# COOLING OF THE SOLID TARGET

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# OUTLINE

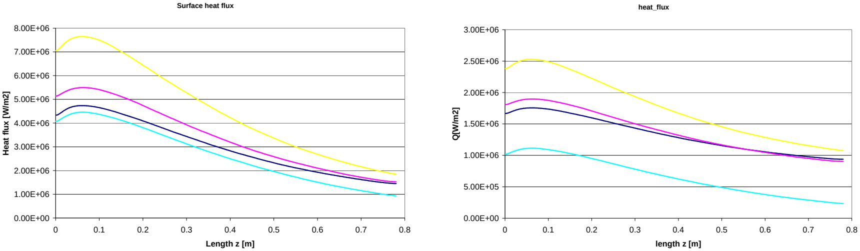
- heat flux
- h convection coefficient range
- cooling requirements
- Cross flow
- Annular flow
- Jets

| material | conductivity [W/mK] | $\sigma^{bm}$ [mm] | $Q_{beam}$ [kW] | $Q_{elec}$ [kW] |
|---|---|---|---|---|
| Al | 170 | 4 | 278 | 60 |
| | | 6 | 256 | 60 |
| Be | 90…200 | 4 | 165 | 56.3 |
| | | 6 | 153 | 56.3 |
| AlBeMet | 210 | 4 | 200 | 51 |
| | | 6 | 185 | 51 |
| Carbon IG 43 | 140 | 4 | 196 | - |
| | | 6 | 182 | - |

TABLE: Total power repartition inside the Aluminium, Beryllium, AlBemet and Carbon target for $\sigma = \{4, 6\}$ mm and $P^{beam} = 4$ MW

- $q_{beam}$ obtain with Fluka simulations (christoph)
- $q_{elec}$ joule losses from Comsol AC/DC
- $Q_{beam} = \{69.5 - 64, 41.2 - 38, 50 - 46, 49 - 45.5\}$ kW for Al, Be, AlBeMet, C at $P^{beam} = 1$ MW and $\sigma = \{4, 6\} mm$

# SURFACE HEAT FLUX



a) Heat flux, 4MW

b) Heat flux, 1MW

FIGURE: Heat flux at the target surface $r = 15$ mm for Al, Be, C, AlBeMet yellow, blue, magenta, pink) and $P^{beam} = \{1, 4\}$ MW

- maximal heat flux located in $z = 5$ cm
- $\{0.75, 0.55, 0.48, 0.45\}$kW/cm$^2$ for Al, AlBeMet, Be and Carbon respectively at 4 MW beam power.
- $\{0.25, 0.18, 0.17, 0.12\}$kW/cm$^2$ at 1 MW beam power.

# CROSS FLOW

Energy balance:

$$q^{''}(r = R^{tg}, z = 5cm) = \frac{Q}{2\pi R^{tg} L} = \bar{h}(T_s - T_\infty) \qquad (1)$$

For maximal surface temperature of $T_{smax} = 200\,^\circ\mathrm{C}$

$$\begin{aligned} \bar{h} &\geq \frac{q^{''}}{\Delta T} && (2) \\ &\geq \{13.8, 10, 9.4, 6.6\} kW/(m^2 K) && (3) \end{aligned}$$

$q^{''}$: heat flux at the target surface,
$q^{''} = \{0.25, 0.18, 0.17, 0.12\}$kW/cm$^2$.
Total power deposited inside the targets are: $\{130, 101, 97, 46\}$ kW for Al, AlBeMet, Be and C
Assume uniform energy deposition, heat flux are:
$\{0.17, 0.14, 0.13, 0.06\}$ kW/cm$^2$.
Using eq 2, the condition is: $\{9.4, 7.7, 7.2, 3.3\}$ kW/(m$^2K$)
Conclusion: $\bar{h} \sim$ 10kW/(m$^2$K)

# ANNULAR FLOW

| h kW/(m$^2K$)/$\{u, Re\}$ | $\{1, 6.3E3\}$ | $\{5, 3.1E4\}$ | $\{10, 6.4E4\}$ |
|---|---|---|---|
| Colburn | 6 | 23 | 40 |
| Dittus-bolter | 7 | 25 | 44 |
| Sieder and Tate | 9 | 34 | 59 |
| Gnielinski | 6 | 28 | 50 |

TABLE: Convection correlation for an annular fully developed turbulent flow, mean velocity $u = \{1, 5, 10\}$ m/s, F. Incropera and D. Dewitt

with a 2 mm annular channel ($D_i = 15$ mm and $D_0 = 17$ mm), the flow rate is: $\{0.28, 2.8\}$ l/s for mean velocity $\{1, 10\}$ m/s.

