Review General Response

We would like to again thank the reviewers for their detailed assessment of this paper.

Reviewer 1

1. General. This paper applies the well-known fuel cycle simulator Cyclus to analyze the DOE nuclear fuel cycle options. Cyclus is widely recognized as a flexible, fuel cycle analysis computational tool designed for problems such as this. The literature review is satisfactory for the scope of the work. Thank you for including line numbers. Its surprising how many manuscripts do not include them especially since inclusion is not particularly labor intensive. This is a minor criticism, but this reads like a thesis/report. A journal paper is a little more streamlined and focused since the authors do not have to prepare a defense for their work.

   Solution: Thank you for your kind review. I have streamlined the paper to make it more focused to read less like a thesis/report. See the responses below for more detail..

2. Section 3. This section turned into largely an information dump. Again, possibly due to the report v journal paper issue. There is a lack of the so what that is needed for journal papers. Its not easy, especially with so many figures. There is a lot of performs best being thrown around, but not really what that means. I dont know if it would be better to segregate the results into further subsections, but the impact of the work risks being lost. Dont assume the reader is going to understand the implications just because

   Solution: ?? I don't really know what I should fix here. I made the description of this section more clear (pg 18).

3. Figures. This might be a bit picky, but is there a way to line the figures up more with the text? For instance, Figures 7,8,9 are referenced on p21, but you have to scroll down several pages to see them. As someone who includes lots of graphs in their research too, this is understandably a challenge.

   Solution: I shrunk Figure 7 to line it more with its text. Now, Figure 7 and its associated text are found on pg 22, Figure 8 and 9 and their associated text are found on pg 24, 25, and 23 respectively.

4. Conclusion. This section is rather glib, given what seems like a quite a body of work that was produced. I would recommend to include major findings and implications clearly.

   Solution:

5. Future work. Similarly, after all this work, only a sensitivity analysis is suggested. Is there anything more? What is envisioned the long term use of d3ploy?

> **Solution:** The future works passage has been modified to read:
>
> We simulate transition scenarios to predict the future; however, when implemented in the real world, the transition scenario tends to deviate from the optimal scenario. Therefore, nuclear fuel cycle simulators must be used to conduct sensitivity analysis studies to understand the subtleties of a transition scenario better to reliably inform policy decisions. Previously it was difficult to conduct sensitivity analysis with Cyclus as users have to manually calculate the deployment scheme for a single change in an input parameter. By using the `d3ploy` capability, sensitivity analysis studies are more efficiently conducted as facility deployment in transition scenarios are automatically set up.
> `d3ploy` will also be open-source and available for the forseeable future on github [**?**], to be used with Cyclus for conducting any transition scenario analysis.

6. Acknowledgments. I dont know if its necessary to include author contributions. Given that Prof. Huff is the author of record; i.e., listed last, it is known she directed the work, and given her reputation, there is no doubt anyone listed as an author contributed meaningfully to the work. Ive never really seen that in journal papers anyway, but authors discretion.

> **Solution:** I will leave it as is.

7. Line Items (Abstract)

   1) Abstract - Not everyone is going to know what d3ploy is. Either elaborate (a short sentence) or remove it and just explain it later on in the paper.
   2) Abstract - The claim of more efficient should be supported by a clearer context; i.e., efficient in what way?

> **Solution:** The abstract has been modified to read:
>
> The demand-driven deployment capabilities are referred to as `d3ploy`. We demonstrate `d3ploy`'s capability to predict future commodities' supply and demand, and automatically deploy fuel cycle facilities to meet the predicted demand in four transition scenarios. Using `d3ploy` to set up transition scenarios saves the user simulation set-up time compared to previous efforts that required a user to manually calculate and use trial and error to set up the deployment scheme for the supporting fuel cycle facilities.

8. Line Items

   3) 3-30 - While there are certainly many people familiar with the capabilities of Cyclus, there may be some who are not. It might be instructive for some more description of it, either here or in a separate section. Only a paragraph or two, maximum. Some newer readers might not know what agent-based means.

