Radiation Treatment Planning Using Discrete Ordinates Codes

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Outline

- Motivation
- Investigation
- Results
- Conclusions
- Future Work

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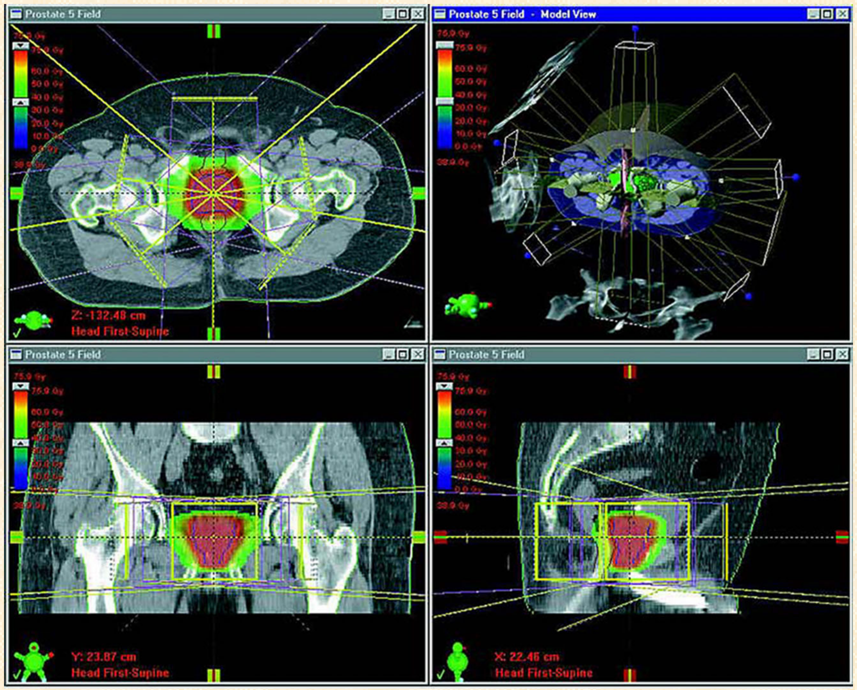
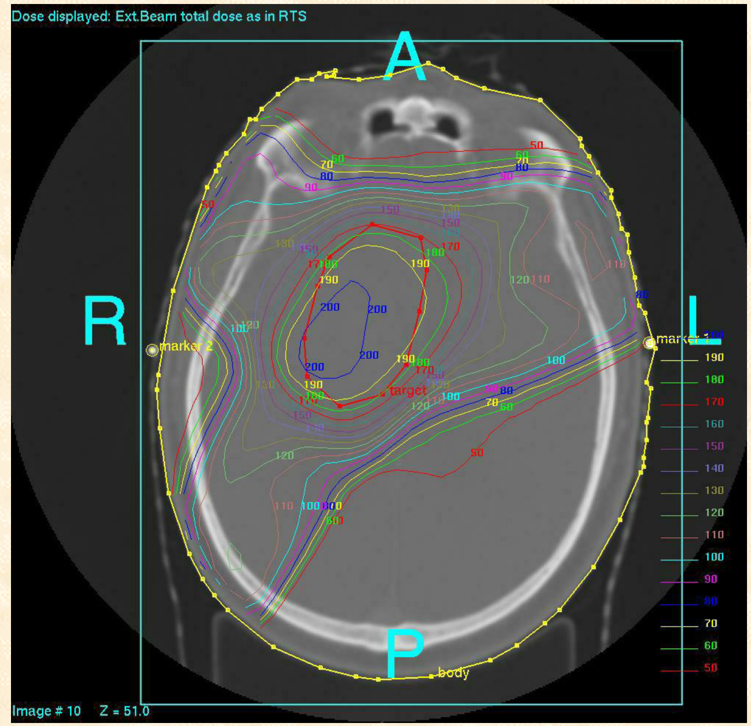
Motivation

- Cancer can be treated with external gamma beams which generate the electrons that cause the dose to the patient.





- As treatment methods become more precise we need to quickly model electron transport.

Motivation(2)

- Monte Carlo methods can model electrons accurately, but this takes a long time.
- Discrete Ordinates methods run quickly but have not been developed for electron transport*.
- Speed and accuracy are important for treatment optimization.
- Can TORT handle charged particle transport without modification if cross sections are defined in a manner that accounts for the electrons?

