Project: PS-TGT-12-001 Hall A Tritium Target

Tittle: Beam energy loss in the target

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Code(s) of Record:

Reference:

Leo: Techniques for Nuclear and Particle Physics

Description:

General calculations for beam energy loss in the T2 target cell and Be isolation window. Calc follows Bete-Bloch with simplified parameterization of density effect instead of full Sternheimer's. Only electron collision energy loss is considered.

Loss is considered for aluminum windows and T2 gas.

Reference Drawing(s):

TGT-103-1000-0012 Cell assy

Units and constants:

$$eV := 1.602 \cdot 10^{-19} \cdot J$$

$$MeV := 10^{6} \cdot eV$$

$$r_e := 2.817 \cdot 10^{-13} \cdot cm$$ classical radius of electron

Collision energy loss of elecron beam on target material. The method is from Leo. The shell correction is neglected.

Beam properties:

$I_{beam} := 20 \cdot \mu A$ beam current

$m_e := 0.511 \cdot \frac{MeV}{c^2}$ electron rest mass

$E_e := 10000 \cdot MeV$ Beam energy

$\tau := \frac{E_e - m_e \cdot c^2}{m_e \cdot c^2} = 1.957 \cdot 10^4$ kinetic enervy of e- in units of $m_e c^2$

$P_e := \frac{1}{c} \cdot \sqrt{{E_e}^2 - \left(m_e \cdot c^2\right)^2}$ momentum of e-

$v_e := \sqrt{\frac{{P_e}^2}{{m_e}^2 + \frac{{P_e}^2}{c^2}}}$ velocity of e-

$\beta := \frac{v_e}{c}$ beta

$\gamma := \frac{1}{\sqrt{1 - \beta^2}}$ gamma

$X := \log(\beta \cdot \gamma) = 4.292$

$\eta := \beta \cdot \gamma = 1.957 \cdot 10^4$

Aluminum entrance window

7075 aluminum is treated as pure aluminum for this calculation with the higer density of 7075.

$L_x := 0.010 \cdot in = 0.254\ mm$ length of absorber material

$Z := 13$ Atomic number

$A := 26.98 \cdot \frac{gm}{mol}$ Atomic weight

$\rho := 2.69 \cdot \frac{gm}{cm^3}$ density

$$I := \text{if } Z < 13 \;\; \|\, (12 \cdot Z + 7) \cdot eV \;\; \text{else} \;\; \|\, \left(9.76 \cdot Z + 58.8 \cdot Z^{-0.19}\right) \cdot eV$$

Ionization potential

$hv_p := 28.816 \cdot \sqrt{\frac{\rho \cdot Z}{A}} \cdot eV \cdot \sqrt{\frac{cm^3}{mol}} = 32.807\ eV$ plasma energy

$$C_1 := -\left(2 \cdot \ln\left(\frac{I}{hv_p}\right) + 1\right) = -4.206$$

$$\delta := \text{if } X < 3 \;\; \|\, 4.6052 \cdot X + C_1 + \frac{C_1}{27} \cdot (3 - X)^3 \;\; \text{else} \;\; \|\, 4.6052 \cdot X + C_1$$

$$F_t := 1 - \beta^2 + \frac{\frac{\tau^2}{8} - (2 \cdot \tau + 1) \cdot \ln(2)}{(\tau + 1)^2}$$

first function of τ

$$dE := -2 \cdot \pi \cdot N_A \cdot r_e^{\,2} \cdot m_e \cdot c^2 \cdot \rho \cdot \frac{Z}{A} \cdot \frac{1}{\beta^2} \cdot \left(\ln\left(\tau^2 \cdot \frac{(\tau+2)}{2\left(\frac{I}{m_e \cdot c^2}\right)^2} \right) + F_t - \delta + 0.6 \right)$$

$$\frac{dE}{\rho} = -2.234\ \frac{cm^2}{gm} \cdot MeV$$

$$Q_{ent} := dE \cdot L_x \cdot \frac{I_{beam}}{e_c} = -3.053\ W$$

Aluminum exit window
7075 aluminum is treated as pure aluminum for this calculation
Properties of the absorbing material

$L_x := 0.011 \cdot in = 0.279\ mm$ length of absorber material

$Z := 13$ Atomic number

$A := 27 \cdot \frac{gm}{mol}$ Atomic weight

$\rho := 2.72 \cdot \frac{gm}{cm^3}$ density

$$I := \text{if } Z < 13 \;\; \| (12 \cdot Z + 7) \cdot eV \;\; \text{else} \;\; \| \left(9.76 \cdot Z + 58.8 \cdot Z^{-0.19}\right) \cdot eV$$

