INFN
Istituto Nazionale di Fisica Nucleare

Computational dosimetry in BNCT: the ANTHEM project

INSIGHTS - 18/20 October 2023

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13 September 2023

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Computational Dosimetry: computer-based methods to calculate and assess the distribution of radiation dose in a patient's body during radiation therapy. In BNCT this tool has the following requirements:

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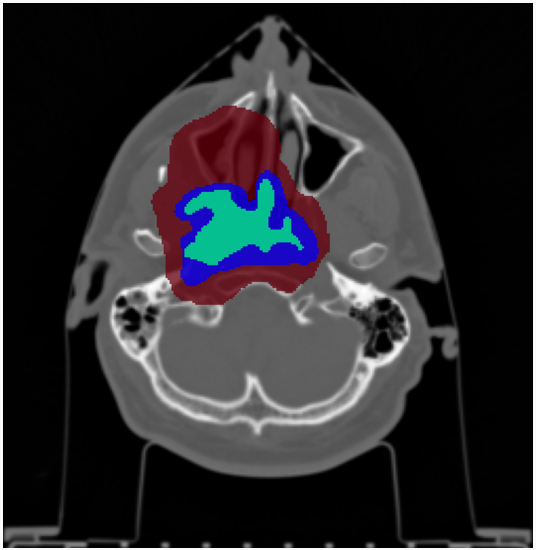
compute a 3D model of the patient

Contain the neutron source difinition

Dose calculation and dosimetry evaluation through MC simulation



3D Patient model

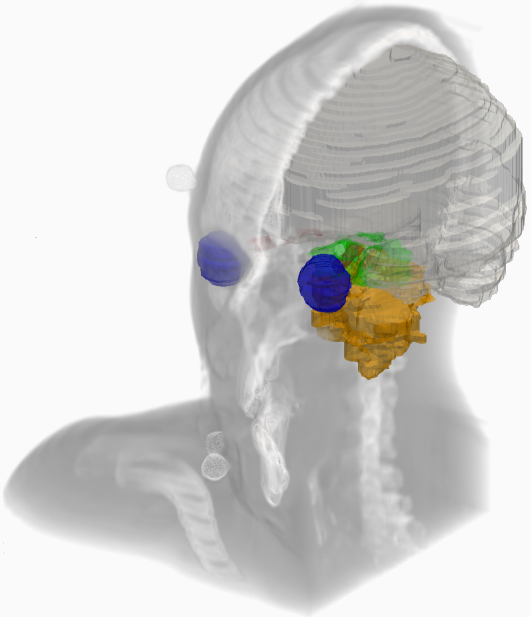
The 3D **voxelisation** of the patient is performed from a **CT scan**.

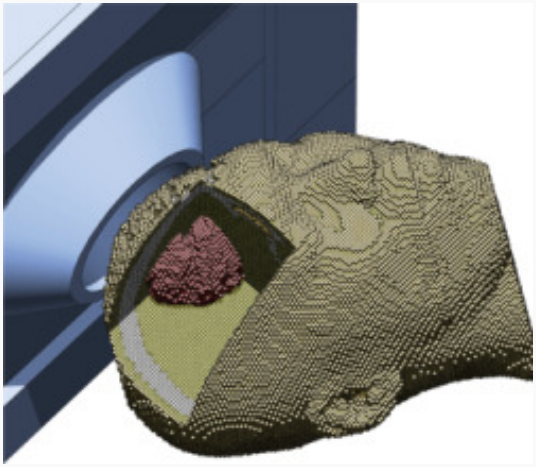
The software should be **compliant with the DICOM standard** and be capable to manage DICOM-RT files.

3D Patient model

Spacial information is combined with material density and atomic composition to define a computational model of the patient.

The newest TP systems combine HU and organ segmentation to implement a voxelisation limited by the spacial resolution of the CT.





Kumada, Hiroaki, et al. "Development of a multi-modal Monte-Carlo radiation treatment planning system combined with PHITS." AIP Conference Proceedings. Vol. 1153. No. 1. American Institute of Physics, 2009.

Beam axis and size

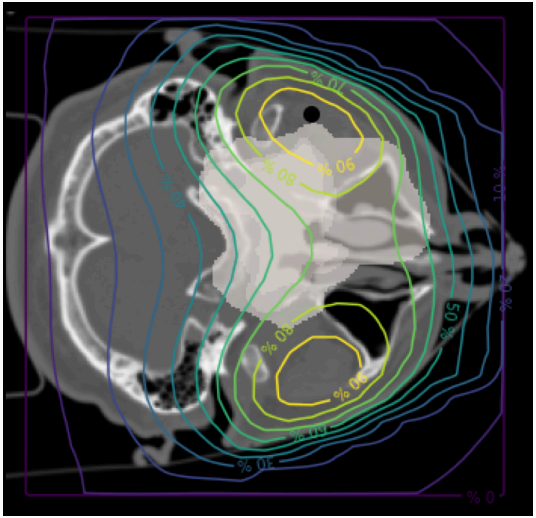
Neutron beam direction and aperture size are parameters to select before proceeding with dose calculations.

