Review and recommended revisions of “Final Burnup Calculator for Multibatch Core Loading”

By: Maria Pinilla

This project seems to be a useful visual display of the relationship between batch size for nuclear reactor refueling, and useful fuel life-time. The presentation of reactor multiplication factor and reactivity as a function of fuel burn-up is a valuable tool in understanding reactor kinematics. This project interprets and presents data that was compiled utilizing previously verified software. While the technical merit for the work is evident, many revisions (some major) are recommended before final submission.

The following comments all reflect three general trends of deficiency in the project report:

1) Insufficient detail
2) Lack of citation
3) Informal presentation

The comments are listed in order of appearance. Major revisions are denoted by bold-facing.

1) Remove or rename
2) Elaborate what costs are reduced
3) Reflective pronouns should be avoided. Consider using the phrase: “A graphical user interface was developed…” and “The PyQt4 module was used to create…”
4) **Results should be included in the abstract**
5) **In general, the abstract seems insufficient**
    a. More descript language should be used
    b. Describe what the goal of the software is… what value it adds
    c. Less objective language should be used (simple, intuitive)
6) This sentence should be rephrased more concisely
    a. Avoid vague words (it, these)
7) **Needs explanation and citation**
8) **Needs citation**
9) **Avoid using the words “I” and “my”**
    a. This is a recurring theme that should be addressed
10) The phrasing makes it sound like you developed Poropy
    a. Rephrase and cite the Poropy software package
11) Make more concise
    a. Consider just using “… multiplication factor (k_{inf}) is the ratio…”
    b. Also, I believe it should be a lower case ‘k’
12) Explain neutron generations
13) These sentences can be rephrases more concisely
14) **This entire paragraph needs numerous citations**
    a. Unless the knowledge was developed specifically by the present work, or is ‘common knowledge’ you need a citation
    b. I would consider the content of this paragraph to not be common knowledge for the present audience

15) Remove ‘it’, replace with ‘and’
16) Use proper equation notation (you will need to verify with the formatting guide)
17) Requires citation
18) Requires citation
    a. Intuition suggests that this relationship is not linear… if it is you should show how / why
19) Consider rephrasing with “Nuclear reactor cores are refueled in batches”
20) Explain why this is and add a citation
21) Are the characteristics the same or similar, explain why
22) Explain how the energy output is increased, and by how much (citation would also help)
23) Explain why refueling is expensive (add citation)
24) Remove a word to fix this typo
25) Consider rephrasing as “… a two-batch core was considered …”
26) Quoting a reference directly is undesirable
    a. Either show the calculation process (with citation) and report the conclusion or,
    b. Just report the conclusion with a citation
27) Sentence is vague
28) Please explain how the old fuel actually removes neutrons from the fresh fuel
    a. It seems more likely that the old fuel simply produces fewer neutrons from fission than the fresh fuel
    b. The particular wording here seems un-physical
29) This sentence is unclear and should be rephrased for clarity
30) An equation would help explain this more concisely
31) I agree that additional content should be added regarding burnable poisons
32) Rephrase for clarity and professional presentation
33) This sentence adds no content. Remove.
34) Remove marked section
35) More specificity would help clarify
36) Similar to 9)
37) Similar to 9)
38) User defined batch numbers would be far more useful
    a. Consider changing this from a selection to user input value for the final version
39) User defined enrichment would be far more useful
    a. Consider changing this from a selection to user input value for the final version
40) This acronym is not defined
41) Use k_{inf} instead
42) Figure title should be more descriptive and point out a conclusion
43) Vague language (These) should be avoided
    a. Reword for conciseness
44) Please elaborate on how this is accomplished
45) A description of useful applications would be beneficial
46) Please describe how the software handles a situation where the parameters do not correspond to the selected display (if this is possible)
47) Similar to 9)
48) Please elaborate on why this is

49) Please draw a conclusion from these figures rather than just listing them as examples
    a. If the figure does not add to the report, it should be removed
50) This wording is vague, please rephrase
51) The results suggested here would add greatly to the report
    a. Please add as suggested
52) Make sure the citations have the correct formatting
    a. Line up the hanging indent
53) Do these things and then remove the list

Maria Pinilla
1207 Kearney St. Apt. 3
Manhattan, KS 66502

December 19, 2014

Dr. Jeremy Roberts
137D Ward Hall
Manhattan, KS 66506

Dear Dr. Roberts:

Please find enclosed my manuscript, "Final Burnup Calculator for Multibatch Core Loading," which I would like to submit to you as part of the course requirements of ME 701.

This paper outlines an overview of the theory behind multibatch core loading and why it is important for nuclear reactor fuel management. I also describe the application I have created to calculate and compare the final burnup from a multibatch or a single-batch core loading cycle. The application models an infinite core with three user selected parameters: number of batches, fuel enrichment, and type of burnable poison. The user can select to view three types of plots and see the calculated fuel efficiency displayed under the plot. My hope is that this can be a useful tool to those working with or studying in-core fuel management.

