PDD - Percentage depth dose

SSD -

IAEA Training Material: Radiation Protection in Radiotherapy

Radiation Protection in Radiotherapy



Dosimetry and Equipment

IAEA Training Material: Radiation Protection in Radiotherapy

- Radiation dose delivered to the target and surrounding tissues is one of the major predictors of radiotherapy treatment outcome (compare part III of the course). It is generally assumed that the dose must be accurately delivered within +/-5% of the prescribed dose to ensure the treatment aims are met.

Delivery of dose within +/-5%

- Sources of uncertainty:
  - Absolute dosimetry/calibration
  - Relative dosimetry (%depth dose, profiles, output factors)
  - Treatment planning (estimated uncertainty of the order of +/- 2%)
  - Machine performance on the day (+/- 2%)
  - Patient set-up and movement (+/- 3%)

1. Absolute and relative dosimetry

- **Absolute dosimetry** is a technique that yields information directly on absorbed dose in Gy. This absolute dosimetric measurement is also referred to as calibration. All further measurements are then compared to this known dose under reference conditions, this means
- **relative dosimetry** is performed. In general no conversion coefficients or correction factors are required in relative dosimetry since it is only the comparison of two dosimeter readings, one of them being in reference conditions.

Absolute dosimetry

- Required for every radiation quality once
- Determination of absolute dose (in Gy) at one reference point in a phantom
- Well defined geometry (example for a linear accelerator measurements in water, at 100cm FSD, 10x10cm^2 field size, depth 10cm

1. Calibration

- Determine absolute dose in Gy at one reference point in the beam
- Determines the beam on time or the number of monitor units required to deliver a certain dose
- Very important - if this is wrong, everything will be wrong

Optimization of protection in therapeutic exposure

- BSS appendix II.18. "Registrants and licensees shall ensure that:
  - (a) exposure of normal tissue during radiotherapy be kept as low as reasonably achievable consistent with delivering the required dose to the planning target volume, and organ shielding be used when feasible and appropriate; ...
  - (e) the patient be informed of possible risks."

Important note on optimization

1. The dose [redacted] to normal tissues shall be kept as low as reasonable achievable
2. In practice, the dose to the target in radical radiotherapy shall be as high as possible to maximize the chances of tumor control

Mis-calibration is an important contributor to accident in EBT

- **Calibration of beams**
  - **Accidents due to mistakes in the determination of the dose rate caused overdosage to as many as 115, 207, 426 patients... by as much as 60%**

Accidents due to calibration mistakes

- **Contributing factors to accidents**
  - **Lack of understanding of beam calibration, certificates, conversion factors and dosimetry instruments... lack of training and expertise with radiotherapy physics**
  - **Lack of redundant and independent determination of the absorbed dose (mistakes were not detected)**
  - **Lack of formal procedures for communication and change of personnel**

Accidents due to calibration mistakes

- **Contributing factors to accidents**
  - **In one of the cases, for 22 months, there was no verification of the beam; the physicist was devoted to a new accelerator and "ignored" the Co-60 unit (There was a lack of revision of the staff needs when a new accelerator was installed)**



BSS appendix II.19.

- "Registrants and licensees shall ensure that:
  - (a) the calibration of sources used for medical exposure be traceable to a Standards dosimetry laboratory; ..."

BSS appendix II.19.

- "Registrants and licensees shall ensure that: ...



(b) radiotherapy equipment be calibrated in terms of radiation quality or energy and either absorbed dose or absorbed dose rate at a predefined distance under specified conditions, e.g. following the recommendations given in IAEA Technical Reports Series No. 277 [20];

..."

Calibration

- Determination of the dose at a reference point - correlation of treatment time or 'monitor units' with absolute dose
- Absolute dosimetry required:

Dose = const * Detector Signal

- Const. must be well known and fundamental:
  - Calorimetry
  - Ionometry W/e
  - Chemical dosimetry g

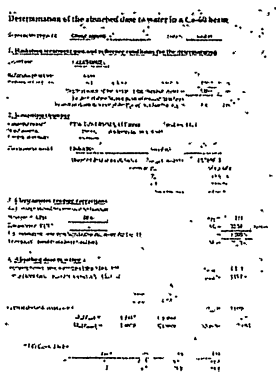
Calibration protocols

- Calibration is a complex process requiring an expert in radiation oncology physics
- There are many protocols which can provide guidance
  - international (eg IAEA TRS 277 or TRS 398)
  - national (usually developed by the national medical physics association) - eg. AAPM TG 21, AAPM TG 51, DIN 68, ...

Calibration protocols

- It is essential to follow ONE protocol
- It is essential to follow the protocol BY THE LETTER - there is no room for error...





Forms are available

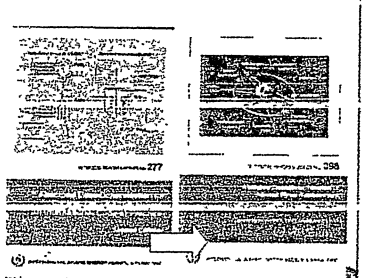
- Very helpful for guidance
- Available for most protocols
- Here shown for IAEA TRS 398

Calibration protocols

- There has been a development from protocols based on calibrations at the national standard lab in air as air KERMA or exposure to calibration in terms of absorbed dose to water...
- This development has been in parallel at the IAEA and many national associations (eg AAPM)

Move to absorbed dose to water calibration

- Follows improved capability of national standard labs
- Same in US by moving from AAPM TG21 (1983) to AAPM TG51 (2000)

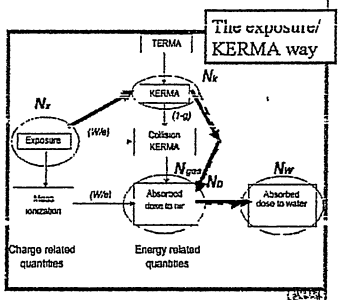


Which protocol to use?