Ionization potential

$hv_p := 28.816 \cdot \sqrt{\frac{\rho \cdot Z}{A}} \cdot eV \cdot \sqrt{\frac{cm^3}{mol}} = 32.977\ eV$ plasma energy

$C_1 := -2 \cdot \left(\ln\left(\frac{hv_p}{I}\right) + 1\right)$ constant

$$\delta := \text{if } X < 3 \;\; \| 4.6052 \cdot X + C_1 + \frac{C_1}{27} \cdot (3 - X)^3 \;\; \text{else} \;\; \| 4.6052 \cdot X + C_1$$

$F_t := 1 - \beta^2 + \frac{\frac{\tau^2}{8} - (2 \cdot \tau + 1) \cdot \ln(2)}{(\tau + 1)^2}$ first function of τ

$$dE := -2 \cdot \pi \cdot N_A \cdot r_e^{\,2} \cdot m_e \cdot c^2 \cdot \rho \cdot \frac{Z}{A} \cdot \frac{1}{\beta^2} \cdot \left(\ln\left(\tau^2 \cdot \frac{(\tau+2)}{2 \left(\frac{I}{m_e \cdot c^2} \right)^2} \right) + F_t - \delta \right)$$

$$dE \cdot L_x = -0.136\ \boldsymbol{MeV}$$

$$Q_{exit} := dE \cdot L_x \cdot \frac{I_{beam}}{e_c} = -2.719\ \boldsymbol{W}$$

Energy loss in the T2 gas. Average density of the gas is considered. local variations along path are ignored. Properties of the absorbing material

$L_x := 250 \cdot mm$ length of absorber material

$Z := 1$ Atomic number

$A := 3 \cdot \frac{gm}{mol}$ Atomic weight

$\rho := 0.004 \cdot \frac{gm}{cm^3}$ density

$$I := \text{if } Z < 13 \;\; \| (12 \cdot Z + 7) \cdot eV \;\; \text{else} \;\; \| \left(9.76 \cdot Z + 58.8 \cdot Z^{-0.19}\right) \cdot eV$$

Ionization potential

$$hv_p := 28.816 \cdot \sqrt{\frac{\rho \cdot Z}{A}} \cdot eV \cdot \sqrt{\frac{cm^3}{mol}} = 1.052 \; eV$$

plasma energy

$$C_1 := -2 \cdot \left(\ln\left(\frac{hv_p}{I}\right) + 1\right)$$

constant

$$\delta := \text{if } X < 3 \;\; \| 4.6052 \cdot X + C_1 + \frac{C_1}{27} \cdot (3 - X)^3 \;\; \text{else} \;\; \| 4.6052 \cdot X + C_1$$

$$F_t := 1 - \beta^2 + \frac{\frac{\tau^2}{8} - (2 \cdot \tau + 1) \cdot \ln(2)}{(\tau + 1)^2}$$

first function of τ

$$dE := -2 \cdot \pi \cdot N_A \cdot {r_e}^2 \cdot m_e \cdot c^2 \cdot \rho \cdot \frac{Z}{A} \cdot \frac{1}{\beta^2} \cdot \left(\ln\left(\tau^2 \cdot \frac{(\tau+2)}{2\left(\frac{I}{m_e \cdot c^2}\right)^2} \right) + F_t - \delta \right)$$

$$dE \cdot L_x = -0.133\ MeV$$

$$Q_{T2} := dE \cdot L_x \cdot \frac{I_{beam}}{e_c} = -2.652\ W$$

Total energy lost in the target is then:

$$Q_{tot} := Q_{T2} + Q_{ent} + Q_{exit} = -8.424\ W$$

Energy Density:

For a 2x2 raster with 20 μA beam current the power density in the aluminum is

$d_{raster} := 2 \cdot mm$ raster leg size

$A := d_{raster}^{2}$ raster area

$t := 0.01 \cdot in$ thickness of entrance window

$V := t \cdot A = \left(1.016 \cdot 10^{-9}\right) m^{3}$ Volume of material impacted by the beam

$q := \frac{Q_{ent}}{V} = -3.005 \cdot 10^{9} \frac{W}{m^{3}}$ volumetric heat density from beam

This result is applicable to the exit window as well. It shall be used in the thermal FEA.

With no raster the beam is assumed to be 150 μm in diameter. While there are safegaurds to prevent running in this condition, they take some time to implement. The power density for this case shall be used to model the raster off conditons for the cell.

$d_{beam} := 0.150 \cdot mm$

$A_{beam} := \frac{\pi}{4} \cdot d_{beam}^{2}$

$V_{beam} := t \cdot A_{beam}$

$q_{beam} := \frac{Q_{ent}}{V_{beam}} = -6.801 \cdot 10^{11} \frac{W}{m^{3}}$