Monte Carlo methods for dose homogeneity simulations in cell nuclei exposed to alpha particles under different setup conditions

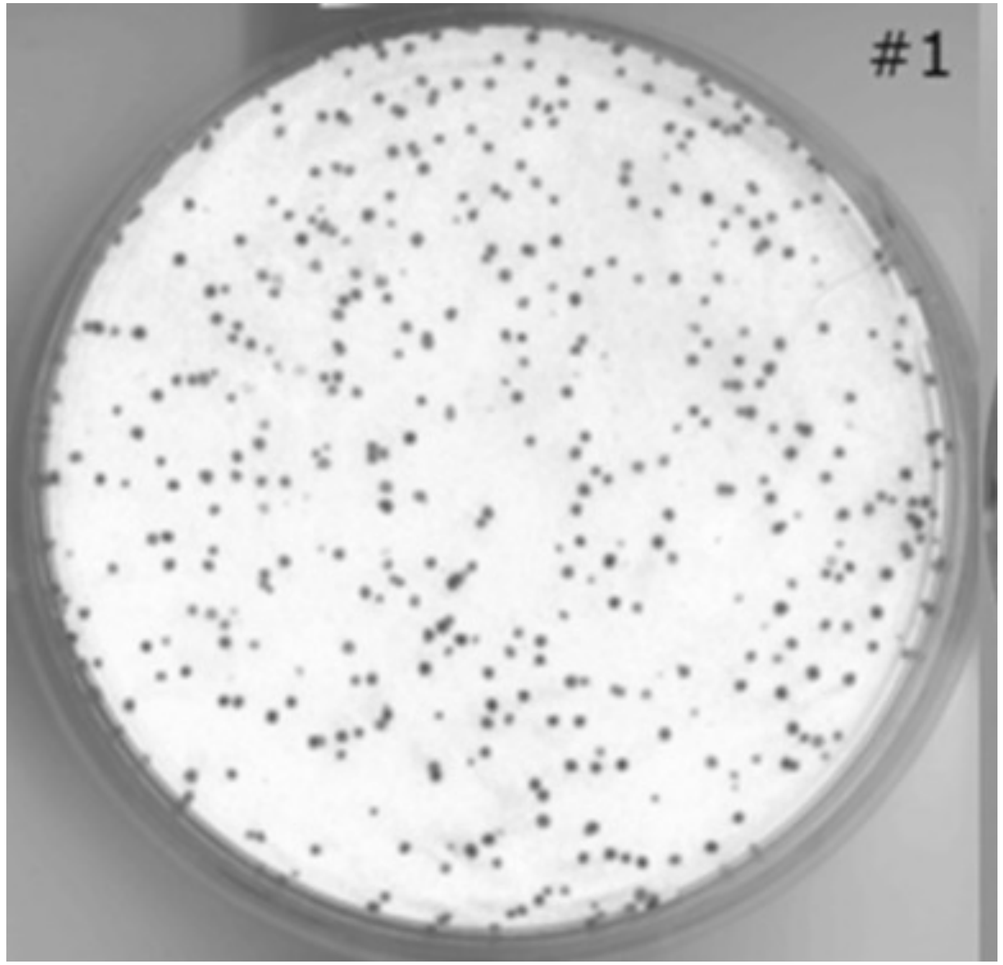
Adrianna Tartas

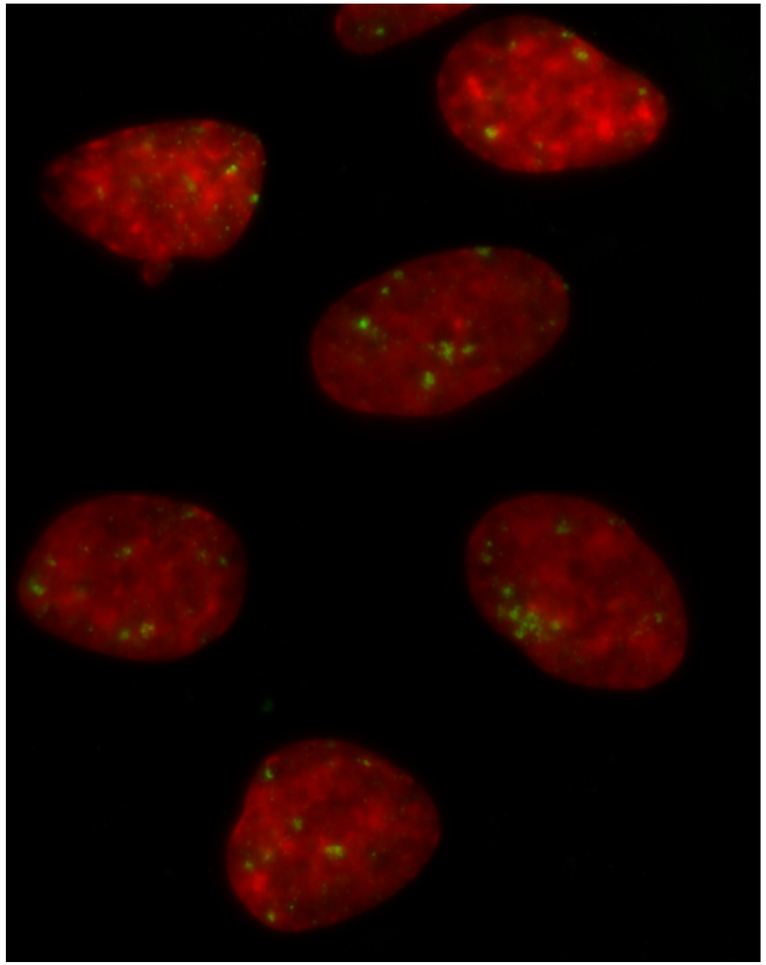
Biomedical Physics Division, Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Poland

9th Annual Loma Linda Workshop on Particle Imaging and Radiation Treatment Planning

