

Three-Dimensional MRI-Based FXO Gel Dosimetry for Verification of HDR Venezia Applicator Cervix Brachytherapy

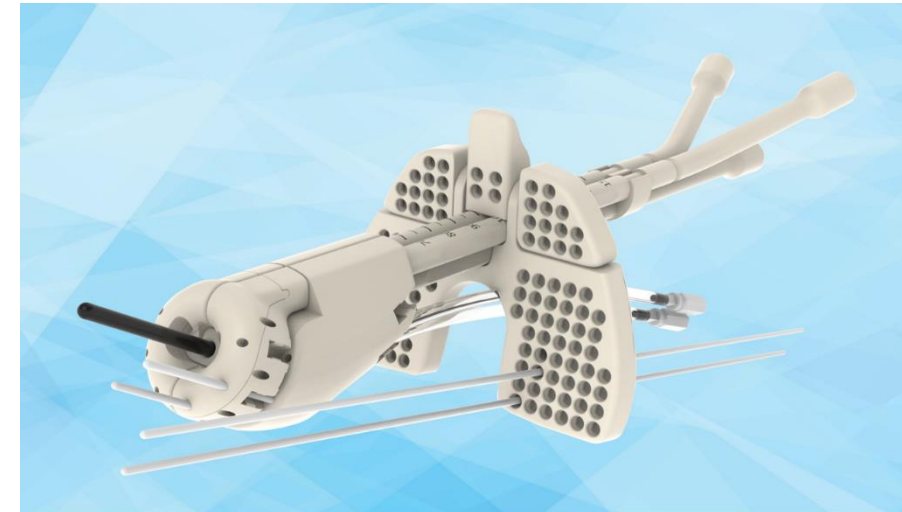
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The Clinical Problem

- HDR brachytherapy is essential for the curative treatment of locally advanced cervical cancer
 - Uses highly non-uniform dose near targets and organs at risk
- Hybrid applicators (e.g. Venezia applicator) improve target coverage – but add geometric and dosimetric complexity
- Conventional QA is limited to point or planar measurements
 - Poorly suited to the steep 3D dose gradients in gyne HDR



Experimental verification of the delivered 3D dose distribution remains a challenge!

Past HDR Dosimetry Efforts

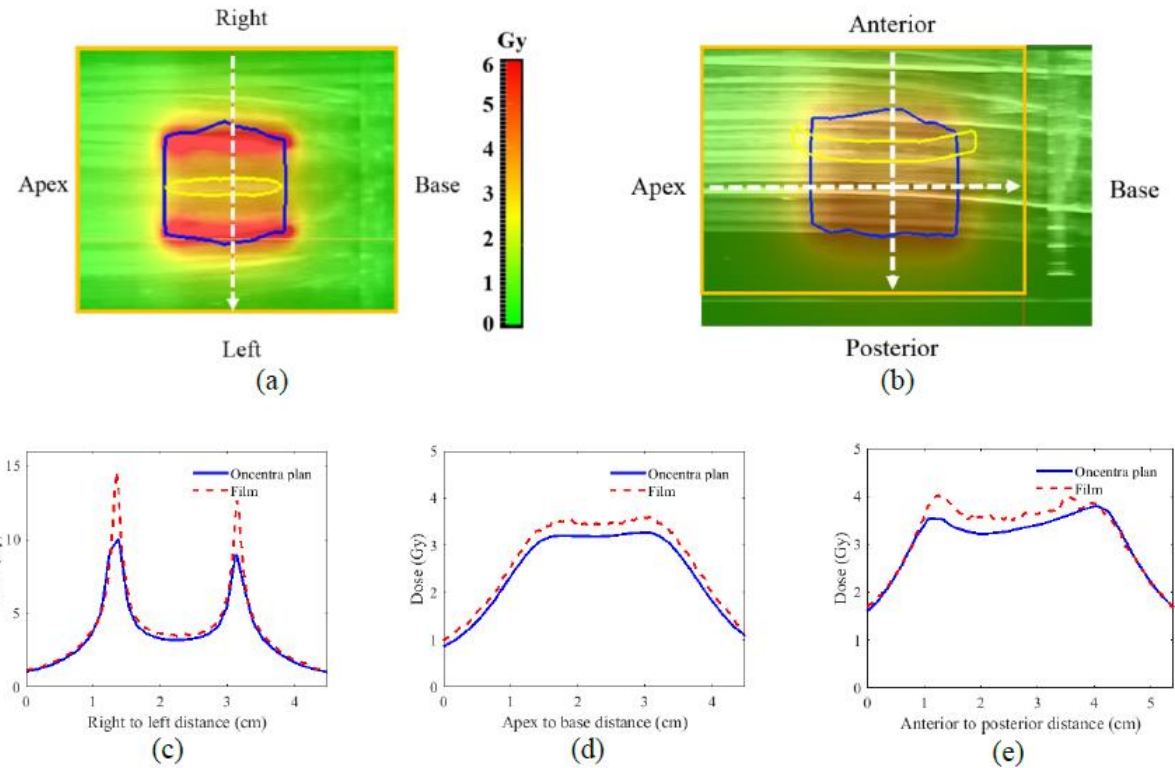
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Validation of an ultrasound-guided prostate HDR brachytherapy dose delivery