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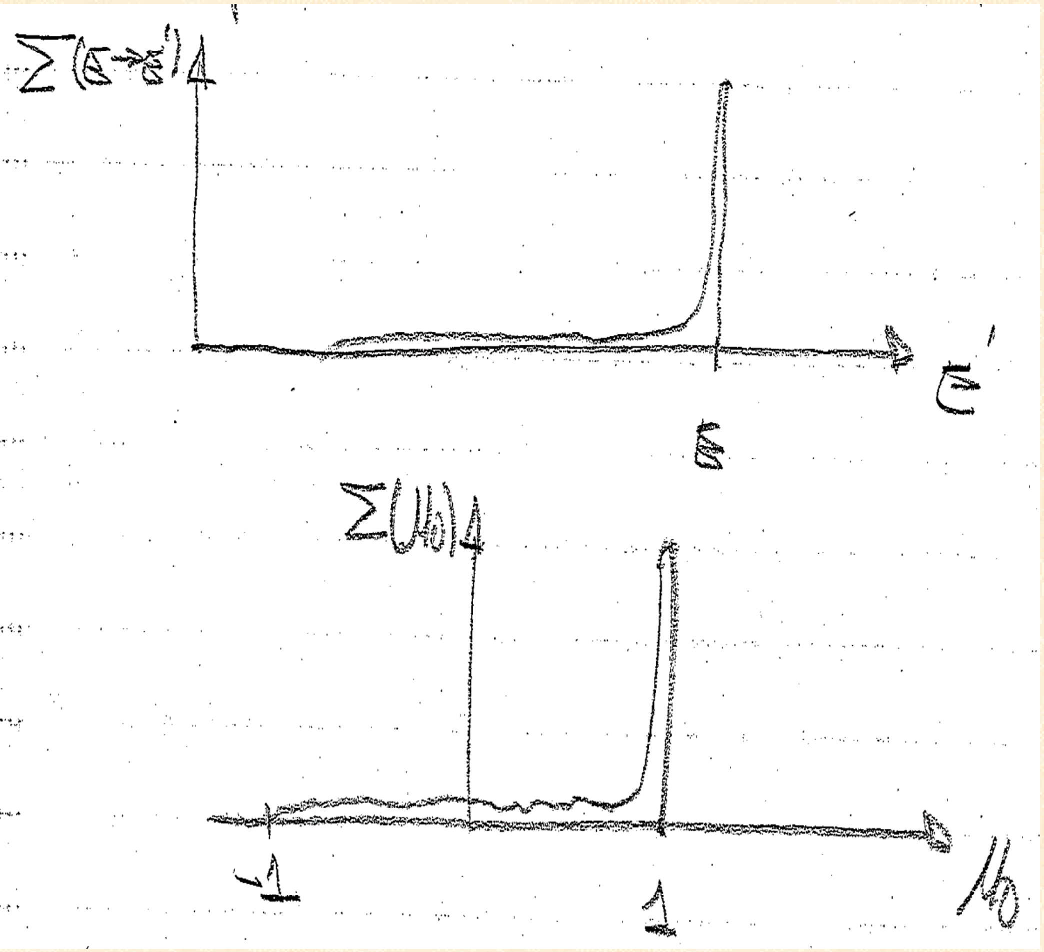
Electron Cross Sections



- Electron cross sections have two major pieces: a smooth part and a singular part.
- It is difficult to account for this type of interaction.
- Solution: make continuous slowing down (CSD) and continuous scattering (CS) approximations.

Boltzmann-Fokker-Planck

- The BFP equation is a Boltzmann equation that has been modified to treat charged particles.

$$-\frac{\partial}{\partial E}\left[\beta(\vec{r},E)\psi\right] - T(\vec{r},E)\left\{\frac{\partial}{\partial\mu}\left[(1-\mu^2)\frac{\partial\psi}{\partial\mu}\right] + \frac{1}{1-\mu^2}\frac{\partial^2\psi}{\partial\varphi^2}\right\} + (\vec{\Omega}\vec{\nabla})\psi +$$

$$\sigma_t(\vec{r},E)\psi(\vec{r},\mu,\varphi,E) = \int_0^{\infty} dE'\int_0^{2\pi} d\varphi'\int_{-1}^{+1} d\mu'\sigma_s(\vec{r},E'\rightarrow E,\mu_s)\psi(\vec{r},\mu',\varphi',E')$$

$$+F(\vec{r},\mu,\varphi,E)$$

- The first two terms are the Fokker-Planck operators:
  - The first term represents the CSD term.
  - The second term represents the CS term.

Boltzmann-Fokker-Planck(2)

- Details of these two terms:

$$\beta(E) = \int_0^E 2\pi \int_{-1}^{+1} \sigma_{\sin g}(E \to E', \mu_s)(E - E')\, d\mu_s\, dE'$$

➢Restricted stopping power

$$\sigma_{\sin g}(E \to E', \mu_s)$$

➢Singular part of cross section

$$T(E) = \frac{\alpha(E)}{2}$$

$$\alpha(E) = \int_0^E 2\pi \int_{-1}^{+1} \sigma_{\sin g}(E \to E', \mu_s)(1 - \mu_s)\, d\mu_s\, dE'$$

➢Restricted momentum transfer

- The remaining terms make up the Boltzmann equation.

Codes Used

- CEPXS-BFP: generated cross sections
- ARVES: processed cross sections
- GIP: formatted cross sections
- GRTUNCL3D: generated uncollided plus a first-collided source
- DOORS3.2a (ANISN, DORT, TORT): transport with discrete ordinates
- EGSnrc: transport with Monte Carlo, used for reference case

Problems Solved

1) Varying density 1-D water layers (all)
   - Represents lung phantom
   - Taken from CT data
   - Isotropic Source normalized to 1
2) Homogeneous water cube (TORT only)
   - Density 1
   - Isotropic source normalized to 1
3) Sources
   - Photons only
   - Electrons only
   - Photons generating electrons