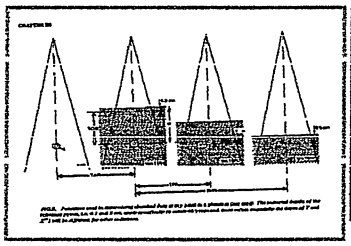
- Depends on how the ionisation chamber has been calibrated in the standards lab. If one has an air KERMA calibration factor (N_K) or an exposure factor (N_X), TRS-398 CANNOT be used...
- If also the dose to water factor (N_{Dw}) can be provided by the laboratory, TRS 398 can be used.

Advantages of absorbed dose calibration

- Easier for the user
- Less factors required
- Get N_{Dw} directly - only conversion for beam quality required



A second note: Calibration can link the absolute dose to a variety of different reference conditions



It is essential to know what your reference conditions are. (They are typically linked to the treatment planning system in use)

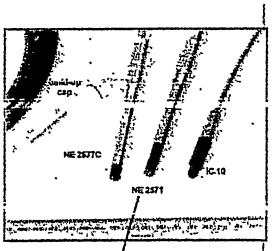
BSS appendix II.19.

- "Registrants and licensees shall ensure that: ...
  - (e) the calibrations be carried out at the time of commissioning a unit, after any maintenance procedure that may have an effect on the dosimetry and at intervals approved by the Regulatory Authority."

The maximum interval in practice for re-calibration is 1 year - less if there is any indication of problems

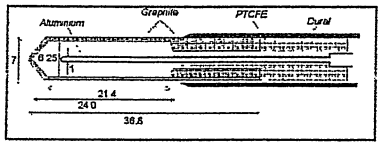
Absolute dosimetry

- Can be done in principle using calorimetry, chemical dosimetry or ionization chambers
- For radiotherapy practice all protocols are based on ionization chambers



Tools required for calibration

- In practice a Farmer type ionisation chamber - air volume 0.6cc for photons and high energy electrons

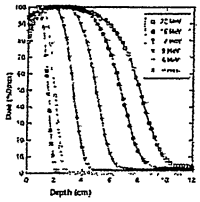


Plane parallel chamber

- Required for low energy electrons (<5MeV) and recommended for electrons with energy below 10MeV due to steep dose gradients



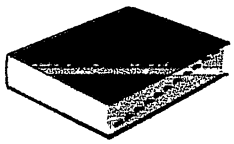
PTW Markus chamber



Ionization Chamber reading require correction for

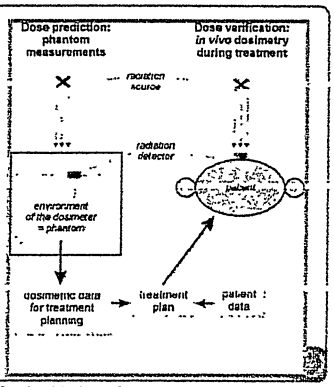
- Air pressure require an accurate barometer for calibration purposes
  - an error of 10 mBar will give an error of 1% in the calibration
- Temperature: accurate thermometer
  - an error of 3 degrees centigrade will give an error of 1% in the calibration

Calibration Records



- BSS appendix II.32. "Registrants and licensees shall keep and make available, as required, the results of the calibrations and periodic checks of the relevant physical and clinical parameters selected during treatments."

There are multiple objectives for dose measrue-ments in radiotherapy practice



Clinical Dosimetry

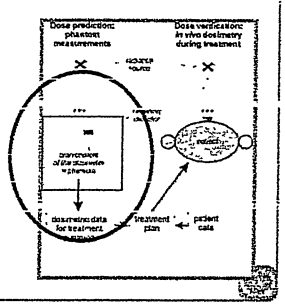
- BSS appendix II.20. "Registrants and licensees shall ensure that the following items be determined and documented:

...

(b) for each patient treated with external beam radiotherapy equipment, the maximum and minimum absorbed doses to the planning target volume together with the absorbed dose to a relevant point such as the centre of the planning target volume, plus the dose to other relevant points selected by the medical practitioner prescribing the treatment; ..."