Optimising the treatment is done by selecting the most promising configurations and evaluate their dosimetric performances.

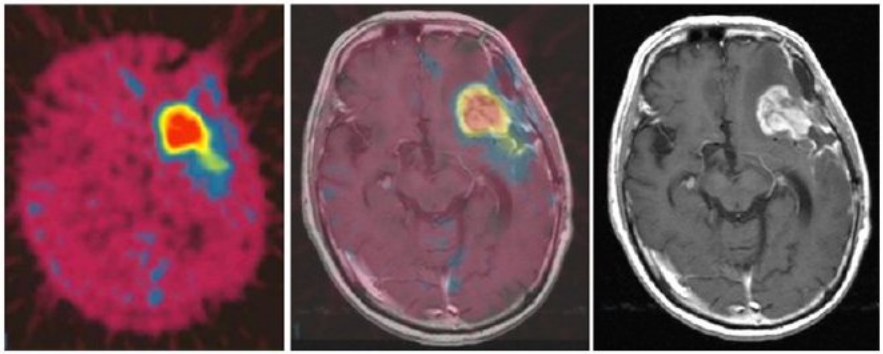
Dose evaluation

Monte Carlo particle simulation tools such as MCNP, PHITS, Geant4, Fluka and OpenMC are used to compute the dose distribution.

The dosimetry is then combined with relevant ROI masks and readiobiological models to evaluate the treatment.

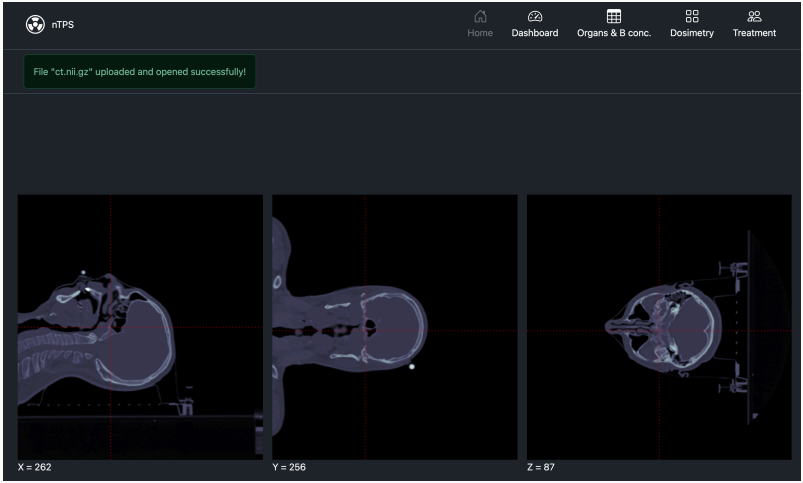


^{10}B concentration is measured from blood samples taken just before the treatment. This value is then multiplied by appropriate factors to obtain the boron concentration of a specific tissue. Future TP systems could combine or obtain this information from MRI or PET scans.

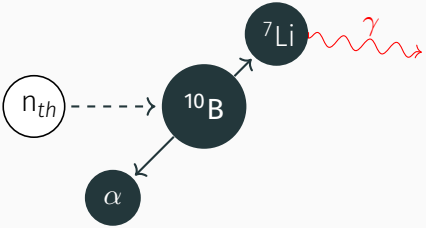


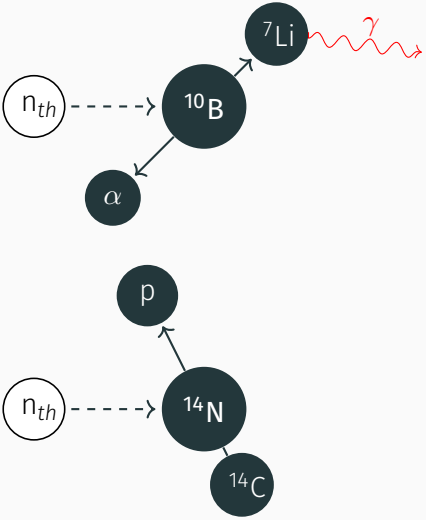
Miyatake, Shin-Ichi, et al. "Boron neutron capture therapy for malignant brain tumors." Journal of neuro-oncology 149 (2020): 1-11.