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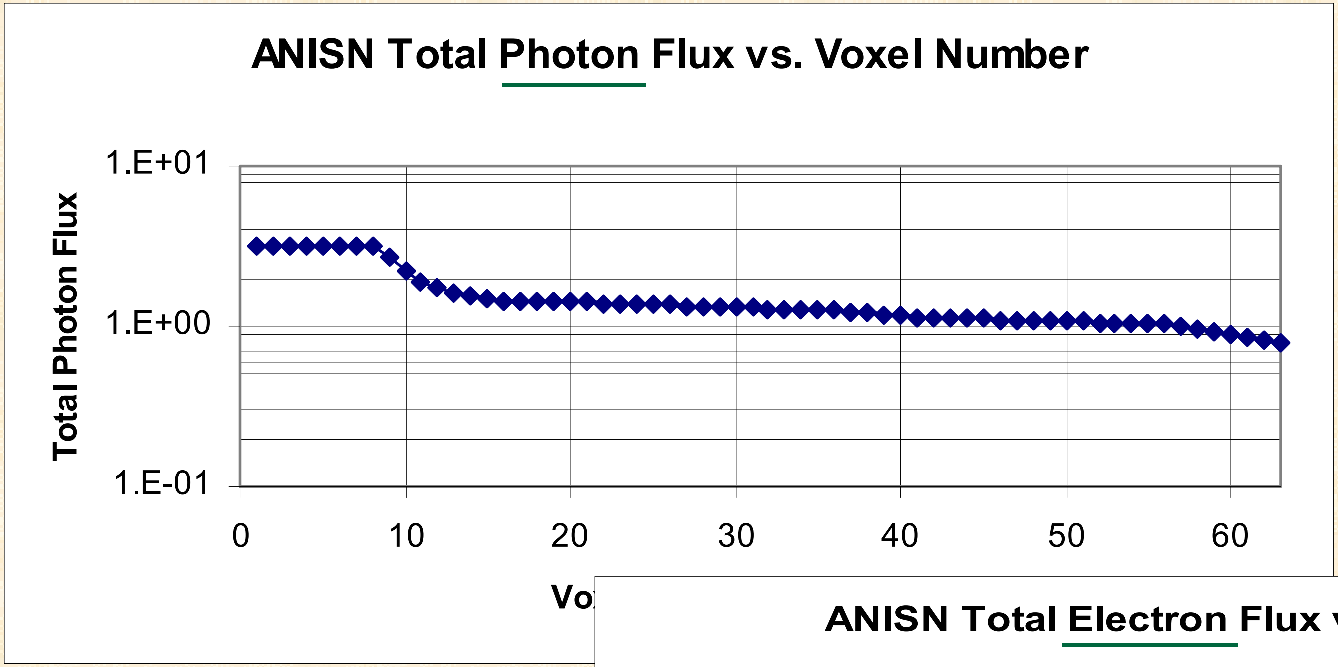
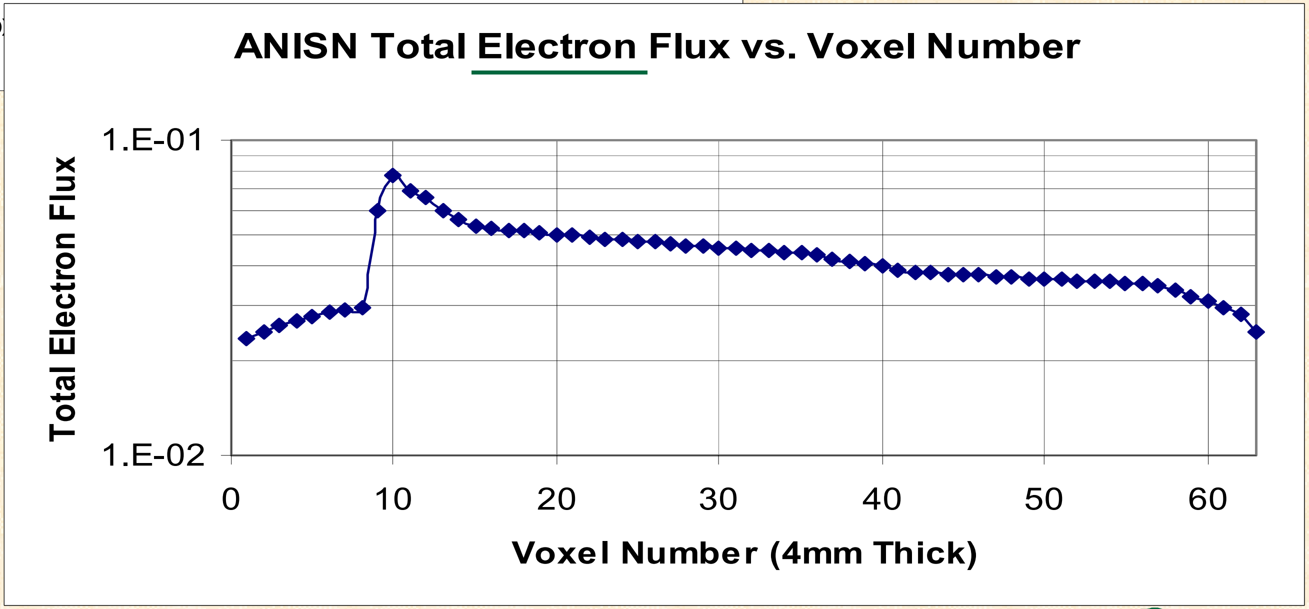
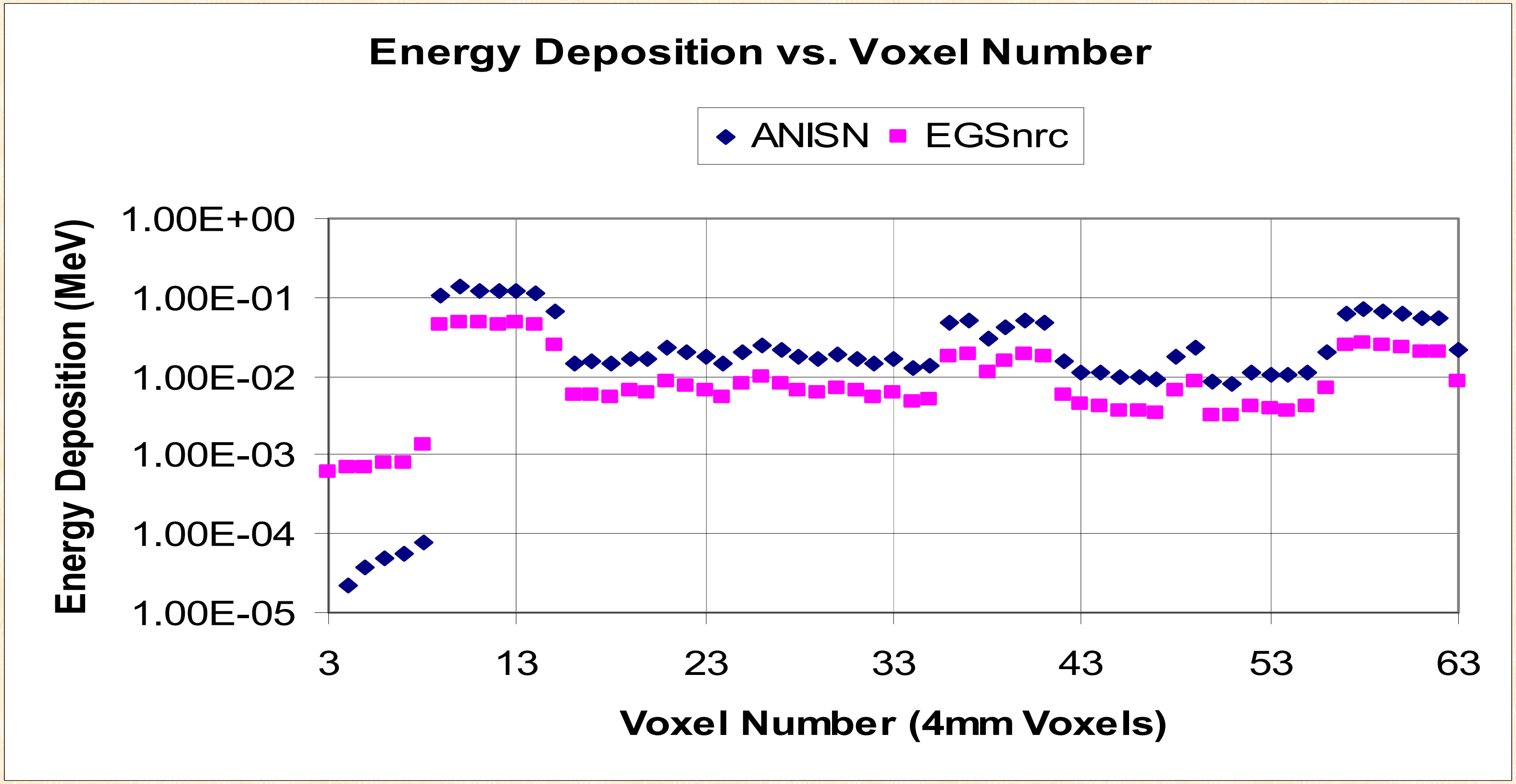
ANISN Flux in Lung Phantom



