**Joint ICTP-IAEA Workshop on Monte Carlo Radiation Transport and Associated Data Needs for Medical Applications**
28 October – 8 November 2024
ICTP, Trieste, Italy

Lecture 12

# Statistical uncertainties in EGSnrc - Quiz

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# Questions

# Quiz 1: what is a history?

**1.** What is a history?

(a) The phase space information of a source particle;

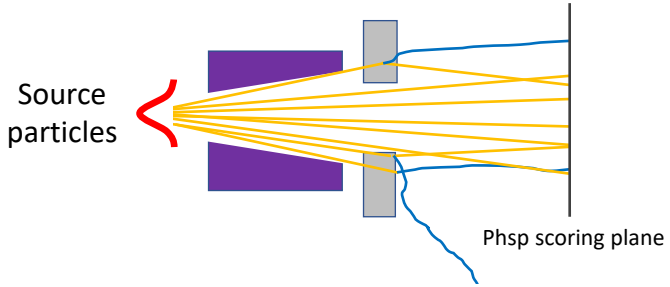
(b) The transport of a source particle before its reaches a scoring plane or a scoring volume;

(c) The transport of all source particles before they reach a scoring plane or a scoring volume;

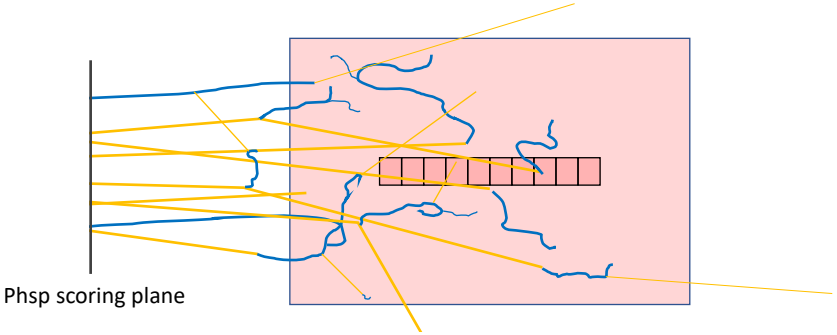
(d) A complete set of interactions of an independent source particle in the whole geometry before its transport in terminated

# Quiz 2: Are particles from a phase space file independent source particles?

**Phase space file being generated: a BEAMnrc simulation**




**Phase space file being used: a user code simulation**



# Quiz 3: How many histories do I need?

- Let's assume I ran a simulation to score absorbed dose in some geometry.
- My result with $10^6$ histories was

  `1.657E-13+- 8.0%` (in Gy$\cdot$ cm$^2$)

- How many histories do I need to get 1% uncertainty?

# Quiz 4a: are quantities correlated?

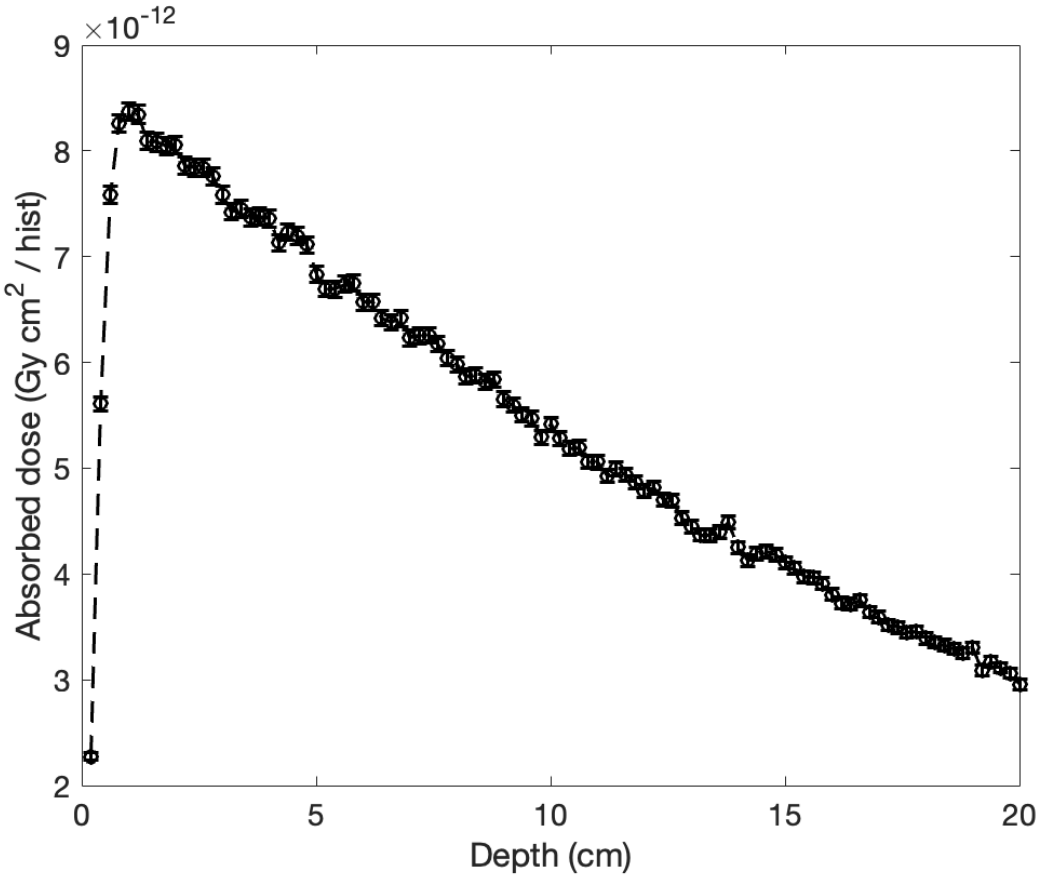
- I am using `egs_chamber` to simulate the ratio of absorbed dose to my chamber's sensitive volume relative to absorbed dose in a small volume of water. I am using a single input file. Are scoring quantities correlated?

