A NEW BERYLLIUM TARGET FOR THE ORLEANS NEUTRONTHERAPY FACILITY

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(1) Introduction

The Orleans Neutrontherapy Unit started in 1981. About 350 patients have been treated with the C.N.R.S. Cyclotron C.G.R. 680 type.

A vertical neutron beam is produced by a (p.n) nuclear reaction with a 34 Mev proton beam on a beryllium target.

Acceptable dose rates for medical purposes are obtained with a high proton current in the 40-45 μA range. Consequently target has to be designed for a favorable power dissipation.

In order to treat deeply-located tumors with minimal dose distribution out of tumor volume, it is necessary to use fast neutron beams with the highest average energy.

In September 1983, the basic thick target was replaced by a semithick one to improve the clinical quality of the beam.

(2) Proton beryllium fast neutron production with middle energy cyclotron

New neutrontherapy centers adopt p-Be reaction for economical reasons (smaller cyclotron for similar depth dose data compared to d-Be reaction with a same deuton energy).

Neutron yield and penetration increase when increasing proton energy on target.

For a given incident proton energy, two points improve central axis depth dose distribution but result is a lower neutron dose rate :

- the use of additionnal hydrogenous filters behind target,
- the reduction of target thickness and use of an appropriate backstop material absorbing the excess proton energy.

The choice of target configuration has to make a balance between neutron yield and beam penetration (ref.1,2,3).

p(42)-Be neutron beams have been investigated in terms of dose rate and penetration as a function of target thickness and beam filtration (ref.3).

As it was not possible to extrapolate some empirical relations only valid for this energy, we have investigated several target configurations for a p(34)-Be neutrontherapy beam.

The performance parameters we must take into consideration for a direct comparison with the initial thick target are :

- depth dose distribution,
- dose rate,
- γ contribution to total dose (wich must be close to the initial value because of the Relative Biological Effect),
- skin sparing.

(3) Experimental arrangement

Proton beam was focalised on a target area smaller than 1cm^2.

All targets were investigated in the medical beam with 10x10 cm^2 and a source to surface distance of 135 cm.

The facility does not allow measurements without any material in the beam because of the 10mm plexiglass mirror for light simulation and parallel plate ionisation chambers for dose monitoring during treatments. Both materials are an initial specific filtration system.

Additionnal beam hardening polyethylene filters were placed 5 cm behind the target.

Chambers used were a 1.6 cc A150 thimble C.E.N.F. chamber flushed with T.E. gas and an aluminium chamber of same geometry flushed with Argon ; first, a fixed Ku value of 0.14 was arbitary elected for all calculations.

(4) Target design

Initial thick target

The basic target manufactured by C.G.R. Mev which was in use since 1981 was composed of 2 beryllium disks 3mm and 6mm thick with a 0.5mm layer of flowing cooling water in between.
The 6mm thick beryllium disk is followed by a second 0.5mm layer of water and 3mm of copper.
This target was designed for a 38 Mev proton energy with intensity beam in the 50-100 μA range.

New target design

- Backstop material

For semithick beryllium target, the outgoing protons have to be stopped in a material with good thermal properties, small neutron production cross sections and small γ generation.

Graphite appears to be a suitable material ;

A thick layer of flowing cooling water was not adopted in order to minimize radionuclide production and reliability for mechanical interventions. Only the 6mm target was investigated with water instead of graphite.

- Target structures

. Beryllium is high purity grade N 50 C (1.84 g.cm^{-3}) for "C", "D" targets and S 200 E for "A", "B", "C".
. Flowing cooling water is demineralised.
. Graphite is FHAN (1.68 g.cm^{-3}).
. Target holder consist of 3mm or 2mm thick copper layer.

In all, five target thicknesses were used for this investigation :

- "A" : basic thick target,
- "B" : 6mm beryllium thick wich would remove 20.7 Mev from a 34 Mev proton beam followed downstream by a 2mm layer of flowing cooling water and 3mm of copper.

This structure is summarized as : p(34)-Be(20.7)/2H_2O-3Cu,

- "C" : 5mm thick : p(34)-Be(15.8)/0.5H_2O-2.5C-0.5H_2O- 2Cu,
- "D" : 4mm thick : p(34)-Be(11.8)/0.5H_2O-3C-0.5 H_2O-2Cu,
- "E" : 3mm thick : p(34)-Be(8.5)/0.5 H_2O-3.5C-0.5H_2O-3Cu.