ANISN was within 4.5% of EGSnrc results after voxel number 10.



ANISN Energy Deposition in Lung Phantom

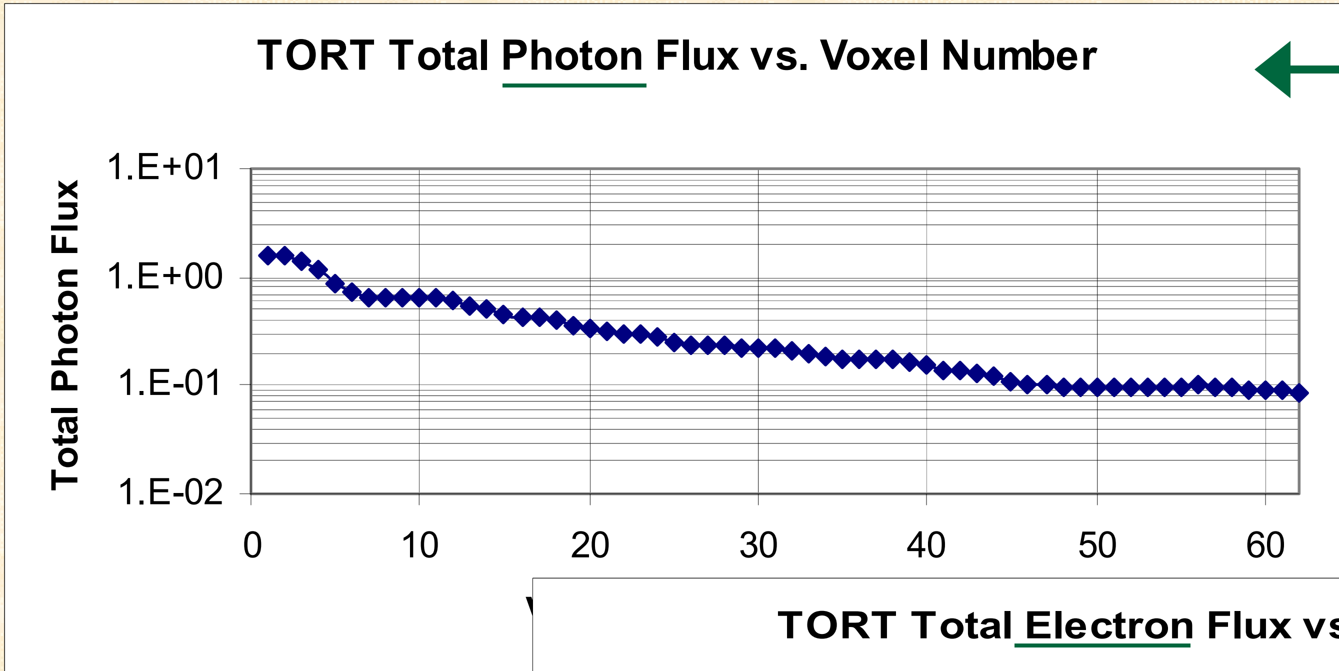


- High by a factor of 3.8, but the general trend is correct.
- Treatment of the kerma factors needs further investigation.

