Finding the Geometric Buckling Value (B_g^2) For a Practical Nuclear Reactor

Problem Statement:

Nuclear reactors around the world work on the principle of nuclear fission. Nuclear fission proceeds through fission chain reaction, in which a single neutron is bombarded onto enriched Uranium isotopes such as U^{235} or U^{238}. The nucleus of these isotopes splits into two or more nuclei along with some neutrons which are utlized to continue the chain reaction. This nuclear fission reaction is controlled by a particular multiplication factor called the effective neutron multiplication factor (k). This multiplication factor determines whether a reaction is controllable or uncontrollable. In simple terms we can denote it as follows:

$$\mathbf{k} = \frac{number\ of\ neutrons\ in\ one\ generation}{number\ of\ neutrons\ in\ preceding\ generation}$$

But when we perform it practically in real-life reactors a lot of factors come into play. So we are required to modify the formula as follows:

$$\mathbf{k} = \eta f p \varepsilon P_{FNL} P_{TNL} \qquad \textit{(Six - Factor Formula)}$$

η = Thermal fission factor
f = Thermal utilization factor
p = Resonance escape
ε = Fast fission factor
P_{FNL} = Fast non-leakage probability
P_{TNL} = Thermal non-leakage probability

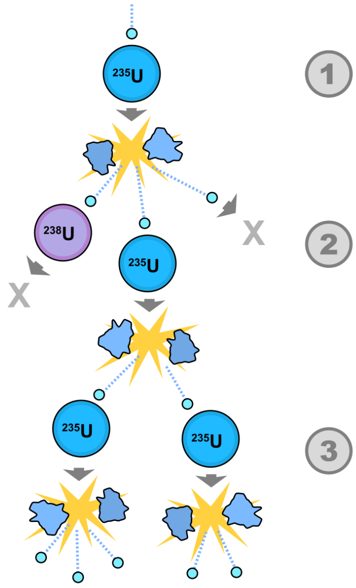
But here the P_{FNL} and P_{TNL} are dependant on an important value called Geometric Buckling (B_g^2) which is a measure of neutron leakage. During the fission chain reaction some neutrons produced escape from the reactor, and that is directly proportional to geometric buckling. So, practically a nuclear reactor tends to have k < 1. In order to have a k value less than 1 we need to find the geometric buckling value when all other parameters are easily available or provided to us. The equations for this problem statement will be shown below.

Theory:

- Geometric buckling is a measure of neutron leakage in the nuclear reactors.
- It is a simple Helmholtz eigenvalue problem that is simply solved for different geometries.
- The buckling value is crucial for determining the spatial behavior of neutron flux within the reactor, which in turn affects how neutrons interact with fissile material and influence the multiplication factor.
- It takes into account the curvature of neutron flux and describes how the neutron population changes as a function of distance within the reactor.

Approach:

- Implement an appropriate numerical method to find the value of geometrical buckling with a *good accuracy*.
- Develop *test cases* with known solutions to validate our computed results.
- Explore *multiple methods* (open and bracket methods) to improve efficiency of the algorithm.
- Try implementing the algorithm in *different programming languages* to get a more precise value.
- Investigate how *changes in input parameters* impact the calculated value.



Equations:

$$k \;=\; \eta f p \epsilon P_{FNL} P_{TNL} \;(Six - factor\ Formula)$$

$where,$

$$P_{FNL} \;=\; e^{-B_g^2 \tau_{th}}$$

$$P_{TNL} \;=\; \frac{1}{1 + L_{th}^2 B_g^2}$$

τ_{th} : $Age\ to\ thermal$

L_{th}^2 : $Diffusion\ length\ of\ thermal\ neutrons$

$$\therefore\; k \;=\; \eta f p \epsilon e^{-B_g^2 \tau_{th}} \frac{1}{1 + L_{th}^2 B_g^2}$$

$The\ value\ of\ k\ in\ practical\ nuclear\ reactors\ is\ always\ less\ than\ 1$

$Thus,$

$$\eta f p \epsilon e^{-B_g^2 \tau_{th}} \frac{1}{1 + L_{th}^2 B_g^2} \;<\; 1$$

Equation provided to solve for geometric buckling (B_g^2).

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