difference between EL and PH
- The authors stated that this could explain the difference of tumor regression between two kinds of treatment.

- Complications?

Yes, 10% deviations in dose can be detected

Andrée Dutreix, Radiotherapy and oncology, 2 (1984) 275-292

INTRODUCTION

Requirements on accuracy in radiotherapy

Single uncertainties [E. Hassenstein, F. Nüsslin 1985]

- uncertainties in therapy planning: 5.3%
- uncertainties in dose delivery: 4%
- patient setup uncertainties: 2%
- calibration of Dosimeter: 2.1%
- actual dose rate of the Linac: 3%

Combined uncertainty: 3-4%

E. Hassenstein, F. Nüsslin, Medizinische und physikalische Aspekte der Qualitätssicherung in der Radioonkologie, Strahlentherapie 161, 685-693 (1985)

INTRODUCTION

Requirements on accuracy in radiotherapy

Dose intercomparison 2022 Switzerland

The distribution of the D_s/D_m ratio for all the photon beams is illustrated in Figure 6.

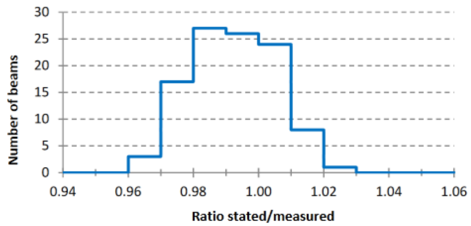


Figure 6. Histogram of D_s/D_m ratio for all 106 photon beams

The statistics of the D_s/D_m ratio for all the photon beams are given in Table 2.

Table 2. Ratio "stated dose/measured dose" (FF=conventional beams with flattening filter, FFF=flattening filter free beams)

Parameter	FF beams	FFF beams	Both types
Beam number	61	45	106
Mean	0.991	0.995	0.993
Std dev.	1.3%	1.4%	1.3%
Minimum	0.970	0.961	0.961
Maximum	1.017	1.016	1.017

The distribution of the D_s/D_m ratio for all the electron beams is illustrated in Figure 4.

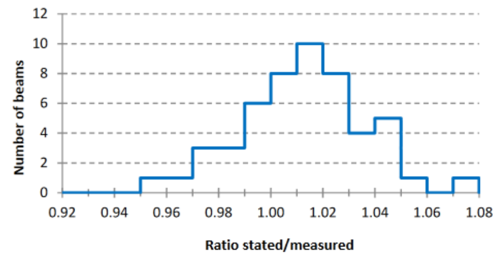


Figure 4. Electron beams: histogram of D_s/D_m ratio for all 51 beams

Table 1. Electron beams: observed ratio "stated dose/measured dose"

Parameter	Electron beams
Beam number	51
Mean	1.013
Std dev.	2.4%
Minimum	0.956
Maximum	1.079

SSRPM-Report: Results of the TLD Intercomparison for Megavoltage Units 2022 in Switzerland

Thierry Buchillier and Claude Bailat , CHUV - Institut de radiophysique (IRA), Lausanne

RADIATION DOSIMETERS

RADIATION DOSIMETERS

TABLE OF CONTENTS

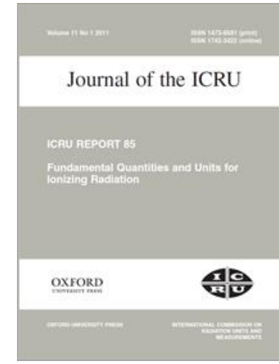
1) Introduction
2) Properties of dosimeters
3) Ionization chamber dosimetry systems
4) Film dosimetry
5) Luminescence dosimetry
6) Other dosimetry systems
   - Semiconductor dosimetry
   - Portal dosimetry

INTRODUCTION

What is a dosimeter?

- A **dosimeter** is a device that measures directly or indirectly
  - absorbed dose
  - exposure
  - equivalent dose
  - or other related quantities.

-> ICRU Report 85



- The dosimeter along with its reader is referred to as a **dosimetry system**.

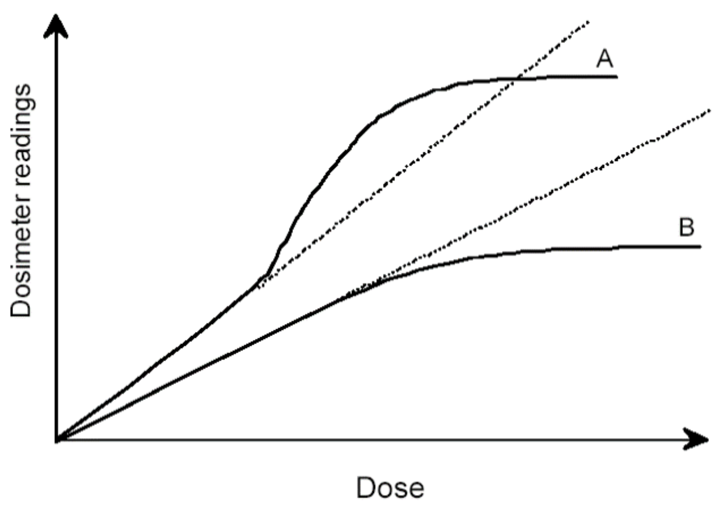
Properties of dosimeters

A useful dosimeter exhibits the following properties:

- High accuracy and precision
- Linearity of signal with dose over a wide range
- Small dose and dose rate dependence
- Flat Energy response
- Small directional dependence
- High spatial resolution
- Large dynamic range

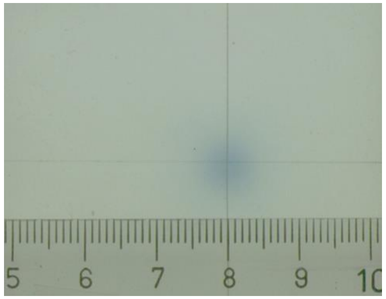
Linearity

- The dosimeter reading should be linearly proportional to the dosimetric quantity.
- Beyond a certain range, usually a non-linearity sets in.
- This effect depends on the type of dosimeter.



Case A: TLD
- linearity
- supralinearity
- saturation

Case B: Radiographic Film
- linearity
- saturation



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Dose rate dependence

Example: <u>Diode</u> detector and <u>Diamond</u> detector

The response of the detectors is dose rate dependent. This dependence can be taken into account by a correction factor that is a function of dose rate.

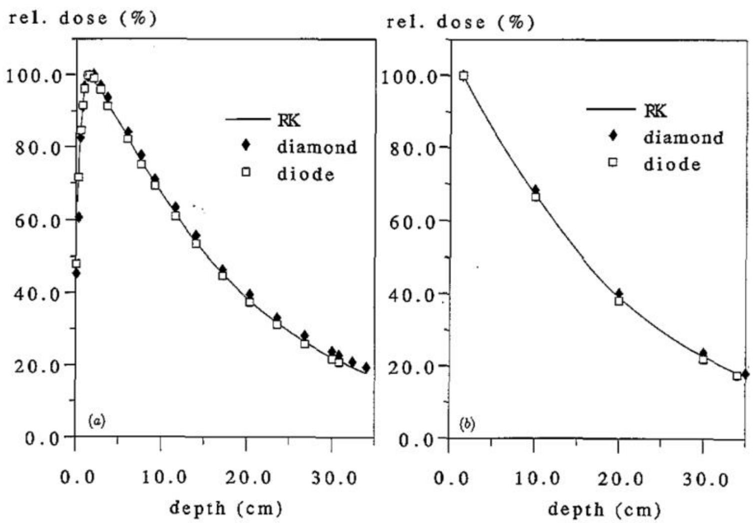


Figure 4. Percentage depth–doses measured with diamond, diode and RK ionization chamber using (*a*) the RFA-7 beam data acquisition system and (*b*) Nuclear Enterprises Farmer electrometer. Dose rate increases from 0.35 to 2.0 Gy min^{-1} as depth decreases from 35 cm to d_{max}.

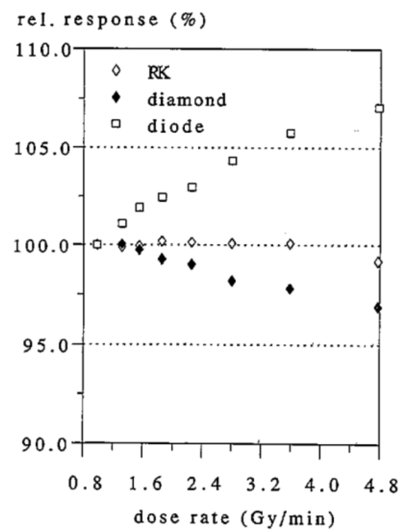
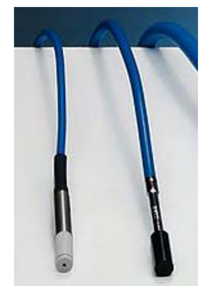


Figure 2. Response of diamond, diode and RK ionization chamber as average dose rate varies from 0.98 to 4.77 Gy min^{-1} by changing FSD from 140 cm to 60 cm. Dose per pulse varies from 0.079 to 0.387 mGy. Values on the graph are the ratio of each detector reading to Farmer ionization chamber reading, normalized to 100% at 0.98 Gy min^{-1}.



P W Hoban et al 1994 Phys. Med. Biol.39 1219

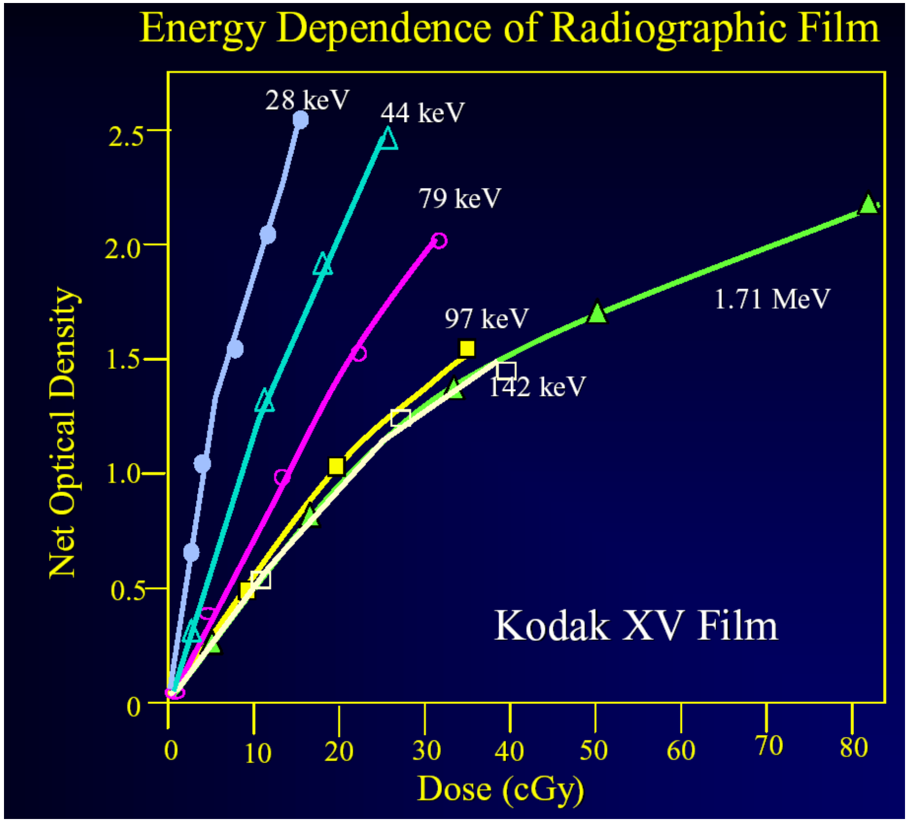
This dependence can be taken into account by a correction factor that is a function of dose rate.

Energy dependence

The response of a dosimetric system is generally a function of the radiation energy.

Example:

Energy dependence of radiographic film.



Energy dependence

- The term "radiation quality" is frequently used to express a specific distribution of the energy of radiation.
- Therefore, dependence on energy can also be called dependence on radiation quality
- Since calibration is done at a specified beam quality (e.g. ^{60}Co), a reading should generally be corrected if the user's beam quality is not identical to the calibration beam quality.

Energy dependence

- *Example*:
  A well known example of energy dependence is the determination of absorbed dose by an ionization chamber calibrated in terms of absorbed dose to water in a calibration radiation quality (usually ^{60}Co beam)
- The determination of absorbed dose in a user beam - different from a ^{60}Co beam – requires a quality correction factor

$$D_{W,Q} = M_Q \cdot N_{Dw(60Co)} \cdot k_Q$$

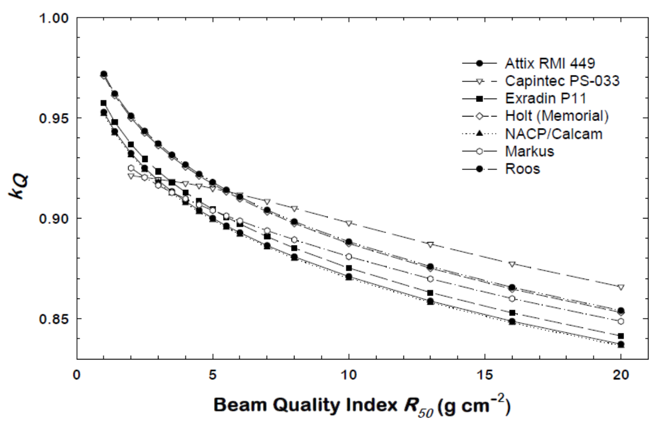


Figure 7.1. Calculated k_Q values for electron beams, for various plane-parallel chamber types calibrated in ^{60}Co gamma radiation.

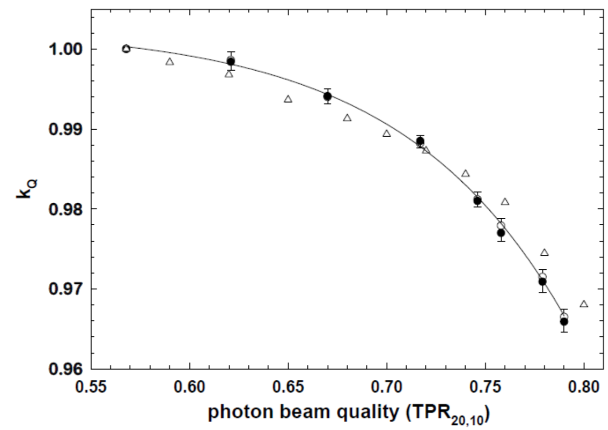


Fig. 4.1. Mean values of k_Q at various photon beam qualities measured at the NPL for Secondary Standard ionization chambers of the type NE 2561 (open circles) and NE 2611 (filled circles) [60]. The solid line is a sigmoidal fit to the experimental data. The uncertainty bars represent chamber to chamber variations, determined as the standard deviations of samples of 13 NE 2561 (upper half) and 11 NE 2611 (lower half) chambers. The values of k_Q are normalized to a $TPR_{20,10}$ of 0.568 (^{60}Co beam at the NPL). Calculated values of k_Q for these chambers given in Table 6.III are included for comparison (triangles); note that the calculated values do not distinguish between the two types of chamber.

