LMECA2600 - Project 2025

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First part : model of a simplified thermal nuclear reactor

Consider a Pressurized Water Reactor (PWR), using classically natural UO_2 enriched at 3%. You are asked to first develop the system of equations that describes the kinetic of the latter using the guidelines provided below. Based on the species that are used in your system of ODE's, create a database [1] that will be used for the project. Based on your database, you are first asked to discuss the reactions that could be neglected *apriori* (relevant figures are expected in the report to illustrate the discussion). N.B. : there is not one exact answer expected, what is expected is a **relevant** and **personal** discussion.

After you discussed the ODE's system, start developing your `python` code by applying the following guidelines :

— The volume of the reactor is $10\,[m^3]$.

— The temporal integration of your ODE's system will be performed with a constant time step $\Delta t = 10^{-4}\,[s]$, using an explicit Euler scheme. *You can, of course, implement another numerical scheme if you would like.*

— The model of the reactor is based on two energy levels characterized by the $E_{fast} \sim 1\,[MeV]$ and $E_{thermal} \sim 0.025\,[eV]$.

— Consider that a fission produces $\overline{\nu} = 2$ prompts neutrons, and that the the half-time for a fast neutron to become thermal is $T_{1/2} \sim 5 \times 10^{-4}\,[s]$.

— Consider that a fission produces 2 unstable fission products, with a half-life of $T_{1/2} \sim 1\,[s]$. *Hint : for ^{239}Pu and ^{235}U, you can consider that they have the same fission products ; consider that one of them is ^{135}Xe. What percentage of the fission products are ^{135}Xe ? What other isotope could be used for the second FP ? Apply the same reasoning for the other nuclides in the core. How do you determine the proportion of ^{135}Xe vs other isotopes ? In your model, consider that "other isotopes" are a same "nuclide", and that they are the source of the delayed neutrons.*

— There are three sources of energy in the reactor : fission, stabilization of the FP's, and neutrons that are slown down by diffusion. *Hint : you should be able to find an approximate value that you can assume constant for every fission.*

1. Cross sections of the different species can be found here : `https://www-nds.iaea.org/exfor/endf.htm` ; the mass of the isotopes can be found here : `https://wwwndc.jaea.go.jp/NuC/`

- Use as the mass of the fuel $25\,[kg]$, otherwise, the critical mass is overtaken and it is impossible to control the reactor.
- Control rods should be used for the power control. Take also into account some leaks for the neutrons. *Hint : a simple way to take into account the presence of the control rods and leaks is to use a macroscopic cross section of capture that can vary in a given range (the min. value corresponding to the case where the control rods are out of the core, while the max. corresponds to the control rods fully down). You shoul define some range of minimum and maximum values for the control, by using a macroscopic cross section for the control bars :* $\Sigma_{fast} \sim [0; 20]$ *and* $\Sigma_{thermal} \sim [0; 20]\,[1/s]$*, so that* $dn/dt = ... - \Sigma \times [n]$.

Code

For the python codes, you are asked to provide a *readme* file that briefly and clearly explains the goal of the functions. The following templates are provided ; you have to use those file names and the docstring of the functions in order to fill them. The functions of each file will be tested individually. You can define additional functions if you want, but they will not be tested. Still, they should be described in the *readme* file.

- `crossSection.py`
- `halfLife.py`
- `molarMass.py`
- `reactorModel.py` : main function, we will use the function `reactorModel` to assess your code.
- `project.py` : if you perform several analyses by calling `reactorModel` with different arguments, the list of all the runs should be in project.py.

The main goal of the function `reactorModel` is to simulate the behaviour of the PWR over short times, and to achieve a steady power. The control of the power is performed through the control rods that you will use.

Examination and deadline

No report is expected for this project. However, the evaluation will be based on a max. 15 minutes oral presentation by group. The schedule of the oral will be provided later, but it will be at the end of the semester (week 08/12 or week 15/12).

1. ODE's system of the kinetic in the PWR.
2. Brief explanations of your database.
3. Discussion on the reactions that could be neglected based on your database.
4. Methodology of the code : every assumption you use should be explained and justified, the implementation of the control rods for achieving a constant nominal power. Do not explain the code, but the methodology only.
5. Second discussion on the reactions that could be neglected based on the first discussion, and the results obtained with your detailed.
6. Relevant analyses on the evolution of the species inside the reactor, the power control, etc.

7. Bonus : try to make the model more physical by removing some assumptions, changing some parameters.

It is expected that you support with consistent information or results all the discussions of your report. Clarity of the results and of the communication is very important. The quality of the oral communication is also evaluated.

For the oral discussion during the exam, keep in mind that we expect you to have a critical discussion regarding the assumptions made in this simplified model of the nuclear reactor. It is important to clearly understand the physical technical aspects of a real reactor.

The slides of the presentation must be submitted on moodle (*.pdf* file, and additional animation files if you want) and should be named *lmeca2600-project-group-X*, where X is the letter of your group. The codes, the readme file, and the slides file should be compressed into one single archive with the same name as the report.