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“Pseudo-3D”

Why MRI-based FXO gel dosimetry?

Volumetric

- True 3D dose measurement
- High spatial resolution matched to steep gradients
- Captures the whole surrounding dose cloud



FXO Gel

- Simple preparation, inexpensive ingredients
- MRI-compatible

MRI Readout

- Artefact-free with applicators in place
- Optical CT suffers reconstruction artefacts near needles
- Quantitative T1 mapping

The Clinical Problem – Applicator Commissioning



IMAGING OF HDR BRACHYTHERAPY DOSE DISTRIBUTIONS USING NMR FRICKE-GELATIN DOSIMETRY

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The application of NMR Fricke-gelatin dosimetry to the imaging of dose distributions around high dose rate (HDR) radioactive Ir-192 seeds in brachytherapy is presented. The duration of the irradiations required to give changes of the Fricke-gelatin NMR characteristics, which were readily detected by the magnetic resonance imager, typically ranged from 4 to 25 min for single source and multiple source (33 : catheters) geometries, respectively. A fast approach for determining radiis a calibration curve is described. NMR Fricke-gel dosimetry is shown to distributions from brachytherapy sources.

Keywords: Radiation dosimetry; MRI based dosimetry; Fricke-gel; Br

The marriage of brachytherapy with remote after-loaders and NMR-based dosimetries shows promise. The 3-D MRI measurements can assist in the evaluation of the complete clinical irradiation procedure from treatment planning through to dose delivery. Also, with the development of improved techniques and new dosimeter materials,²³ MR dosimetry may be useful in basic brachytherapy dosimetry research. For example, the influence of inhomogeneities such as air or bone on the dose distributions around sources,⁹ and the effects of source transit time between positions,²⁴ could be explored with MR-based techniques.

Study Objective

Apply MRI-based FXO gel dosimetry as an end-to-end verification tool for clinically relevant HDR cervix brachytherapy.

1

Reproduce TPS dose in intracavitary and hybrid interstitial configurations

2

Identify regions where quantitative interpretation is limited

3

Establish the basis for future error-detection studies

Methods – Phantoms & FXO Gel

Optimized FXO formulation

- 6% w/w gelatin, 0.3 mM ferrous ammonium sulfate, 0.05 mM xylene orange, 100 mM H₂SO₄

Two custom cylindrical phantoms

- 14.0 cm diameter × 8.8 cm height
- Supports for the Elekta Venezia applicator (two ovoids + tandem)
- Optional 6F interstitial needles
- 3 fiducial markers on the cylinder for registration
- Companion jar poured each batch for calibration

