Problem Set 4

22.211 Fall 2023

Due Date 3/22/2023

Question 1: Using OpenMC, build a 2D Cartesian pin cell with 3.0% enriched UO2 fuel (10.31341 g/cm3) in a light water moderator 1.25 cm pitch (example notebook provided for a similar case).

Fuel pin outer radius = 0.39218 cm
Clad outer radius = 0.45720 cm

Run a reference case (kref) with Zirconium clad (density of 6.55 g/cm3), at 600K water at 15 MPa. Make sure to include thermal neutron scattering.

- Temperatures are 600K for moderator and clad, 900K for fuel.
- To add thermal scattering: water.add_s_alpha_beta('C_H_H20') (the borated water function adds it automatically)
- 0 ppm Boron

Compute the reactivity change (in pcm) for the following perturbations (always starting from the reference case):

$$\text{Reactivity (in pcm)} = (k_{new} - k_{ref}) / (k_{new}\, k_{ref}) \times 100{,}000$$

a) Replace the Zr clad by Iron (density of 7.87 g/cm3), and record the change in pcm.
b) Remove the S(a,b) in the moderator, and record the change in pcm.
c) Perturb the fuel temperature and calculate the reactivity coefficient (pcm/K).
d) Perturb the water temperature and calculate the reactivity coefficient (pcm/K).
e) Find the critical boron level.
f) Perturb the boron concentration and calculate the boron worth (pcm/ppm).

Note: Make sure that your results are statistically significant and discuss the choices made for parts c to f.

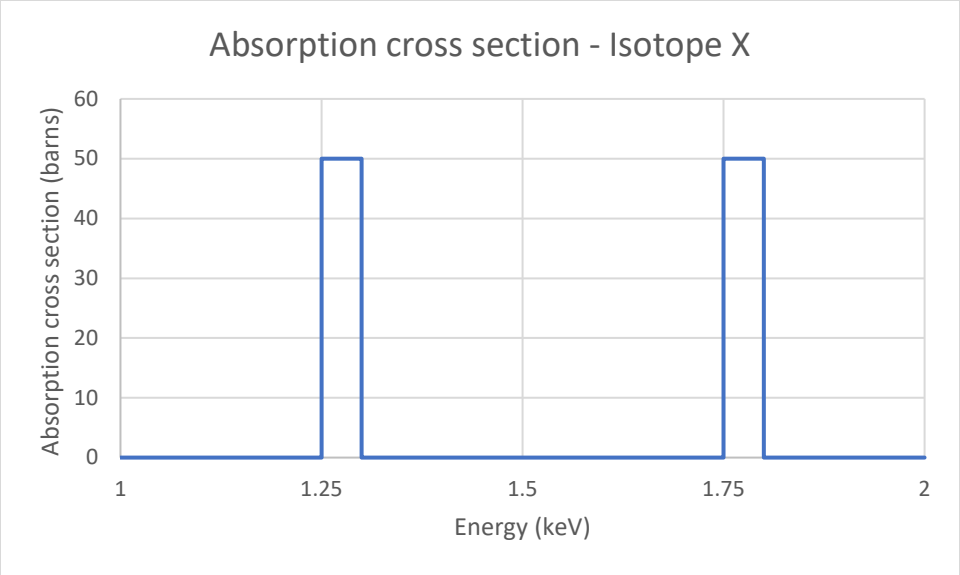
Question 2: Using the same **fuel material, dimensions and volume** (area in the 2D model) as in Q1, design a system with the largest possible reactivity.

- You can neglect thermo-hydraulic considerations (i.e. don't worry about having to cool it)
- Material densities must be realistic and documented

Question 3 (Heterogeneous resonance absorption)

You are tasked with generating multigroup cross sections for a new reactor design. The reactor can be approximated by an infinite 2D square lattice with a pin diameter of 0.5 cm and a lattice pitch of 0.625 cm. The fuel contains only resonant nuclide X (nuclide density of $2x10^{22}$ at/cm3) with absorption and total cross sections illustrated in Figure 1, and the moderator includes only H-1 with a potential scattering of 20 barns and a nuclide density of $3x10^{23}$ at/cm3. The Dancoff correction curve for a square lattice is provided in Figure 2.

a) Calculate the **two background cross sections** needed when using the Carlvik rational approximation.
b) Calculate the **group total cross sectio**n for the 1 to 2 keV range using the Narrow Resonance model.
c) Calculate the **group absorption cross section** for the 1 to 2 keV range using the Narrow Resonance model.
d) Compute the **group average** fuel-to-moderator and fuel-to-fuel first flight collision probabilities using the **group average** cross section previously computed.
e) If the **nuclide density of X is doubled**, what is the change total macroscopic reaction rate and absorption reaction rate?
f) If instead of doubling the nuclide density of X, what **geometrical change** could we do to achieve the same absorption rate?
g) If instead of using H-1, it is decided to use H-2 with a potential scattering cross section of 3.4 barns with a nuclide density of 1.5×10^{23}, what are the new background cross sections used in the Carlvik approximation.
h) To preserve the absorption rate of the original geometry with H-1 moderator, when using the new H-2 moderator, it is decided to switch our fuel form from a X metal to a XC carbide (carbon potential cross section is 4.7 barns). How much carbon should we add to the fuel to preserve the initial reaction rate?



