

Smart BNCT Planning: When Artificial Intelligence Meets Radiobiology

Cristina Pezzi

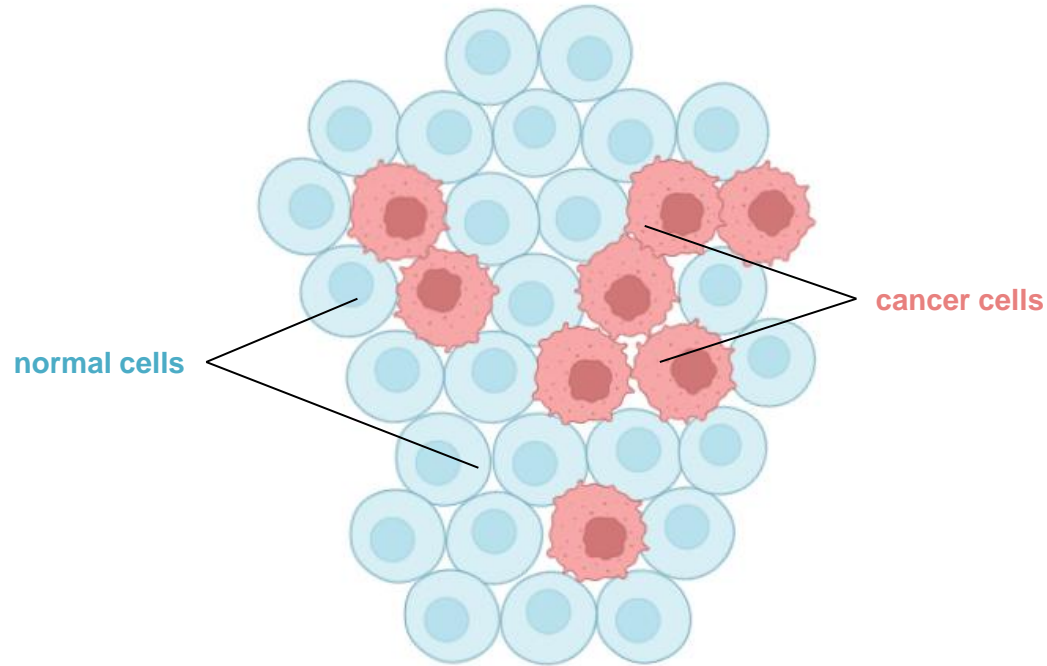
Università degli Studi di Pavia

17th September 2025

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State of Art : Boron Neutron Capture Therapy (BNCT)



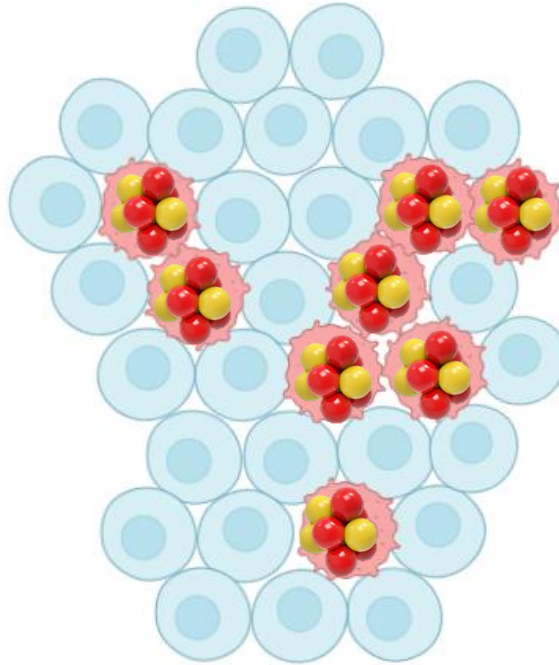
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State of Art : Boron Neutron Capture Therapy (BNCT)



✓ Boron-10 atoms



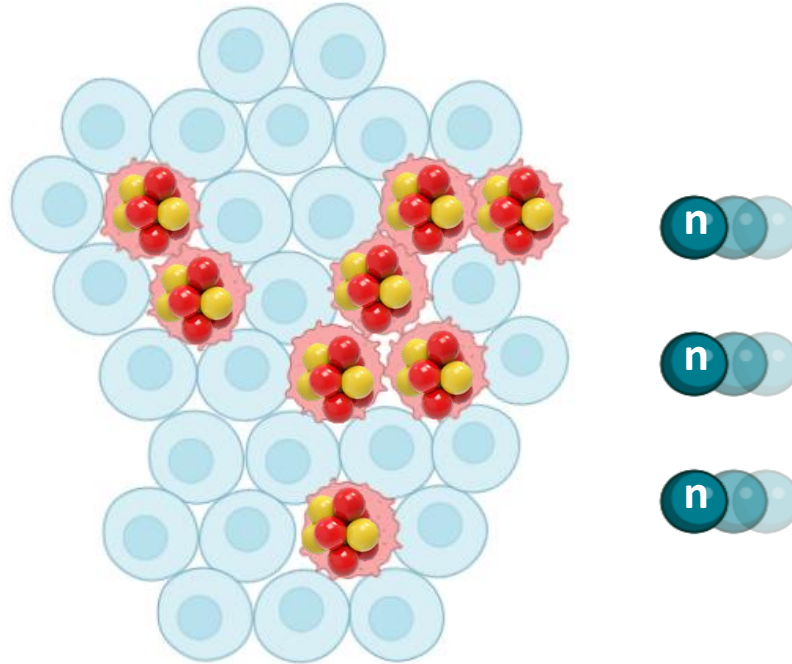
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- ✓ Boron-10 atoms
- ✓ Thermal neutron beam



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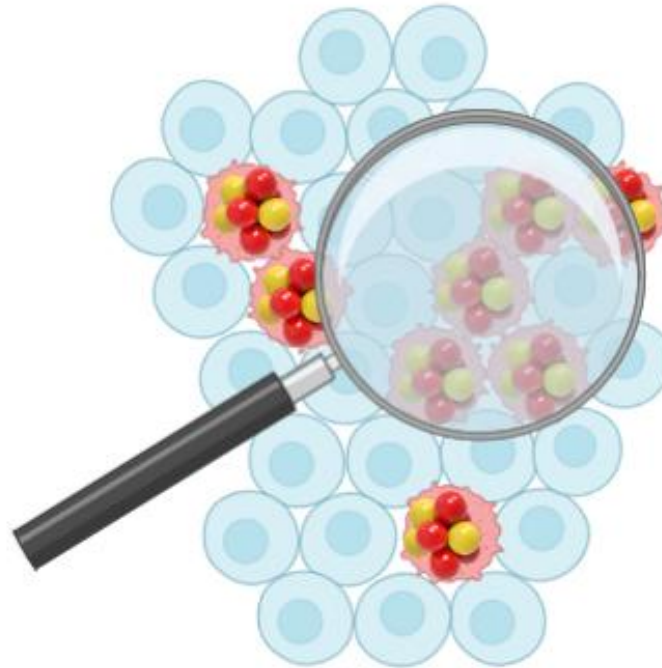
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✓ Boron-10 atoms

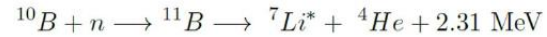
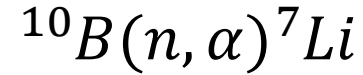
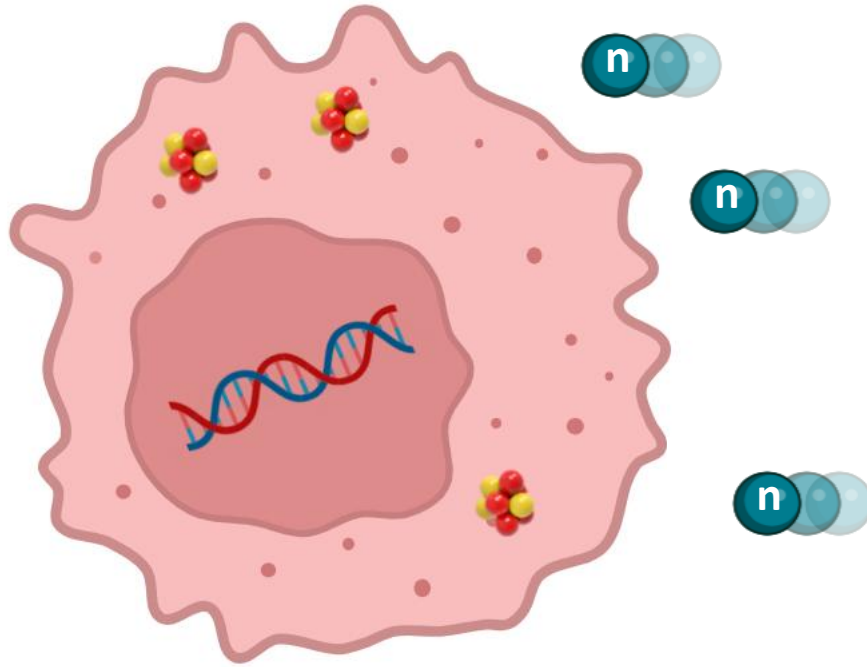
✓ Thermal
neutron beam