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ABSORBED DOSE DETERMINATION IN EXTERNAL BEAM RADIOTHERAPY:
AN INTERNATIONAL CODE OF PRACTICE FOR DOSIMETRY
BASED ON STANDARDS OF ABSORBED DOSE TO WATER
IAEA, VIENNA, 2000

PROPERTIES OF DOSIMETERS

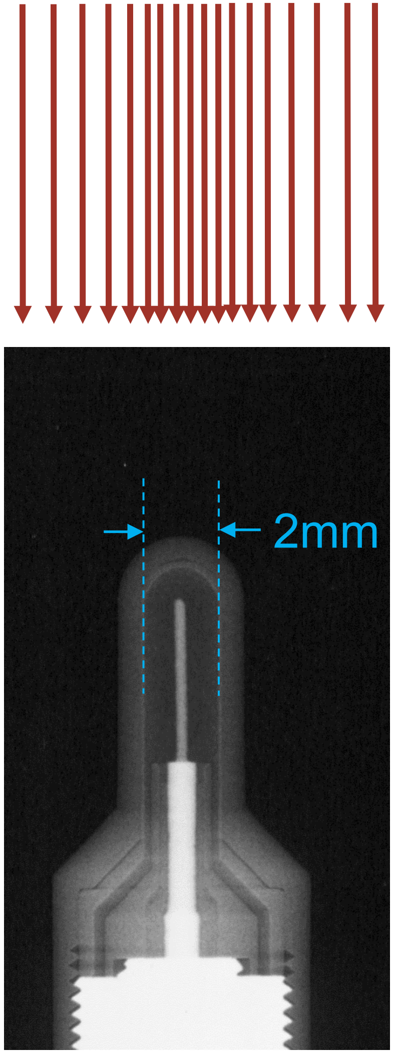
Directional dependence

- The variation in response as a function of the angle of the incidence of the radiation is called the directional dependence of a dosimeter.
- Due to construction details and physical size, dosimeters usually exhibit a certain directional dependence.

Spatial resolution and physical size (1)

- The quantity absorbed dose is a “point-like” quantity.
- Ideal measurement requires a point-like detector
- Examples that approximate a ‘point’ measurement are:
  - Pin-Point Micro-Chamber
  - Diodes, Diamond detectors
  - TLDs

  - Radiographic film, where the ‘point’ is defined by the resolution of the film scanner

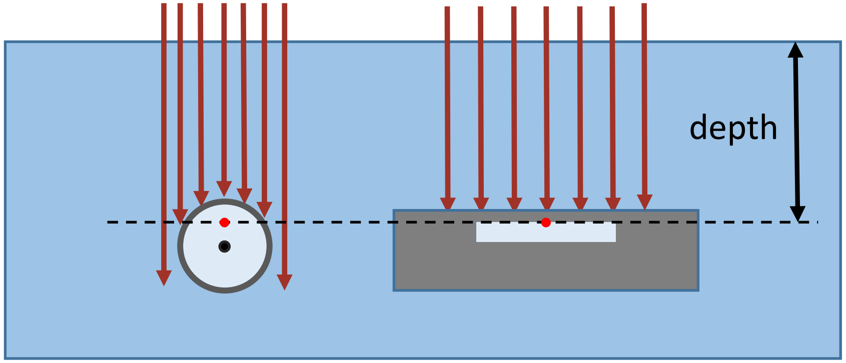


Spatial resolution and physical size (2)

- Ionisation chamber-type dosimeters normally have a larger finite size.
  - Therefore the measurement results correspond to the integral over the sensitive volume.
  - But the measurement results can be attributed to a point within the volume referred to as

    effective point of measurement.
  - Correct positioning of the ionisation chamber is important

effective point of measurement ●



Convenience of use (1)

- Ionization chambers are re-usable with no or little change in sensitivity.
- Semiconductor dosimeters are re-usable but with a gradual loss of sensitivity.
- Some dosimeters are not re-usable at all:
  - film
- Some dosimeters measure a dose distribution in a single exposure:
  - films
  - TLD / OSLD

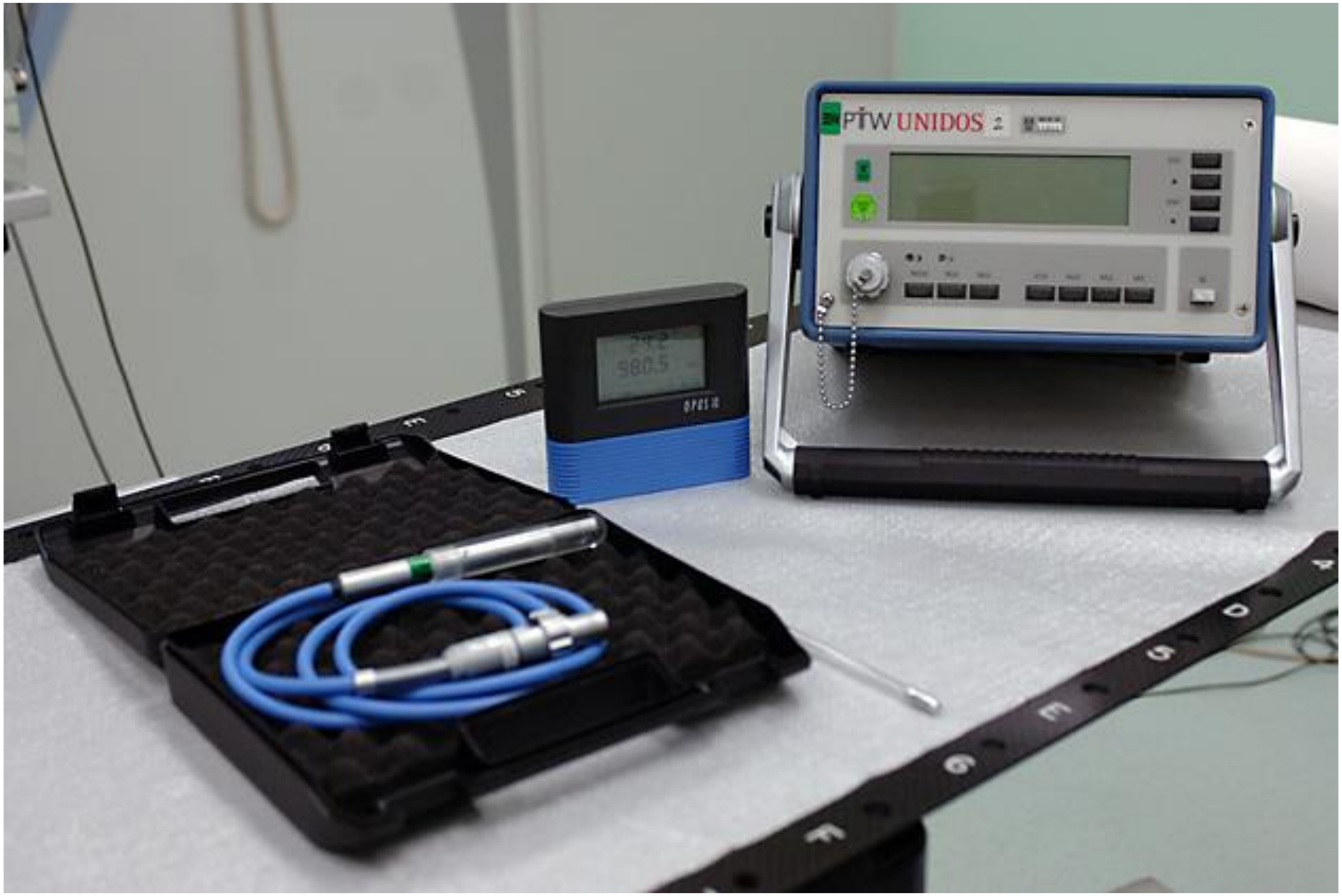
PROPERTIES OF DOSIMETERS

Convenience of use (2)

- Re-usable dosimeters that are rugged and handling does not influence their sensitivity are:
  - ionization chambers
  - Diodes, diamonds
- Re-usable dosimeters that are sensitive to handling are:
  - TLDs

IONIZATION CHAMBER DOSIMETRY

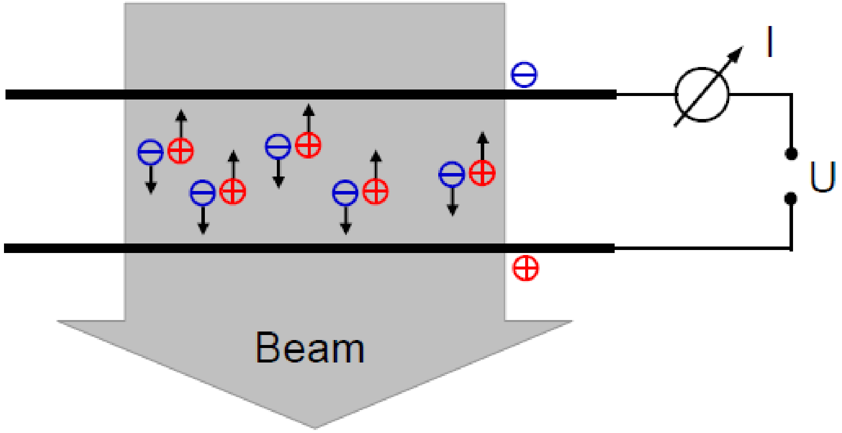
IONIZATION CHAMBER DOSIMETRY
Chambers and Electrometers



Chambers and electrometers

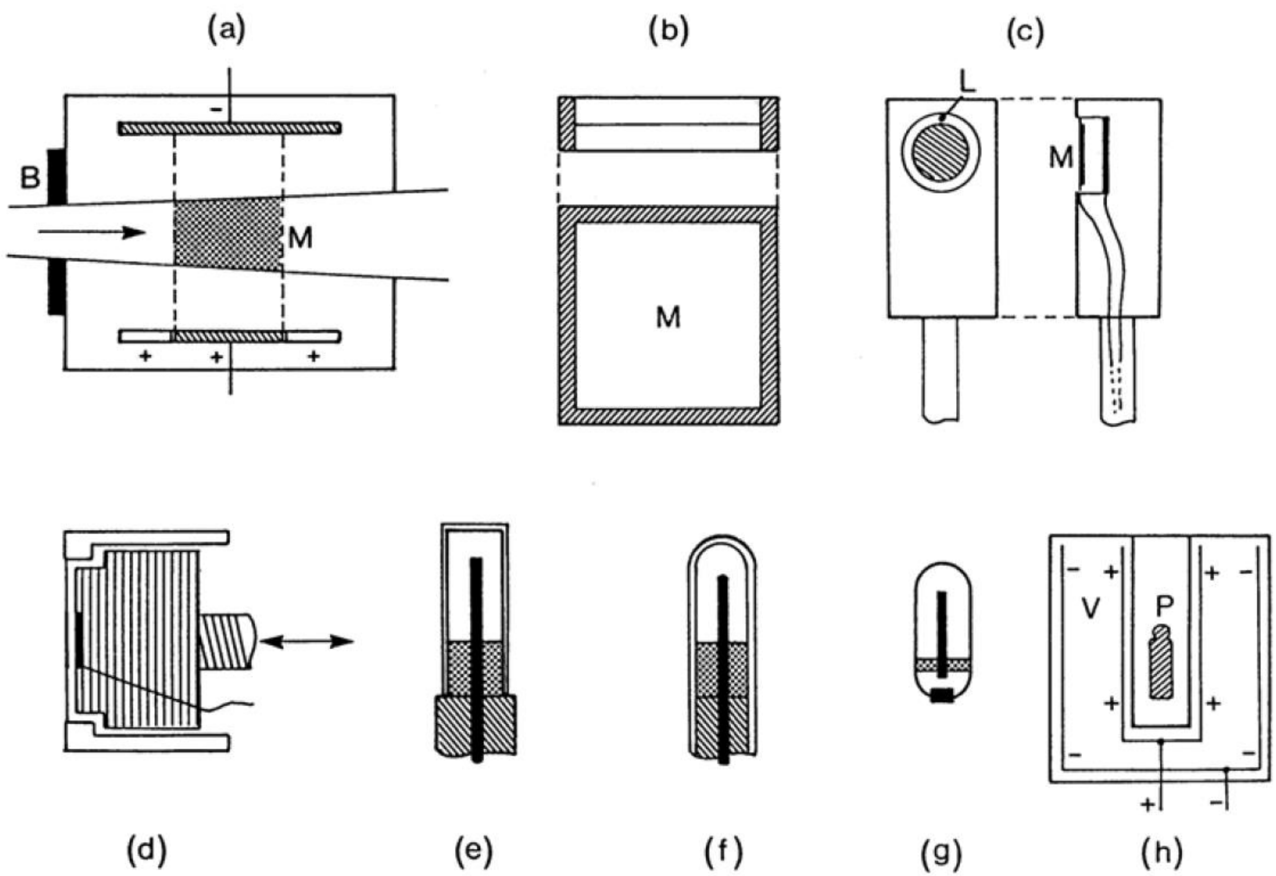
What is an ionisation chamber and how does it work?

- Cavity filled with gas (usually air)
- Two electrodes on HV (U)
- Beam ionises air molecules
- Charge separation in electric field
  - Current (I) ~ Dose rate
  - Charge (Q=∫ I dt) ~ Dose
- Usually open to ambient air
  (p vary -> correction)



Chambers and electrometers

Variety off different shapes and constructions



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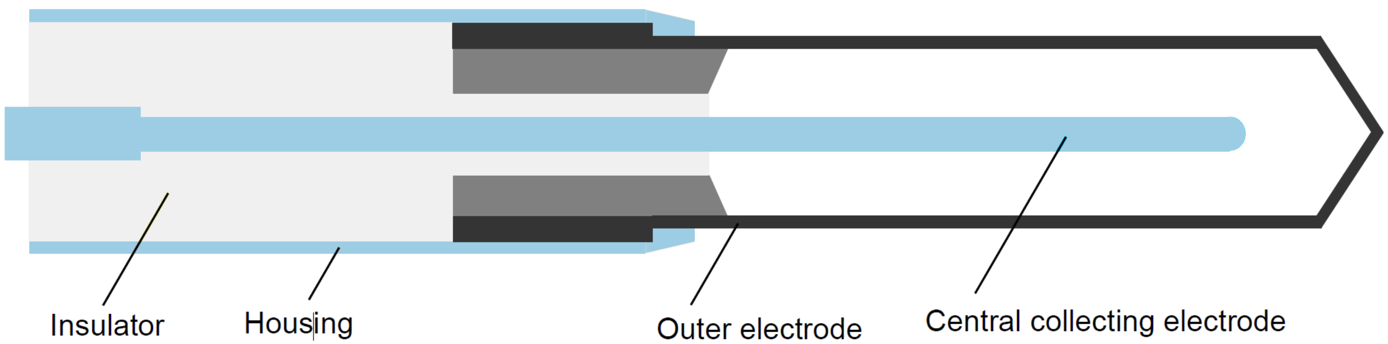
IONIZATION CHAMBER DOSIMETRY

Cylindrical ionization chamber

- Most popular design
- Independent of radial beam direction
- Typical volume between 0.05 ⍰ 1.00 cm^3
- Typical diameter ~ 3 - 7 mm
- Length ~4 - 25 mm
- Thin walls: ~0.1 g/cm^2
- Used for:
  - electron, photon, proton, or ion beams.

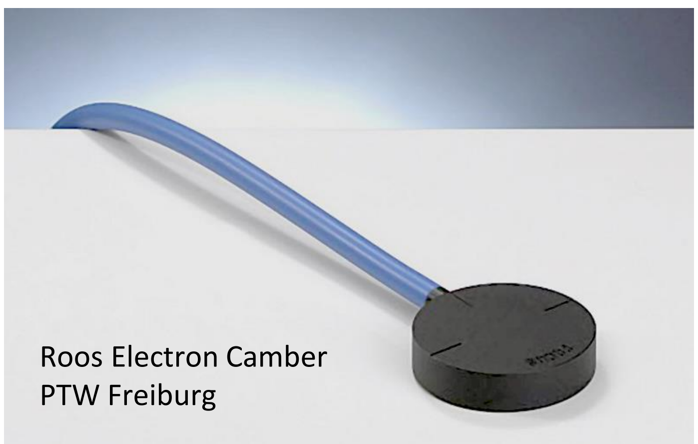
Basic design of a cylindrical ionization chamber.

