BNCT/BNCS

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Why I'm Taking Eng. Phys. 4D3

- To develop a better understanding of neutron transport modeling and interactions
- 3 types of neutron sources for medical use, at present:
  - -radioactive isotopes (i.e. ^{252}Ca)
  - -accelerator (i.e. protons on Li)
  - -fission reactor (i.e. beam port)

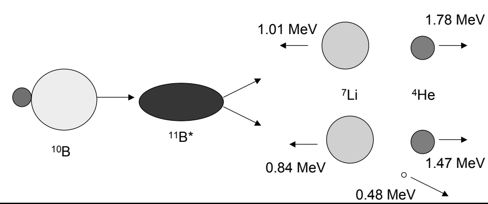
Introduction

- BNCT stands for Boron Neutron Capture Therapy - refers to cancer treatment
- BNCS stands for Boron Neutron Capture Synovectomy - refers to treatment for symptoms of rheumathoid arthritis

Boron Neutron Capture Reaction

$$^{10}B + n_{thermal} \xrightarrow{6.3\%} {}^{7}Li_{1.01\ MeV} + \alpha_{1.78\ MeV}$$

$$^{10}B + n_{thermal} \xrightarrow{93.7\%} {}^{7}Li_{0.84\ MeV} + \alpha_{1.47\ MeV} + \gamma_{0.48\ MeV}$$



What Happens on a Cellular Level?

- Both the Li and α particles have high linear energy transfer (LET)
- The path length of these particles is approx. 8 μm (about the size of a cell)
- The particles deposit almost all their energy in the cell

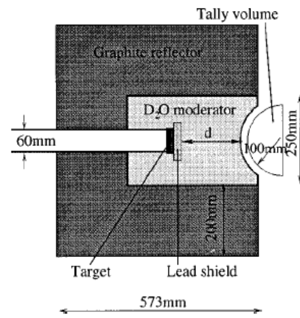
Idea

- If we can get tumour (or synovial) cells to specifically uptake the Boronated compounds we can kill the cells preferentially
- i.e. Kill tumour cells
  Spare normal tissue

Multi-Disciplinary Field

- Chemistry → -produce boron compounds
- Biology → -determine if compound is preferentially taken up into target cells
- Physics → -modeling neutron transport
  -determine dose to each tissue
- Engineering → -target design
  -moderation process
  -reflector design

Modeling Transport



Allen et al., Med. Phys. Vol. 26, No.1

Monte Carlo

- Monte Carlo actually tracks individual particles from the source

Probability of a first collision for a particle between l and dl along its line of flight is given by:

$$p(l)d = e^{-\Sigma^* l}\Sigma dl$$

Setting the random number as:

$$\xi = {}_0\int^l e^{-\Sigma^* l}\Sigma ds = 1- e^{-\Sigma^* l}$$

Distance to collision is:

$$l = -1/\Sigma^*\ln(1-\xi) = -1/\Sigma^*\ln(\xi)$$

Collision Sequence

1. Collision nuclide is identified
2. Elastic or Inelastic scattering is selected based on probability data
3. New direction and Energy is determined
4. Neutron Capture occurs for neutrons based on probability data
5. Photons are optionally generated

Selection of Nuclide

- If there are n different nuclides forming the material in which the collision occurred and ξ is the random number [0,1) then the k^{th} nuclide is chosen as the collision nuclide if:

$$\sum_{l=1}^{k-1} \Sigma_{t,l} < \xi^* \sum_{l=1}^{n} \Sigma_{t,i} \leq \sum_{l=1}^{k} \Sigma_{t,i}$$

What the User Must Define

- Spatial and energy distributions of the source (i.e. point source, flat flux, etc.)
- Boundaries of cells using surfaces
- Material composition of the cells
- Scattering and absorption cross sections
- Tallies required (i.e.flux, fluence, dose, etc.)
- Variance reduction techniques

Variance Reduction

- Flux of about 10^9 n/s is required
- MCNP gives feedback as to how statistical soundness of the model
- Results are deemed acceptable when $R \leq 0.05$ where:

$$R \equiv S_{mean}/mean \approx \sigma_{mean}/mean$$

- But is the mean correct?

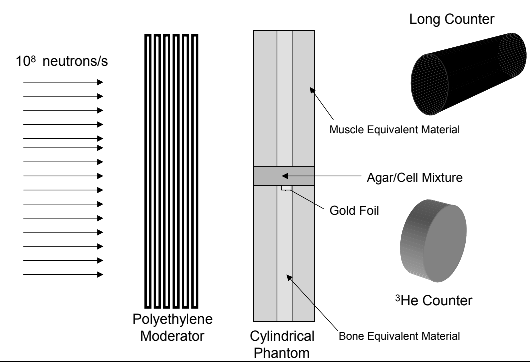
Some Variance Reduction Techniques

- Truncation Methods
  - i.e. energy cutoff, geometry cutoff
- Population Control Methods
  - i.e. particle splitting, Russian roulette
- Modified Sampling Methods
  - i.e. implicit capture, forced collisions
- Partially Deterministic Methods
  - i.e. random walk biasing, next event estimators

