ECATS : Target cooling first investigations

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A. Bergeron : CEA/Saclay

FRANCE

Target cooling investigation

- Requirements

  - Avoid boiling crisis during ***normal*** and ***transient*** operations

    - Start-up, shut-down, loss of coolant if forced convection

  - Water ***bubles*** along the target or not?

  - Necessity to get ***real power*** delivered to the target during operations?

➢ Determine free or force convection for target cooling

  ➢ TRADE : forced convection

CHF in a pool

- CHF in pool boiling for large surfaces

$$\phi_{CHF} = C(\theta).K.\ \rho_v^{0.5}.h_{fv}.(\sigma .g.(\rho_l - \rho_v))^{0.25}.f(\Delta T_{SUB})$$

- $C(\theta)$: Angle to horizontal dependency
  - 90 ° : $0.75 \leq C \leq 1$ for water according to authors
- K : Contant ≈ 0.13, 0.14
- h_{fv} : Latent enthalpy
- σ : Surface tension
- G : Gravity
- $\rho_{l,v}$: Saturated liquid and vapeur densities
- ΔT_{SUB} : Subbcooling = Twater-Tsat

Ivey and Morris : $f(\Delta T_{SUB}) = 1+0.1*(\rho_v/\rho_l)^{0.75}\ (C_{pl}/h_{fv})\ \Delta T_{SUB}$

C_{pl} : Specific heat

- Small heating surface : Corrections

Critical Heat flux estimation

- Pressure : 1.6 bars
- Water temperature : Between 50 °C and 80°C
  - Tsat : 113 °C
  - Horizontal saturated CHF : 136 W/cm^2
  - Vertical saturated CHF : Between 100 W/cm^2 and 136 W/cm^2
- To investigate CHF at very low flow (free convection within the core)
  - Groeneveld look-up data tables for examples
  - Sar Report . Bernath correlation .
    - Tinlet 49 ºC ϕ_cri **106 W/cm^2**
    - **DNBR = 2**
    - **First step : We take this value as a reference**

ISU-Target conditions – 1kW

- 30 Mev, 33 μA, 1 Kw
- Rbeam = 1.5 cm
- Rtarget = 3.5 cm
- W-Cu
- DAPNIA calculations
    - Interaction thickness : < 1 cm
    - 700 W delivered into the target
    - 1D radial conduction → Maximal wall surface heat flux : 43 W/cm^2
    - 3D conduction more realistic : ***10 W/cm^2***
        - Heating height very low ---- : Radial conduction within the water pool
        - Very far below the CHF

ISU-Target conditions – 30 kW

- 30 Mev, 33 microA, 30 Kw
- Rbeam = 1.5 cm, Rtarget = 3.5 cm, W-Cu
- From 1 kW DAPNIA calculations, propotional calculations
  - **Linear effects assumptions**
  - ***Interaction thickness (30 kW, 30 Mev) = Interaction thickness (1 kW,30 Mev)***
  - *70 % of power delivered into the target*
  - 3D conduction : 30 * 10 W/cm^2 = ***300 W/cm^2***
    - Heating height very low ---- : Efficiency of free convection ?
    - In the range of CHF ---------→ **Not Suitable** for operations
  - Solution
    - As in TRADE speading the heat flux to cool
    - ***Conical inner interaction surface***

Simplified Power Density Distribution:

The « real power density distribution » (MCNPX Calculations) was replaced by a simplified and ***equivalent*** *one:*