FACULTY OF PHYSICS
UNIVERSITY OF WARSAW

Our studies


#1

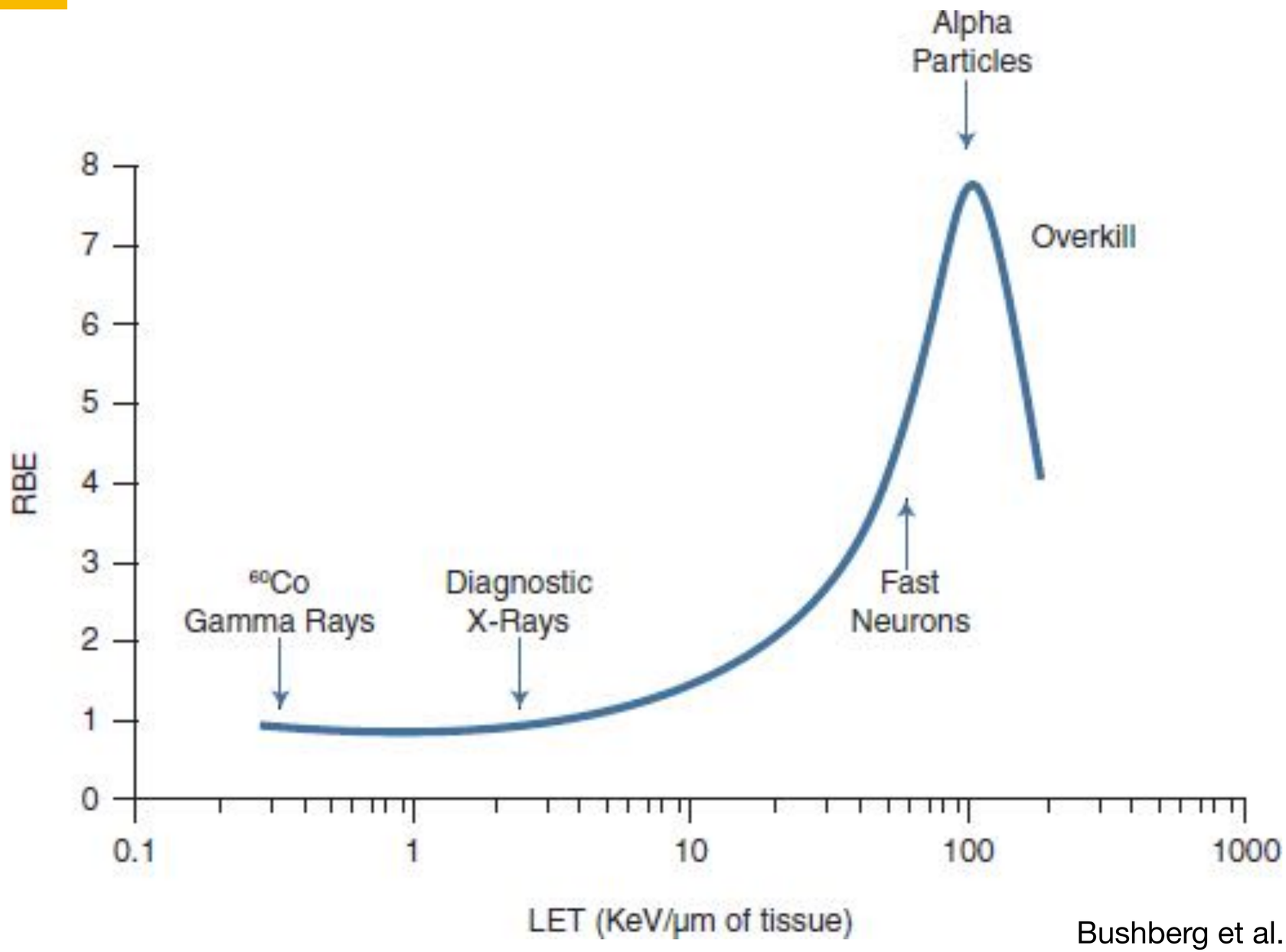



241Am isotope

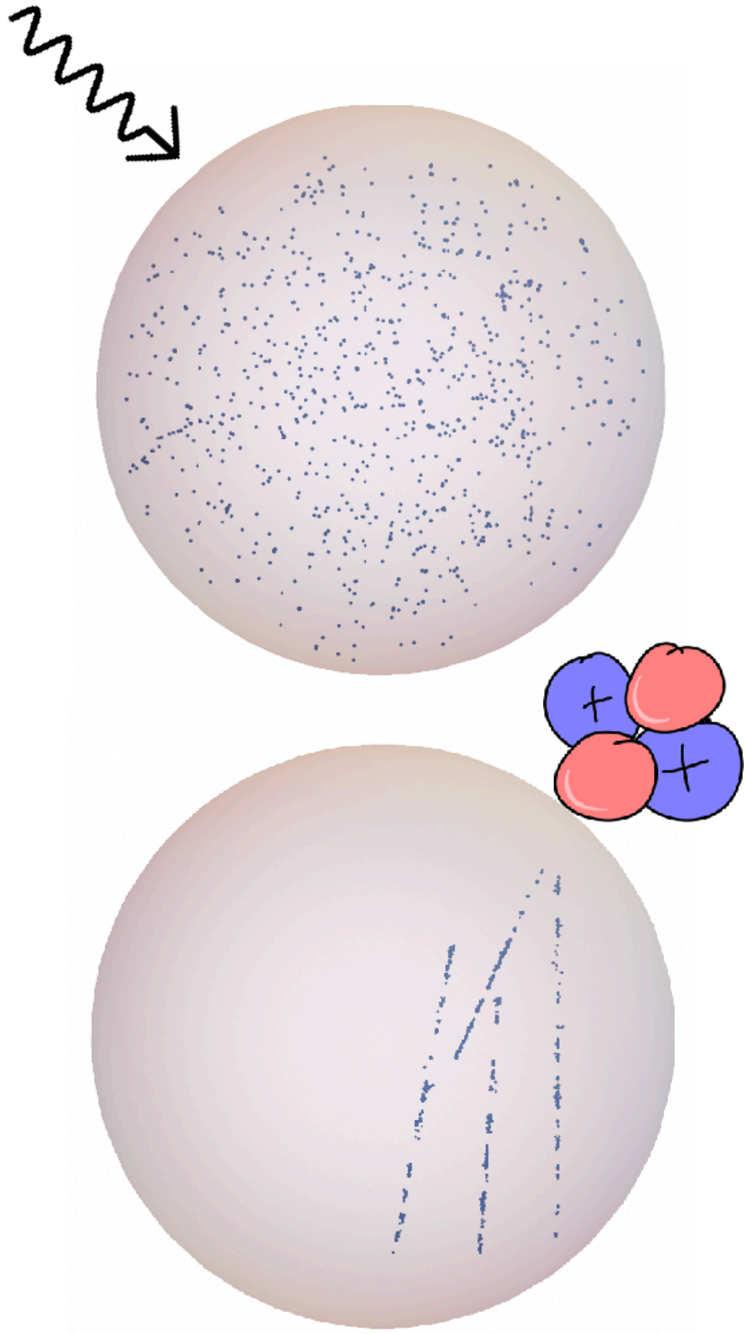

Sr-90
0.1 µCi 28.8 Yrs
Radioactive Material
March 2019
Spectrum Techniques
USNRC & State License
Exempt Quantity


Cs-137
1.0 µ Ci. 30.2 yrs
Radioactive Material
s/n
USNRC and State License
Exempt Quantity

Types of ionizing radiation



Bushberg et al., 2012



Brzozowska et al., 2020

Motivation

A major problem associated with alpha exposure setups lacking a collimator is dose heterogeneity inside the irradiated cell nuclei.

Because the cell response is dependent on the LET, shifts in LET values have a strong impact.

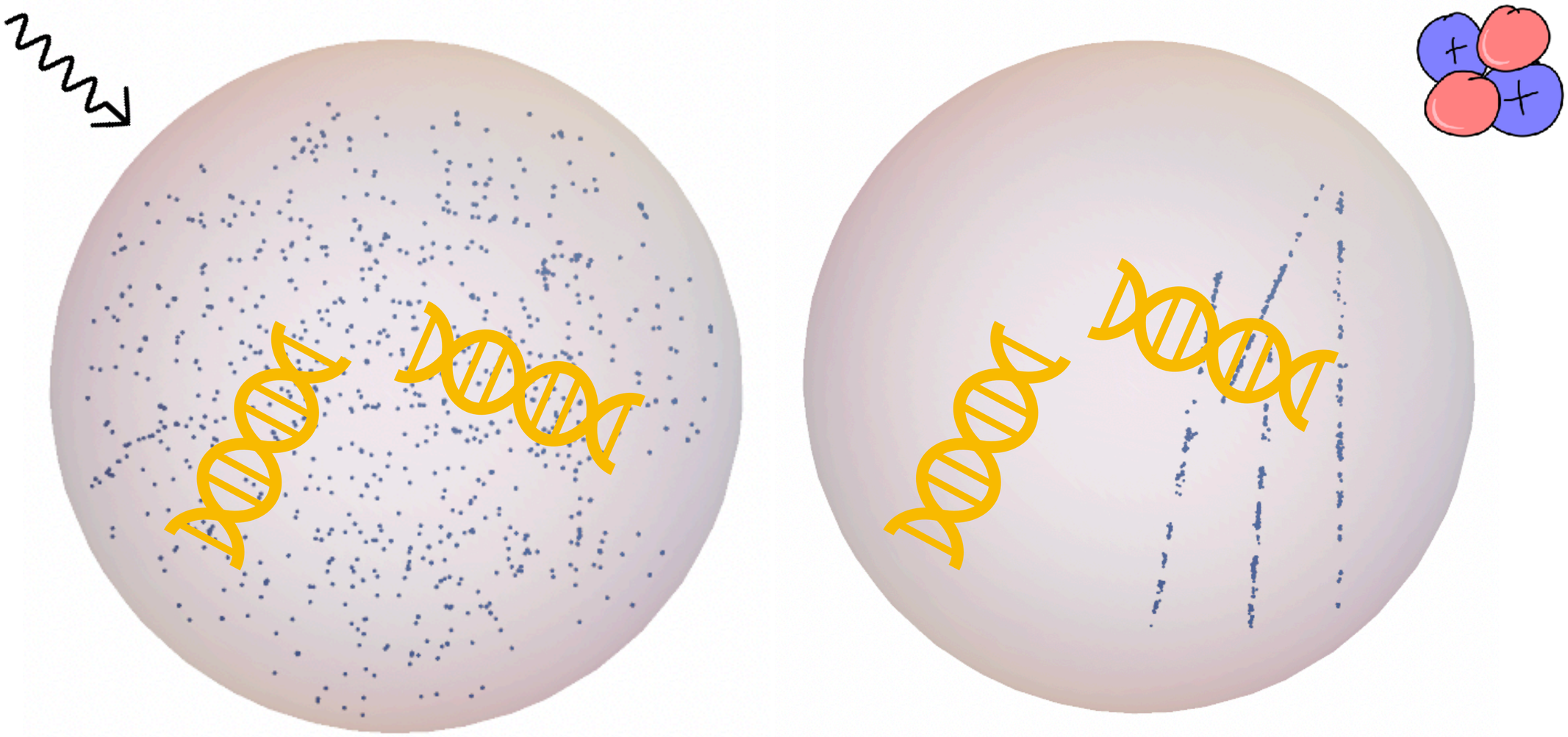
Our issues: differences in experimental results

problems with comparing results with different publications

Gamma radiation and alpha particles

	Source	Cell line	RBE	LET	Collimator
Edwards et al. 1980	Cm-242 (4.9 MeV)	human blood (CA)	17.9	1550 MeV cm^2 /gm	stationary
Goodhead et al. 1991	Pu-238 (5.5 MeV)			121 keV/μm	stationary
Neti et al. 2004	Am-241	human fibroblasts (AG1522)	7.6 ± 1.6	132 keV/μm	stationary
Esposito et al. 2009	Cm-244 Am-241	human fibroblasts		122 keV/um, 125 keV/μm	no collimator
Thompson et al. 2019	Pu-238 (3.3 MeV)	lung cells		120 keV/um	stationary
Tracy et al. 2015	Pu-238	V79-4 Chinese hamster cells	10.2 9.0	131 keV/um, 87 keV/um, 112-201 kev/um	
Griffiths et al. 1994	Pu-238 (5.5 MeV)	Lymphocyte Progenitor Cells	1.5 - 4	121 keV/um	stationary
Raju et al. 1974	Pu-238	kidney cells	2.4	140 keV/um	stationary