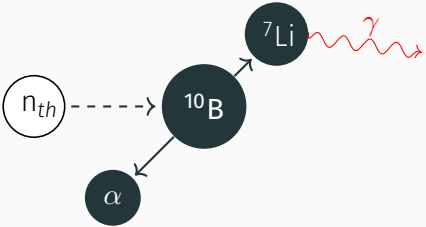
A research BNCT TP software was developed through the **INFN Gr V young researchers grants**: **IT_STARTS** and **AI_MIGHT**

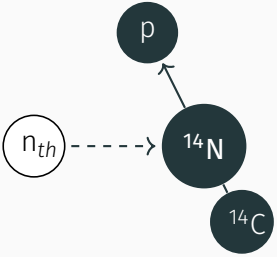


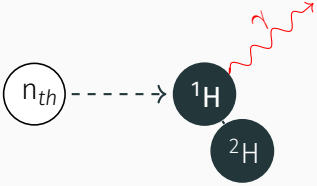
What is special about BNCT dosimetry ?

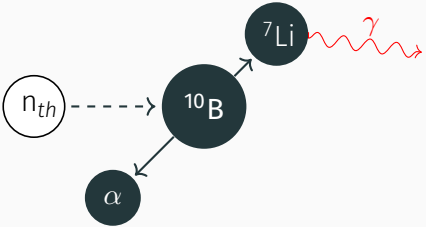

^{7}Li
γ
n$_{th}$
^{10}B
α

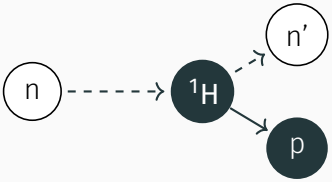

^{7}Li
γ
n_{th}
^{10}B
α
p
n_{th}
^{14}N
^{14}C

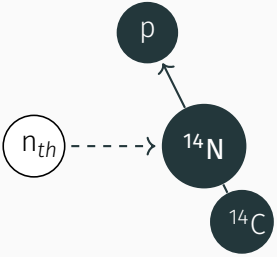

^{7}Li
γ
n_{th}
^{10}B
α

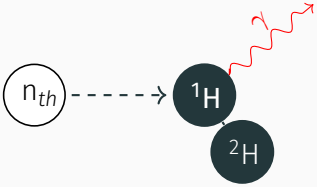

p
n_{th}
^{14}N
^{14}C


γ
n_{th}
^{1}H
^{2}H


^{7}Li
γ
n_{th}
^{10}B
α


n'
n
^{1}H
p

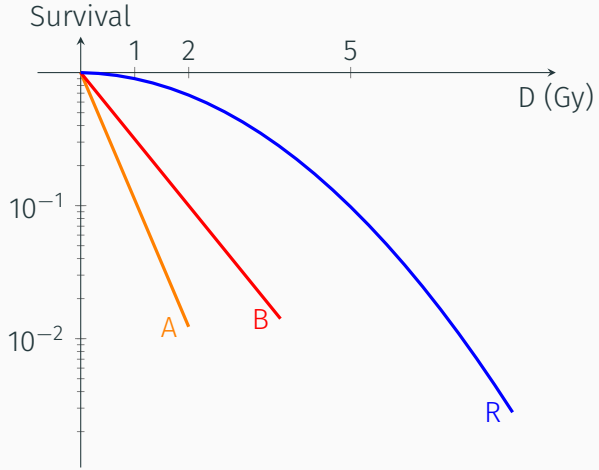

p
n_{th}
^{14}N
^{14}C


γ
n_{th}
^{1}H
^{2}H

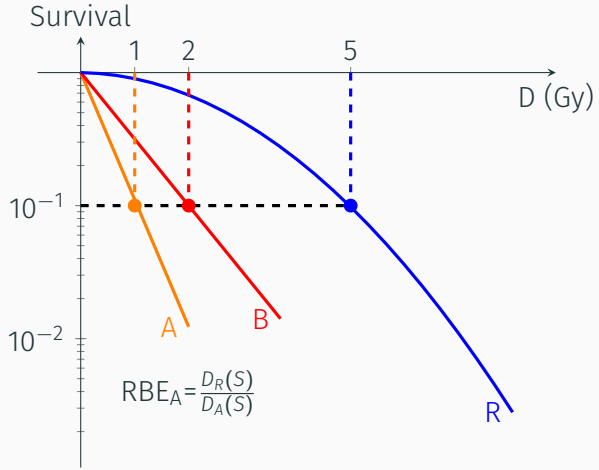
$$\mathbf{D}_W = \sum_{i=1}^{i=4} \mathbf{D}_i \cdot W_i$$

D_i are the absorbed dose components

w_i are the weight factor for each component



González, Sara J. et al. Radiation research 178.6 (2012): 609-621.



