Clinical Validation of the PEREGRINE Monte Carlo Dose Calculation System for Photon Beam Teletherapy

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Abstract

PEREGRINE is a 3-D Monte Carlo radiation transport system designed to provide the most accurate dose calculations for radiation therapy treatment planning. PEREGRINE combines Monte Carlo-based modeling of the accelerator beam delivery system, Monte Carlo simulation of treatment-specific beam modifiers, and Monte Carlo transport in the patient to provide a robust and accurate representation of the radiation source, the beam modifiers, and heterogeneities in patients. To validate the PEREGRINE dose calculation system, we have developed a comprehensive set of tests comparing PEREGRINE results to high-quality dosimetric measurements made with standard 6 and 18 MV clinical beams. These tests stress the physics algorithms for a full range of clinically relevant materials, densities, and beam energies for open, blocked, wedged, and compensated fields incident on a simple water phantom and water-equivalent phantoms with a variety of surface and sub-surface heterogeneities. Measurements were made with a variety of detectors, including cylindrical (IC-10) and thin-window (Markus) ionization chambers and photon diodes, chosen for the specific dose-distribution characteristics being studied. We report that PEREGRINE accurately models the absolute dose per monitor unit for a comprehensive set of clinically relevant cases.

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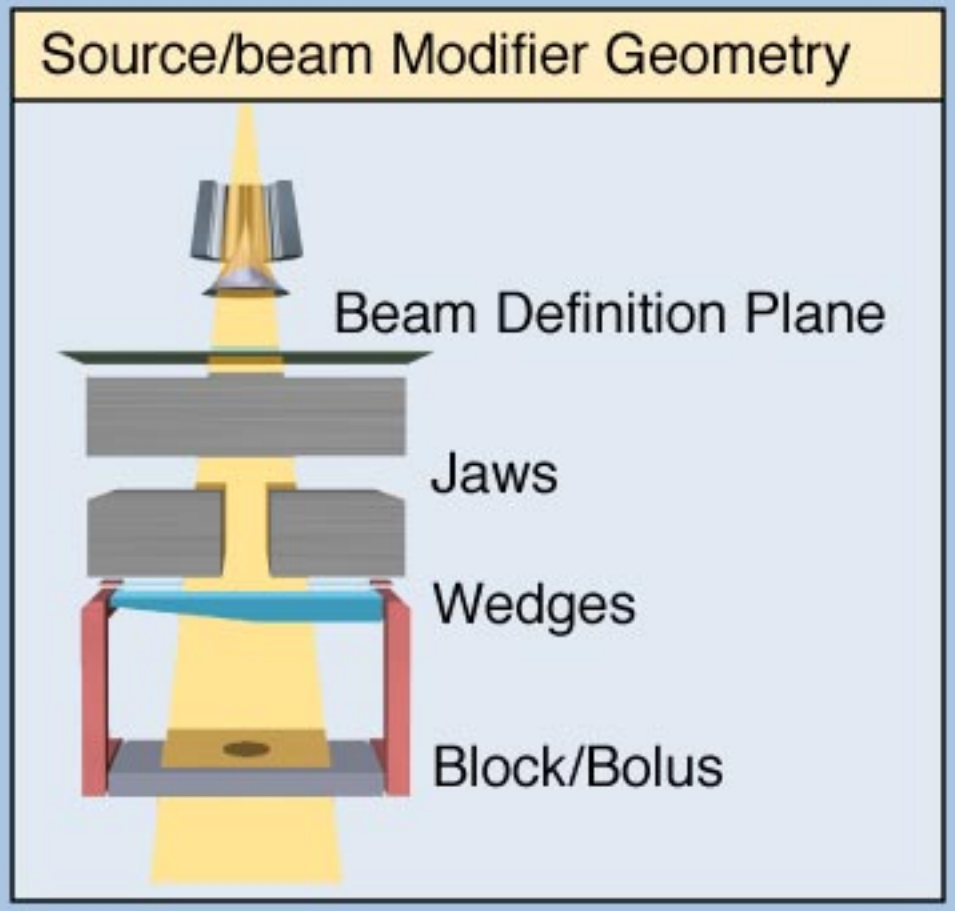
PEREGRINE
3D Monte Carlo

Outline

- PEREGRINE source and transport models
- Validation plan
- Example comparisons
- Conclusion

The PEREGRINE source model

- PEREGRINE relies on predefined radiation sources to describe the portion of the source that does not change from patient to patient
- PEREGRINE transports particles through patient-dependent beam modifiers during each radiotherapy calculation



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Photon/Electron physics in PEREGRINE

Photon Physics Analog transport (Single Scatter)	— Coherent scattering (Thomson) — Incoherent scattering (Compton) — Photoelectric effect — Pair production
Electron/Positron Physics Class II Condensed History Transport	— Bremsstrahlung production — Møller/Bhabha — Annihilation (positrons) — Continuous energy loss — Multiple scattering (Goudsmit-Saunderson) — Random hinge

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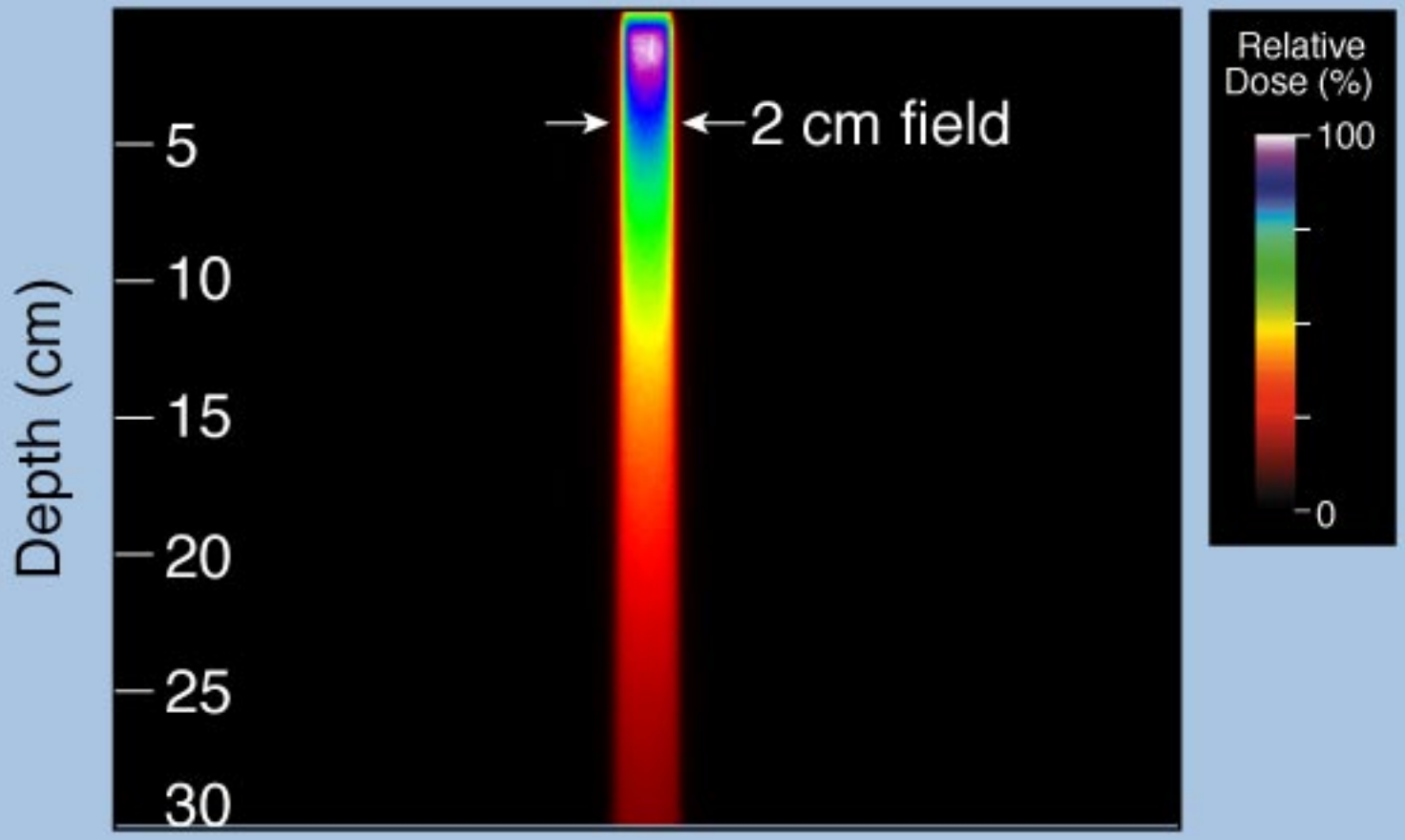
PEREGRINE Validation

