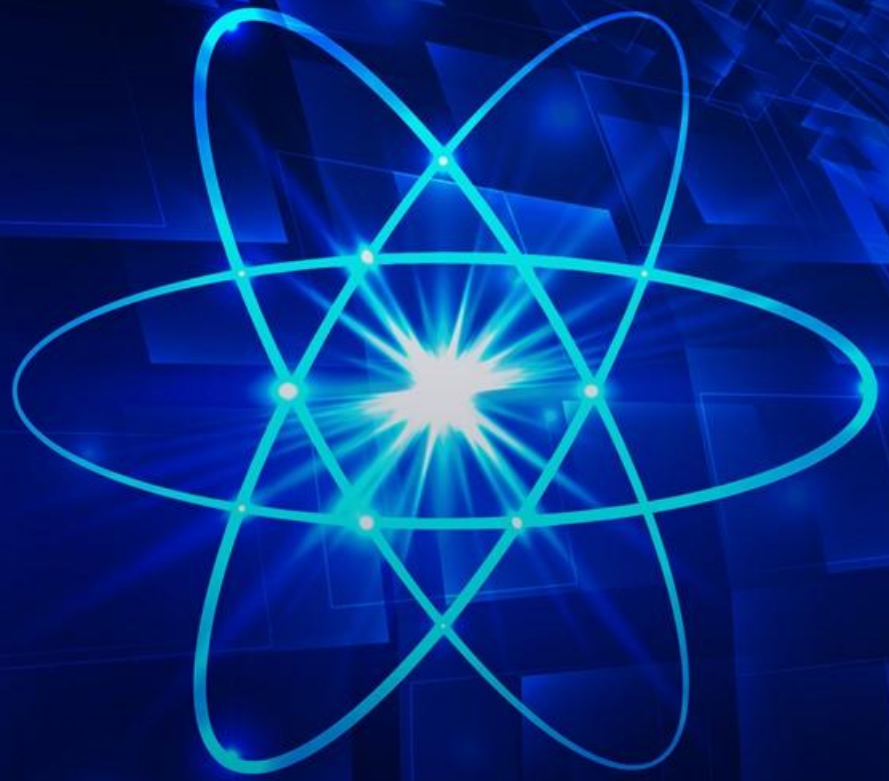

Aplicações de Simulações Monte Carlo em Dosimetria e Física Médica

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Comissão Nacional de Energia Nuclear

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Sumário

- Otimização na radioterapia
- Otimização na braquiterapia
- Protonterapia
- BNCT

Campos Pequenos

Novas máquinas: aumento do uso de técnicas mais modernas de radioterapia

Técnicas modernas de radioterapia possibilitam um tratamento mais preciso e acurado do tecido doente, enquanto preserva o tecido sadio:

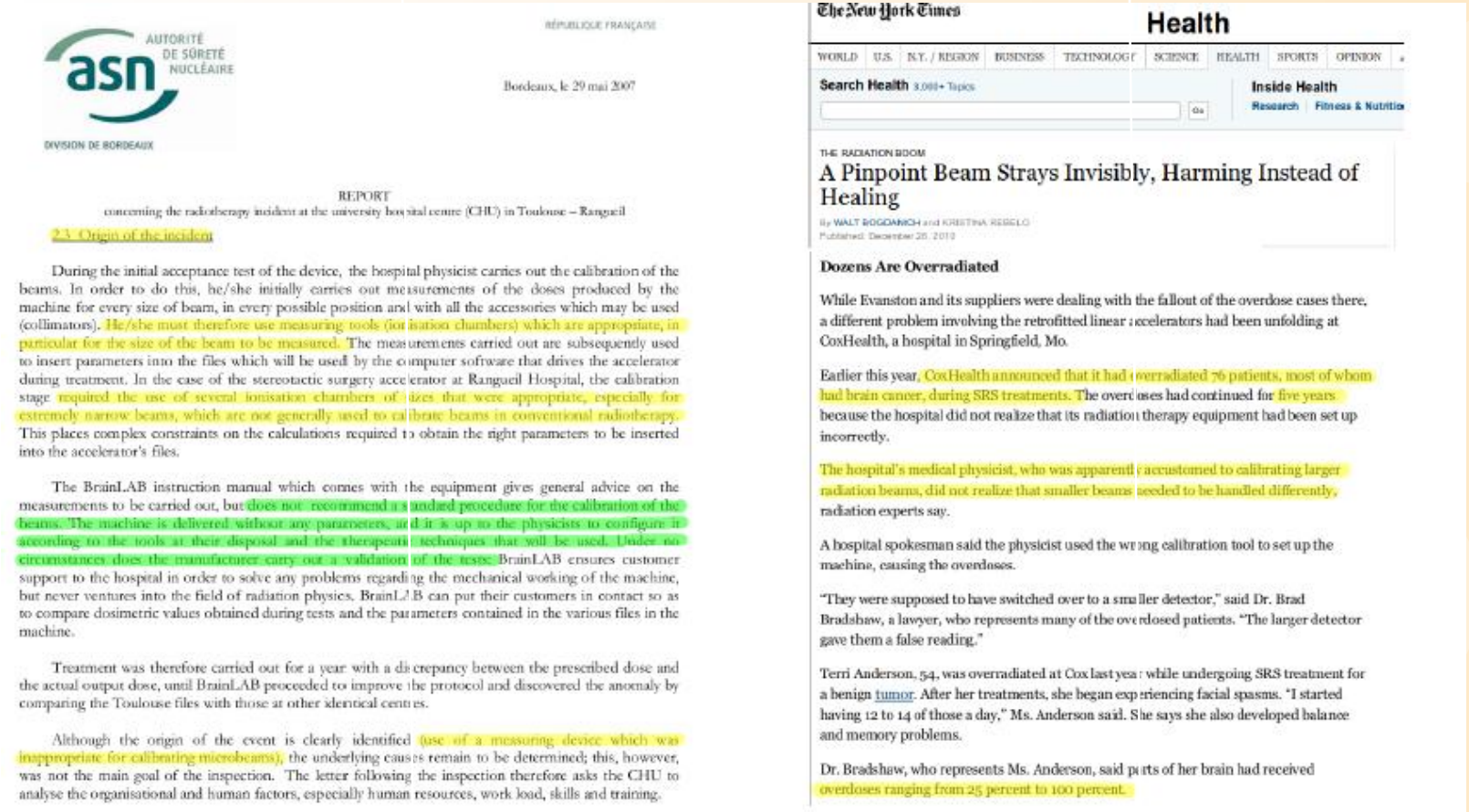
- Volumes menores
- Tempos mais curtos
- Melhores resultados
- Diminuição da toxicidade

Para isso, muitas vezes, são necessários campos de radiação menores que os campos convencionalmente utilizados na radioterapia

Definição de campos pequenos

Um tamanho de campo é dito pequeno quando, ao menos, uma das três condições a seguir é satisfeita:

1. Perda de equilíbrio eletrônico lateral
2. Oclusão parcial da fonte
3. Detector do mesmo tamanho ou maior que o tamanho de campo



RÉPUBLIQUE FRANÇAISE

AUTORITÉ DE SÛRETÉ NUCLÉAIRE

DIVISION DE BORDEAUX

Bordeaux, le 29 mai 2007

REPORT

concerning the radiotherapy incident at the university hospital centre (CHU) in Toulouse – Rangueil

2.3. Origin of the incident

During the initial acceptance test of the device, the hospital physicist carries out the calibration of the beams. In order to do this, he/she initially carries out measurements of the doses produced by the machine for every size of beam, in every possible position and with all the accessories which may be used (collimators). He/she must therefore use measuring tools (ionisation chambers) which are appropriate, in particular for the size of the beam to be measured. The measurements carried out are subsequently used to insert parameters into the files which will be used by the computer software that drives the accelerator during treatment. In the case of the stereotactic surgery accelerator at Rangueil Hospital, the calibration stage required the use of several ionisation chambers of sizes that were appropriate, especially for extremely narrow beams, which are not generally used to calibrate beams in conventional radiotherapy. This places complex constraints on the calculations required to obtain the right parameters to be inserted into the accelerator's files.

The BrainLAB instruction manual which comes with the equipment gives general advice on the measurements to be carried out, but does not recommend a standard procedure for the calibration of the beams. The machine is delivered without any parameters, and it is up to the physicists to configure it according to the tools at their disposal and the therapeutic techniques that will be used. Under no circumstances does the manufacturer carry out a validation of the tests. BrainLAB ensures customer support to the hospital in order to solve any problems regarding the mechanical working of the machine, but never ventures into the field of radiation physics. BrainLAB can put their customers in contact so as to compare dosimetric values obtained during tests and the parameters contained in the various files in the machine.

Treatment was therefore carried out for a year with a discrepancy between the prescribed dose and the actual output dose, until BrainLAB proceeded to improve the protocol and discovered the anomaly by comparing the Toulouse files with those at other identical centres.

Although the origin of the event is clearly identified (use of a measuring device which was inappropriate for calibrating microbeams), the underlying causes remain to be determined; this, however, was not the main goal of the inspection. The letter following the inspection therefore asks the CHU to analyse the organisational and human factors, especially human resources, work load, skills and training.

The New York Times

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THE RADIATION ROOM

A Pinpoint Beam Strays Invisibly, Harming Instead of Healing

By WALT BOGDANICH and KRISTINA REBELO

Published: December 26, 2010

Dozens Are Overradiated

While Evanston and its suppliers were dealing with the fallout of the overdose cases there, a different problem involving the retrofitted linear accelerators had been unfolding at CoxHealth, a hospital in Springfield, Mo.

Earlier this year, CoxHealth announced that it had overradiated 76 patients, most of whom had brain cancer, during SRS treatments. The overdoses had continued for five years because the hospital did not realize that its radiation therapy equipment had been set up incorrectly.

The hospital's medical physicist, who was apparently accustomed to calibrating larger radiation beams, did not realize that smaller beams needed to be handled differently, radiation experts say.

A hospital spokesman said the physicist used the wrong calibration tool to set up the machine, causing the overdoses.

"They were supposed to have switched over to a smaller detector," said Dr. Brad Bradshaw, a lawyer, who represents many of the overdosed patients. "The larger detector gave them a false reading."

Terri Anderson, 54, was overradiated at Cox last year while undergoing SRS treatment for a benign tumor. After her treatments, she began experiencing facial spasms. "I started having 12 to 14 of those a day," Ms. Anderson said. She says she also developed balance and memory problems.

Dr. Bradshaw, who represents Ms. Anderson, said parts of her brain had received overdoses ranging from 25 percent to 100 percent.