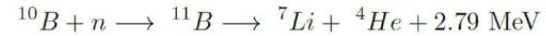
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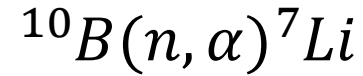
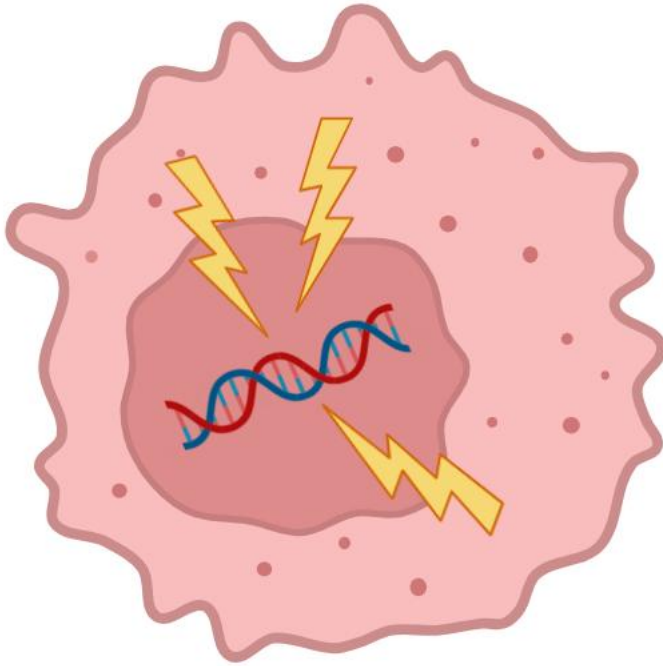


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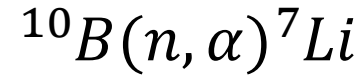
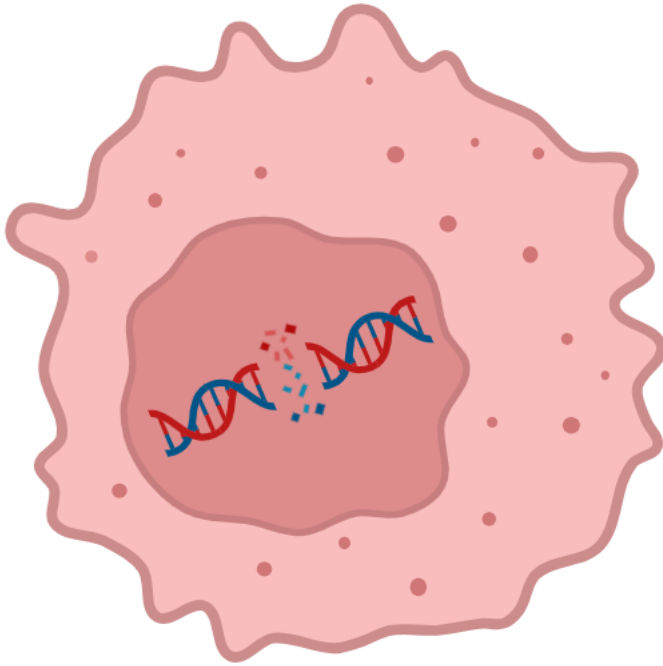


High LET radiations

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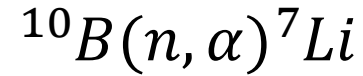


High LET radiations

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High LET radiations

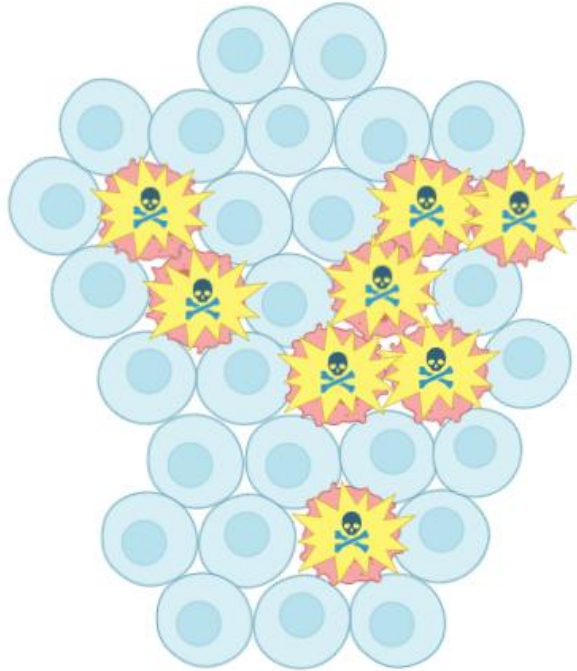
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- ✓ Boron-10 atoms
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Short range radiations

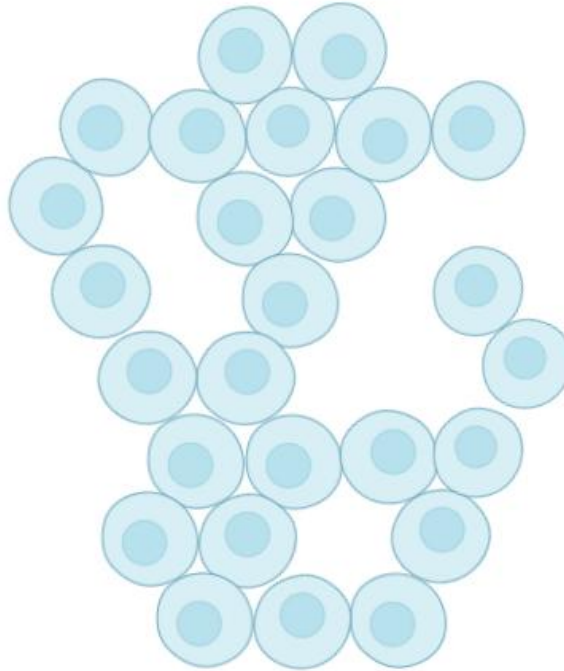
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Short range radiations



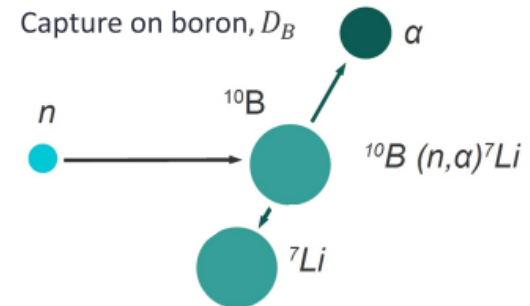
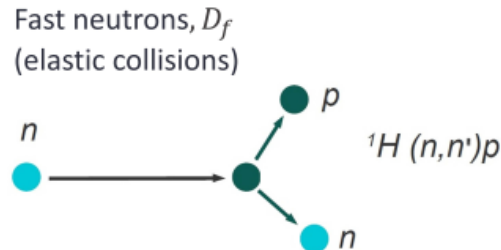
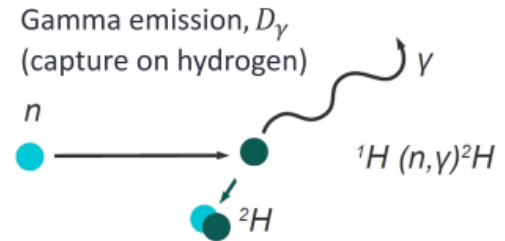
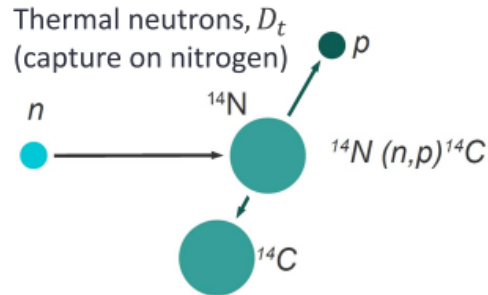
High Selectivity