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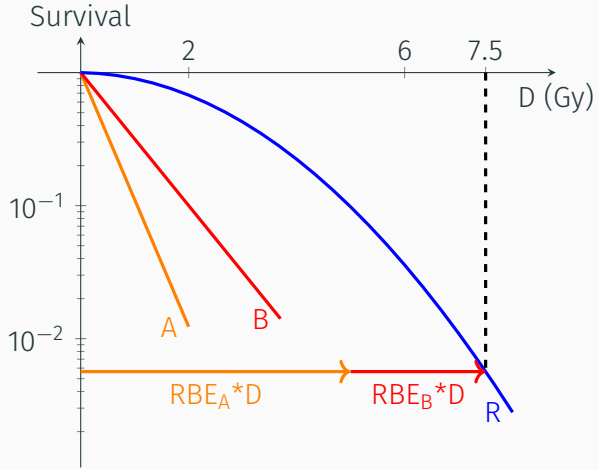

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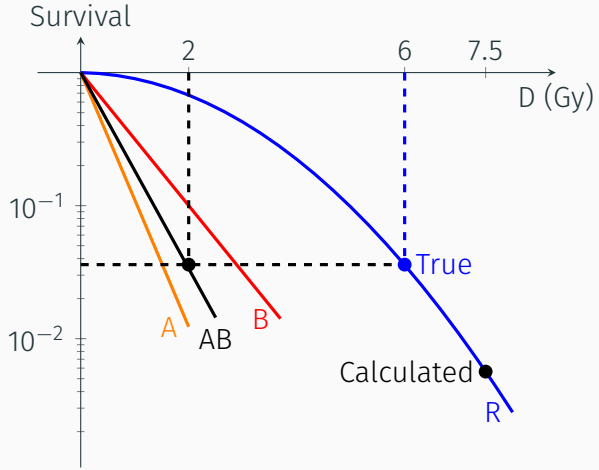

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Photon Isoeffective Dose

It is the biological dose from a mixed radiation field, for which the same effect (TCP or NTCP) as the reference photon radiation is achieved.

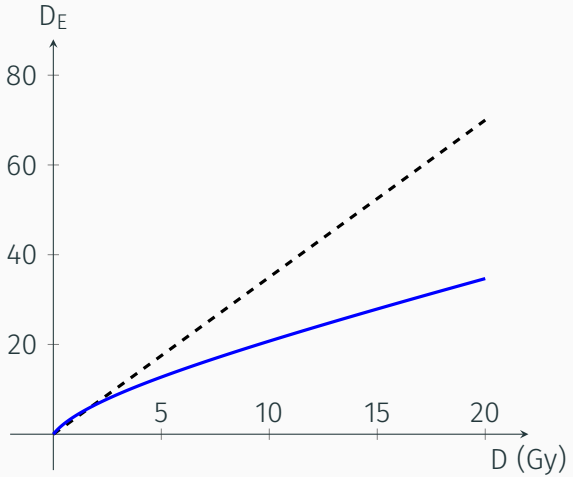
$$D_R(D_1,\ldots,D_4)=$$

$$\frac{(\alpha/\beta)_R}{2G_R}\left(\sqrt{1+\frac{4G_R}{\alpha_R(\alpha/\beta)_R}\left(\ln\left(\frac{c_1^*}{c_1}v^{c_2^*-c_2}\right)+\sum_{i=1}^{4}\alpha_1 D_i+\sum_{i=1}^{4}\sum_{j=1}^{4}G_{ij}(\theta)\sqrt{\beta_i\beta_j}D_iD_j\right)}-1\right)$$

D_w dotted line

D_{isoe} blue line

The overestimation of the equivalent dose calculated with fixed RBE factors increases with the increase in the physical dose.



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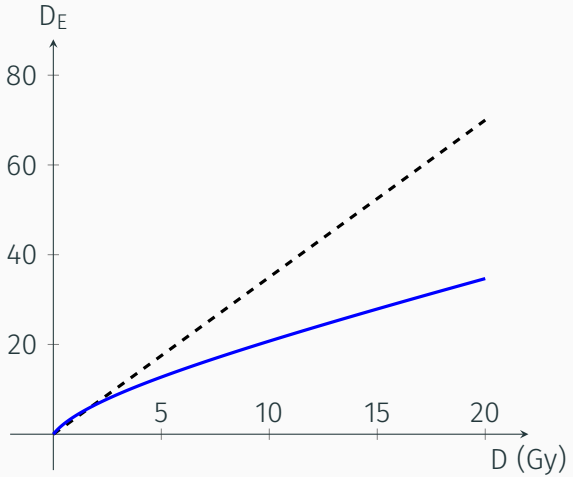

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To work properly,
what does the Photon Isoeffective dose model need?