Intracavitary applicator

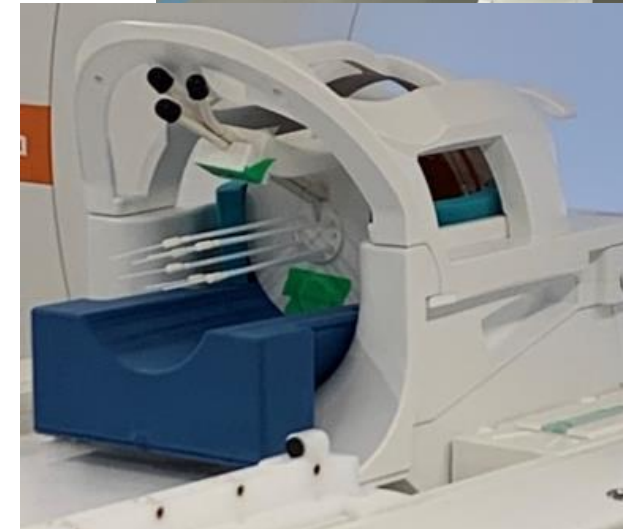


Hybrid interstitial applicator



Methods – MRI Acquisition

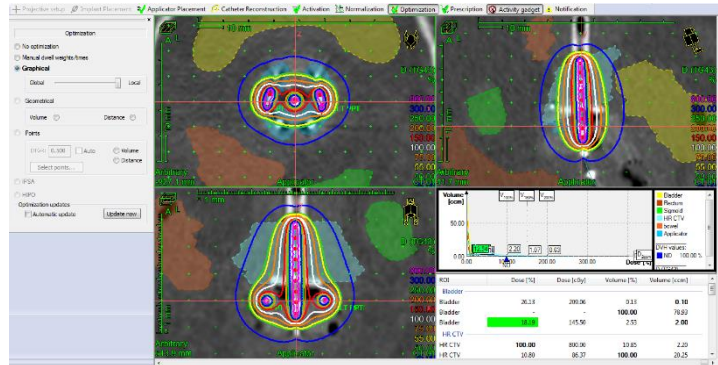
- **Siemens Magnetom Vida 3T**
 - 20-channel head & neck coil, tandem aligned with B_0
- **Planning MR Volume:**
 - 3D T1-weighted VIBE for applicator reconstruction and dose calculation
- **Dosimetry MR Volume:**
 - MP2RAGE R1 mapping. Fast, high-resolution, low B_1 -sensitivity
 - 1 mm isotropic resolution
 - ~11 minute scan time



Methods – Workflow

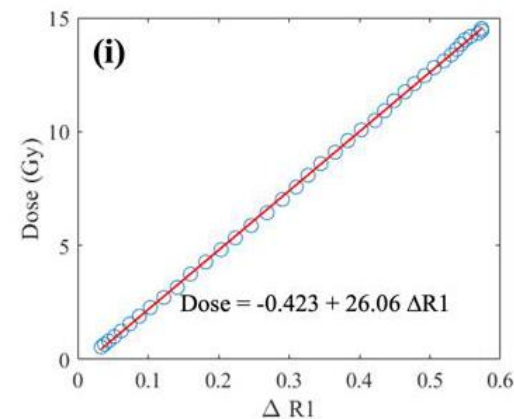
Planning

- Oncentra TPS, TG-43
- Standard clinical applicator reconstruction; needles digitized
- Volume-based 6 Gy prescription



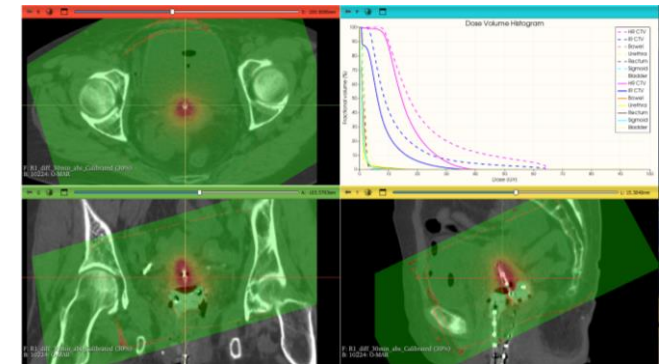
Delivery

- Elekta Flexitron afterloader, Ir-192 source
- Calibration jars irradiated with 12 MeV electrons on Varian TrueBeam
- PDD-method linear $\Delta R1$ -to-dose fit



