When deuterons are accelerated in a cyclotron to create a fast neutron beam

- Deuterons impinge a beryllium target where they knock out neutrons.
- For each neutron “stripped” from Be-9, one atom of Be-9 is converted to B-9.
- The neutron spectrum consists of a single peak, with a modal value of about 40% of the energy of the incident deuterons.
- The neutron spectrum spans a wide range of energies from zero to the maximum energy of the incident deuterons.

Choice a is false. Proton bombardment is a knock-out process - Protons impinge a beryllium target where they knock-out neutrons. Deuteron bombardment is a stripping process - deuterons impinge a beryllium target where they strip neutrons.

Choice b is false because for each neutron “stripped”, one atom of Be-9 is converted to B-10 (not B-9).

Choice d would be the spectrum for proton bombardment of Be target.

The dashed line in the figure is a neutron spectrum from proton bombardment of Beryllium. Which of the following statements about this spectrum is true?

- Polyethylene is a good material to harden this spectrum because elastic scatter dominates for lower energy fast neutrons and that nuclei with lower mass are more effective on a “per collision” basis for slowing down neutrons.
- Cd-113 would be a good material to harden this spectrum has high thermal neutron absorption cross section and would remove the thermal neutrons.
- Boronated polyethylene would be a good material to harden this spectrum because the low-z polyethylene would thermalize the intermediate and lower energy fast neutrons and the boron would remove the thermal neutrons.

Polyethylene alone would make the problem worse. Polyethylene is a good material to harden this spectrum because elastic scattering dominates for lower energy fast neutrons and that nuclei with lower mass are more effective on a “per collision” basis for slowing down neutrons - but this would effectively soften the spectrum, making it less penetrating.

Cd-113 is not correct. While Cd-113 has a high thermal neutron absorption cross section and would remove the thermal neutrons, but the low energy fast neutrons and the intermediate energy neutrons are still insufficiently penetrating to be effectively removed by Cd-113. These also need to be reduced from the beam.

Boronated polyethylene would be a good material to harden this spectrum because the low-z polyethylene would thermalize the intermediate and lower energy fast neutrons and the boron would remove the thermal neutrons.

Boronated polyethylene would be a good material to harden the spectrum in the previous example. What additional shielding is required to make this beam useful for patient?

- High-Z material to absorb subsequent characteristic x-rays and Auger electrons.
- High-Z material to absorb the 0.48 MeV gamma that is emitted when the excited $^1$B returns to ground state.
- High-Z material to absorb the 1.47 MeV α and 0.84 MeV $^7$Li recoil nucleus.

The energetic 0.48 MeV gamma that is emitted when the excited $^1$B returns to ground state has sufficient energy to increase patient dose especially near the surface and in build-up region. These gammas can be effectively filtered from the beam by adding a thin layer of lead behind the boronated polyethylene.
Why is there such a large distance between the target and isocenter in Fast Neutron RT?

a. To accommodate a thick collimator which includes both boronated hydrogenous material, which is used to thermalize and then absorb intermediate and slower fast neutrons, and a high-Z material to remove energetic gamma rays.
b. The large distance (typically 1.4 m) of air is included in the beam path length to preferentially filter out the lowest energy neutrons while not removing fast neutrons from the beam.
c. The Be neutron target becomes extremely hot during bombardment and the increased distance is required to allow space to water cool the target as well as for safety considerations and patient comfort.
d. This is a historical carry-over from early neutron therapy facilities which were at large research institutions such as Fermilab where physical space was not as big of a consideration as in a beamline located in a hospital.

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Early clinical trials with BNCT trials failed to show any evidence of therapeutic efficacy because

a. They used boron compounds that were preferentially absorbed in normal tissue rather than tumor.
b. They used Cd-113 containing compounds, which were toxic when incorporated into the blood.
c. They used fast neutron beams.
d. They used thermal neutron beams.

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Secondary neutron production from photon radiation therapy is higher for 18 MV than for 15 MV because

a. $(\gamma,n)$ reactions from a 15 MV beam result in lower energy neutrons, which then have higher probability of being absorbed in the collimators.
b. $(\gamma,n)$ reactions from an 18 MV beam result in higher energy neutrons which can then have higher probability of $(n,xn)$ reactions.
c. There are more photons above the $(\gamma,n)$ reaction threshold and in the energy region where there is dramatic increase in cross section.

d. There are more photons above the $(\gamma,n)$ reaction threshold and in the energy region where there is dramatic increase in cross section.