Monte Carlo modeling of an electronic brachytherapy source using MCNP5 and EGSnrc

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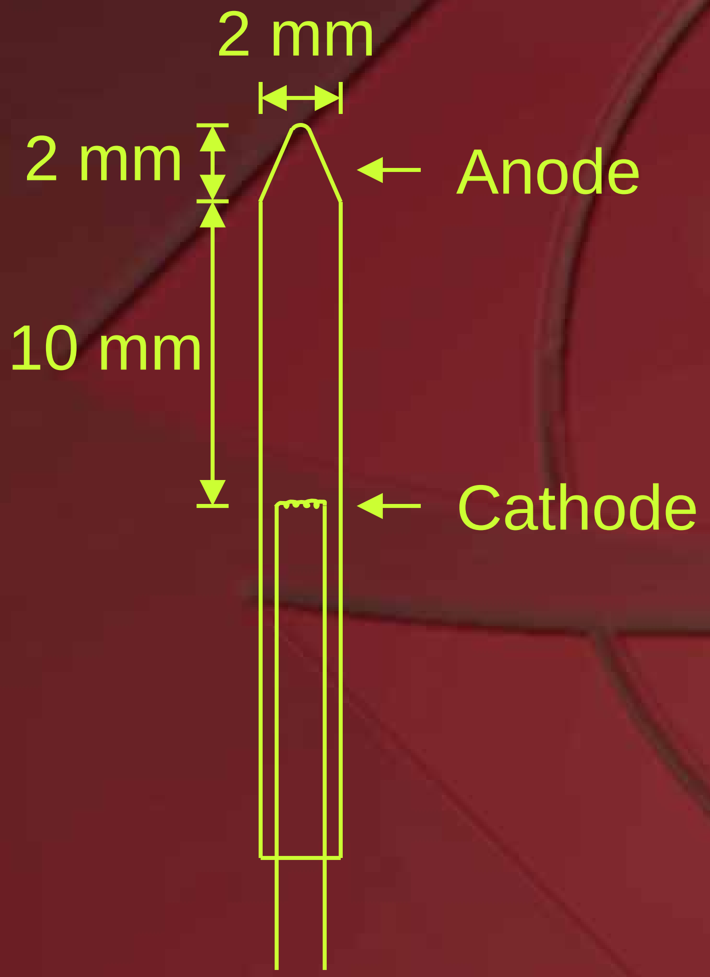
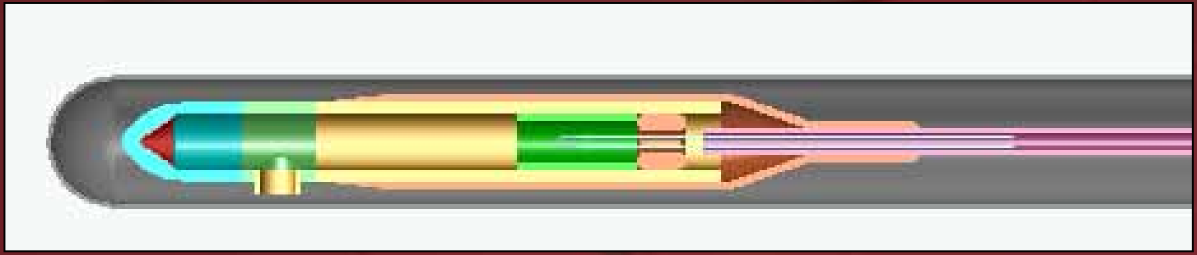
Xoft Axxent^{TM} electronic brachytherapy source



Photos courtesy of Xoft, Inc.

Xoft Axxent^{TM} electronic brachytherapy source



X-Ray Probe Tip Detail

Photos courtesy of Xoft, Inc.