In radiotherapy practice:

- This means dose measurements are required as
  - as dose determination for the treatment of individual patients
  - input for treatment planning systems



Dose measurement for individual patients

- In vivo dosimetry
- Determination of output for electron cut-outs or compensators
- Assessment of dose distribution in complex treatments (eg IMRT)

Relative dosimetry

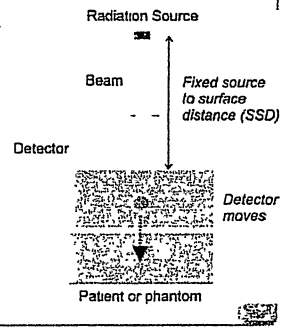
- Relates dose under non-reference conditions to the dose under reference conditions
- Typically at least two measurements are required:
  - one in conditions where the dose shall be determined
  - one in conditions where the dose is known

Examples for relative dosimetry

- Characterization of a radiation beam:
  - percentage depth dose, tissue maximum ratios or similar
  - profiles
- Determination of factors affecting output
  - field size factors, applicator factors
  - filter factors, wedge factor
  - patient specific factors (eg electron cut-out)

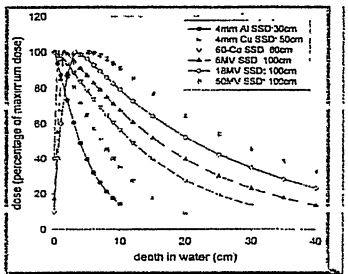
Percentage depth dose measurement

- Variation of dose in a medium (typically water) with depth
- Includes attenuation and inverse square law components



Percentage depth dose

Relates dose at different depth in water (or the patient) to the depth at the dose maximum - note that the y axis is relative!!!

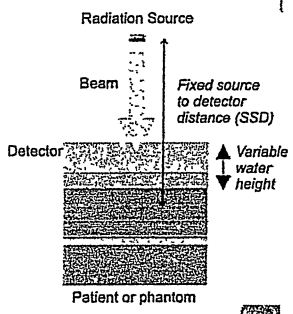


TAR, TMR, TPR

- Relative dosimetry for isocentric treatment set-up (compare part V)
- All can be converted into percentage depth dose
  - TAR = ratio of dose in phantom with x cm overlaying tissue to dose at the same point in air
  - TMR = ratio of dose with x cm overlaying tissue to dose at dose maximum
  - TPR as TMR but as a ratio to dose at a reference point (eg 10cm overlaying tissue)

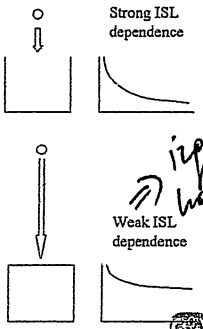
TMR, TPR

- Mimics isocentric conditions
- TMR is a special case of TPR where the reference phantom depth is depth of maximum dose



PDD and TMR

- Percentage depth dose (PDD) changes with distance of the patient to the source due to variations in the inverse square law (ISL), TAR, TMR and TPR do not.

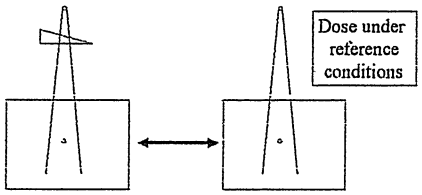


izgleda kot večji MV

Output factors

- Compare dose with dose under reference conditions
  - different field sizes
  - wedge factor
  - tray factor
  - applicator factor
  - electron cutout factor

Example: wedge factor

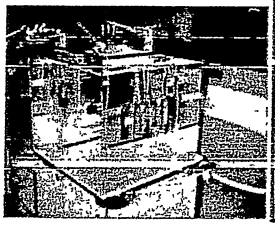


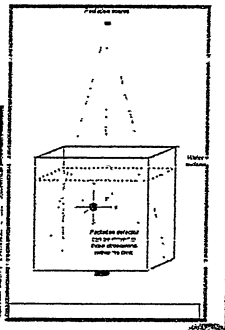
Could also involve different field sizes and/or different depths of the detector in the phantom

2. The dosimetric environment:

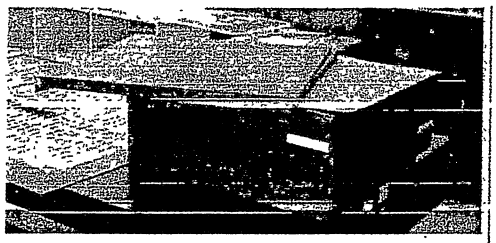
- Phantoms:
  - A phantom represents the radiation properties of the patient and allows the introduction of a radiation detector into this environment, a task that would be difficult in a real patient.
  - A very important example is the scanning water phantom.
  - Alternatively, the phantom can be made of slabs of tissue mimicking material or even shaped as a human body.

Scanning water phantom





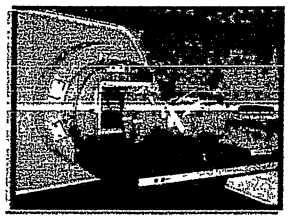
Slab phantoms



Tissue equivalent materials

- Many specifically manufacturer materials such as solid water (previous slide), white water, plastic water, ...
- Polystyrene (good for megavoltage beams, not ideal for low energy photons)
- Perspex (other names: PMMA, plexiglass) - tissue equivalent composition, but with higher physical density - correction is necessary.

Anthropomorphic phantom



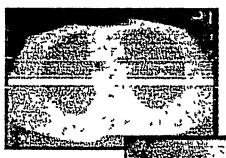
Whole body phantom: ART

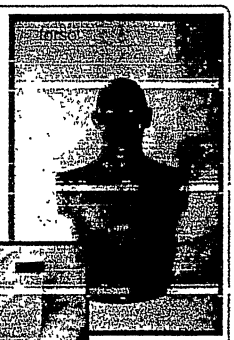
Allows placement of radiation detectors in the phantom (shown here are TLDs)