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**Mixed Radiation
Field**

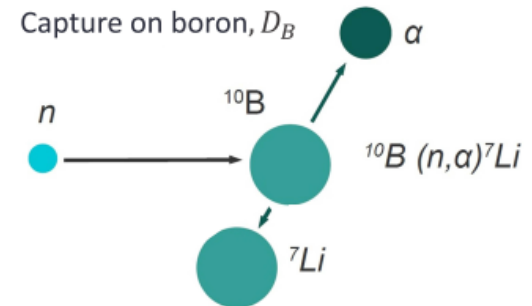
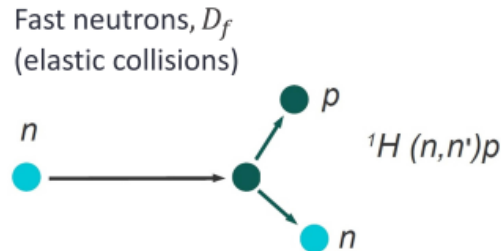
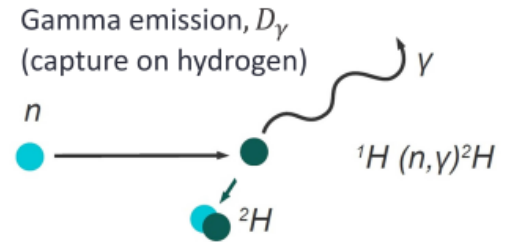
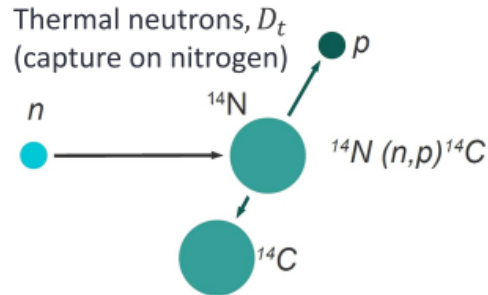


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Mixed Radiation
Field



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Dosimetric Models

✓ ***RBE-weighted Dose Model***

$$D_w = CBE \cdot D_B + RBE_{th} \cdot D_{th} + RBE_f \cdot D_f + RBE_{\gamma} \cdot D_{\gamma}$$



$$RBE_X = \frac{D_R}{D_X}$$

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Dosimetric Models

✓ **Photon Isoeffective Dose Model**

$$D_R(D_1, ..., D_4) = \frac{1}{2} \frac{\left(\frac{\alpha}{\beta}\right)_R}{G_R} \times \left(\sqrt{1 + \frac{4G_R}{\alpha_R \left(\frac{\alpha}{\beta}\right)_R} \left(\sum_{i=1}^4 \alpha_i D_i + \sum_{i=1}^4 \sum_{j=1}^4 G_{ij}(\theta) \sqrt{\beta_i \beta_j} D_i D_j \right)} - 1 \right)$$



The survival dose-response relationship is described by **linear quadratic model** that accounts for dose-rate dependent **sublesion repair**

Radiation synergism, the survival dose-response is modulated by Lea-Catcheside factors G for simultaneous mixed irradiation

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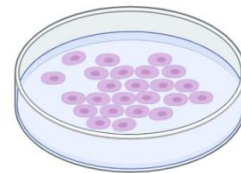
Dosimetric Models

✓ *Photon Isoeffective Dose Model*

$$D_R(D_1, \dots, D_4) = \frac{1}{2} \frac{\left(\frac{\alpha}{\beta}\right)_R}{G_R} \times \left(\sqrt{1 + \frac{4G_R}{\alpha_R \left(\frac{\alpha}{\beta}\right)_R} \left(\sum_{i=1}^4 \alpha_i D_i + \sum_{i=1}^4 \sum_{j=1}^4 G_{ij}(\theta) \sqrt{\beta_i \beta_j} D_i D_j \right)} - 1 \right)$$



2D CELL CULTURE



How can we apply it in clinic ?



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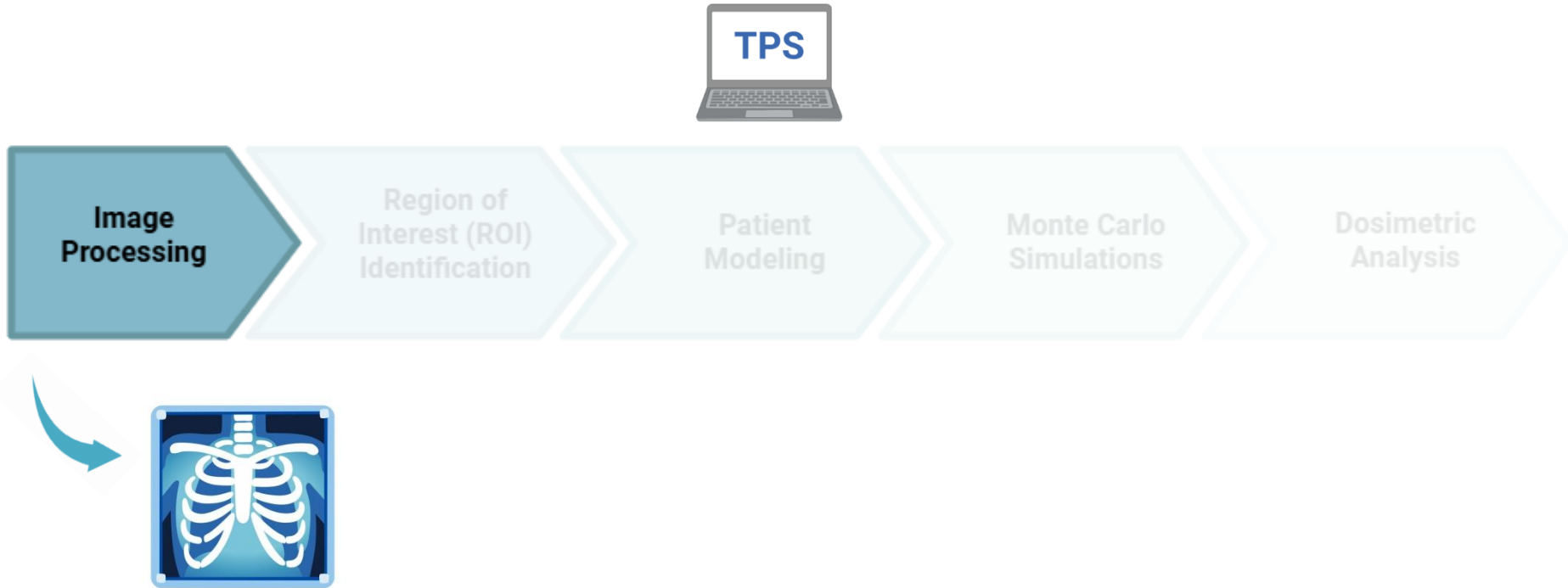
State of Art : Treatment Planning System (TPS)



