

## *Preliminary Thermal Evaluations of the RACE Target*

---



- ISU-RACE Target Thermo-mechanical first Calculations
- RACE Target Preliminary Considerations
- Conclusions

*Cécile KRAKOWIAK*  
*DEN/DER/SESI/LCSI*

# Preliminary Thermal Evaluations of the RACE Target

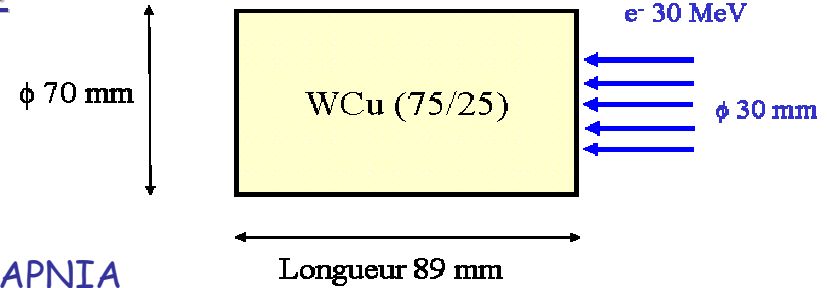
## ISU-RACE Target Thermo-mechanical first Calculations



### DATA for the CAST3M Calculations (1/2):

#### ❖ Geometry = cylinder

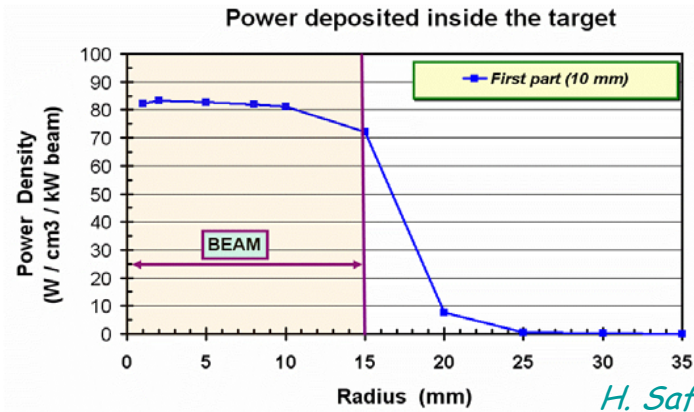
- diameter = 70 mm
- length = 89 mm



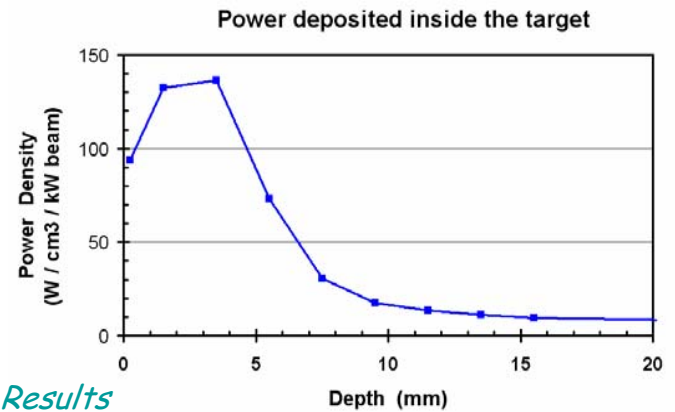
#### ❖ Power Density Distribution = from CEA/DAPNIA MCNPX Calculations (H. Safa)

#### Electron Beam Characteristics:

- diameter = 30 mm
- energy = 30 MeV
- intensity = 33  $\mu$ A  $\Rightarrow$  Beam Power = 1 kW  
and Target Power  $\approx$  700 W



*H. Safa Calculations Results*



# Preliminary Thermal Evaluations of the RACE Target

## ISU-RACE Target Thermo-mechanical first Calculations



### DATA for the CAST3M Calculations (2/2):

#### ❖ Material = W 75% - Cu 25% alloy

Properties at room temperature ([www.matweb.com](http://www.matweb.com)) :

- $\lambda = 220 \text{ W/m/K}$  thermal conductivity
- $\alpha = 8.5 \cdot 10^{-6} \text{ }^\circ\text{C}^{-1}$  thermal expansion coefficient
- $E = 234000 \text{ MPa}$  Young's Modulus
- $\nu = 0.3$  (assumed) Poisson's coefficient
- $\rho = 14840 \text{ kg/m}^3$  density
- $C_p = 192 \text{ J/kg/}^\circ\text{C}$  specific heat
- $\sigma_y = 524 \text{ MPa}$  yield stress