Includes inhomogeneities

RANDO phantom



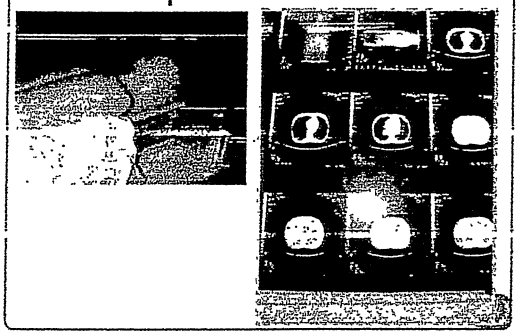


CT slice through lung



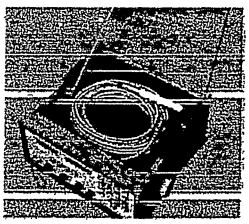
Head with TLD holes

Pediatric phantom



Ionization chamber
Thermoluminescence dosimetry
Film
Semiconductors

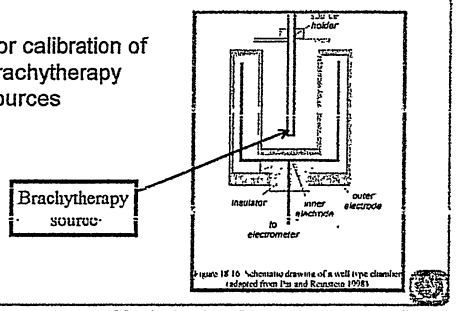
Ionization Chambers



- Farmer 0.6 cc chamber and electrometer
- Most important chamber in radiotherapy dosimetry

Well type ionization chamber

- For calibration of brachytherapy sources



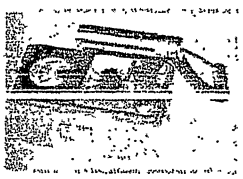
Geiger Mueller Counter

- Not a dosimeter - just a counter of radiation events
- Very sensitive
- Light weight and convenient to use
- Suitable for miniaturization



Geiger-Muller (GM) Devices

- Useful for
  - area monitoring
  - room monitoring
  - personnel monitoring

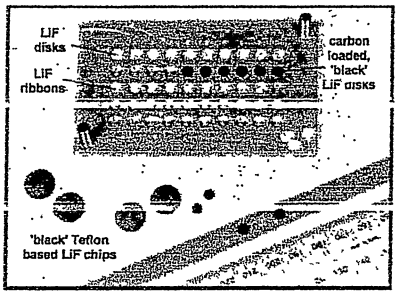


- Care required in regions of high dose rate or pulsed beams as reading may be inaccurate

Thermoluminescence dosimetry (TLD)

- Small crystals
- Many different materials
- Passive dosimeter - no cables required
- Wide dosimetric range (μGy to 100s of Gy)
- Many different applications

Various TLD types



What can one expect...

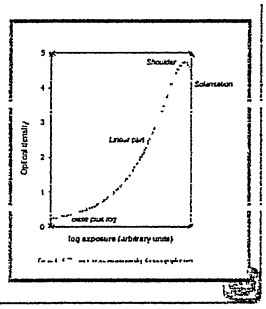
- Reproducibility: single chip ± 2% (0.1Gy, 1SD)
- Accuracy (4 chips standard, 2 chips measurement) ± 3% (0.1Gy, 95% confidence)
- about 30 minutes per measurement...

Radiographic film

- Reduction of silver halide to silver
- Requires processing ---> problems with reproducibility
- Two dimensional dosimeter
- High spatial resolution
- High atomic number ---> variations of response with radiation quality

Film: dose response

- Evaluation of film via optical density
- OD = log (I_0 / I)
- Densitometers are commercially available



Radiographic film dosimetry in practice

- Depends on excellent processor QA
- Commonly used for demonstration of dose distributions
- Problems with accuracy and variations in response with X-ray energy



Radiographic film as a radiotherapy dosimeter

Advantages

- Two dimensional
- Widely available
- Relatively cheap
- Provides a dose record
- Highly sensitive

Disadvantages

- Depends on developing
- Not very accurate
- Could be too sensitive

Semiconductor Devices

- Diodes
- MOSFET detectors

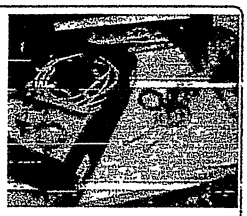


Diodes for water phantom measurements

Diodes and other Solid State Devices

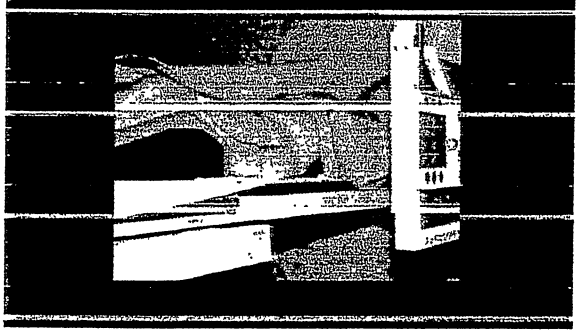
- Advantages
  - direct reading
  - sensitive
  - small size
  - waterproofing possible
- Disadvantages
  - temperature sensitive
  - sensitivity may change –> re-calibration necessary
  - regular QA procedures need to be followed

In vivo dosimetry

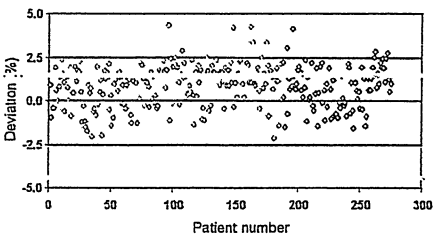


- Measurement of entrance and exit dose, if possible.
- Determination of the dose delivered to the reference point.
- Comparison of measured dose with prescribed dose.
- Investigation if action level is exceeded.
- Analysis of EPID image to verify position of diodes.