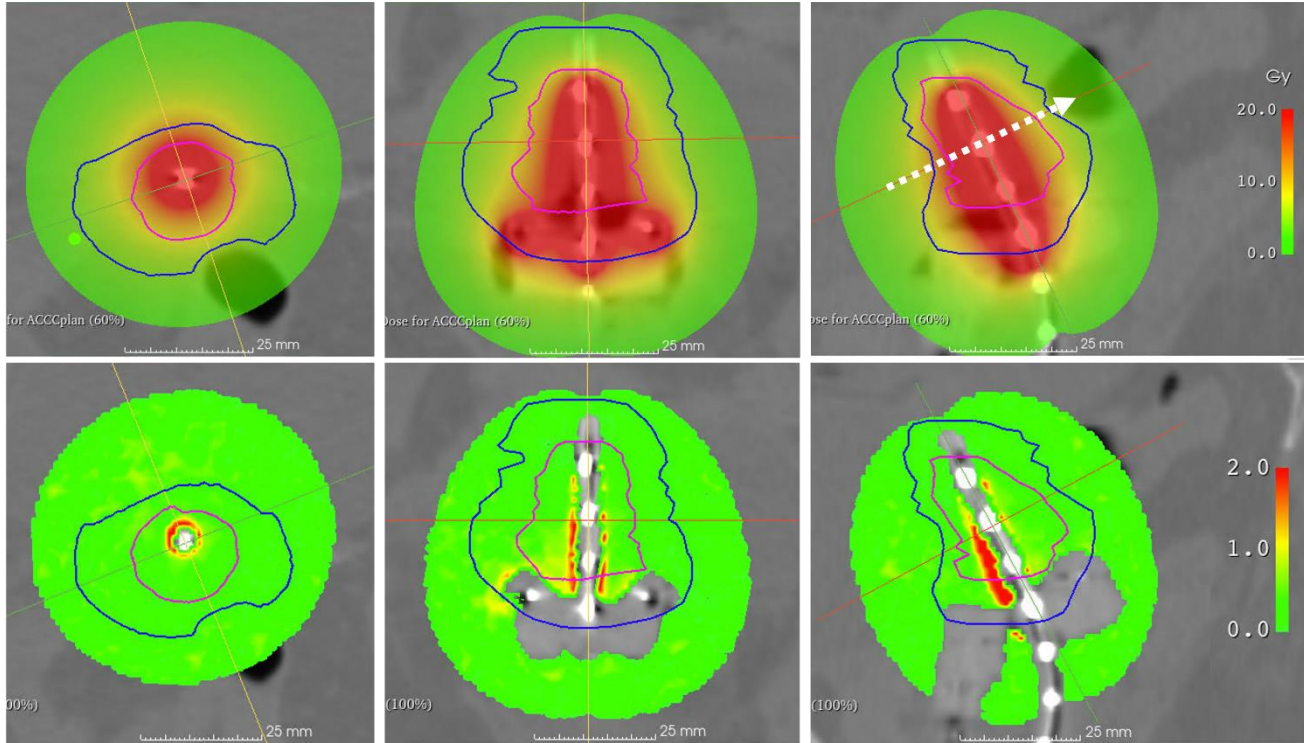
Analysis

- All processing in 3D Slicer (SlicerRT)
- Dose profiles + 3D gamma comparison vs. Oncentra
- Geometric gamma; 40% low-dose threshold