3 additionnal high density polyethylene filters were used for each target : 0, 30, 50 mm.

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(5) Results and discussion

Influence of Cu target holder

With "A" total dose attenuation in a narrow beam is about 7 % for a 3mm thick copper layer.

The target "A'" was p(34)-Be(34)/3Be-1H_2O-6Be without holder. No significant changes were noticed on the half Dmax value or in γ contribution but dose rate increased of 5 %.

Assuming an exponential dose attenuation in the first millimeters, these results show that difference between 2 and 3mm copper thicknesses is lesser than 2% on dose rate. This was taken into account for dose rates "C", "D" fitted further.

Tissue dose rate in air

TE/TE chamber is used with a 5mm thick A150 shonka cap.

Dose rates decrease with thinner targets and thicker filters (fig. 1).

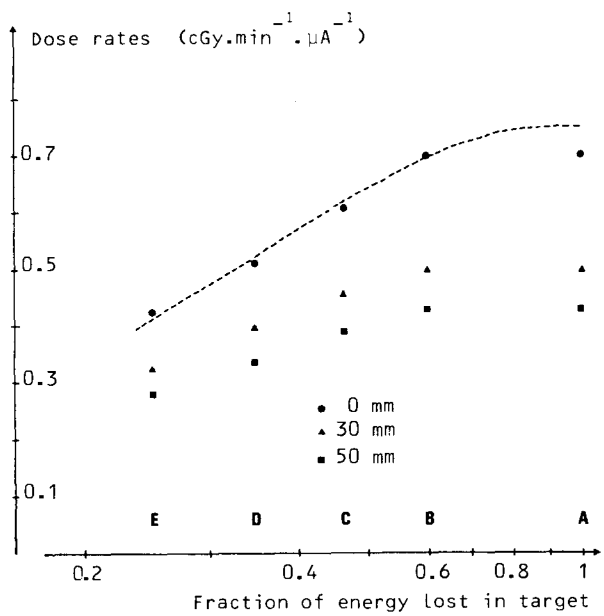

Fig. 1 : dose rates for various target/filter configurations.

Similar dose rates are obtained for "A" and "B", this could be explained by the particular configuration of the basic thick target "A" :

- outgoing protons of the 3mm Be disk loose about 1 Mev in the 0.5mm water sheet before reaching the second disk.
- target is too thick (attenuation of neutron beam).

An empirical relation for unfiltered beams agrees with doses rates obtained without any additionnal filter :

$$D(e) = D(E_0) \cdot \left[1 - \left(\frac{E_0 - e}{E_0} \right)^{\beta} \right]$$

D is dose rate, E_0 initial energy, and e the energy lost in the beryllium disk.
Dashed line in fig.1 is fitted for a β value of 2.8 assuming a dose rate derived from this formula for an "optimum" thick target.

Central axis depth dose

Penetration of the beam increases with thinner targets and thicker filters (fig. 2).

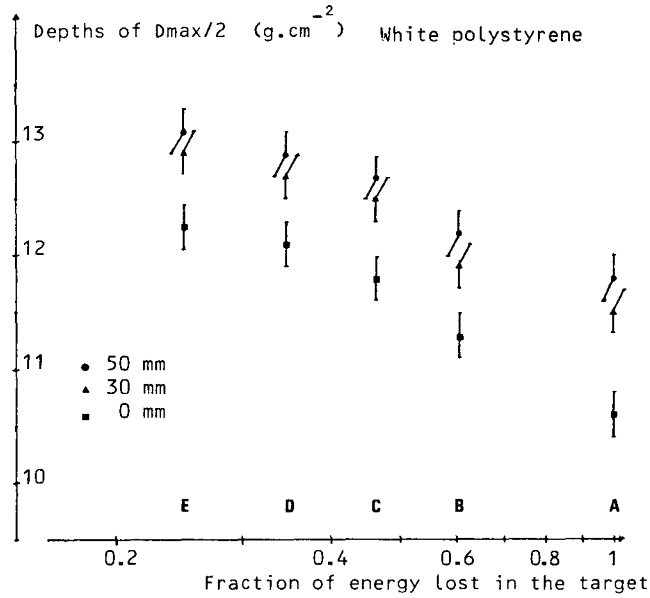

Fig. 2 : Depths of half maximum dose for various target/filter configurations.