# Quiz 4b: are quantities correlated?

- I am using `egs_chamber` to simulate the ratio of absorbed dose to my chamber's sensitive volume relative to absorbed dose in a small volume of water. I am using one input file for each scoring volume and different random seeds. Are scoring quantities correlated?

# Quiz 5: normalization of a percent-depth dose curve

- I simulated a percent-depth dose curve. How do I normalize it?



# Questions and answers

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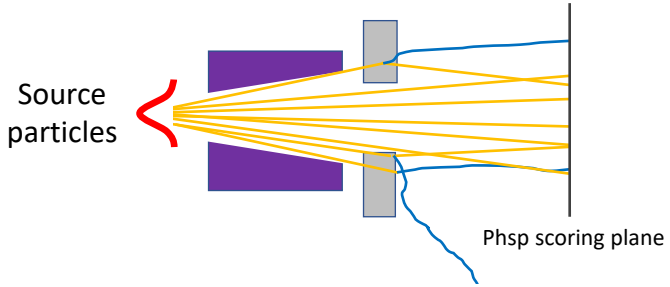


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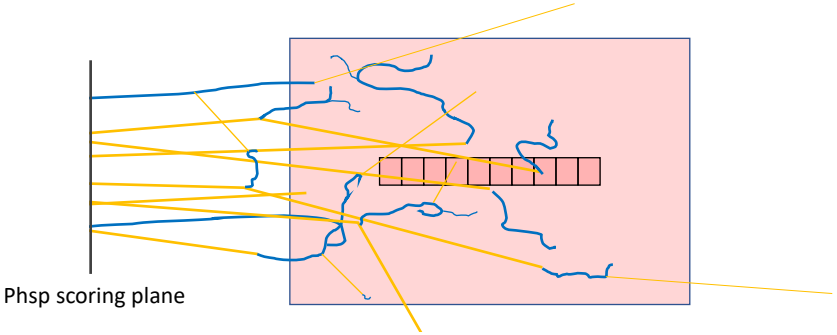
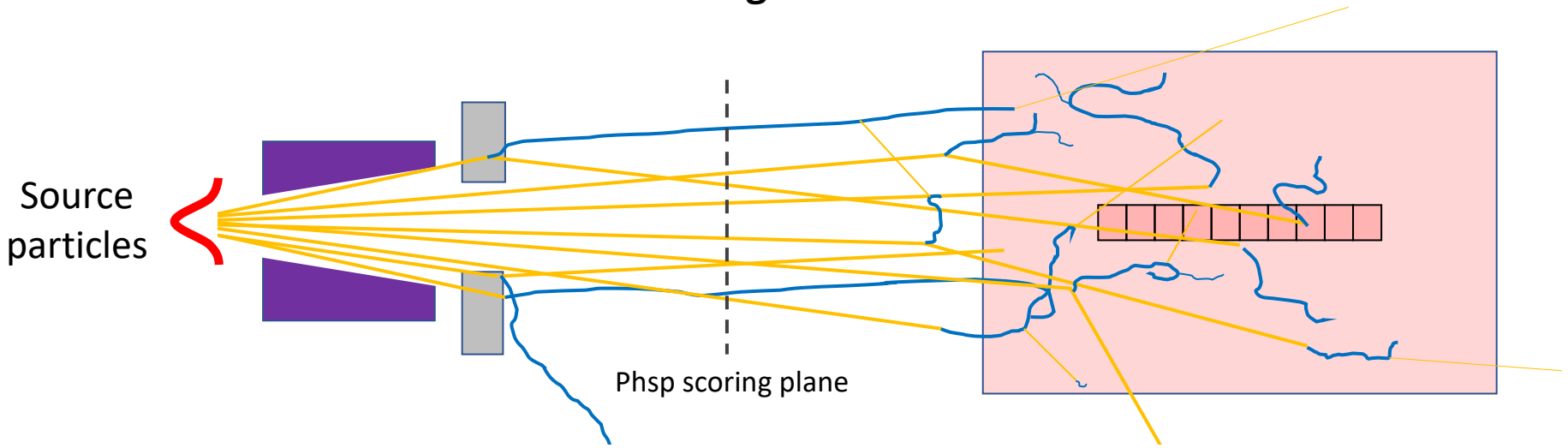