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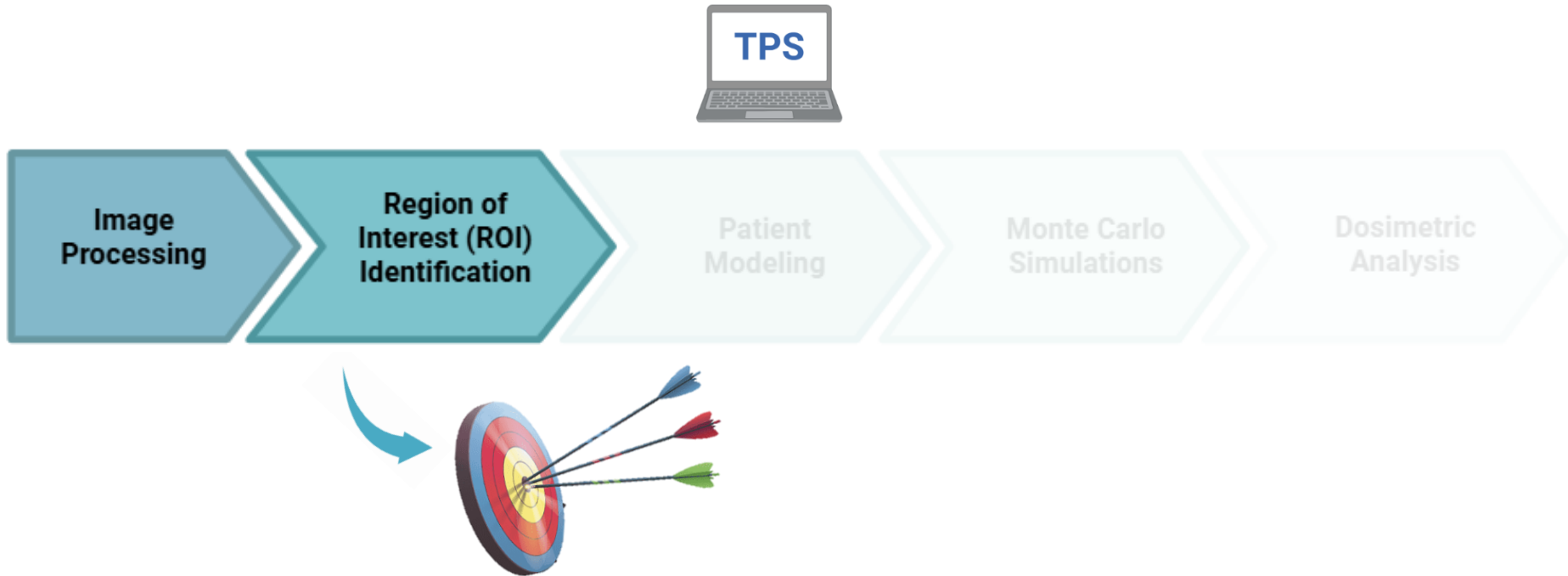
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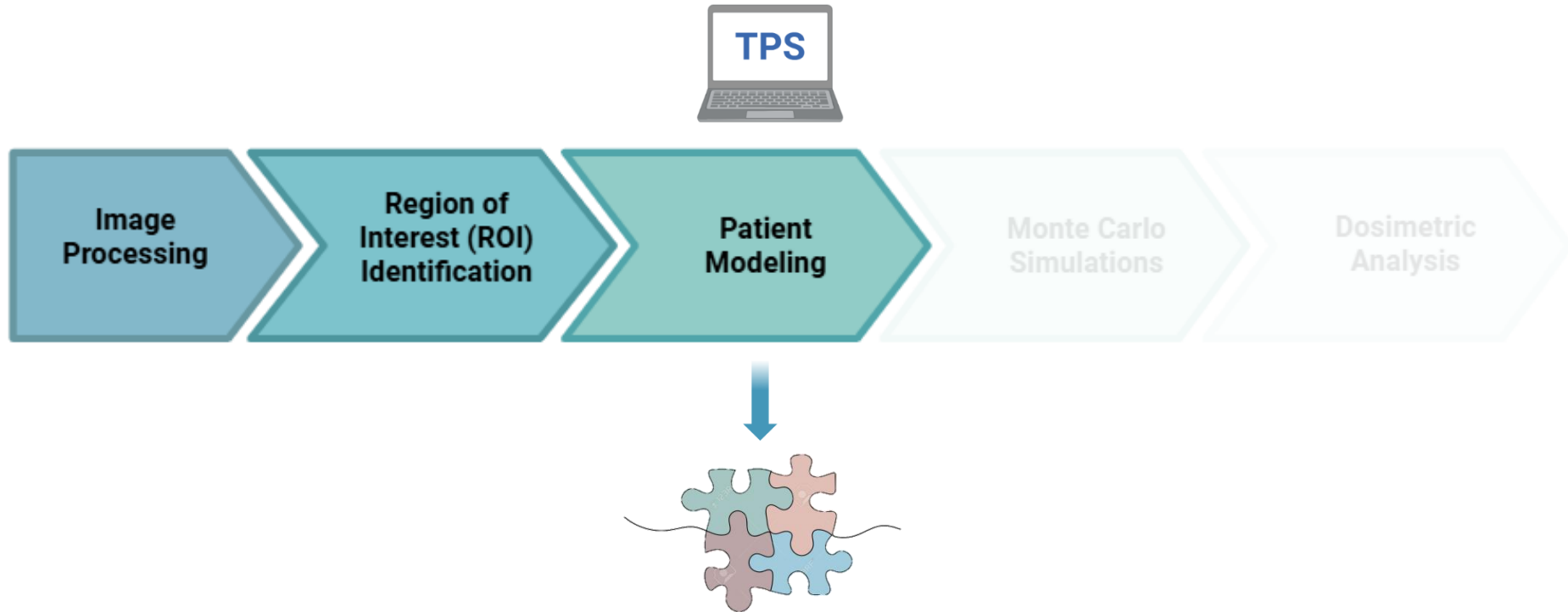
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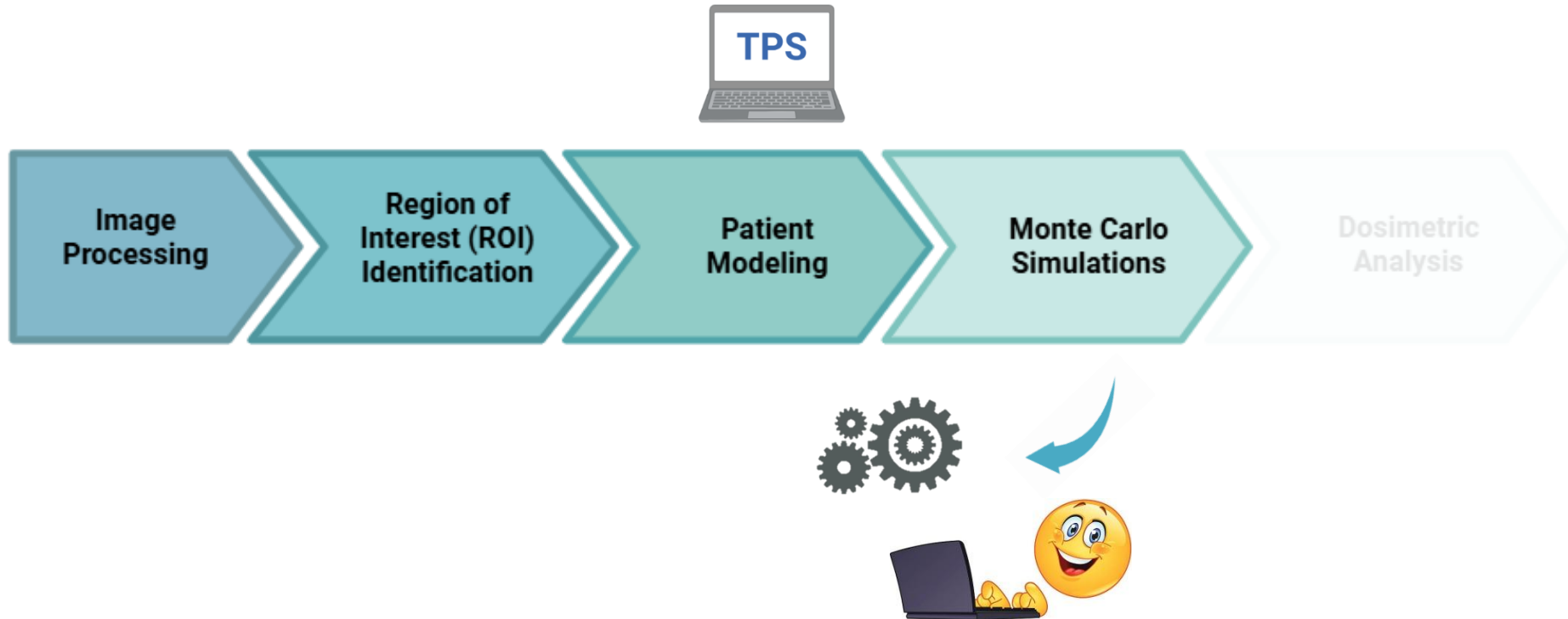
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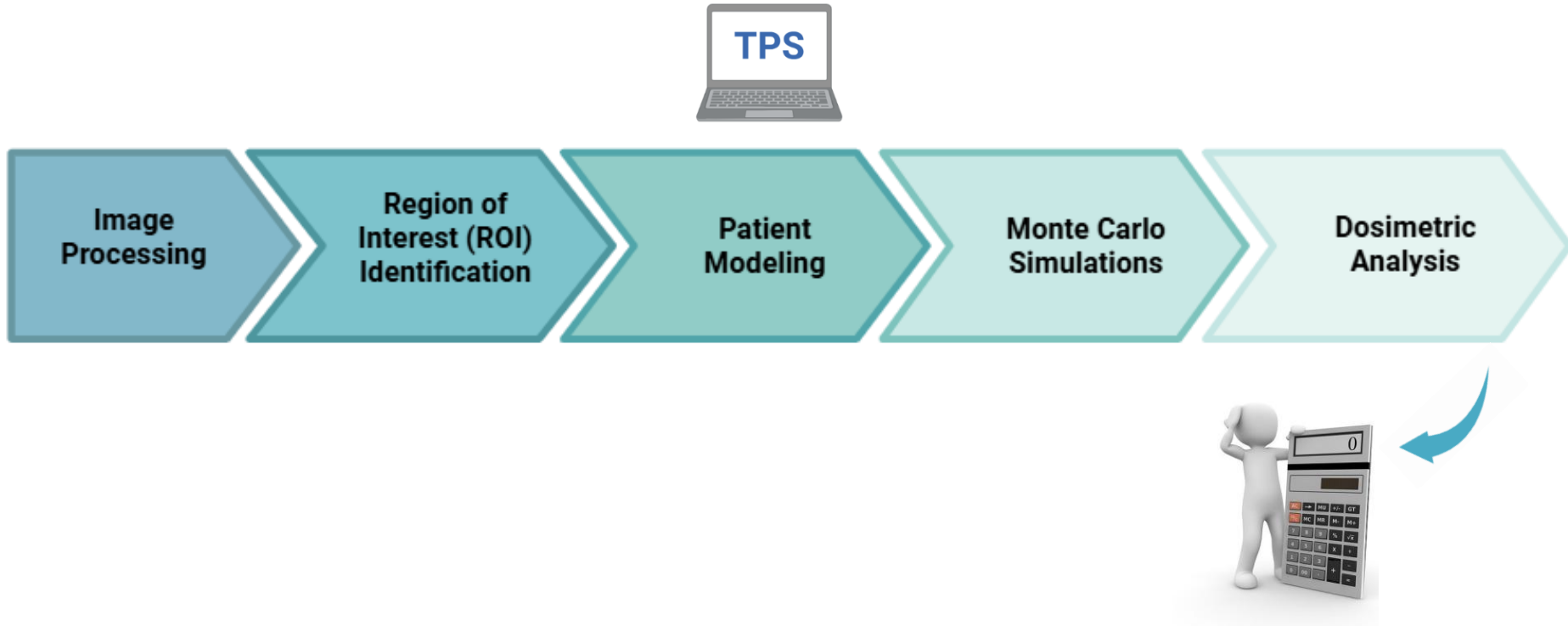
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State of Art : Treatment Planning System (TPS)



