1st Practical Task: SRIM and TRIM Hadrontherapy Simulation

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Abstract. *The objective of this task is to simulate heavy ion irradiation of organic tissues, simulating hadron therapy for cancer treatment, as a way to familiarize yourself with the TRIM software. We will use helium, carbon, and oxygen ions as examples of treatment ions, chosen based on experimental reports from several institutions that perform this type of therapy, such as the HIT (Heidelberg Ion Beam Therapy Center), located in Heidelberg, Germany, considered the largest and best cancer treatment center in the world. This type of treatment is not available in Brazil or throughout Latin America. There is one unit in South Africa, two in Asia, and several in Europe and the United States.*

Script for the 1st Practical Task: SRIM and TRIM - Hadrontherapy Simulation

A. Reproduce the simulation described below

To create the simulation scenario, we chose the example of breast cancer, due to the simplicity of the organic tissue layout and the easy-to-illustrate dimensions, as the target tumors are located at shallow depths. Real-life hadron therapy treatments include a wide range of cancer types, and breast cancer is not necessarily a special case. However, the availability of tissues in the TRIM dictionary was a determining factor. We chose epithelial tissue with a thickness of 2 mm, adipose tissue with a thickness of 10 mm (1 cm), followed by mammary gland tissue with a thickness of 10 mm (1 cm), with the target located 20 mm (2 cm) from the skin surface. In other words, a tumor close to the skin surface.

The 20 mm target was bombarded with helium, carbon, and oxygen ions, meaning the irradiation energy was chosen so that the Braag peak occurred 20 mm from the skin surface. In the case of He ions, the peak occurred at 20 mm for an irradiation energy of 190 MeV. We then compared this with the effect that carbon and oxygen beams would cause if irradiated with the same energy.

B Create another Hadrontherapy simulation example scenario

Escolha outro exemplo de aplicação de terapia empregando o método usado na simulação descrita no item anterior.

C. Other Applications

Suggest other examples of applications for irradiation of substances by ions and other radiation sources.

A. Reproduce the simulation described below

SRIM/TRIM Installation Script: *Installation Notebook Hyperlink (GitHub)*

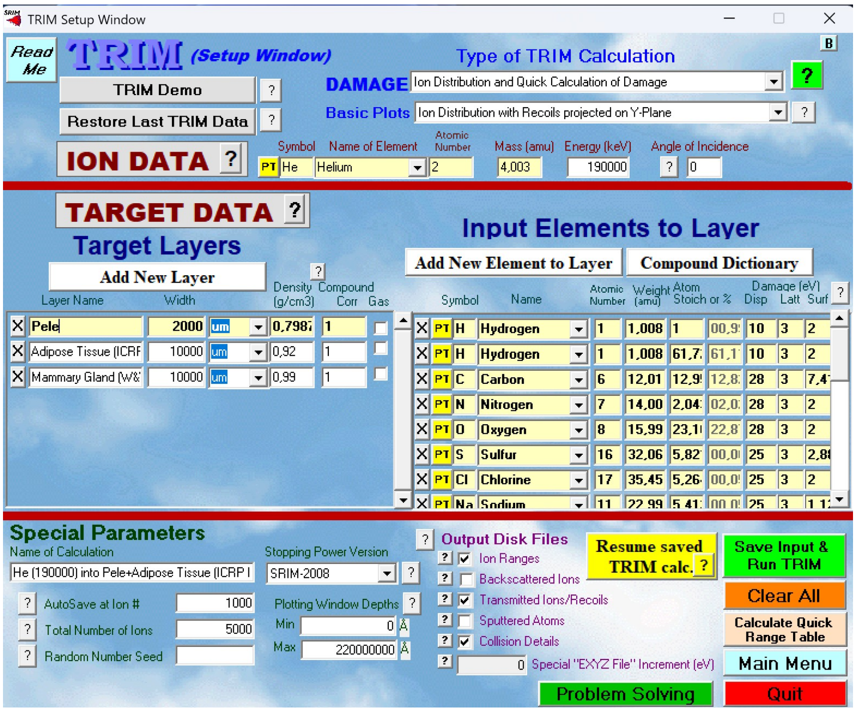

Figura 1. TRIM setup for the didactic example of *breast cancer*: layers skin (2 mm) $\rightarrow$ adipose tissue (10 mm) $\rightarrow$ mammary gland (10 mm); He beam = 190 MeV ($0°$); window 0–$2{,}2 \times 10^8$ Å; $N = 5000$ ions.