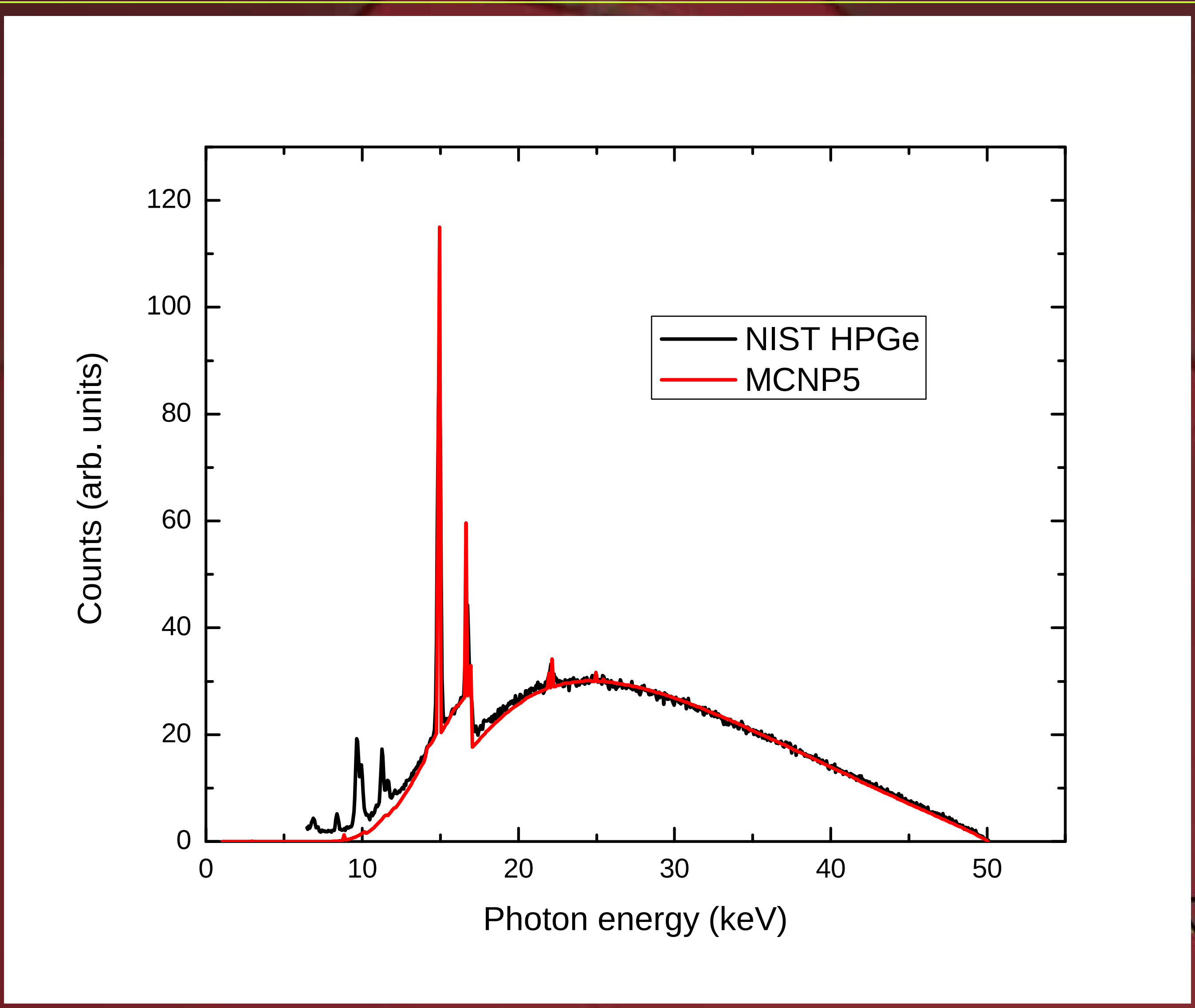
Motivation

- Brachytherapy uses air-kerma strength, S_K, as the measurement of source strength
- Air kerma rates can be measured using free-air ionization chambers, but S_K is defined *in vacuo*
- Correction is required for attenuation in air from the source to the point of measurement (100 cm in our case)
- Air cross sections change rapidly at photon energies < 20 keV
- Photon spectrum needs to be accurately known for a low uncertainty on the air attenuation correction

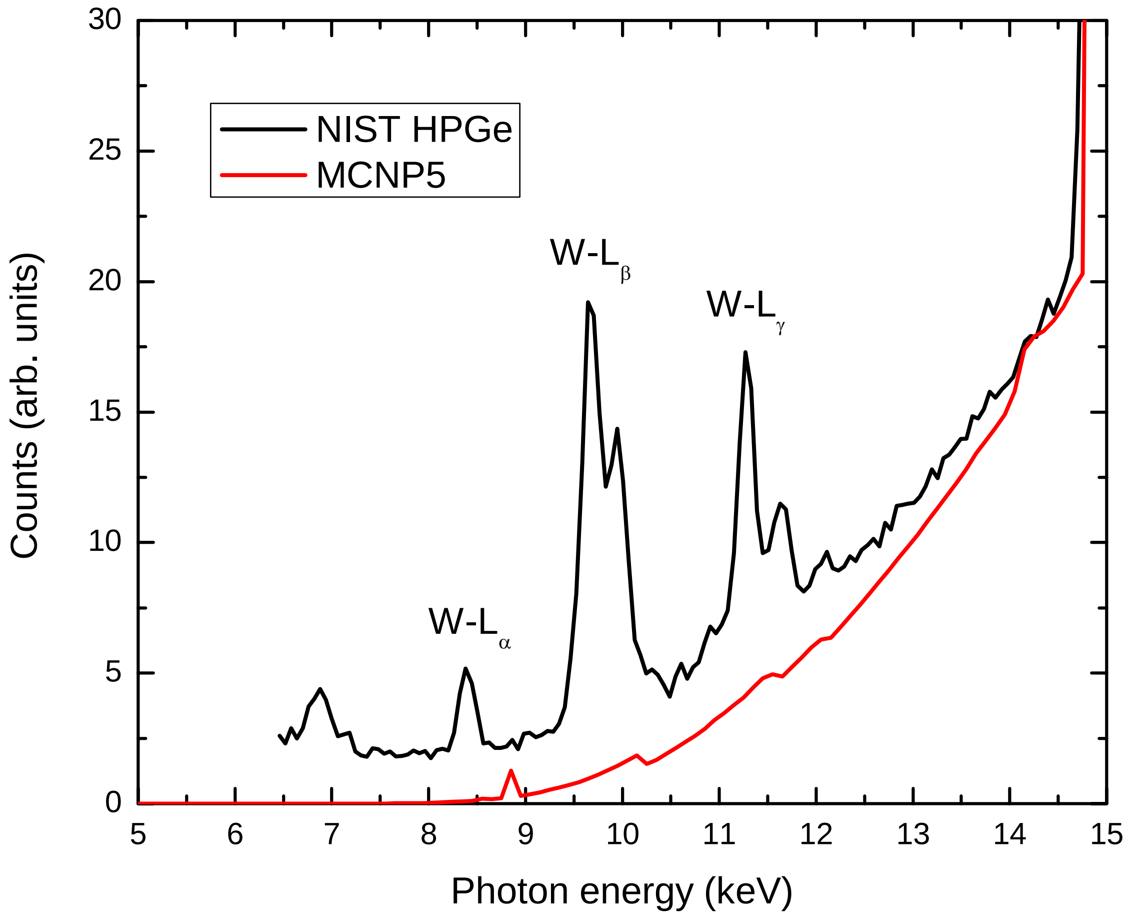
Photon spectra

- Measurements with high purity germanium spectrometer
  - Requires correction for the energy response of the detector
- Monte Carlo simulations
  - Assumes Monte Carlo code has the low energy physics included to model x-ray spectra accurately