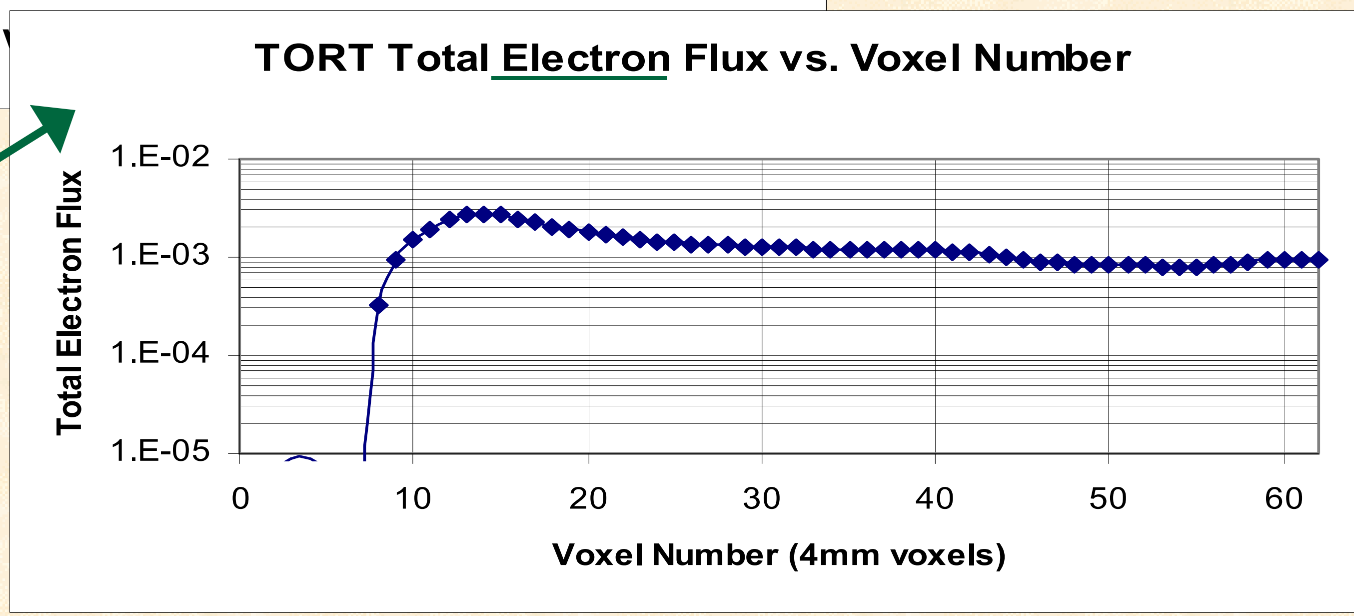
DORT Flux in Lung Phantom

- For photon flux most voxels had errors of less than 5%; the largest error was within 10%.
- For electron flux DORT generally overestimated the electron flux by about 10%.
- The energy deposition exhibited the same behavior as in ANISN.
- Some error may have come from approximating a 1-D solution with a 2-D code.
- This confirms the need to look further in to the kerma factors.

TORT Flux in Lung Phantom

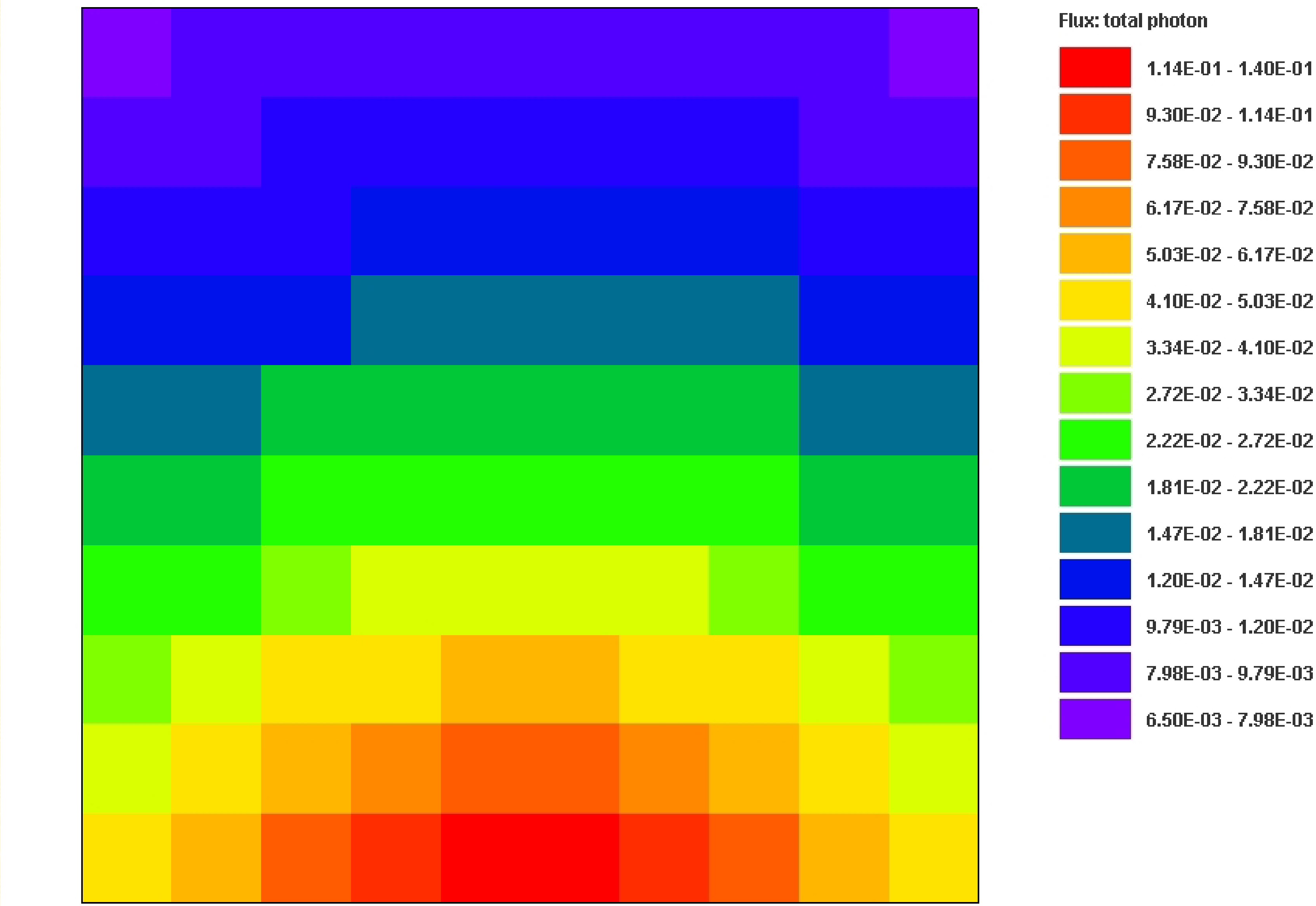


TORT photons did not agree with EGSnrc: modeling a 1-D problem in 3-D.

