

(11.3) A water-cooled copper foil (0.1 mm thick) is irradiated by the internal beam of a sector focused cyclotron with 1.2 mA H⁺ ions of 24 MeV for 90 min. The reaction ⁶³Cu(p,pn)⁶²Cu occurs with a probability of 0.086 b. Copper consists to 69% of ⁶³Cu. The proton beam has a cross-section of only 15 mm². (a) How many ⁶²Cu atoms have been formed? (b) What fraction of the projectiles have reacted to form ⁶²Cu? (c) What cooling effect is required (kW) at the target?

$$N_A := 6.022137 \cdot 10^{23} \cdot \text{mole}^{-1} \quad q_e := 1.6021773 \cdot 10^{-19} \cdot \text{coul} \quad \sigma_{Cu} := 0.086 \cdot 10^{-28} \cdot \text{m}^2$$

$$M_{Cu} := 63.54 \cdot \text{gm} \cdot \text{mole}^{-1} \quad x_{63Cu} := \frac{69}{100} \quad \text{density} := 8.93 \cdot \text{gm} \cdot \text{cm}^{-3}$$

$$\text{thickness} := 0.1 \cdot \text{mm} \quad N_{vX} := \frac{N_A \cdot \text{density} \cdot \text{thickness} \cdot x_{63Cu}}{M_{Cu}} \quad \text{eqn. (11.5)}$$

$$z := 1 \quad I_p := 1.2 \cdot \text{mA} \quad \phi := \frac{I_p}{z \cdot q_e} \quad \text{eqn. (13.3)} \quad \phi = 7.49 \cdot 10^{15} \cdot \text{sec}^{-1}$$

$$t_{irr} := 90 \cdot \text{min} \quad t_{half} := 9.74 \cdot \text{min} \quad \lambda := \frac{\ln(2)}{t_{half}}$$

$$(a) \quad N_{62Cu} := \frac{1}{\lambda} \cdot \phi \cdot \sigma_{Cu} \cdot N_{vX} \cdot (1 - \exp(-\lambda \cdot t_{irr})) \quad \text{eqn. (11.7)} \quad N_{62Cu} = 3.166 \cdot 10^{14}$$

$$(b) \quad \Delta\phi := \phi \cdot \sigma_{Cu} \cdot N_{vX} \quad \text{fraction} := \frac{\Delta\phi}{\phi} \quad \text{fraction} = 5.022 \cdot 10^{-5} \quad \text{fraction} = 0.005 \cdot \%$$

(c) If we consider only the beam loss by the given reaction, the heating will be as follows:

$$E_{proj} := 24 \cdot 10^6 \cdot 1.6021773 \cdot 10^{-19} \cdot \text{joule}$$

$$P_{heating} := \Delta\phi \cdot E_{proj} \quad P_{heating} = 1.446 \cdot \text{watt} \quad \text{This is a lower bound for the heating power.}$$

If we assume all beam lost in the target we get an upper bound for the possible heating power:

$$P_{max} := \phi \cdot E_{proj} \quad P_{max} = 28.8 \cdot \text{kW}$$