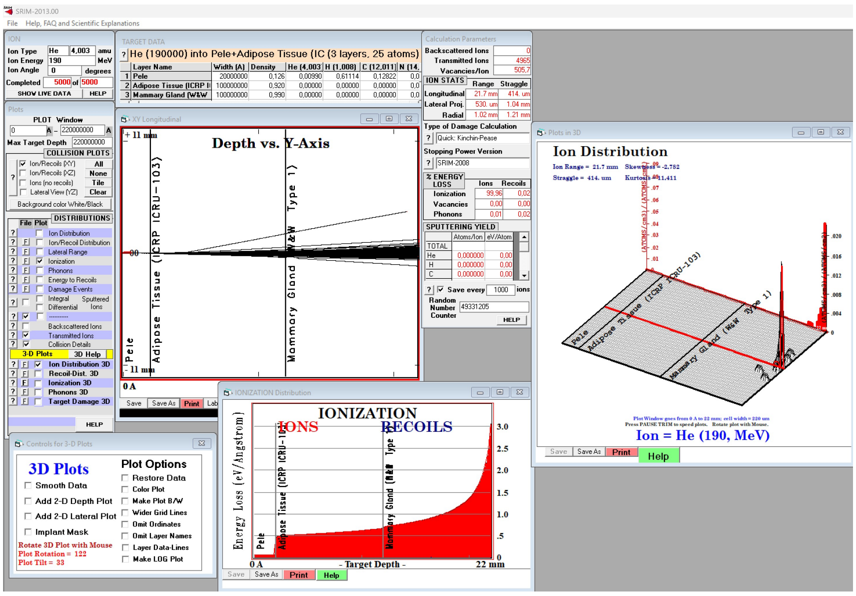

Figura 2. Breast example results: ion distribution and ionization curve showing the Bragg peak near 22 mm, consistent with He = 190 MeV and the three target layers.

B. Create another Hadrontherapy simulation example scenario

1. Introduction

Hadron therapy is an advanced form of radiotherapy created by Robert Wilson in the 1940s. It stands out for allowing a higher dose to the tumor and lower radiation to healthy tissue, surpassing conventional photon beams. Currently, the use of protons is common in several countries, while the clinical success of carbon ions in Japan has spurred their adoption in Europe. Research is also exploring heavier ions, such as helium, lithium, beryllium, and boron, which may offer greater dose precision and control of resistant tumors. The choice of the ideal ion depends on the depth of the tumor, the required dose, and the radiosensitivity of the tissues.

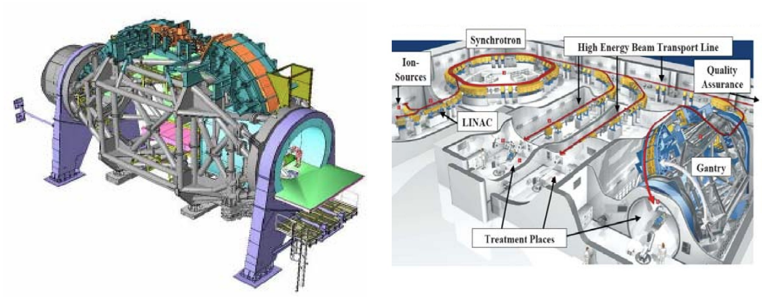

Figura 3. Example of a hadron therapy facility in Heidelberg (right). Isocentric gantry used in this facility and designed for carbon ions (left) Herranz et al. [2008].

Computer simulations are essential when beam lines are not available. SRIM/-TRIM Ekinci et al. [2023] allows predicting ion energy deposition in tissues; in the breast example, a tumor at 20 mm was modeled by adjusting the energies to position the Bragg peak in the lesion (e.g., He $\approx$ 190 MeV at 20 mm). These simulations also provide metrics such as LET, recoils, and lateral scattering, useful in optimizing the treatment plan.

*The simulation proposed in this work, **deep melanoma**, with layers of epithelium, adipose tissue, and muscle, adopts the same modeling and analysis methodology proposed by Ekinci et al. [2023], but does not correspond to a clinical case in the article.*

The new scenario was developed exclusively for Exercise 2, as requested, using its own parameters, such as cancer type, tumor depth, and the energies of the helium, carbon, and oxygen beams.