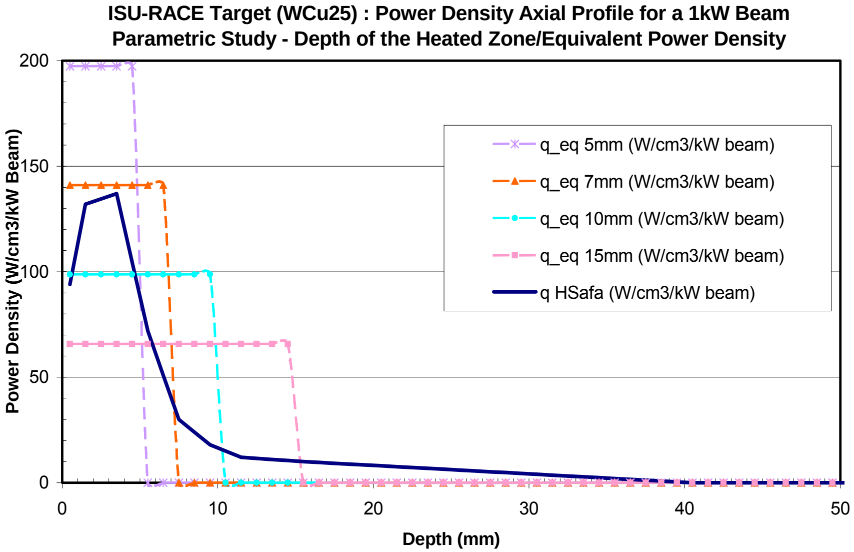
Identification of q_eq and d_eq :

$$\pi . R_{beam}^2 . q_{eq} . d_{eq} = P_{target} \text{from\_HSafa}$$

- **R_beam** = radius of the electron beam (cm)
- **q_eq** = uniform power density (W/cm3/kW beam power)
- **d_eq** = corresponding depth of the heated volume (cm)

The heated volume is supposed to be a cylinder having:

- R_beam as radius
- d_eq as height



➯ d_eq = 0.7 cm was selected

➯ **q_eq = 141 W/cm3/kW beam**

Conical inner shape – 30 kW

- The maximal heat flux at the target surface reads :

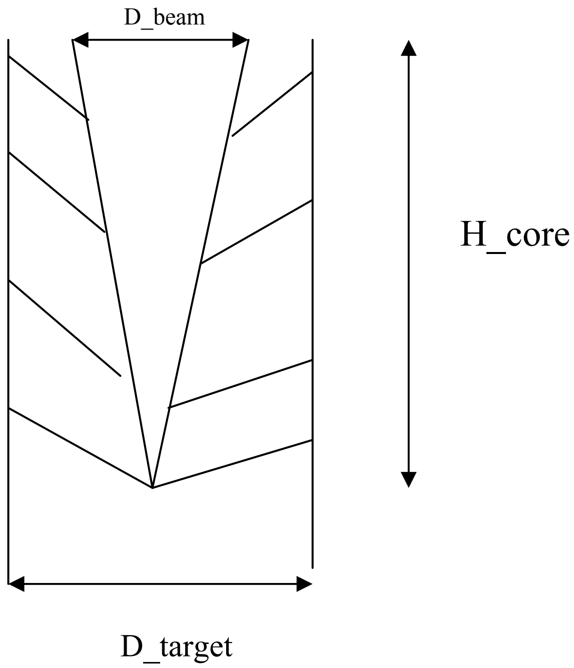
- $Phi\_max = (1/H\_core) *2*\pi*Q*D*(R\_beam)^2$

  Q : Equivalent power density calculted from the 1 kW calculation : $Q = 141\ W/cm^3$