To work properly,
what does the Photon Isoeffective dose model need?

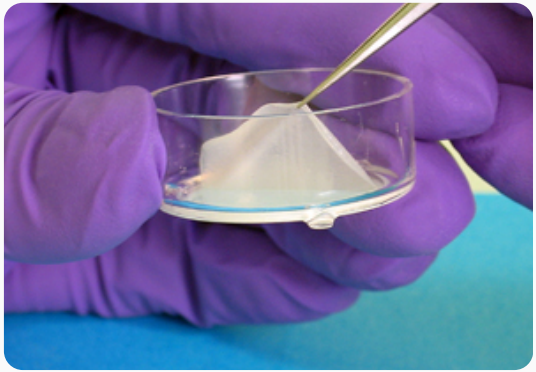
DATA

To work properly,
what does the Photon Isoeffective dose model need?

Radiobiological

DATA

Episkin™



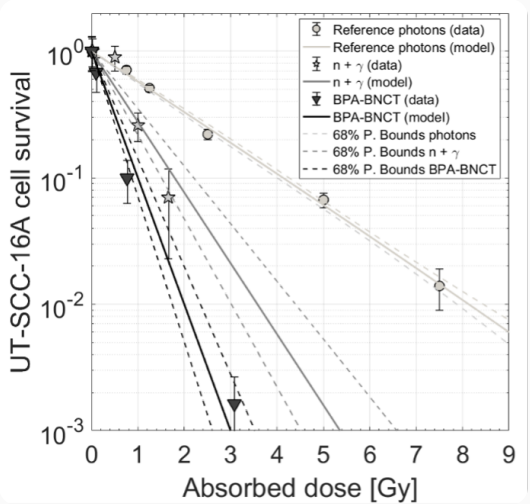
Healthy **skin tissue** grown in vitro.

A robust model of healthy tissue complications helps to improve the **prediction of adverse effects** caused by the BNCT treatment.

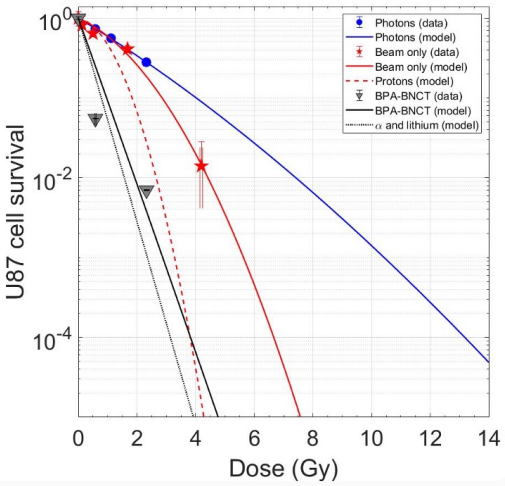
UTSCC

Primary tumor cells from a patient treated with BNCT in Finland.

Evaluation of the **biological endpoint** through clonogenic assays.



U87



Immortalized human glioblastoma cells.

Evaluation of the **biological endpoint** through clonogenic assays

Measuring radiobiological parameters is not effort free, what is the impact?

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Compare different radiation treatments

Measuring radiobiological parameters is not effort free, what is the impact?