Field Types	Features
Open fields	
Square fields	2x2 cm, 5x5 cm, 10x10 cm, 20x20 cm, 38x38 cm
Rectangular fields	5x20 cm, 20x5 cm, 5x30 cm, and 38x5 cm
Asymmetric fields	5x5cm (offset 10 cm), 10x10 cm (offset 5 cm)
Beam modifiers	
Blocks	Central, Half, Quarter, Transmission, Irregular (L-shape), Stereotactic
Wedges	Multiple angles, materials, tray positions
Compensator	Multiple steps
MLC	Diagonal, irregular (L-shape)

PEREGRINE Validation

Phantoms	Features
Missing tissue	
Tangential fields	45° angle with and without wedge
Sloped surfaces	Partial cylinder
Irregular surfaces	Step
Flashing	Half of 20 x 20 cm field out of phantom
Heterogeneities	
Full slab	Air, Lung, Bone, Steel
Half slab	Air, Lung, Bone, Steel

Small Field



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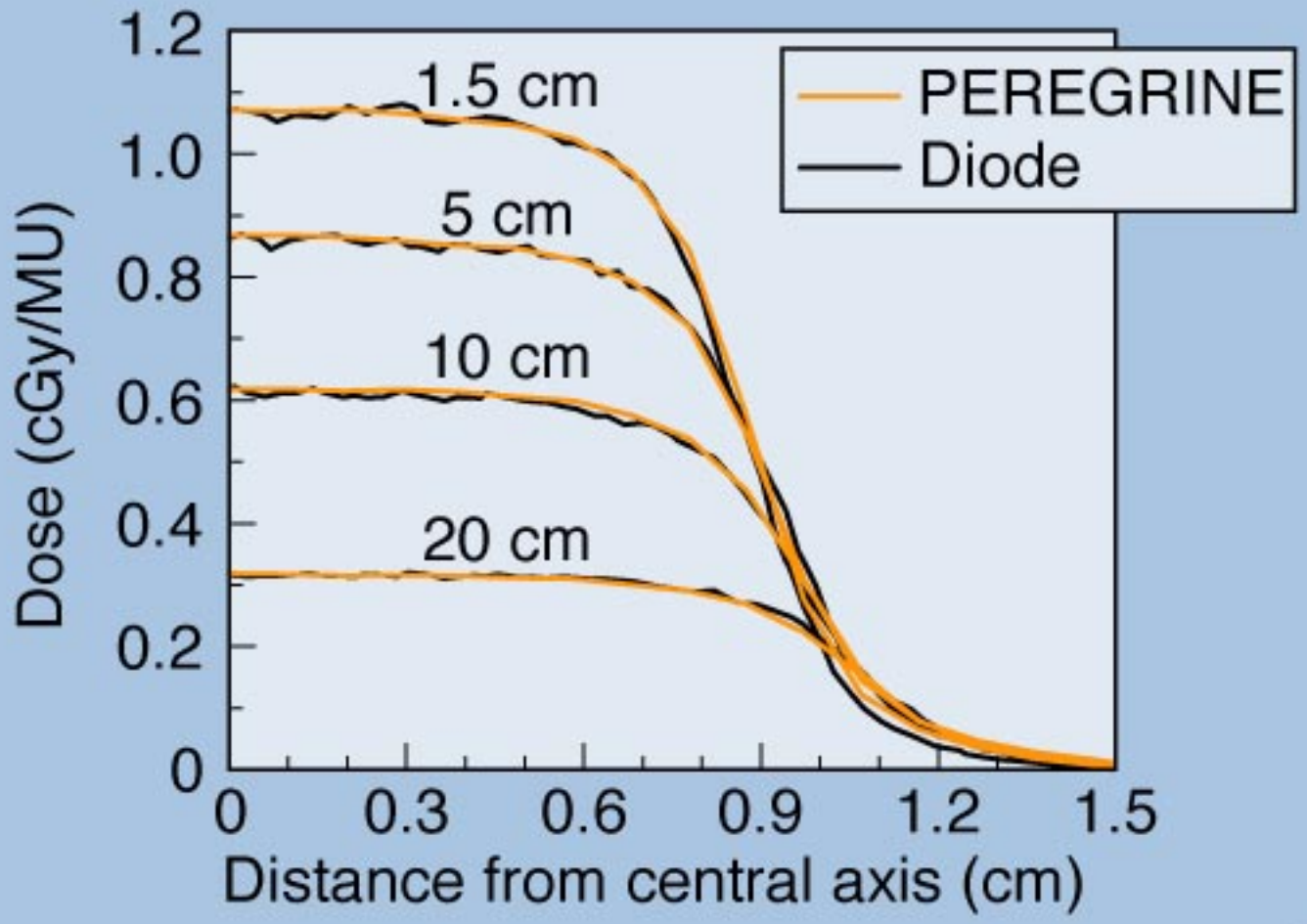
2x2 cm Open Field, 6 MV



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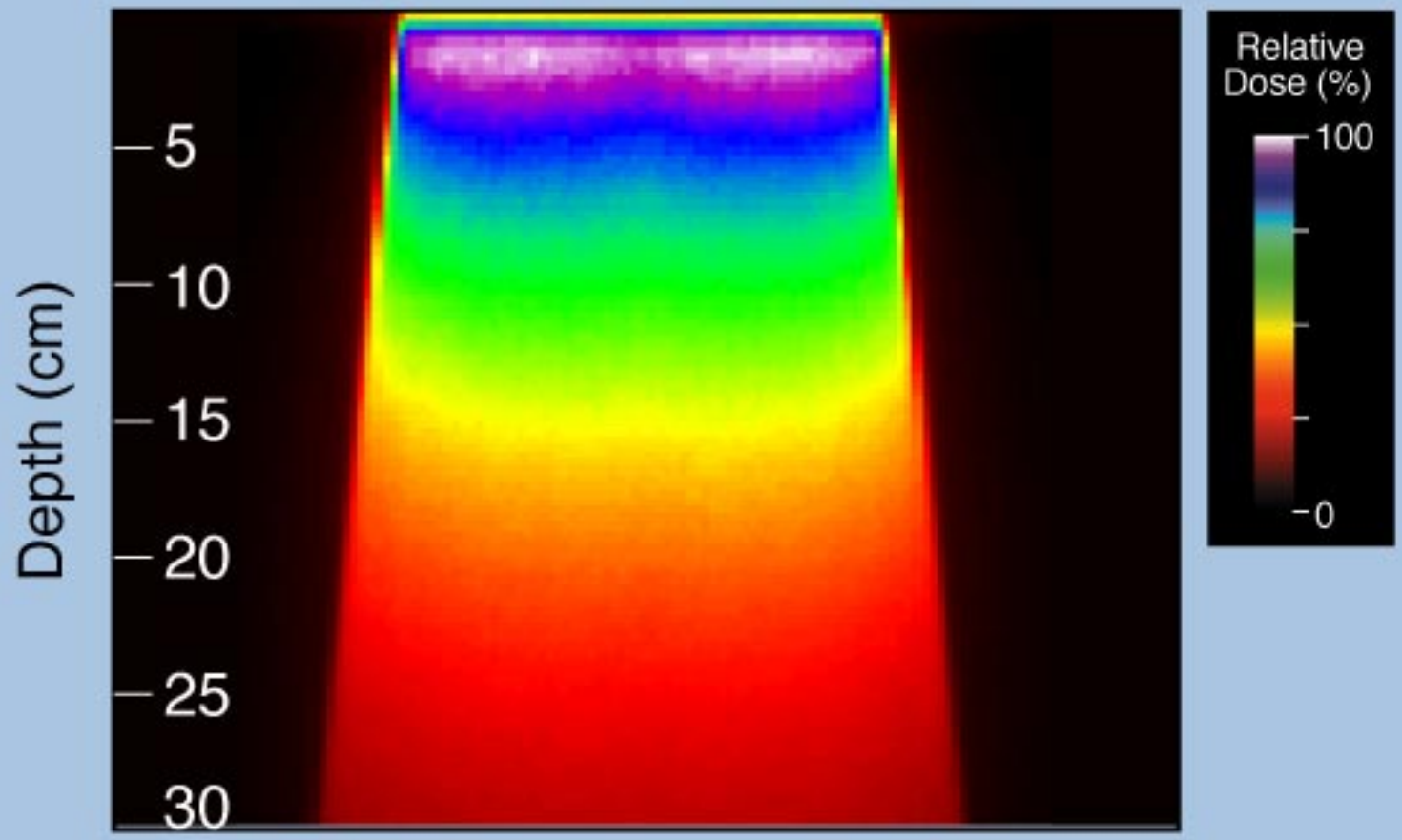
Large Fields