Ratios Dmax/2 (additionnal filter) Dmax/2 (initial filtration) decrease with thinner targets (fig. 2) just as the attenuation by filters (fig. 1). Both facts indicating a harder initial beam.

γ contribution to total dose in air

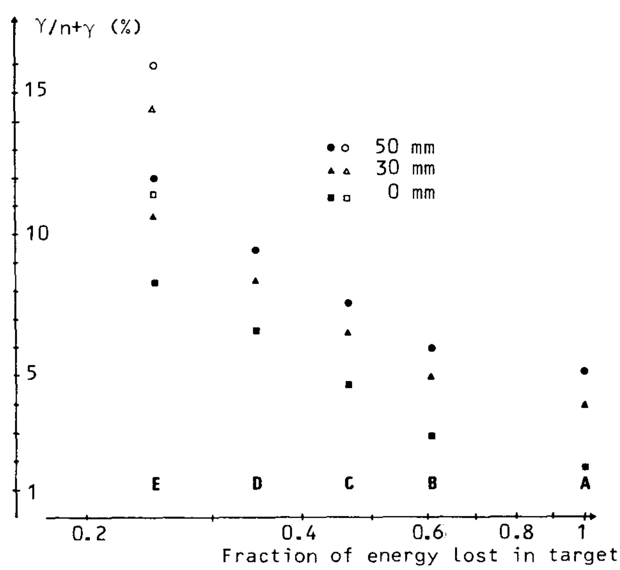

Fig. 3 : γ contributions for various target/filter configurations.

Fig. 3 shows the increase of γ contribution with thicker filters.

Increasing of γ contribution with thinner targets indicates a γ generation in backstoppers. These results have yet to be taken with restrictions : for all calculations, the Al/Ar chamber Ku value is fixed to 0.14;

moreover, initial calculations for backstoppers underestimate unfortunately their optimal thickness (because a wrong value of graphite density). Specially for "E" target, protons of few Mev reach the copper holder.

"E'" is a target p(34)-Be(8.5)/0.5$H_2$0-3Al-0.5$H_2$0-3C with an unappropriate backstop material, the high values of γ/n+γ so obtained are plotted with hole symbols in fig. 3.

Optimum semithick target

For selecting the optimum combination of target and filter, total dose rates per µA are plotted in fig. 4 against the corresponding depth for half maximum dose.

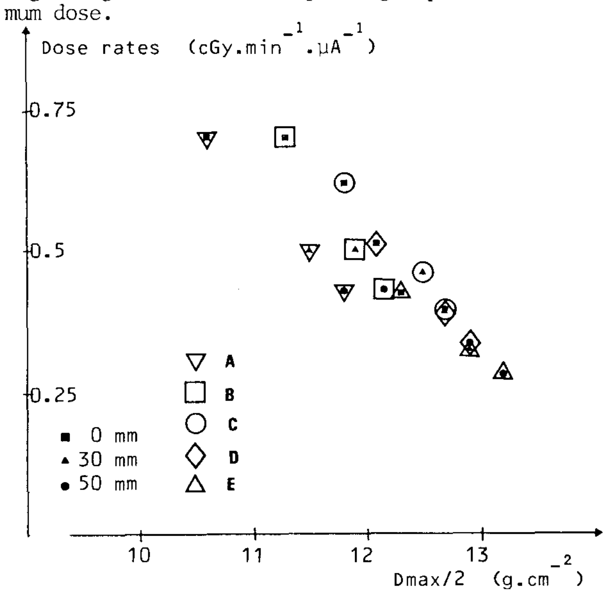

Fig. 4 : dose rates versus Dmax/2 for various target/filter configurations.

Optimum configuration has to be close to the upper right hand corner of the graph.
"C" target seems to be optimum.