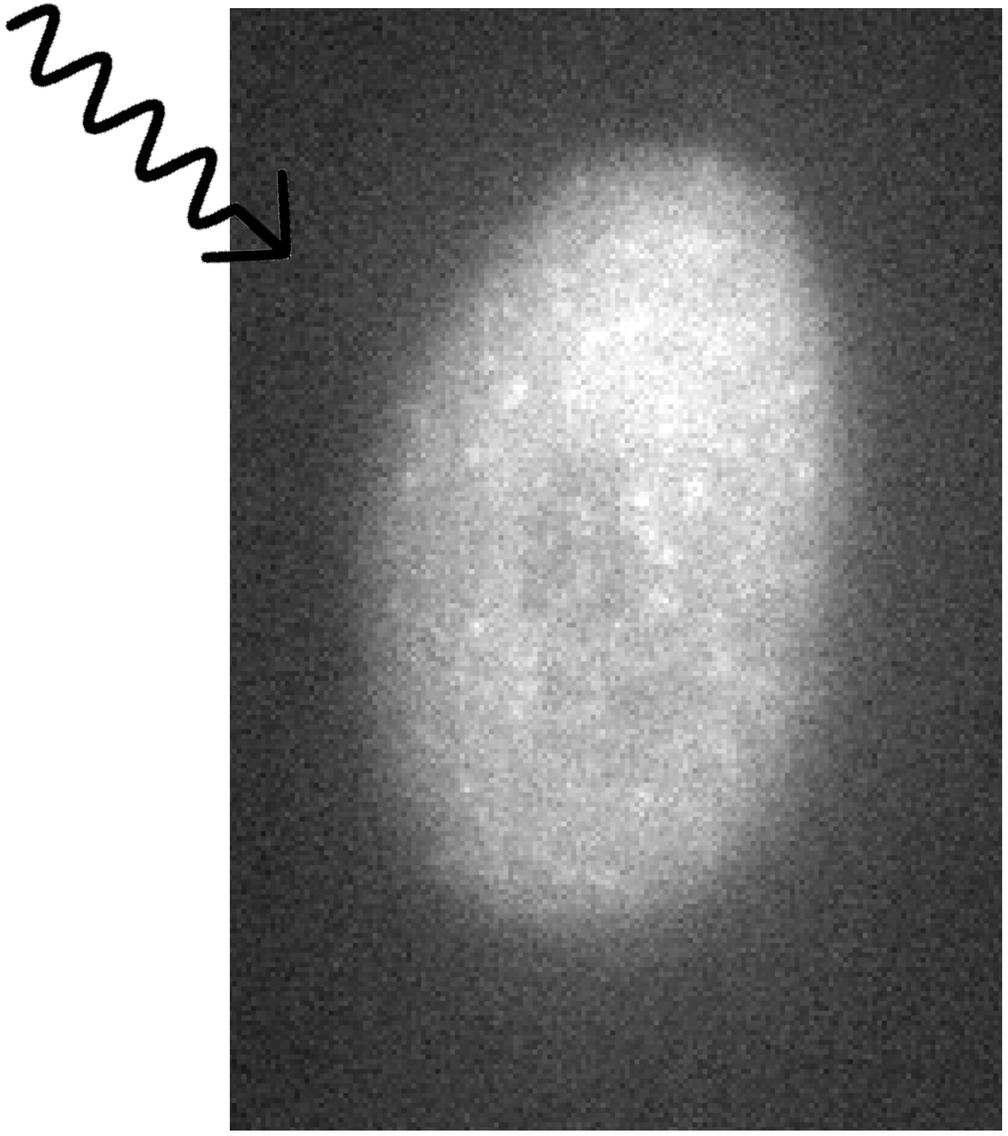
Gamma radiation and alpha particles

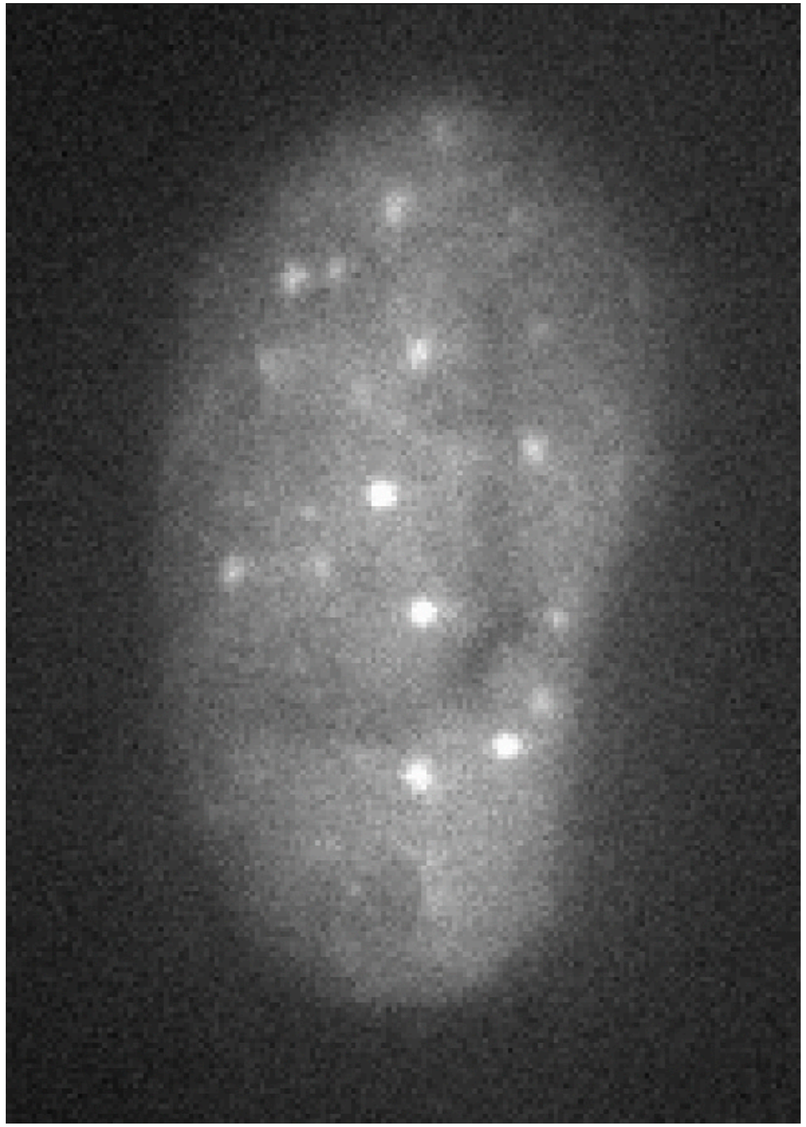


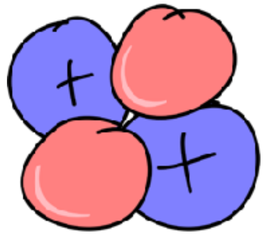
Poisson distribution

Brzozowska et al., 2020

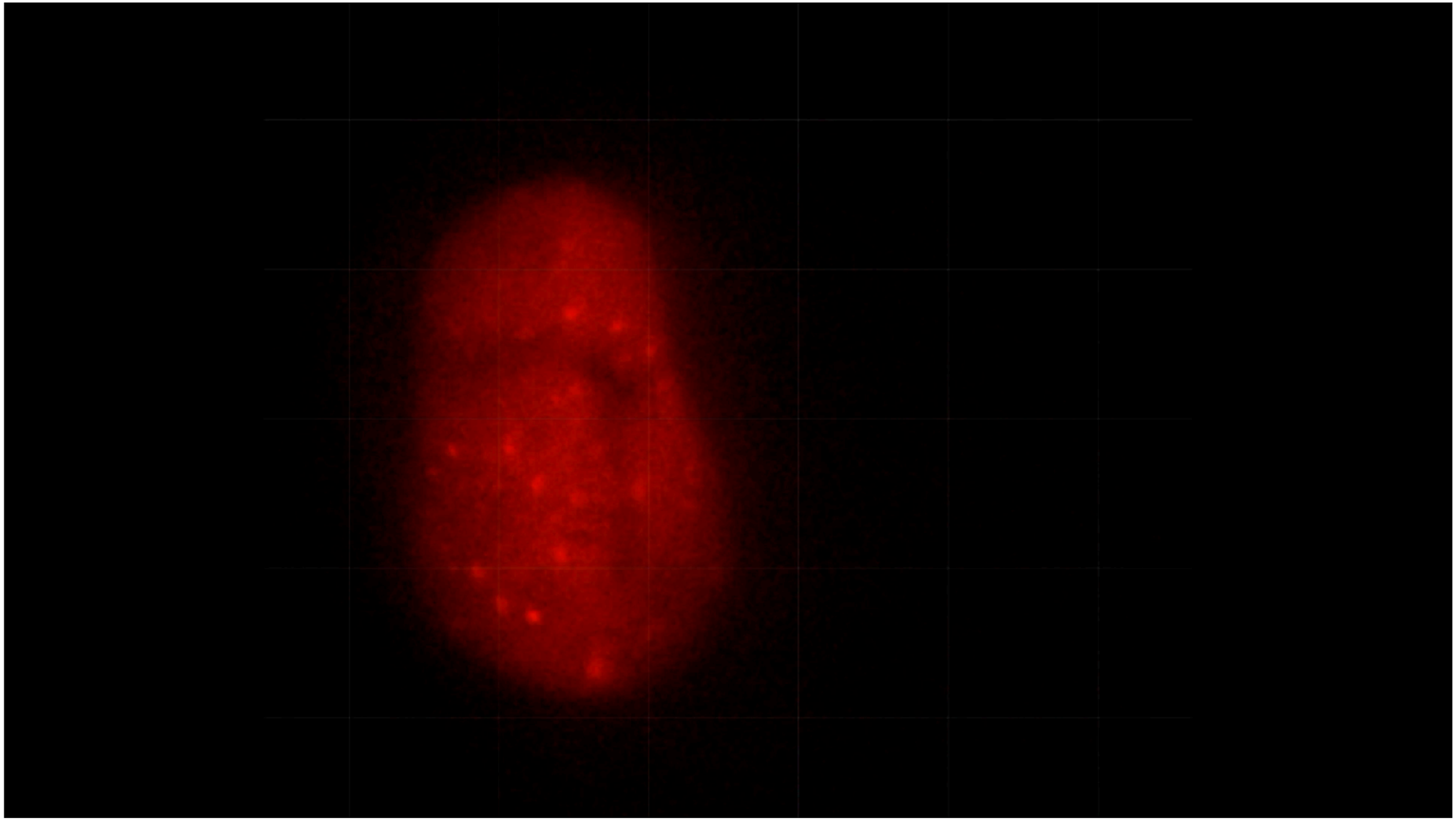