Erro não descoberto por um ano,
145 pacientes superdosados

Erro não descoberto por cinco anos,
76 pacientes superdosados

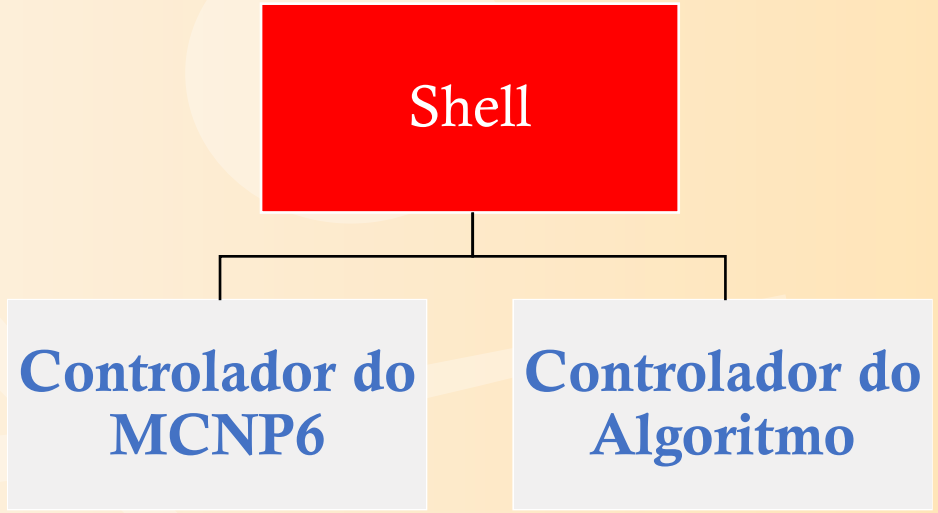
AutoOptMCNP

1. Desenvolvido em *Python*

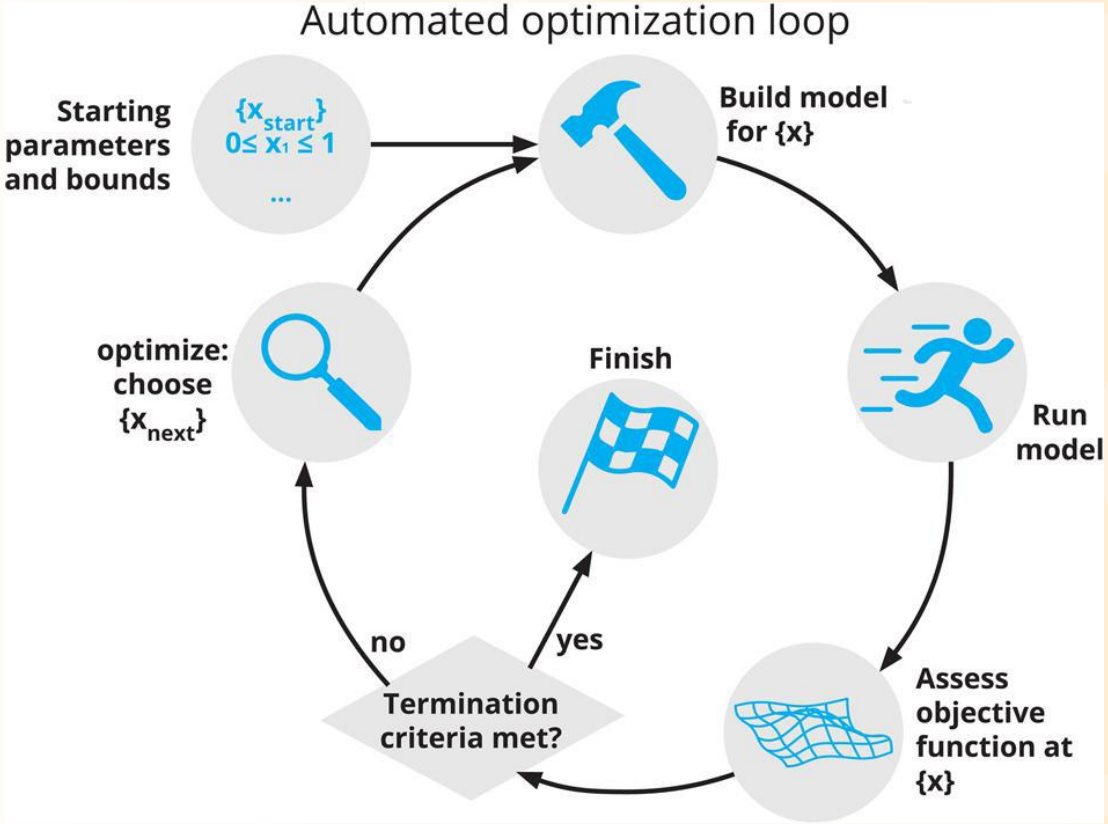
2. Registro do Programa junto ao INPI: BR512024000342-8

Três *scripts* principais:

- Controlador do MCNP6
- Aplicador das funções do algoritmo
- Shell para concatenar os scripts anteriores



AutoOptMCNP



Metodologia: ajuste automatizado de parâmetros pelo AutoOptMCNP

Ajuste de parâmetros em três etapas

Etapa 1

MDADE

Parâmetros: E_0 do feixe de elétrons e ângulo Θ de abertura do FF

Etapa 2

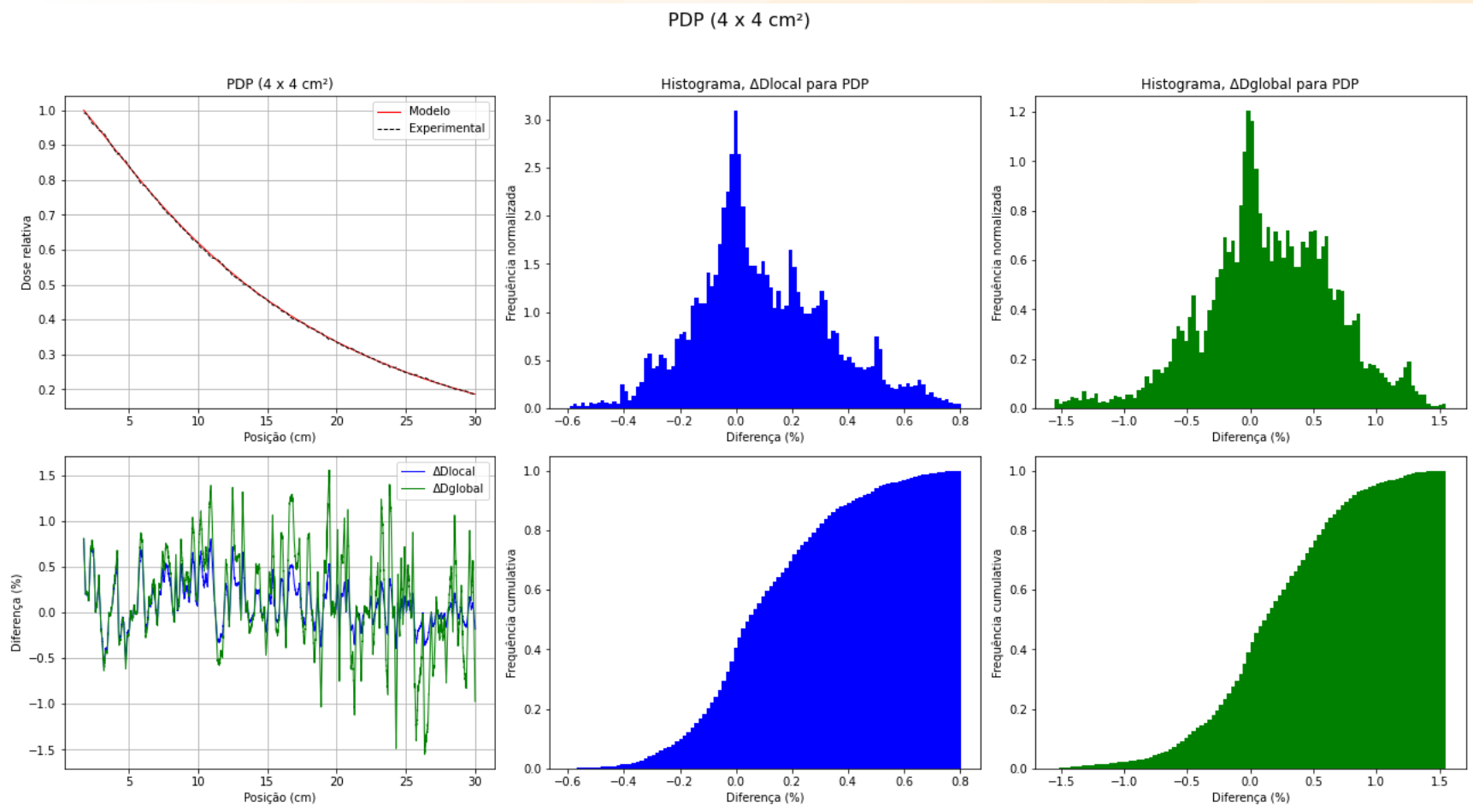
Parâmetros: DASC, DAIC e t_{col}

Etapa 3

Parâmetros: DASC, DAIC, Θ e s_{FWHM}

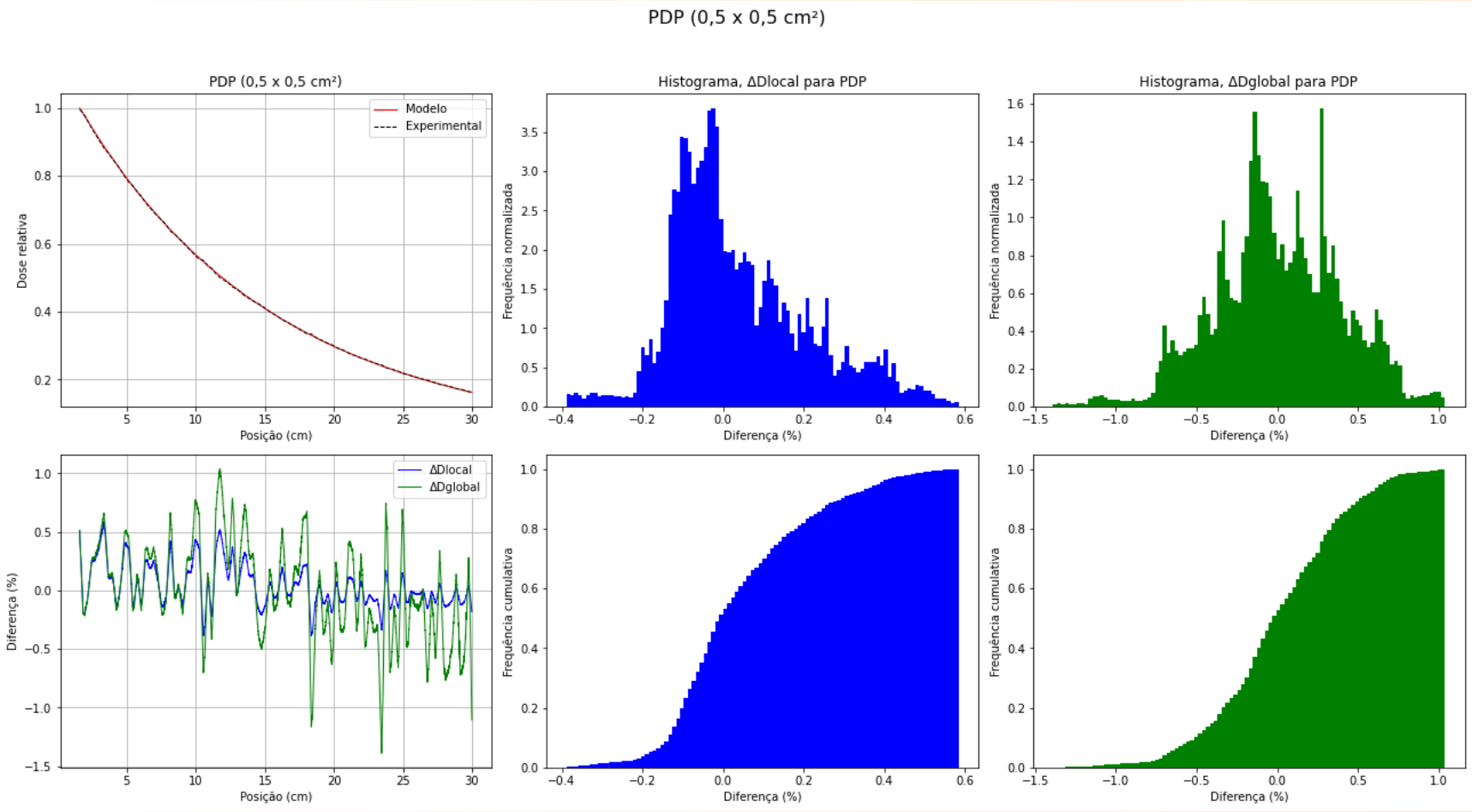
Varian 2100CD

PDP (4 x 4 cm²)



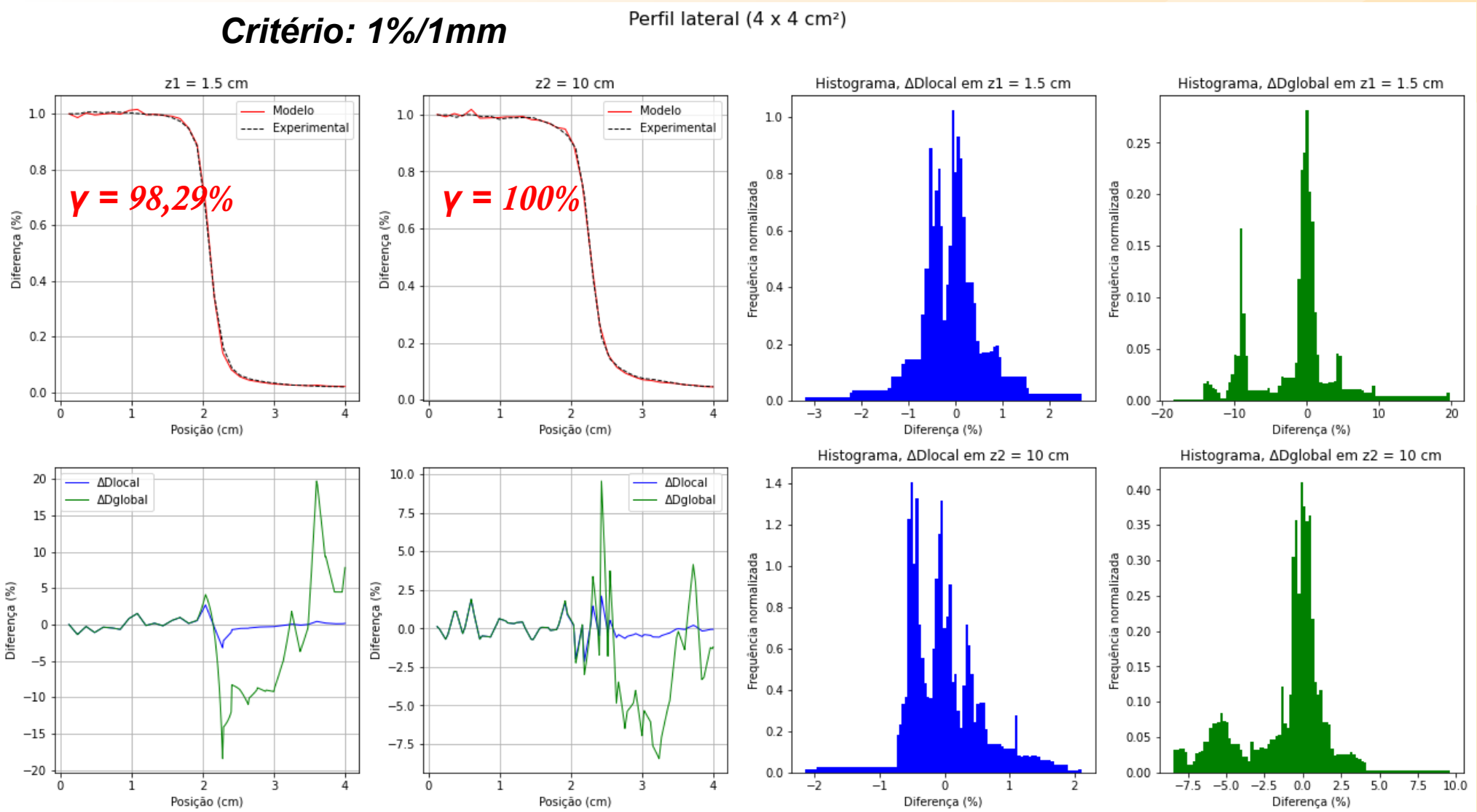
Varian 2100CD

PDP (0,5 x 0,5 cm²)



