Q 1.

Referring to the attached paper, perform a stability analysis either one of the Generation IV nuclear reactor designs (VHTR, MSR, SFR, GFR, LFR) or the TRIGA Mark II nuclear reactor. Your work should follow the steps below:

1. Derive the non-linear model (neutronics + thermal-hydraulics + primary loop / secondary loop / pool);
2. Linearise the model equations;
3. Write the state-space representation;
4. Retrieve the system transfer function and study the unitary step response;
5. Compute the eigenvalues of the matrix A and plot them (you can also plot the maximum eigenvalue for different values of the inputs);
6. Plot the stability maps (varying the feedback coefficients);
7. Compute the matrix exponential (see example) for different values of the feedback coefficients and the inputs;
8. Verify the stability map using the non-linear model;
9. Reproduce the transients reported in the article using the non-linear model.
10. Compare the closed loop (with primary and secondary loop) with the open loop (only neutronics + thermal-hydraulics) results (in terms of transients and (**optional**) stability).

Note 1: you are required to use the neutronic + thermal-hydraulics + pool / primary loop + secondary loop model with constant mass flow rate. For what concerns the TRIGA Mark II reactor case, the model reported in the paper also includes the ODE for mass flow rate and poison concentrations. You can neglect these two equations by assuming constant mass flow rate (equal to the stationary value) and null poison feedbacks (so $\alpha_{Xe} = \alpha_{Sm} = 0$), and neglecting the respective equations (but feel free to add them as well).

Note 2: the two papers also report also the root loci for the five reactors considered. Neglect these plots (if you want, you can try to replicate them by plotting the different eigenvalues changing the value of power and inlet temperature and the re-compute the matrix A and its eigenvalues).

Note 3: if you choose to analyse the MSFR, please note that the nonlinear model equations also include a time delay. In this case, you cannot solve the nonlinear model with *solve_ivp* but you need to install and use a specific routine, *ddeint* (in Colab, *!pip install ddeint*). During tutoring we will see how to use it.