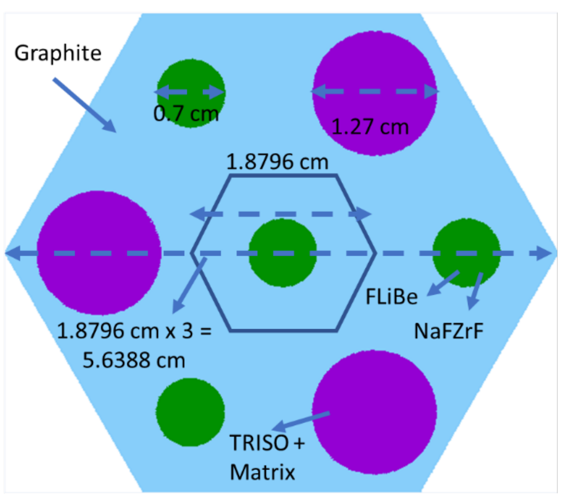
22.211 Final Project

Due date 5/16/2023

Model the 2D assembly from Figure 1 in OpenMC and answer the questions below. Please provide your answers in a single PDF document with plots and explanations and include input files or notebook as separate attachments.

Assembly details

- Graphite moderated
- Salt coolant channels
- TRISO fuel compacts (example file provided on how to generate TRISOs)
- Temperatures: 1000K for fuel and 900K for everything else
- Periodic boundary condition
- Fixed lattice spacing, coolant channel size and compact size
- 20 kW/L Power Density



mat NaFZrF4
2.96 g/cm3
Weight fraction
9019 0.4537
11023 0.1475
40000 0.3988

mat FLiBe
1.925 g/cm3
Weight fraction
3000 0.1414*
4009 0.0909
9019 0.7677
Enriched Li-6

mat Graphite
1.65 g/cm3
Weight fraction
6000 0.99998985
5010 0.00000015
7014 0.00001

mat Fuel
10.5 g/cm3
Weight fraction
92238 0.7502
92235 0.1376
8016 0.0897
6000 0.0224

TRISO Particle (Radii)
Fuel 0.02125 cm
buffer 0.03125 cm (Carbon@1 g/cc)
iPyC 0.03475 cm (Carbon @1.9 g/cc)
SiC 0.03825 cm (SiC @ 3.2 g/cc)
oPyC 0.04225 (Carbon @ 1.9 g/cc)
Matrix Graphite on Outside (Graphite)
Fuel Packing fraction in 1.27 OD Fuel Compacts: 35%

Assume 2 cm height (practically 2D)

Fig 1. "2D" Problem Specification (Fuel is shown homogenized in the picture)

1) Evaluate the performance of different salts listed below and report the **k-infinity** and specify the **melting point** and **moderator density coefficient** in units of PCM/% change in density for each case.
    a. Case 1: NaFZrF4
    b. Case 2: FLiBe – Natural Lithium
    c. Case 3: FLiBe – Li-7 99.95%
    d. Case 4: FLiBe – Li-7 99.995%

    Describe the observed trends. Discuss the parameters you selected (batches, particles per batch, inactive batches, …)

Note that enrichment capability for Lithium in the US does not exists and both enriched Li-7 and Be are extremely expensive. **<u>As such NaFZrF4 (Case 1) is utilized for the remainder of the class project.</u>**

2) Using OpenMC, for case 1 (NaFZrF4 salt) as a reference, compute

    a. Fuel reactivity coefficient (pcm/K)
    b. Coolant temperature coefficient (pcm/K)
    c. Moderator temperature coefficient (pcm/K)
    d. Plot the flux spectrum in the fuel, moderator and coolant
    e. Resonance escape probability
    f. Percentage of fast fission
    g. **Estimate** background cross-section of U-238 in the fuel in the 6-10eV group and the associated Dancoff factor if using a Carlvik 2-term approximation
    h. **Estimate** axial leakage if the fuel assembly was 2m tall with vacuum BC at top and bottom
    i. Heat deposition in coolant, graphite and fuel regions (from both neutrons and photons)
    j. Calculate the worth of impurities in the graphite block in terms of equivalent boron (pcm/ppm)

3) **Estimate the kinetics parameters** for case 1 and state your assumptions (Neutron prompt lifetime and delayed neutron fraction (average)). **Estimate the no-feedback power increase** (i.e prompt-jump) with half dollar of reactivity step insertion.

4) Fully homogenize the fuel compact as shown in Fig. 1 and calculate the reactivity, U235 fission and U238 capture rate differences between the heterogeneous model and homogeneous model. **Explain the trends seen in your analysis.**

5) Develop an **equivalent model** (that we will call Case 5) that homogenizes the TRISOs in the fuel compact and conserves fuel mass, while still preserving reactivity throughout irradiation history. Demonstrate the accuracy and efficiency (e.g, Memory requirements and runtime) of this model, explain what the model seeks to preserve and describe your approach.

6) Model Case 5 using CASMO4e and compare your results.
    a. Describe computational efficiency and accuracy, and discuss potential sources of error/differences observed.

7) In order to achieve longer fuel cycles and increase fuel utilization, Thorium is proposed. Your objective is to maximize the fissile inventory ratio at a burnup of 50 MWD/kgU starting from the case 5 model using CASMO4e. Free parameters are the **thorium-to-uranium ratio** and **uranium enrichment up to 20%**. Please utilize the following constraints:
    - Fuel is an homogenous mixture of thorium and uranium Fuel volume (whether uranium or thorium oxy-carbides) will stay fixed along with other geometry parameters.
    - Uranium enrichment should not exceed 20%
    - k-infinity should be greater than 1 by 50 MWD/kgU

8) Discuss the use of CASMO4e when modelling a system with Thorium and verify it’s accuracy.