What is the State of Art of TPS ?



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State of Art : Treatment Planning System (TPS)

MacNCTPlan (1990, MIT – USA)



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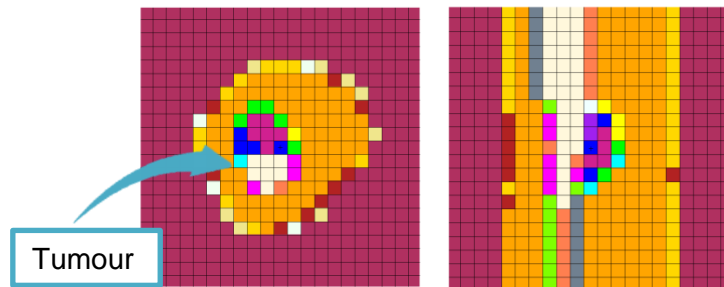
MacNCTPlan (1990, MIT – USA)



Voxel size = 1 cm³

56 materials (mixture of air, bone, normal soft tissue, tumor soft tissue)

MCNP as Monte Carlo simulation code



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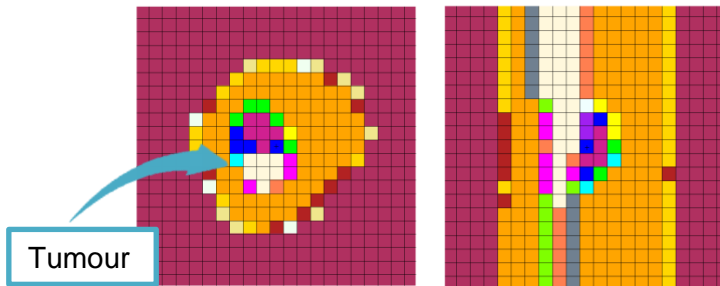
MacNCTPlan (1990, MIT – USA)



Voxel size = 1 cm³



TOO BIG!



56 materials (mixture of air, bone,
normal soft tissue, tumor soft tissue)



BIG UNCERTAINTIES (calculation error above 20%)!

MCNP as Monte Carlo simulation code



LONG CALCULATION TIME!



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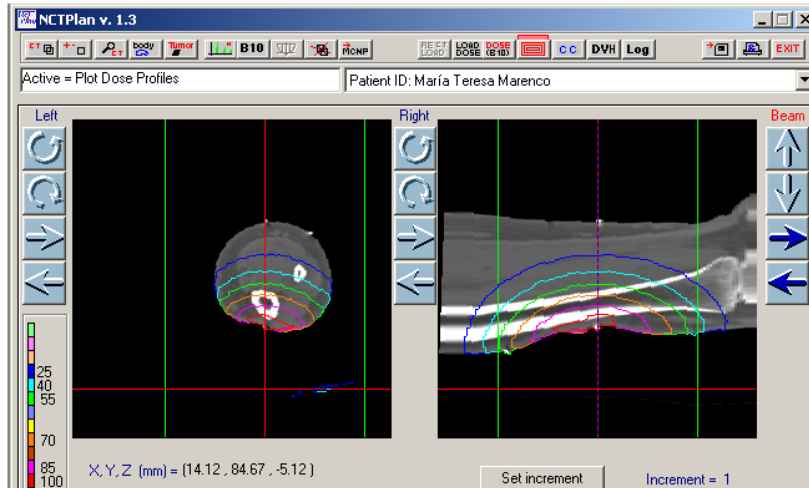
NCTPlan (2002, Argentina + MIT)



Superimposition of dose contours on CT images



IMPROVEMENT OF DOSE VISUALIZATION



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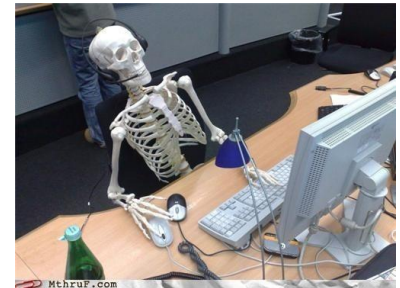
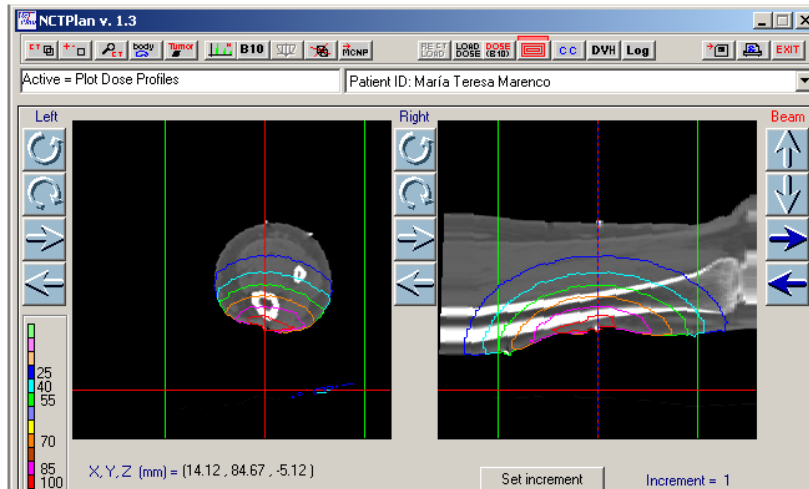
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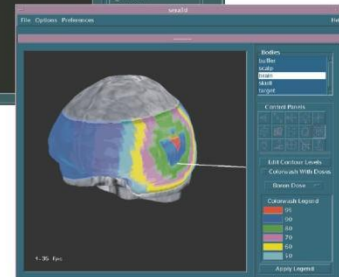
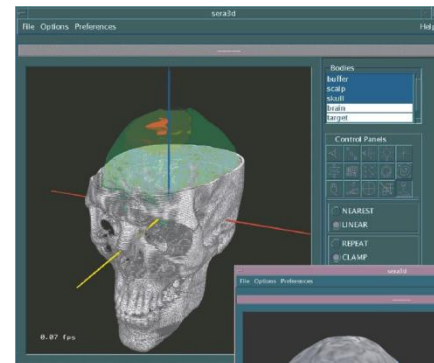
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State of Art : Treatment Planning System (TPS)

SERA (1999, Idaho National Engineering and Environmental Laboratory + Montana State University)