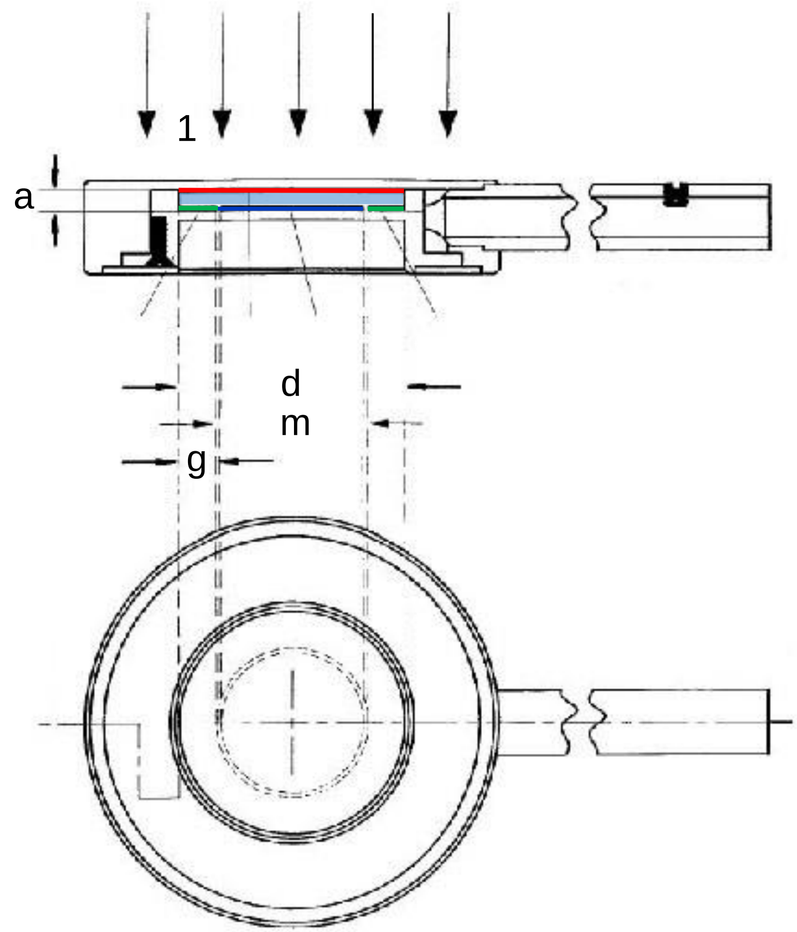


- A cylindrical ionization chamber is basically a gas filled cavity surrounded by a conductive outer wall and having a central collecting electrode.
- The outer electrode is either made of conducting plastics, graphite or Perspex with a thin layer of graphite on the inner surface.

IONIZATION CHAMBER DOSIMETRY
Parallel-plate (plane-parallel) ionization chamber

1 Polarizing electrode
2 Measuring electrode
3 Guard ring



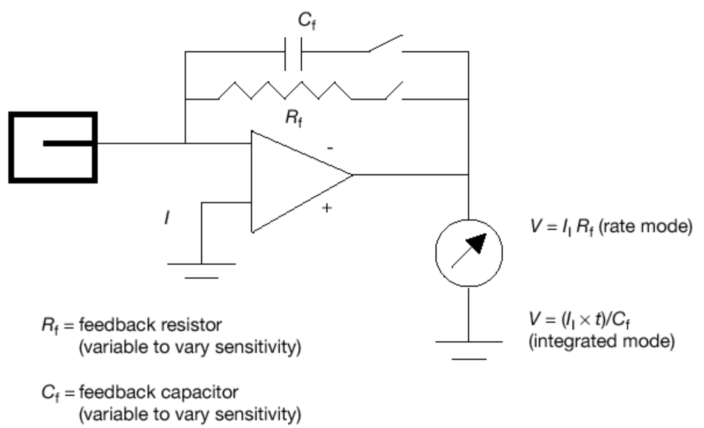


Parallel-plate (plane-parallel) ionization chamber

- The parallel-plate chamber is recommended for dosimetry of electron beams with energies below ~20 MeV.
- For low energy X-rays, special designs are recommended
- It is useful for depth dose measurements.
- It is also used for surface dose and depth dose measurements in the build-up region of megavoltage photon beams.

Chambers and electrometers

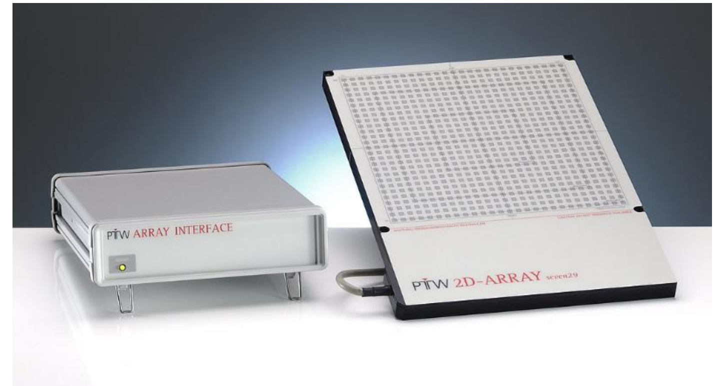
An electrometer is a high gain, negative feedback, operational amplifier with a standard resistor or a standard capacitor in the feedback path to measure the chamber **current** and **charge**, respectively, collected over a fixed time interval.

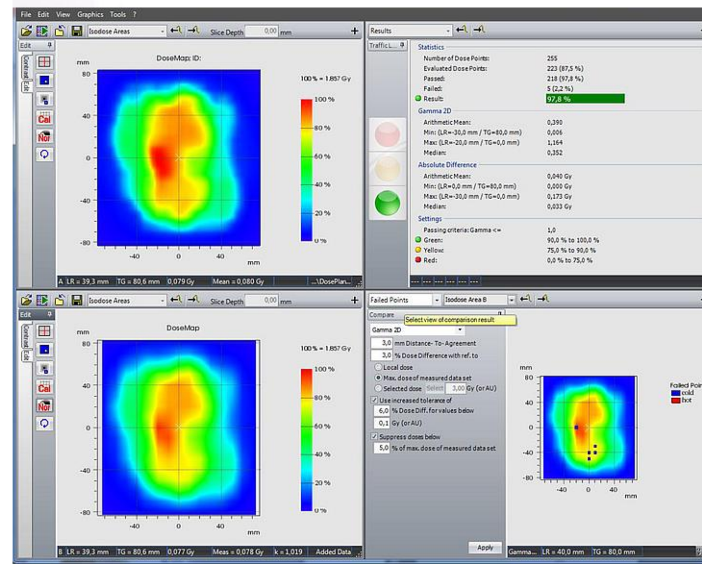


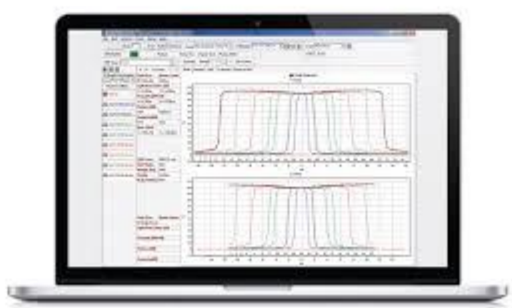
IONIZATION CHAMBER DOSIMETRY
Chamber arrays

Examples of a chamber arrays

- 729 ionization chambers
- Volume of each: 5 mm x 5 mm x 4 mm
- Calibrated in terms of absorbed dose
- Commercialized software vailable



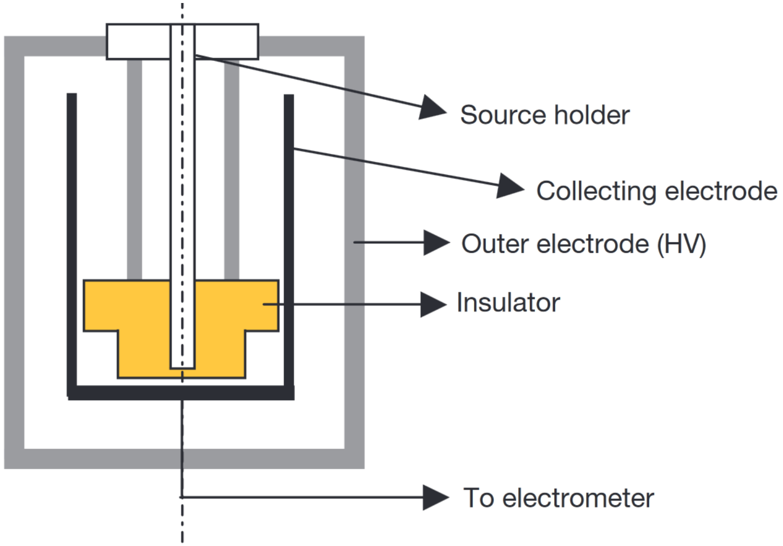




IONIZATION CHAMBER DOSIMETRY
Brachytherapy chamber

Well type chamber

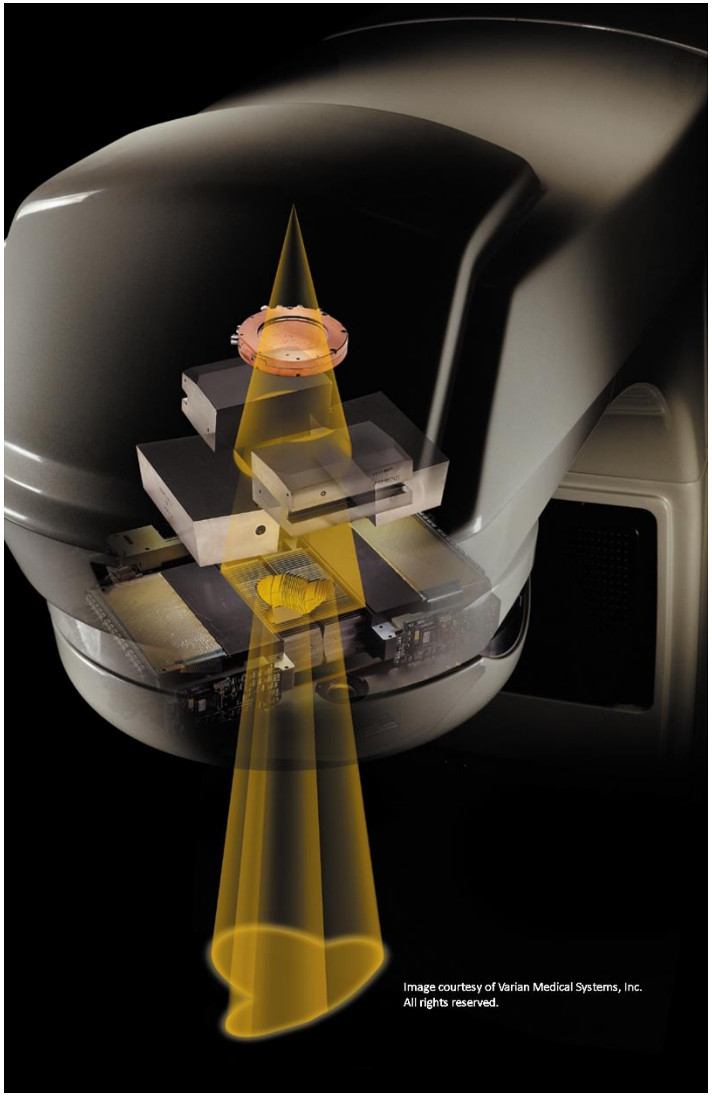
- High sensitivity (useful for low rate sources as used in brachytherapy)
- Large volumes (about 250 cm^3)
- Can be designed to accommodate various sources sizes



Monitor Chamber

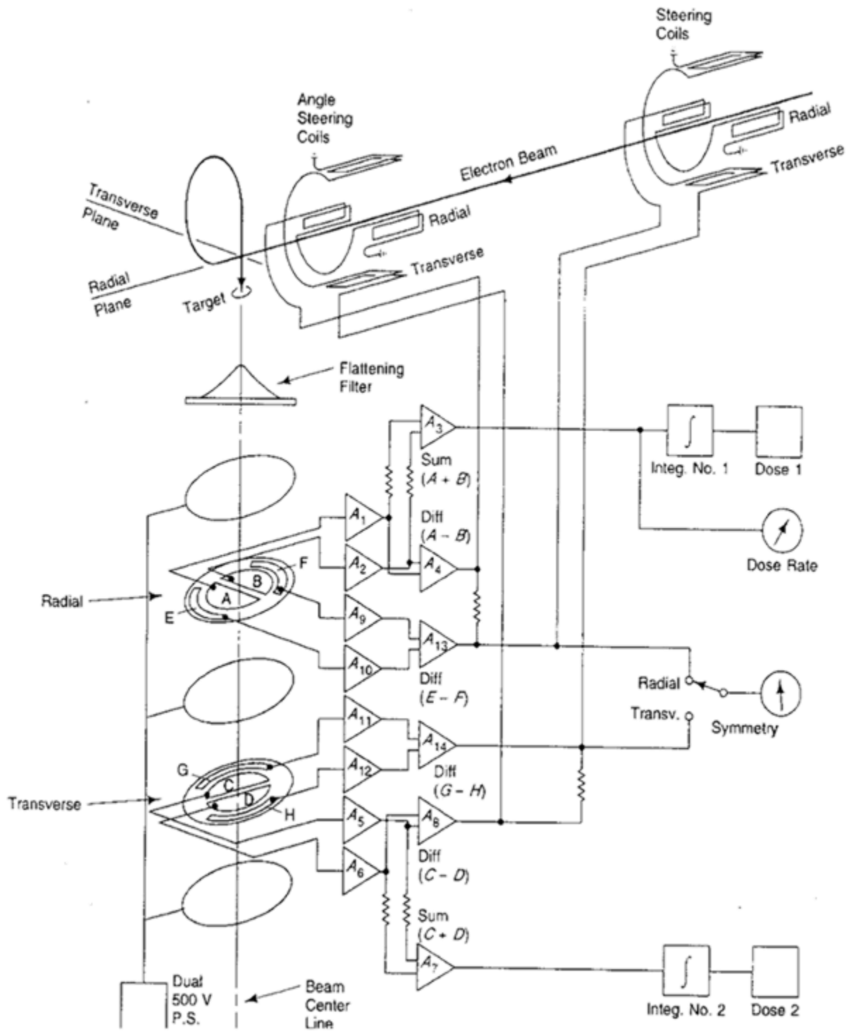
Monitor chamber of a Linac

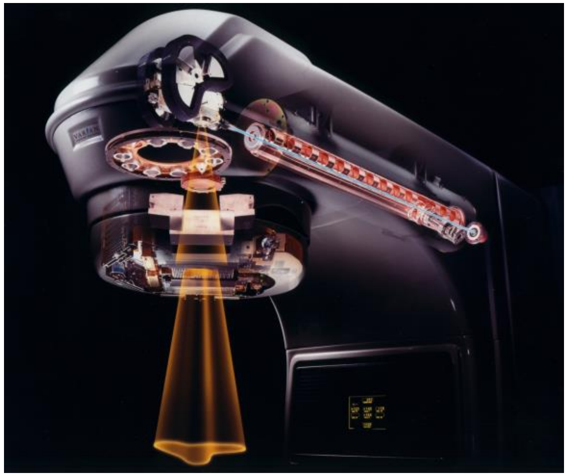
- Terminates the exposure at a predefined number of monitor units
- Radiation exposure is controlled by two integrated chamber systems (backup monitor)
- segmented chamber
- Usually air-filled, sealed
- used also for beam steering in a feedback loop

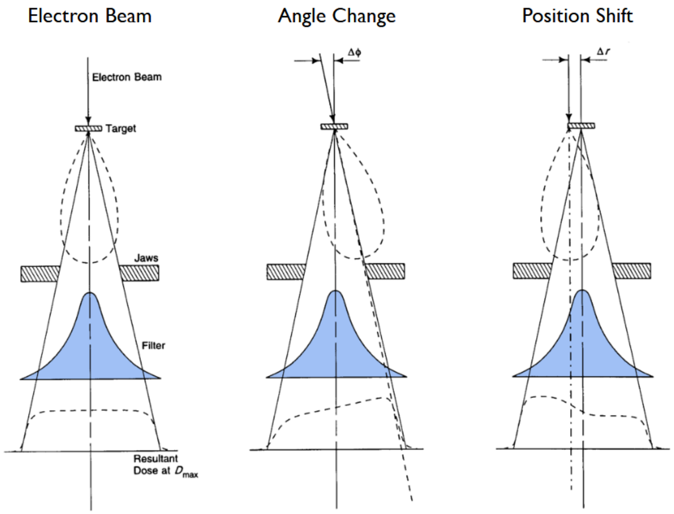


Monitor Chamber (2)

Monitor chamber (segmentation)







IONIZATION CHAMBER DOSIMETRY

Monitor Chamber (3)

- The monitor chamber must be calibrated under reference conditions with a reference chamber, traceable to a PDSL (primary standard dosimetry laboratory).

absolute dosimetry

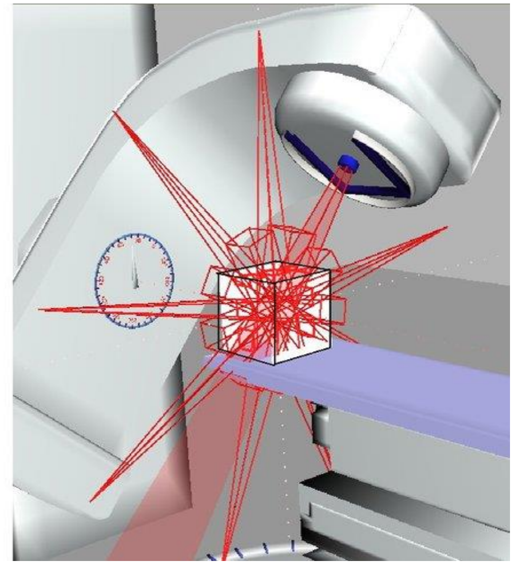
- Open monitor chambers must be continuously monitored for pressure and temperature. The reading must be corrected accordingly.