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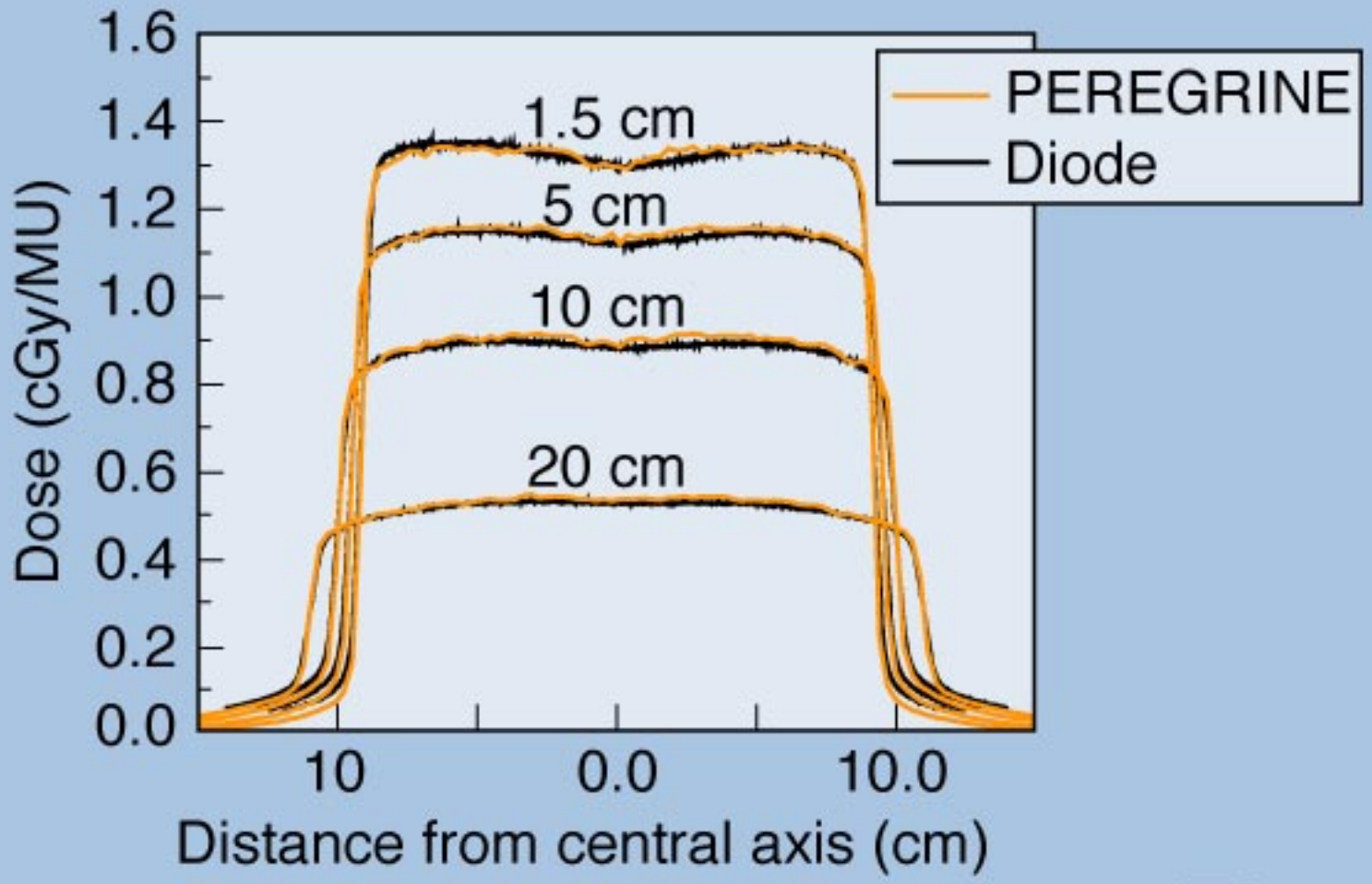
20x20 cm Open Field, 6 MV



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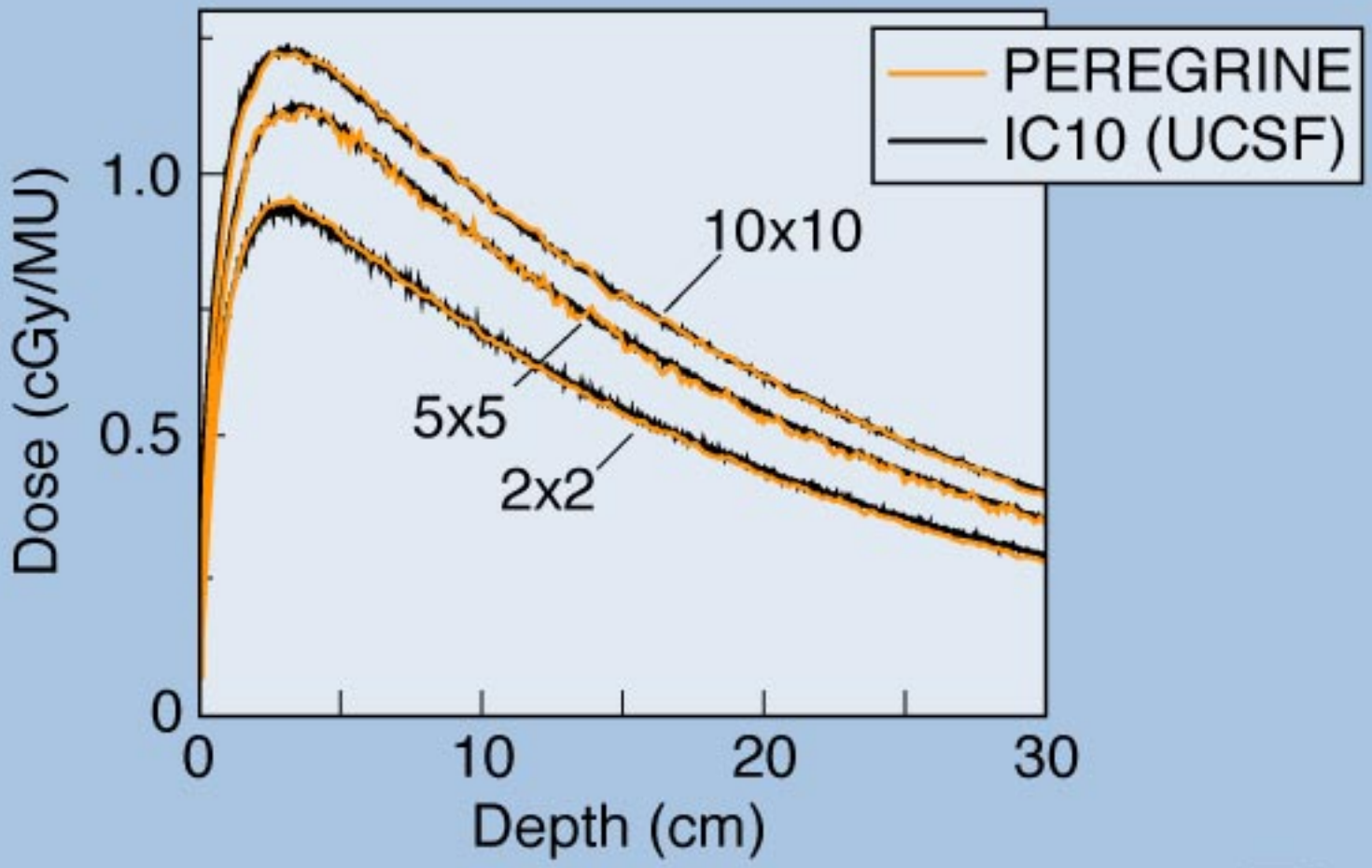
Depth dose, 18 MV