#### ❖ Finite Elements Model = 2D (r,z)

- axial-symmetric
- 2D thermal conduction

#### ❖ Thermal-Hydraulic Boundary Conditions = water cooling, natural convection:

On the outer surface:

- $T_{\text{water}} = 30^\circ\text{C}$
- $H_{\text{conv}} = 500 \text{ W/m}^2/\text{K}$



ISU-RACE WCu25 Target: Power Density ( 1.0000 kW Beam Power)

CAST3M Power Density Distribution  
for a 1 kW Beam Power

# Preliminary Thermal Evaluations of the RACE Target

## ISU-RACE Target Thermo-mechanical first Calculations



### CAST3M Calculations (1/2):

❖  $T_{max\_int} = 136 \text{ }^\circ\text{C}$

(at the top of the target)

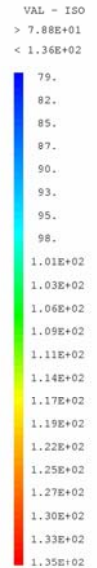
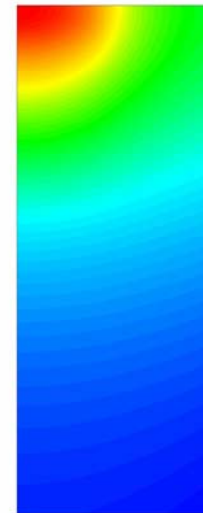
for a 1 kW Beam Power

❖  $T_{max\_ext} = 105 \text{ }^\circ\text{C}$

(at the top of the target)

for  $H_{conv} = 500 \text{ W/m}^2/\text{ }^\circ\text{C}$

and  $T_{water} = 30^\circ\text{C}$



ISU-RACE Wcu25 Target: Temperature Field at time 4000.0

↪  $\Delta T_{radial} = 31^\circ\text{C}$

for a 1 kW Beam Power

↪  $\Delta T_{radial} \approx 900^\circ\text{C}$

for a 30 kW Beam Power

*CAST3M Temperature Field for a 1 kW  
Beam Power, and  $H_{conv} = 500 \text{ W/m}^2/\text{K}$*

# Preliminary Thermal Evaluations of the RACE Target

## ISU-RACE Target Thermo-mechanical first Calculations

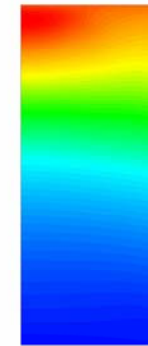
### CAST3M Calculations (2/2):

*The stress state highly depends on the applied mechanical boundary conditions:*

❖  $UR = 0$  on the outer surface

and  $UZ = 0$  at the top (outer diameter)

↳ **Max (Von Mises) = 253 MPa**  
(top, center of the target)  
for a 1 kW Beam Power



❖  $UZ = 0$  at the top (outer diameter)

↳ **Max (Von Mises) = 25 MPa**  
(top, periphery of the target)  
for a 1 kW Beam Power

CAST3M Von Mises Stress Fields for a 1 kW  
Beam Power, and  $H_{conv} = 500 \text{ W/m}^2/\text{K}$



➤ Real boundary conditions are in between the 2 above cases

➤ What about a **30 kW Beam Power** ?

↳ necessity to spread the power deposition

↳ enlarge the beam radius

↳ **improve the target geometry**  
(cf. the TRADE conical target)



# Preliminary Thermal Evaluations of the RACE Target

## RACE Target Preliminary Considerations (1/2)



### Simplified Power Density Distribution:

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

Identification of  $q_{eq}$  and  $d_{eq}$  :

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

- $R_{beam}$  = radius of the electron beam (cm)
- $q_{eq}$  = uniform power density (W/cm<sup>3</sup>/kW beam power)
- $d_{eq}$  = corresponding depth of the heated volume (cm)