  D : Interaction thickness at 1 kW : 0.7 cm

  R_beam : Beam radius : 1.5 cm

  H_core : Active length of interaction



- Application

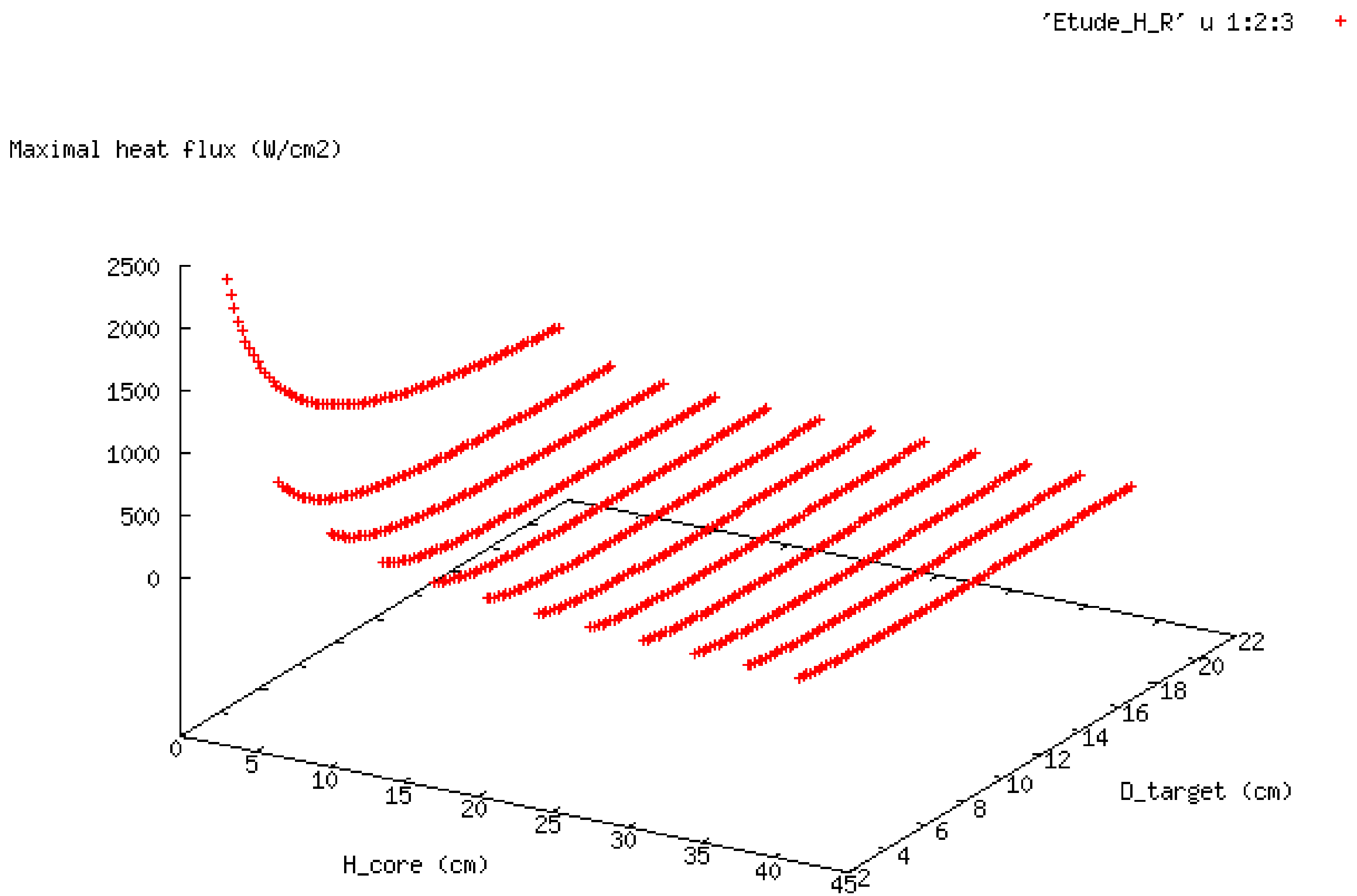
  - R_beam = 1.5 cm, R_target = 3.5 cm, H_core = 8.89 cm