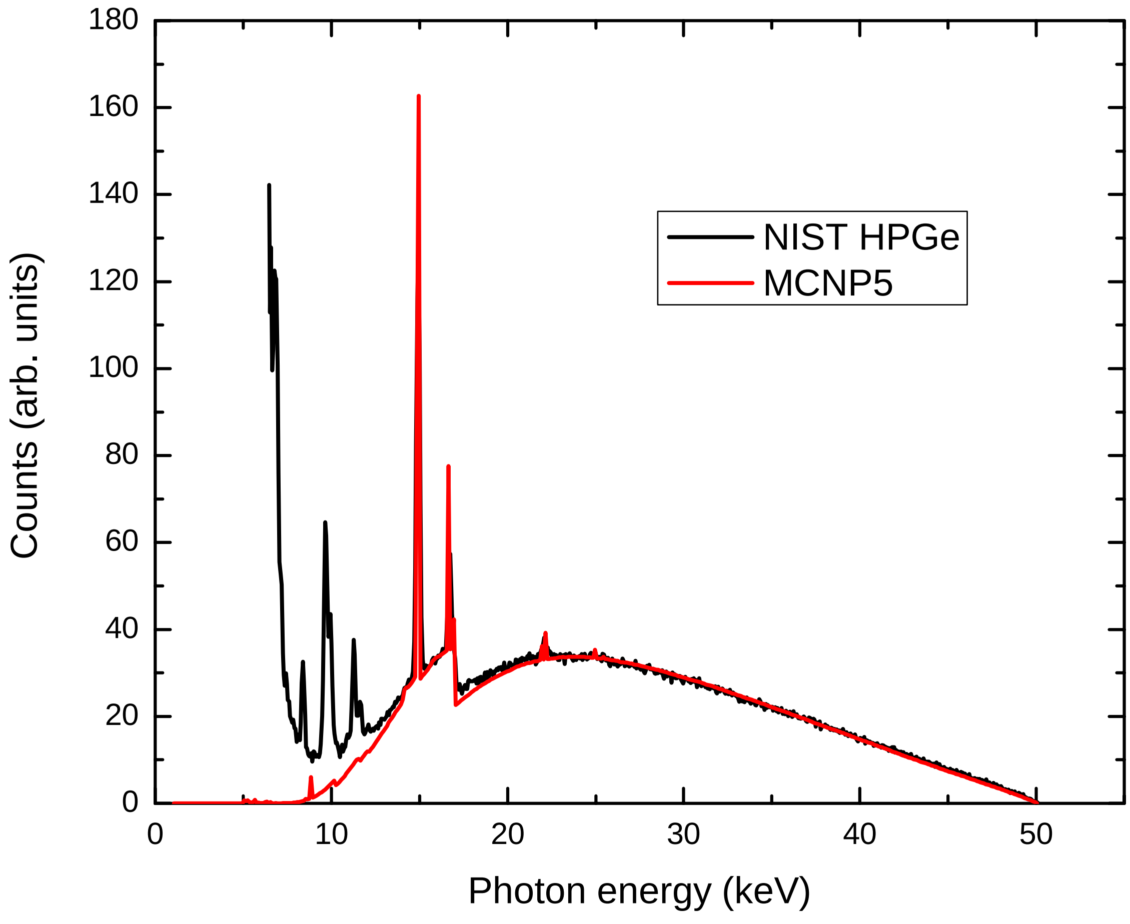
Photon spectra at 178 cm in air



Photon spectra at 178 cm in air



Photon spectra at 0 cm in air



EGSnrc

- January 2005 release included model by Iwan Kawrakow for electron impact ionization for K- and L-shells with binding energies above 1 keV
- October 2005 release included C++ class library with general purpose geometry modeling and user code cavity.cpp
- February 2007 release allowed for scoring of photon spectra in a circular plane using cavity.cpp

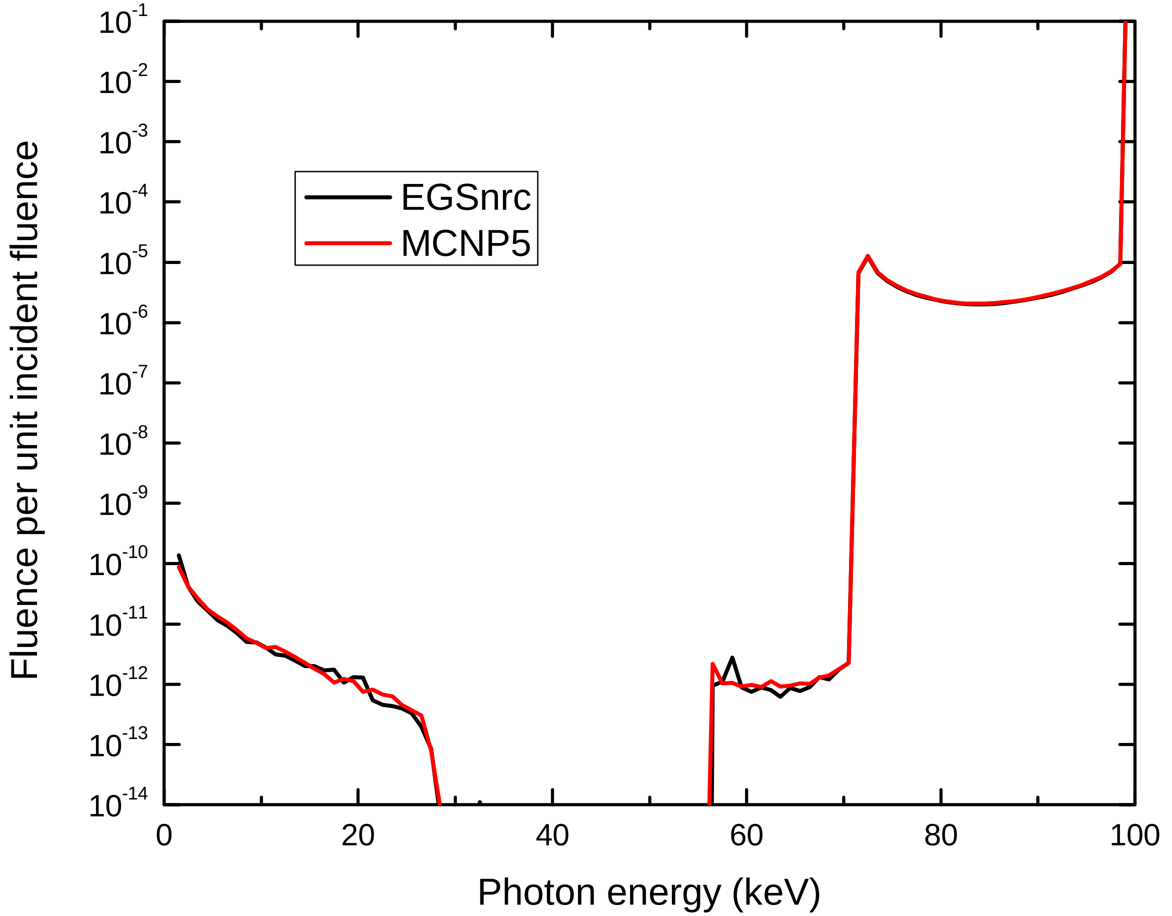
EGSnrc vs. MCNP5

- Two codes have differences in:
  - Electron impact ionization
  - Binding effects and Doppler broadening for Compton interactions
  - Atomic relaxation
  - Electron transport
  - Variance reduction techniques
  - Scoring options