2. Description of the Task Performed

A stratified target composed of ***skin****,* ***adipose tissue****, and* ***skeletal muscle****, with no bony structures in the path, was adopted. The materials were selected from the ICRP/ICRU TRIM dictionary and checked against the* ***NIST/STAR – Composition of Materials*** *database. The total target depth was kept at* ***25 mm****.*

Tabela 1. Target parameters (25 mm) for the "skin + fat + muscle" scenario"

Layer	Thickness	Density (g/cm^3)	TRIM Material / Note
Layer 1 – Pele (Skin)	2 mm (2 000 µm)	1.09	*Skin_Human (W&W) / Skin (ICRP).*
Layer 2 – Tecido adiposo (Fat)	10 mm (10 000 µm)	0.92	*Adipose Tissue (ICRP).*
Layer 3 – Músculo esquelético	13 mm (13 000 µm)	1.06	*Muscle, Skeletal (ICRP).*

The initial energies used to position the Bragg peak at ≈ ***25 mm*** *(soft tissue) were:*

- *Helium (He):* ***200 MeV*** *(200,000 keV)*
- *Carbon (C):* ***1,15 GeV*** *(1 150,000 keV)*
- *Oxygen (O):* ***1,75 GeV*** *(1 750,000 keV)*

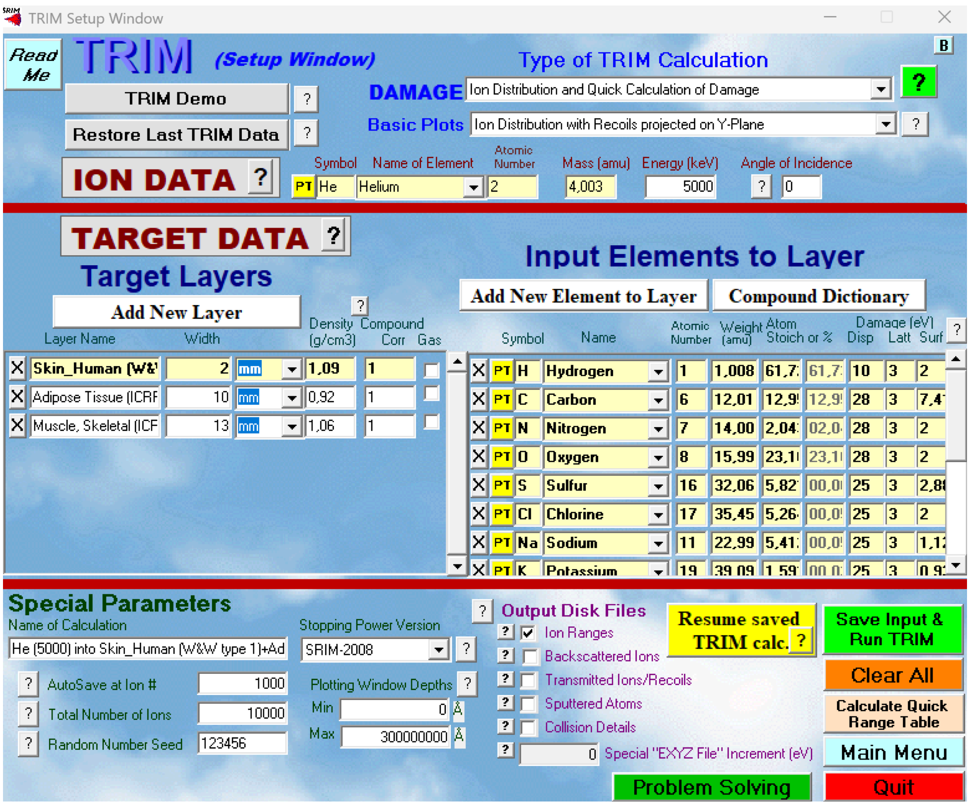

Figura 4. Setup do TRIM in 25 mm.

3. Presentation of Results

*For the skin (2 mm) → adipose (10 mm) → muscle (13 mm) target, irradiated with **He = 200 MeV**, TRIM predicted a longitudinal range of **21,9 mm** and a Bragg peak within the muscle layer (Fig. 5). There were no transmitted ions and the lateral scattering was in the range of **0,16–0,25 mm**, indicating good conformity. To position the peak at **25 mm**, it is recommended to raise the energy to **205–210 MeV** and refine in steps of 5 MeV.*

