

BACKGROUND

ARRONAX cyclotron: 68 MeV proton beam

- To investigate the FLASH effect at ultra-high dose rates (up to 60000 Gy/s)
- To modify the beam structure.

Impact of energy:

- Compatible with the irradiation of small biological samples in the plateau (cells or zebrafish embryos)
- **Need to increase the dose homogeneity in the plateau to irradiate larger target volumes** (mice)

AIM

To evaluate the feasibility of maximizing the dose homogeneity in the plateau by adjusting the collimator material

MATERIAL & METHODS

Gate Monte Carlo model (v9.0 [1])

- **Hadronic physics list:** QGSP_BIC with EM option 4, EMZ
- **Proton source:** elliptical (FWHM 2 and 3 mm) and placed in vacuum, 10 μm before the Kapton window
- **Energy:** 68±0,35MeV
- **Cut production for secondary e⁻, e⁺, and γ particles:** 10 mm in all geometries and 0.1 mm the collimators and the target
- **Maximum step size:** limited to 1 mm in all geometries and 100 μm in the targets.

Material	Geant4 name	Density (g/cm ³)	I value (eV)
Aluminium	G4_Al	2.699	166
Brass	G4_BRASS	8.52	349.845

Table 1: Collimator's material used in GATE

Setup and materials

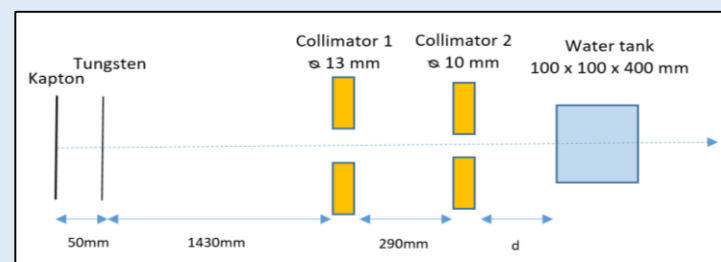


Figure 1: ARRONAX proton beam line (d = 1, 40 or 80 mm).

Studied data

- Impact of the collimator material (Table 1) on homogeneity
- Optimal distance d between collimator 2 and the water tank (Figure 1)

$$HI = \frac{D_{max} - D_{min}}{D_{mean}} \quad \text{eq. 1}$$

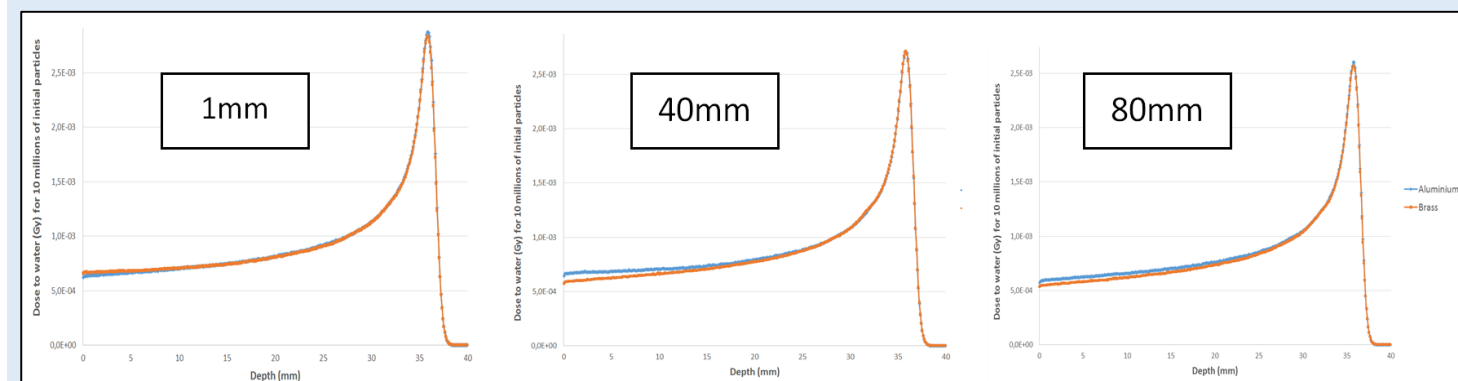
Homogeneity Index (HI) is obtained from eq. 1 :