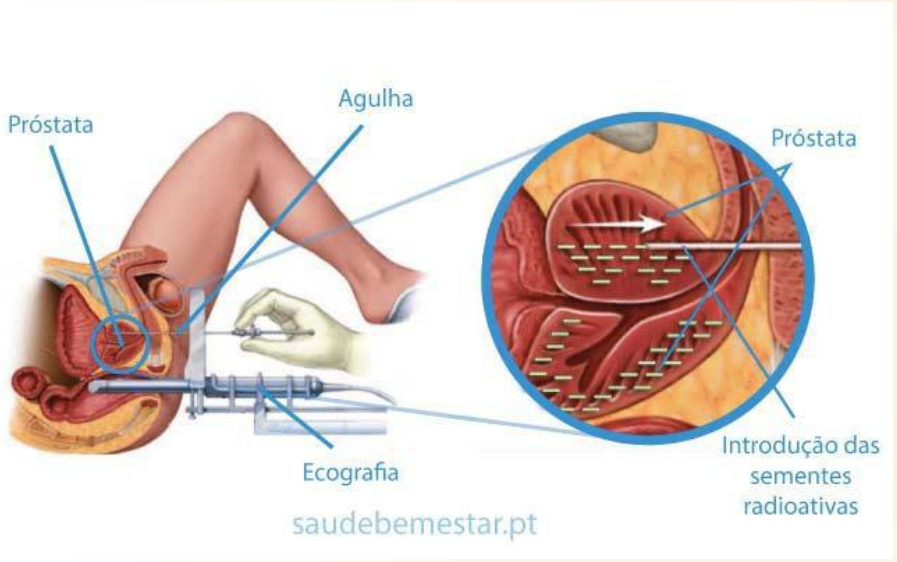
Varian 2100CD

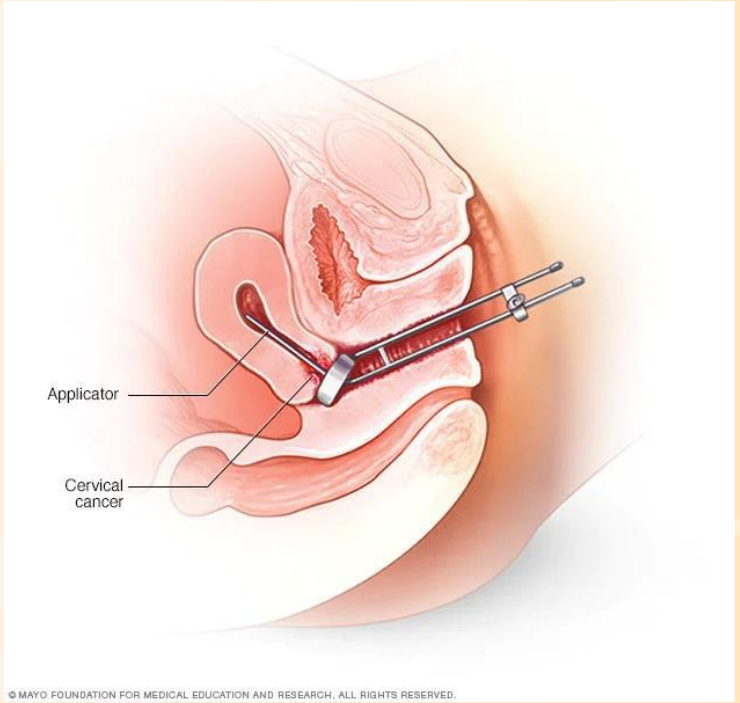
Critério: 1%/1mm



Braquiterapia

- ❑ Braquiterapia consiste em fontes seladas: filamentos, “sementes”, tubos, agulhas e outros:
- ❑ Intersticial;
- ❑ Intracavitário;
- ❑ Intravenosa;
- ❑ superficial;





Taxa de dose:

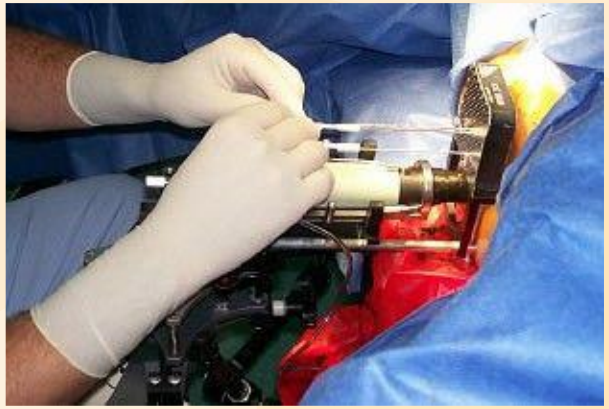
- ❑ *Low Dose Rate* (LDR): Taxa de Dose ≤ 2 Gy/h;
- ❑ *Medium Dose Rate* (MDR): 2 Gy/h < Taxa de Dose ≤ 12 Gy/h;
- ❑ *High Dose Rate* (HDR): Taxa de Dose > 12 Gy/h.

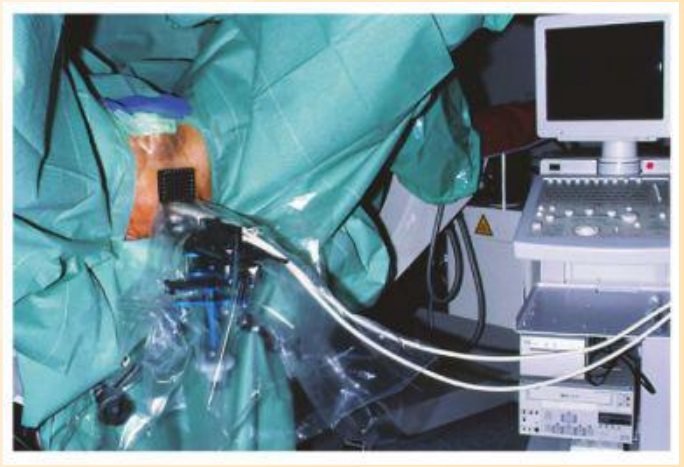
"*Afterloading*":

- ❑ Fontes colocadas com cateteres posicionados;
- ❑ Dose de trânsito;
- ❑ Proteção Radiológica.

Escolha do radionuclídeo da fonte:

- ❑ Energia;
- ❑ Tempo de meia-vida





Otimização Bayesiana

◆ A Otimização Bayesiana é uma técnica sofisticada e aprimorada para encontrar o valor ótimo de uma função objetivo custosa e de difícil convergência, em um número pequeno de avaliações;

◆ Com um conjunto inicial de dados é possível aplicar um modelo que se adeque a distribuição a priori, capturando essa informação e a englobando em uma equação que pode se manipulada a fim de encontrar a solução ótima para o problema tratado;

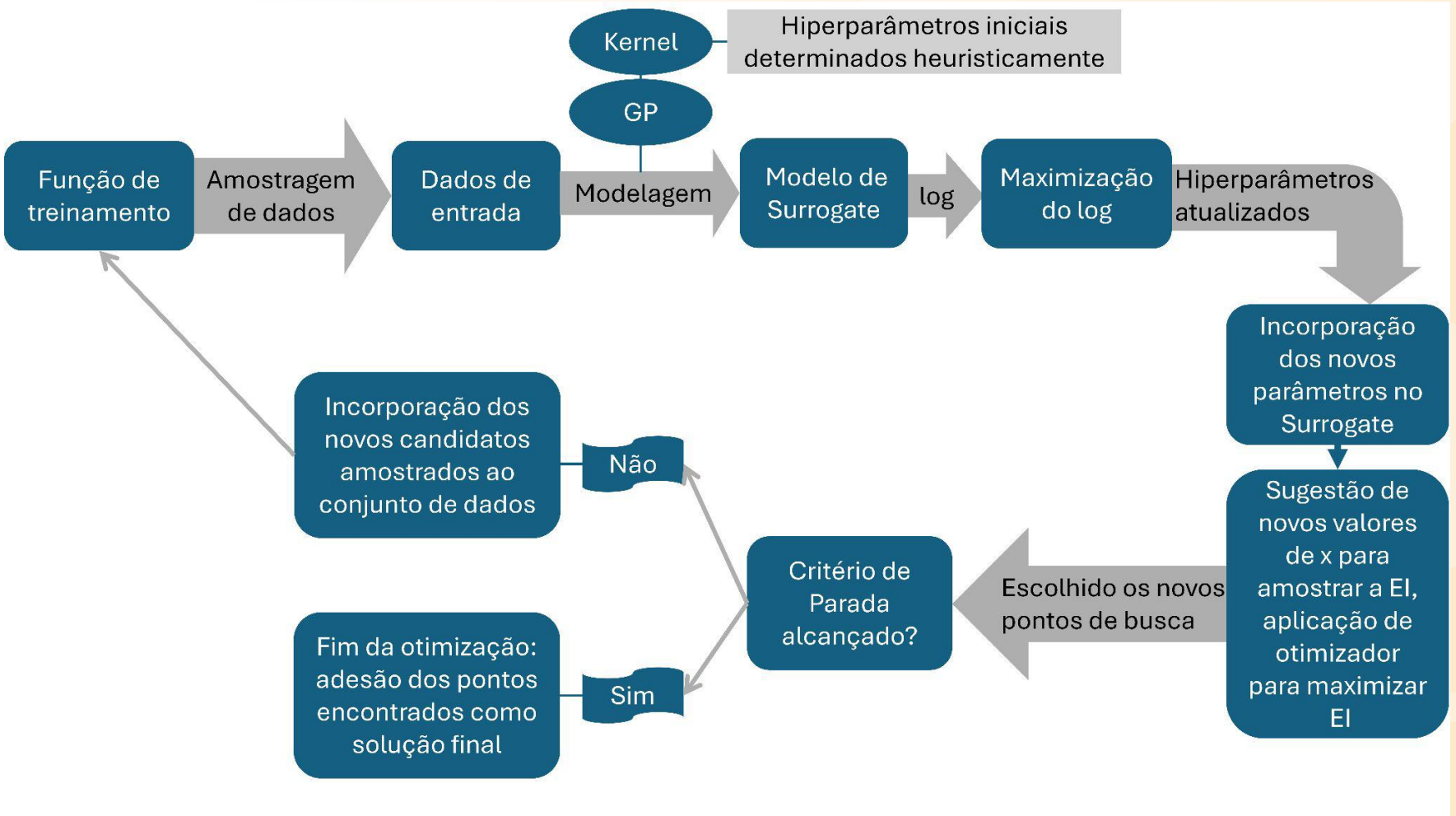
◆ Seu ciclo sequencial e adaptativo permite a atualização do modelo probabilístico a priori, por meio da incorporação dessas novas crenças no modelo a posteriori.