Gamma radiation and alpha particles



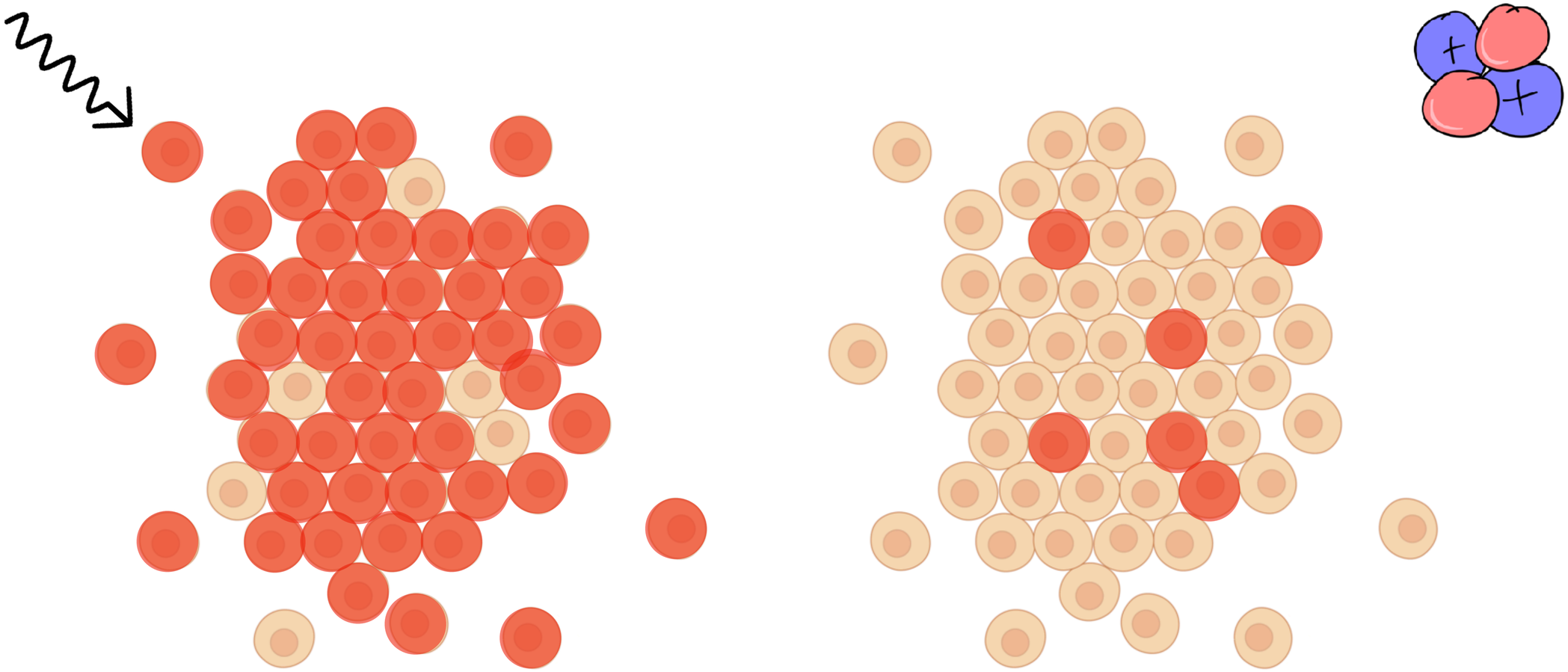




Live cell imaging



Gamma radiation and alpha particles



Materials and methods

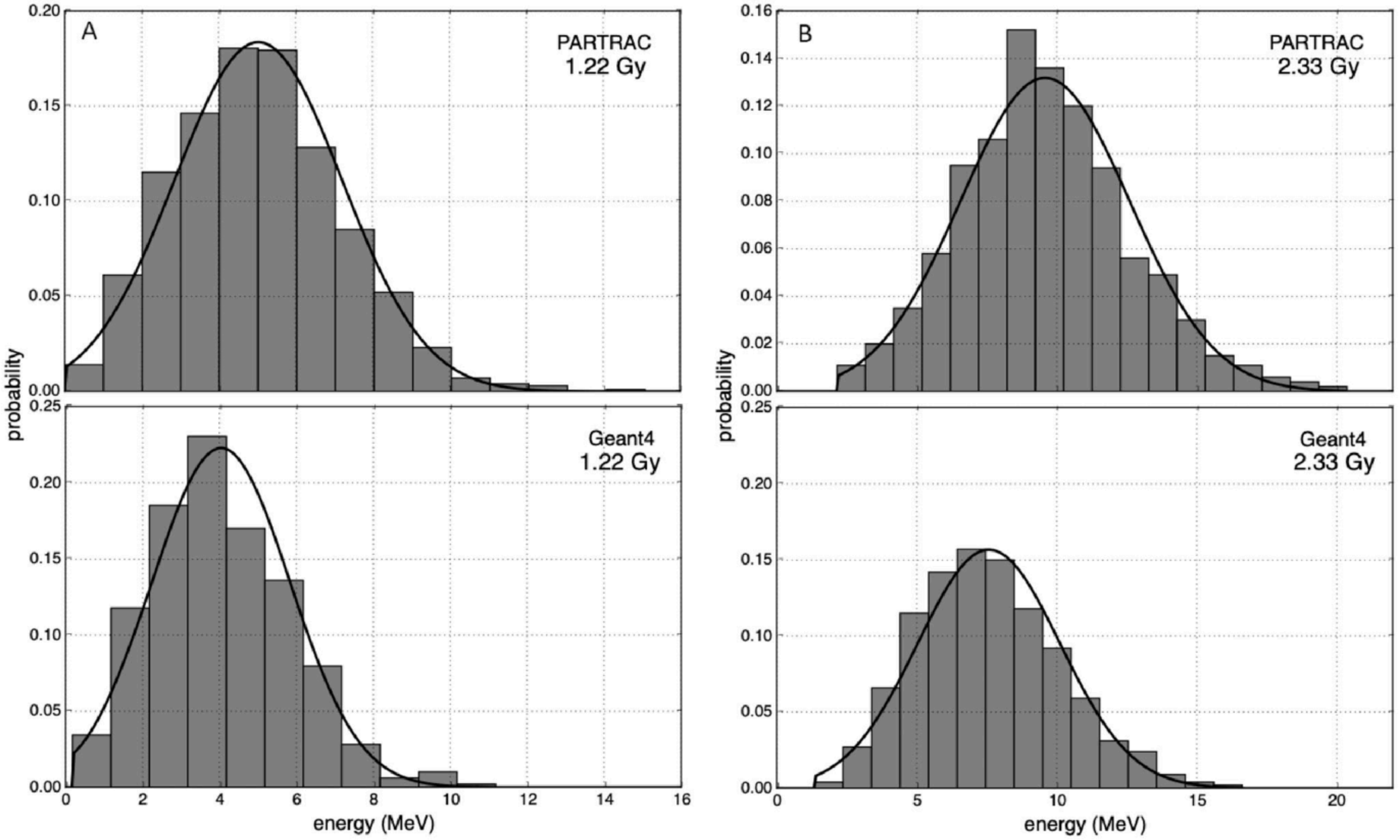
PARTRAC code and Geant4 simulations (ver. 10.06.p01)

