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Title: CALCULATIONS OF MEDICAL PHYSICS RADIATION DOSIMETRY SYSTEMS USING MCNP VERSION 5

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Calculations of Medical Physics Radiation Dosimetry Systems Using MCNP Version 5

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Introduction

MCNP™ Version 5 has just been released to the Radiation Shielding Information Computational Center.[1,2] The code has new features that greatly facilitate the simulation of complex radiation transport problems, including those in Medical and Health Physics.[3] In this work, two of these features, Doppler energy broadening of low energy photons, and pulse height tally variance reduction for photons, were used in calculations of radiation dosimetry and detector problems. A total of seven of these problems were analyzed as part of an international intercomparison of radiation dosimetry computer codes, sponsored by the European Commission committee on the quality assurance of computational tools in radiation dosimetry.[4] Our results were submitted to the committee, which will perform the inter-code comparison and will publish the results independently. The focus of this work is to exercise the new version of the code in an international code comparison effort, and to highlight the new features of the code relevant to these problems.

Description of the Radiation Dosimetry and Detector Problems

Problem 1 studied the near-field angular anisotropy and dose distribution from a high dose rate Ir-192 brachytherapy source in a surrounding water phantom. The Ir-192 source was modeled as a core capsule with radius 0.0325 cm and length of 0.36 cm. Enclosing the Ir-192 source was a stainless steel capsule attached to a woven steel cable. The Ir-192 core, steel encapsulation, and woven steel cable are modeled within a 5 cm sphere of water, which was considered to be near field. The sphere was then divided into wedges with angles of 10 degrees from 0 to 180 to determine anisotropy factors, while cylinders with radii increasing by 1 cm increments where used to determine radial dose depth.

Problem 2 looked at both the radial and axial dose in a vessel wall from an intravascular brachytherapy P-32 source contained in a polyethylene matrix. The source is cylindrical with a diameter of 0.24 mm and length of 27 mm. It is encapsulated within NiTi with a 1 mm long Tungsten cylindrical marker (0.24 mm diameter). The radial dose is measured in a water phantom by concentric cylinders while axial dose is measured in disks. The addition of a plaque on the artery walls and its affect upon the radial and axial dose is also modeled.

Problem 3 investigated the response of a four-element TLD-albedo personal dosimeter from neutrons and/or photons. Elements 1 and 2 are bare ^{6}LiF and ^{7}LiF detectors, respectively, with boron-loaded plastic behind them. Elements 3 and 4 are covered with a 1 mm thick aluminum

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* Work performed as a Graduate Research Assistant at Los Alamos National Laboratory, X-5 Group, Summer 2002.

disc plus 4 mm of boron-loaded plastic. The photon response is determined by measuring dose to the TLD elements while neutron response is measured by counting $^{6}Li(n,t)^{4}He$ capture reactions. The fraction of neutron and photon response due to backscatter from a water phantom is also determined.

Problem 4 modeled air kerma backscatter profiles for X-ray tubes with voltages of 150 and 200 kV. The air kerma backscatter is determined at the front face of a 30 cm x 30 cm x 15 cm ISO slab water phantom.

Problem 5 involved neutron field perturbation measurements at two points behind a shadow cone. The shadow cone consists of iron and polyethylene layers designed to suppress direct contributions to the detector from the source. The distribution of neutron fluence in energy at the two positions is determined as well as the contribution to the neutron spectral fluence from the different directions. The contributions to the energy fluence from air and walls are also differentiated.

Problem 6 studied detector peak efficiencies and pulse height distributions for a germanium detector with a photon source. The detector includes dead layers and is partially imbedded in an aluminum holder.

Problem 7 modeled a polyethylene sphere with a spherical proportional He-3 counter as a neutron measuring device. Uncertainties in the position of the instrument and the radioactive source are examined to determine the constancy of the calibration.