Skin sparing

Relative build-up was compared for "A" and "C" in fig. 5 with different cap thicknesses on the TE chamber in air.
Skin sparing is better with "C" target

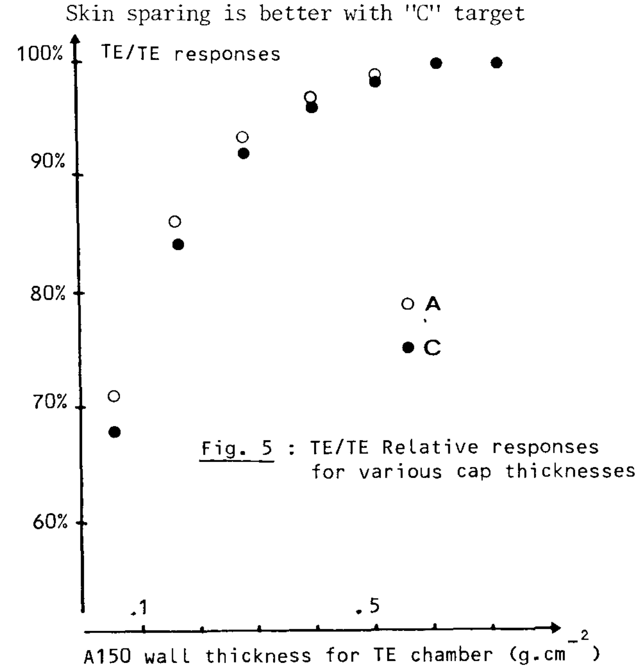

Fig. 5 : TE/TE Relative responses for various cap thicknesses

⑥ Conclusions

Ours results are in agreement with the previous work in ref. 3.
In Orleans, a "C" target with a 30 mm thick additionnal filter was chosen to replace the basic target used with a 50 mm thick filter.
Fig. 6 shows the design of the "C" target used since September 1983.

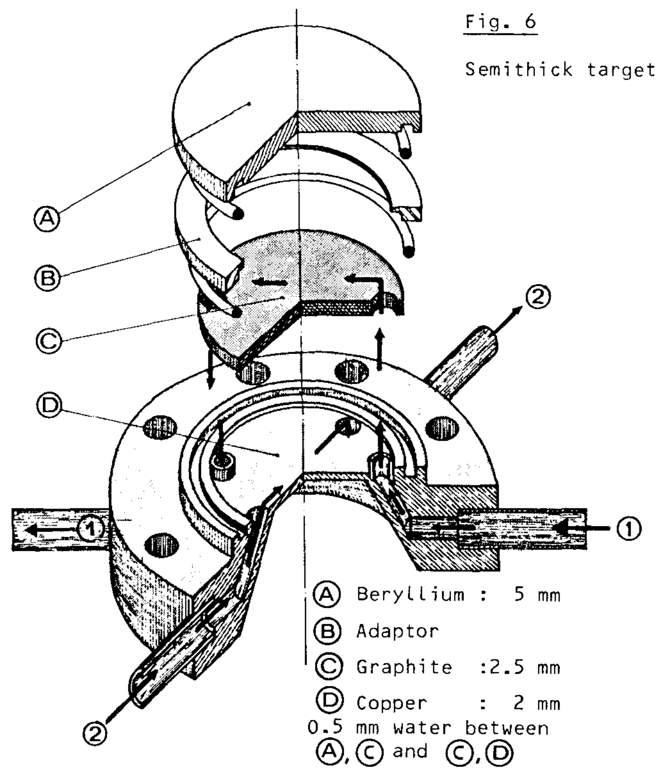

Fig. 6

Semithick target

Table 1 compares the most important dosimetric data

	Thick "A" filter : 50mm	Semithick "C" Filter : 30mm
Dose rate in air (Gy.min^{-1}.µA^{-1})	4.2 10^{-3}	4.6 10^{-3}
Dmax/2 in water (cm)	11.3	12
γ/n+γ (%) in air (GM ZP 1300 assuming Ku : 0.02)	4.5	5.5

For a similar γ contribution, the semithick target configuration here used gives :
- an higher half maximum depth dose value,
- an higher dose rate per µA,
- a better skin sparing.

No higher activation of the target area was noticed.

References

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2. M. Awschalom - Med. Phys. 7, 495 (1980)
3. I. Rosenberg - Med. Phys. 8, 808 (1981)