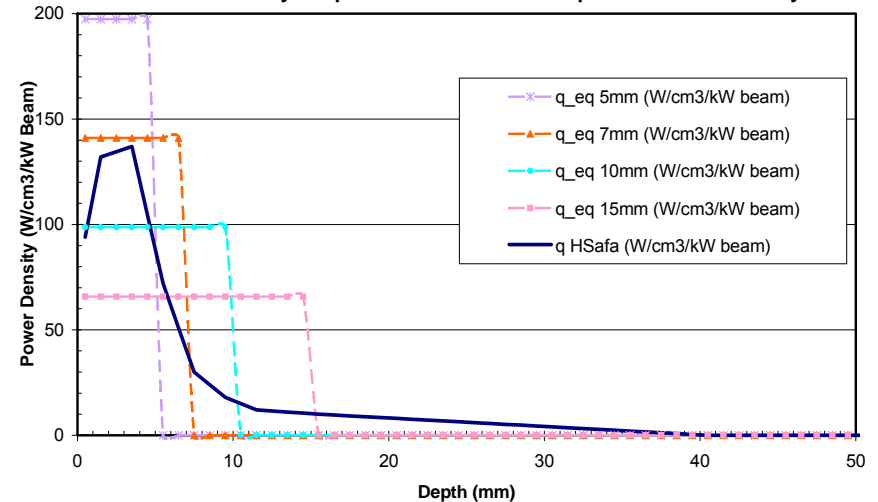
The heated volume is supposed to be a cylinder having:

- $R_{beam}$  as radius
- $d_{eq}$  as height

↪  $d_{eq} = 0.7$  cm was selected

↪  $q_{eq} = 141$  W/cm<sup>3</sup>/kW beam

ISU-RACE Target (WCu25) : Power Density Axial Profile for a 1kW Beam  
Parametric Study - Depth of the Heated Zone/Equivalent Power Density



# Preliminary Thermal Evaluations of the RACE Target

## RACE Target Preliminary Considerations (2/2)



### Application to a conical geometry:

*Preliminary study of a parametric internal cone geometry for the RACE target*

### Parametric study of $H_{\text{cone}}$ :

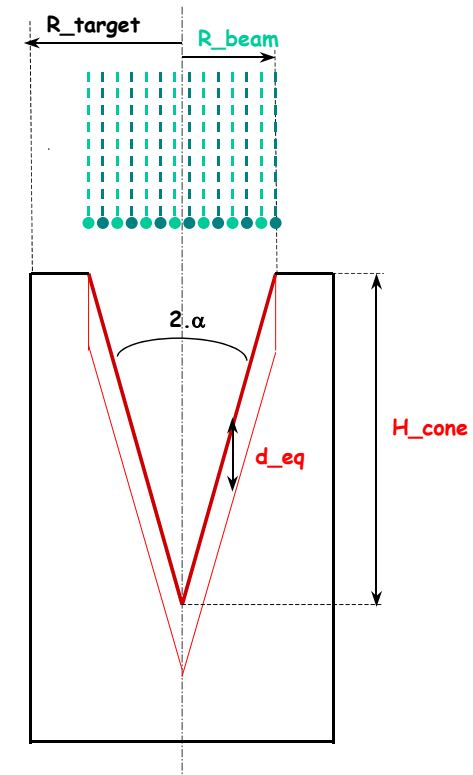
- $R_{\text{beam}}$  = radius of the electron beam (cm)  
= radius at the top of the cone
- $H_{\text{cone}}$  = length of the inner cone (cm)
- $\alpha$  = half angle at the cone tip  
 $\text{tg}\alpha = R_{\text{beam}} / H_{\text{cone}}$

### Analytic formulations can be derived for:

- $\text{Plin}_{\text{max}}$  = maximum axial linear power (W/cm)  
 $\text{Plin}_{\text{max}} = 2\pi q_{\text{eq}} d_{\text{eq}} R_{\text{beam}} \text{tg}\alpha$
- $\text{Phi}_{\text{max}}$  = maximum outer wall heat flux (W/cm<sup>2</sup>)  
 $\text{Phi}_{\text{max}} = \text{Plin}_{\text{max}} / (2\pi R_{\text{target}})$

Where  $R_{\text{target}}$  is the target outer radius

- **thermal-hydraulics preliminary evaluations**
- **thermo-mechanical parametric calculations**



Conical concept for the RACE target

## Preliminary Thermal Evaluations of the RACE Target

---

### Conclusions



❑ ISU-RACE target preliminary thermo-mechanical evaluation: this target will not be able to sustain a 30 kW beam => necessary to spread the power deposition:

- optimization of the electron beam (enlargement)
- optimization of the target geometry (conical inner shape, cf. TRADE)

❑ RACE target for a 30 kW beam: a simplified power density distribution is proposed in order to obtain simple analytic formulations for the maximum linear power, and the maximum outer wall heat flux:

- quick thermal-hydraulics evaluations (cooling modes, critical values)
- quick thermo-mechanics parametric studies (maximum temperatures and stresses)

↪ goal = definition of a suitable target geometry



Needs of material characterization