I thank you for your consideration and look forward to your decision.

Sincerely,

Maria Pinilla

Maria Pinilla

Proceedings of ME 701 (Development of Computer Applications in Mechanical Engineering)
December 19, 2014, Manhattan, KS

FINAL BURNUP CALCULATOR FOR MULTIBATCH CORE LOADING

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ABSTRACT

In order to increase fuel efficiency and reduce cost, nuclear power plants utilize a multiple-batch core refueling process. I created a graphical user interface to calculate and plot the increase in fuel efficiency provided by increasing the number of batches in a full refueling cycle. I used PyQt4 to create this simple and intuitive application which models an infinite core using nuclear data from Poropy software. Will add good/bad results when program is fully functional.

INTRODUCTION

In nuclear reactor operations, it has become incredibly important to optimize core fuel management for many reasons. These include the cost of the fuel, since it cannot be reprocessed or bred in reactors, and the limited on-site spent fuel storage capabilities of most plants.

Multibatch core loading is a technique in refueling, where a portion of the core is replaced with new fuel periodically, which greatly increases the total burnup of the core for the same amount of fuel. This technique reduces the enrichment requirements for criticality, lowering operation costs and helping to maintain good safety standards.

For this project I my intent was to create a graphical user interface (GUI) that computes and plots the fuel burnup for a multibatch core. I used PyQt4 in Python to create a GUI and a software package called Poropy to obtain the data used for the calculations.

THEORY

The infinite multiplication factor K, ~~also denoted by K_{inf}~~, is the ratio of neutrons produced by fission in one generation to the number of neutrons lost through absorption in the previous generation. K_{inf} is a measure of the increase or decrease in neutron flux for an infinitely large reactor, where there is no neutron leakage. Criticality is defined as K = 1, that is the number of neutrons in the reactor maintains constant from one generation to the next. When K is less than 1, the reactor is said to be subcritical and each generation thereafter would have less neutrons than the previous one. When K is greater than 1, the reactor becomes supercritical, generating more and more neutrons with time.

Reactivity is an important measure that describes the behavior of the reactor when K deviates from criticality, it can be calculated using Equation 1. Just like the infinite multiplication factor, K, reactivity is proportional to the fuel enrichment, which diminishes almost linearly as a function of burnup, i.e. time.

Equation 1 → $$\text{reactivity} = (k-1)/k$$

When a reactor core is refueled, it is done so in batches. A batch is a group of fuel elements of the same characteristics that enters or leaves the core at the same time. By increasing the number of batches within a time period, the total energy output of the fuel can be greatly increased. While it is important to get the most fuel efficiency possible, it is critical to keep in mind the costs of refueling a nuclear reactor and attempt to balance the two.

To understand the how multiple batches affect the reactivity and total burnup we can look at a two-batch core. The final burnup is "1/3 more than that obtained in a one-batch core for the same initial reactivity," or the same initial enrichment [1]. This can be explained by the negative reactivity the burned fuel has in relation to the fresh fuel inserted on the second batch. The burned fuel acts as a neutron sink, ~~which removes~~ excess neutrons from the fresh fuel. This decreases the necessity for poisons or other means of compensating for the excess reactivity that fresh fuel has.

The final burnup is equal to the average of the sum of the reactivities supplied by each batch. By combining multiple batches, the fresh fuel keeps older fuel, which would have already become subcritical, burning for a longer period of time, greatly increasing fuel efficiency.

(I intend to add content about burnable poisons.)

TOOLS AND IMPLEMENTATION

To create the graphical user interface I used PyQt4, which is a tool that brings together Python with Digia's Qt C++ application framework. PyQt4 utilizes python's object oriented programming to "employ a signal/slot mechanism for communicating between objects" [2]. It is an intuitive, yet powerful tool that is easy to implement. It contains all the basic objects needed to create a GUI, like textboxes, drop boxes, buttons, and more. It can also be coupled with matplotlib to create updatable graphs.

All of the nuclear data for this application was obtained from Poropy, ~~which was provided by Dr. Roberts. Poropy~~ is a software package that contains extensive data for nuclear reactor analysis and has a specific focus on in-core fuel management optimization. It is accessible through python by calling specific functions (with various parameters) from the software. ~~For this project, I utilized~~ the nuclear data package to obtain values for K_{inf} which depend on the fuel enrichment and type of burnable poison, ~~as selected by the user~~.

For this project, I created a two column interface where the user can select the desired parameters on the left and select the type of plot they want to see on the right, as seen in Figure 1. The application begins with a sample K_{inf} vs. fuel burn up plot on the right. The user is then able to select the number of batches (1-6), the fuel enrichment (3%, 4%, and 5%), and the type of burnable poison (none, gadolinium, or IFBA).