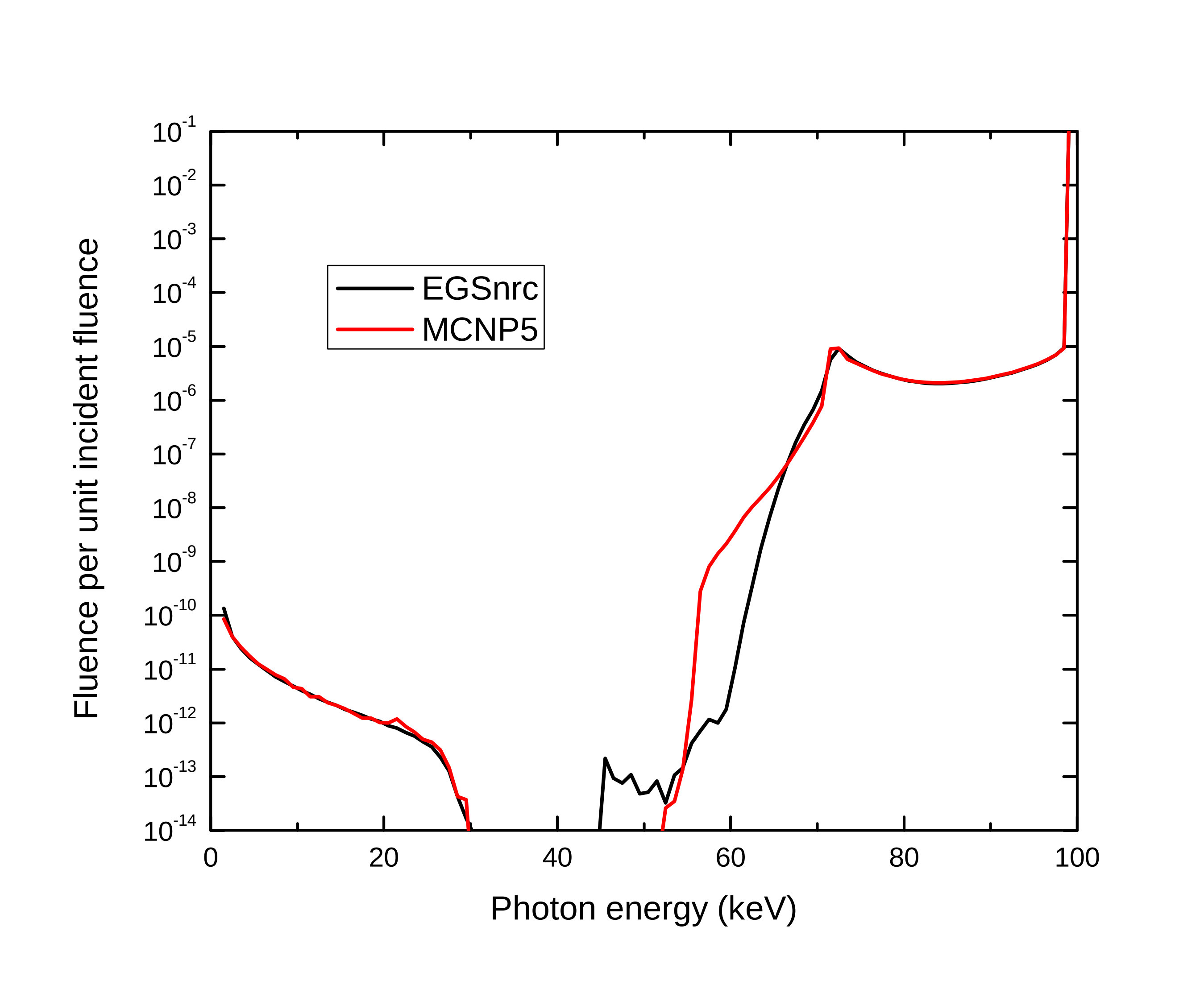
Doppler broadening

- “Broomstick problem” from MCNP5 LANL document
- 100 keV photons incident on 10 cm graphite rod with 10^{-6} cm radius

