Alexei Kosykhin

Assignment 3

a) $W_{\substack{pellet-\\electric}} = 150\,MJ \times 33\% = \underline{49.5\,MJ}$

Frequency at which pellets should be installed in the reactor

$$f_{pellet} = \frac{1\,GW}{49.5\,MJ} = 20.2 \approx 20 \;\frac{times}{sec}$$

As the reactor has an internal radius $R = 5\,m$, speed at which pellets should travel inside the reactor

$$v_{pellet} = R \cdot f_{pellet} = 5 \cdot 20 = \underline{100\,\frac{m}{sec}}$$

b) Total fussion energy of the reactor

$$W_{fusion} = 20.2 \times 150\ MW = \underline{3\ GW}$$

$$W_{\alpha\ particles} = \frac{1}{5} W_{fusion} = 600\ MW$$

α power per m^2 of the wall

$$w_\alpha = W_{\alpha\ part.} / S$$

$$S = 4\pi R^2 = 4 \cdot 3.14 \cdot 5^2 = 314\ m^2$$

S – area of internal reactor wall

$$w_\alpha = 600/314 = 1.91\ MW/m^2$$

Inner wall surface temperature

$$T = \frac{w_\alpha \cdot d}{K} + T_{cool}$$

d is thickness of the wall

K is thermal conductivity

c) According Stefan-Boltzman law heat flux emitted from the hot surface is

$$Q_{IR} = \varepsilon \sigma A\left(T_2^4 - T_1^4\right),$$

where A is area of the surface
ε - is emissivity
σ is Stefan-Boltzman constant
T_2 - surface temperature
T_1 - background temperature.

For steel with $\varepsilon = 0.6$

$$Q_{IR} = 0.6 \times 5.67 \times 10^{-8} \left(1.300^4 - 300^4\right) =$$

$$= 0.6 \times 5.67 \times 10^{-8} \times 3.0 \times 10^{12} = 100 \frac{kW}{m^2}$$

For tangsten with $\varepsilon = 0.2$ and temperature $260\ ^\circ C = 530\ K$

$$Q_{IR} = 0.2 \times 5.67 \times 10^{-8} \left(530^4 - 300^4\right) =$$

$$= 0.2 \times 5.67 \times 10^{-8} \times 0.071 = 801\ W/m^2$$

d) The pellet surface

$$S_{pellet} = 4\pi r^2 = 4 \cdot \pi (0.001)^2 =$$

$$= 12.56 \times 10^{-6} = \underline{1,256 \times 10^{-5}\, m^2}$$

Heat absorbed by a pellet in case of steel during being in a reactor for $\tau \approx 0.05$ sec.

$$q_{IR\,pellet} = Q_{IR} \cdot S_{pellet} \cdot \tau =$$

$$= 100\ KW \cdot 1.256 \cdot 10^{-5} \times 0.05 =$$

$$= 10^{5} \times 1,256 \times 10^{-5} \times 5 \times 10^{-2} =$$

$$= 10^{5-5-2} \times 6,3 = \underline{0,063\ J}$$

In case of tungsten, heat absorbed by the pellet will be

$$q_{IR} = 801 \times 1,26 \times 10^{-5} \times 5 \times 10^{-2} = \underline{5 \cdot 10^{-4} J}$$

Volume of D-T ice

$$V_{DT\,ice} = \frac{4}{3}\pi\left(r_2^3 - r_1^3\right) =$$

$$= \frac{4}{3}\,3.14\left(1.^3 - 0.8^3\right) = 2.04\ mm^3 \approx$$

$$\approx 2 \cdot 10^{-9}\ m^3$$

pellet mass

$$m_{pellet} = \rho \cdot V = 2 \cdot 10^5 \times 2 \times 10^{-9} =$$

$$= \underline{4.4 \cdot 10^{-4}\ g}$$

In case of steel the pellet temperature will increase by

$$\Delta T = \frac{q_{IR\ pellet}}{C\ m_{pellet}} = \frac{0.063}{8.8 \times 4.4 \times 10^{-4}} = \underline{16.3\ K}$$

In case of tungsten the pellet temperature will increase by

$$\Delta T = \frac{5 \cdot 10^{-4}}{8.8 \times 4.4 \times 10^{-4}} = \underline{0.13\ K}$$

e) The intensity at which a pellet absorbs heat from a hot surface is

$$P_{pellet} = \frac{q}{\tau} = \frac{0.063\,J}{0.05} = 1.26\,W$$

where q is energy received from a hot surface during being in a reactor.

In the case of filled in a reactor gas Xe, molecules of the gas will move towards the pellet and heat the pellet. at energy flux

$$\boxed{\Gamma_{\varepsilon} = \frac{1}{4} \langle v \rangle n\, \varepsilon_K\, S_{pellet}},$$

where $\langle v \rangle$ average gas speed,

ε_K energy of a gas molecule,

S area of the pellet

$$\varepsilon_K = \frac{3}{2} K_B T$$

$$n = \frac{p}{K_B T}$$

$$\langle v \rangle = \left(\frac{3 K_B T}{m_{Xe}} \right)^{\frac{1}{2}}$$

$$\Rightarrow \frac{q}{\tau} = \Gamma_\varepsilon = \frac{1}{4} \left(\frac{3 K_B T}{m_{Xe}} \right)^{\frac{1}{2}} \frac{p \quad 3/2 \, K_B T}{K_B T}$$

$$= \frac{1}{4} \frac{\sqrt{3}\, 3}{2} \left(\frac{K_B T}{\cancel{x} m_{Xe}} \right)^{\frac{1}{2}} p \, \delta_{pellet}$$

$$p = \frac{q/\tau}{\delta_{pellet} \left(\frac{K_B T}{m_{Xe}} \right)^{1/2}} \frac{8}{3\sqrt{3}}$$

$$\boxed{p = \frac{8}{3\sqrt{3}} \frac{q/\tau}{\left(\frac{K_B T}{m_{Xe}} \right)^{1/2} \delta_{pellet}}}$$

$S = 1{,}26 \cdot 10^{-5}\ M^2$

$q/\tau = 1{,}26\ W$

$k_B = 1{,}38 \cdot 10^{-23}$

$m_{Xe} = 1.31 \times 1.61 \times 10^{-27} = 2.2 \cdot 10^{-25}\ kg$

$T = 1300\ K = 1{,}3 \times 10^3\ K$

$$P = \frac{8}{3\sqrt{3}} \frac{1.26}{\left(\frac{1{,}38 \cdot 10^{-23} \cdot 1{,}3 \cdot 10^3}{2{,}2 \times 10^{-25}}\right)^{1/2} \cdot 1{,}26 \cdot 10^{-5}} =$$

$$= \underline{550\ Pa}$$

If we fill xenon with pressure of $P = 550\ Pa$ in a reactor temperature of the pellet will increase by 16 K, as in the case of the hot wall radiation.