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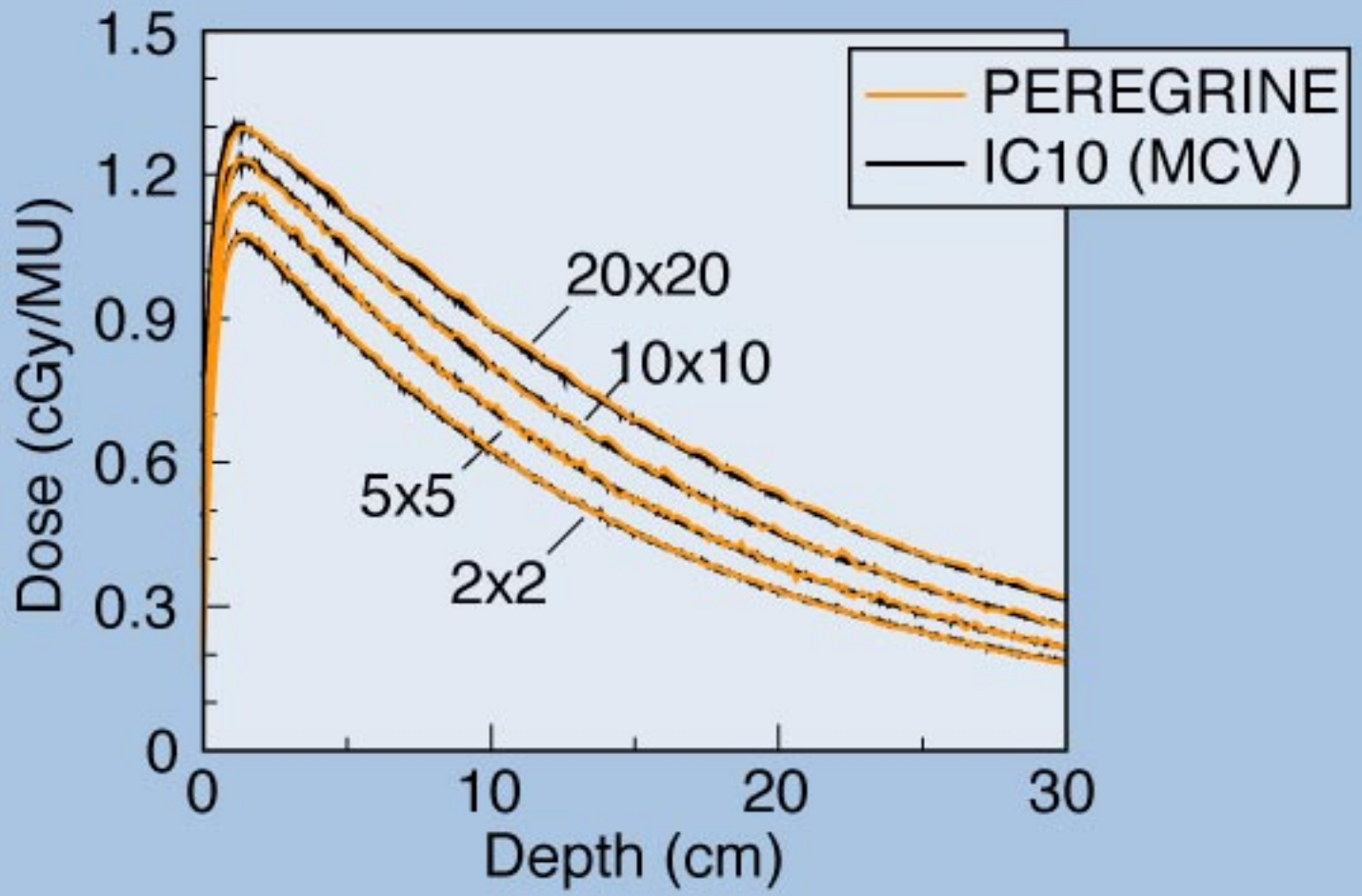
3D Monte Carlo

Depth dose, 6 MV



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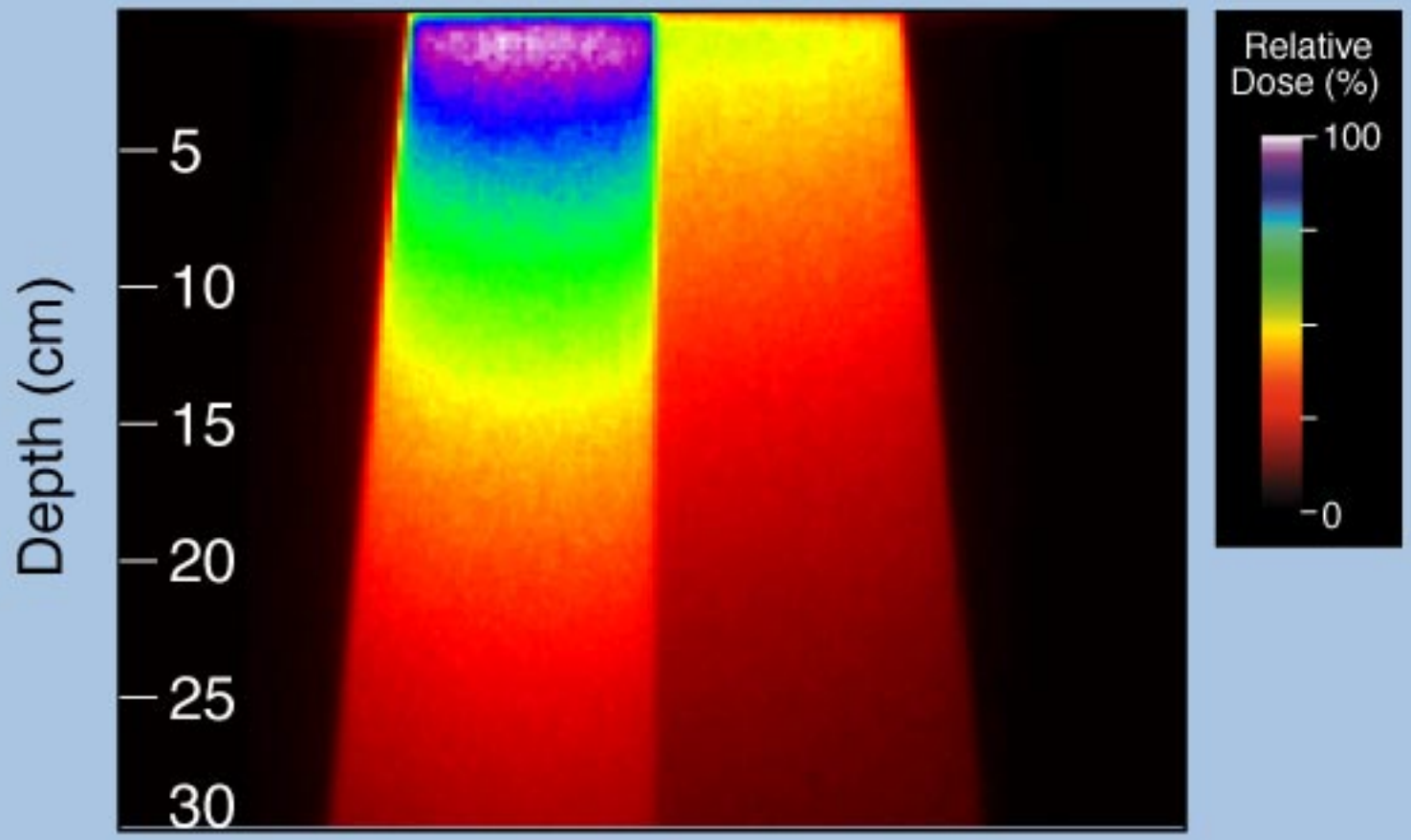
Partial Transmission Block