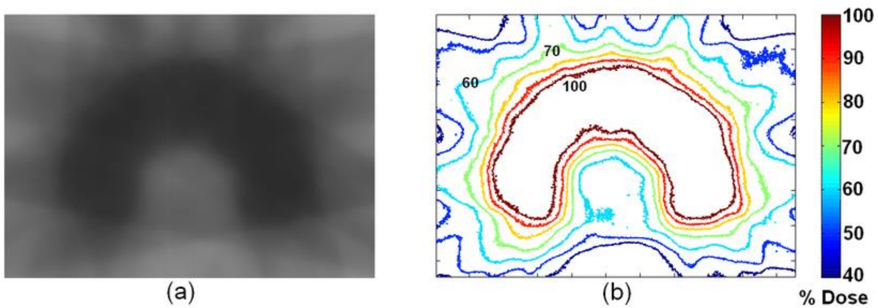
FILM DOSIMETRY

FILM DOSIMETRY

Radiographic film

AgBr based





(a) (b)

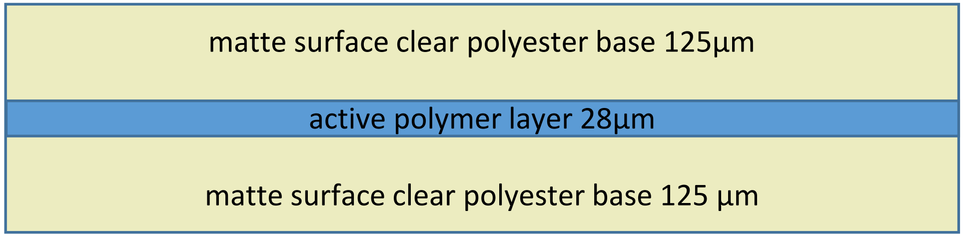
Obsolete, due to disadvantages in film handling

Important aspect:
Film has also an archival property

FILM DOSIMETRY

Radiochromic film

- Radiochromic film is a new type of film well suited for radiotherapy dosimetry.
- 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.
- Similarly to the radiographic film, the radiochromic film dose response is determined with a suitable densitometer (flat bed scanner in transmission mode).

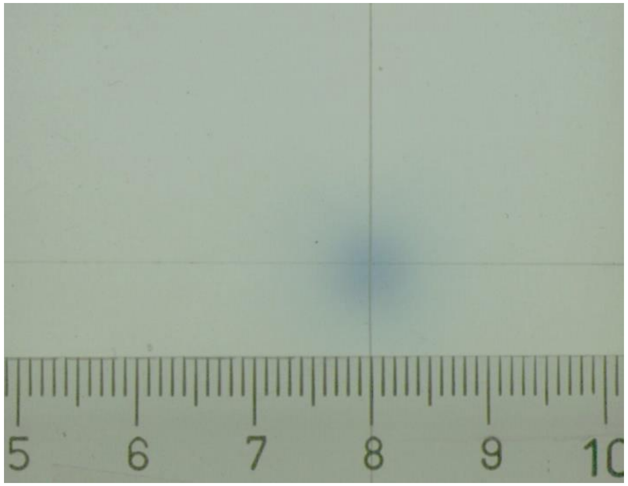


FILM DOSIMETRY

Radiochromic film

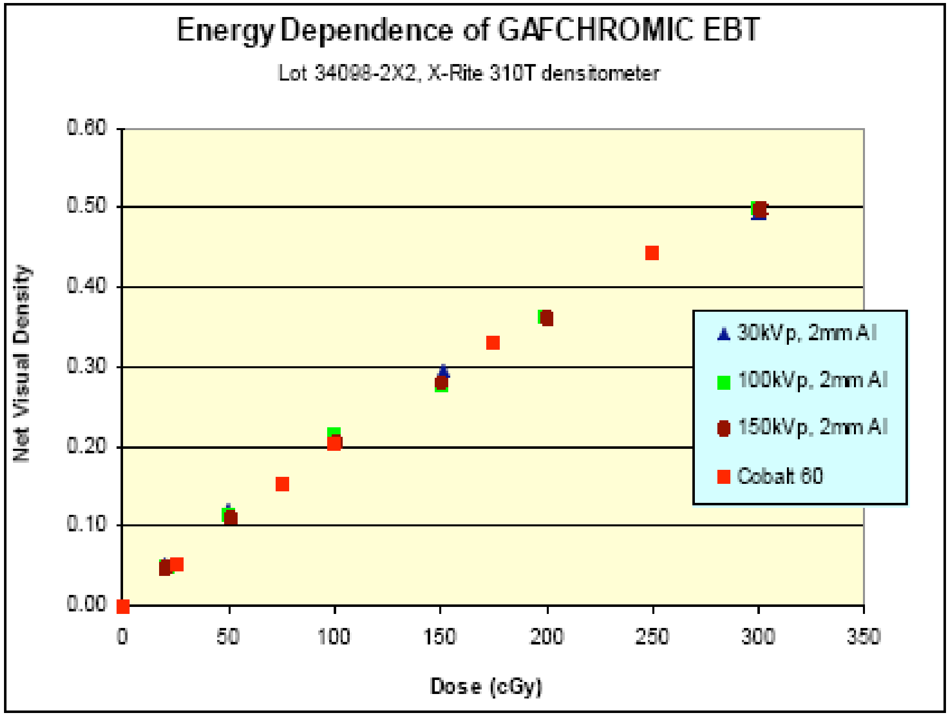
Example: (QA Test of target positioning at a Gamma Knife):

Blue color produced by the focused radiation
in a Gamma Knife



FILM DOSIMETRY

Radiochromic film



FILM DOSIMETRY

Radiochromic film

Advantages

- No quality control on film processing needed
- Radiochromic film is grainless
  very high resolution
- Useful in high dose gradient regions for dosimetry, such as in:
  - stereotactic fields
  - the vicinity of brachytherapy sources
- Dose rate independence.
- Can be immersed in water
- cheap scanners

Disadvantage

- GafChromic films are generally less sensitive than radiographic films

LUMINESCENCE DOSIMETRY

LUMINESCENCE DOSIMETRY
definition of terms

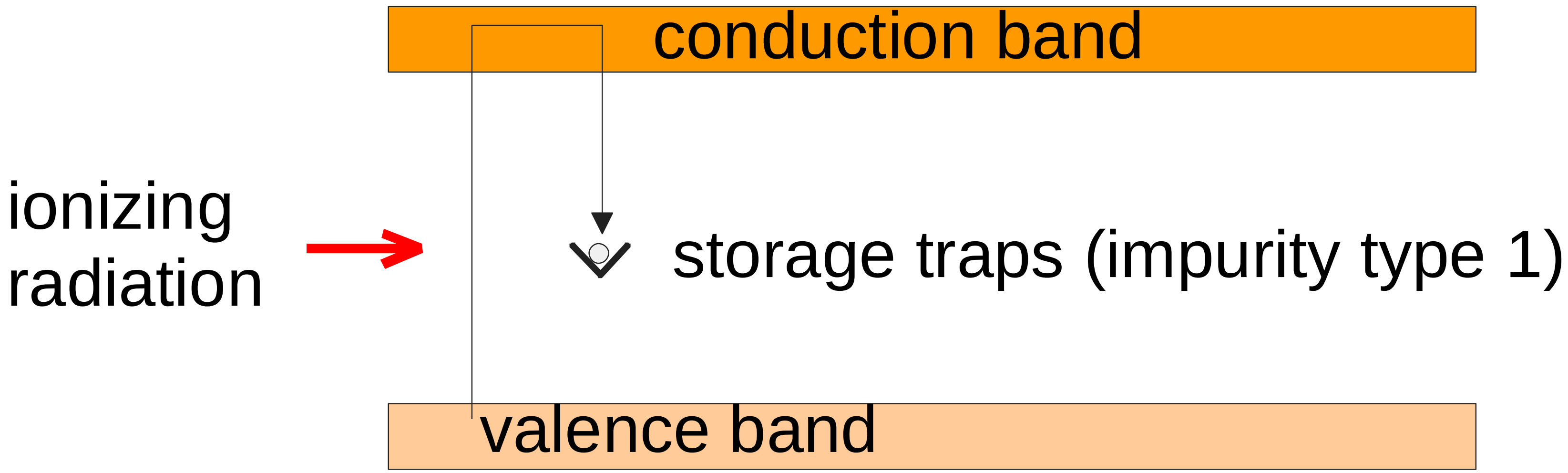
- Upon absorption of radiation, some materials retain part of the absorbed energy in metastable states.

- When this energy is subsequently released in the form of ultraviolet, visible or infrared light, this phenomenon is called

Luminescence

LUMINESCENCE DOSIMETRY

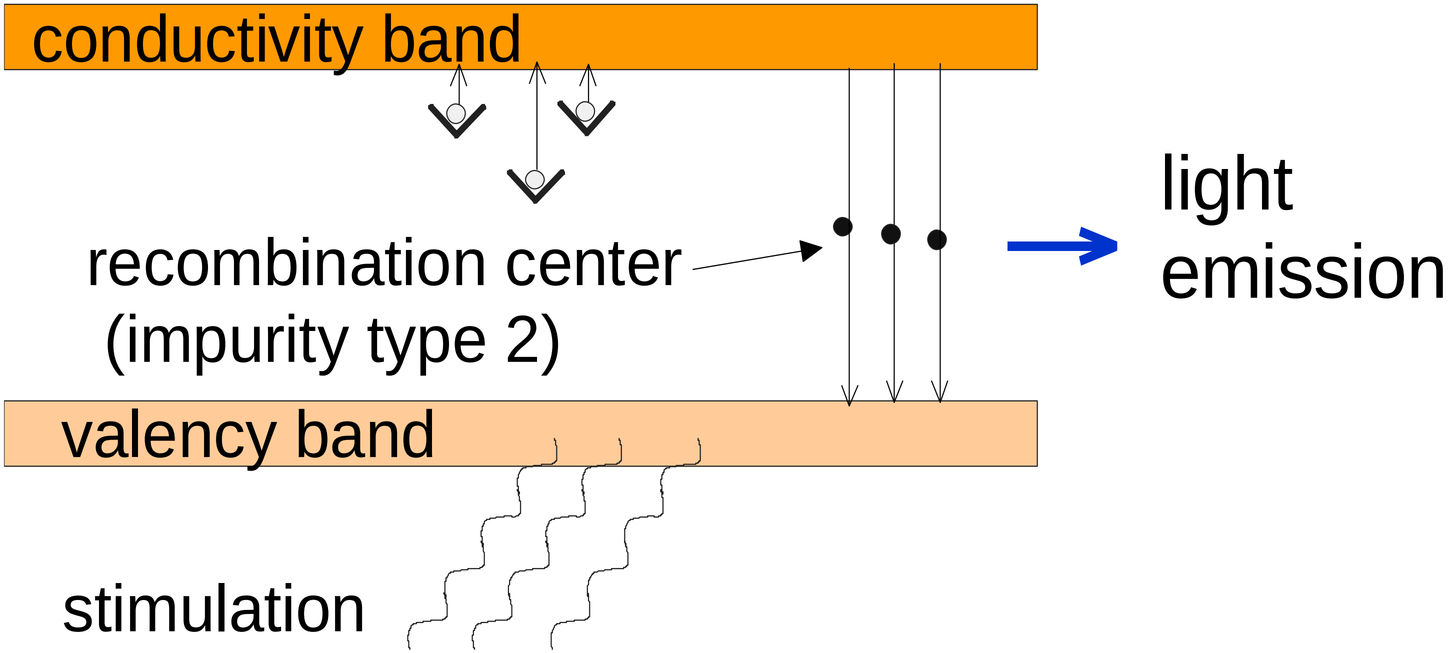
The principle



- Upon radiation, free electrons and holes are produced.
- Luminescence material contains so-called *storage traps.*
- Free electrons and holes will either recombine immediately or become trapped (at any energy between valence and conduction band) in storage traps.

LUMINESCENCE DOSIMETRY

The principle



- Upon stimulation, the probability increases for the electrons to be raised to the conduction band ….