Seven modules covering processes

modeling, MC calculation, dose results visualization



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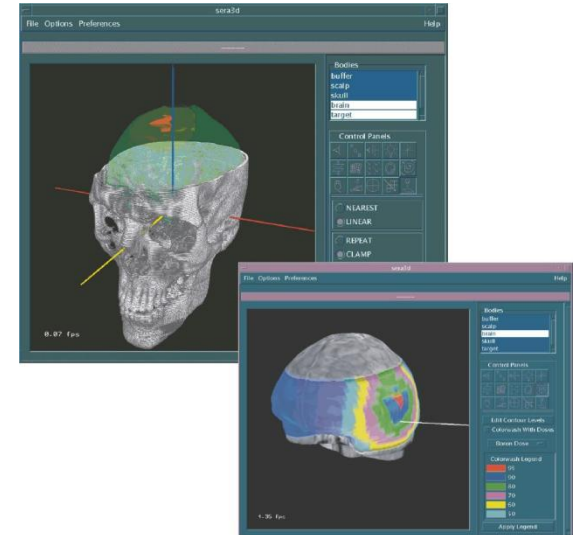
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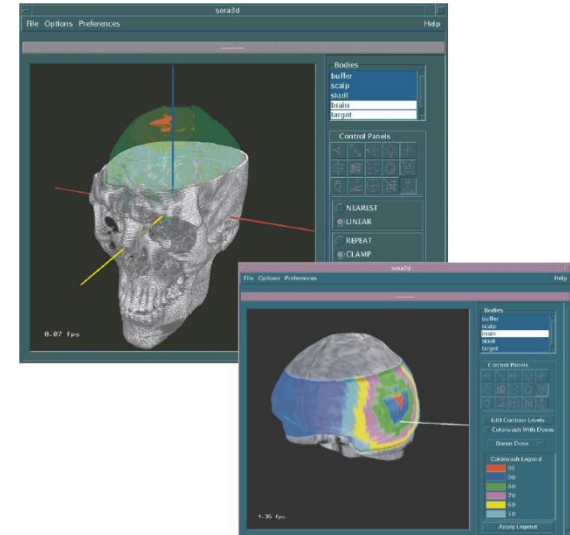
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SeraMC



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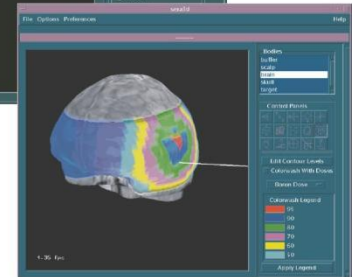
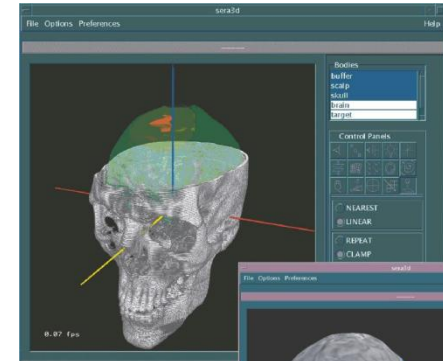
Seven modules covering processes

modeling, MC calculation, dose results visualization

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SeraMC

Parallel computing



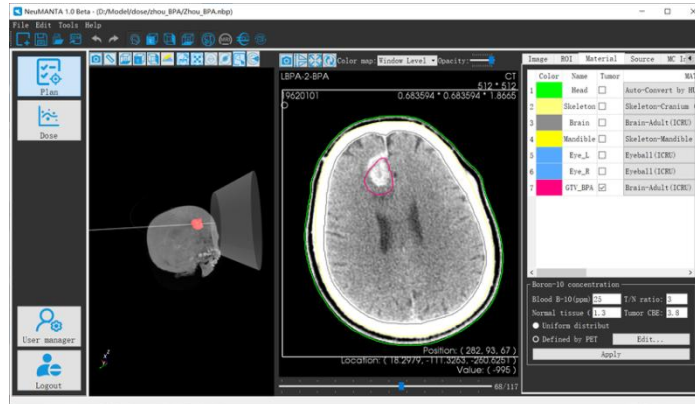
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State of Art : Treatment Planning System (TPS)

NeuMANTA (2022, China Neuboron Medical Group)

Three modules: model building, MC calculation, and dose calculation



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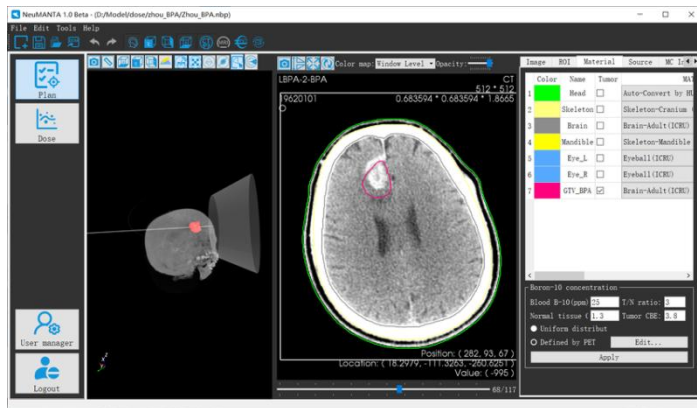
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Three modules: model building, MC calculation, and dose calculation

capability to read CT, MRI
and PET images (material
definition)

heterogeneous boron
distribution in patients through
PET images



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Three modules: model building, MC calculation, and dose calculation

capability to read CT, MRI
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heterogeneous boron
distribution in patients through
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self-developed MC engine
COMPASS (high calculation
efficiency)



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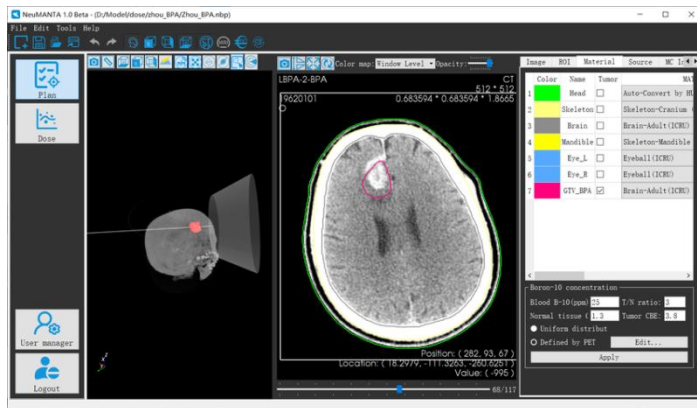
capability to read CT, MRI
and PET images (material
definition)

heterogeneous boron
distribution in patients through
PET images

self-developed MC engine
COMPASS (high calculation
efficiency)



Isodose curves and Dose Volume
Histograms (DVH)



What Can We Add Next ?



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State of Art : Treatment Planning System (TPS)



**Image
Processing**

**Region of
Interest (ROI)
Identification**

**Patient
Modeling**

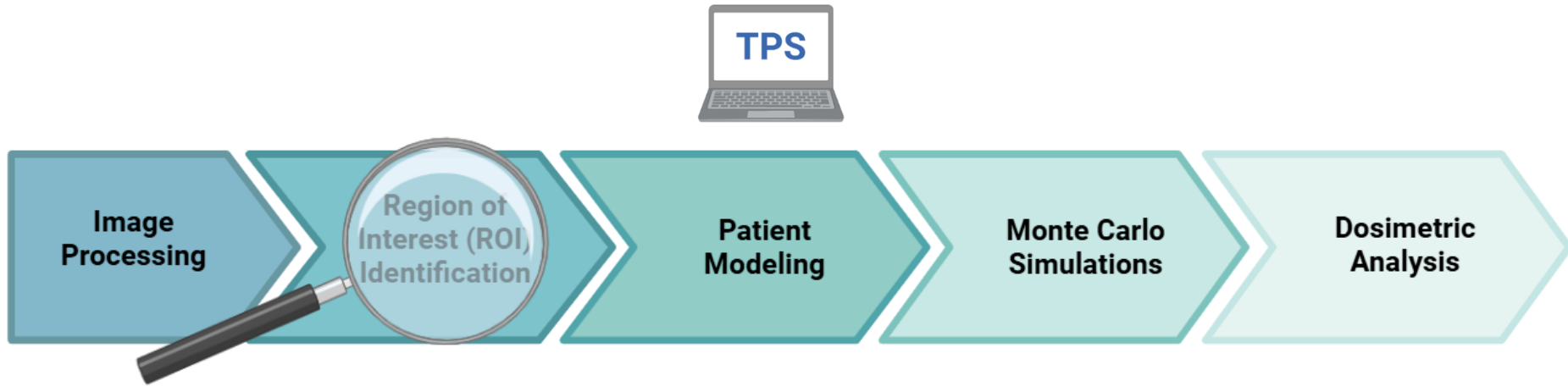
**Monte Carlo
Simulations**

**Dosimetric
Analysis**

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New Goal : IT_STARTS



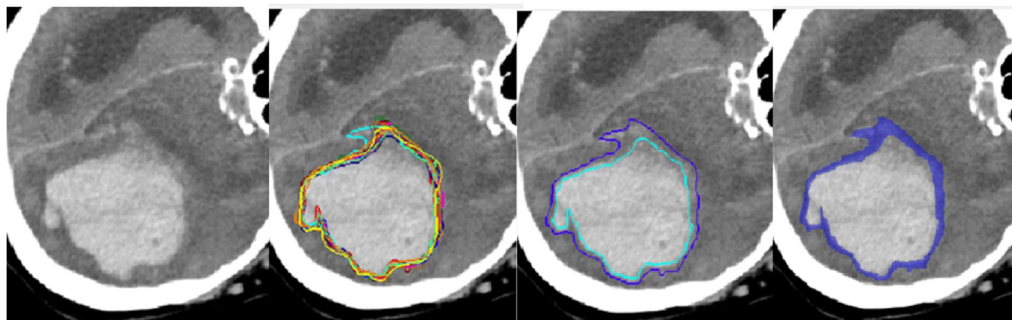
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State of Art : ROI Identification