# Quiz 2: Are particles from a phase space file independent source particles?

**Full simulation combining BEAMnrc and the user code**




- **A history must include the independent source particles to the end of transport. Phase space files should be seen as intermediate steps. So no, phase space particles are not all statistically independent, only some are.**

# Quiz 3: How many histories do I need?

- Let's assume I ran a simulation to score absorbed dose in some geometry.
- My result with $10^6$ histories was

$$\texttt{1.657E-13+- 8.0\%} \quad (\text{in Gy} \cdot \text{cm}^2)$$

- How many histories do I need to get 1% uncertainty?

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- Let's assume I ran a simulation to score absorbed dose in some geometry.
- My result with $10^6$ histories was

  `1.657E-13+- 8.0%` (in Gy$\cdot$ cm$^2$)

- How many histories do I need to get 1% uncertainty?
  **The solution is $64 \times 10^6$.**

$$S_1 \propto \frac{1}{\sqrt{N_1}} \quad \text{and} \quad S_2 \propto \frac{1}{\sqrt{N_2}}$$

$$\Rightarrow \quad \frac{S_1}{S_2} = \sqrt{\frac{N_2}{N_1}}$$

$$\Rightarrow \quad \frac{S_1^2}{S_2^2} N_1 = N_2$$

$$\Rightarrow \quad \frac{(8\%)^2}{(1\%)^2} 10^6 = 64 \times 10^6$$

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- I am using egs_chamber to simulate the ratio of absorbed dose to my chamber's sensitive volume relative to absorbed dose in a small volume of water. I am using a single input file. Are scoring quantities correlated?

  **Yes, and they are positively correlated, meaning that:**

  1. When energy is scored in the chamber, it is also likely to be scored in the water scoring volume (event above average).
  2. When no energy is scored in the chamber, it is also likely that no energy is scored in the water scoring volume (event below average).

  **If I ignore those correlations, I will overestimate my uncertainty!**

$$s_{\frac{\overline{X}}{\overline{Y}}} = \frac{\overline{X}}{\overline{Y}}\sqrt{\left(\frac{s_{\overline{X}}}{\overline{X}}\right)^2 + \left(\frac{s_{\overline{Y}}}{\overline{Y}}\right)^2 - \frac{2s_{\overline{X},\overline{Y}}}{\overline{X}\,\overline{Y}}} < \frac{\overline{X}}{\overline{Y}}\sqrt{\left(\frac{s_{\overline{X}}}{\overline{X}}\right)^2 + \left(\frac{s_{\overline{Y}}}{\overline{Y}}\right)^2}$$

# Quiz 4b: are quantities correlated?

- I am using `egs_chamber` to simulate the ratio of absorbed dose to my chamber's sensitive volume relative to absorbed dose in a small volume of water. I am using one input file for each scoring volume and different random seeds. Are scoring quantities correlated?