…and to release energy (light) when they combine with a positive hole

LUMINESCENCE DOSIMETRY

The principle

- If the stimulating agent is **heat**, the phenomenon is known as

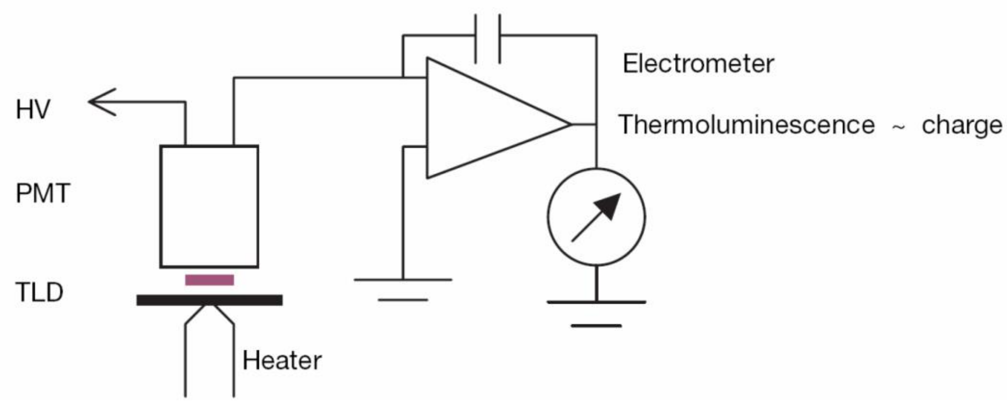
Thermoluminescence (TL)

- If the stimulating agent is **light**, the phenomenon is referred to as

Optically Stimulated Luminescence (OSL)

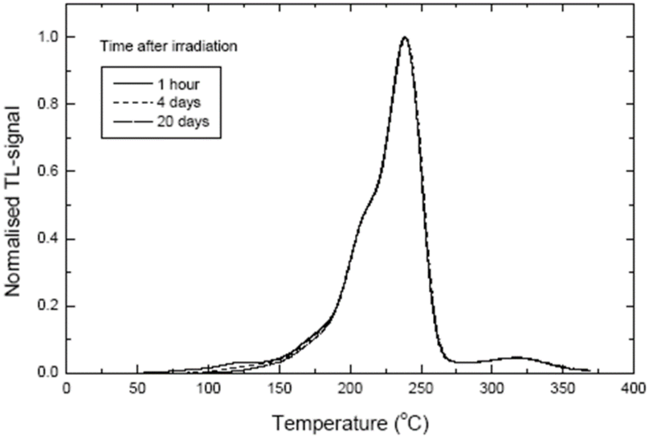
LUMINESCENCE DOSIMETRY

Thermoluminescence detector systems



A basic TLD reader system consists of:

- Planchet for positioning and heating the TLD dosimeter;
- Photomultiplier tube (PMT) to detect the TL light emission, convert it into electrical signal, and amplify it.
- Electrometer for recording the PMT signal as charge or current.
- Computer for evaluation



LUMINESCENCE DOSIMETRY

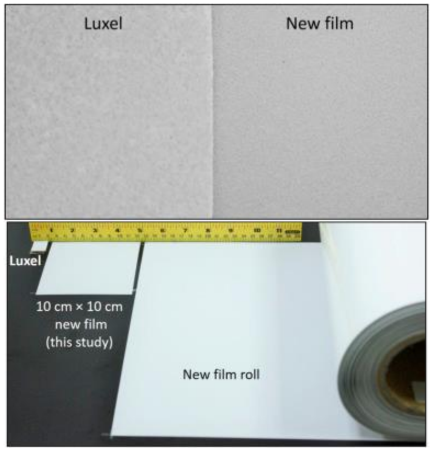
Optically stimulated luminescence systems

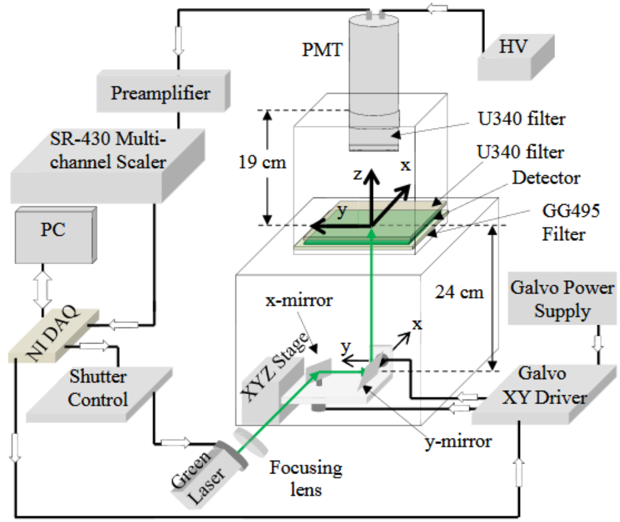
- Optically stimulated luminescence (OSL) is based on a principle similar to that of the TLD.
- Instead of heat, light (from a laser) is used to release the trapped energy in the form of luminescence.
- OSL is a novel technique offering a potential for *in vivo* dosimetry in radiotherapy.
- The most promising material is Al_2O_3:C

LUMINESCENCE DOSIMETRY

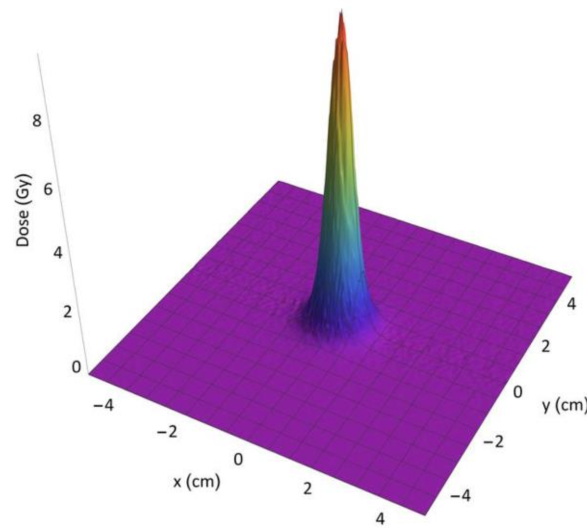
Optically stimulated luminescence systems

2dimensional OSLD

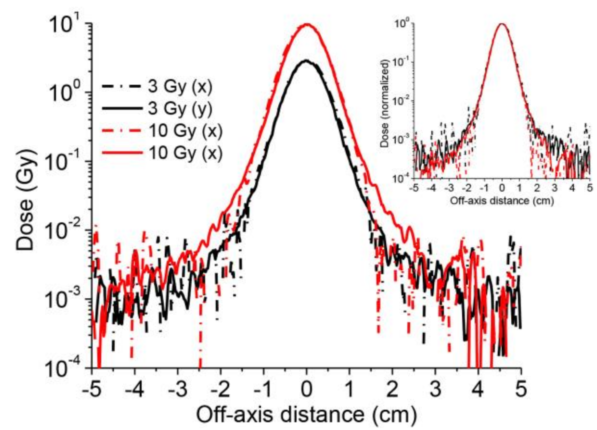




(a)



(b)



Development of a 2D dosimetry system based on the optically stimulated luminescence of Al_2O_3

M.F. Ahmed [a], S.A. Eller [a], E. Schnell [b], S. Ahmad [b], M.S. Akselrod [a,c], O.D. Hanson [a,d], E.G. Yukihara [a,*]

[a] *Physics Department, Oklahoma State University, Stillwater, OK 74078, USA*
[b] *Department of Radiation Oncology, The University of Oklahoma Health Sciences Center, Oklahoma City, OK 73104, USA*
[c] *Landauer, Inc., Stillwater Crystal Growth Division, Stillwater, OK 74074, USA*
[d] *St. John Medical Center, 1923 S. Utica Ave., Tulsa, OK 74104, USA*

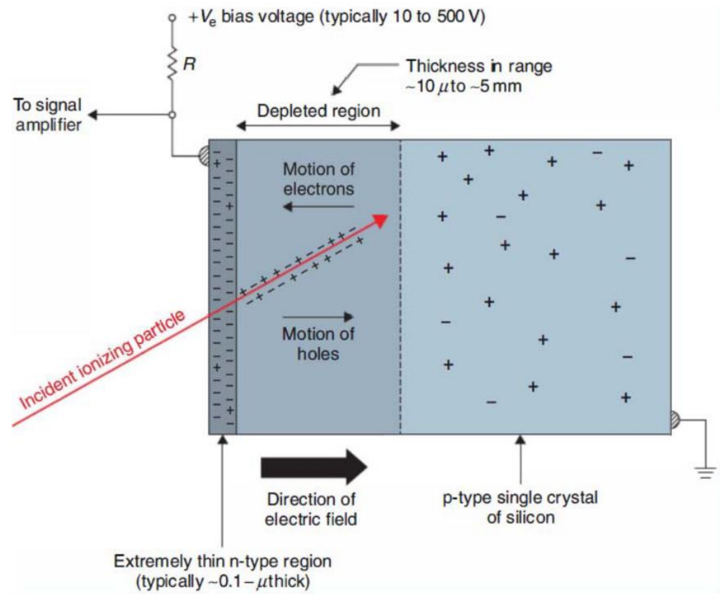
OTHER DOSIMETRY SYSTEMS

- solid state Dosimeters like diodes and diamonds
- portal dosimetry systems
-
-

(list by far not complete)

OTHER DOSIMETRY SYSTEMS
Semiconductor Dosimetry Systems

- A silicon diode dosimeter is working like a …



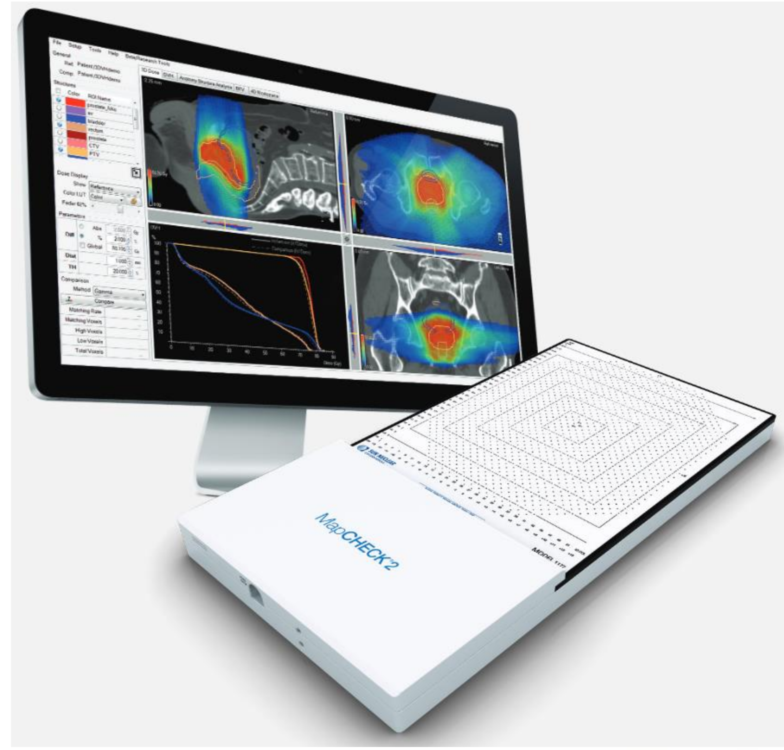
Semiconductor Dosimetry Systems

Some Properties

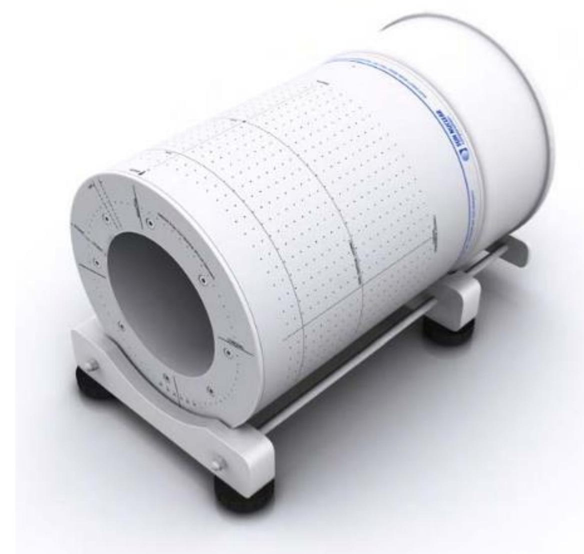
- Diodes are more sensitive and smaller in size than typical ionization chambers.
- Diodes require no external bias voltage -> invivo dosimetry
- Diodes are particularly useful for measurement in phantoms, for example of small fields used in stereotactic radiosurgery or high dose gradient areas such as the penumbra region.
- Diodes show a variation in dose response with temperature. -> invivo dosimetry
- Diodes show a dose rate dependence of the signal.
- They are relative dosimeters and should not be used for beam calibration, since their sensitivity changes with repeated use due to radiation damage.

OTHER DOSIMETRY SYSTEMS
Semiconductor Dosimetry Systems

Set of diodes for in-vivo dosimetry

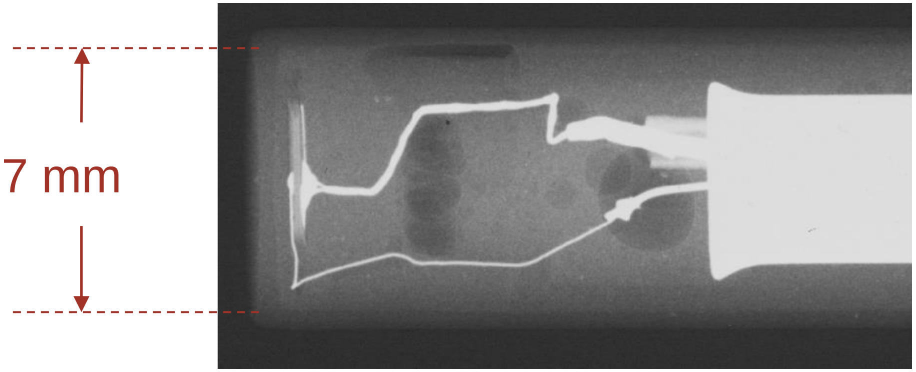


Diode for relative dose measurements in a water phantom



Diamond Detector Systems

- The diamond detector is based on a natural diamond crystal sealed in polystyrene housing with a bias applied through thin golden contacts.
- Diamonds change their resistance upon radiation exposure.
  Under a biasing potential (100V), the resulting current is proportional to radiation dose rate.



Diamond Detector Systems

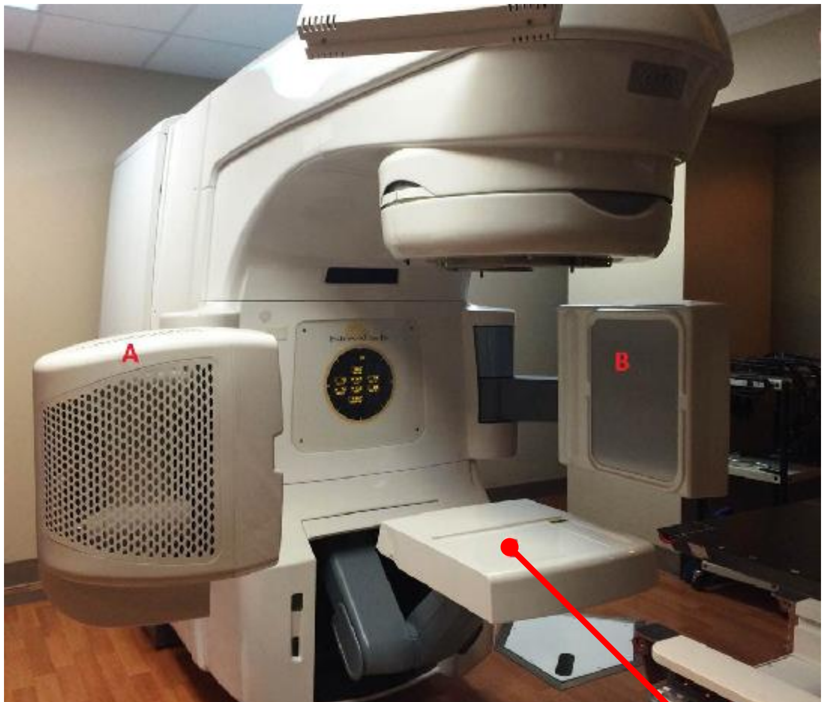
Advantages:

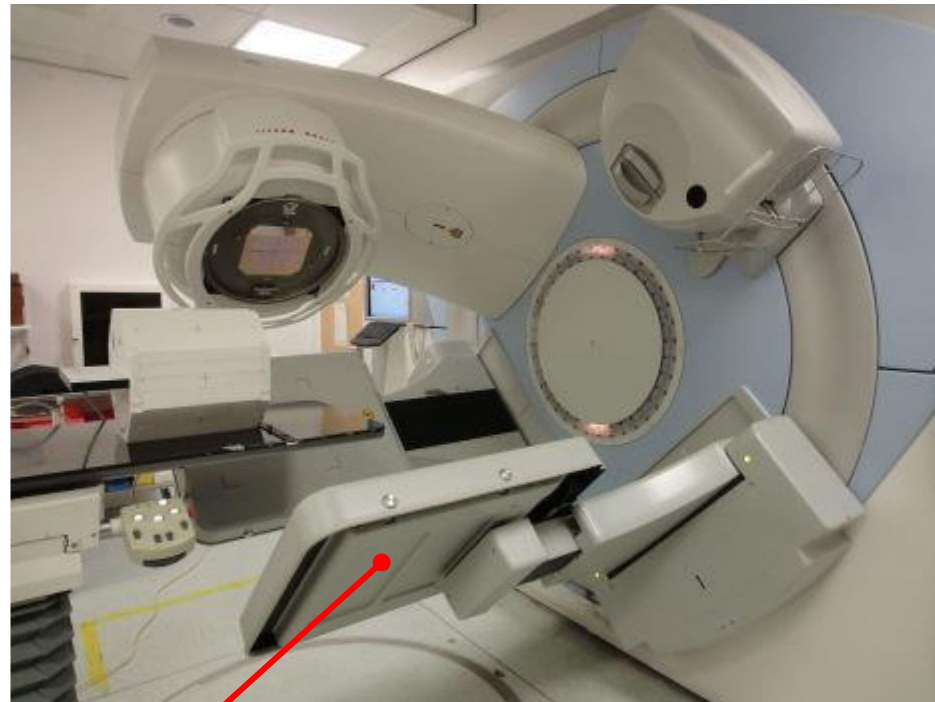
- Diamond dosimeters are waterproof and can be used for measurements in a water phantom.
- They are tissue equivalent and require nearly no energy correction.
- They are well suited for use in high dose gradient regions, (e.g., stereotactic radiosurgery).