Results

The key results obtained included radial and axial dose profiles, energy deposition tallies including the pulse height tallies. Angular flux distributions were obtained for many of the systems. Some of the new features of the code that were tested are the Doppler energy broadening of low energy photons and the usage of variance reduction with pulse height tallies for photons. For many of the problems, sensitivity studies were carried out to examine the effects of different physics assumptions, cross section libraries and tally specifications. Comparisons were also made with selected problem results generated with MCNP version 4C2.

References

1. J. F. Briesmeister, Ed., "MCNP – A General Monte Carlo N-Particle Transport Code, Version 4C," LA – 13709-M (April 2000).
2. F.B. Brown, "MCNP Version 5," ANS Winter Meeting, November 2002.
3. E.C. Selcow, J.T. Goorley, " Medical Physics Applications of MCNP," Presented at the Radiation Protection & Shielding Division of the American Nuclear Society, 12th Biennial RPSD Topical Meeting, Santa Fe, NM, April 14-17, 2002. LA-UR-02-2043, Los Alamos National Laboratory.
4. B. Siebert, "Intercomparison on the Usage of Computational Code in Radiation Dosimetry", developed by the European Commission Concerted Action Group on the Quality Assurance of

Computational Tools for Dosimetry. http://www.nea.fr/download/quados.html

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Presentation

- Introduction
- Goals
- Description of problem suite
- MCNP5 features
- Summary

Intercomparison on the Usage of Computational Codes in Radiation Dosimetry

An international effort supported by the European Union

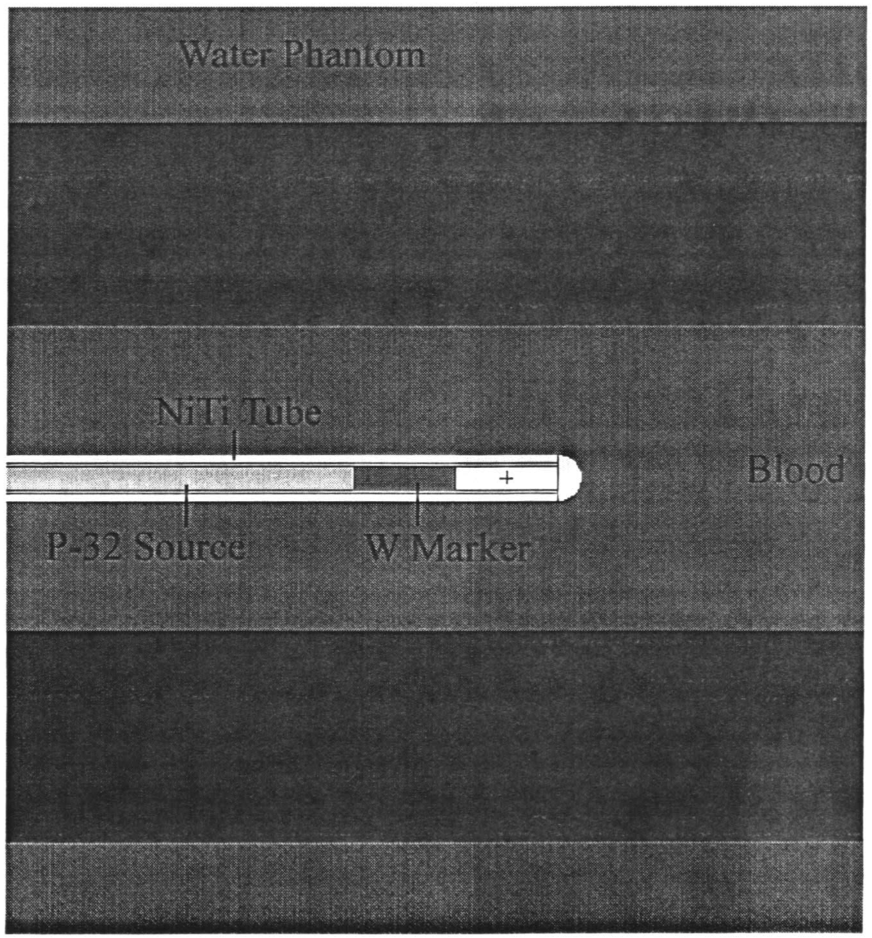
- Provide a snapshot of the methods and codes currently in use.
- Disseminate “good practice” throughout the radiation dosimetry community.
- Provide the users of computational codes with an opportunity to quality assure their own procedures.
- Inform the community about more sophisticated approaches that may be available to them.