$Re \geq 2300$, regime should be turbulent.

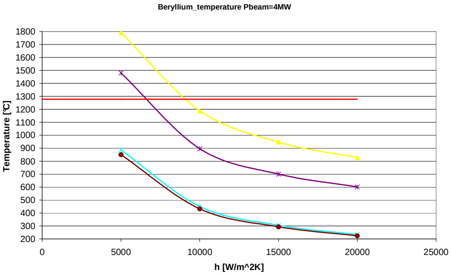
$h$ $\{6.6 \leq \bar{h} \leq 50.5\}$kW/(m$^2$K) for $\{1 \leq u \leq 10\}$ m/s.

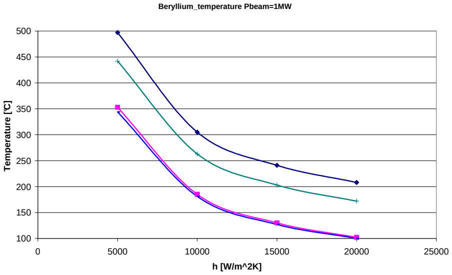
to be confirm with thermal/ turbulent flow model and literature.

check the water pressure to maintain liquid water.

$P_s = \{1, 15, 85\}$ bars for $T_s = \{100, 200, 300\}$ °C

# TEMPERATURE VERSUS CONVECTION COEFF H, BE





- $T^{4mm}_{core}$, $T^{6mm}_{core}$, $T^{4mm}_{s}$, $T^{6mm}_{s}$ (yellow, purple, blue, brown) for $\sigma^{bm} = \{4, 6\}$ and $P^{beam} = 4$ MW
- $T_{core} - T_s \backsimeq 900, 600\,^\circ\mathrm{C}$, $\sigma = 4, 6$ mm
- $T_{core\ \sigma=4} - T_{core\ \sigma=6} \backsimeq 220 - 290\,^\circ\mathrm{C}$
- high temperature
- Max temperature lower with $\sigma = 6$ mm

- $T^{4mm}_{core}$, $T^{6mm}_{core}$, $T^{4mm}_{s}$, $T^{6mm}_{s}$ (dark blue, green, pink, blue) for $\sigma^{bm} = \{4, 6\}$ and $P^{beam} = 1$ MW
- $T_{core} - T_s \backsimeq 144, 98\,^\circ\mathrm{C}$, $\sigma = 4, 6$ mm
- $T_{core\ \sigma=4} - T_{core\ \sigma=6} \backsimeq 55\,^\circ\mathrm{C}$
- $T_{core} \lesssim 300\,^\circ\mathrm{C} \rightarrow \bar{h} \gtrsim 8, 10 kW/m^2K$ $(\sigma = 6, 4mm)$

# JETS

- locally very high heat flux removal, heat flux above 1 $kW/cm^2$
- concentrate the jets on the high heat flux zone
- mechanical stress.
- phase change, boiling

# CONCLUSION – NEXT STEPS

- Study of target cooling for $\{1,4\}$ MW - beam and Joule effect
- Possible for Beryllium (and also AlBeMet, Carbon)
- Ok at 1 MW with high cooling rate $\bar{h} \sim 10kW/(m^2K)$
- Cross flow configuration possible but need to check the pressure field; if phase change can lead to destruction.
- Turbulent annular; look feasible, check water pressure.
- Jets: feasible but could degrade the focusing performance of the horn if too much nozzles inside the magnetic field.
- Next steps
  turbulent model; literature.
  energy deposition in water from secondary particles;

# REFERENCES

incroperap445 F. Incropera and D. Dewitt, “Fundamentals of heat and mass transfer,” School of mechanical engineering Purdue University, John Wiley and Sons, 1996, p 445.