Prostate treatment showing patient with a diode and EPID



Results IVD prostate treatments



Sources of error discovered by means of IVD during CRT of prostate cancer

- Wrong SSD + PDD correction on the wedge factor for the simultaneous boost technique.
- Shift of the dose specification point to the thinner part of the wedge.
- Dose distribution calculated on a non-CT basis.
- Higher output for the lateral fields of one accelerator.
- Position of the dose specification point behind the dense part of the femoral head.

IMRT / 3D-CRT hypothesis

A lower dose to normal tissue (organs at risk)

⇓

allows a higher dose to the target volume for the same level of accepted toxicity

⇓

results in improvement of local control

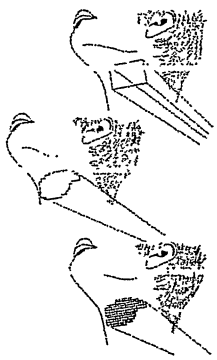
⇓

yields improvement of (disease free) survival

Key differences between:

- Conventional radiotherapy (RT)
- Conformal radiotherapy (CFRT, CRT, 3D-CRT)
- Intensity-modulated radiotherapy (IMRT).

(From: Steve Webb, Intensity- Modulated Radiation Therapy, IoP publishing, 2001)

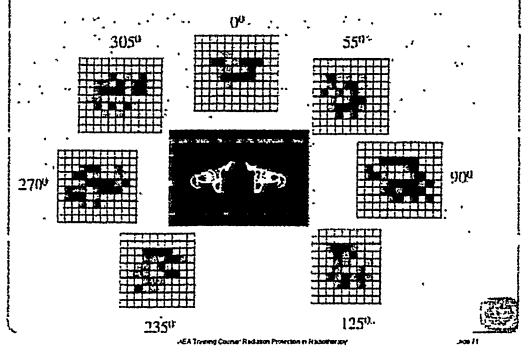


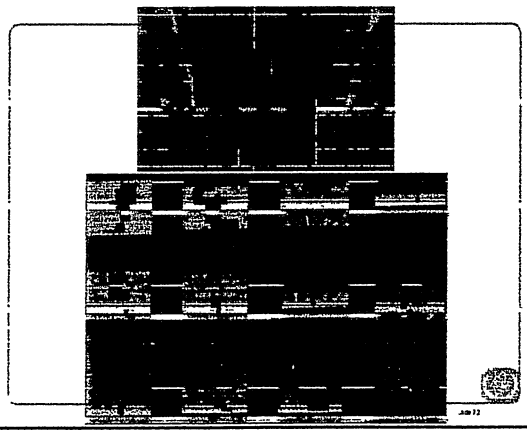
Definition

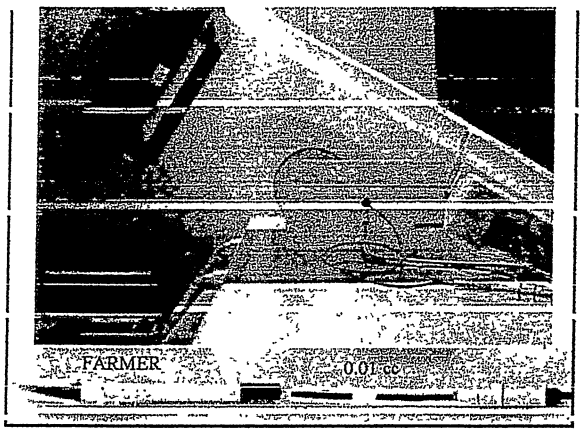
Intensity-modulated radiotherapy (IMRT):

An advanced form of 3D-conformal radiotherapy (3D-CRT) that uses non-uniform radiation beam intensities incident on the patient that have been determined using various computer-based optimization techniques.

(Report of the IMRT Collaborative Working Group: Int J Radiat Oncol Biol Phys 51: 880 – 914, 2001)







ΕΠΙΒΕΒΑΙΩΣΗ ΠΛΑΝΟΥ ΘΕΡΑΠΕΙΑΣ IMRT

ΕΠΩΝΥΜΟ : .....
ΟΝΟΜΑ : .....
ΑΡΙΘΜΟΣ ΠΛΑΝΟΥ: 2599
ΘΕΡΑΠΕΙΑ : προστατης

ΠΛΑΝΟ ΘΕΡΑΠΕΙΑΣ

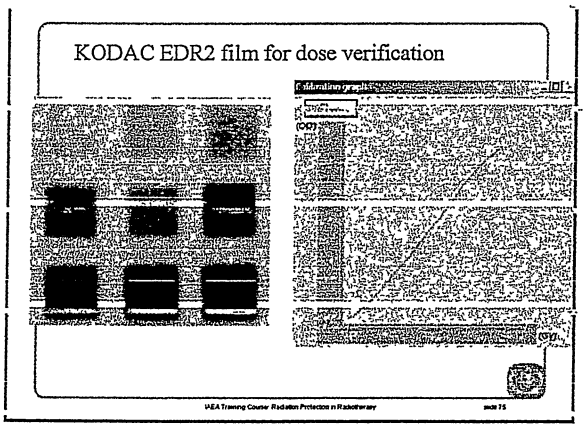
		Gantry	Couch	Segments	MU
prescribed dose	πεδία 1.	270	0	9	308
2 Gy/Fr	2.	0	0	10	299
	3.	90	0	8	305
	5.	210	0	8	151
	6.	60	0	9	280
	7.	300	0	10	247