http://www.nea.fr./download/quados/quados.html

Goals for MCNP5 study

- Participate in intercomparison.
  - Verification with other codes
- Illustrate new MCNP5 features
  - Doppler photon broadening
  - Improved plotting capabilities
  - Neutral particle radiography
- Verify MCNP5 with 4C3, 4C2
  - Use problems as test suite
  - Consistency checks

Problems 1 and 2: Intravascular Brachytherapy Irradiation

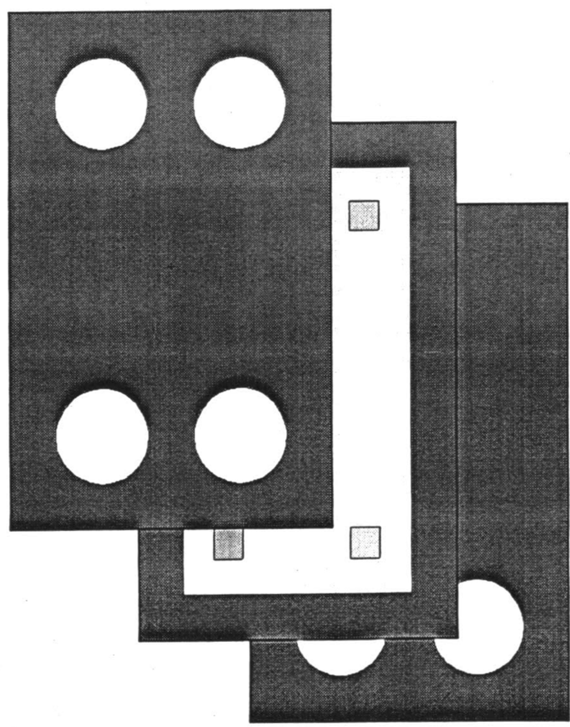


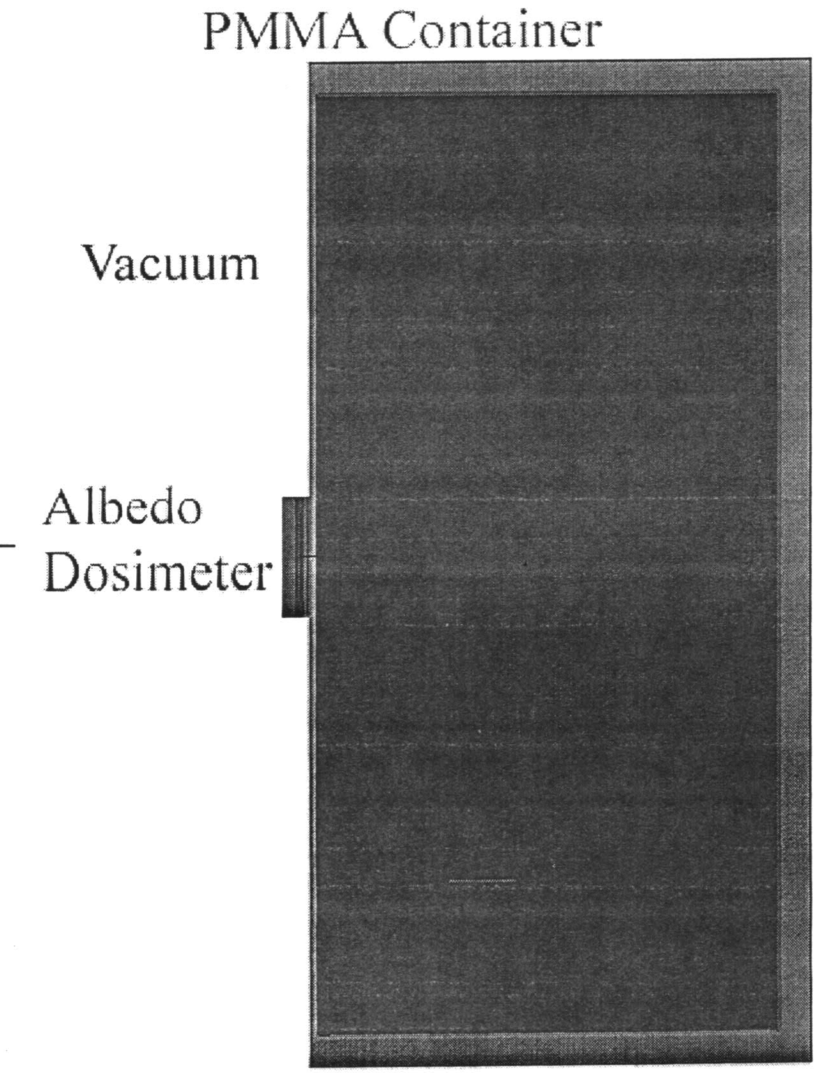
Calculate dose profiles from Ir-192 and P-32 catheter sources

