(14.3) 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 ^{63}Cu(p,pn)^{62}Cu occurs with a probability of 0.086 b. Copper consists to 69% of ^{63}Cu. The proton beam has a cross-section of only 15 mm^2. (a) How many ^{62}Cu atoms have been formed? (b) What fraction of the projectiles have reacted to form ^{62}Cu? (c) What cooling effect is required (kW) at the target?

Constants, data, and units:

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

$M_{Cu} := 63.54\cdot gm\cdot mole^{-1}$ $\quad x_{63Cu} := 69\cdot\%$ $\quad density := 8.96\cdot gm\cdot cm^{-3}$

Data for the current case:

$thickness := 0.1\cdot mm$ $\quad z := 1$ $\quad I_p := 1.2\cdot mA$ $\quad t_{irr} := 90\cdot min$

Calculations:

$$N_{vX} := \frac{N_A\cdot density\cdot thickness\cdot x_{63Cu}}{M_{Cu}} \qquad \text{eqn. (14.5)}$$

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

$$t_{half} := 9.74\cdot min \qquad \lambda := \frac{ln(2)}{t_{half}}$$

(a) $N_{62Cu} := \frac{1}{\lambda}\cdot\phi\cdot\sigma_{Cu}\cdot N_{vX}\cdot\left(1 - exp\left(-\lambda\cdot t_{irr}\right)\right)$ $\quad$ eqn. (15.7) $\quad N_{62Cu} = 3.18\cdot 10^{14}$

(b) $\Delta\phi := \phi\cdot\sigma_{Cu}\cdot N_{vX}$ $\quad fraction := \frac{\Delta\phi}{\phi}$ $\quad fraction = 5.039\cdot 10^{-5}$

$fraction = 5.04\cdot 10^{-3}\cdot\%$

$\frac{1}{fraction} = 19845$

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

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

$P_{heating} := \Delta\phi\cdot E_{proj}$ $\quad P_{heating} = 1.451\cdot watt$ $\quad$ 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:

$P_{max} := \phi\cdot E_{proj}$ $\quad P_{max} = 29\cdot kW$