Disadvantages:

- In order to stabilize their dose response (to reduce the polarization effect) diamonds should (must!) be irradiated prior to each use.
- They exhibit a small dependence on dose rate, which has to be corrected for when measuring:
  - depth dose.
  - absolute dose.
- Applying a higher voltage than specified (>100V) will immediately destroy the diamond detector.

OTHER DOSIMETRY SYSTEMS
Electronic Portal Imaging Devices

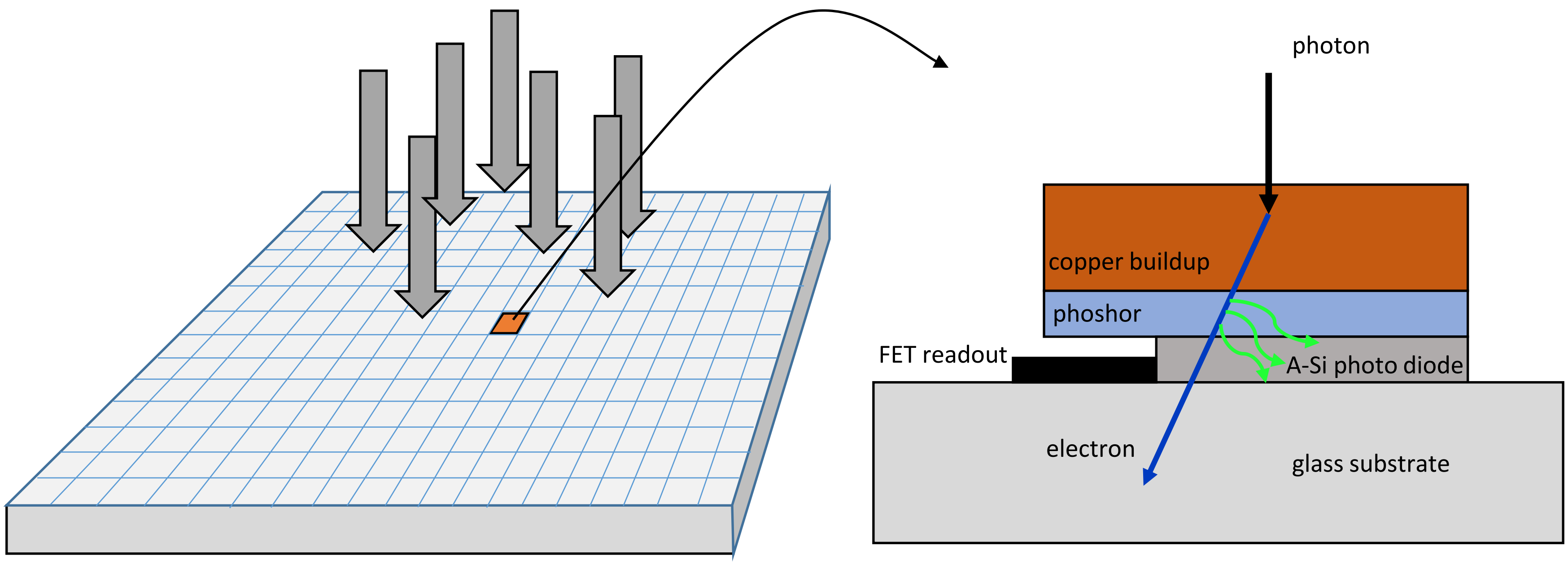




EPID = Electronic portal imaging device

Electronic Portal Imaging Devices

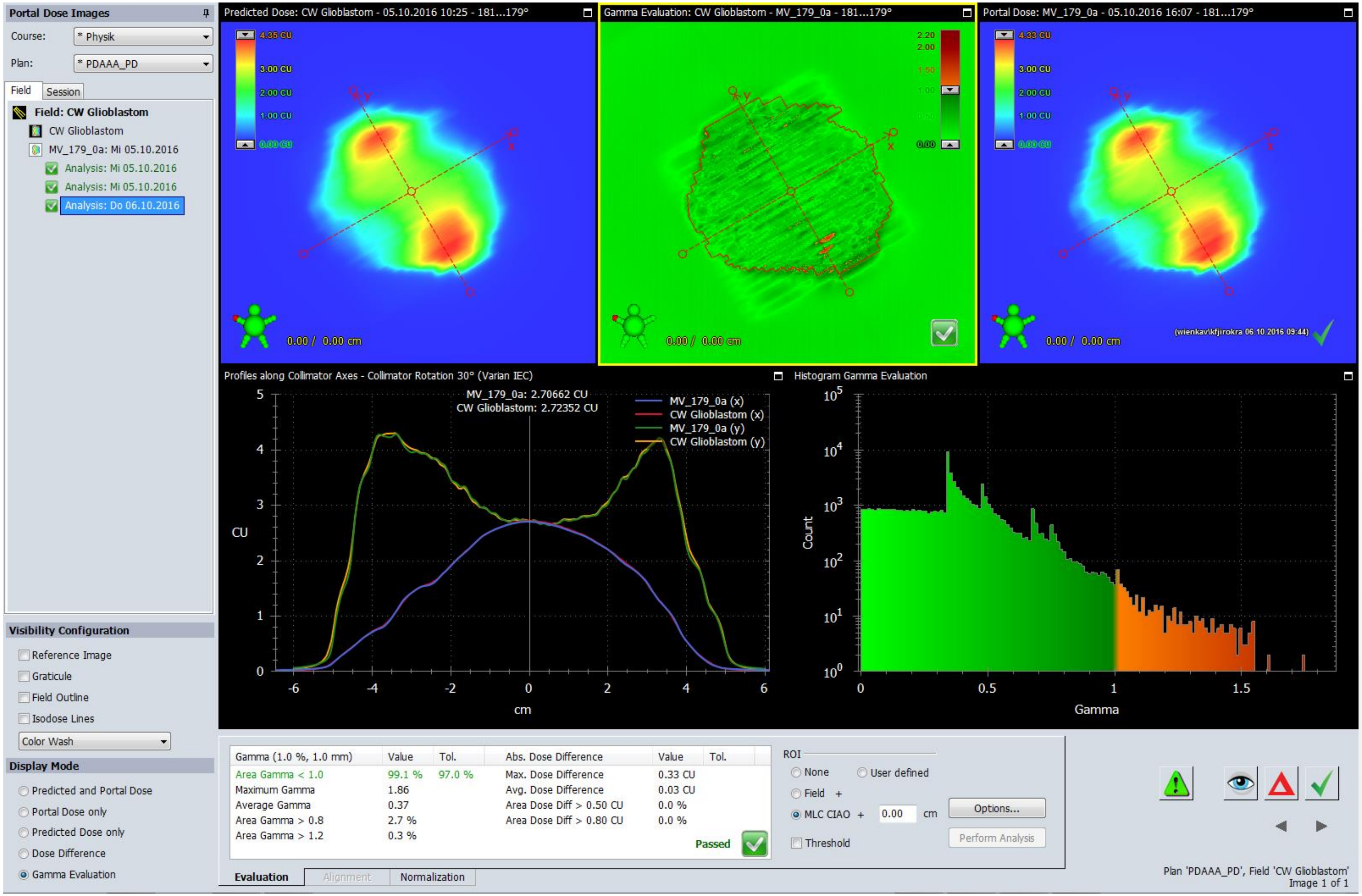
- <u>Amorphous Silicon Detector</u>
- Array of typically 200 000 ... 1000000 pixels
- Pixel pitch: 0.4 ... 0.8 mm



Matrix of 1024 x 1024 detectors

OTHER DOSIMETRY SYSTEMS

Electronic Portal Imaging Devices - Portal Dosimetry



https://www.wienkav.at/kav/kfj/91033454/physik/ARIA15/AAAPDP.html

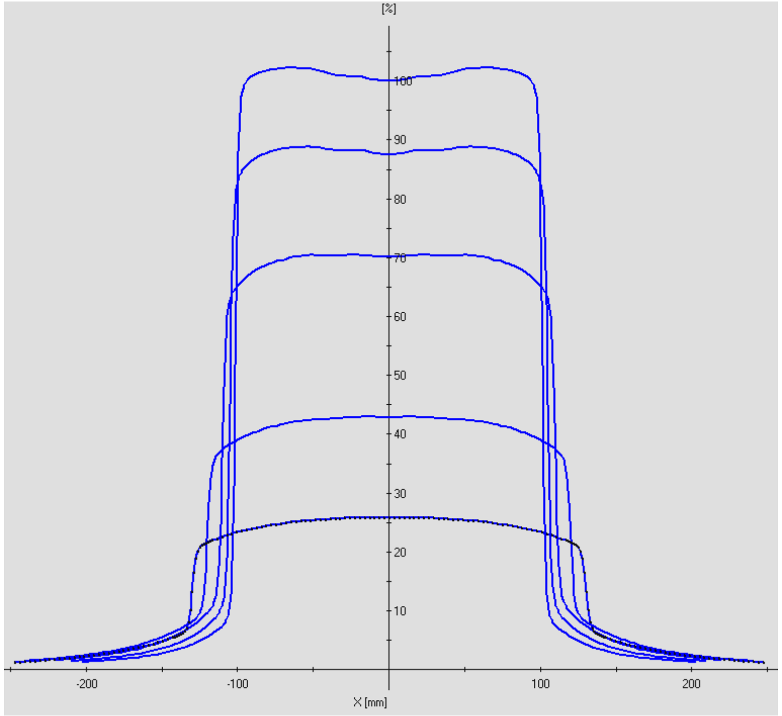
RELATIVE AND ABSOLUTE DOSIMETRY

Relative Dosimetry

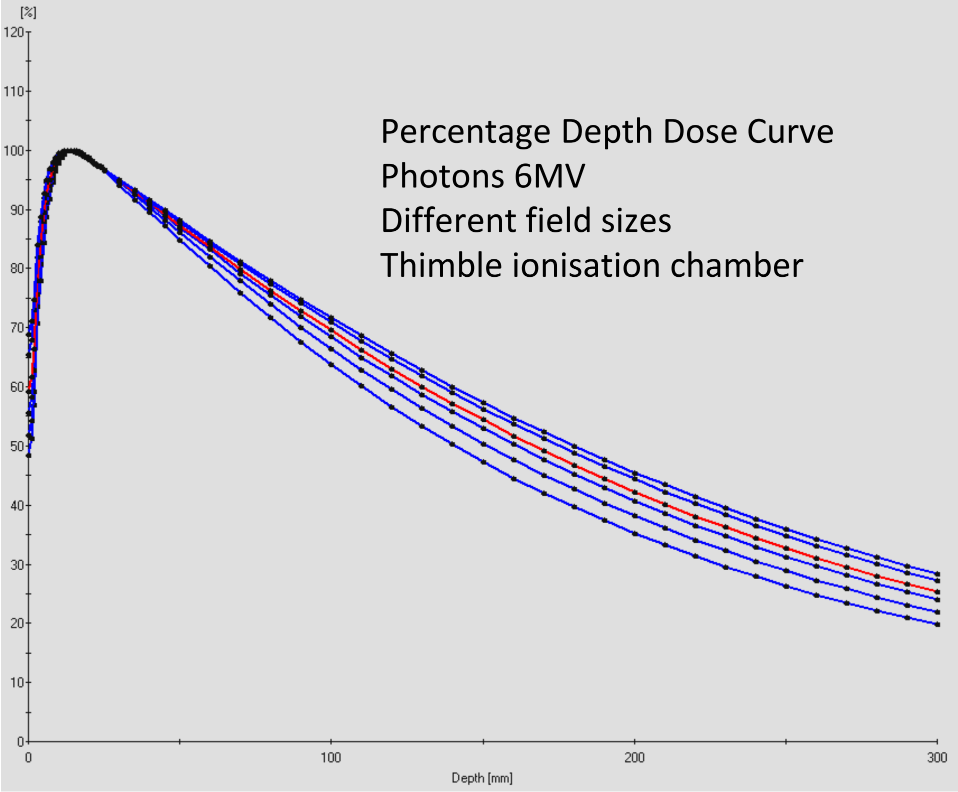
- Is the measurement of dose relative to the reference point
  - Depth dose curve on central ray of the beam
  - Transverse dose distributions in different depths