Compare different radiation treatments

Evaluate the combination of two radiation therapy modalities

CIRT

BNCT

TCP

CIRT

Dose is translated into single fraction using BED formalism

BNCT

TCP

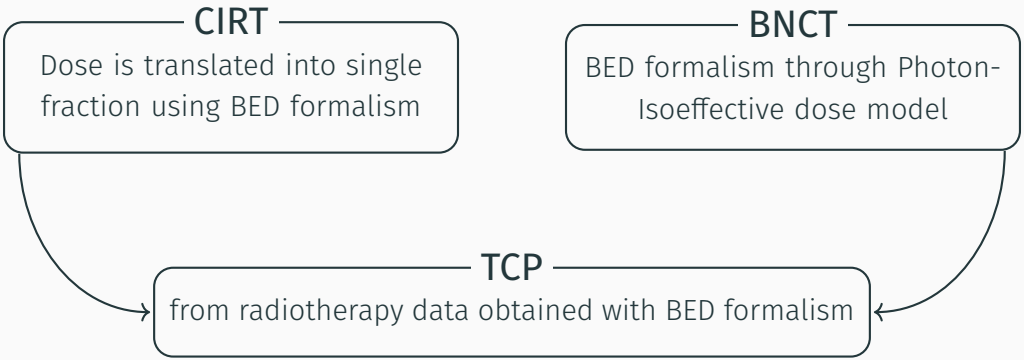
CIRT

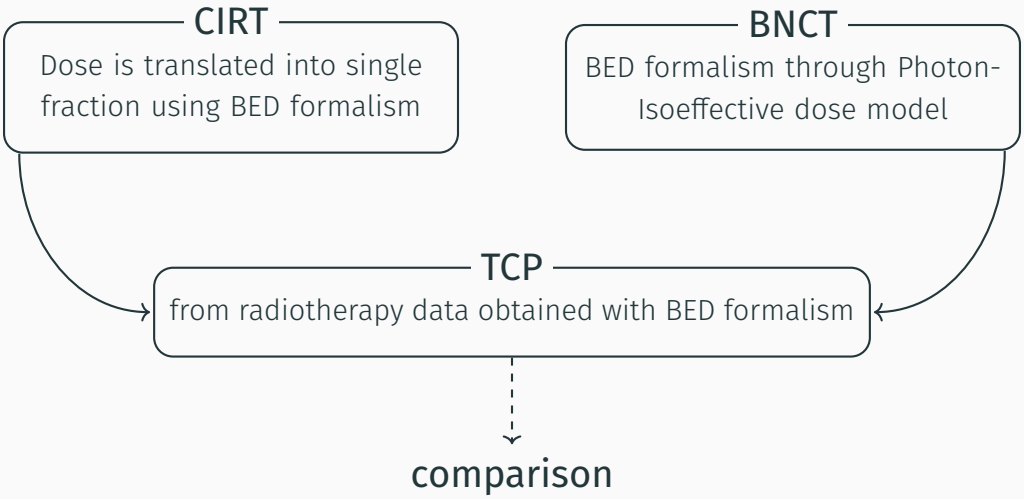
Dose is translated into single fraction using BED formalism

BNCT

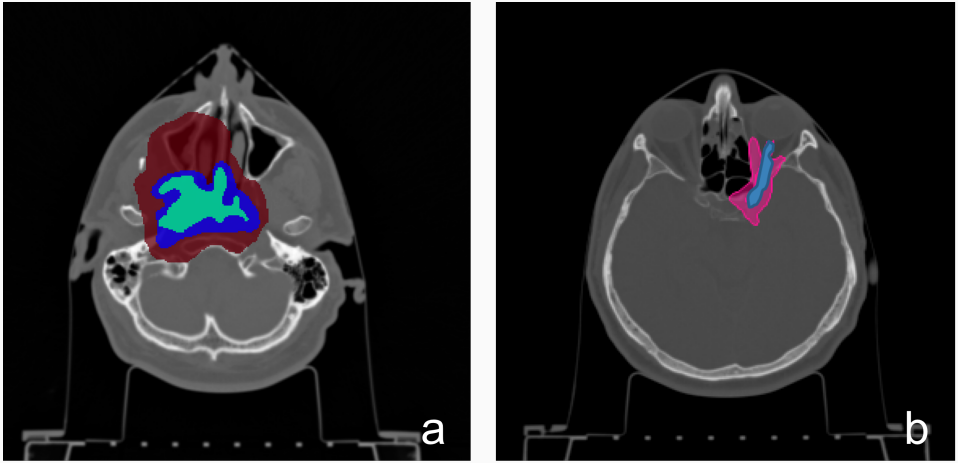
BED formalism through Photon-Isoeffective dose model

TCP

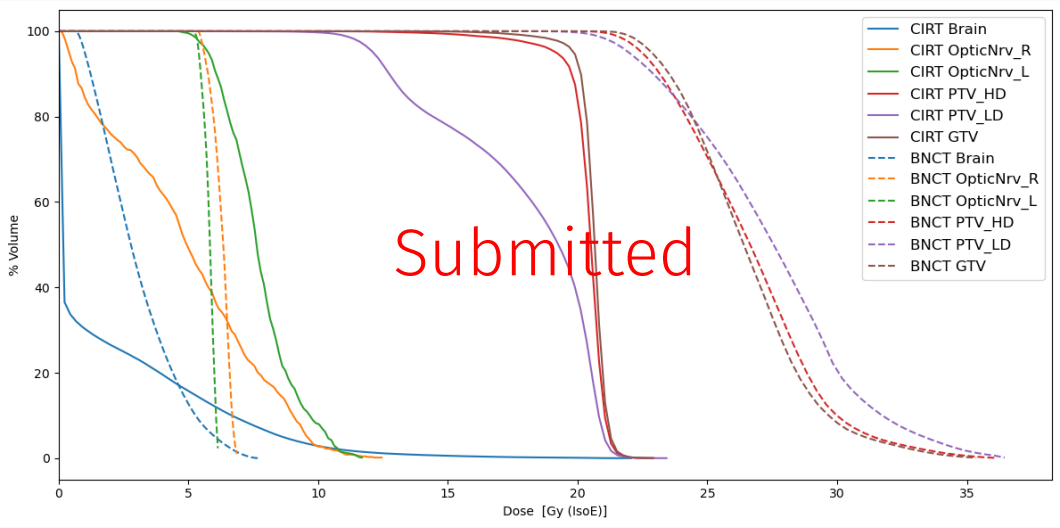

CIRT
Dose is translated into single fraction using BED formalism
BNCT
BED formalism through Photon-Isoeffective dose model
TCP
from radiotherapy data obtained with BED formalism