No Doppler broadening



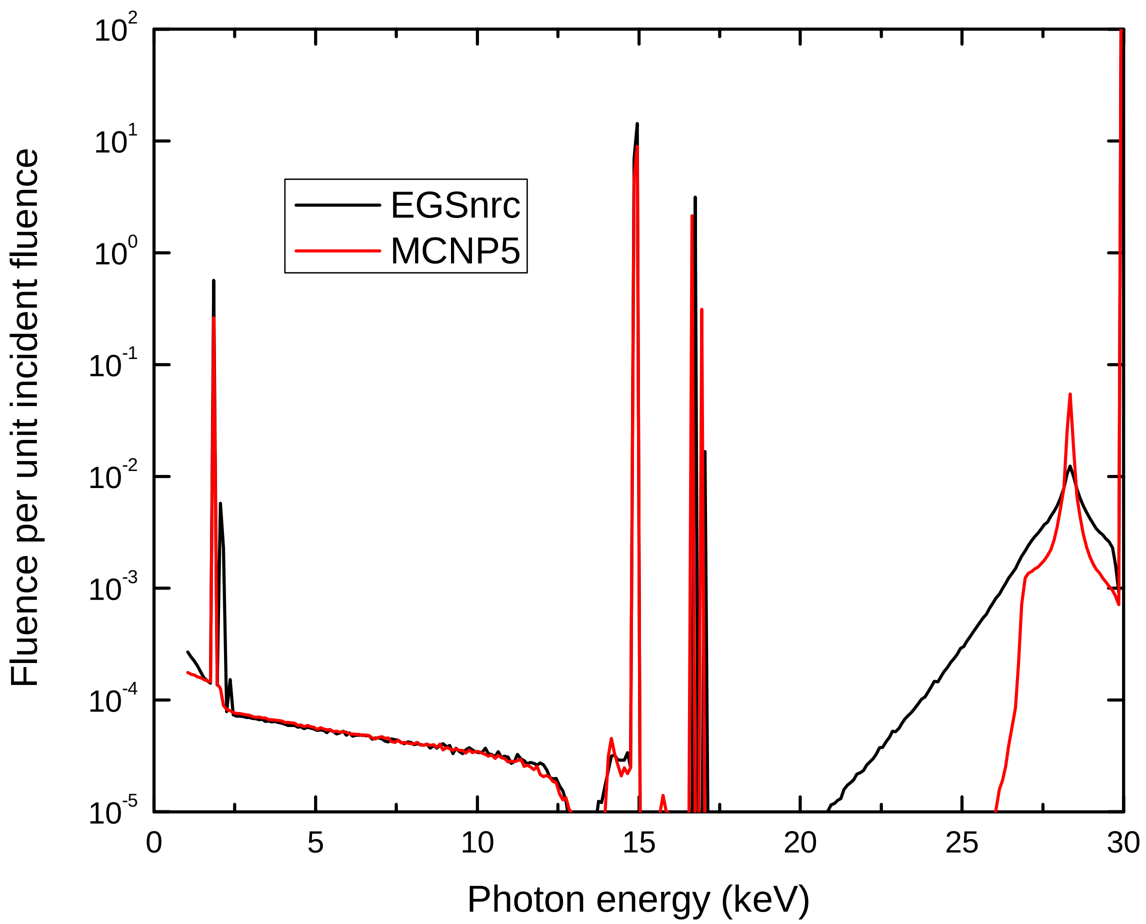
With Doppler broadening



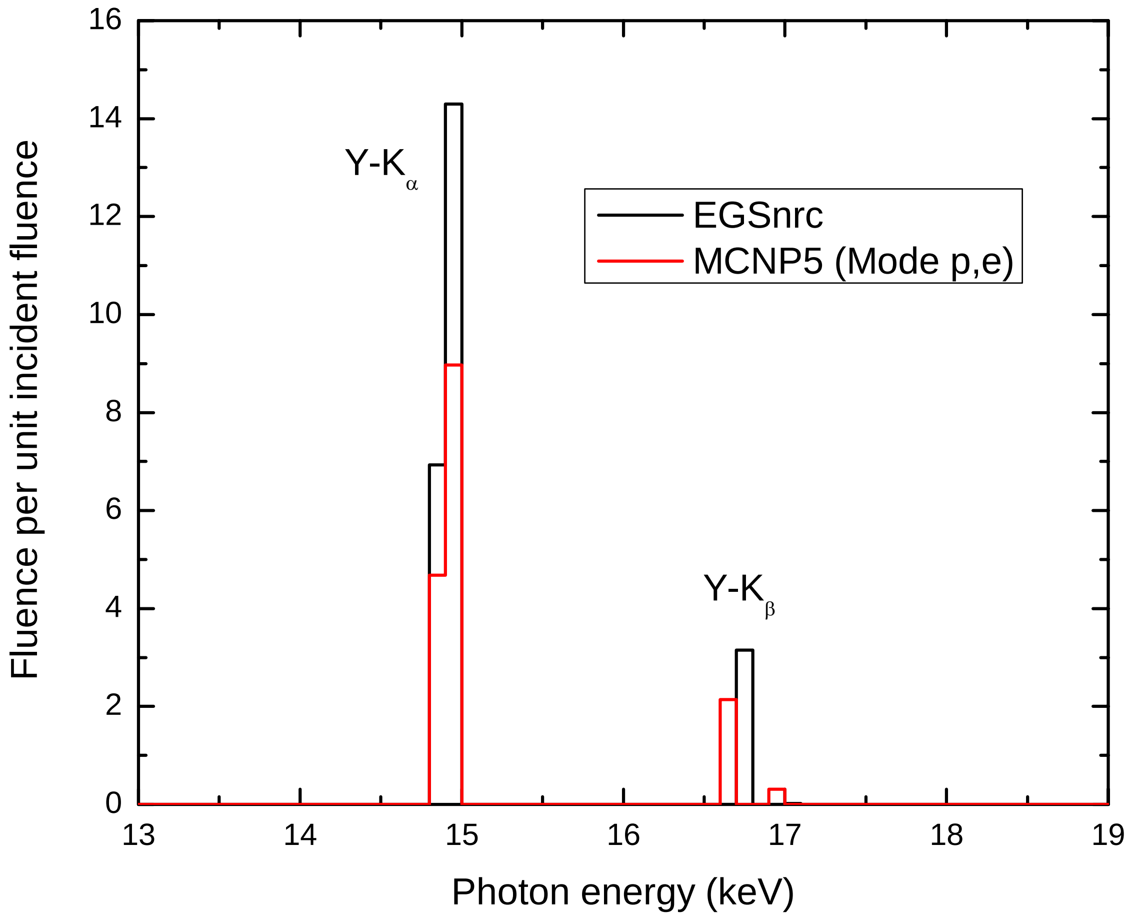
Atomic relaxation

- 30 keV photons incident on 10^{-5} cm thick yttrium slab

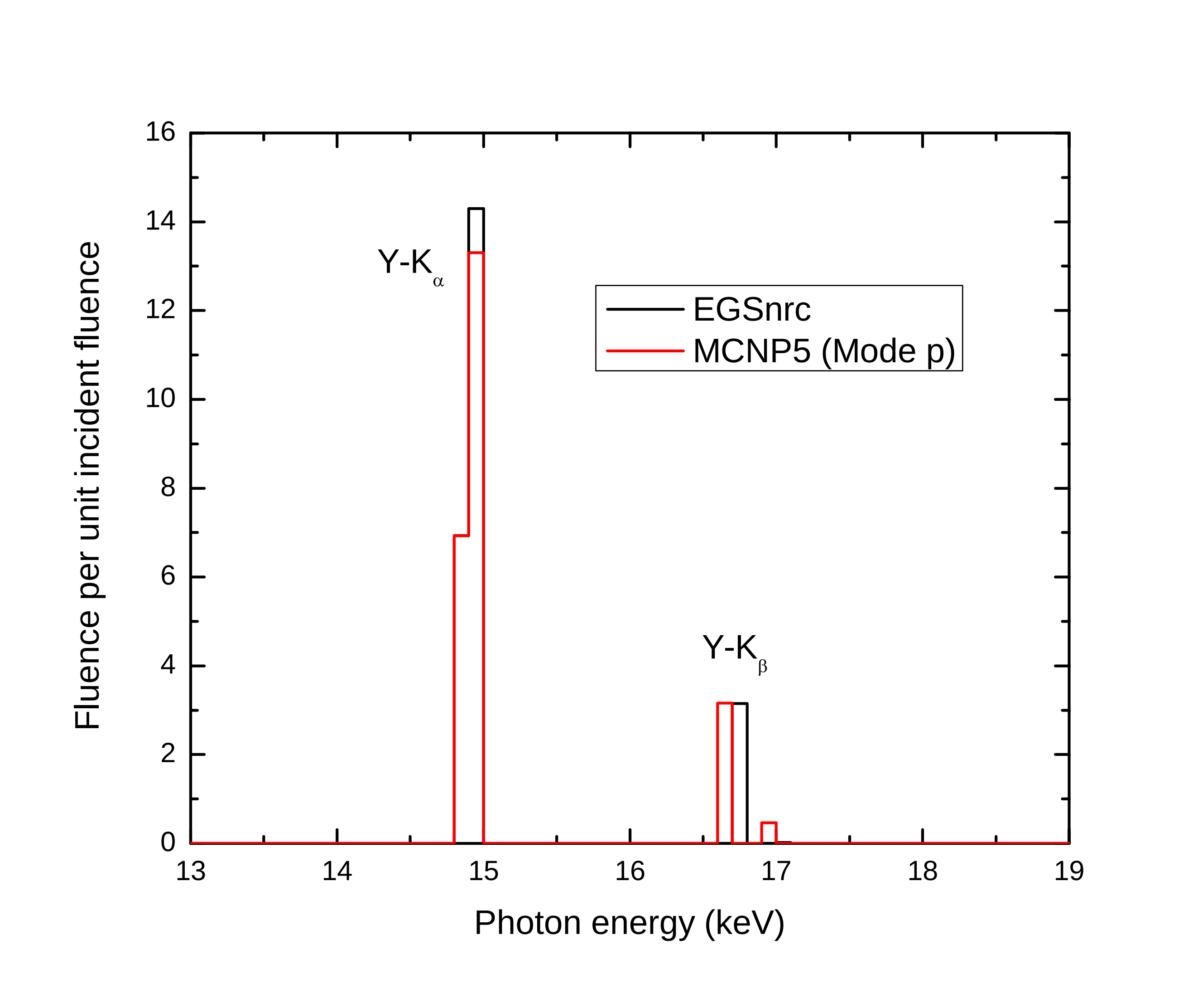
Atomic relaxation (cont.)