Problem 4: Photon and Neutron Response in a TLD on a ISO Slab Phantom

Calculate in LiF chips:

- Photon Energy Absorbed
- $^{6}Li(n,t)^{4}He$ Reaction Rate





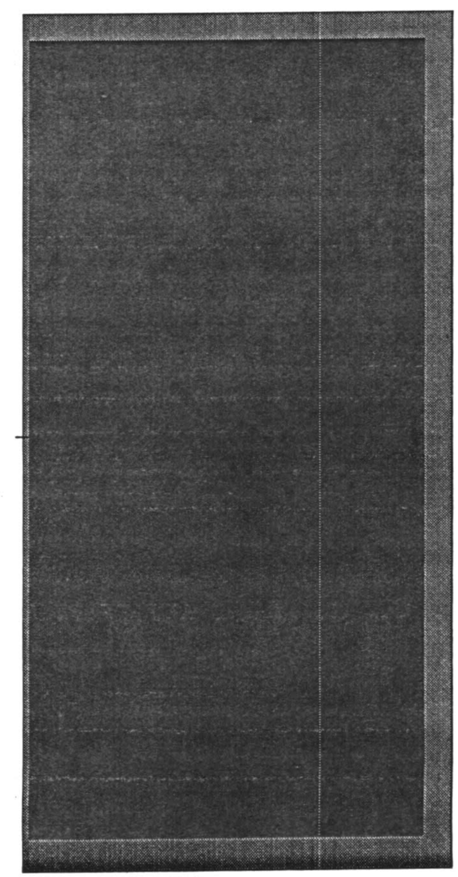
Problem 5: Backscatter from Slab Phantom