RELATIVE AND ABSOLUTE DOSIMETRY

Relative dosimetry, profiles and depthdose curves

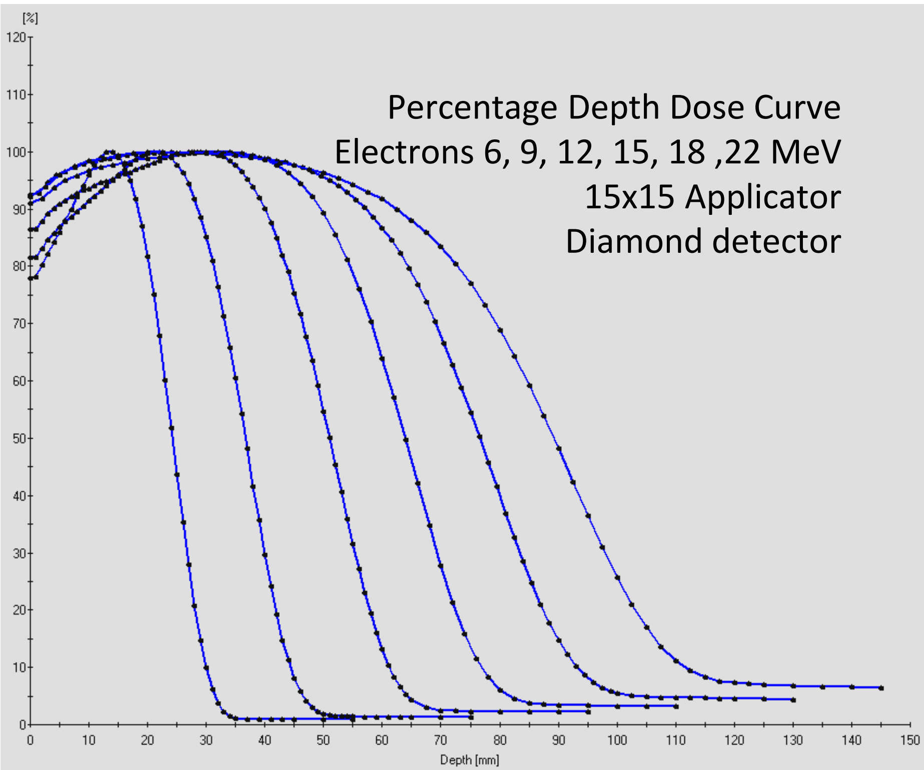


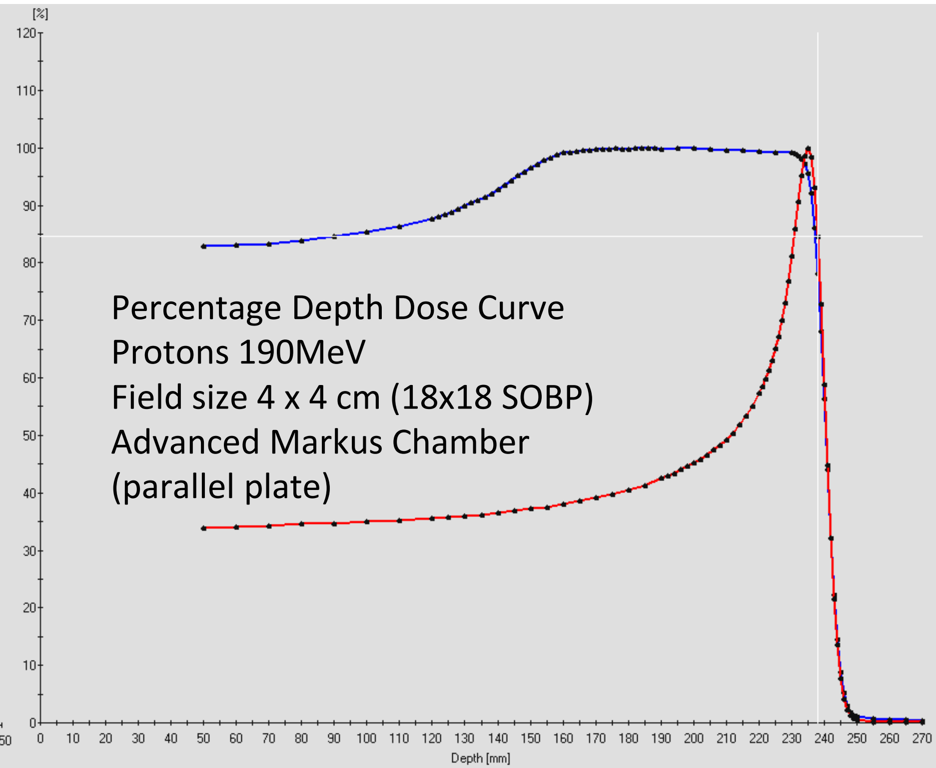
Beam profiles X-Direction, different depths
Photons 6MV
Field size 20x20
Diode Detector



RELATIVE AND ABSOLUTE DOSIMETRY

Relative dosimetry, depth dose curves



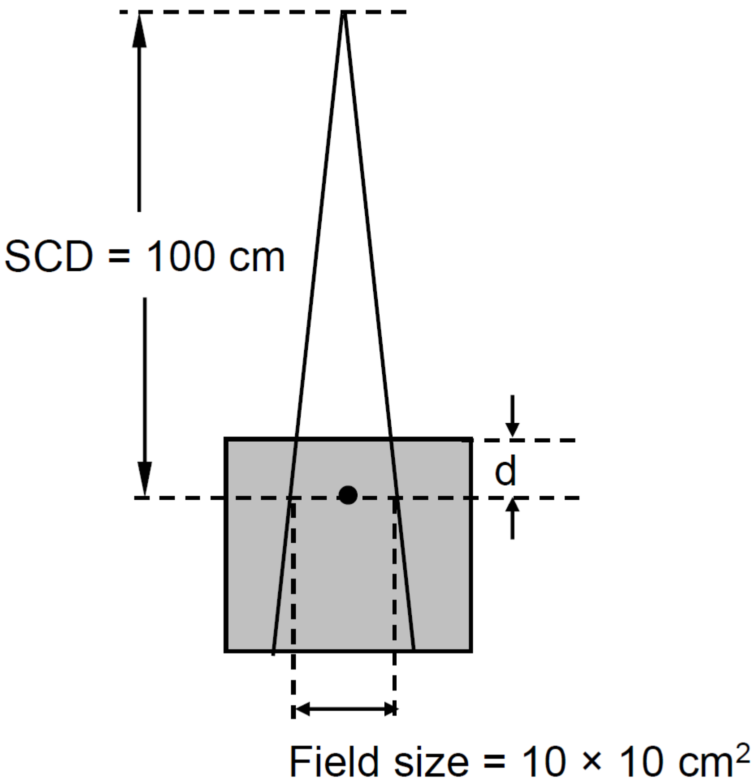


Absolute dosimetry

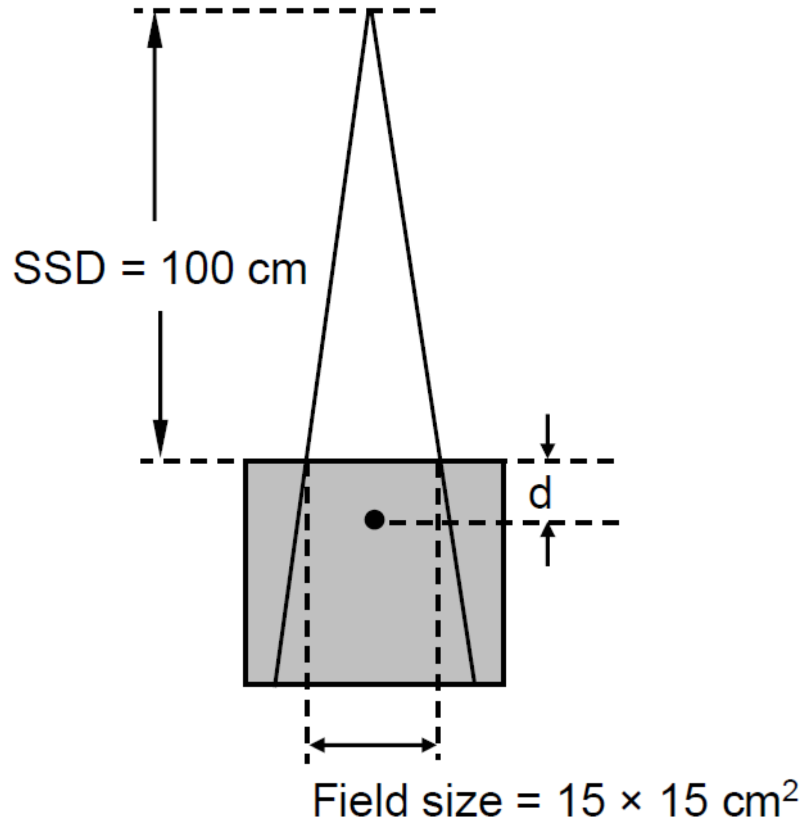
- Is the measurement of the absolute absorbed dose at a reference point on the central ray of a beam
- In the hospital it is accomplished by using *local reference standards.*
- Local reference standards are: ionisation chambers
- Additional equipment beside the ionization chamber:
  - water phantom
  - electrometer
  - thermometer
  - barometer

Setup and reference conditions

Photons



Electrons



METROLOGICAL TRACEABILITY

METROLOGICAL TRACEABILITY

Calibration chain

- Ionization chambers used in hospitals for calibration of radiotherapy beams must have a calibration coefficient traceable (directly or indirectly) to a primary standard.
- Primary standards are not used for routine calibrations, since they represent the unit for the quantity at all times.
- Instead, *Primary Standards Dosimetry Laboratories (PDSLs)* calibrate secondary standard dosimeters for *secondary standards dosimetry laboratories* (SSDLs) that in turn are used for calibrating the reference instruments of users, such as therapy level ionization chambers used in hospitals.

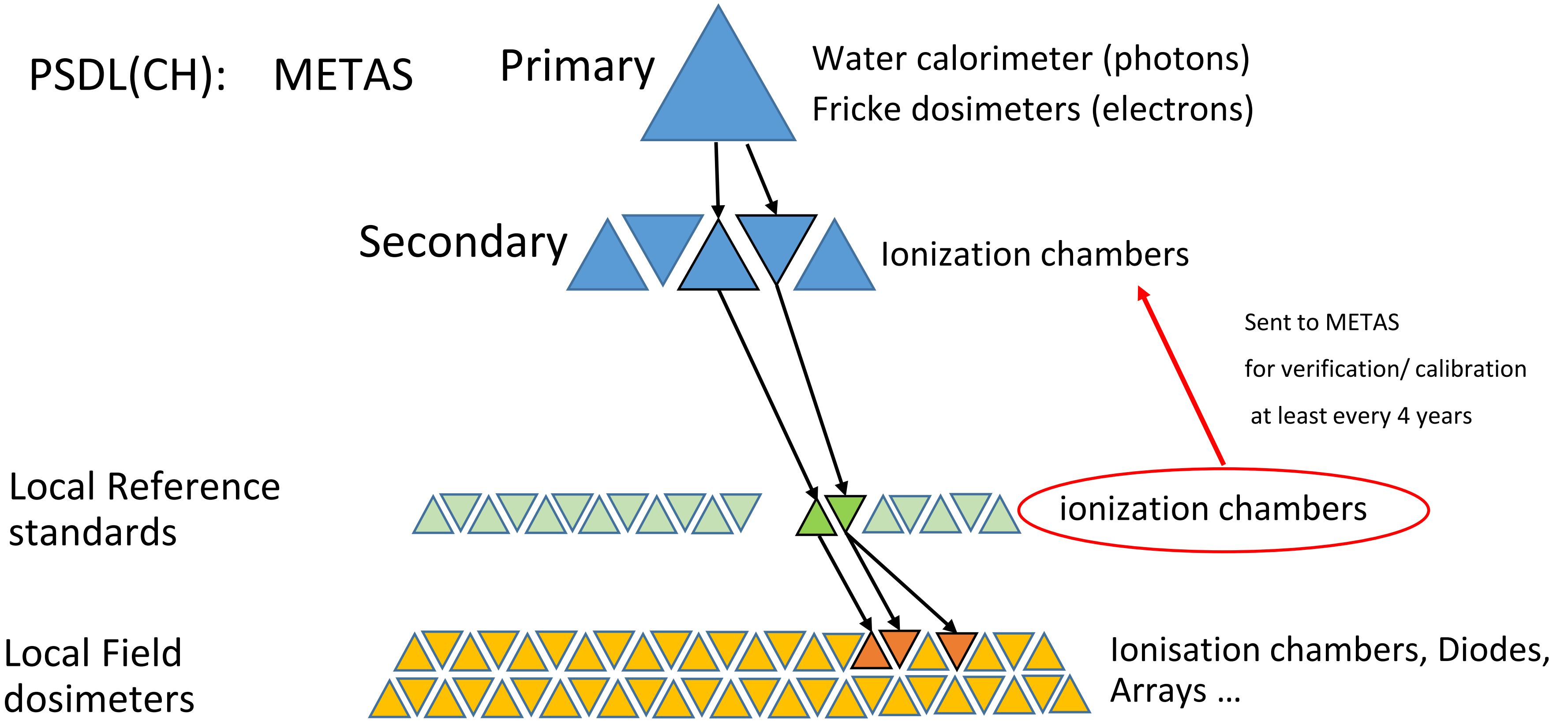
METROLOGICAL TRACEABILITY

Primary Standards

- Primary standards are instruments of the highest metrological quality that permit determination of the unit of a quantity from its definition, the accuracy of which has been verified by comparison with standards of other institutions of the same level.
- Primary standards are realized by the *primary standards dosimetry laboratories* (PSDLs) in about 20 countries worldwide.
- Regular international comparisons between the PSDLs, and with the International Bureau of Weights and Measures (BIPM, Paris), ensure international consistency of the dosimetry standards.

METROLOGICAL TRACEABILITY

Metrological pyramid



*Metrological traceability is defined as "the property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty".

In simple terms, metrological traceability is a direct link between a result of a measurement made in the field and a result of the best possible measurement made in a calibration laboratory.

* World Meteorological Organization, Commission for Instruments and Methods of Observation

Calorimetry

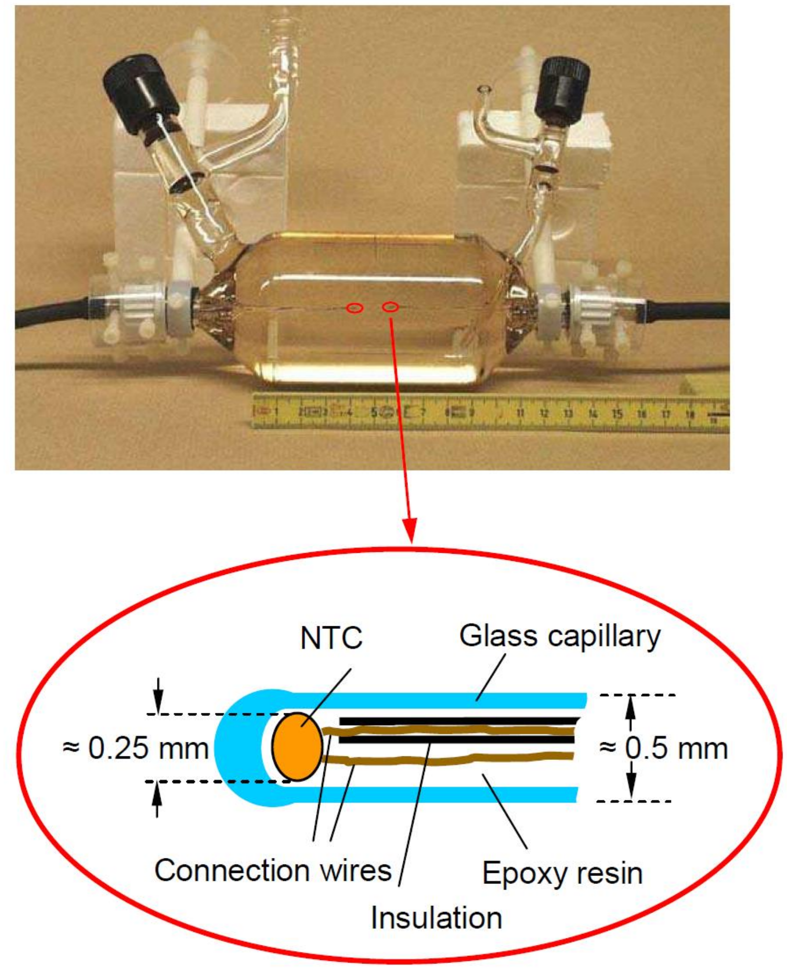
METROLOGICAL TRACEABILITY

Water Calorimetry

- Calorimetry is the measurement of heat quantities that are linked to biological, chemical or physical processes.
- Most direct measurement of absorbed dose $D_w \sim \Delta T$
- Calorimetry is the primary standard for MV-Photon beams at most PSDLs

$$D_w = c_w \cdot \Delta T \cdot hd$$

D_w: *Absorbed dose to water*
c_w: *specific heat capacity of Water*
4.204 J/(kg·K)
ΔT: *Temperature increase*
hd: Heat defect (practically 1)



- Glass vessel filled with ultra pure Water + two miniature temperature probes (NTC-thermistors)