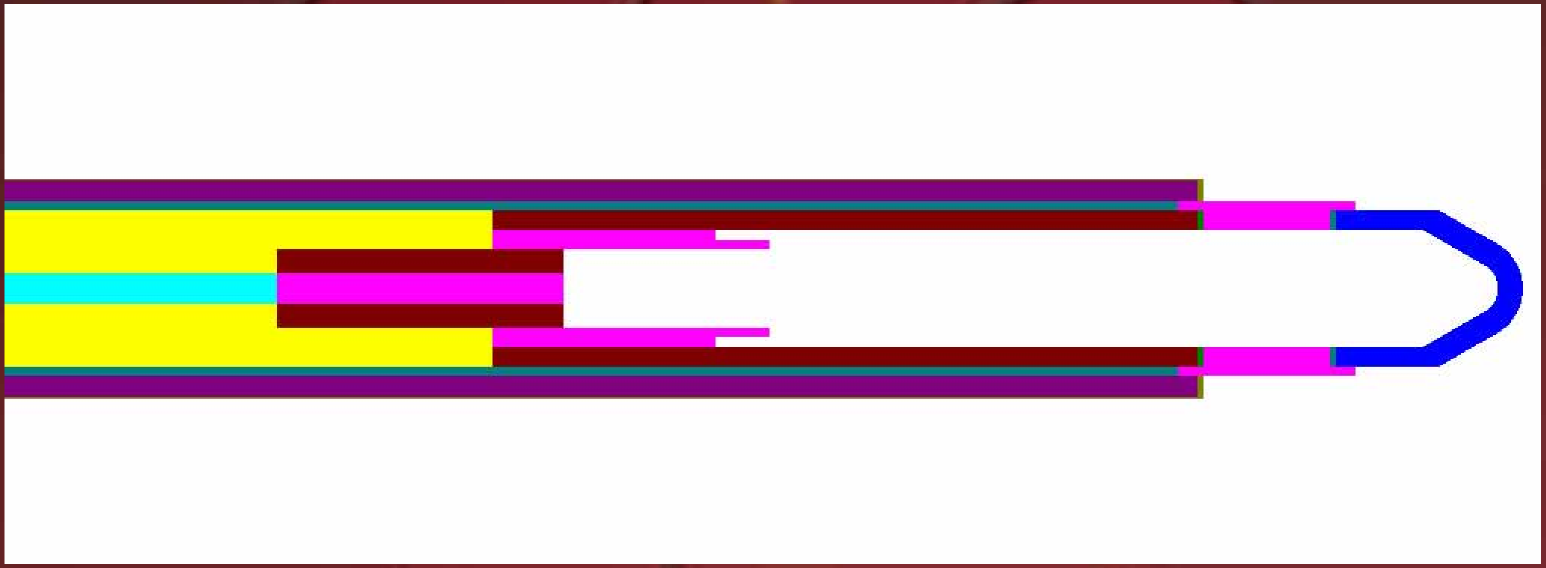
Atomic relaxation (cont.)



Atomic relaxation (cont.)