Human peripheral blood lymphocytes

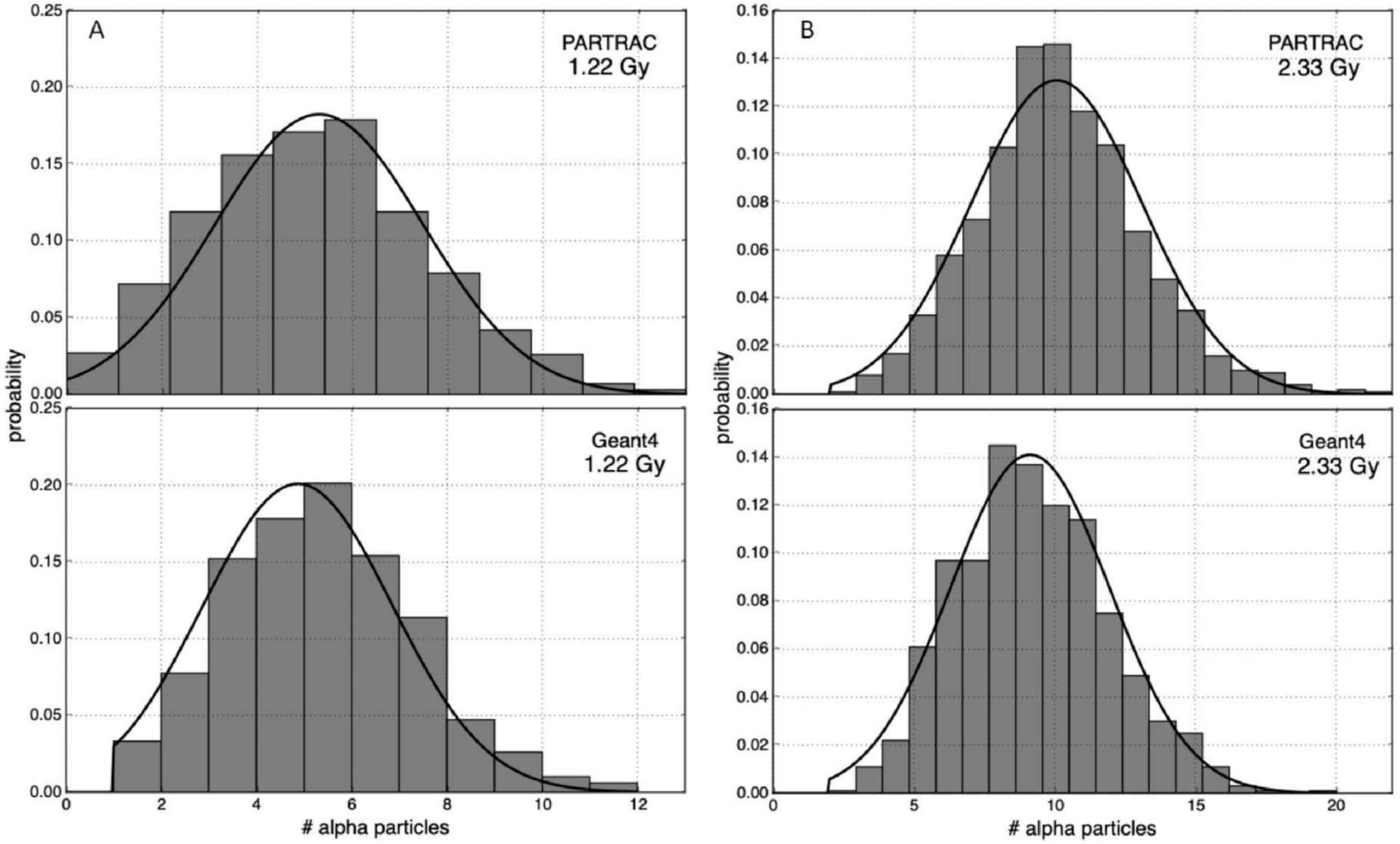
Doses: 1.22 Gy and 2.33 Gy

Two geometries: simple and more complex

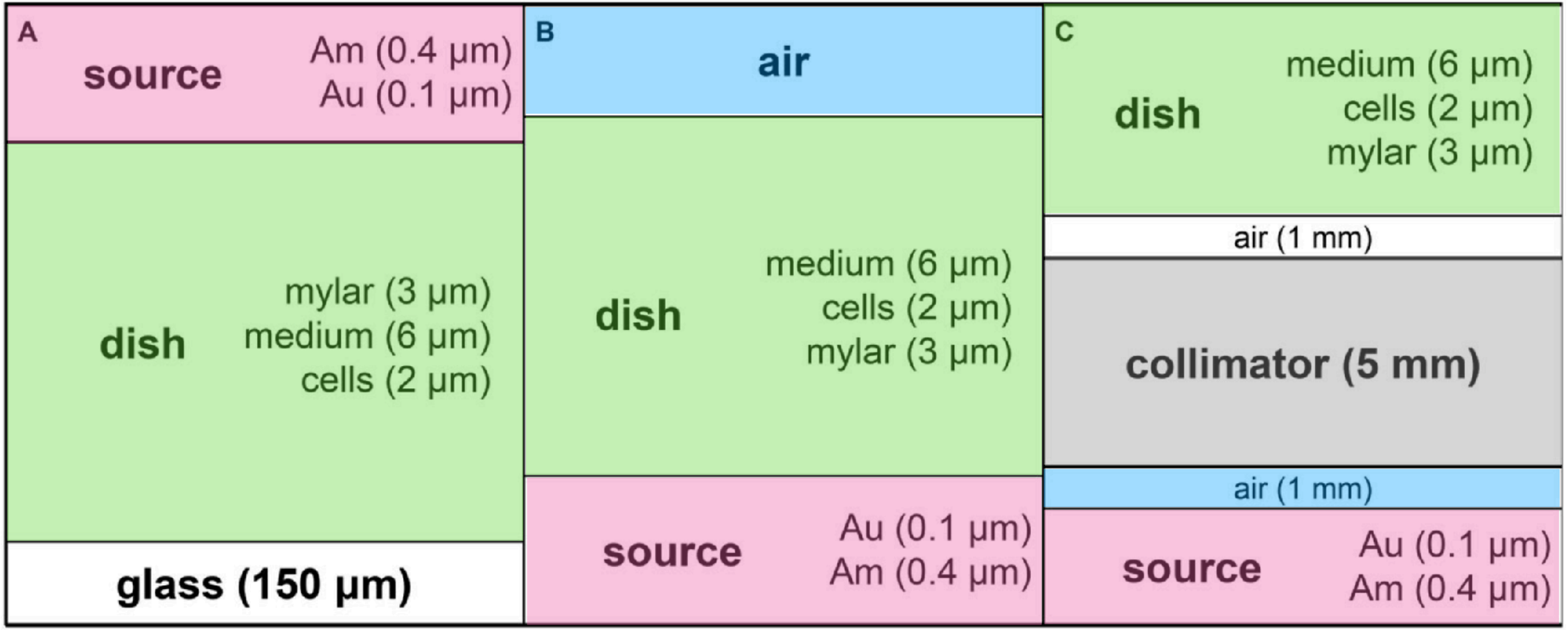
Deposited energy distributions



Alpha particle track numbers

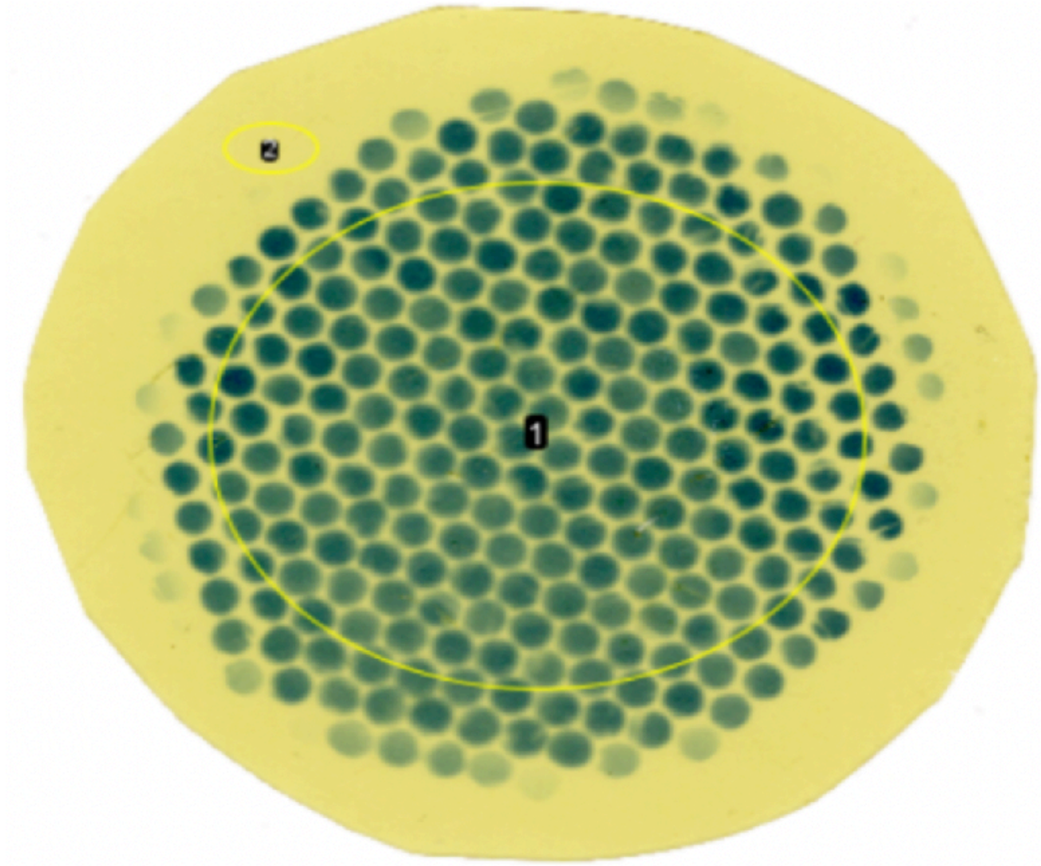


Geometries of the setup