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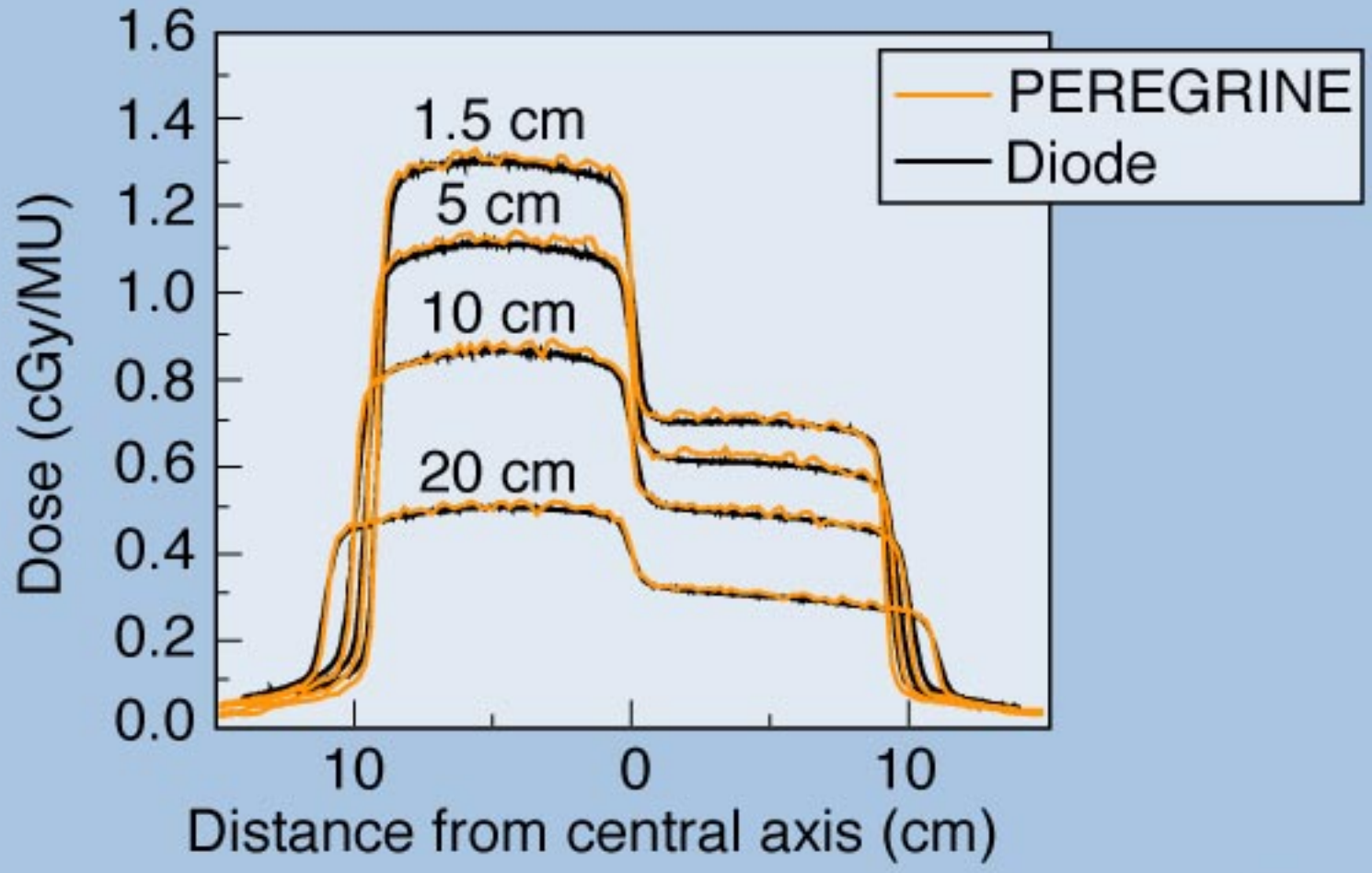
20x20 cm Field, Partial Transmission Block, 6 MV



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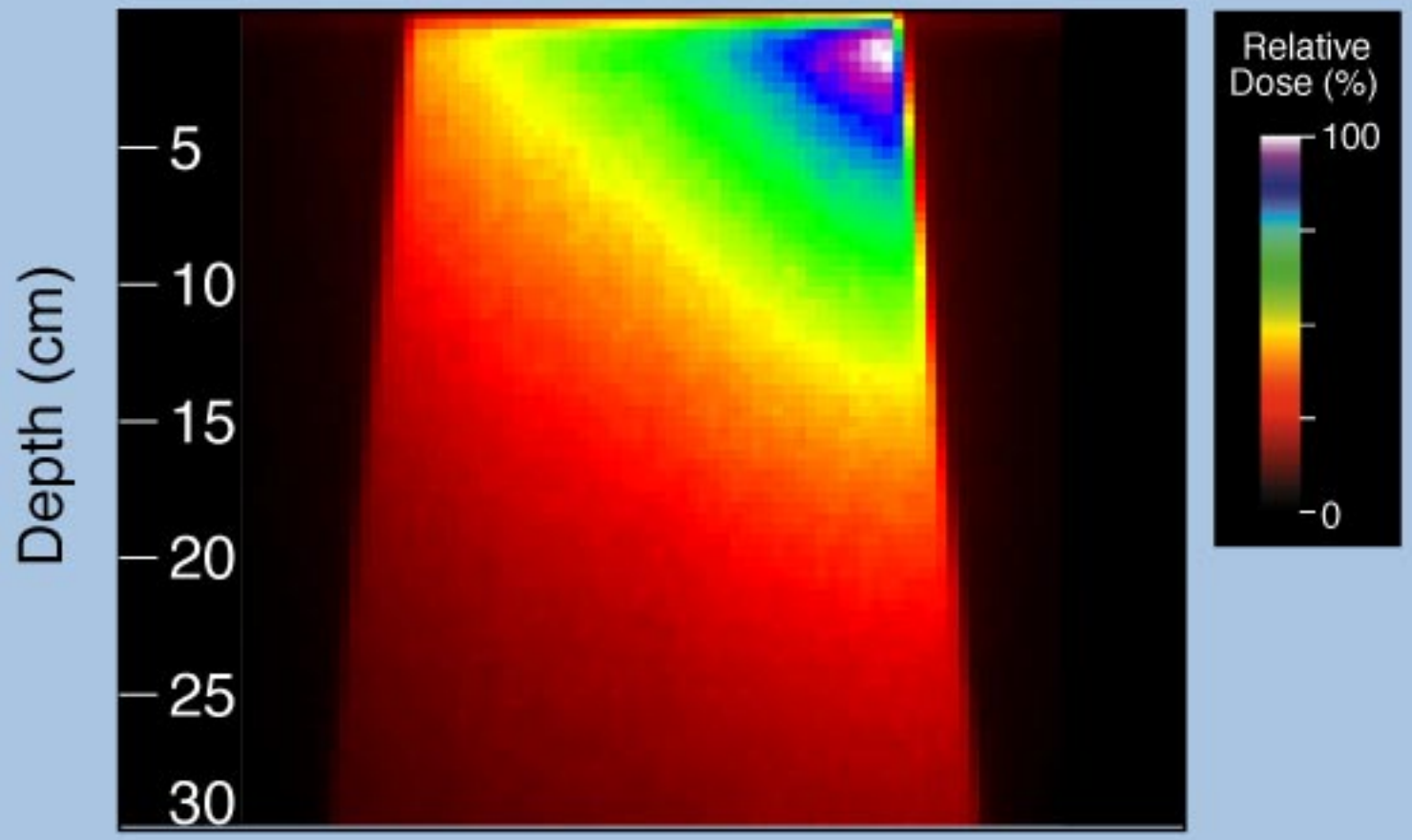
Wedges



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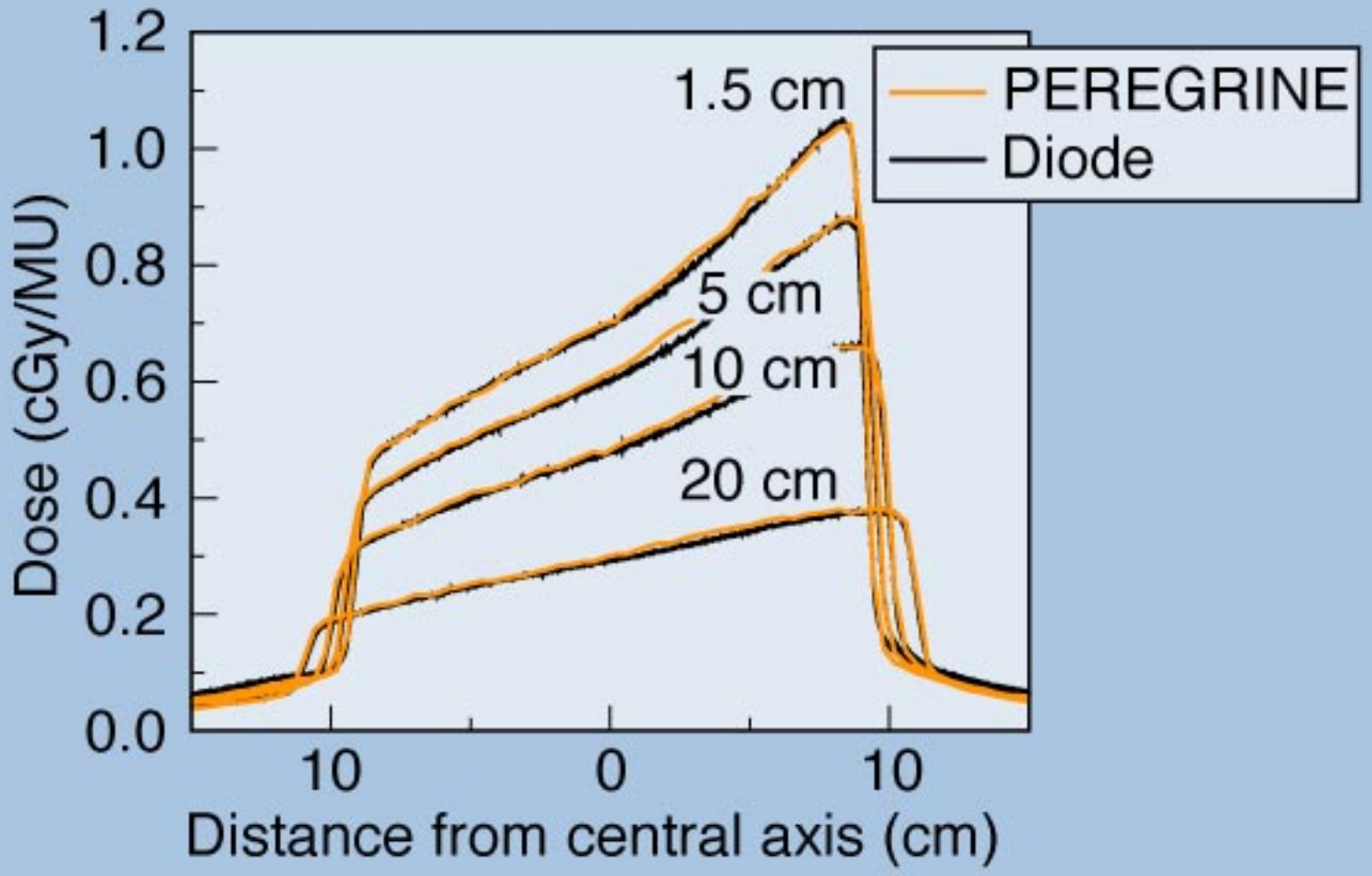
20x40 cm Field, 45 Degree Wedge, 6 MV