cavity.cpp model of Axxent™ source



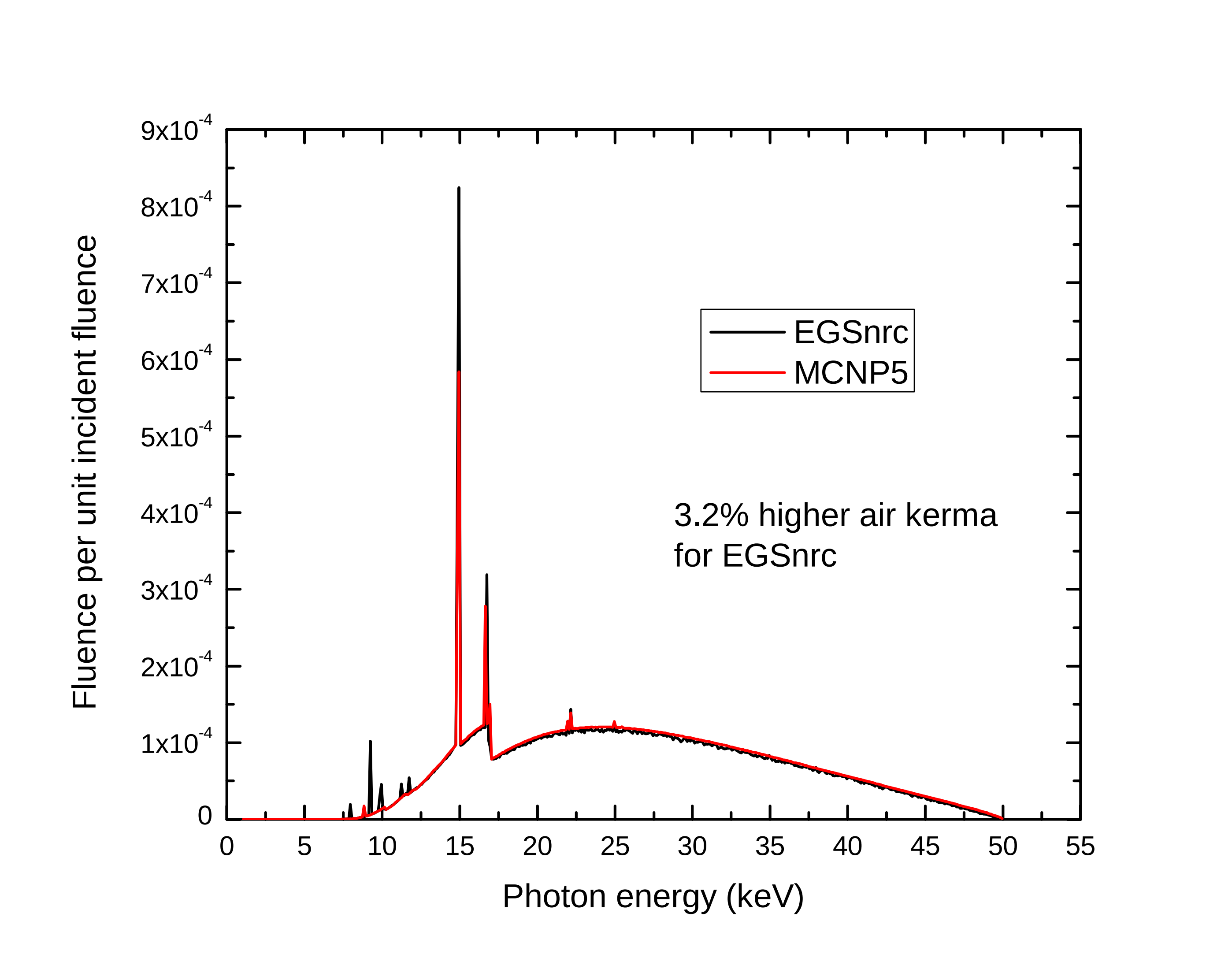
Dose rates at 1 cm in water

MC code	$P\ (r_0, \theta_0)$ [cGy·h^{-1}·μA^{-1}]
MCNP5	345 ± 0.1%
EGSnrc	346 ± 2.0%
EGSnrc/MCNP5	1.003 ± 2.0%

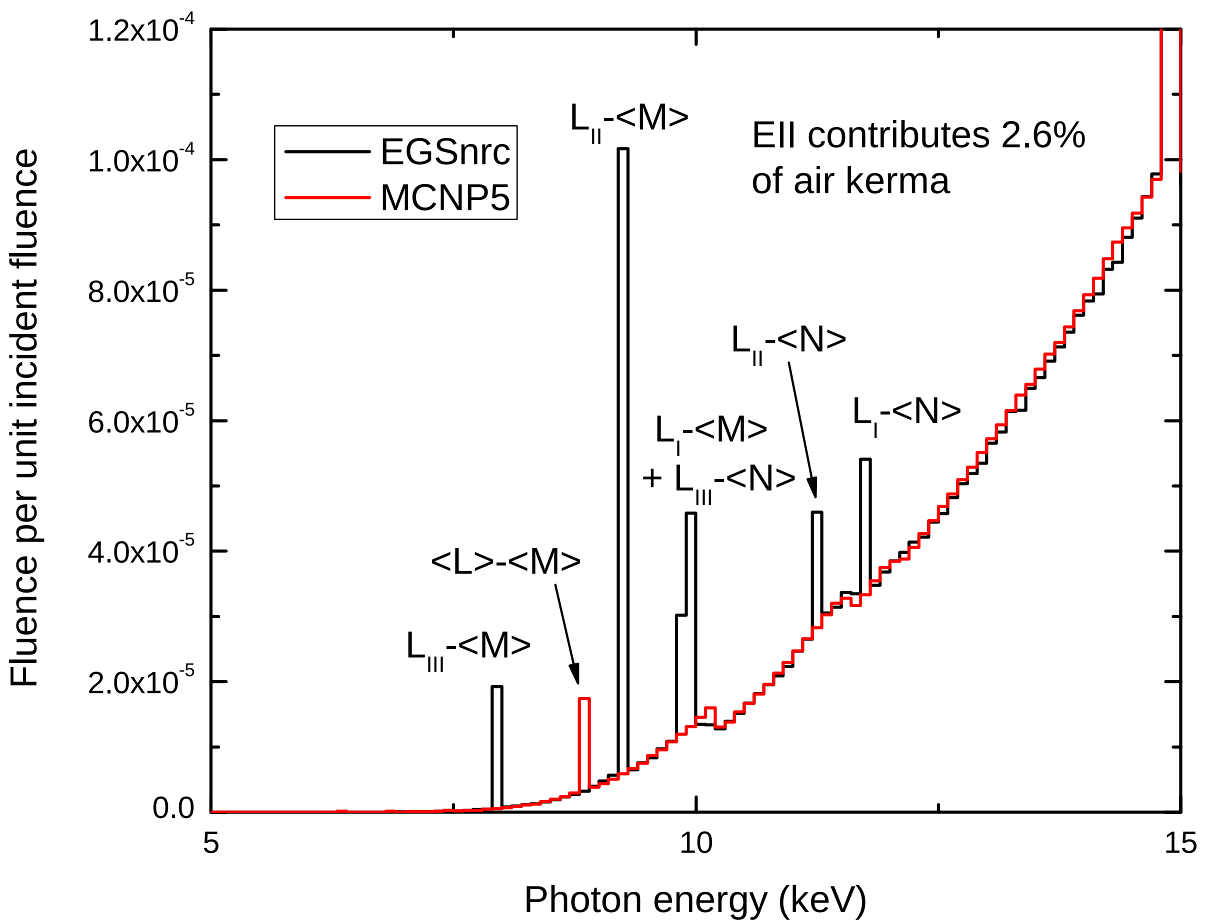
Air kerma rates at 100 cm in air

MC code	$P(r_0,\theta_0)$ [$cGy \cdot h^{-1} \cdot \mu A^{-1}$]
MCNP5	$4.81 \cdot 10^{-2} \pm 0.1\%$
EGSnrc	$4.72 \cdot 10^{-2} \pm 3.1\%$
EGSnrc/MCNP5	$0.981 \pm 3.1\%$