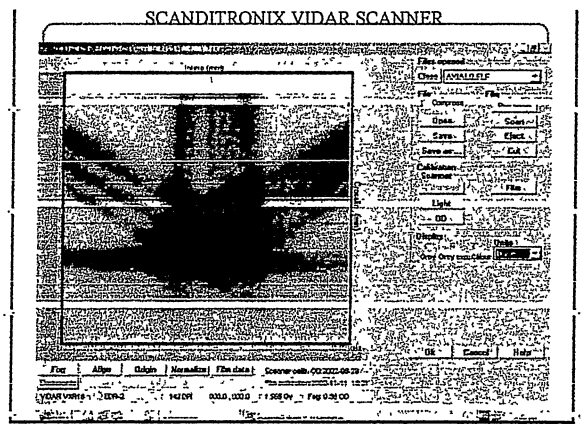
ΑΠΟΛΥΤΗ ΔΟΣΙΜΕΤΡΙΑ

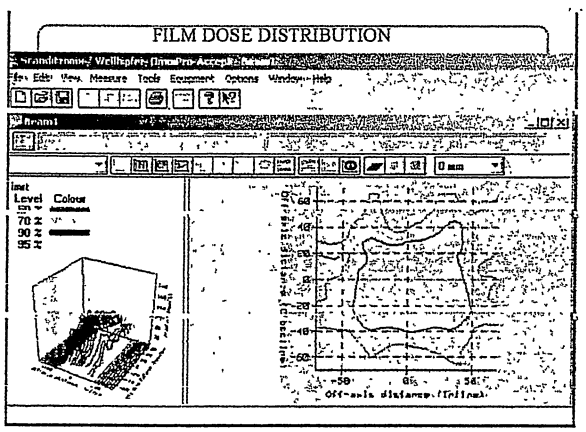
ΕΠΙΒΕΒΑΙΩΣΗ ΠΛΑΝΟΥ ΘΕΡΑΠΕΙΑΣ

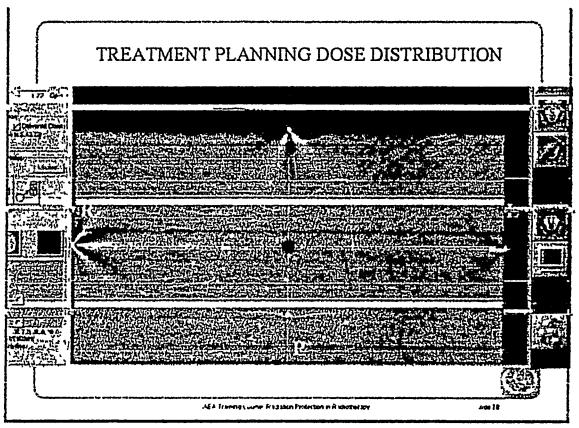
Hybrid plan: Hybrid

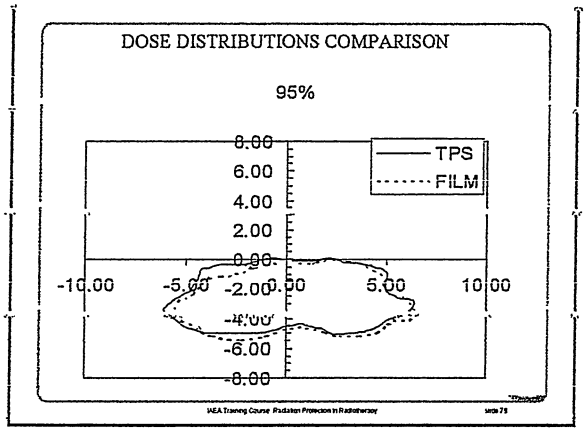
	ISOCENTER		RECTUM	
Calculated dose	189	cGy	98	cGy
Measured dose	191	cGy	100.5	cGy
Απόκλιση	1	%	2	%

