Creative Simulation:

A Flexible Hands-on Approach to Building a Deeper Understanding of Critical Concepts in Radiation Physics

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SAINT AGNES

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CONFLICT OF INTEREST

None

Evolution of Teaching method

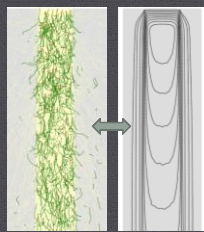
Teaching method evolved over time with the experience of teaching and one to one interaction with

- Radiation oncology residents
- Dosimetry school students
- Postdocs from secondary fields
- Starting medical physicists

at University of Maryland, Baltimore from 2001-2010

Students attitudes to learning Radiation Physics

- The teaching experience was also a learning experience.
- Some observations include:
  - Students showed a desire to understand the physics, and not just pass exams or be proficient in clinical calculations.
  - trouble connecting the concepts in clinical physics with the underlying basic physics.
  - would quickly get bored if we only focus on clinical problem solving without a clear mental picture of what is happening.



Basic physics   clinical physics

Some common misconceptions…

- "Electronic equilibrium is needed to measure dose."
- "Terma represents primary dose and kernels represent scatter dose"
- "Penumbra is caused by scatter."
- Buildup in photon beams is due to
  - "the fact that photons interact after some distance" or,
  - "the fact that electrons deposit energy after some distance," or,
  - "the fact that the highest energy electrons are released at the surface."
  - "Scatter"

Practically all the misunderstandings are caused by

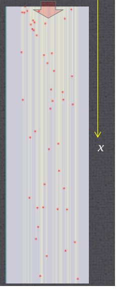
- not appreciating the role of secondary electrons in dose deposition
- indiscriminate use of the word "Scatter!"

Monte Carlo as a teaching tool…

- To facilitate explicit visualization of radiation physics, and
- To enable students to make explicit connections with clinical physics.
- A Monte Carlo code ("Athena") is developed with medical physics education in mind.

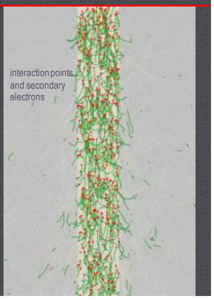
Relating attenuation & photon interactions

- Photons can interact at random depth with the probabilty of surviving a journey of length x through the forest of atoms given by $e^{-\mu x}$
- Each interaction removes a primary photon, which reduces the photon intensity downstream (attenuation) : $\frac{\varphi}{\varphi_0} = e^{-\mu x}$
- The diagram allows the students to "see" that interactions & beam attenuation are flip sides of the same coin.



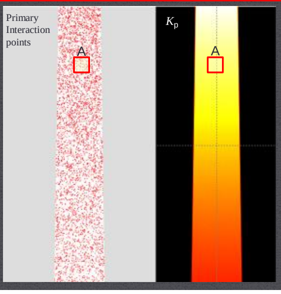
Emphasizing the electrons!

- All dose is due to ionization and excitation produced by secondary electrons released by photons (indirectly ionizing).
- Electrons can travel a few cm from their release site.
- Follow electrons to understand dose!



Interaction density, fluence & Primary Kerma, K_p

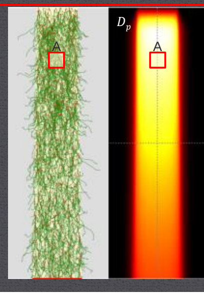
- Interaction density follows the fluence
- fewer photons available downstream produce fewer interactions.
- "Primary kerma" in box A counts energy imparted to electrons in primary photon interactions in A:
  - regardless of where the electrons go.
  - does not depend on electron transport.
- Exponential fall off in primary:
  - fluence,
  - kerma,
  - interaction density.



Primary dose, D_p

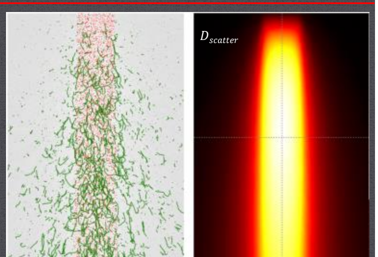
- Dose in "box A" counts energy deposited by electrons in A regardless of where they originate.
- Primary dose deposited electrons released in first photon interactions.
- (D_p does not count interactions of scatter photons).

(Label the order of the interaction in the MC code and display only 1st order interactions).