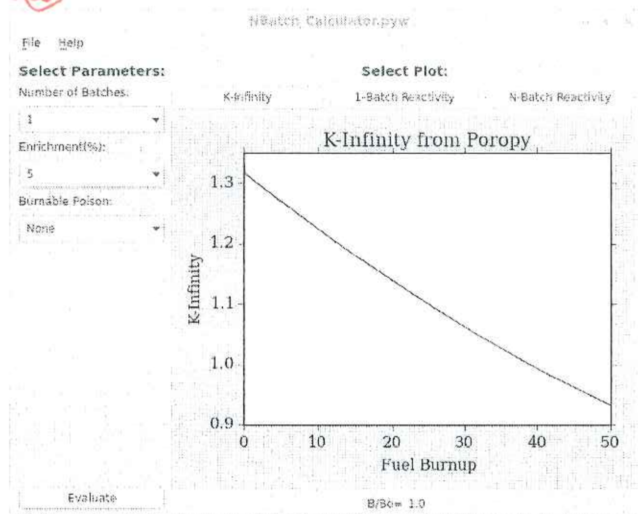
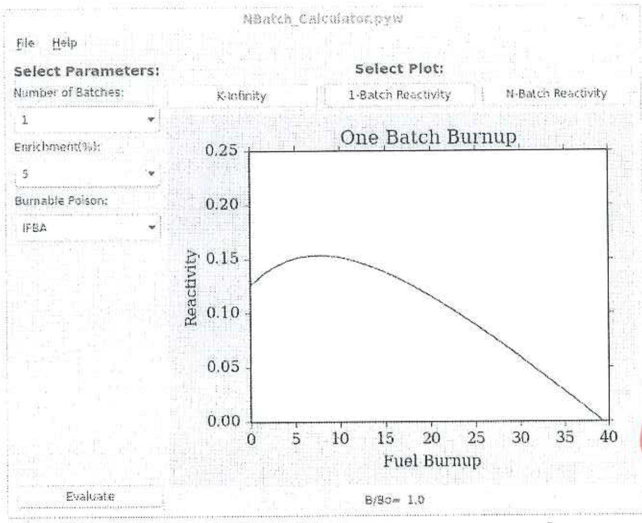


Figure 1: K-inf vs. fuel burn up, data acquired from Poropy

These parameters are entered into the K_{inf} function from Poropy to obtain K_{inf} as a function of burnup. Then the user can click the "evaluate" button to update the graph on the right to display N-batch reactivity vs. fuel burn up. Alternatively, either one of the three buttons above the plot can be clicked to update the plot depending on the parameters entered on the left. An example of the reactivity vs. fuel burn up using IFBA as a poison can be seen in Figure 2, and Gadolinium in Figure 3. I thought it would be important to add the ability to see K_{inf} vs. fuel burnup as well as one-batch reactivity vs. fuel burn up so the user can utilize it as a baseline.



49 **Figure 2: Calculated reactivity vs. fuel burn up for one batch using IFBA as a burnable poison**

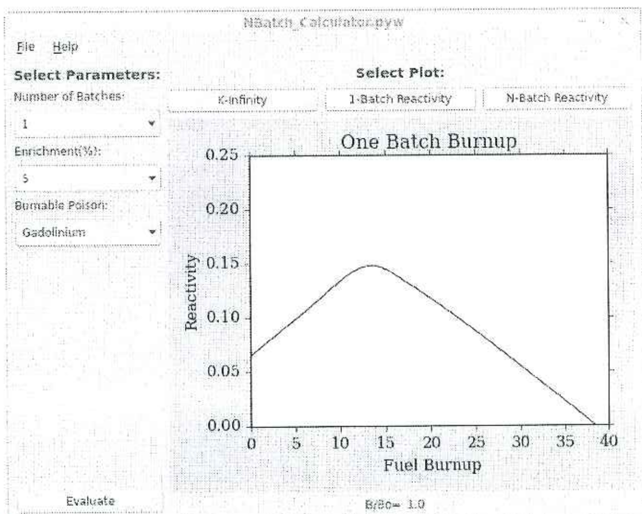


Figure 3: Calculated reactivity vs. fuel burn up for one batch using Gadolinium as a burnable poison

RESULTS

50 The main output of this application is the plot displayed on the right, which can be set to show K_{inf} or reactivity vs. fuel burn up for one or multiple batches. Below is a textbox that displays the ratio of the n-batch to the one-batch burn up so the user can see the increase in fuel efficiency by increasing the number of batches.

Right now I do not have the n-batch reactivity working because I cannot get the math to work. This is something I will be sure to accomplish before the end of the project so I can add some real results to this section. 51

REFERENCES

52
[1] Cochran and Tsoulfanidis, "The Nuclear Fuel Cycle." ←Get real citation from Dr. Robert's book

[2] Riverbank Computing Limited, "What is PyQt?"

53
-Fix citations and formatting errors (add equations, etc.)
-Finish Results section
-Add a discussion section
-future work? Improvements?