Calculate Kerma across face of slab phantom

$$B = \frac{K_a(phantom\ present)}{K_a(free\ in\ air)}$$

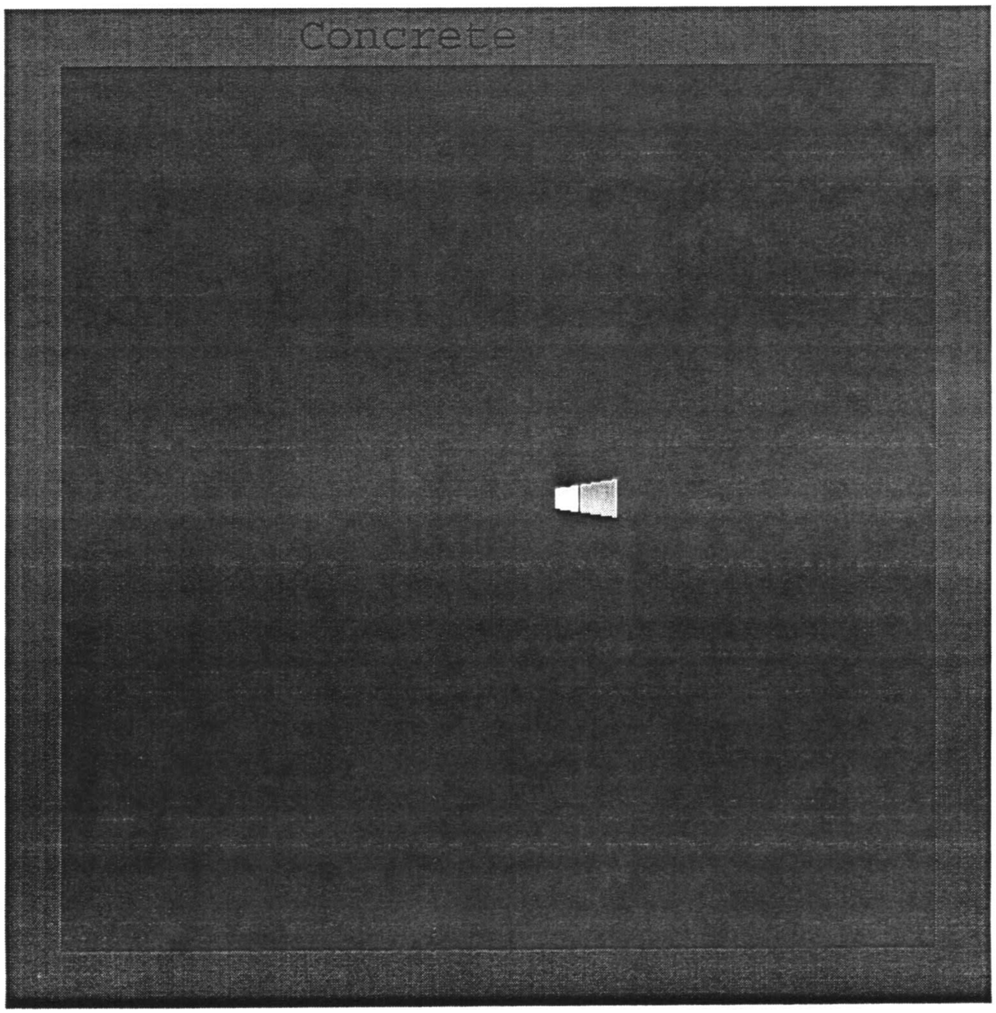
$$K_a = \int_{E_{\min}}^{E_{\max}} \Phi(E)(\mu_{tr}/\rho)_{air}\, E\, dE$$