PSDL: Primary Standard Dosimetry Laboratories – METAS for Switzerland

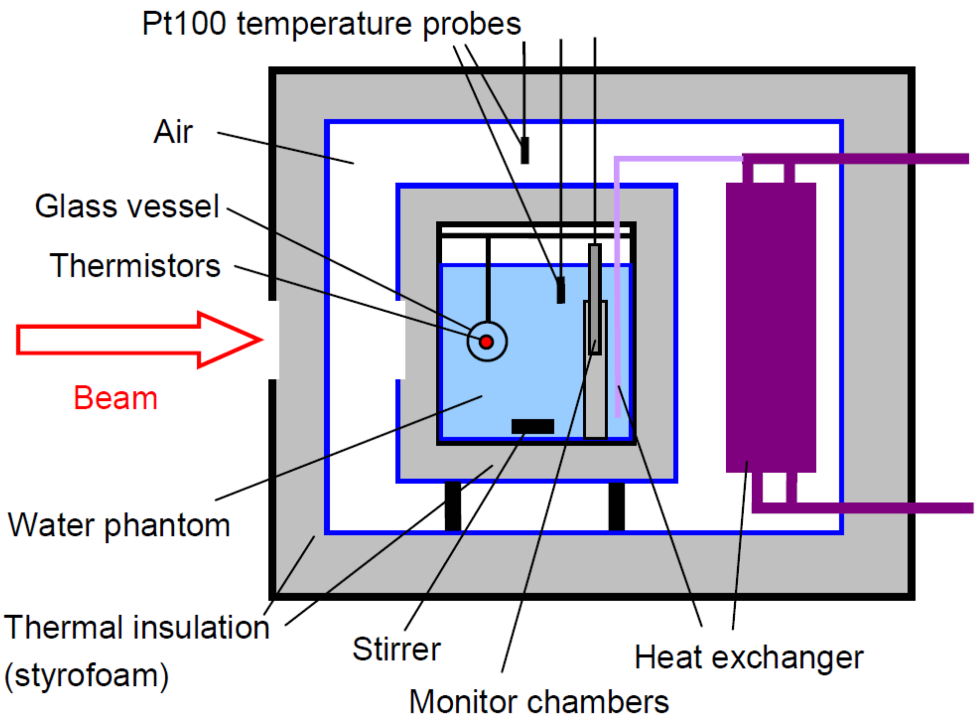
From Dosimetry / 3.9.2007 / Dr. M. Sassowsky

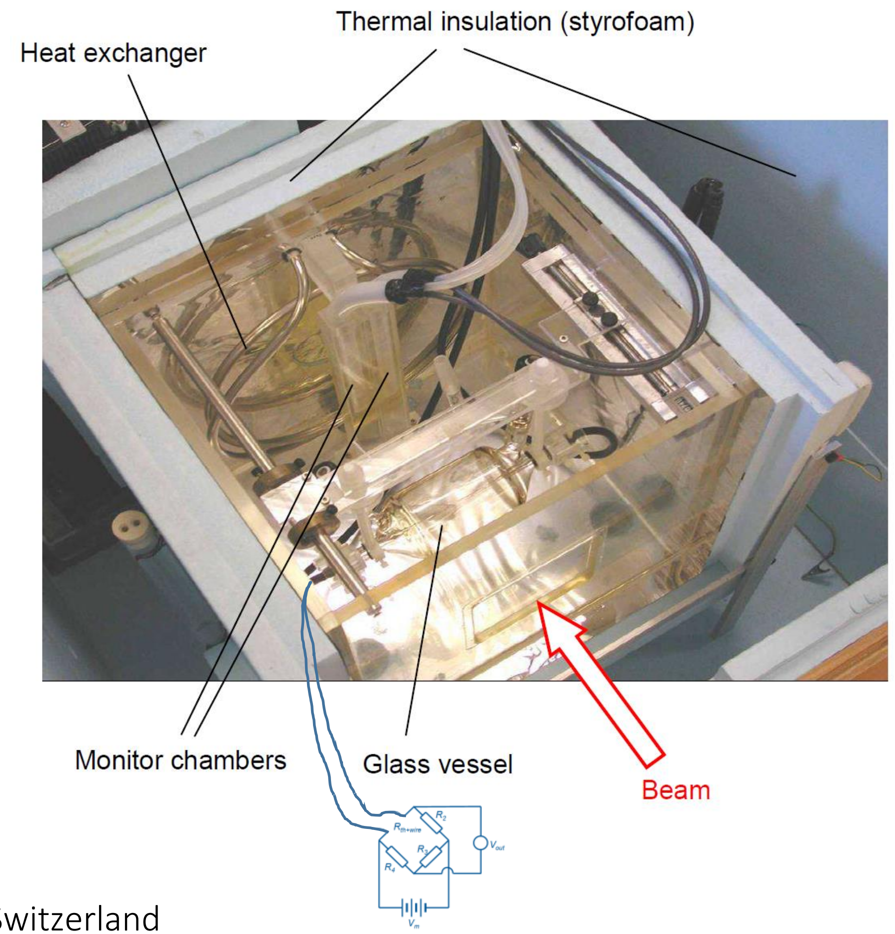
METROLOGICAL TRACEABILITY

Water Calorimetry

- Glass vessel embedded in a waterphantom
- T=4°C stabilized

- Glass vessel filled with ultra pure Water + two miniature temperature probes
- NTC: Thermistor

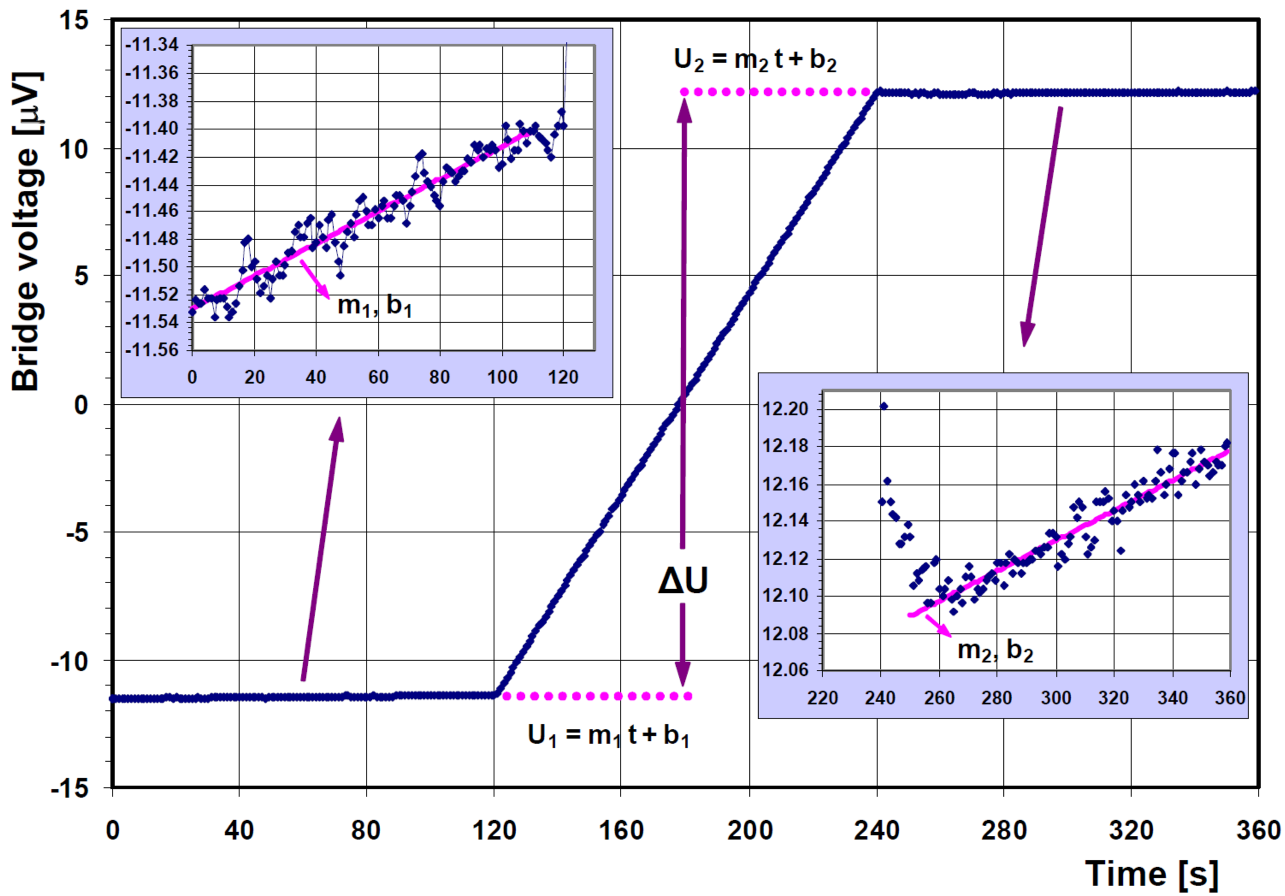




PSDL: Primary Standard Dosimetry Laboratories – METAS for Switzerland

METROLOGICAL TRACEABILITY

Water Calorimetry



- $\Delta U = 24 \mu V$ $\Delta T = 1.2$ mK
- Measurement uncertainty ^{60}Co: 0.41% (k=1)

METROLOGICAL TRACEABILITY

Water Calorimetry

Advantages of Water calorimetry

- Most direct method to measure absorbed dose
- Independent of type and energy of radiation

Disadvantages

- (possible) heat defect
- Not applicable in the clinic
- Very small temperature variation even for high doses in RT
- frequent checking and calibration of components

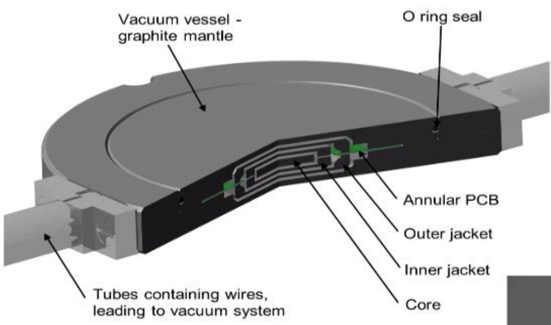
$$D_w = c_w \cdot \Delta T \cdot hd$$

Graphite as an alternative to Water

METROLOGICAL TRACEABILITY

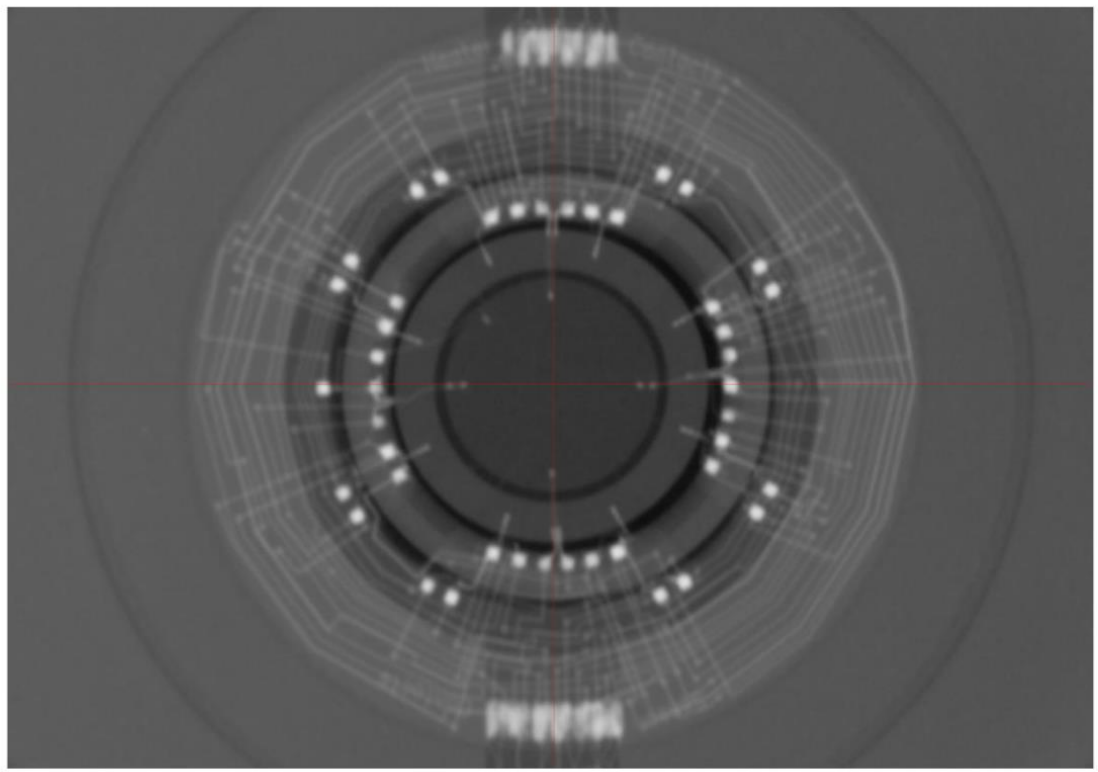
Graphite Calorimetry

NPL National Physical Laboratory



Graphite Calorimeter at National Physics Laboratory

Teddington, England



National Measurement Office

METROLOGICAL TRACEABILITY

Graphite Calorimetry

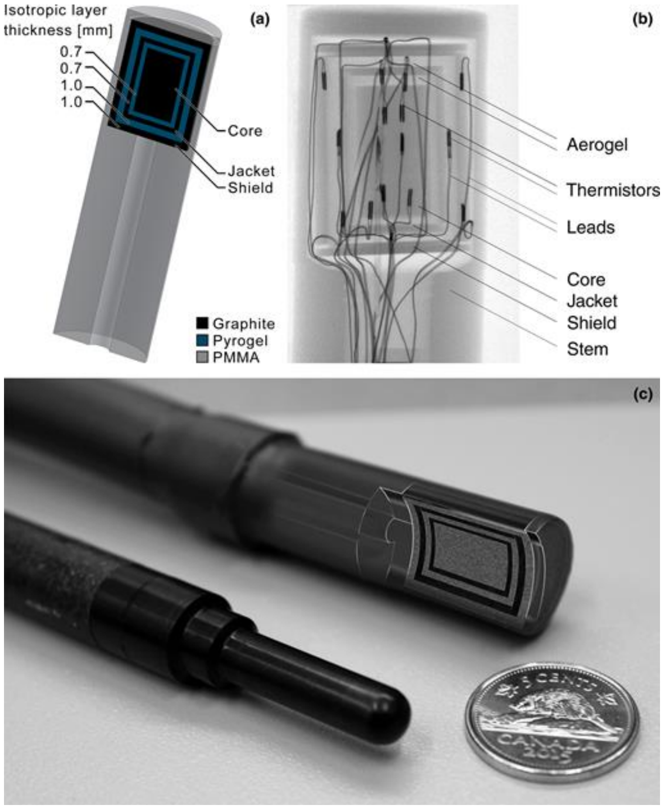
<u>Advantages of Graphite calorimetry</u>

- once built, easy setup
- no heat defect
- larger ΔT per Gray

$$D_c = c_c \cdot \Delta T$$

<u>Disadvantages</u>

- Conversion to D_w ($D_w = C_{scaling} \cdot D_c$)
- ~~As Water calorimeters not applicable in the clinic~~



Aerrow: A probe-format graphite calorimeter for absolute dosimetry of high-energy photon beams in the clinical environment

Medical Physics, Volume: 45, Issue: 1, Pages: 414-428, First published: 13 November 2017, DOI: (10.1002/mp.12669)

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A Handbook for Teachers and Students

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657 pages ¦ 137 figures ¦ € 65.00 ¦ Date published: 2005

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Description

This publication is aimed at students and teachers involved in programmes that train professionals for work in radiation oncology. It provides a comprehensive overview of the basic medical physics knowledge required in the form of a syllabus for modern radiation oncology. It will be particularly useful to graduate students and residents in medical physics programmes, to residents in radiation oncology, as well as to students in dosimetry and radiotherapy technology programmes. It will assist those preparing for their professional certification examinations in radiation oncology, medical physics, dosimetry or radiotherapy technology. It has been endorsed by several international and national organizations, and the material presented has already been used to define the level of knowledge expected of medical physicists worldwide.

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