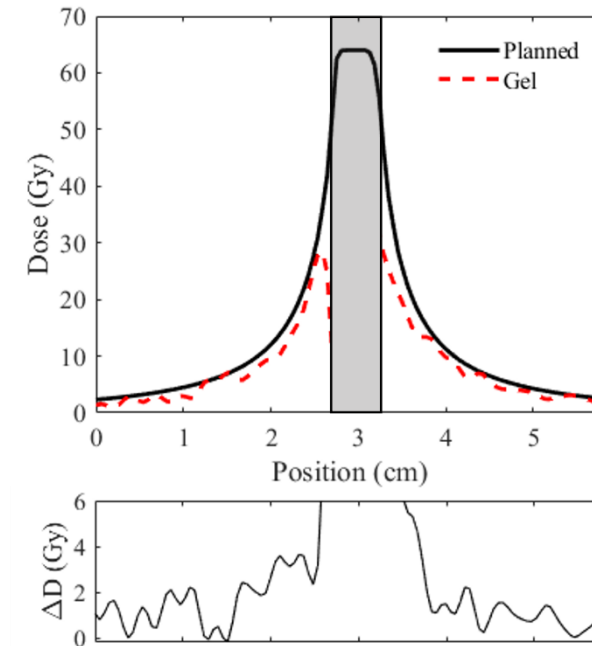


Results – Clinical Intracavitary Case

Plan



Gamma

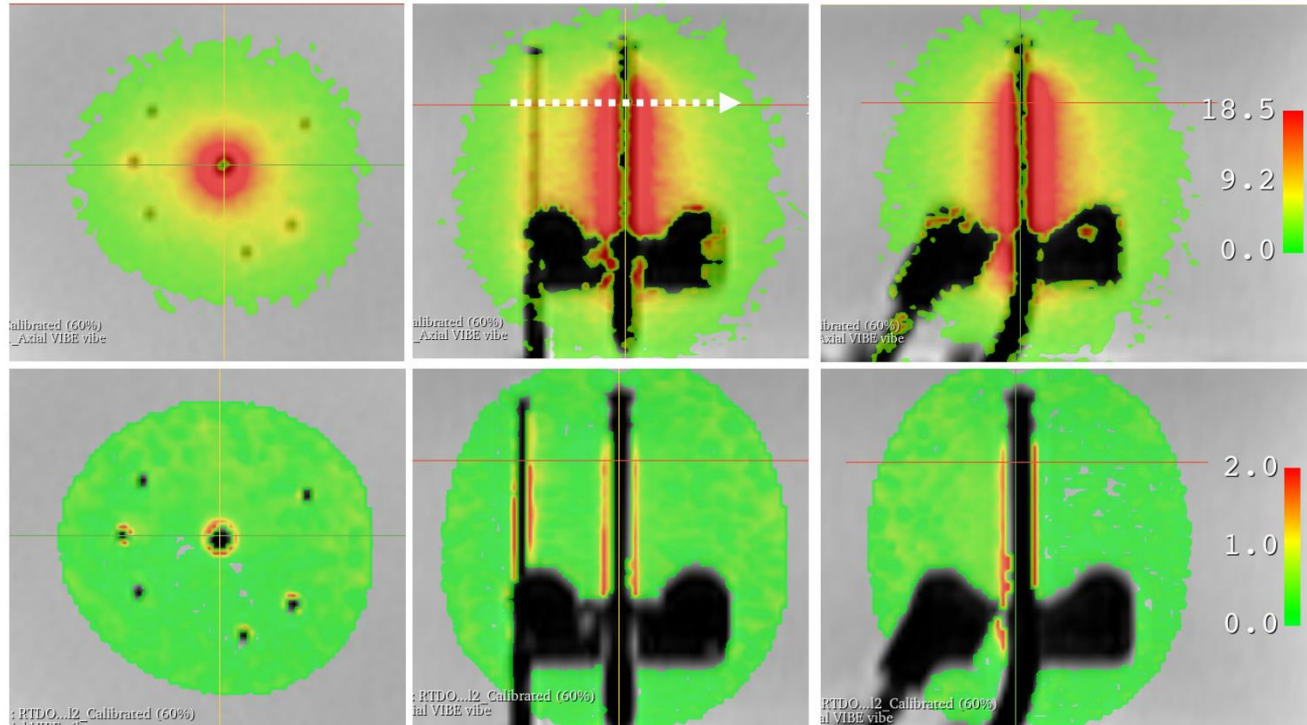


Key findings

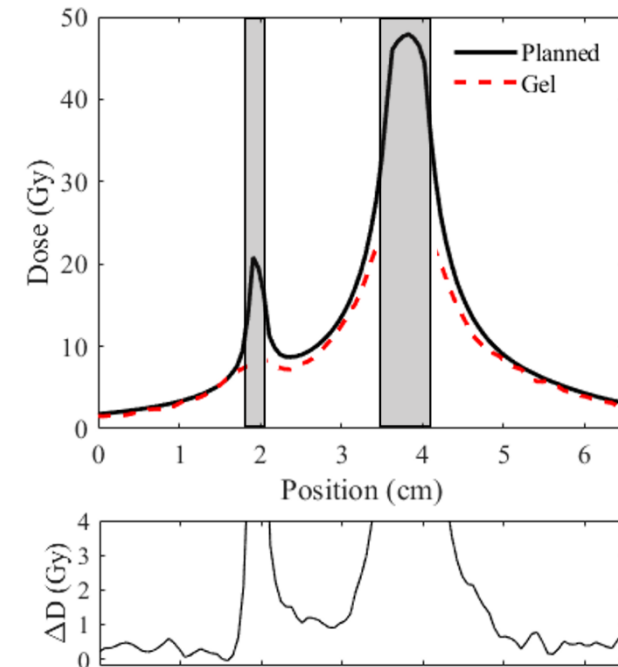
- Measured gel dose tracks the planned profile closely
- $\gamma < 1$ across much of the clinically relevant volume
- Disagreement confined to the region near the tandem