# Quiz 4b: are quantities correlated?

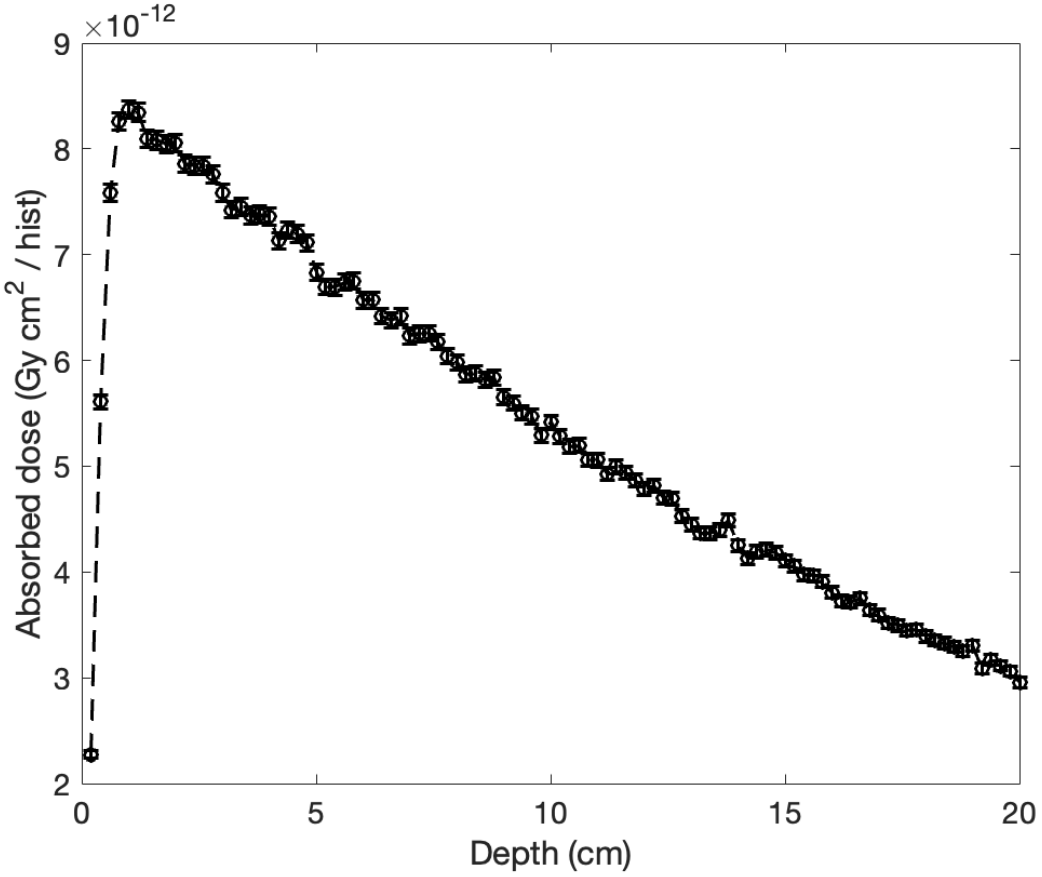
- I am using egs_chamber to simulate the ratio of absorbed dose to my chamber's sensitive volume relative to absorbed dose in a small volume of water. I am using one input file for each scoring volume and different random seeds. Are scoring quantities correlated?

  **No. The simulations are statistically independent.**

  **The fact that random seeds are changed reinforces that fact, i.e., they would likely be independent anyways due to the sequential way RANLUX and RANMAR are called.**

# Quiz 5: normalization of a percent-depth dose curve

- I simulated a percent-depth dose curve. How do I normalize it?