CIRT
Dose is translated into single fraction using BED formalism
BNCT
BED formalism through Photon-Isoeffective dose model
TCP
from radiotherapy data obtained with BED formalism
comparison

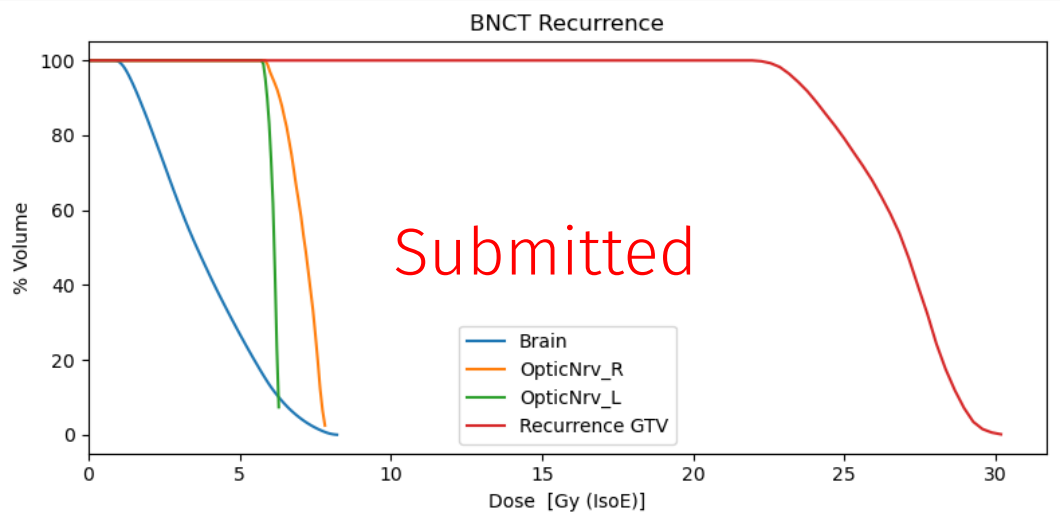
CIRT patient in collaboration with fondazione CNAO
Centro Nazionale di Adroterapia Oncologica per il trattamento dei tumori