Results - Hybrid Interstitial Case

Measured



Gamma



Key findings

- Close agreement even with 6 interstitial needles
- Profile matches both needle and tandem dose peaks
- Failed voxels localized to source channels, not spread through the volume

Results – 3D Gamma Comparison

% of voxels with $\gamma < 1$ (40% low-dose threshold). Pass rates stay high even under tightened criteria.

Gamma Criteria	Clinical Intracavitary Case	Hybrid Interstitial Case
3%/3mm	99.3%	99.2%
3%/2mm	97.6%	98.6%
2%/2mm	97.5%	98.5%

Failed voxels are predominantly near the tandem and needles — not distributed through the clinically relevant volume.

Strengths and Limitations

Where it works

- Reproduces TPS dose outside the near-source region
- Holds under tightened 2%/2mm gamma
- Suited to commissioning and end-to-end workflow validation

Where caution is needed

- Disagreement adjacent to tandem and needles
- Steep gradients amplify reconstruction, partial-volume and registration uncertainty
- Non-linear FXO response above ~ 20 Gy underestimates near-source dose
- A multi-dose calibration could recover near-source quantification
- Temperature effects between irradiation and readout steps need to be controlled

Conclusions & Future Work

- MRI-based FXO gel dosimetry verifies complex Venezia HDR cervix brachytherapy in 3D, agreeing with TG-43 plans to within 2%/2mm across the clinically relevant volume.
- **Next: From agreement to error detection**
 - Introduce controlled errors (dwell position offsets, needles reconstruction errors, applicator shifts, channel assignment errors, registration uncertainties) to test whether gel can inform commissioning tolerances, applicator specific QA, and clinical investigation thresholds

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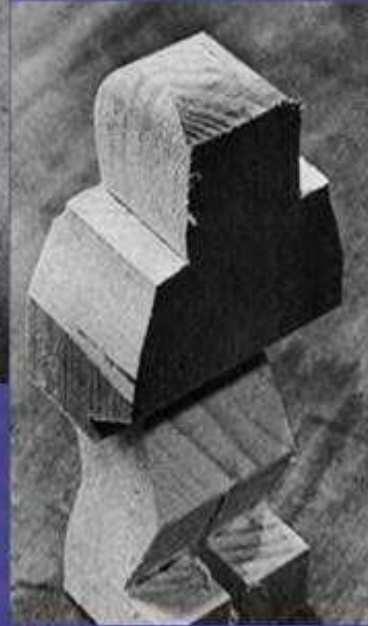
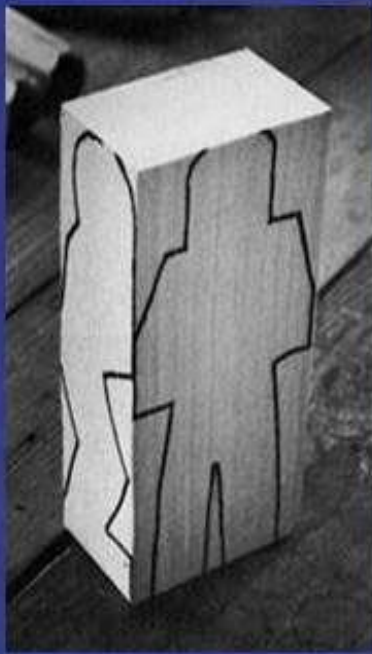
**Arthur J.E. Child
Comprehensive
Cancer Centre**



Perk Lab

Laboratory for Percutaneous Surgery

Evolution of Radiotherapy



3-D

Conformal

Dose
Painting

2-D Planning

Three Dimensional
Dosimetry

IMRT

LJS with mods from R. Mackie