Otimização na Braquiterapia

→ Alcançar a dose prescrita nos tecidos alvo enquanto preserva os tecidos saudáveis adjacentes;

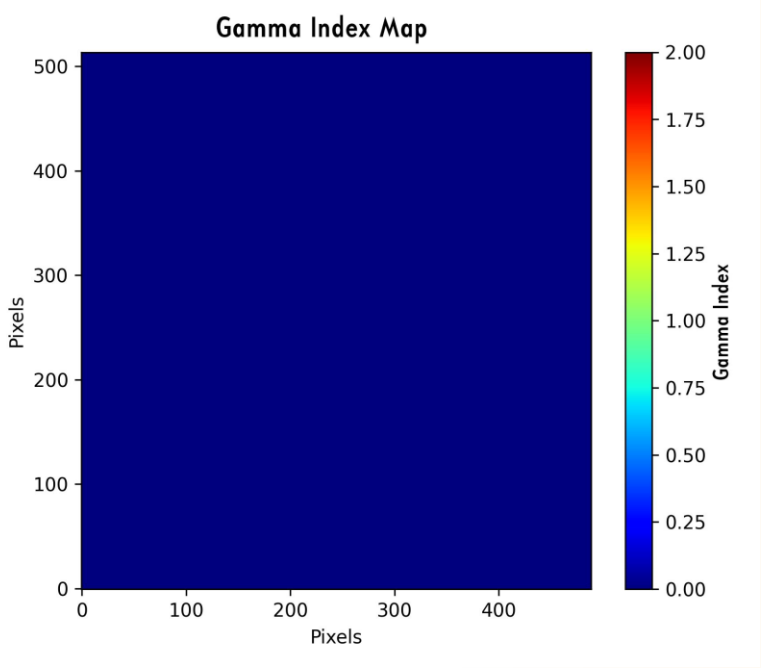
❑ Os modelos voltados a otimização de HDR envolvem a determinação do menor tempo de exposição que garanta as doses prescritas no planejamento;

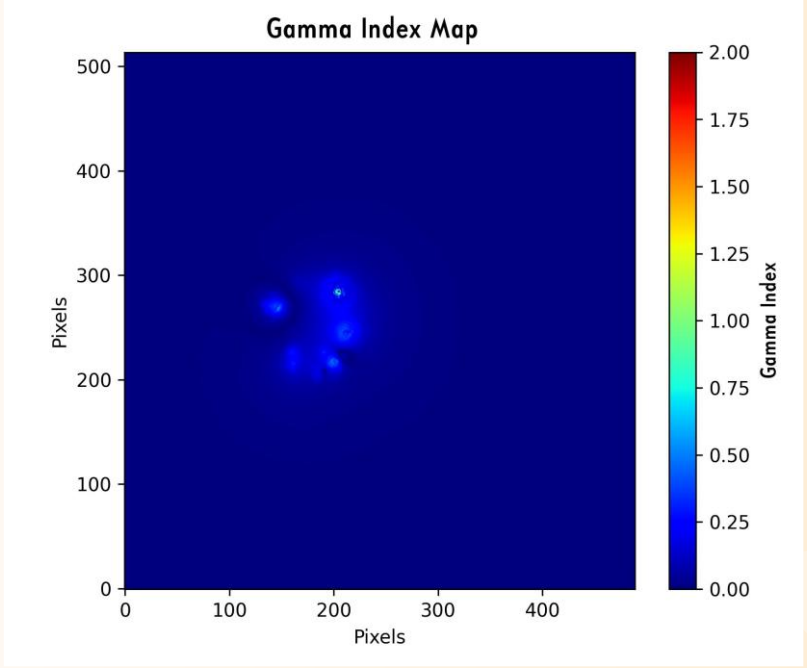
❑ Tentativa de acelerar o processo de planejamento e desvincular essa tarefa de um único profissional;

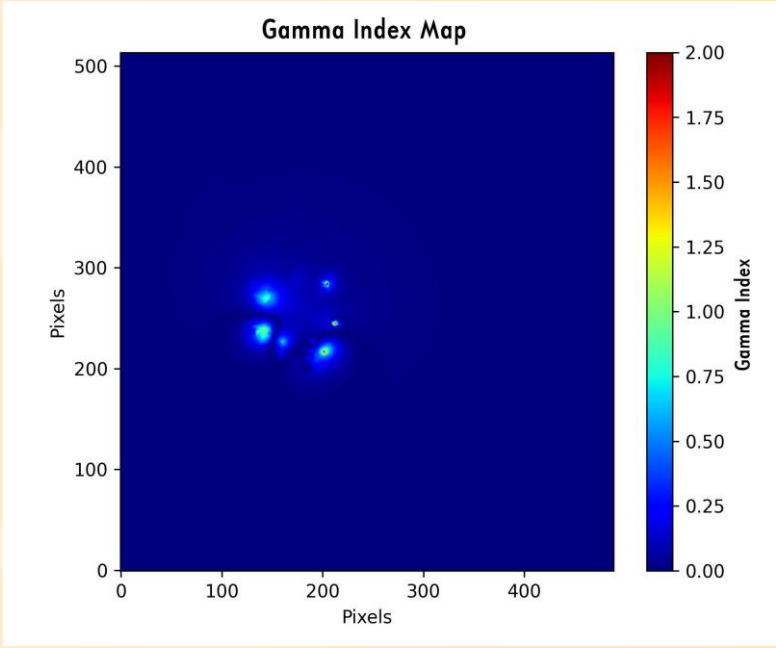

Kernel
Hiperparâmetros iniciais determinados heuristicamente
GP
Função de treinamento
Amostragem de dados
Dados de entrada
Modelagem
Modelo de Surrogate
log
Maximização do log
Hiperparâmetros atualizados
Incorporação dos novos parâmetros no Surrogate
Sugestão de novos valores de x para amostrar a EI, aplicação de otimizador para maximizar EI
Escolhido os novos pontos de busca
Critério de Parada alcançado?
Não
Incorporação dos novos candidatos amostrados ao conjunto de dados
Sim
Fim da otimização: adesão dos pontos encontrados como solução final

Case	Method	Time (min)	Nº. Viables	Nº. Optimal	Prostate Dose (V_{100}%)	Hyperparameters (ls, ots, noise)
1	Optimized (Mean)	51.1 ± 10.9	42.8 ± 7.5	8	96.71%	*Optimized*
	Fixed (Best Result)	71.13	49	1	96.63%	[2.95; 0.74; 0.0061]
	Fixed (Worst Result)	45.98	54	0	-	[2.88; 0.56; 0.0067]
2	Optimized (Mean)	60.9 ± 7.7	35.5 ± 0.6	2	95.02%	*Optimized*
	Fixed (Only Result)	47.94	54	6	97.40%	[2.10; 0.87; 0.0066]
3	Optimized (Mean)	56.2 ± 10.6	41.0 ± 7.2	10	98.92%	*Optimized*
	Fixed (Best Result)	28.34	31	1	95.85%	[1.54; 1.12; 0.0053]
	Fixed (Worst Result)	59.22	48	0	-	[3.64; 0.80; 0.0073]
4	Optimized (Mean)	49.1 ± 10.9	43.8 ± 4.5	20	99.00%	*Optimized*
	Fixed (Best Result)	61.70	55	2	98.28%	[3.00; 0.94; 0.0067]
	Fixed (Worst Result)	57.89	51	1	95.00%	[11.77; 1.80; 0.0066]
5	Optimized (Mean)	53.1 ± 18.0	40.8 ± 3.8	6	97.76%	*Optimized*
	Fixed (Best Result)	52.63	51	1	95.00%	[2.17; 0.47; 0.0066]
	Fixed (Worst Result)	46.58	54	0	-	[2.54; 0.50; 0.0066]
7	Optimized (Mean)	46.5 ± 14.8	48.3 ± 7.6	19	98.19%	*Optimized*
	Fixed (Best Result)	52.25	49	1	98.08%	[4.94; 1.33; 0.0067]
	Fixed (Worst Result)	69.08	51	0	-	[1.44; 1.30; 0.0054]
8	Optimized (Mean)	46.8 ± 11.2	40.8 ± 1.5	0	-	*Optimized*
	Fixed (Best Result)	70.70	53	0	-	[1.43; 1.46; 0.0026]
	Fixed (Worst Result)	31.85	33	0	-	[1.44; 2.47; 0.0014]
9	Optimized (Mean)	57.0 ± 6.8	38.5 ± 3.3	3	95.29%	*Optimized*
	Fixed (Best Result)	64.80	37	1	95.00%	[4.59; 3.08; 0.0055]
	Fixed (Worst Result)	69.04	47	0	-	[2.68; 0.65; 0.0070]
10	Optimized (Mean)	50.1 ± 9.1	39.3 ± 3.7	0	-	*Optimized*
	Fixed (Best Result)	64.39	52	1	97.07%	[5.34; 1.23; 0.0065]
	Fixed (Worst Result)	65.81	42	0	-	[19.86; 3.10; 0.0060]
11	Optimized (Mean)	53.6 ± 12.1	39.8 ± 5.7	3	95.41%	*Optimized*
	Fixed (Best Result)	62.38	49	2	97.35%	[6.76; 1.81; 0.0063]
	Fixed (Worst Result)	56.86	50	1	95.00%	[1.90; 2.35; 0.0040]

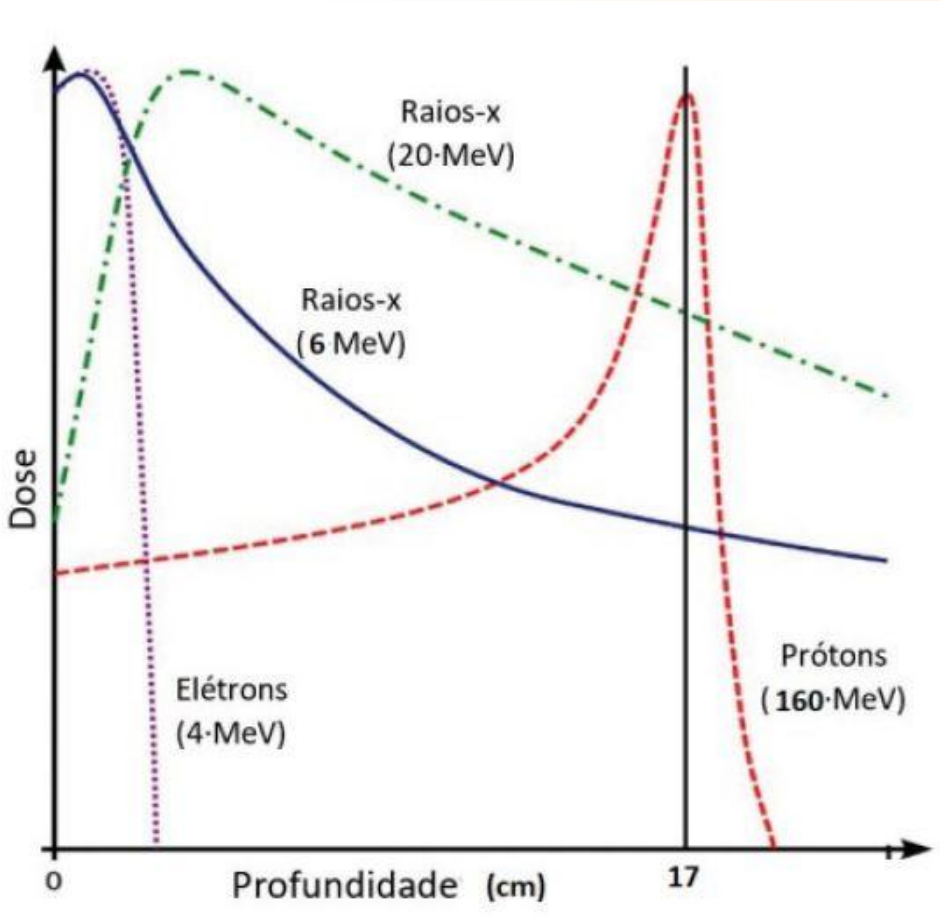
Comparison Scenario	Passing Rate (%)		
	3%/3mm	2%/2mm	1%/1mm
Reference vs. Optimized	100%	100%	100%
Reference vs. Fixed (Best)	100%	99.99%	99.90%
Reference vs. Fixed (Worst)	99.99%	99.90%	99.56%