Air



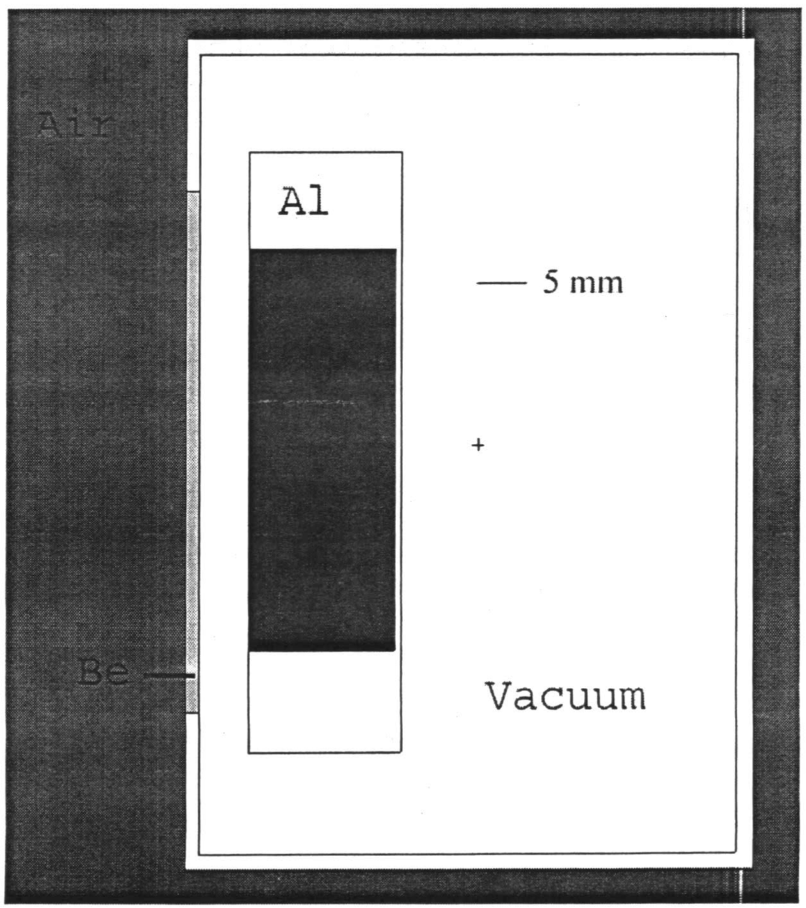
PMMA Container

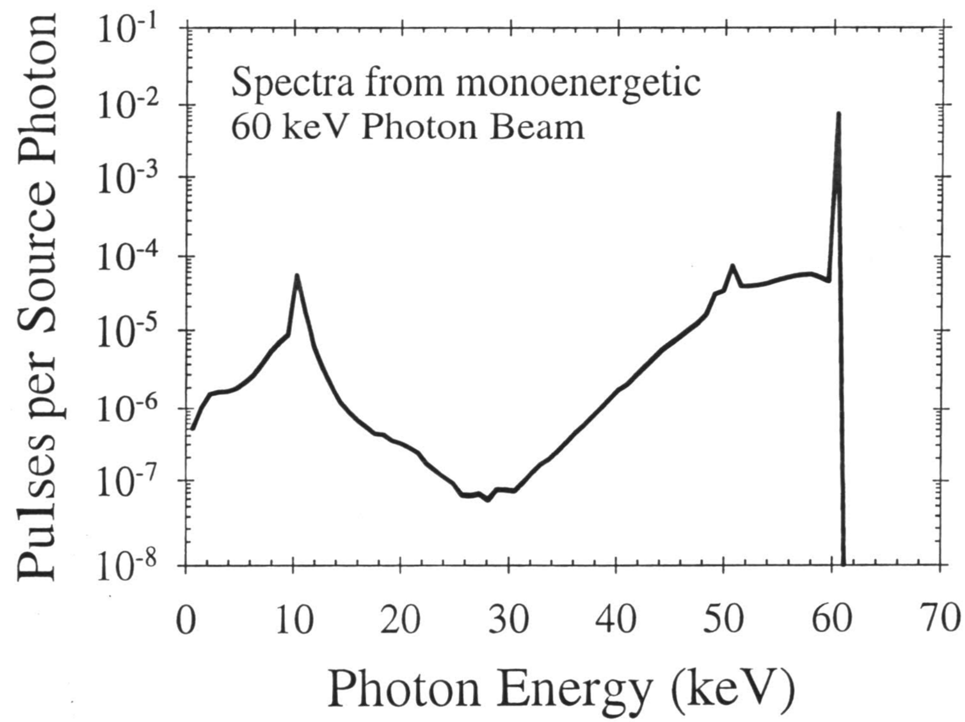
Problem 6: Neutron Detector Calibration



Measure energy and angular dependant neutron flux at detectors in a concrete bunker.