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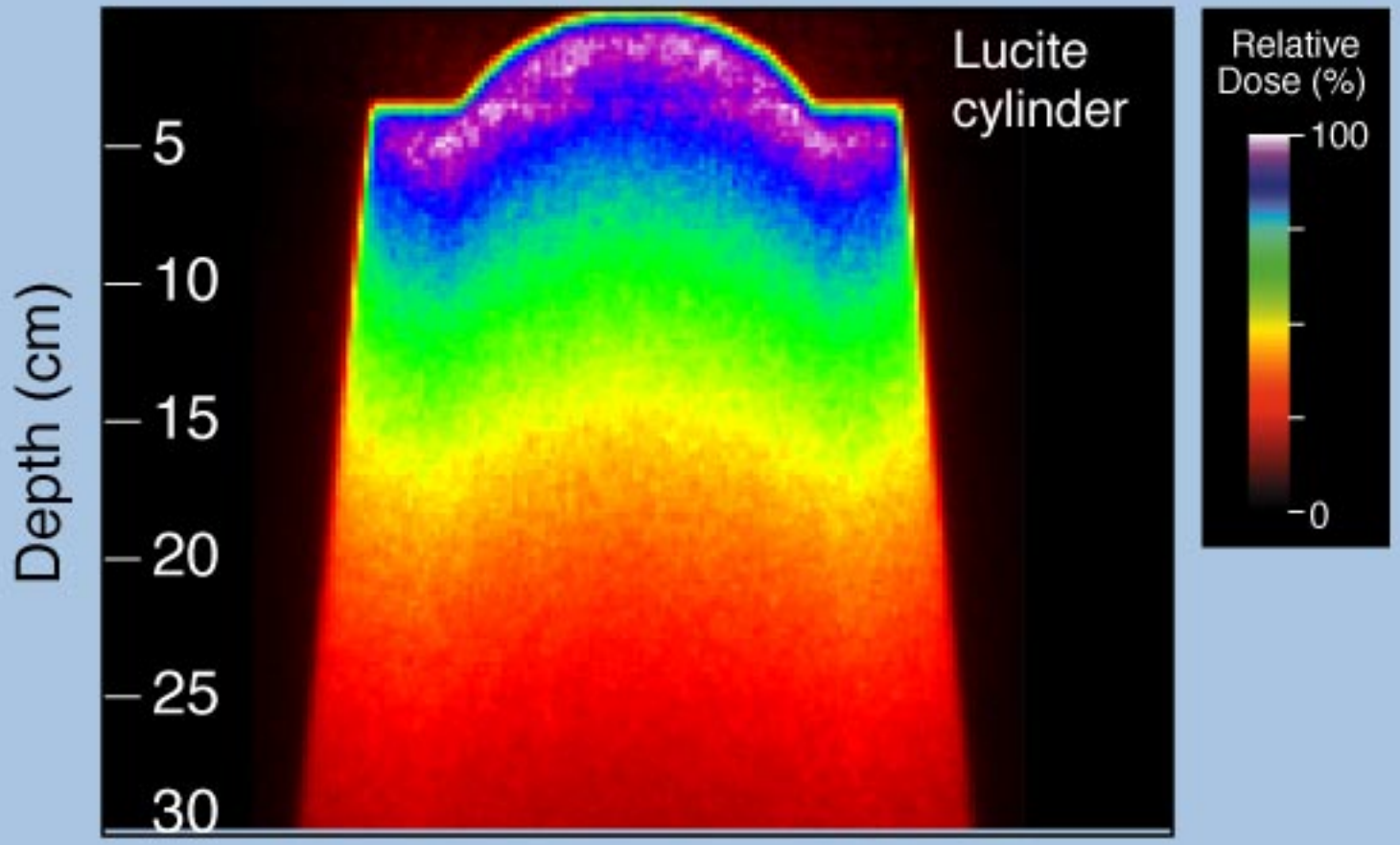
Irregular surfaces



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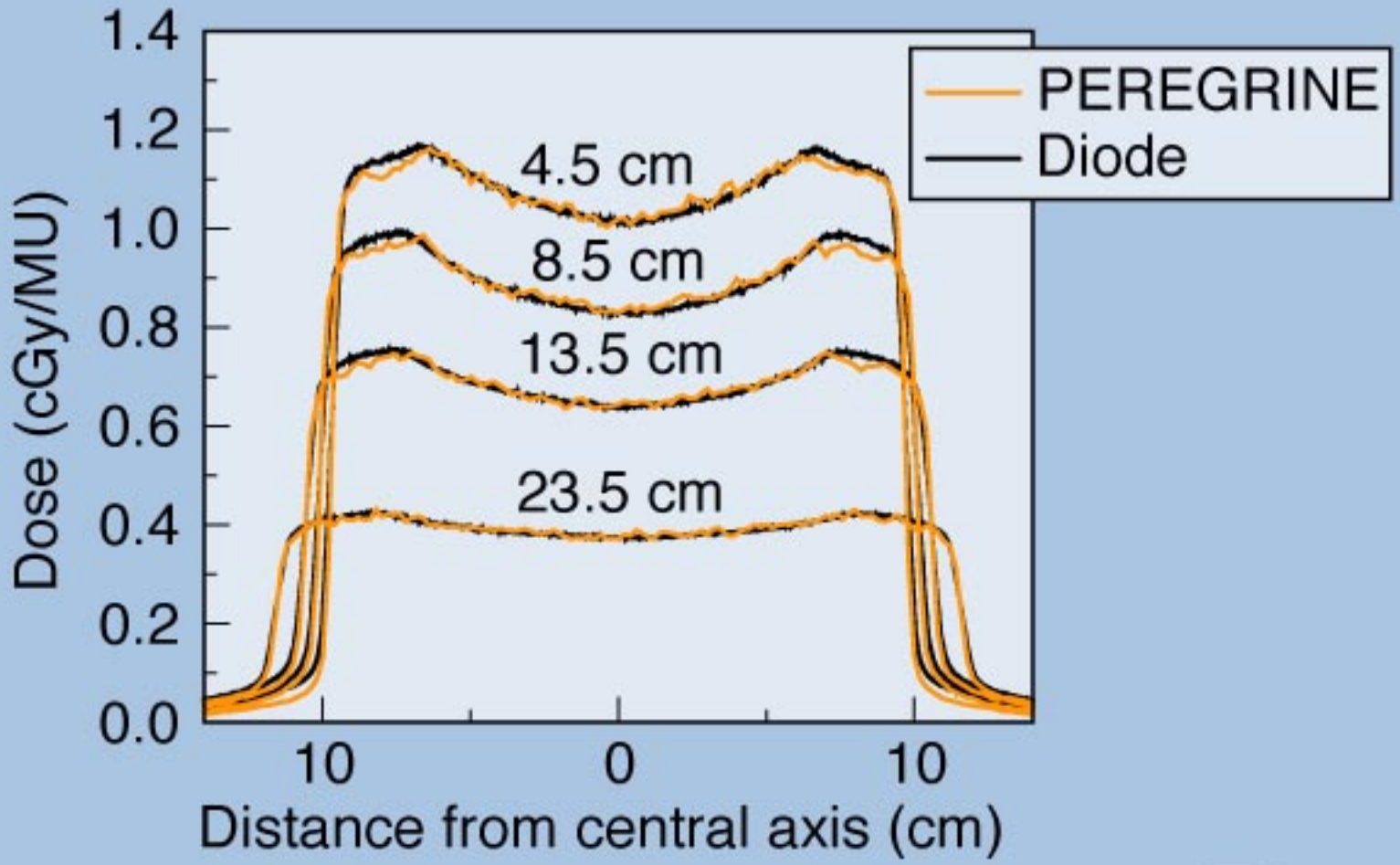
20x10 cm Field, 3.5 cm Lucite Cylinder, 6 MV