Our Goal

- To perform and compare numerical models with experimental tests using the McMaster accelerator and reactor designs to determine feasibility of these treatments here at Mac
- To perform some experiments using synovial cells with already developed boronated-corticosteroids to determine what the potential biological response will be in our design

Proposed Research



Boron Neutron Capture Reaction

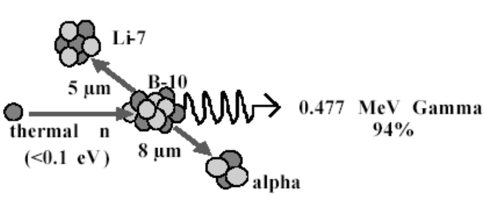


Fig. 1. Nuclear reaction utilized in BNCT. A ^{10}B nucleus absorbs a thermal neutron and promptly emits a back to back ^{7}Li ion and a ^{4}He (alpha) particle. The combined range of 12–13 µm is similar to mammalian cell dimensions.

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Weighted Depth Dose Curves

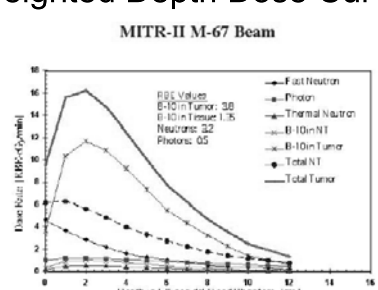

Fig. 2. Weighted depth dose curves showing the various components.

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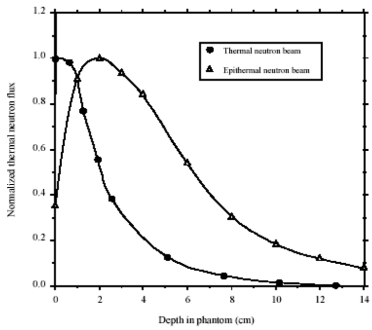
Thermal vs. Epithermal



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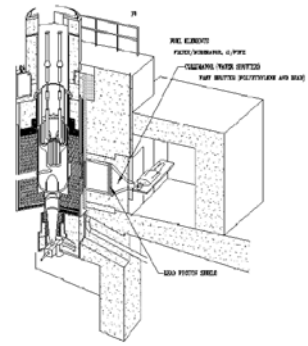
Fission Converter



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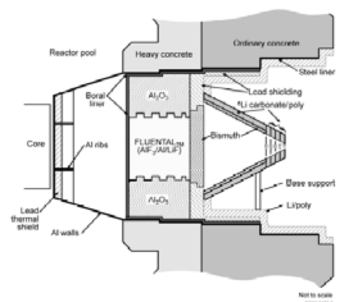

Fig. 3.2. Example of an effort to minimize core to patient distance.

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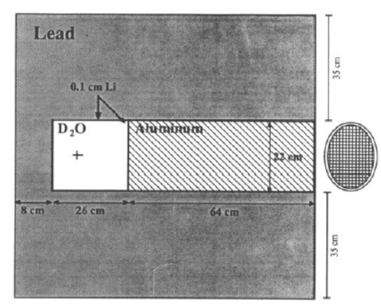
Californium-based Source

Design of Cf-based epithermal neutron beam for NCT



Yanch et al., Phys. Med. Biol., Vol. 38

Reflectors

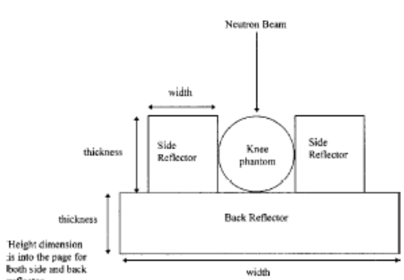
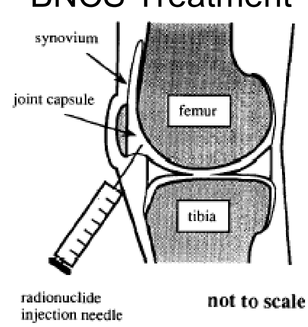


FIG. 2. Schematic of the MCNP model of the knee phantom with side and back reflectors.

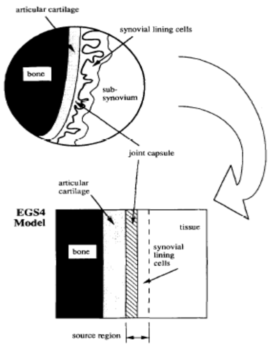
Gierga et al., Med. Phys., Vol. 27, No. 1

BNCS Treatment



Johnson et al., Med. Phys., Vol. 20, No. 3

Synovial Tissue



Johnson et al.,
Med. Phys.,
Vol. 20, No. 3

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