    - $Phi\_max = 214\ W/cm^2$

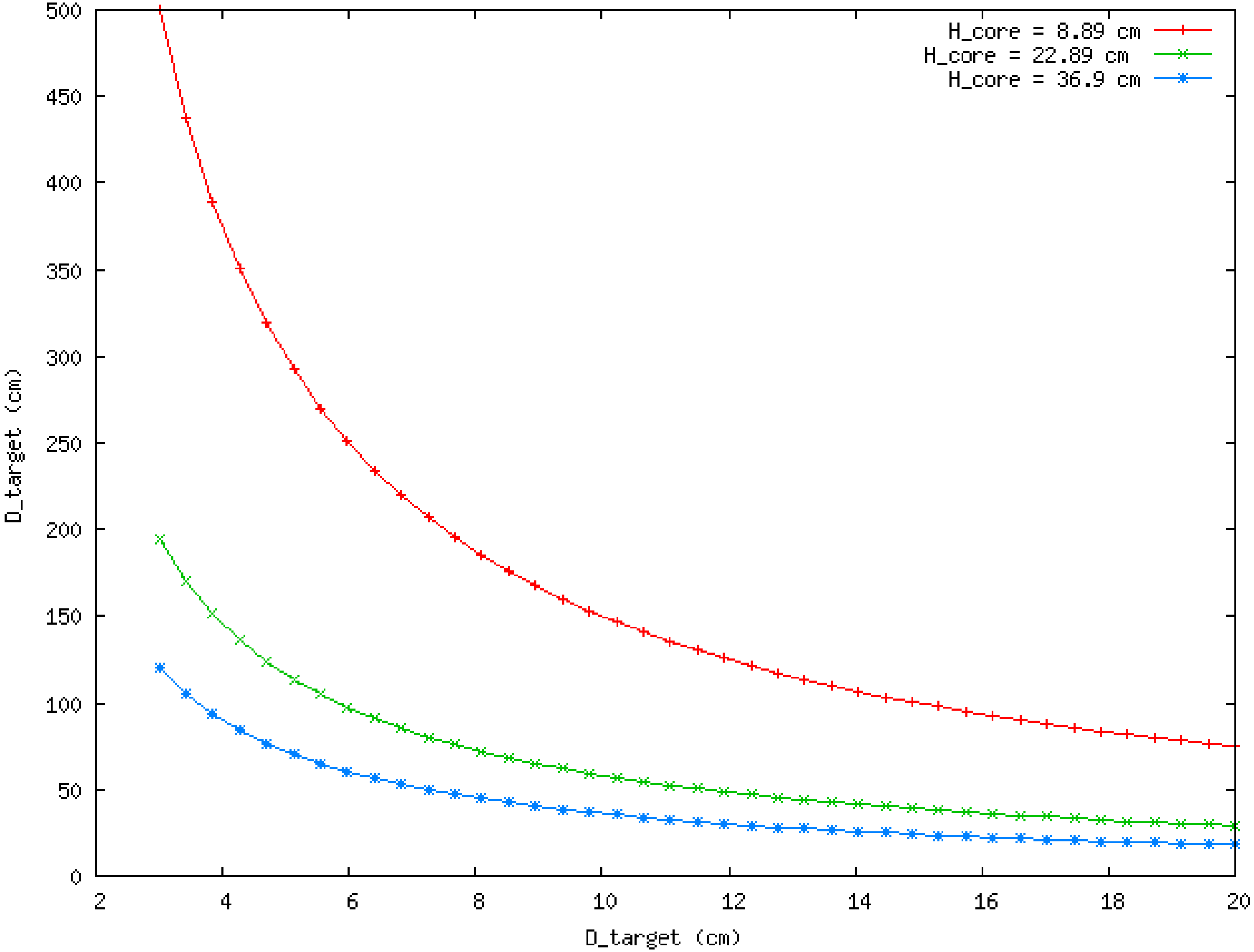
    - Forced convection more suitable for this geometry

Possibility of optimization according to the target outer diameter and the H_core length