Manual Contouring



Intra-observer variability (differences among contours delineated by a single observer on the same target volume at several different tries)

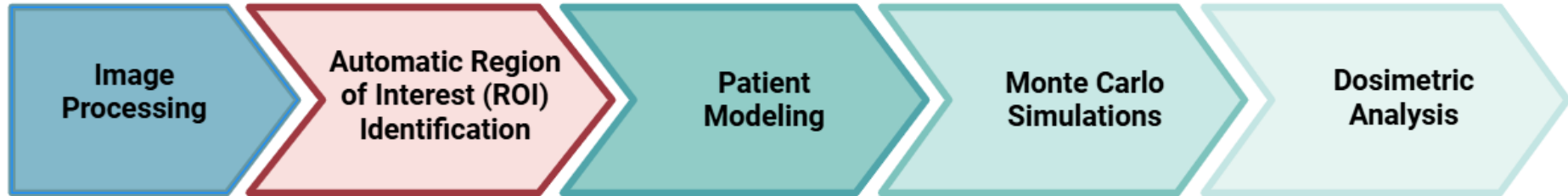
Time-consuming technique

Inter-observer variability (differences among contours delineated by multiple observers on the same target volume)

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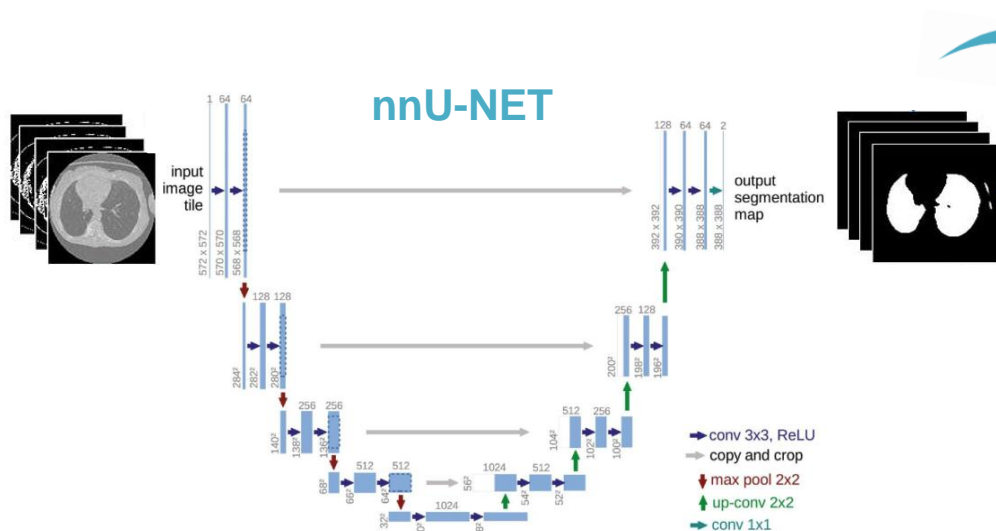
New Goal : IT_STARTS



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Automatic ROI Segmentation



Contracting Path (*encoder*) feature extraction

Expansive Path (*decoder*) spatially locates the features and generates an output map

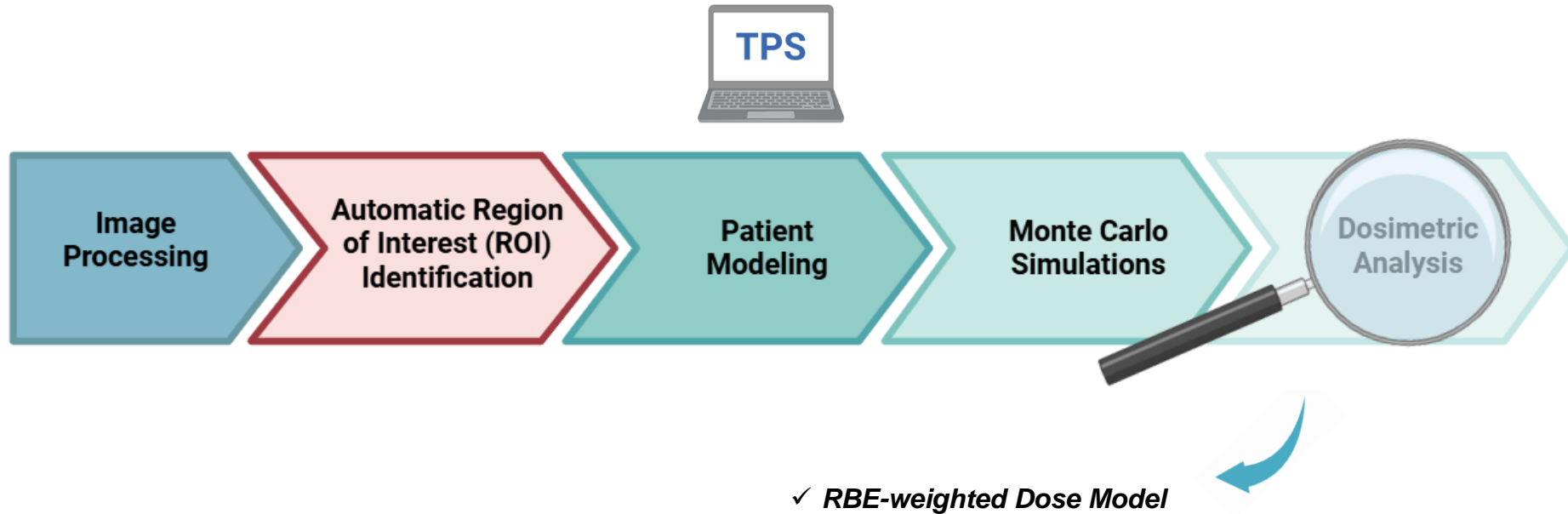
GLIOBLASTOMA
MULTIFORME



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New Goal : IT_STARTS



$$D_w = CBE \cdot D_B + RBE_{th} \cdot D_{th} + RBE_f \cdot D_f + RBE_{\gamma} \cdot D_{\gamma}$$

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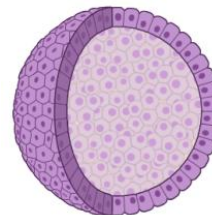
New Radiobiological Models

✓ **Photon Isoeffective Dose Model**

$$D_R(D_1, \dots, D_4) = \frac{1}{2} \frac{\left(\frac{\alpha}{\beta}\right)_R}{G_R} \times \left(\sqrt{1 + \frac{4G_R}{\alpha_R \left(\frac{\alpha}{\beta}\right)_R} \left(\sum_{i=1}^4 \alpha_i D_i + \sum_{i=1}^4 \sum_{j=1}^4 G_{ij}(\theta) \sqrt{\beta_i \beta_j} D_i D_j \right)} - 1 \right)$$