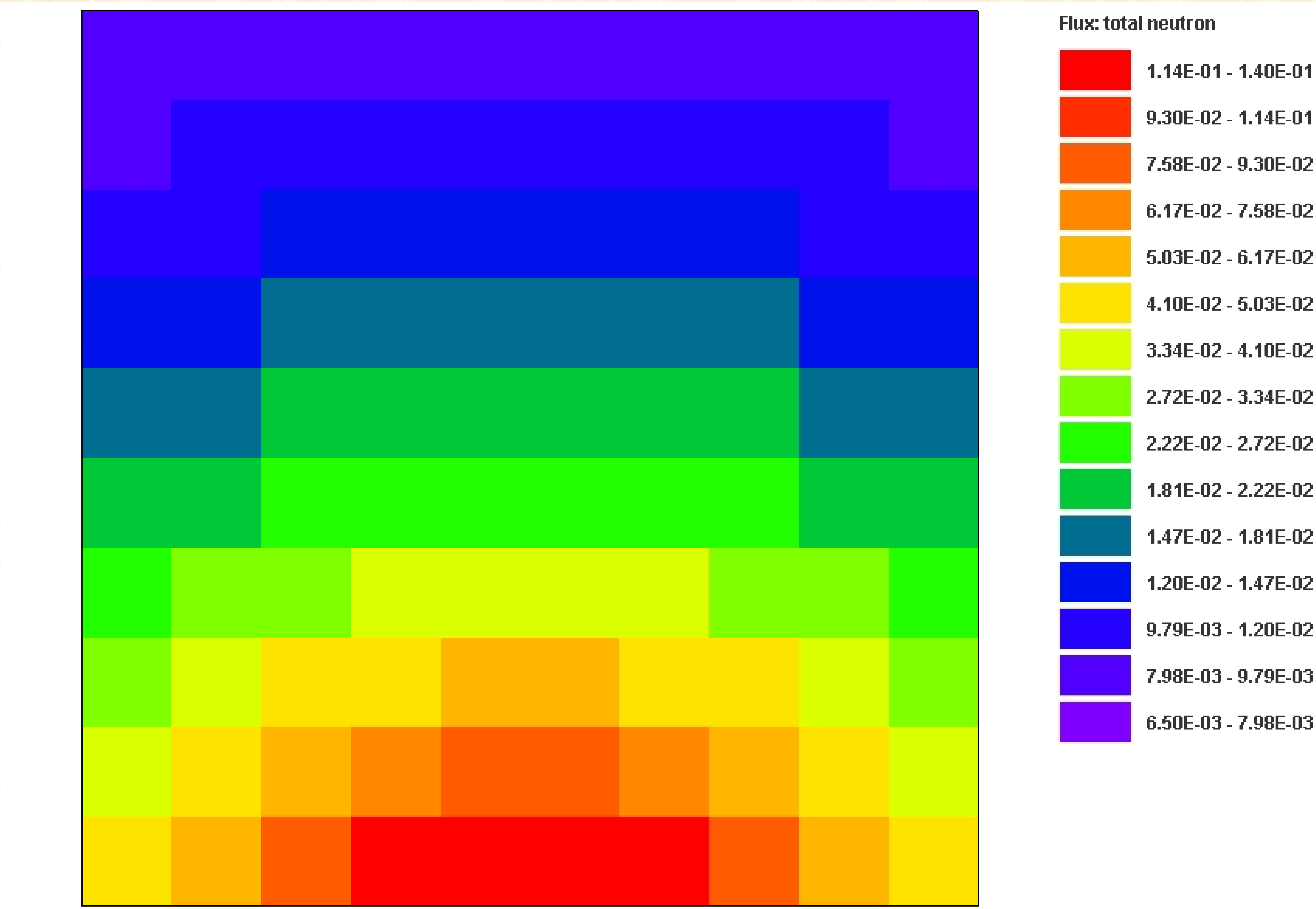


TORT electron flux was not expected to agree well.