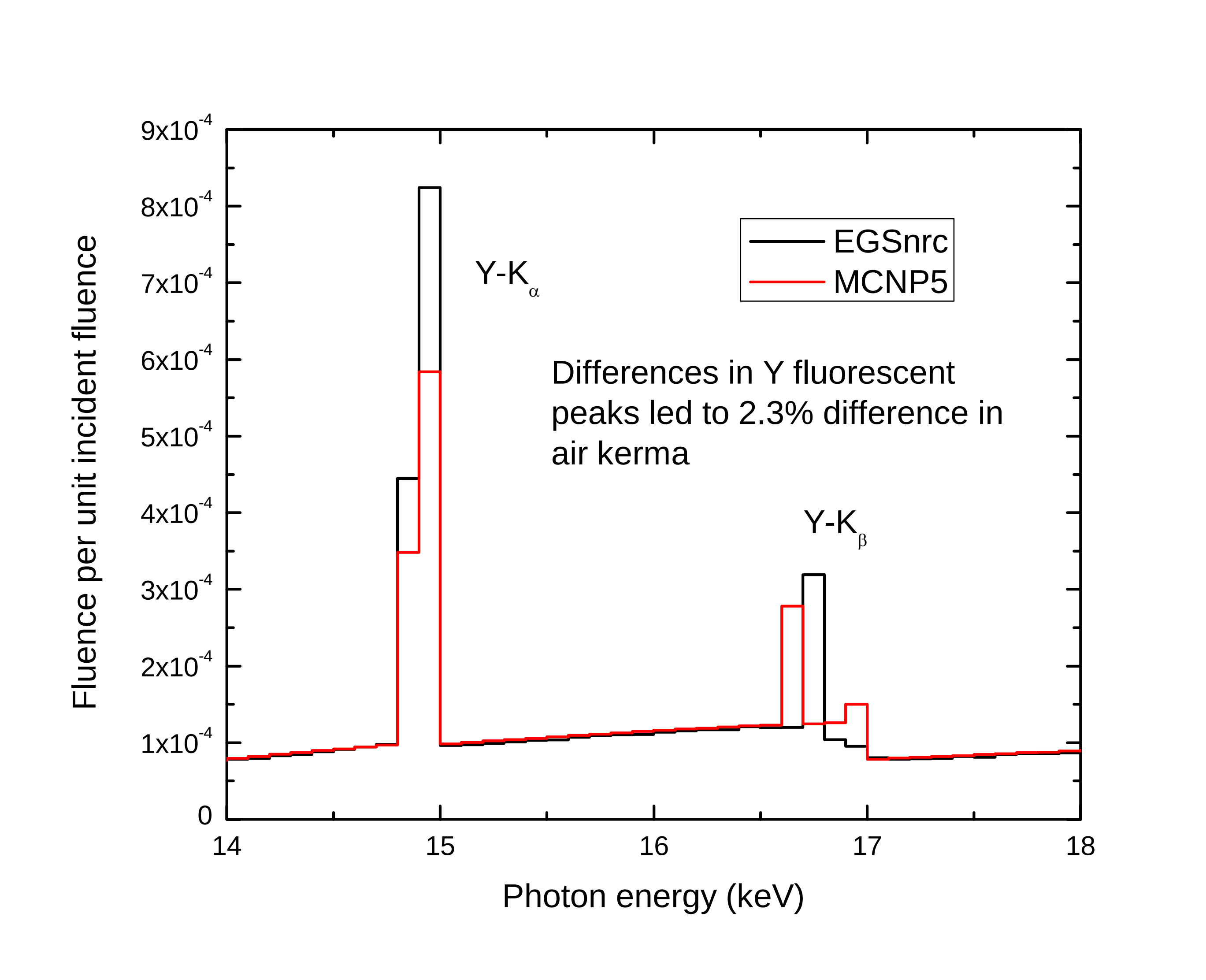
Calculated photon spectra at 1 cm in vacuum



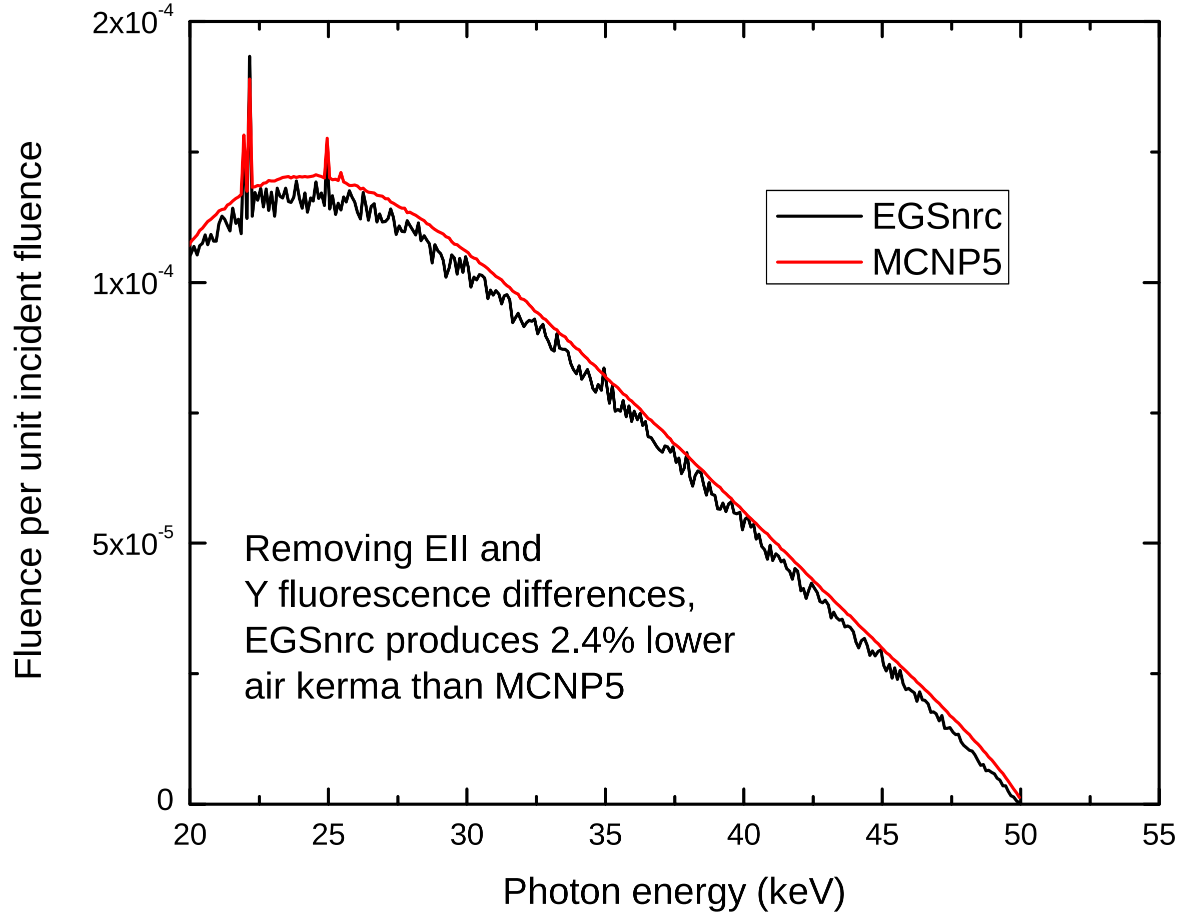
Calculated photon spectra at 1 cm in vacuum



Calculated photon spectra at 1 cm in vacuum



Calculated photon spectra at 1 cm in vacuum



Conclusions

- Both codes produce similar water dose rates, air kerma rates, and photon spectra, and the small differences can be explained by different treatment of the low energy physics

- Further work will be necessary to compare these results to measurements, and to establish the required air attenuation corrections with low uncertainties

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