- on Percent Depth Dose (PDD) calculated in the center of the water tank (5 x 5 x 400 mm³, resolution in depth 0.1mm, SU* < 0.7%)
- on lateral profiles calculated in the first mm of the water tank (100 x 100 x 1 mm³, lateral resolution 0.5mm, SU* < 1.6% in the beam)

The maximal HI is taken to 12%, corresponding to the current practice in radiotherapy [2].

* SU = Statistical Uncertainty

Figure 2: PDD for 3 target positions (d = 1, 40 and 80 mm) and 2 collimator materials (Aluminium and Brass).



RESULTS

- Homogeneous area in depth is longer for Aluminium and for d ≥ 40 mm (Figure 2 and Table 2)

	d = 1 mm	d = 40 mm	d = 80 mm
Aluminium	11.15	16.35	10.35
Brass	15.25	9.65	8.55

Table 2: length (mm) of the plateau with HI < 12% considering 3 target positions (d = 1, 40 and 80 mm) and 2 collimator materials (Aluminium and Brass).

- Lateral homogeneity is acceptable with Brass and with Aluminium for d ≥ 40 mm (Figures 3 and 4 and Table 3)

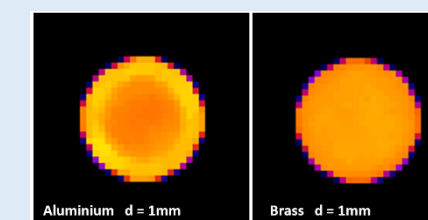
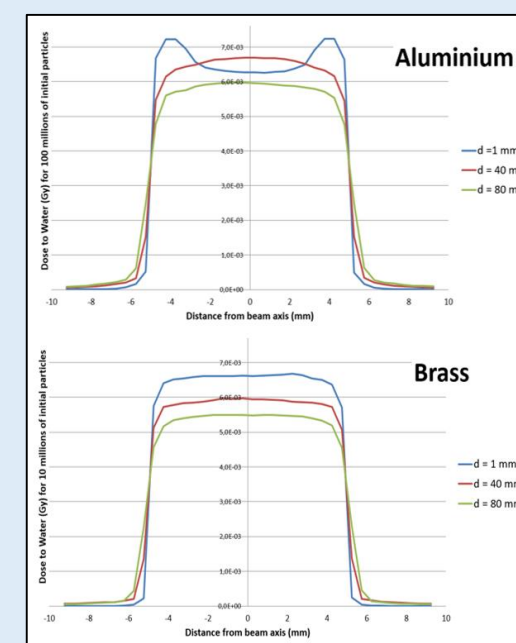


Figure 3: 2D matrix of Dose to Water in the first mm of water for d = 1 mm and two collimator materials (Aluminium and Brass).

Figure 4: lateral dose profiles in the first mm of water for 3 target positions and 2 collimator materials (Aluminium and Brass)

	d = 1 mm	d = 40 mm	d = 80 mm
Aluminium	6.5	8.5	8.5
Brass	8.5	8.5	8.5

Table 3: diameter (mm) of the homogeneous area (HI<12%) considering 3 target positions and 2 collimator materials.

CONCLUSIONS

Use of Al for collimator:

- Increases the dose homogeneity in the plateau

- Degrades the lateral homogeneity

- Associated with a distance between the collimator and the biological sample of at least 40 mm provides the better compromise for homogeneity

Our proton beamline is now ready for future preclinical experiments on FLASH effect using mice.

REFERENCES

- [1] Sarrut D *et al.* *Med. Phys.* 41, 064301, 2014
- [2] Lanberg T. *et al.* ICRU Report, 1999

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