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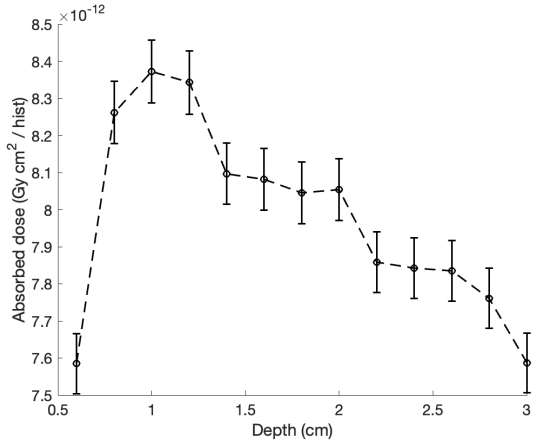
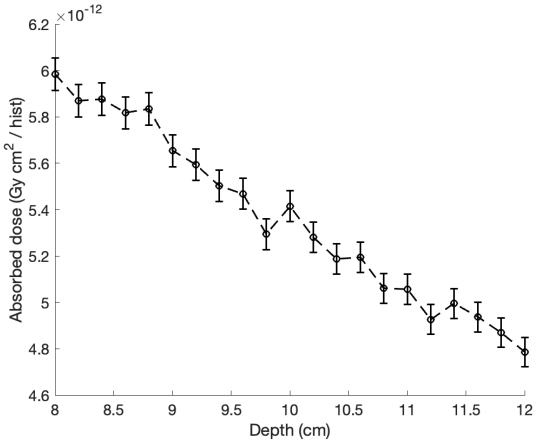
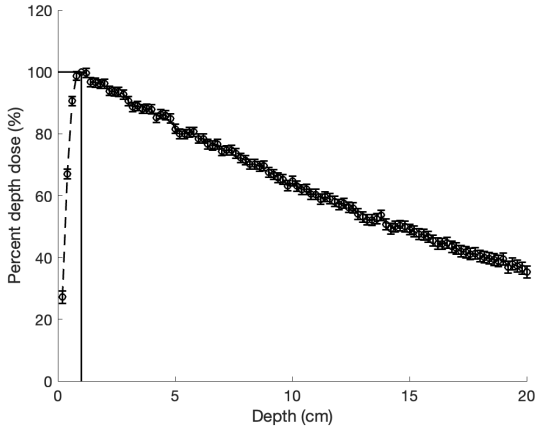
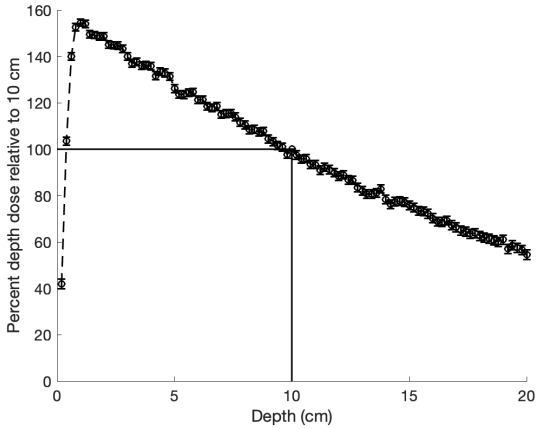



(c) To $d_{\max}$




(d) To 10 cm

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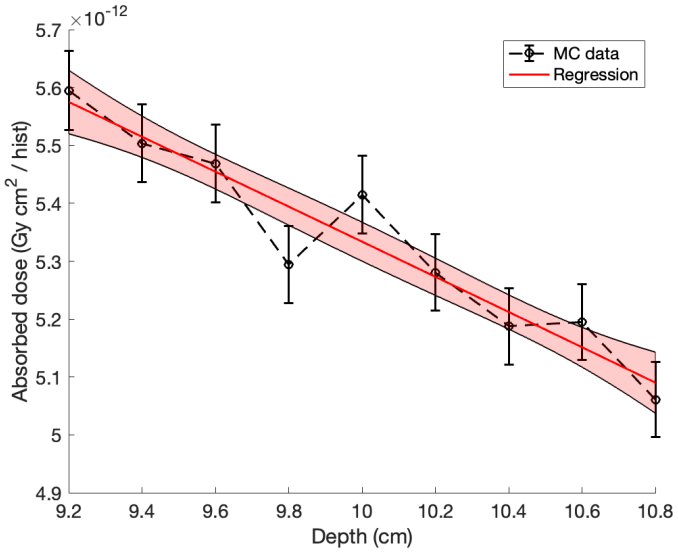
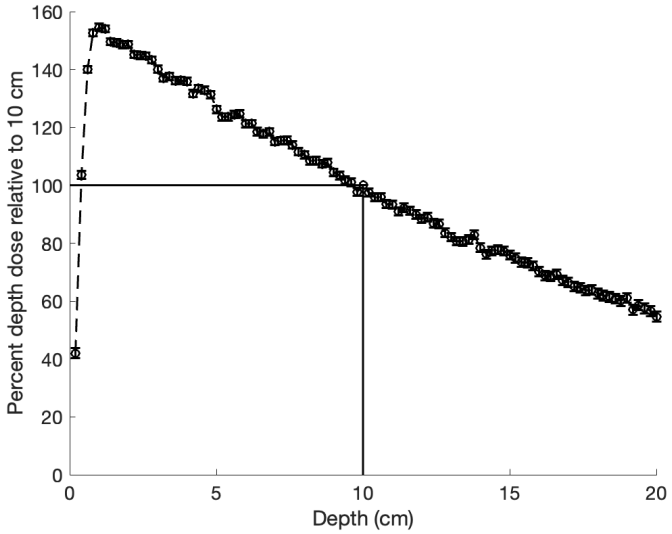



(a) A regression in a smooth region of the curve.




(b) A more precise normalization using the resulting inference from the regression.