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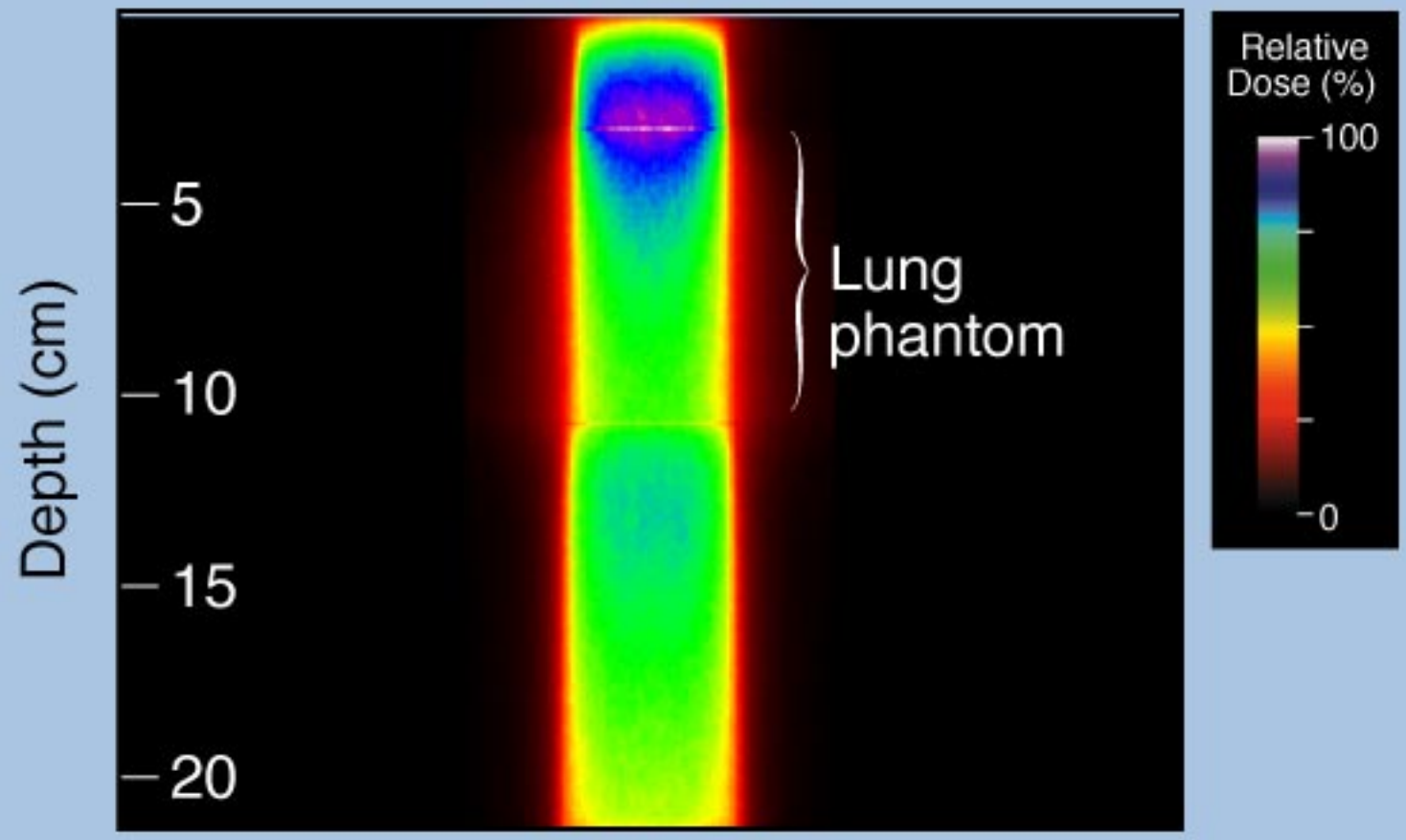
Lung heterogeneity



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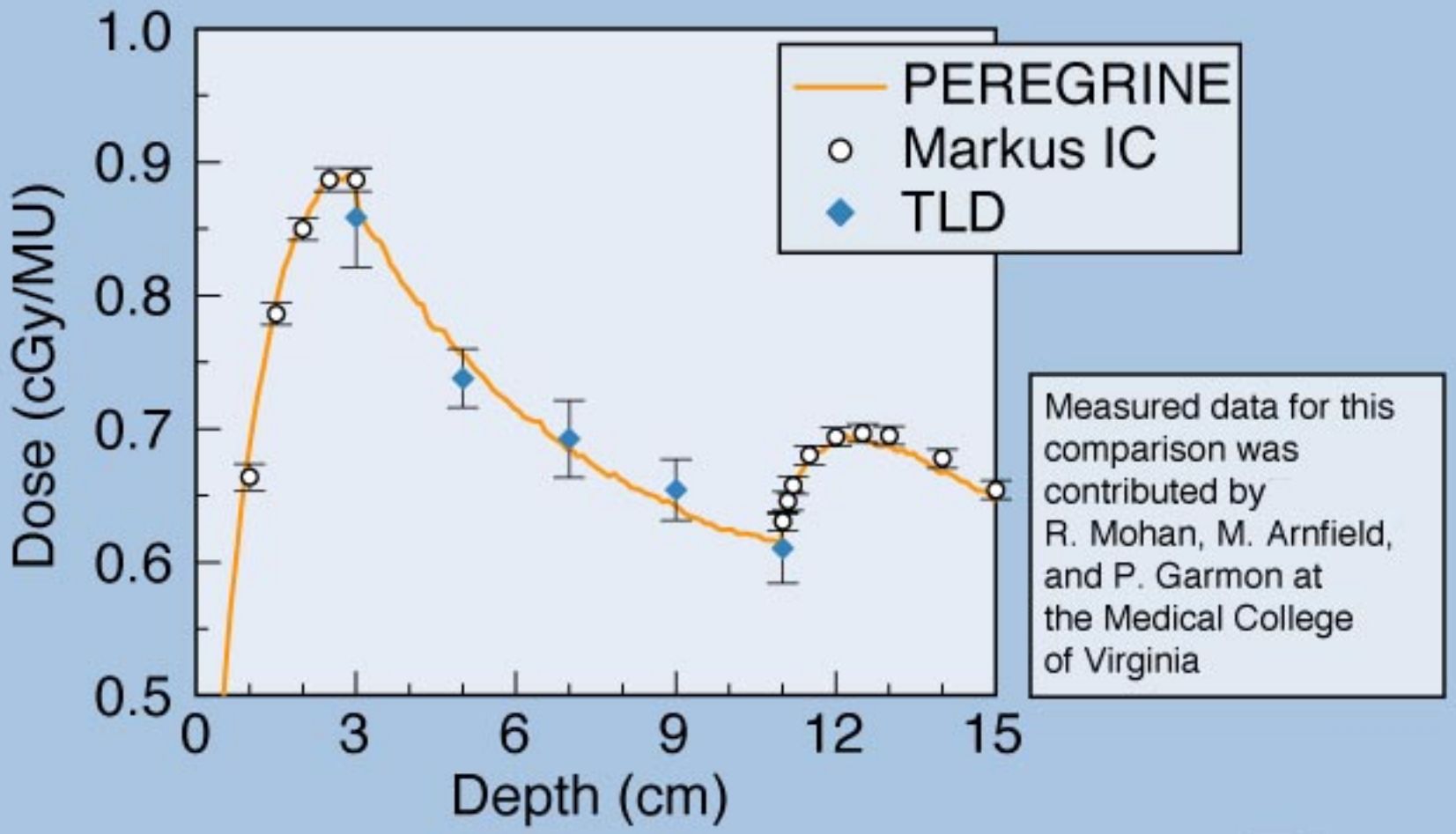
4x4 cm Field, 8 cm Lung Slab, 18 MV