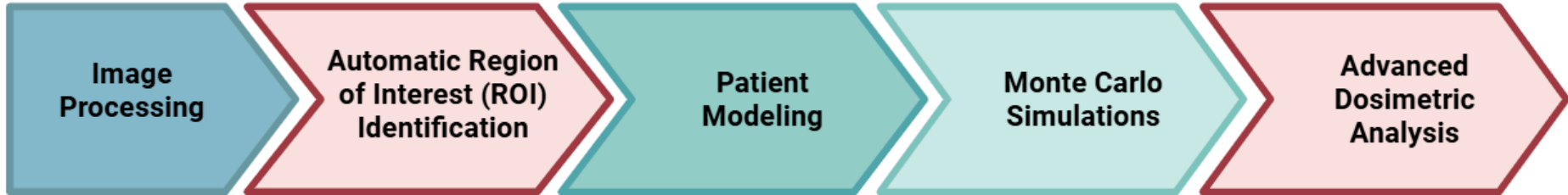
3D SPHEROIDS



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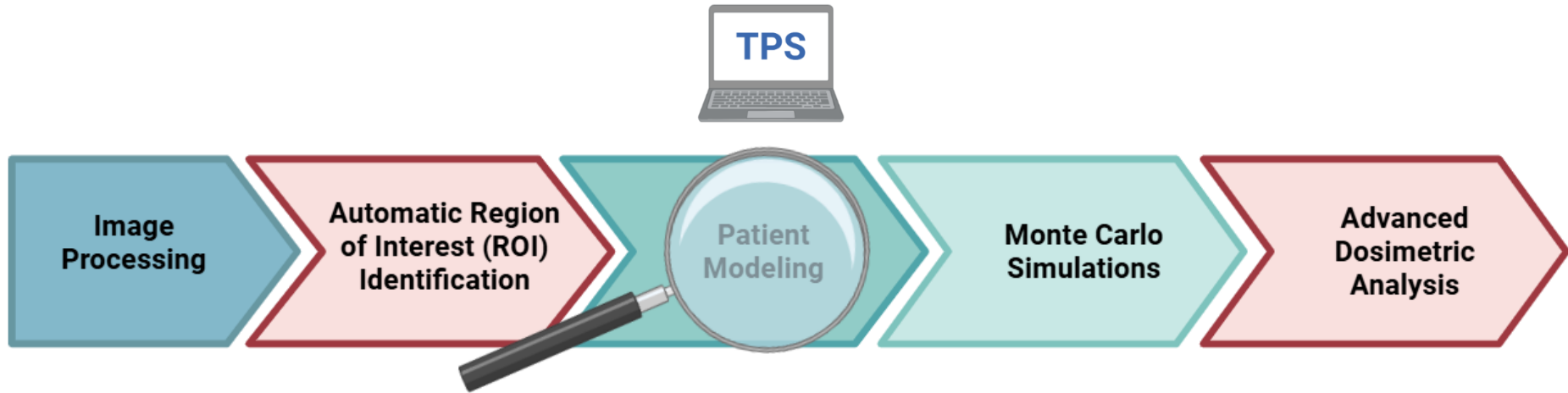
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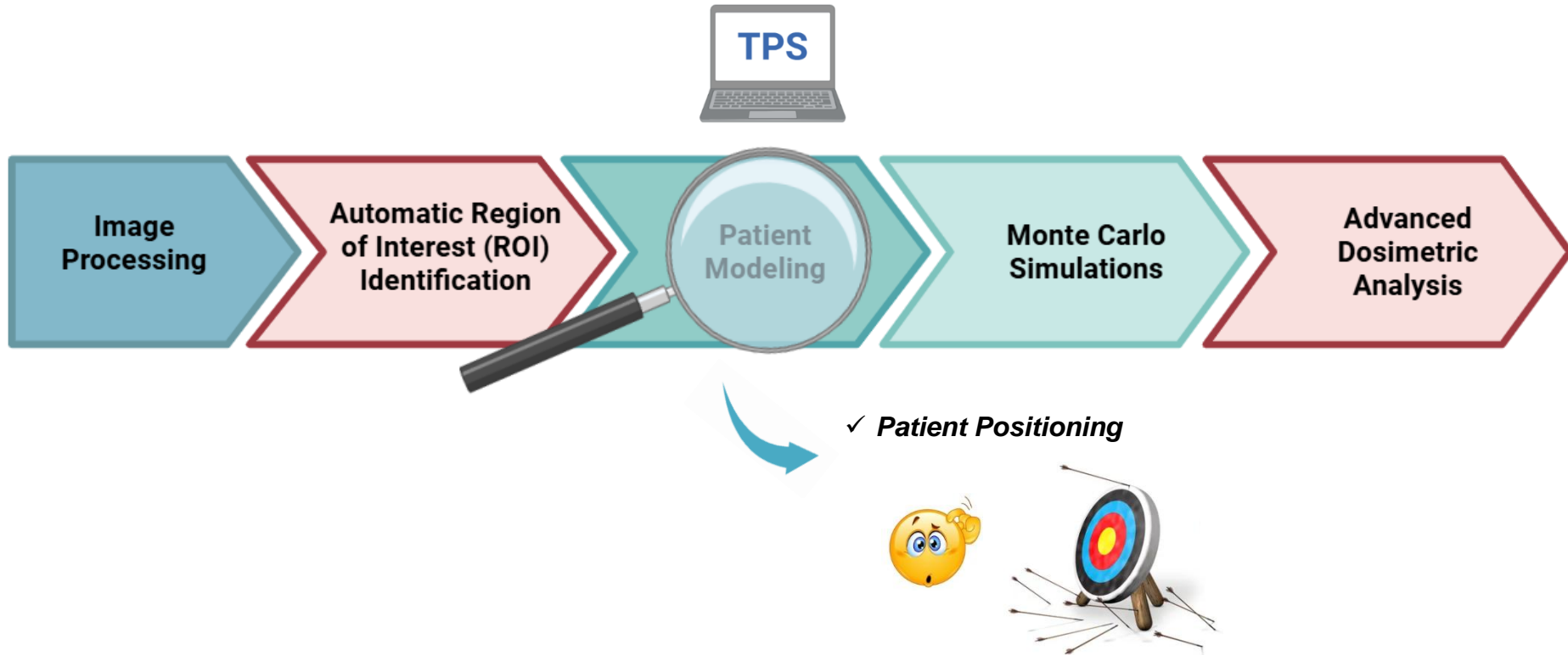
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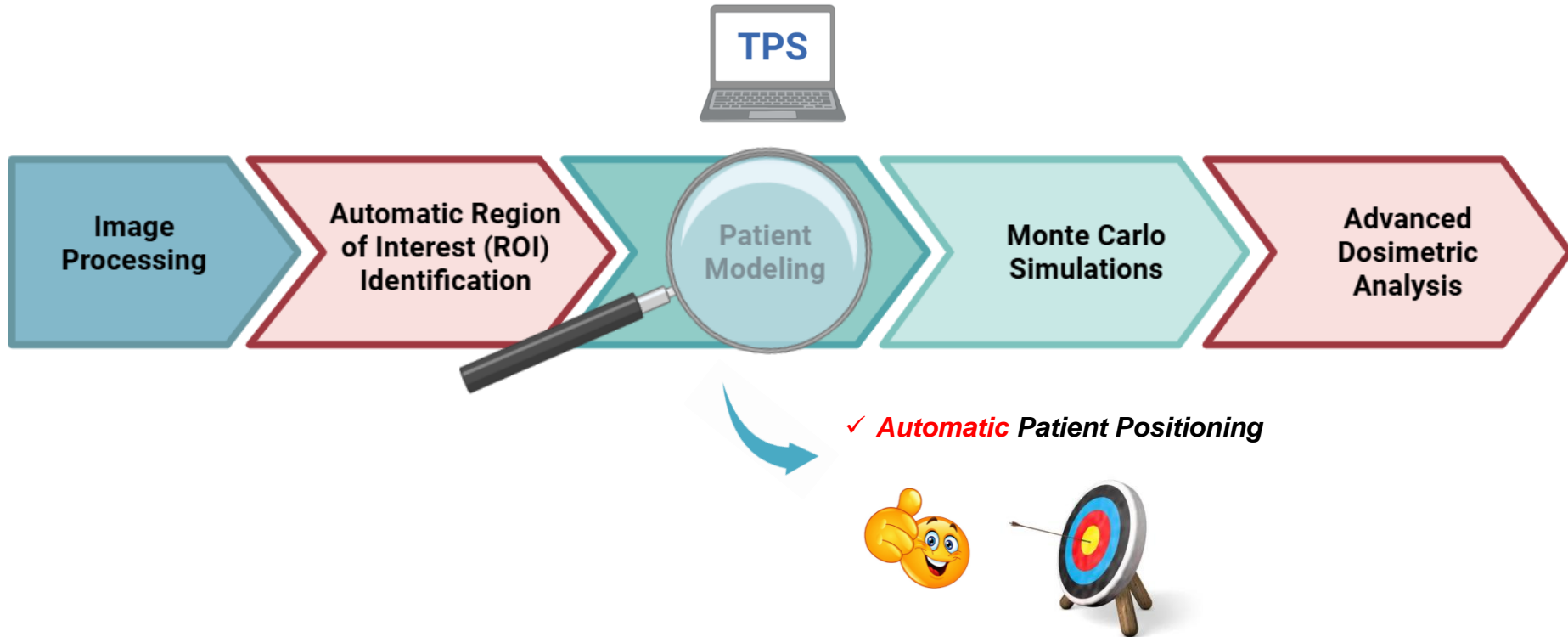
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Feseability

Experimental Activities



Neutron irradiation facility @TRIGA Mark II reactor and fully equipped biology laboratories

Collaborations



INFN projects (AI_MIGHT and IT_STARTS) and international collaborations (Argentina, China, Taiwan, France, Finland, Spain groups)

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Neutron irradiation facility @TRIGA Mark II reactor and fully equipped biology laboratories

Collaborations



INFN projects (AI_MIGHT and IT_STARTS) and international collaborations (Argentina, China, Taiwan, France, Finland, Spain groups)

Impact



Thanks for the Attention

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17th September 2025