(A) cells irradiated from above (top-down setup), (B) cells irradiated from below (bottom-up setup) without a collimator and (C) cells irradiated from below through the stable or rotating collimator

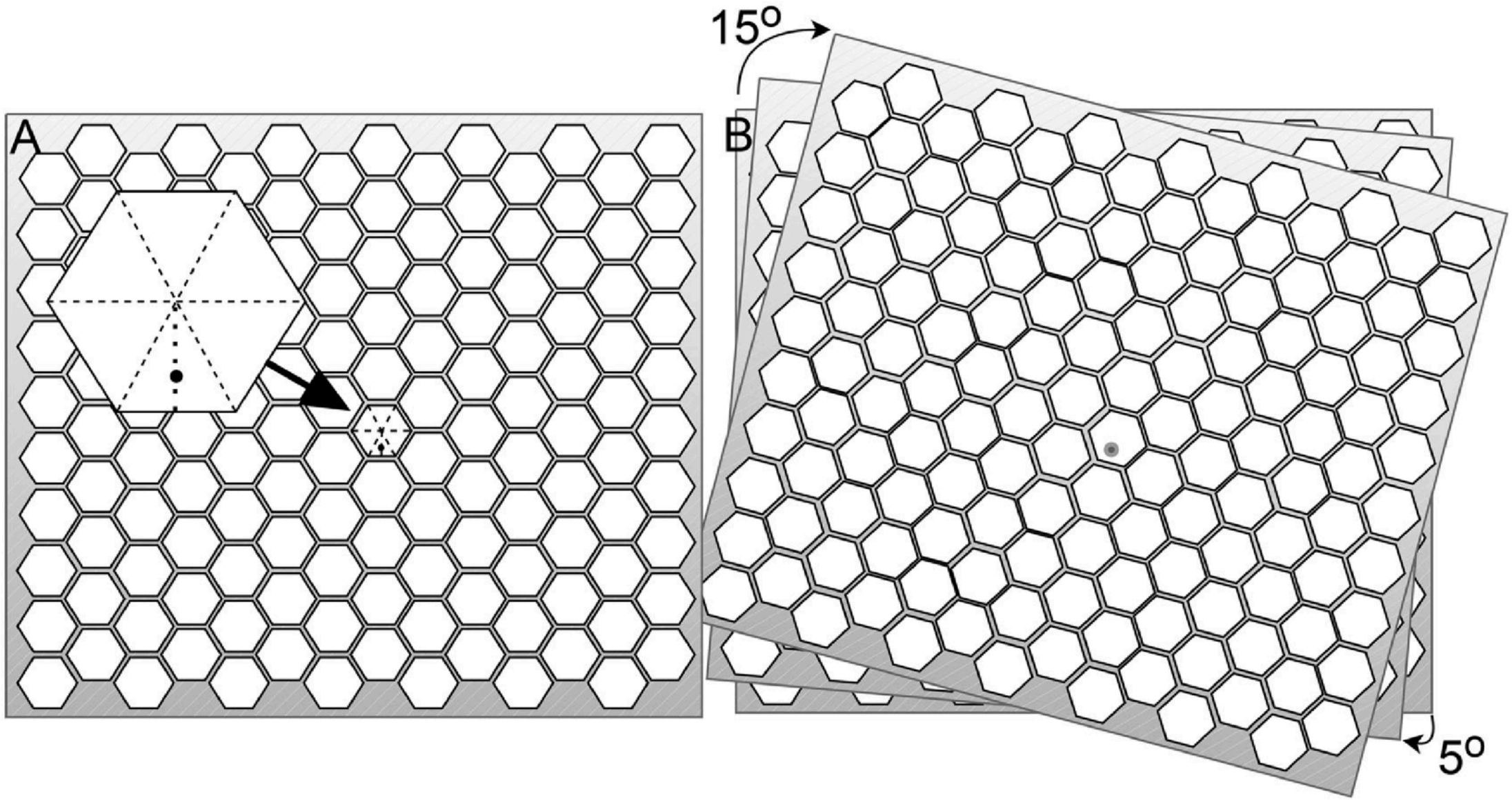
Dosimetry with radiochromic films



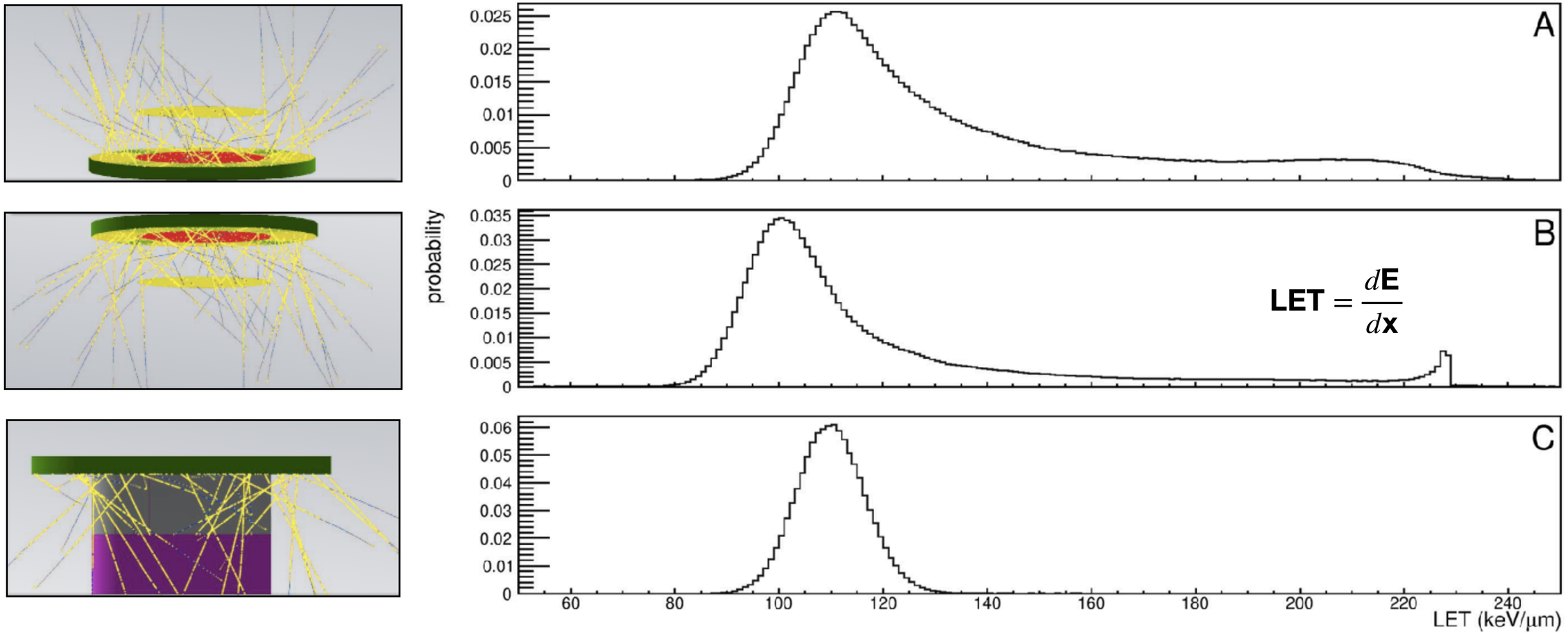
GAFchromic™ film (Ashland Inc., Bridgewater, NJ, USA) irradiated with alpha particles from Am-241 source