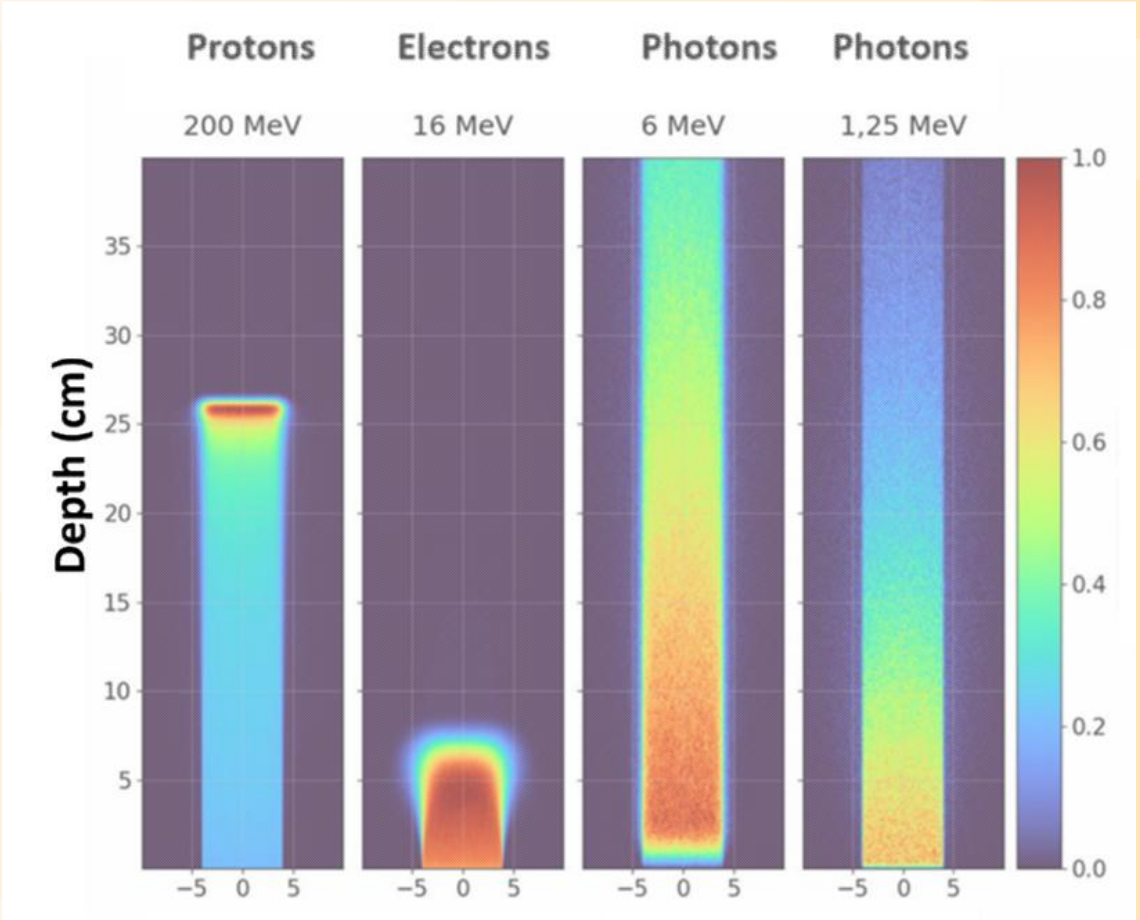




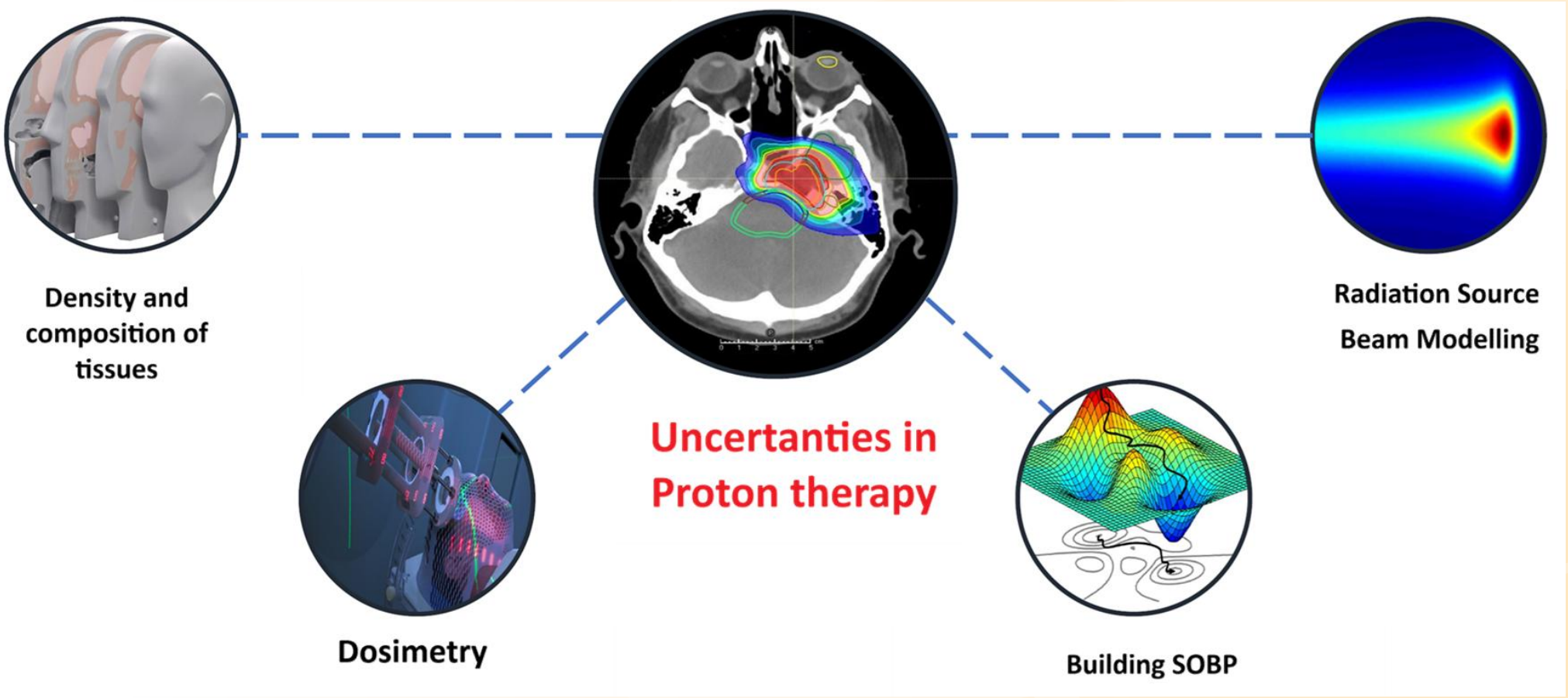


Protonterapia

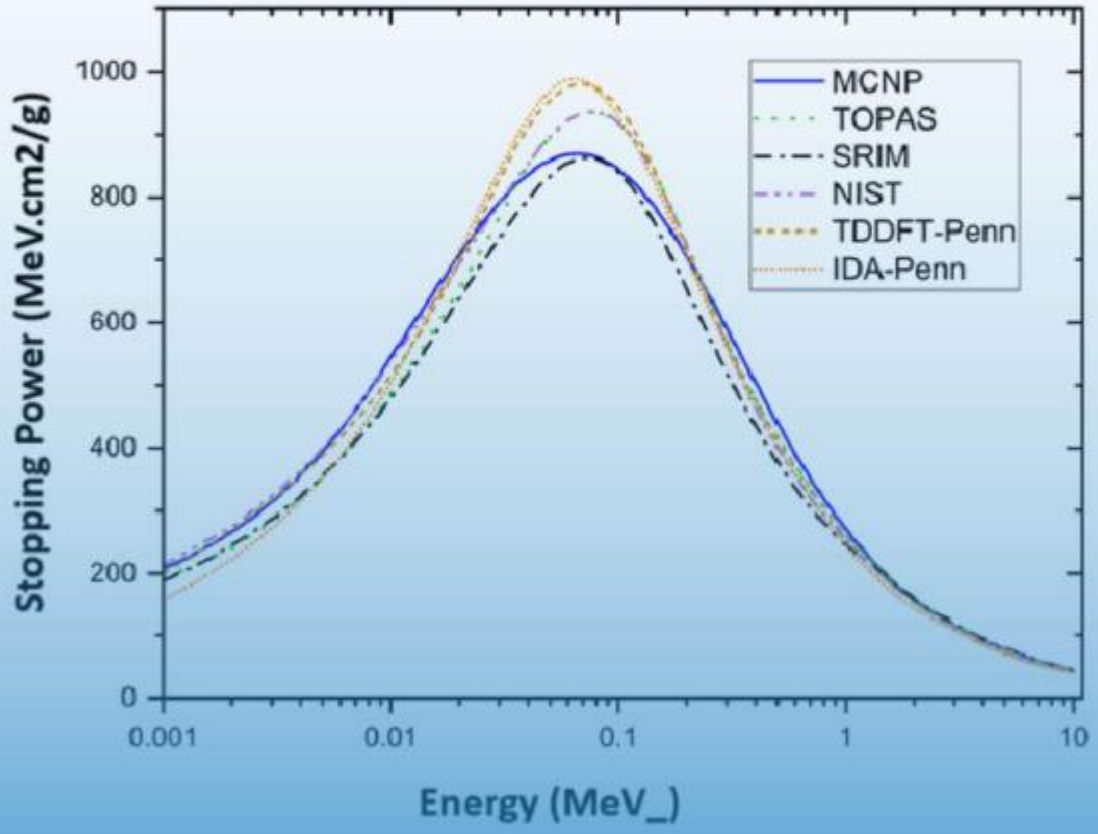




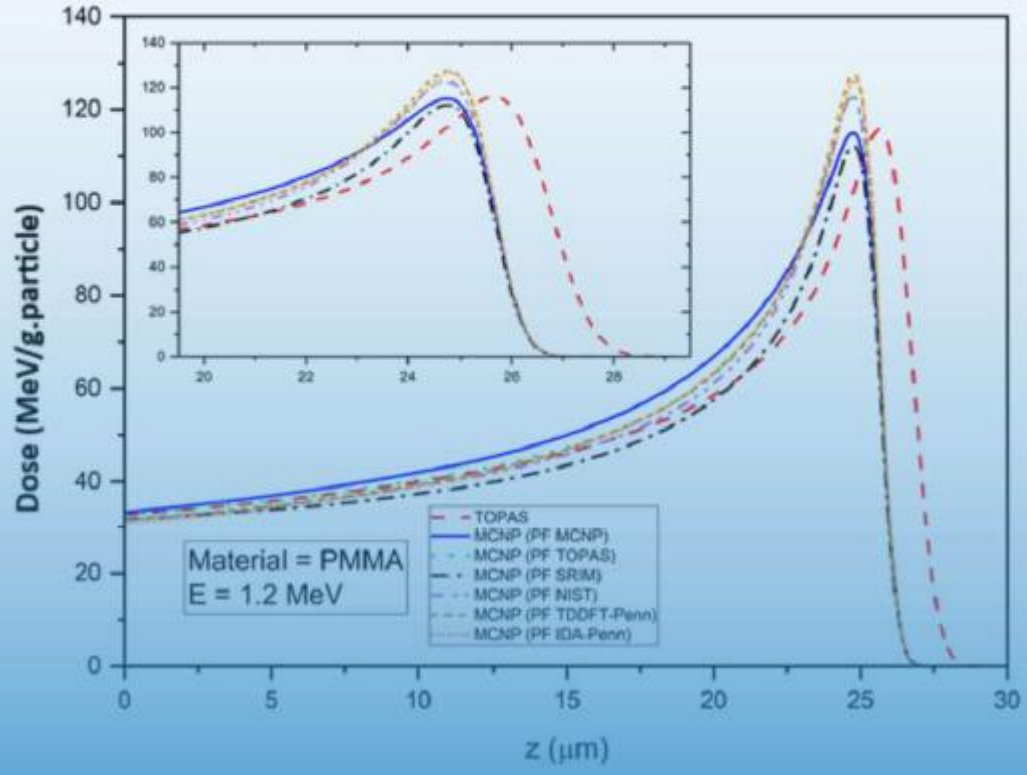
Desafios


Density and composition of tissues
Radiation Source Beam Modelling
Uncertanties in Proton therapy
Dosimetry
Building SOBP

Stopping power models for PMMA



Dose comparison between TOPAS and different stopping power models used in MCNP for 1.2 MeV proton beams hitting a PMMA phantom (the smaller figure shows a zoom on the horizontal axis, highlighting the range between 19.5 µm and 29.5 µm).



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Efficient computational modeling of electronic stopping power of organic polymers for proton therapy optimization

F. Matias, T. F. Silva, N. E. Koval, J. J. N. Pereira, P. C. G. Antunes, P. T. D. Siqueira, M. H. Tabacniks, H. Yoriyaz, J. M. B. Shorto & P. L. Grande

Scientific Reports **14**, Article number: 9868 (2024) | Cite this article

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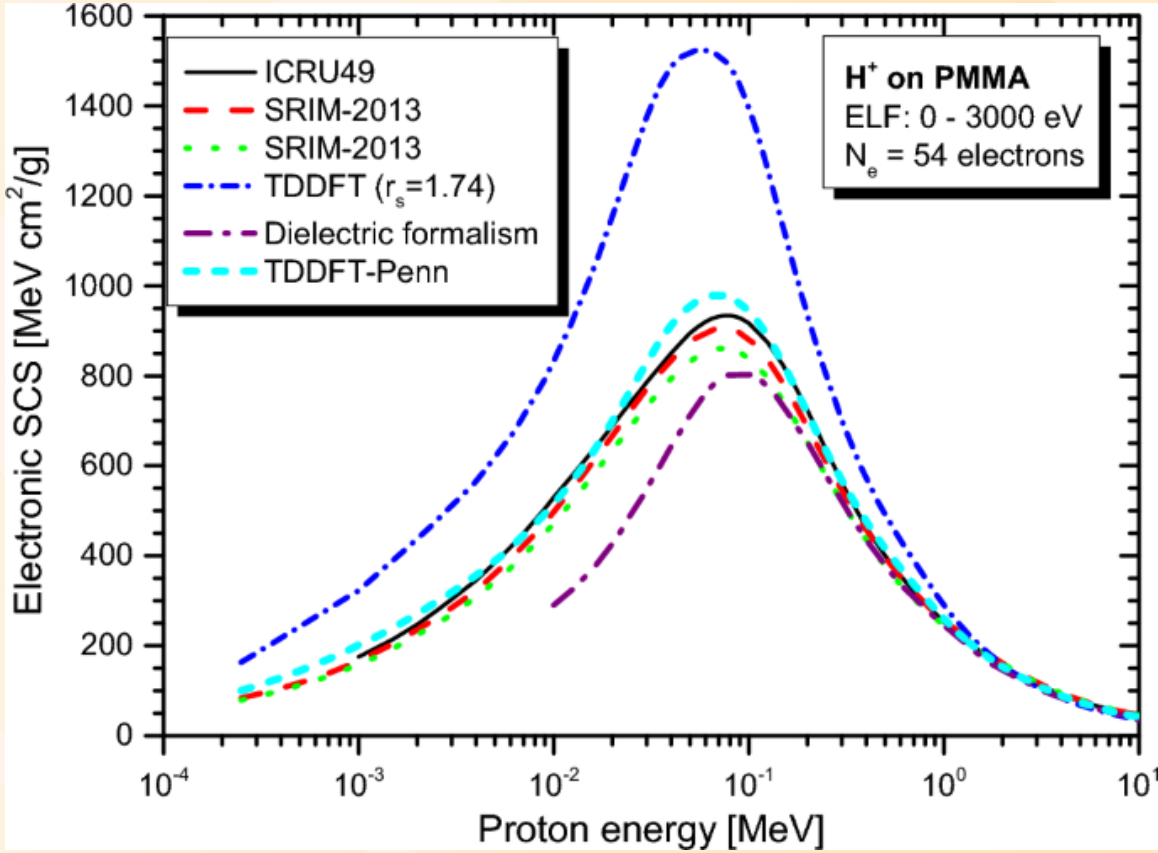