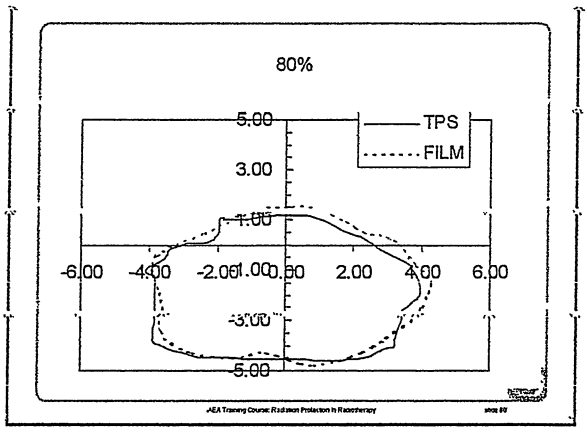


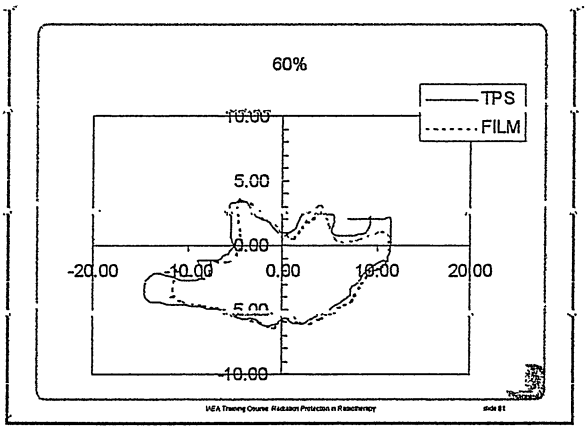


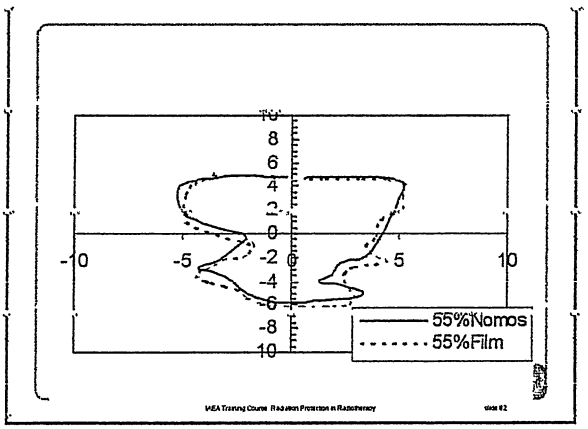


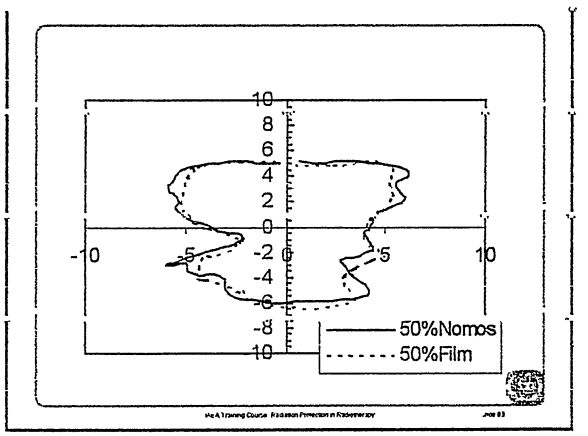


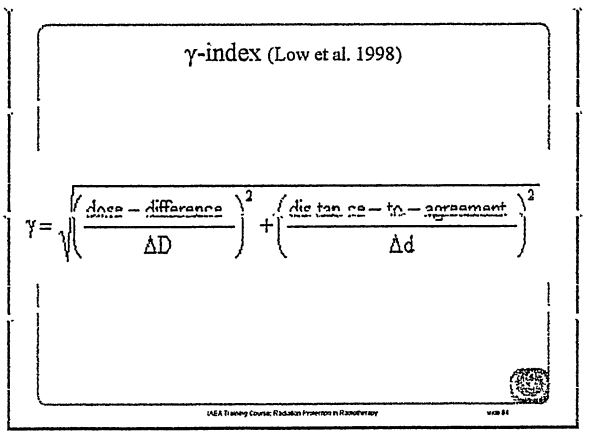

DOSE DISTRIBUTIONS COMPARISON
95%
TPS
FILM

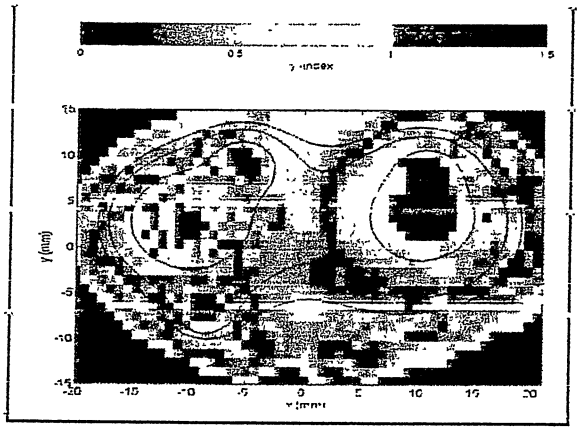

80%
TPS
FILM


60%
TPS
FILM


55%Nomos
55%Film


50%Nomos
50%Film


γ-index (Low et al. 1998)
γ = √((dose − difference / ΔD)² + (distance − to − agreement / Δd)²)



Polymer gel dosimetry

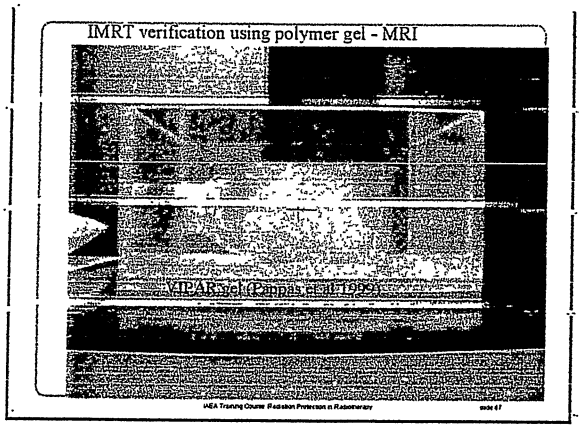
Polymer gels constitute a gelatine matrix in which monomers are embedded