Problem 7: Ge Spectrometer Efficiency



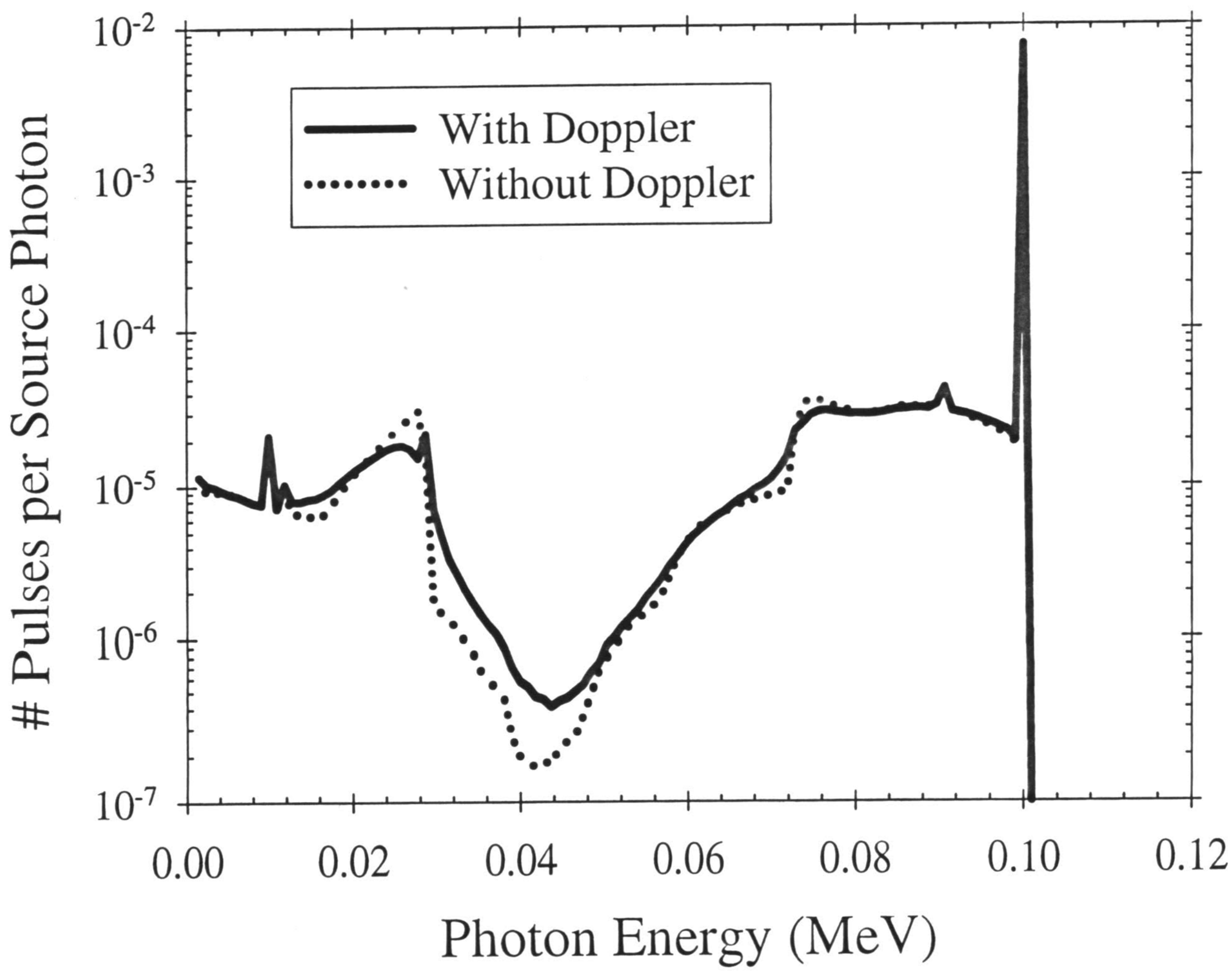


New MCNP5 Features

- Mesh Tally
- Doppler Photon Broadening

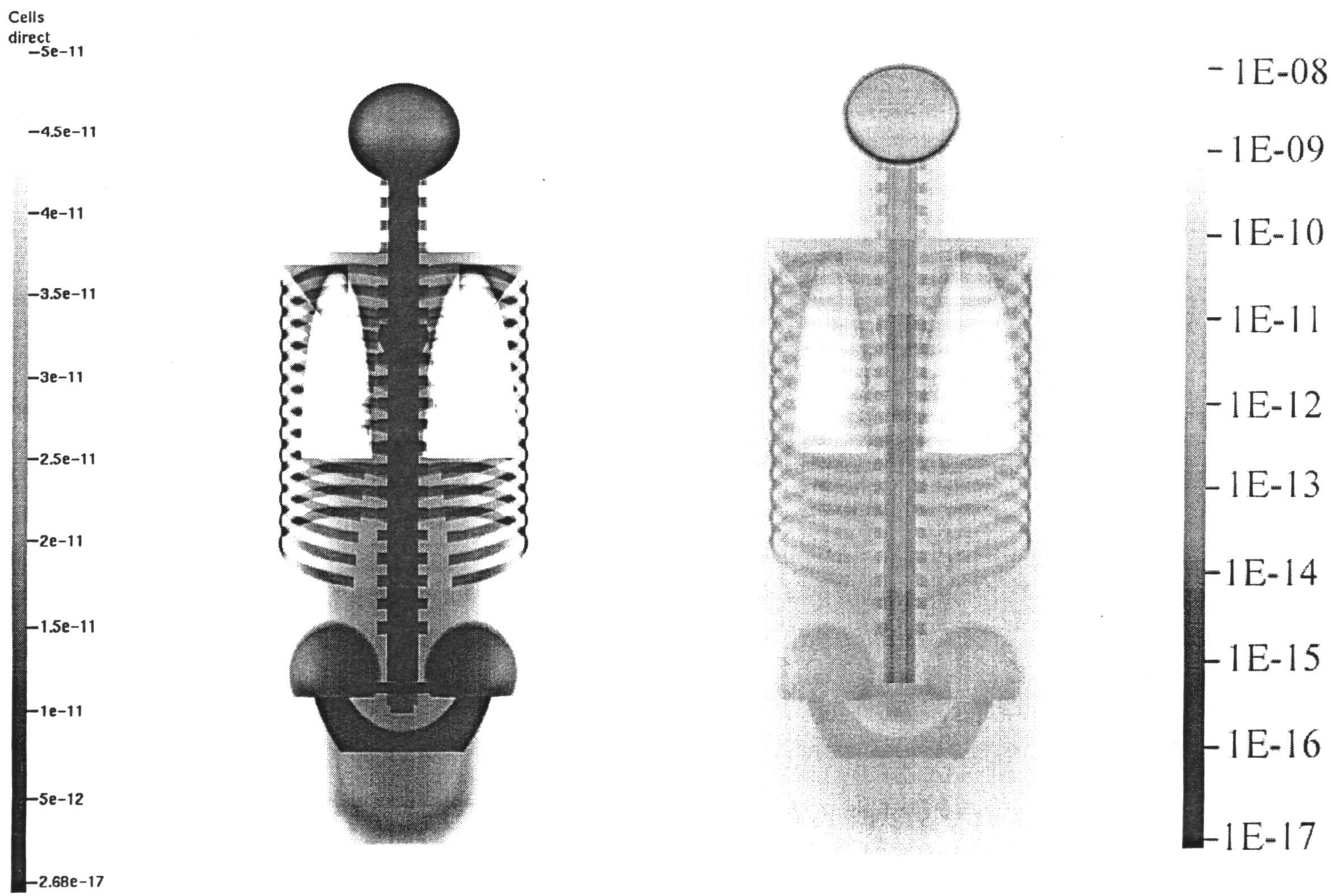
- Neutral Particle Radiography
- Time Importance Weighting

Doppler Photon Broadening



Neutral Particle Radiography

One Million Pixels



Comparison of MCNP 4C2, 4C3, 5

- MCNP5 agrees within statistical error for most cases.

- MCNP5 has comparable, although slightly longer, runtimes than MCNP4C3.

Summary

- These test problems were useful for testing and verifying the new release of MCNP 5.
- New physics and tally features incorporated into MCNP 5 are useful for medical physics problems.
- MCNP 5 and 4c2 produce statistically similar results, but 5 takes slightly longer to run.

Future Work

- Incorporate variance reduction for pulse height tallies (Future version of MCNP5).
- Incorporate additional enhancements for medical physics applications.
- Incorporate these problems into a medical physics class for MCNP.
- Analyze results from EU Intercomparison.