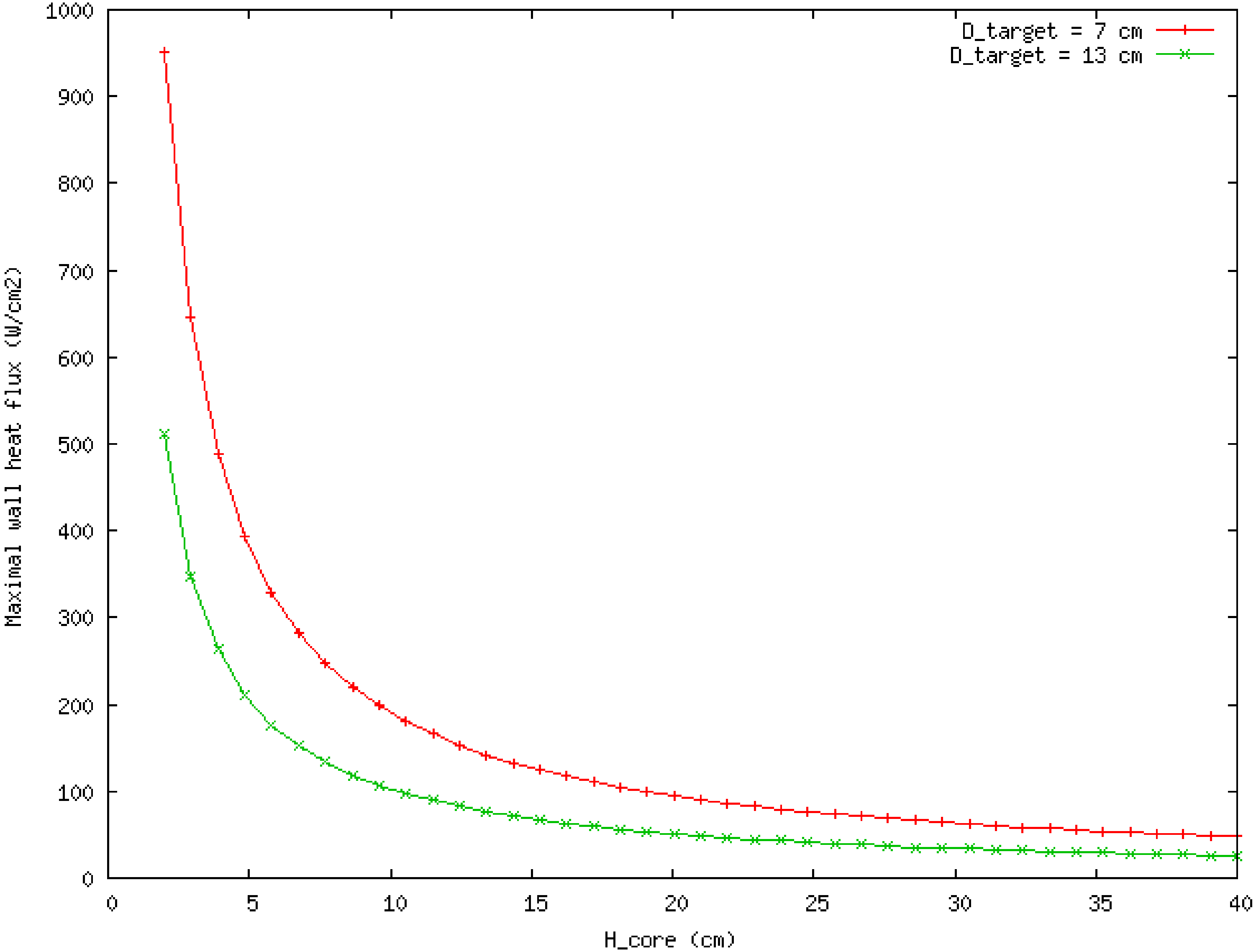
Maximal heat Flux = F(H_core, D_target)



Maximal heat flux as a function of D_target and H_core as parameter



Maximal heat flux as a function of H_core and D_target as parameter



Conclusions

- Preliminary conclusions with the whole assumptions taking into account in this presentation
  - Free convection starting up more possible if great heating length
  - To decrease the wall heat flux increasing the heating length with conical inner shape is more efficient than increasing the outer diameter
  - Of course the best a larger diameter and a large heating length with a conical inner shape
- Future
  - ***Perform accurate energy deposition with appropriate codes for the conical shape***
  - Perform CAST3M calculation for the 3D conduction within the target
  - Perform core calculation with different radial positions of the target
    - Free cooling
    - CHF at low velocity, Pool boiling CHF
  - Begin to design a forced cooling system
    - CHF correlation