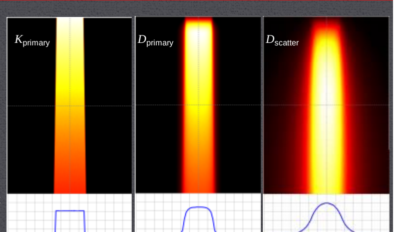
Scatter dose

- "Scatter" dose is due to electrons released in second or higher order photon interactions of
  - compton scatter photons,
  - bremstrahlung photons,
  - annihilation photons.
- e^- tracks are detached from the primary interaction sites.
- Scatter photons can carry energy far away from beam edge.
- But are not the reason for the physical penumbra



Profile comparisons: K_p, D_p, D_s

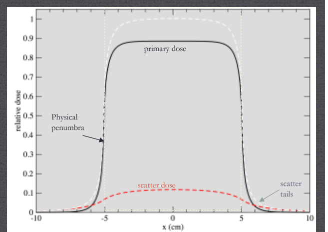
- Primary kerma is sharp for a perfect point source.
- Primary dose has physical penumbra due to lateral spread of electrons.
- Scatter dose is diffuse as scatter photons can interact outside the beam edge.



(profiles are normalized individually)

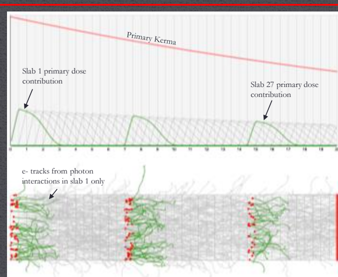
Physical penumbra vs. scatter tails

- Physical penumbra is present in the primary dose profile.
- Tails of the profile are made of scatter dose.
- Scatter does not affect physical penumbra much



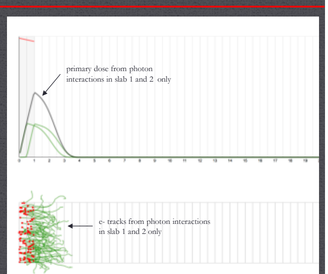
Understanding photon buildup (regional analysis)

- Divide phantom into imaginary slabs.
- Find contribution of each slab.
- Note the shape of the dose distribution does not change
- Height changes due to exponential attenuation of fluence (or kerma)



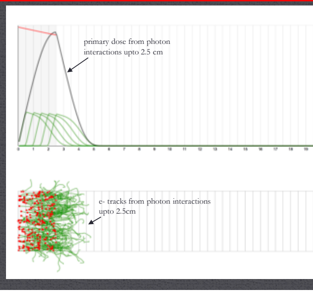
Understanding Buildup: Two slabs…

- 2nd slab receives upstream contribution from 1st slab.
- Keep adding slabs until we are beyond the range of the 1st slab electrons



Understanding Buildup: Five slabs…

- 5th slab receives little contribution from 1st slab.
- "Saturation" is reached.
- Electrons "lost" out of slab5 are essentially replaced by electrons from points upstream, (electronic equilibrium) and
- Kerma and Dose are nearly equal.



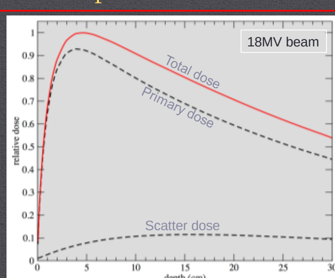
Understanding buildup…

In Summary:

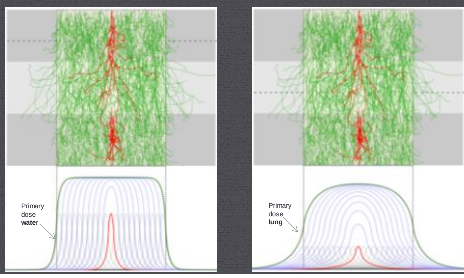
- Dose at each point depends on electrons released in slabs upstream.
- Surface slab has no upstream contribution, hence lowest dose.
- Maximum track overlap is reached around d_{max}, which is one forward e- range away from the surface (~3cm)
- Upstream contribution beyond d_{max} stays constant except for decreasing strength due to attenuation.

PDD: primary and scatter components

- Buildup is mainly in primary dose
- Scatter has little influence on buildup.

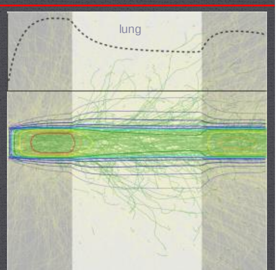


Lateral buildup and lateral equilibrium



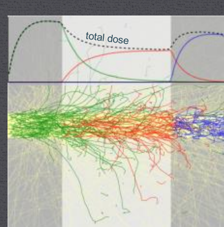
Studying interface effects

- Students find it hard to understand why there are build-up and build-down effects.
- Overlaying the isodose lines on the electron tracks show how the increased e- spread in the low density region results in lateral disequlbrium.