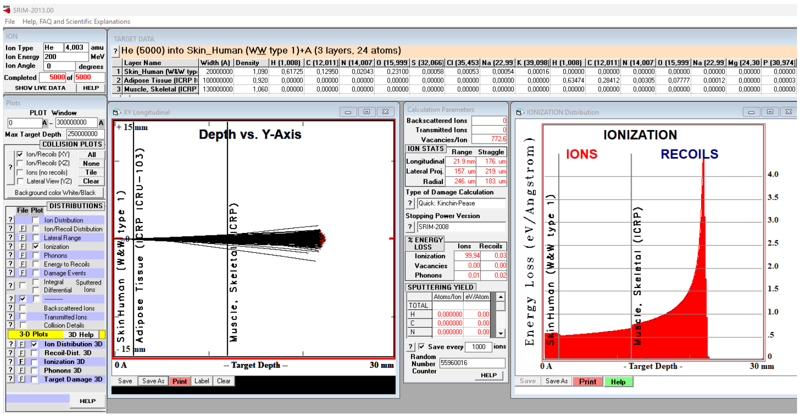

Figura 5. Ionization profile (He 200 MeV) in the skin–fat–muscle target; peak at ∼22 mm (longitudinal range 21,9 mm).

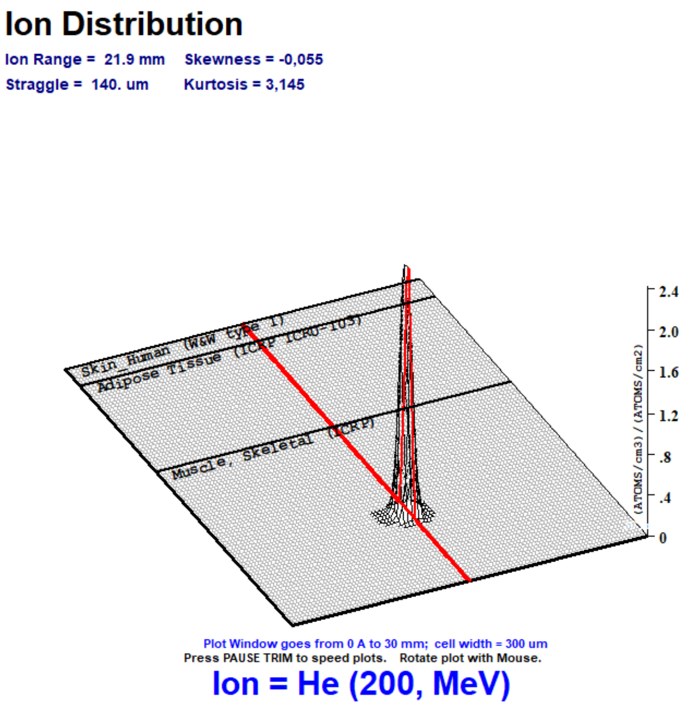

Figura 6. 3D distribution of ions (He 200 MeV): concentrated stop in the Bragg peak region; no transmitted ions.

4. Conclusions

In this activity, a brief tutorial on the installation and configuration of SRIM/-TRIM (A) was prepared and published, ensuring the reproducibility of the environment. Then, using the operational software, the parameters of the didactic example were reproduced and a second scenario was executed in soft tissues (skin–fat–muscle, 25 mm), recording screens, graphs, and energy adjustments to position the Bragg peak (B). As a practical development, applications that are easy to repeat with the same step-by-step process were indicated, such as skull (skin–cortical bone–brain, 25 mm), breast (skin–adipose–mammary gland, 20–25 mm), and ion implantation in silicon for doping profiles (C).

C. Other Applications

Suggested article: *Ion implantation of advanced silicon devices: Past, present and future. (versão para visualizar online: https://sci-hub.se/https://www.sciencedirect.com/science/article/abs/pii/S1369800116304905)*
Ion implantation is important for the future of electronics, especially in nanoscale devices operating in a quantum mechanically dominated regime, facing challenges such as nanowire damage accumulation and quantum confinement effects. To mitigate charge problems in small structures, Neutral Beam Processing (NBP) is a promising solution. Future applications extend to template engineering for the growth of 2D monolayer structures, such as graphene, and to atomic electronics for quantum computing, involving the precise implantation of single or very few atoms. Thus, ion implantation will continue to be essential both for routine ICs and for enabling the smart and quantum electronics of the future [Current, 2017].

Referências

Current, M. I. (2017). Ion implantation of advanced silicon devices: Past, present and future. Materials Science in Semiconductor Processing*, 62:13–22.*

Ekinci, F., Bostanci, E., Güzel, M., and Dagli, O. (2023). Simulation based analysis of 4he, 7li, 8be and 10b ions for heavy ion therapy. International Journal of Radiation Research*, 21(1):131–137.*

Herranz, J., Herraiz, E., Vicente, S., España, J., Cal-Gonzalez, J., and Udías, J. (2008). Hadronterapia. I Encuentro Complutense para la Divulgación en Física Nuclear y de Partículas [Internet]. gfn.