Measured data for this comparison was contributed by R. Mohan, M. Arnfield, and P. Garmon at the Medical College of Virginia

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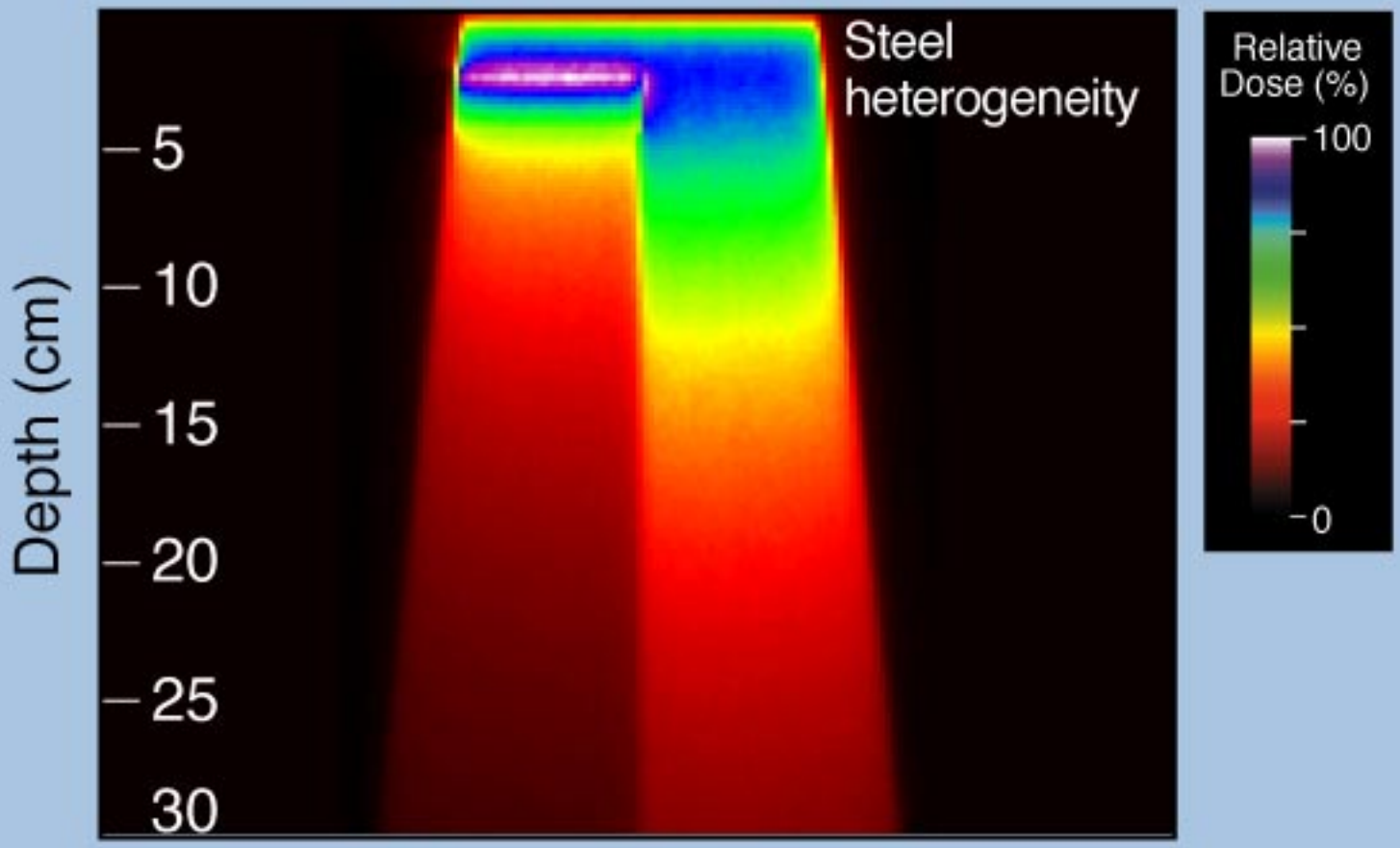
Steel heterogeneity



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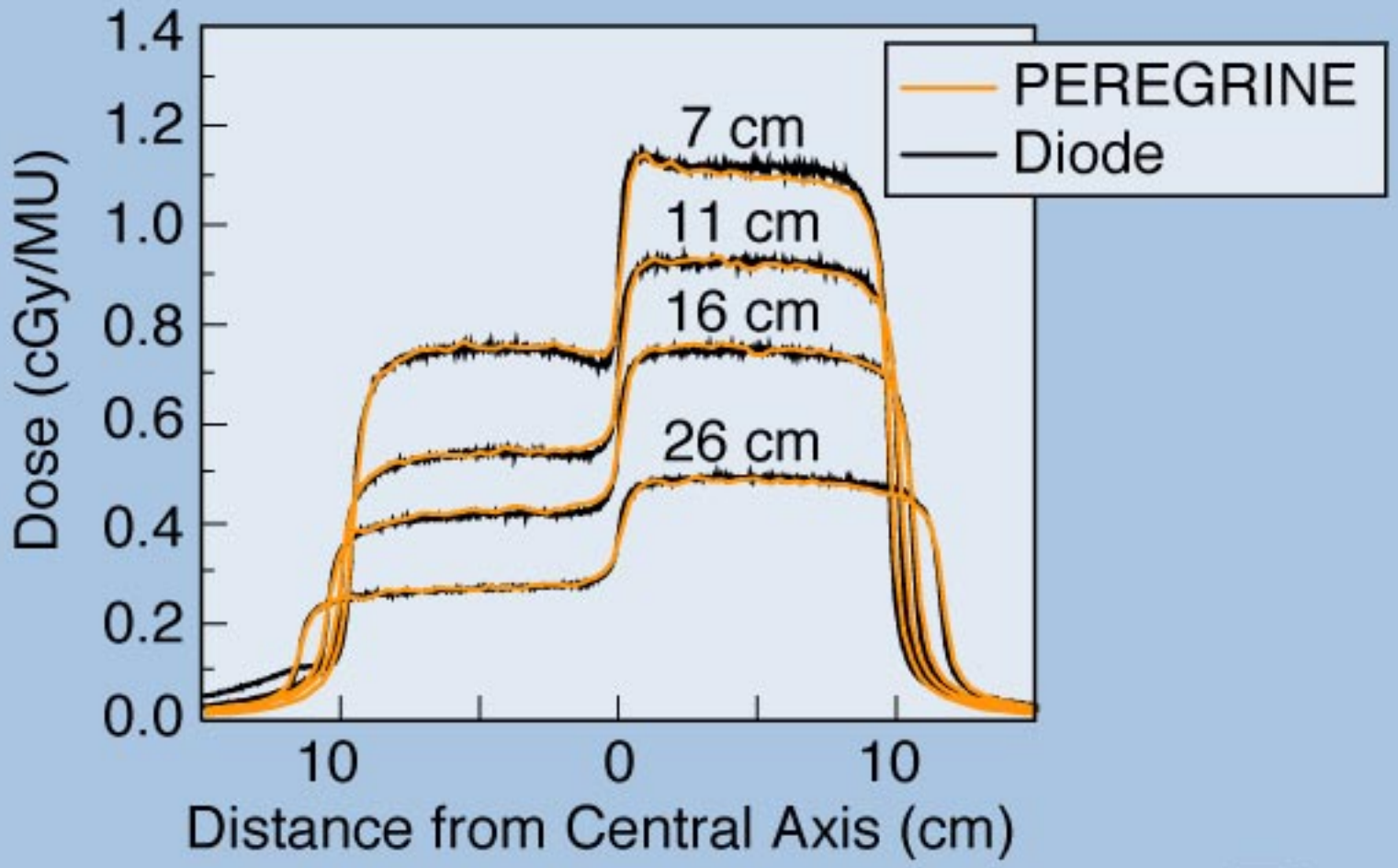
20x8 cm Field, 3.5 cm Steel Half Slab, 18 MV



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3D Monte Carlo

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Conclusion

- PEREGRINE is being validated against a comprehensive set of clinical measurements
- Results show excellent agreement between PEREGRINE and measurements in equilibrium and non-equilibrium conditions

PEREGRINE source model and Monte Carlo transport algorithms are robust and accurate for photon teletherapy applications

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