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Stopping Cross Sections for Protons Across Different Phases of Water

F. Matias[1], N. E. Koval[2], P. de Vera[3], R. Garcia-Molina[3], I. Abril[4], J. M. B. Shorto[1], H. Yoriyaz[1], J. J. N. Pereira[1], T. F. Silva[5] *et al.*

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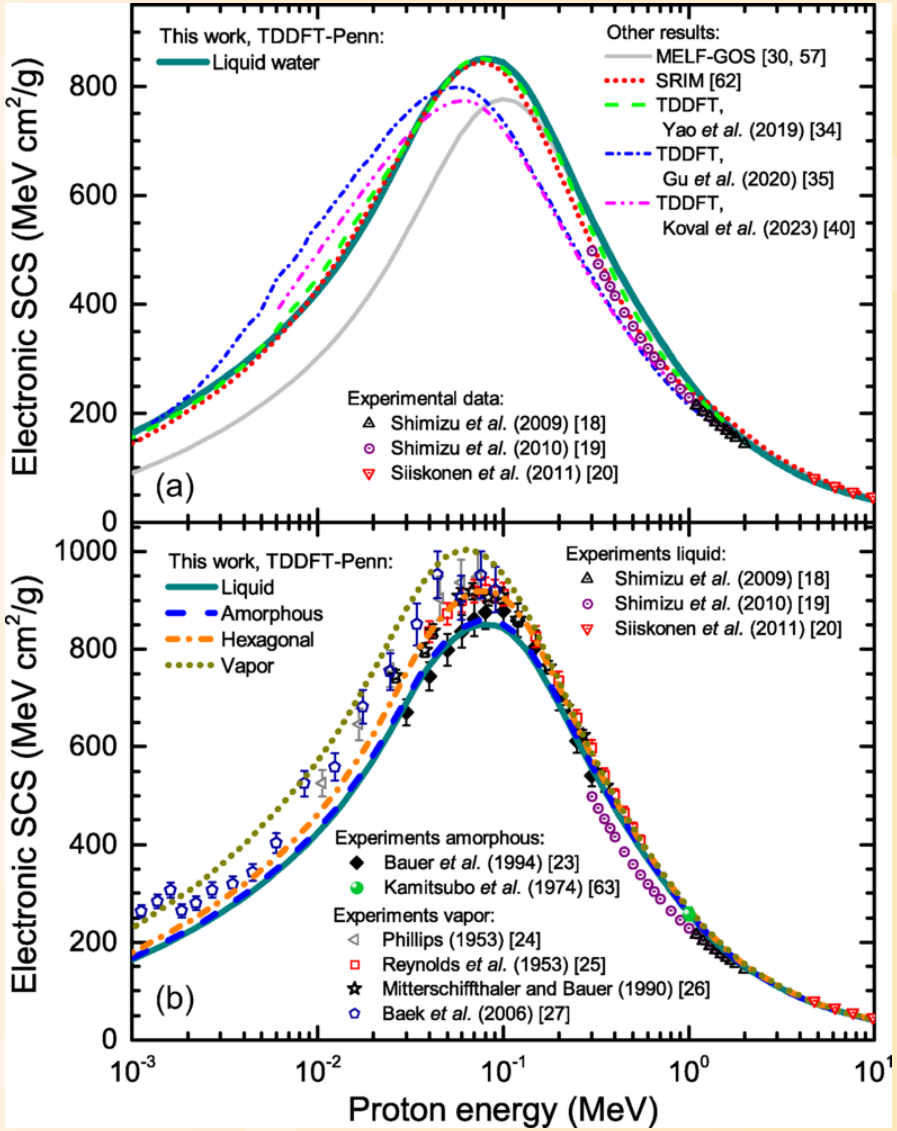

SOBP

Radiation Physics and Chemistry 211 (2023) 111043

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Radiation Physics and Chemistry

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Comparison of methodologies for creating spread-out Bragg peaks in proton therapy using TOPAS and MCNP codes

I.S.L. Branco *, A.L. Burin, J.J.N. Pereira, P.T.D. Siqueira, J.M.B. Shorto, H. Yoriyaz

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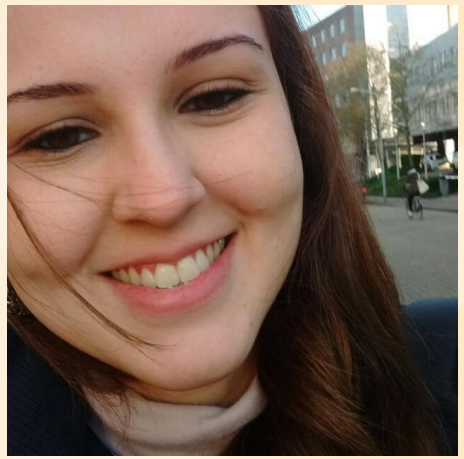
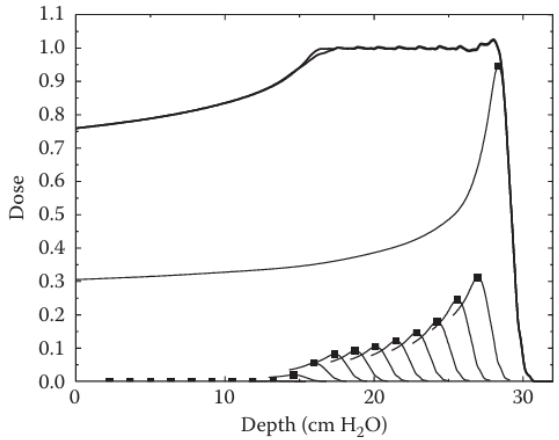
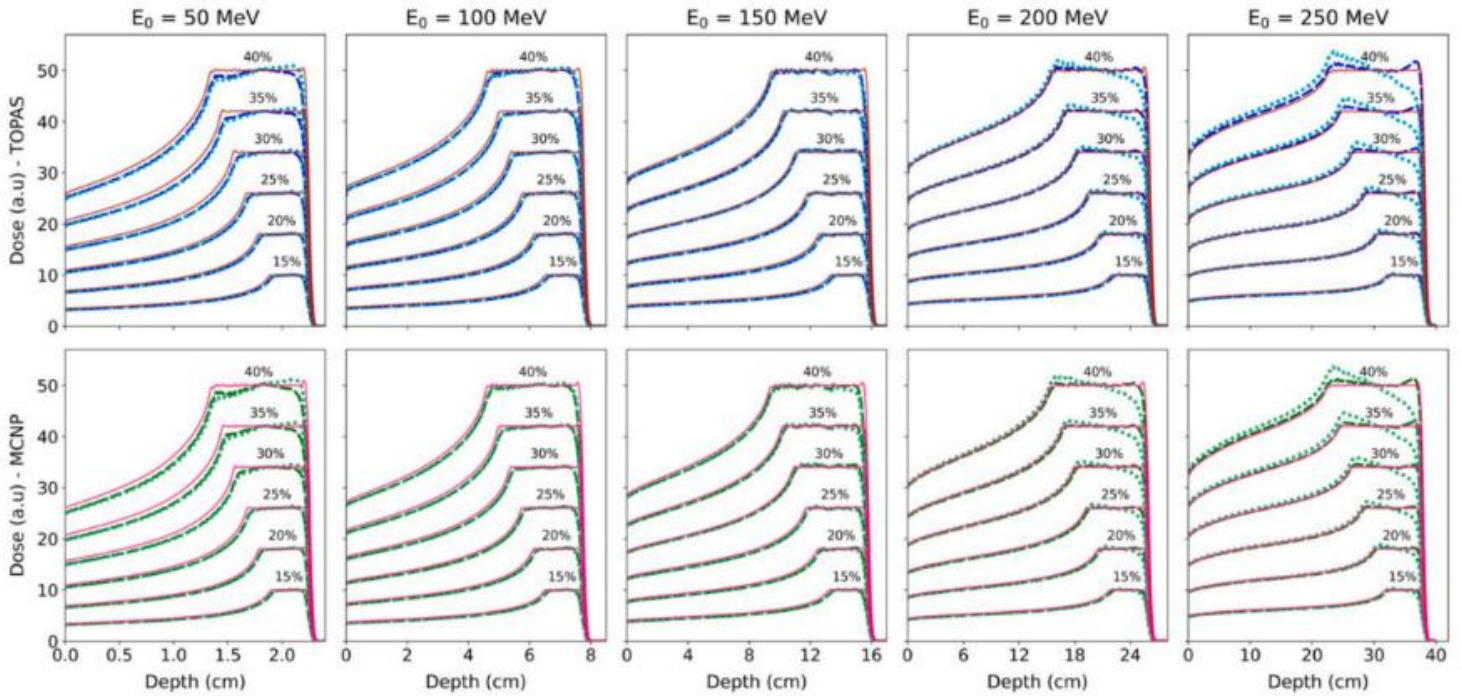
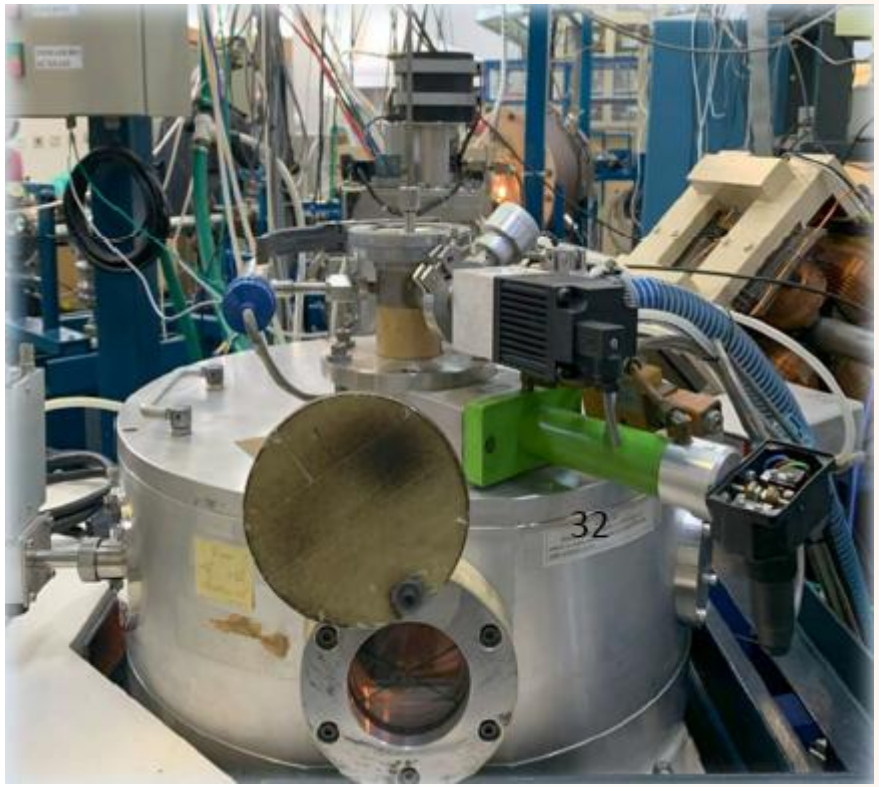
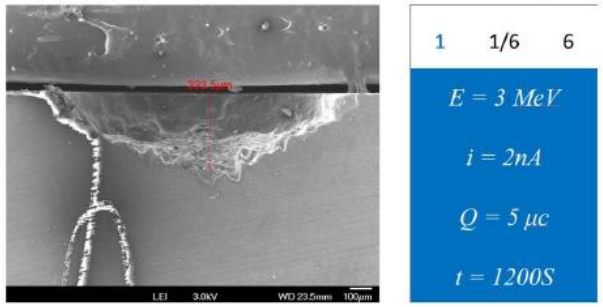










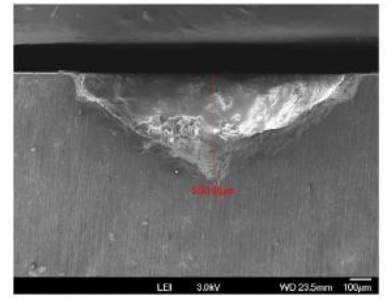
1 1/6 6

$E = 3\ MeV$

$i = 2nA$

$Q = 5\ \mu c$

$t = 1200S$



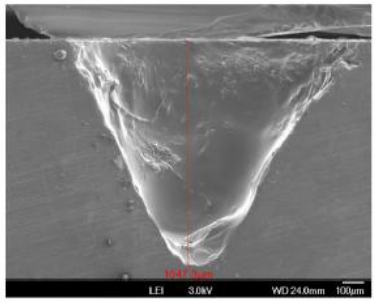
1 1/6 6

$E = 3\ MeV$

$i = 5nA$

$Q = 10\ \mu c$

$t = 600\ s$



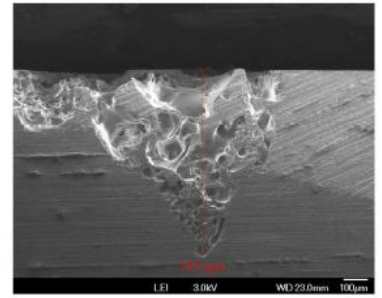
1 1/6 6

$E = 3\ MeV$

$i = 15nA$

$Q = 20\ \mu c$

$t = 300\ s$



$E = 3\ MeV$

$i = 10nA$

2 2/5 5

$Q = 5\ \mu C$

INSTITUTO DE PESQUISAS ENERGÉTICAS E NUCLEARES
Autarquia Associada à Universidade de São Paulo