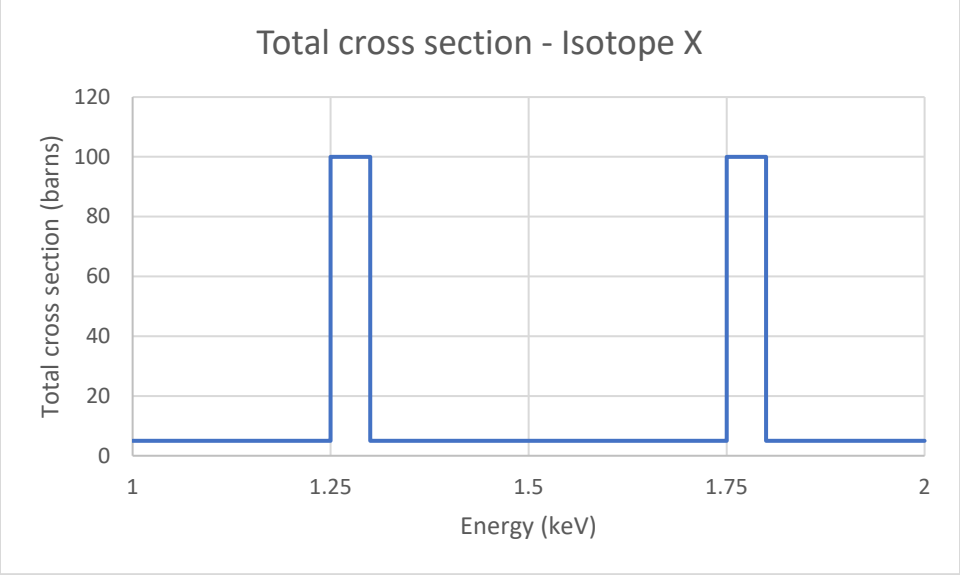


Figure 1: Nuclide X absorption and total cross-sections

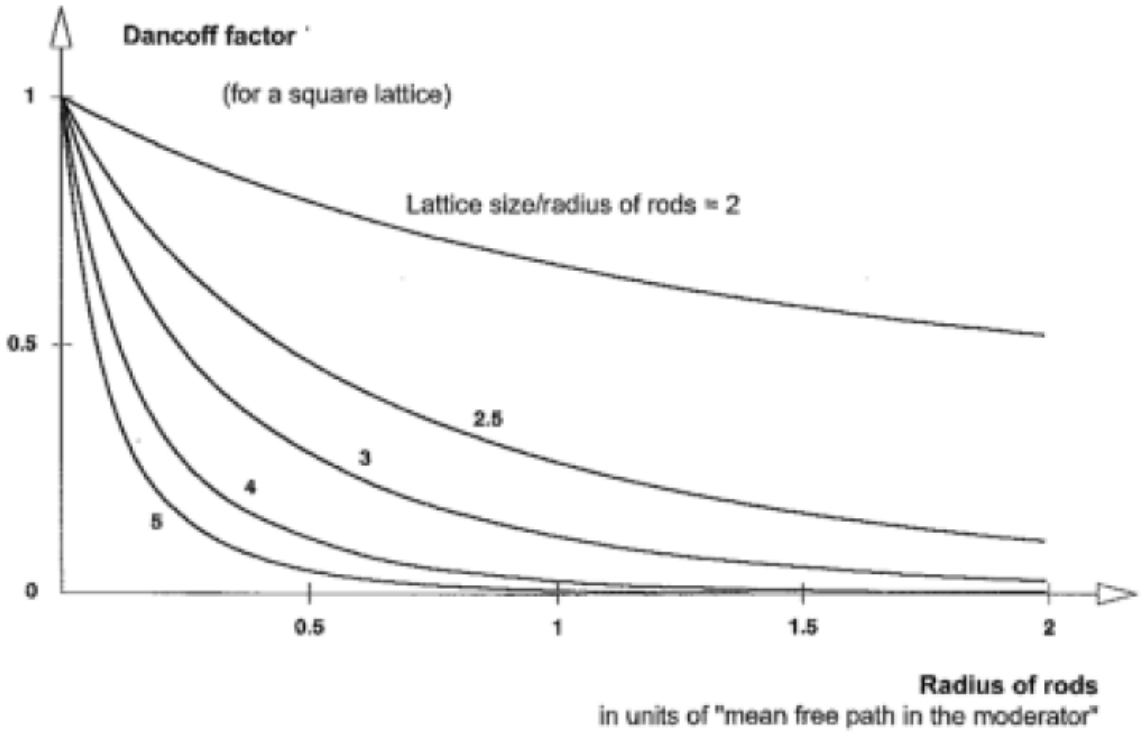


Figure 2: Dancoff for a square lattice (C)