Image from students' project report

Collimator rotation scheme



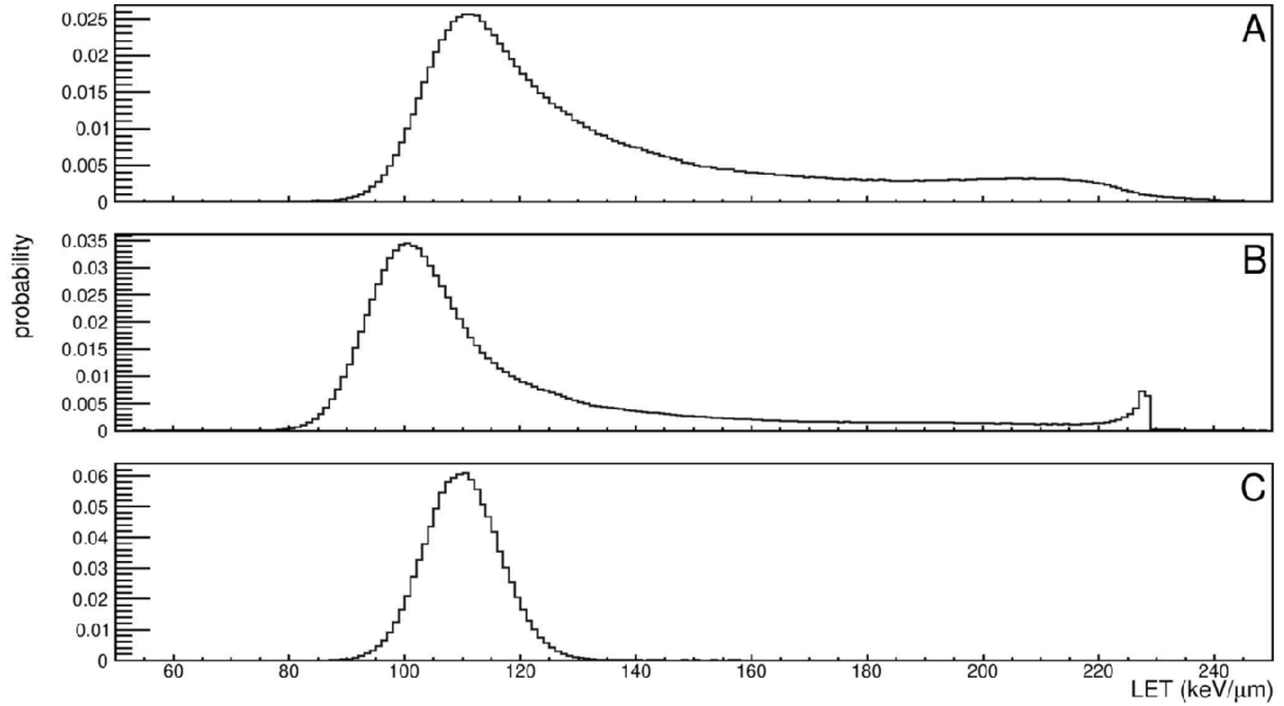
LET distributions in cell nuclei



(A) cells irradiated from above (top-down setup), (B) cells irradiated from below (bottom-up setup) without a collimator and (C) cells irradiated from below through the stable or rotating collimator.