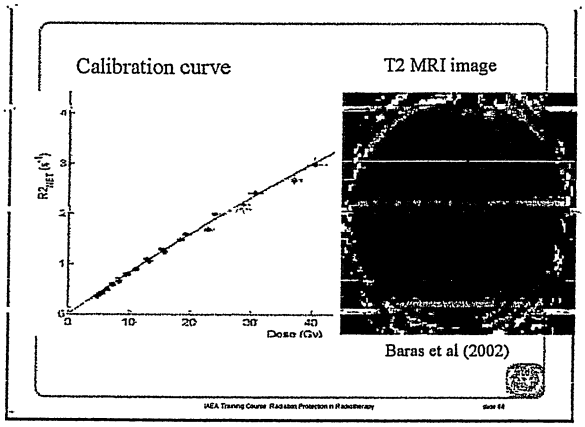
Upon irradiation polymerization occurs which is directly related to the absorbed dose

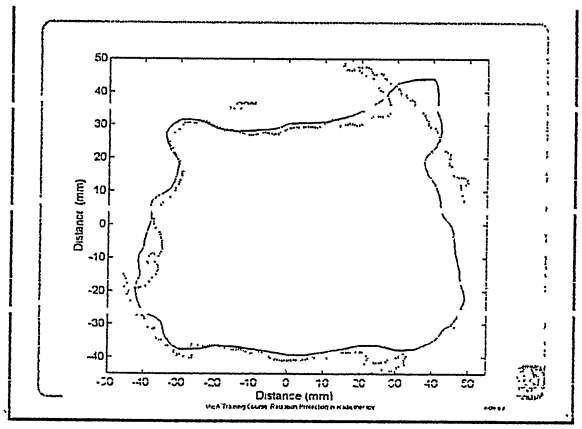
The process results in the change of not only chemical but also physical properties of the irradiated gel such as optical opacity and NMR relaxation rates (T2).

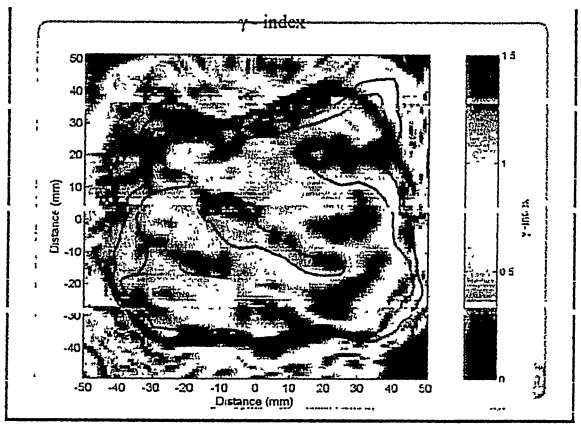
T2 images can be converted to dose maps using appropriate calibration

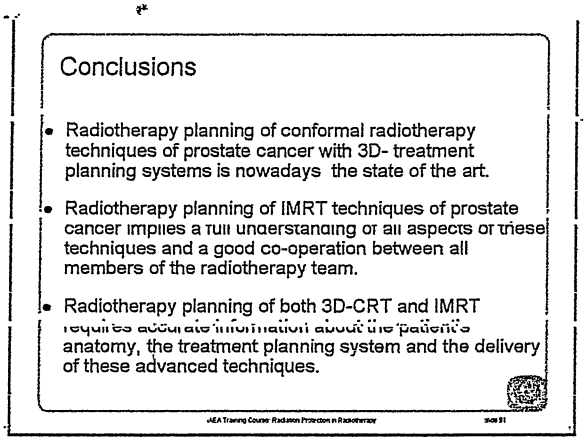
3 D dose verification tool

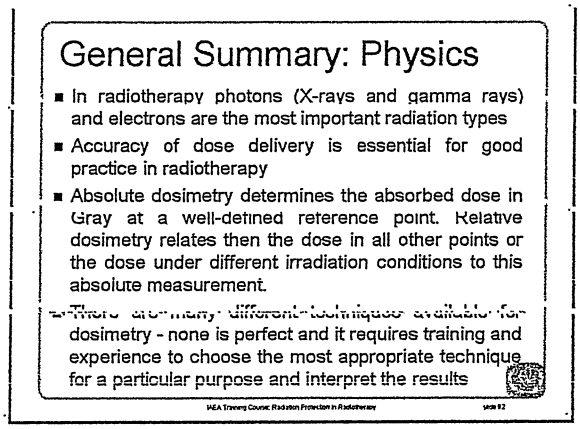









Conclusions
• Radiotherapy planning of conformal radiotherapy techniques of prostate cancer with 3D- treatment planning systems is nowadays the state of the art.
• Radiotherapy planning of IMRT techniques of prostate cancer implies a full understanding of all aspects of these techniques and a good co-operation between all members of the radiotherapy team.
• Radiotherapy planning of both 3D-CRT and IMRT requires accurate information about the patient's anatomy, the treatment planning system and the delivery of these advanced techniques.


General Summary: Physics
■ In radiotherapy photons (X-rays and gamma rays) and electrons are the most important radiation types
■ Accuracy of dose delivery is essential for good practice in radiotherapy
■ Absolute dosimetry determines the absorbed dose in Gray at a well-defined reference point. Relative dosimetry relates then the dose in all other points or the dose under different irradiation conditions to this absolute measurement.
■ There are many different techniques available for dosimetry - none is perfect and it requires training and experience to choose the most appropriate technique for a particular purpose and interpret the results