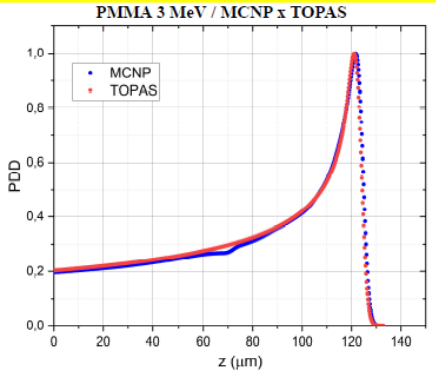
Simulações de ensaios microdosimétricos na região do pico de Bragg

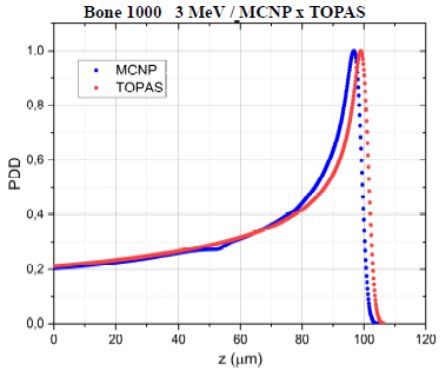
JÚLIO JOSÉ NOGUEIRA PEREIRA

Dissertação apresentada como parte dos requisitos para obtenção do Grau de Mestre em Ciências na Área de Tecnologia Nuclear - Reatores

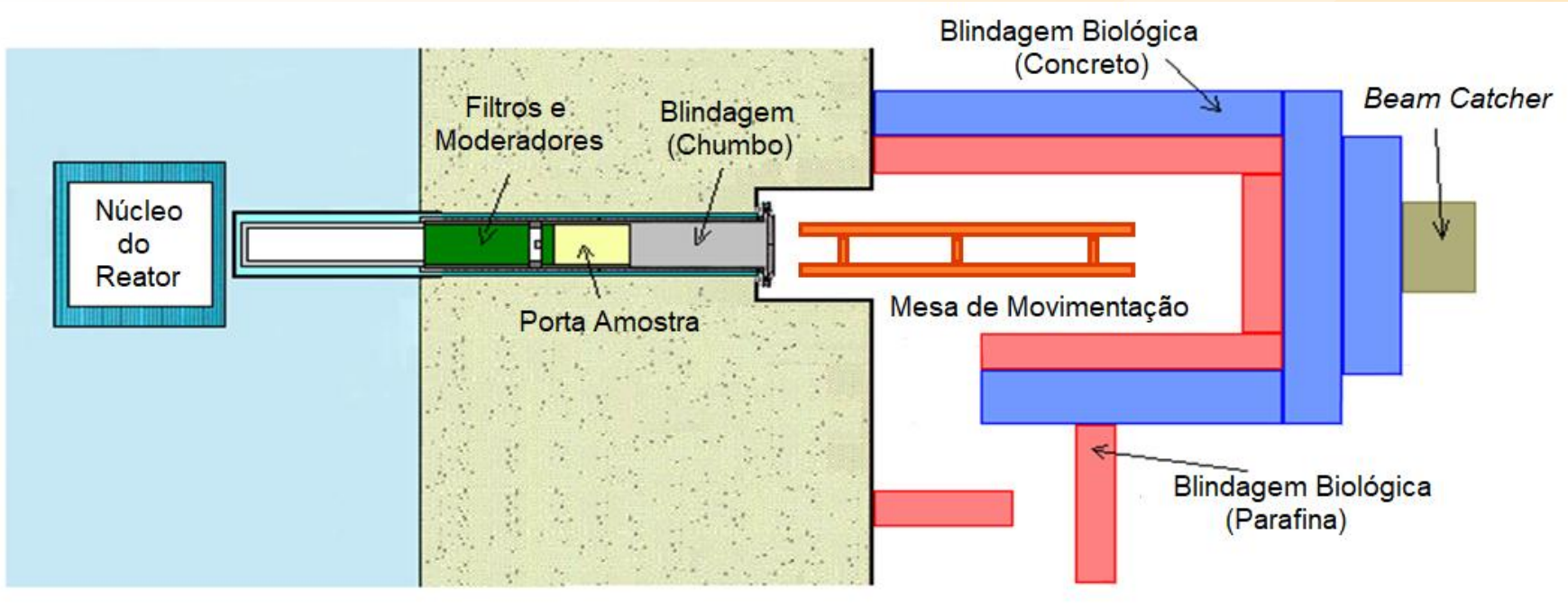
Orientador:
Prof. Dr. Hélio Yoriyaz

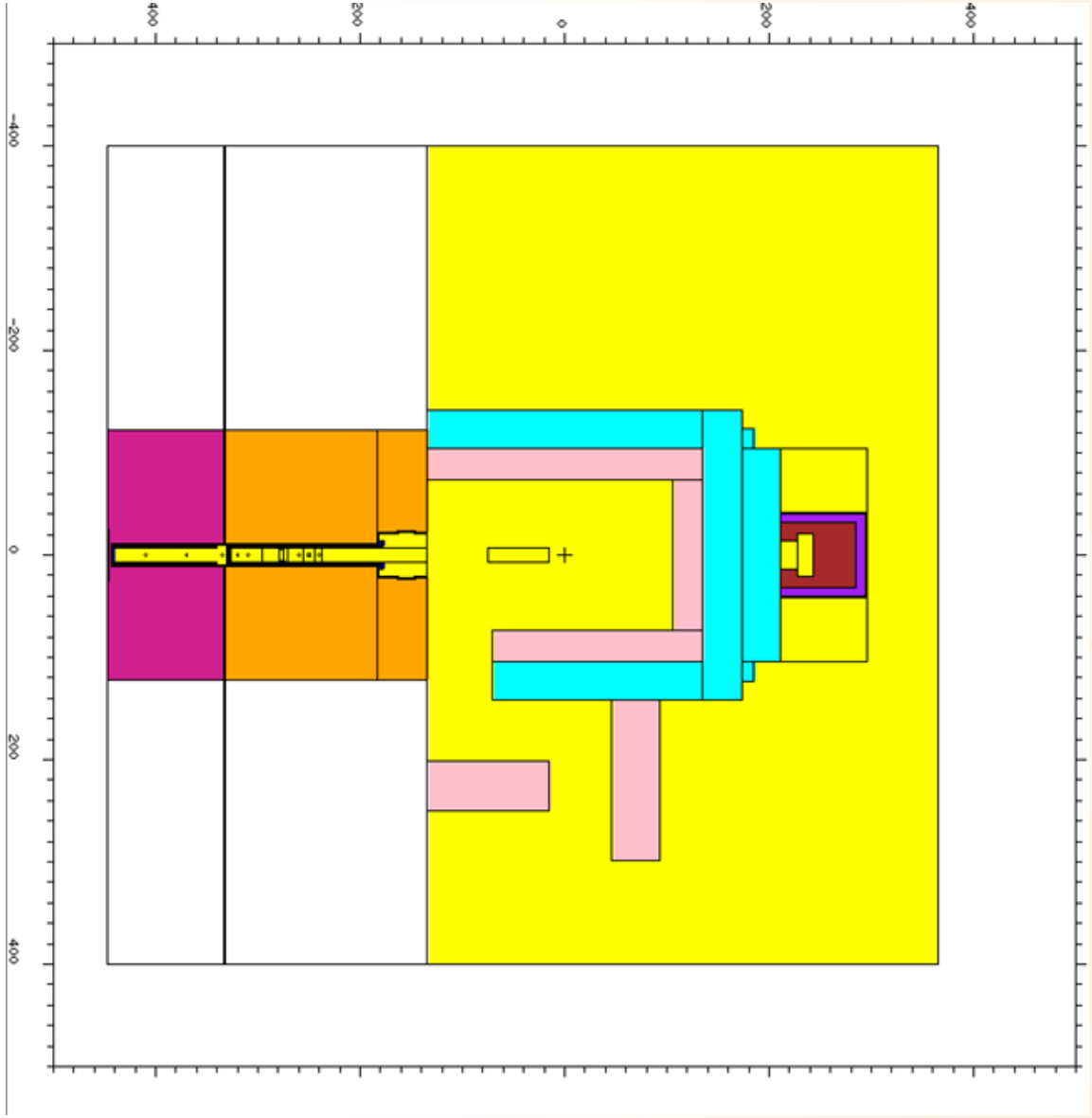
Material	Dens. (g/cm³)	dmax (µm)		Relative Diff (%)
		MCNP 6.2	TOPAS	
Bone 1000 mg/cc	1.66	96.825	99.075	2.27
Bone 800 mg/cc	1.53	101.775	104.025	2.16
PMMA	1.19	121.695	121.125	0.47
Liver	1.072	132.525	131.765	0.58
Breast 50/50	0.991	141.645	140.695	0.68
Adipose Tissue	0.96	145.065	144.115	0.66
Exaled Lung	0.51	279.8	278.2	0.58
Inhaled Lung	0.195	732.5	726.5	0.83