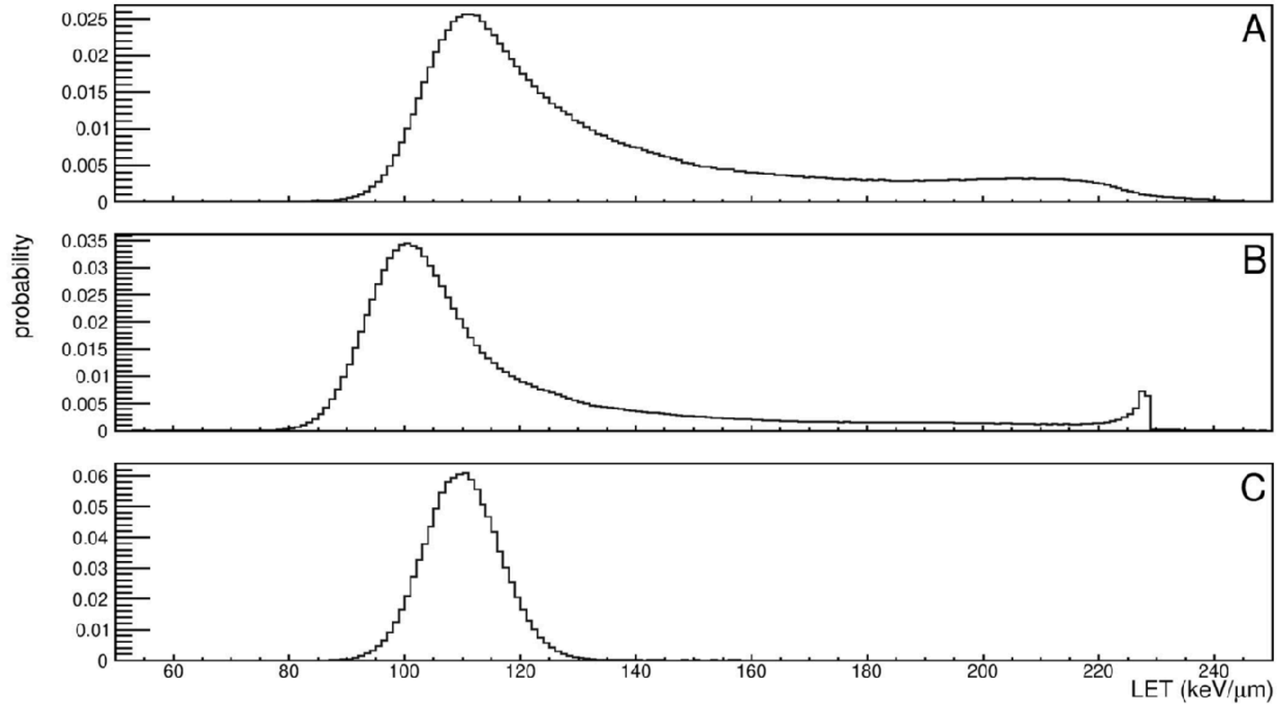
Tartas et al., 2023

LET distributions in cell nuclei



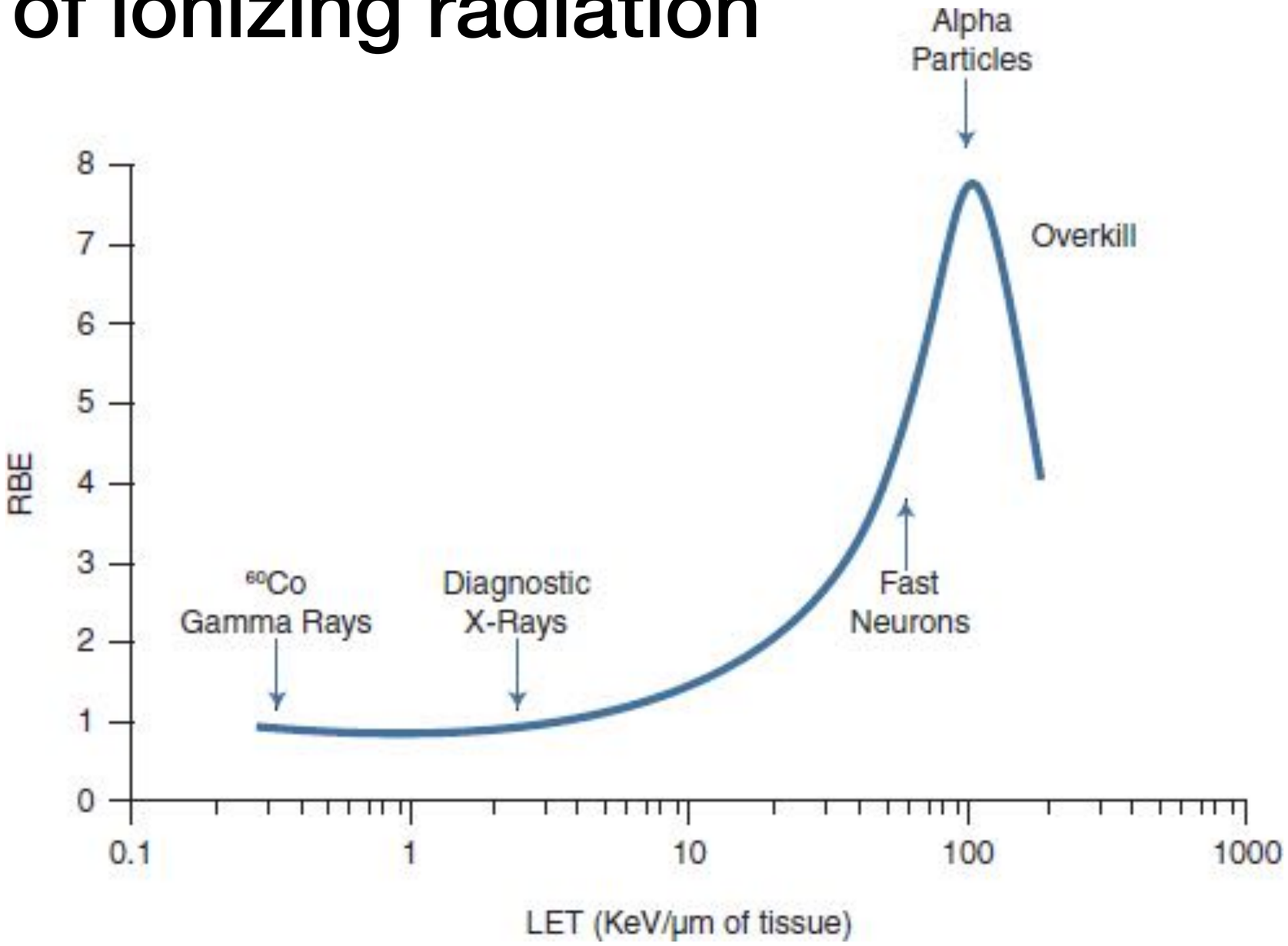
Exposure setup	Mean LET ± SD (kev/μm)	Median LET (kev/μm)	Dose ± SD (Gy)	Dose rate (Gy/min)
Top-down setup, no collimator	135 ± 35	123	1.22 ± 0.04	0.64
Bottom-up setup, no collimator	120 ± 34	107	1.22 ± 0.04	0.86
Bottom-up setup with a collimator	110 ± 9	110	1.22 ± 0.20	0.046
Bottom-up setup with a rotating collimator	110 ± 9	110	1.22 ± 0.14	0.046

LET distributions in cell nuclei



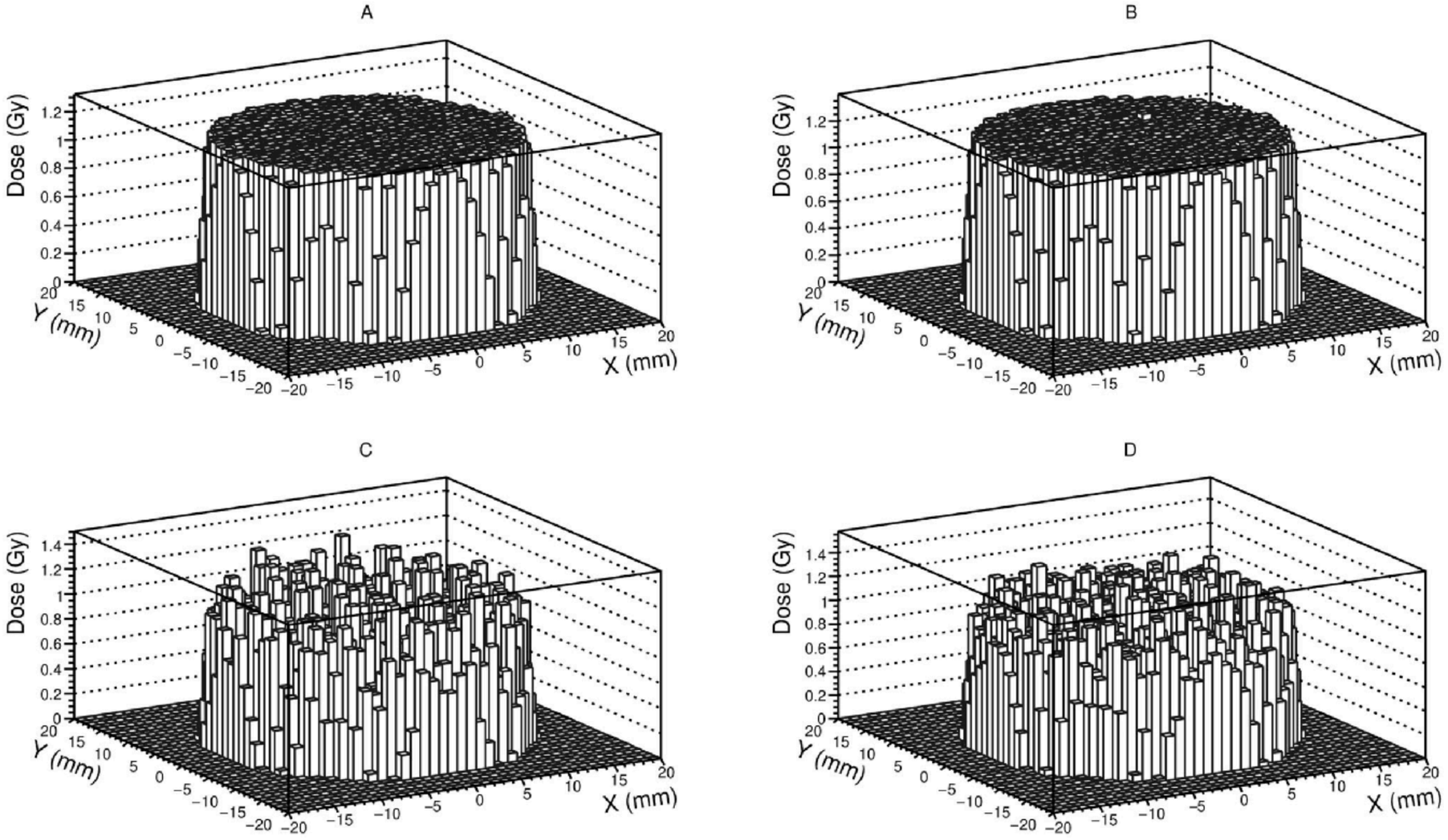
Exposure setup	Mean LET ± SD (kev/μm)	Median LET (kev/μm)	Dose ± SD (Gy)	Dose rate (Gy/min)
Top-down setup, no collimator	135 ± 35	123	1.22 ± 0.04	0.64
Bottom-up setup, no collimator	120 ± 34	107	1.22 ± 0.04	0.86
Bottom-up setup with a collimator	110 ± 9	110	1.22 ± 0.20	0.046
Bottom-up setup with a rotating collimator	110 ± 9	110	1.22 ± 0.14	0.046

Types of ionizing radiation



Bushberg et al., 2012

Dose distributions across cell dishes



(A) cells irradiated from above (top-down setup), (B) cells irradiated from below (bottom-up setup) without a collimator, (C) cells irradiated from below through the collimator and (D) cells irradiated from below through a rotating collimator.

Summary

- The poor dose homogeneity in cell nuclei irradiated through a stationary collimator.
- The dose homogeneity can be improved by wobbling the collimator. But it is technically demanding making the construction of an alpha exposure facility challenging and costly.
- The average LET parameter is not a sufficient quantity to characterize an alpha beam.
- Working with cells requires precision. Slight change in the setup, such as modifying the height of the medium can cause differences in the delivered dose and LET.
- We observe the average response of the cells, so we must be aware of the dosimetry.

Taylor & Francis
Taylor & Francis Group

International Journal of Radiation Biology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/irab20

Modeling of dose and linear energy transfer homogeneity in cell nuclei exposed to alpha particles under various setup conditions

Adrianna Tartas, Mateusz Filipek, Marcin Pietrzak, Andrzej Wojcik & Beata Brzozowska

To cite this article: Adrianna Tartas, Mateusz Filipek, Marcin Pietrzak, Andrzej Wojcik & Beata Brzozowska (2023): Modeling of dose and linear energy transfer homogeneity in cell nuclei exposed to alpha particles under various setup conditions, International Journal of Radiation Biology, DOI: 10.1080/09553002.2023.2161659

To link to this article: https://doi.org/10.1080/09553002.2023.2161659

Acknowledgments

FACULTY OF PHYSICS
UNIVERSITY OF WARSAW

Beata Brzozowska
Mateusz Filipek
Beata Pszczółkowska
Monika Mietelska

NATIONAL CENTRE FOR NUCLEAR RESEARCH
ŚWIERK

Marcin Pietrzak

Stockholm University

Andrzej Wojcik