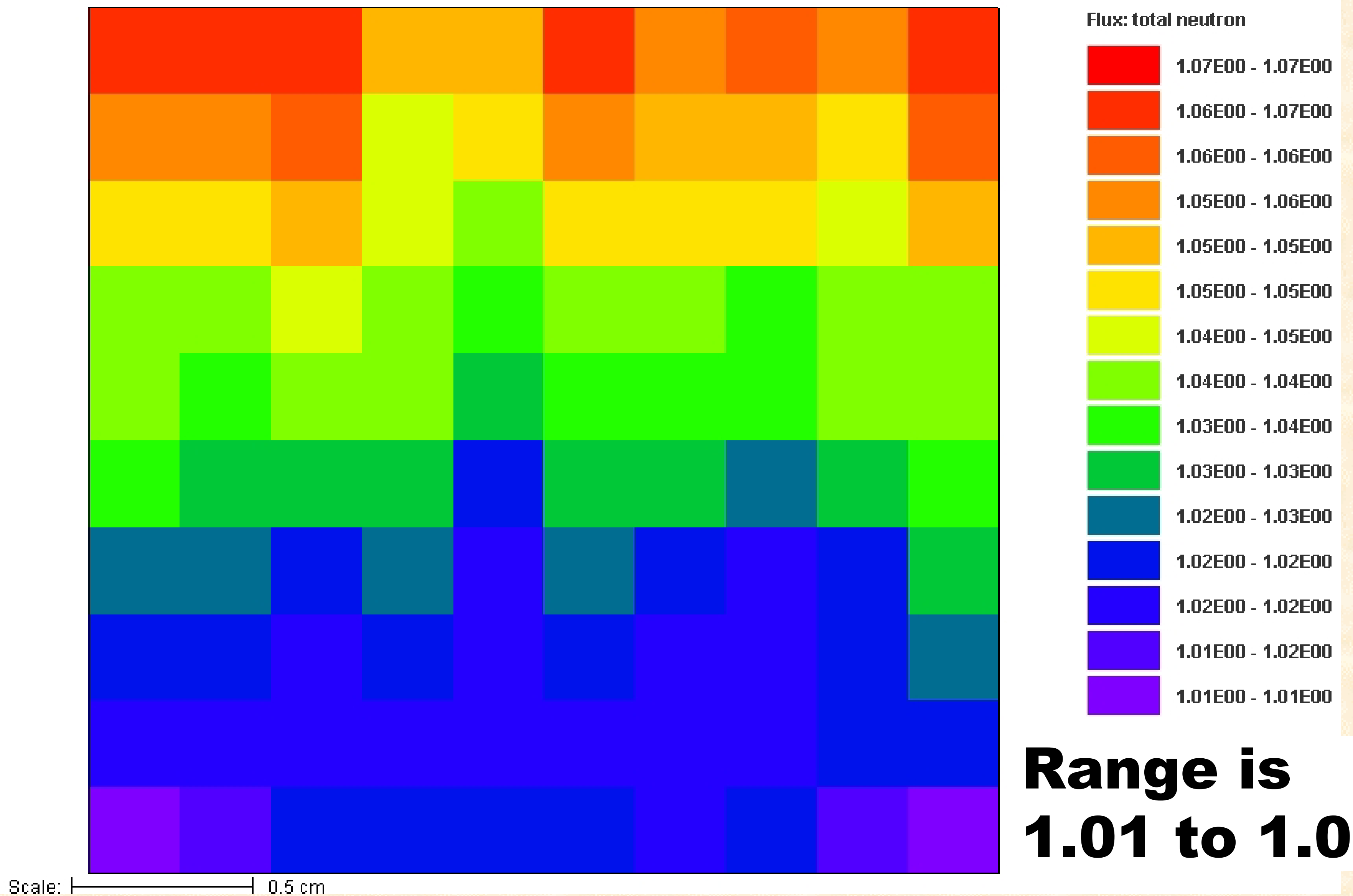
EGSnrc Photon Flux in Water Box



TORT Photon Flux in Water Box

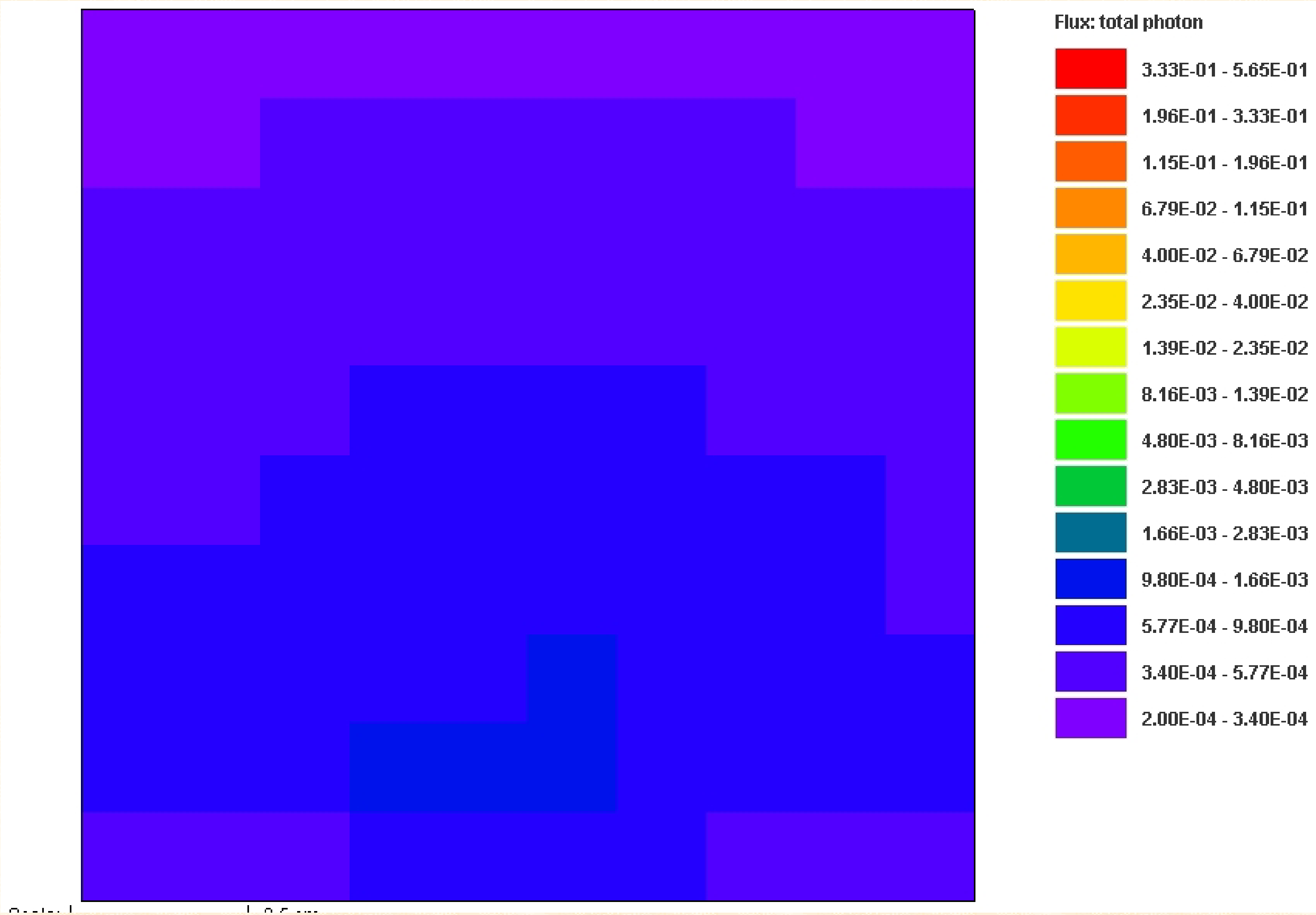


Ratio of EGSnrc to TORT Photon Flux

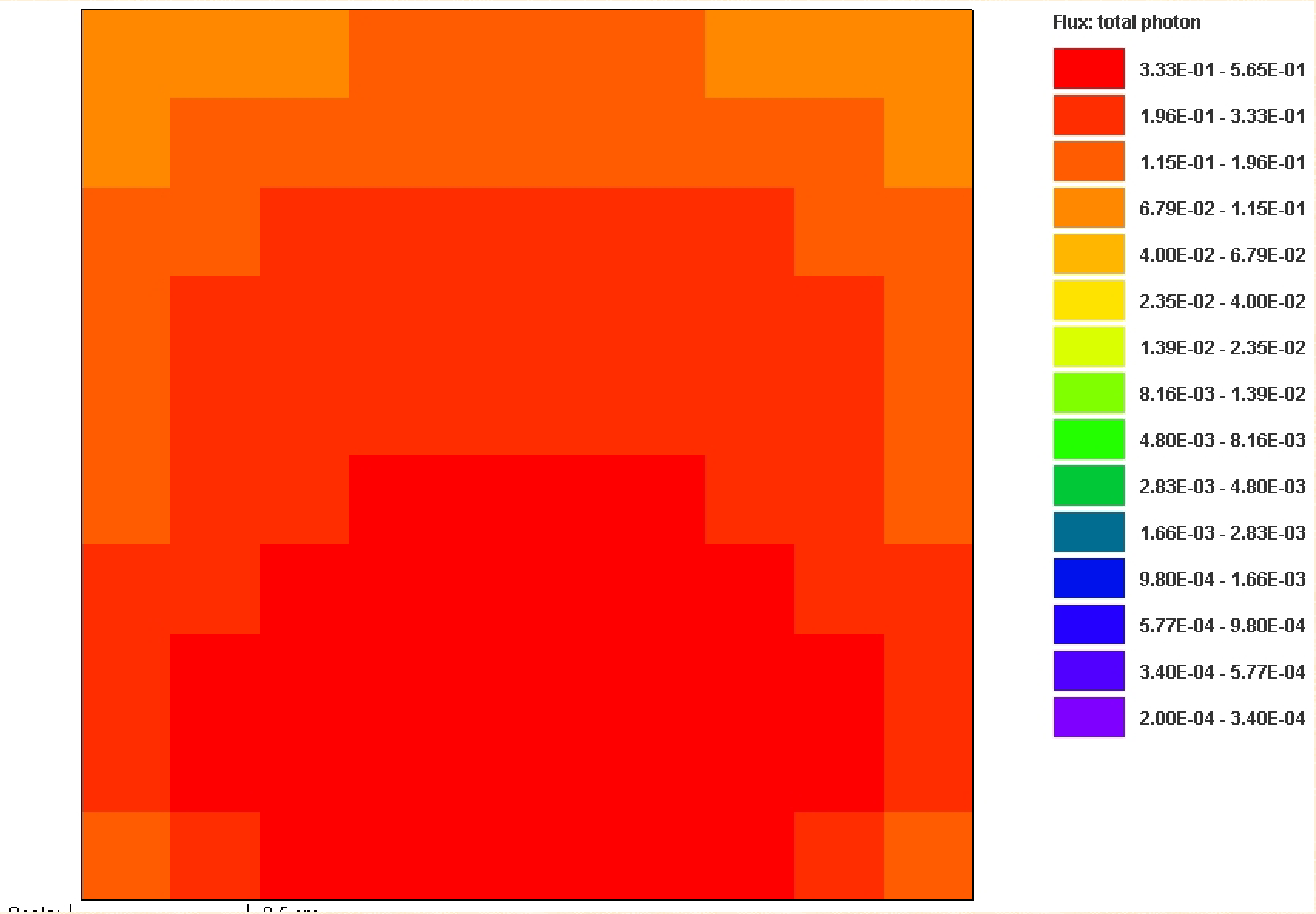


Range is 1.01 to 1.07

EGSnrc Electron Flux in Water Box



TORT Electron Flux in Water Box



TORT Electron Flux in Water Box

- TORT photon flux was within about 5% of EGSnrc photon flux in all cases.
- TORT had disproportionately high electron flux in group 40.
- A source of only electrons was varied by group.
- Groups 1 through 5: flux only in 1 through 5 and in 40
- Beyond group 5: flux in every group beyond the source group
- This anomaly may be due to oscillations in the TORT electron solution.

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Conclusions

- The TORT results, coupled with the DORT results, suggest that the electron cross sections
  1) Are too large for the transport methods to give accurate answers in multi-D; or
  2) Are erroneous due to processing with CEPXS-BFP; or
  3) Large anisotropy might have made the Pn scattering approximation too inaccurate.

Conclusions(2)

- There is promise in continuing to investigate the use of discrete ordinates for RTP.
- ANISN accurately produced photon and electron fluxes, but overestimated the energy deposition.
- DORT overestimated the electron flux and showed the same energy deposition trend as ANISN.
- TORT exhibited strange group behavior of the electron flux.
- The DOORS package proved to be able to handle some aspects of the charged particle transport, but also showed limitations.

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Future Work

- Investigate why the energy deposition results from ANISN and DORT were off by a factor of almost 4 (i.e. kerma factors).
- Determine the source of electron flux error in multi-D.
- Future work could involve using the DOORS package and CEPXS-BFP as a foundation to develop a new code that incorporates the BFP formula for treating charged particles.

Acknowledgement and References

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