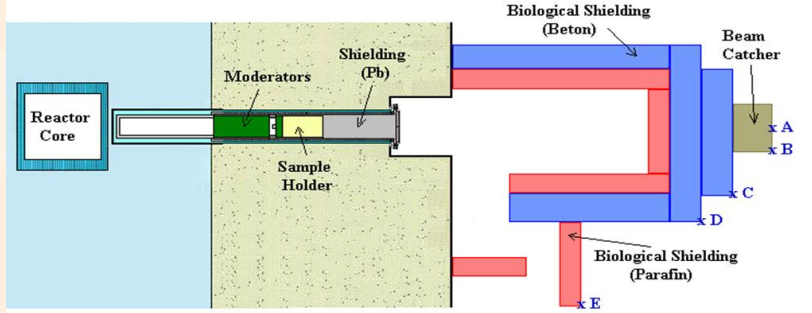


Instalação de BNCT

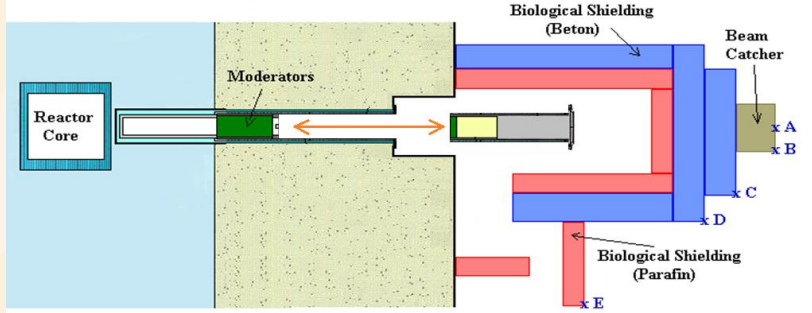




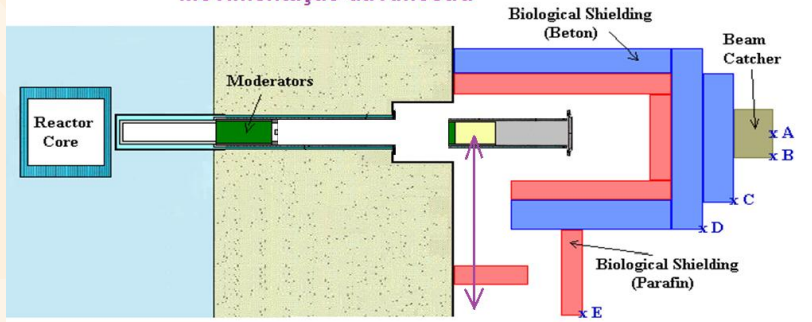
Instalação de BNCT

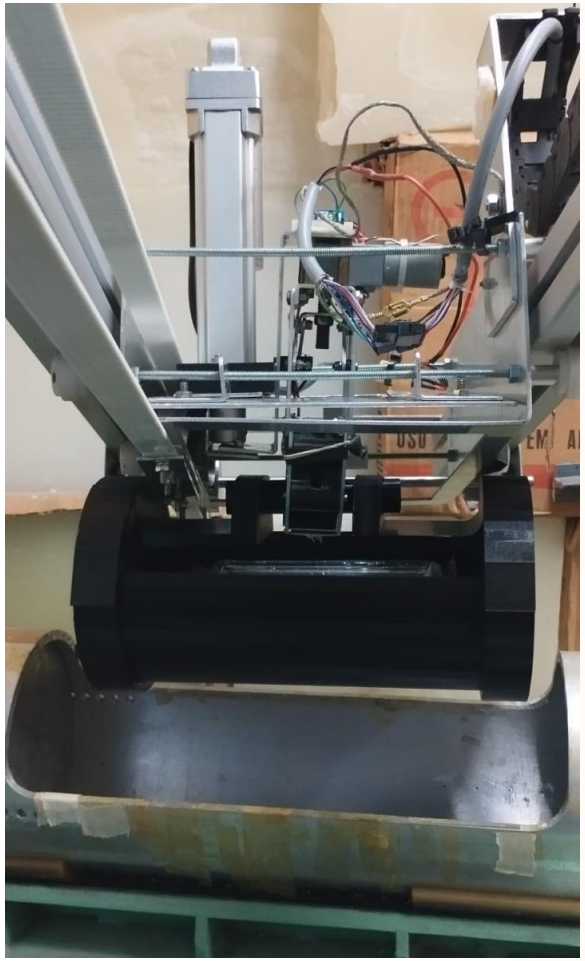


Movimentação do Módulo Posterior



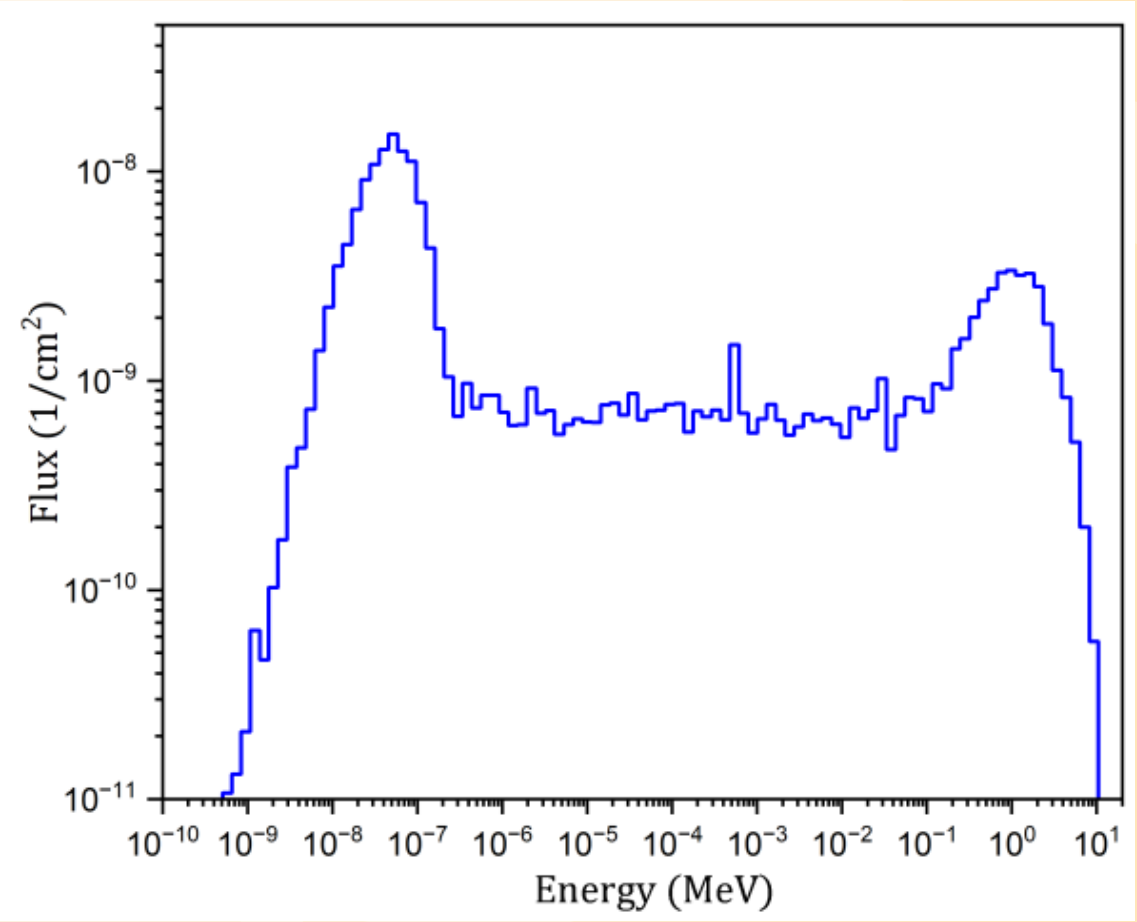
Movimentação da Amostra



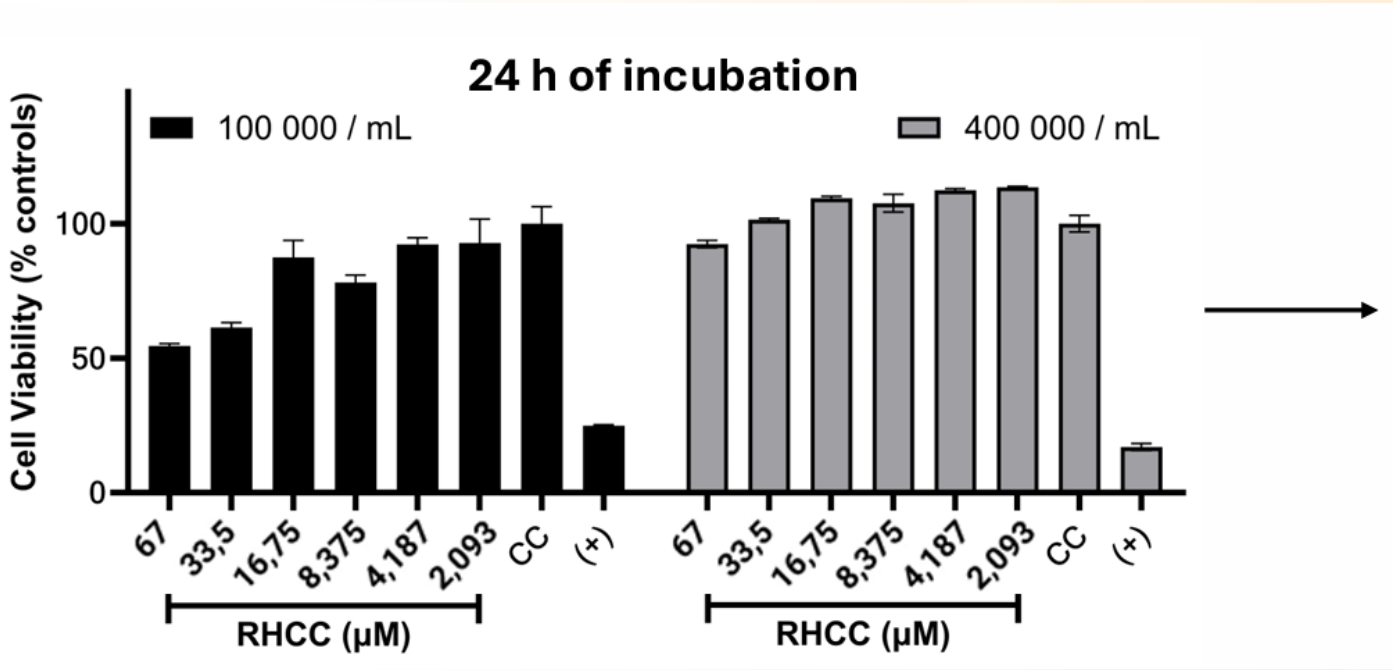


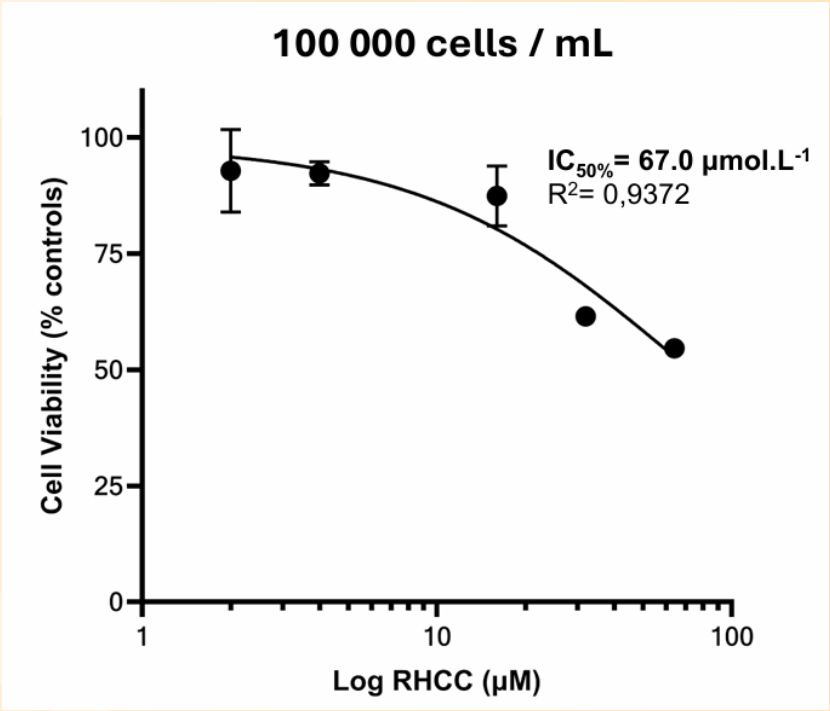
QUÍMICA
GEWAX 145
QUÍMICA
GEWAX 145

Energy ranges	Flux ($n.cm^{-2}s^{-1}$)	Flux share of total
Thermal (0.100 meV – 0.550 eV)	$(2.00 \pm 0.10) \times 10^8$	80.42 %
Epithermal (0.550 eV – 110.0 keV)	$(2.26 \pm 0.14) \times 10^7$	9.10 %
Fast (110.0 keV – 20.0 MeV)	$(2.61 \pm 0.50) \times 10^7$	10.49 %
Total	$(2.48 \pm 0.11) \times 10^8$	100.00 %



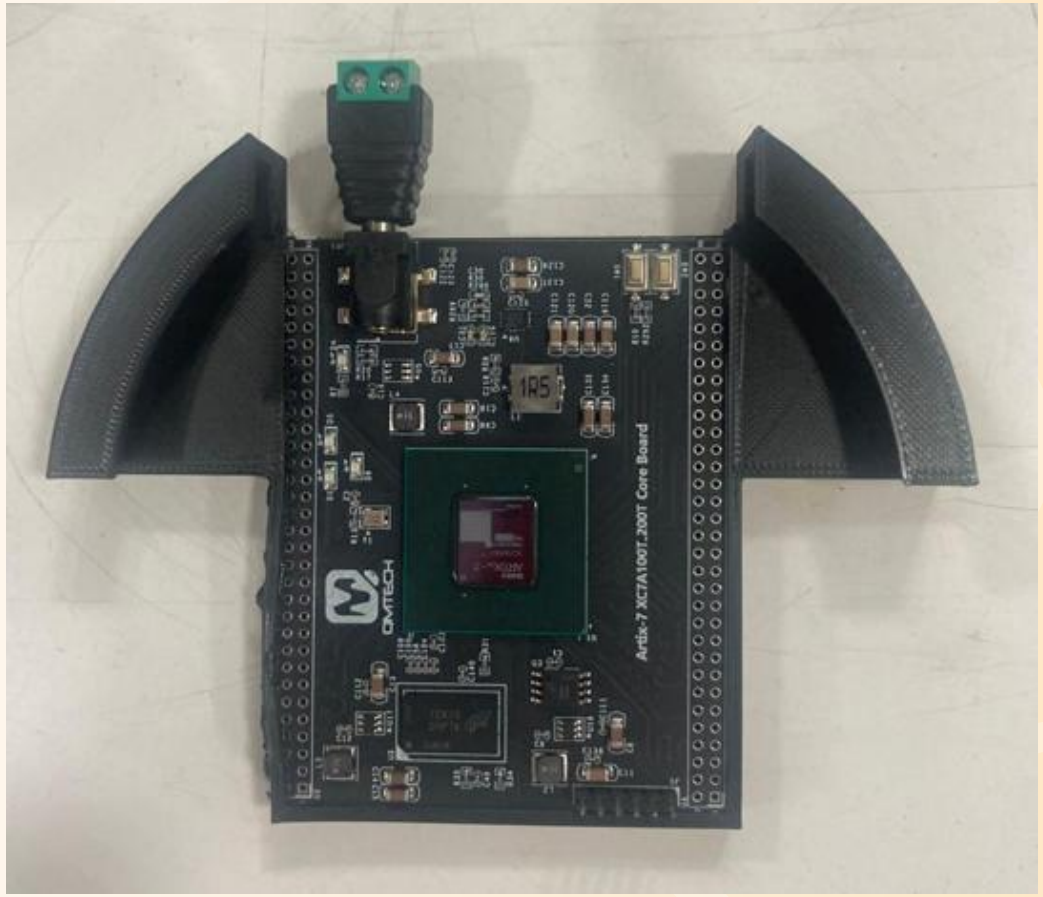
BNCT:
Irradiação de cultura celular: Avaliação de carreadores de B





Danos de irradiação a dispositivos eletrônicos:

- FPGAs
- TEGs
- Detectores de radiação



Obrigado!

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GOVERNO DO BRASIL
DO LADO DO POVO BRASILEIRO