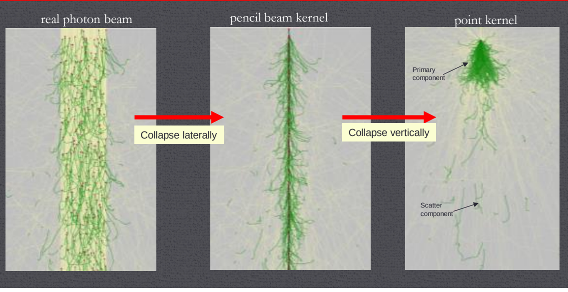


Interface effects: (regional analysis)

- Buildup due to interactions in lung never reach the level of water since
  - Electrons lost outward are not compensated by electrons moving inward.
  - lateral buildup is incomplete (disequilbrium)

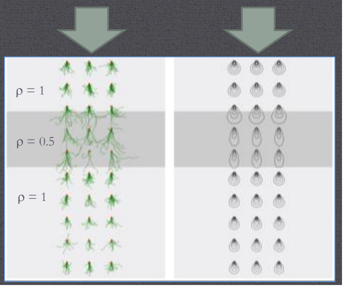


Visualizing a kernel

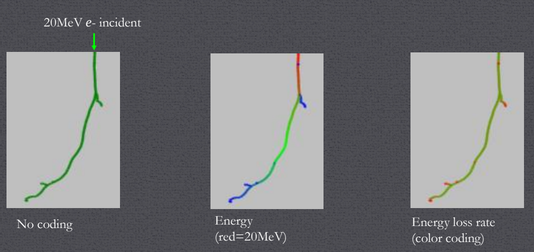


How do kernels look in convolution/superposition

- Allow interactions at only few discrete points:
  - Illustrates kernel shapes in water and low density medium
  - Illustrates reduced weights downstream due to attenuation.
  - Illustrates density scaling of tracks and corresponding kernel stretching
  - Provides insights into convolution superposition method with addition of weighted kernels.

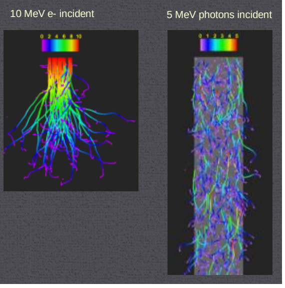


Color coding electron tracks



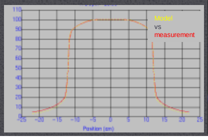
Energy coding application: electron and photon beams

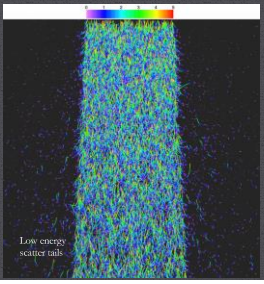
- Illustrates how electron energy spectrum changes with depth in electron beams.
- But photon beam electron spectrum remains essentially fixed.
- Explains need of water-air stopping power ratio in PDD measurement for e- beams with ion-chambers
- No correction generally needed for photons



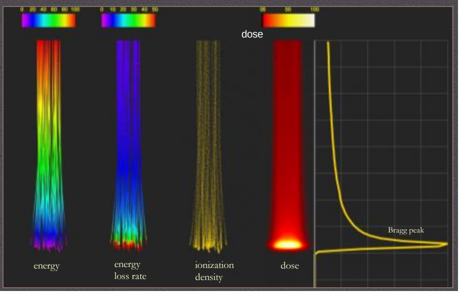
Spectral corrections for detector in tail?

- Corrections needed in the tail at large depths where e- energy is much lower?
- Shall we "force" the model to match measurements everywhere?



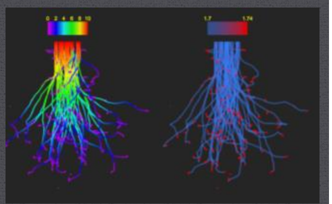


Color coding application: Protons & Bragg peak



Electron Beams: Where is the "Bragg peak" ?

- End of track ionization density is higher as stopping power rises with decreasing energy.
- But increase rate of energy loss happens when there is not much energy left to deposit.
- Also all individual "bragg peaks" get smeared out due to excessive lateral scattering, which this results in no bragg peak!



energy

energy loss rate

Conclusion

- In this work, it is shown
  - Monte Carlo simulations can be used as an effective educational tool
  - help to elucidate the physics by breaking the physical processes into layers of complexity.
  - Help in making explicit connections with clinical concepts.
  - Helps develops physical insight so that new situations can be evaluated with sound judgement.
  - Could excite a sense of "discovery" where a desire for understanding for its own sake overcomes extrinsic motivation factors such as passing exams!
  - Could make learning more fun, and leave a longer lasting understanding of crucial concepts in radiation physics.