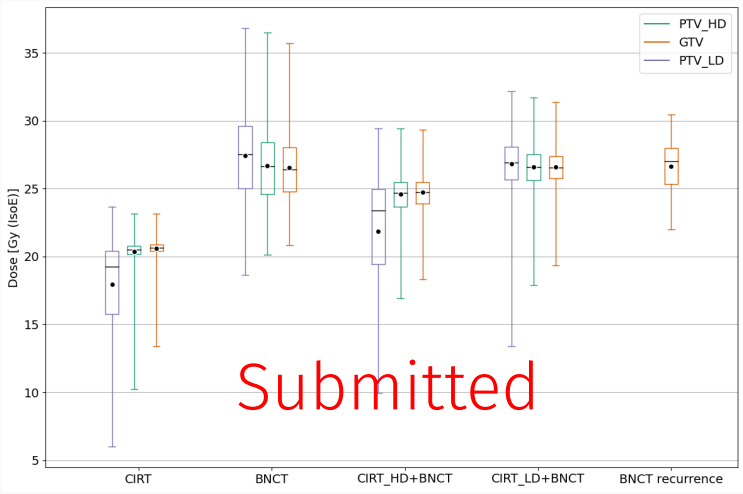
Primary tumor treatment comparison

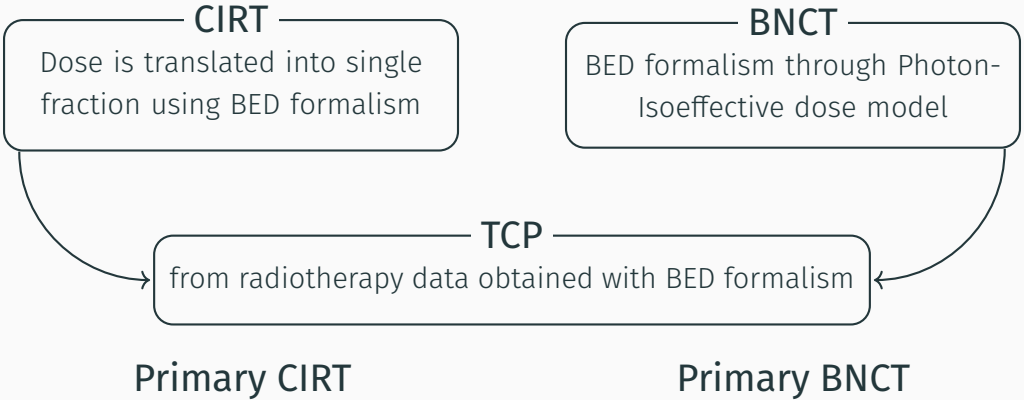


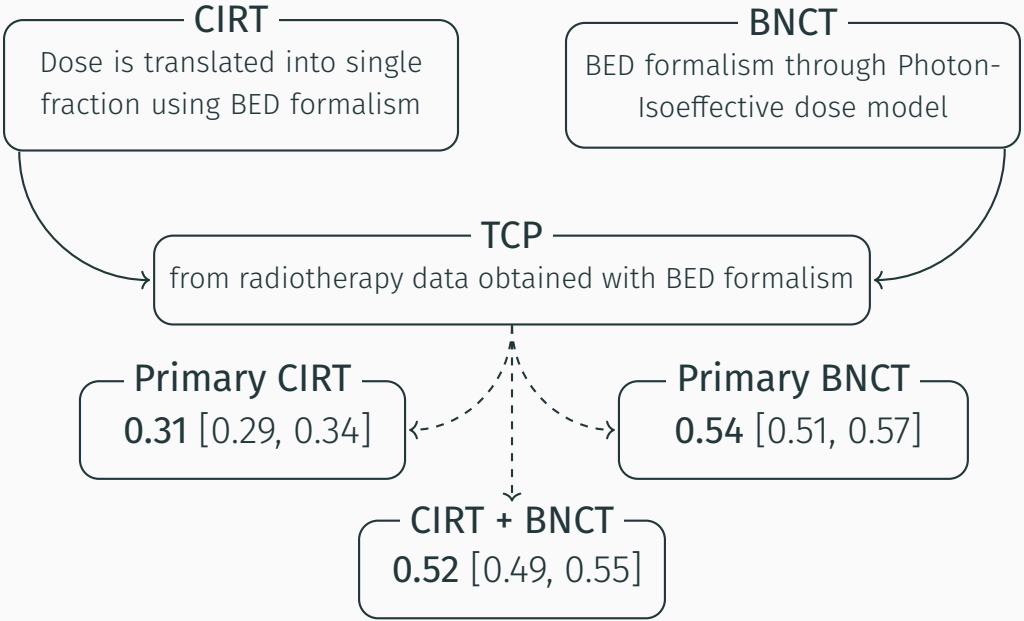
Recurrence treatment with BNCT



By using radiobiological data in combination with the isoeffective model, it is possible to calculate the **BNCT dose equivalent to a single fraction of photons**. This allows us to compare BNCT with other treatments, including hadron therapy.




CIRT
Dose is translated into single fraction using BED formalism
BNCT
BED formalism through Photon-Isoeffective dose model
TCP
from radiotherapy data obtained with BED formalism
Primary CIRT
Primary BNCT
CIRT + BNCT


CIRT
Dose is translated into single fraction using BED formalism
BNCT
BED formalism through Photon-Isoeffective dose model
TCP
from radiotherapy data obtained with BED formalism
Primary CIRT
0.31 [0.29, 0.34]
Primary BNCT
0.54 [0.51, 0.57]
CIRT + BNCT
0.52 [0.49, 0.55]

In Conclusion

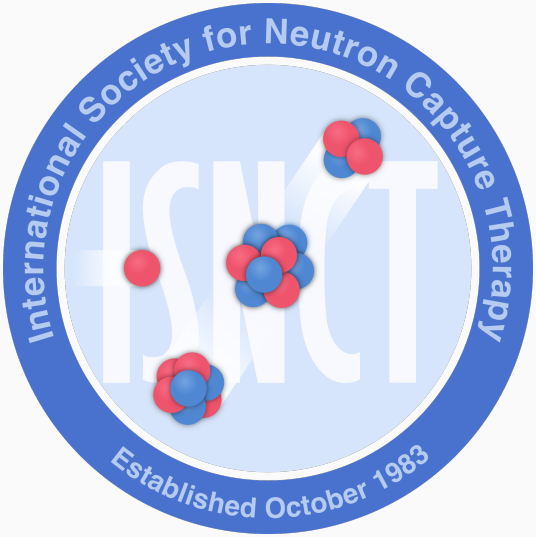
Medicine

Engineering

Chemistry

Biology

Physics



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