Solution:

9. Line Items
   4) 3-51 - Its not clear why the perceived adverse safety, etc., needs to be included. Is Cyclus going to address these issues? (rhetorical) The point being if the paper isnt going to show the research, there really isnt a need to include it since this is a nuclear engineering journal. The nuclear power industry may not necessarily have to overcome the perceived problems if there was a coherent energy policy established in the USA, and while that is a good discussion to have, its probably not part of this paper.

   Solution: Excellent point. I have removed the sentence about perceived adverse safety. You're right, the real purpose of these tools is not interaction with the public so much as providing a tool to potentially drive the R&D directions that are taken by our leadership (DOE) as stated in 1-15.

10. Line Items
    5) 3-58 - Ref. 7 is now 6 years old. Are these fuel cycle options still considered DOE policy? In and of themselves, these are acceptable options for study with Cyclus, but it still begs the comment as to its status.

    Solution: More recent citations can be found to bolster this. We have added the following text: 'Recent statements from Rita Baranwal [1], the Nuclear Energy Innovation Capabilities Act [2], and the Advanced Nuclear Technology Development Act [3] show that there continues to be national interest in pursuing spent fuel recycling and advanced nuclear power technology.'

11. Line Items
    6) 4-63 - What does performance mean in this context?

    Solution: We have added description for the meaning of performance.

    Fuel cycles that involved continuous recycling of co-extracted U/Pu or U/TRU in fast spectrum critical reactors consistently scored high on overall performance based on the nine DOE-specified evaluation criteria: nuclear waste management, financial risk and economics, proliferation risk, nuclear material security risk, safety, environmental impact, resource utilization, development and deployment risk, and institutional issues [4].

12. Line Items
    7) 5-92 - Just curious, what are the CPU demands on using d3ploy?

Solution: `d3ploy`'s CPU demands vary based on the size of the simulation (no. of facilities, etc.) and the prediction method used. We did not record the amount of CPU demands of our simulations because they were not large enough to impact our productivity in producing results. For the complex transition scenarios ('best performance models') discussed in the paper, the simulations took on average 2-3 hours. These simulations were performed on 32 core Dell desktops, not on a supercomputer.

13. Line Items
    8) 5-93 - Do commodities include coolant or reflector materials? Control rods?

Solution: Commodities do not include coolant, reflector, or control rod materials. The commodity associated with each reactor is reactor fuel. However, in `d3ploy`, a user could easily add these other materials as commodities and set up a supply chain for each of them.

14. Line Items
    9) 8-Fig 2 - Again, just curiosity, are there plans to include consolidated interim storage or onsite dry storage in Cyclus? Does the model include outages?

Solution: A storage facility archetype is available in Cyclus. The archetype can be customized by the user to be a consolidated interim storage or onsite dry storage. This model does not include outages.

15. Line Items
    10) 11-Sec 2.3 - Could d3ploy be used for hybrid systems; e.g., used with renewables or industrial product?

Solution: Yes, `d3ploy` can be used for hybrid systems. `d3ploy` is used with any assortment of Cyclus archetypes. However, there are currently no Cyclus archetypes for modeling hybrid systems. An interested user could design Cyclus archetypes that represent various facilities in a hybrid system and then use them with `d3ploy`.

16. Line Items
    11) 13-Sec 2.4 - Why were these time series methods selected? (There isnt any dispute with the selection.)

Solution: We chose an assortment of non-optimizing, deterministic-optimizing, and stochastic optimizing time series methods that are commonly used and readily available in Python packages for quick and easy implementation.

17. Line Items
    12) 28-333 cf. Section 3. Why is 6 or 8 extra reactors unrealistic?

> **Solution:** This passage has been modified to explain why 6 to 8 extra reactor unrealistic. It reads:
>
> We varied the power buffer size for the EG01-EG24 and EG01-EG30 linearly increasing power demand transition scenarios. Figures **??**, **??**, and Table **??** show that increasing the buffer size increases the robustness of the supply chain by minimizing power undersupply. The cumulative undersupply is minimized with a 6000MW and 8000MW buffer for EG01-EG24 and EG01-EG30 respectively. In Figure **??**, a 4000MW buffer size has 8 time steps with undersupply, while a 6000MW buffer size has 7 time steps with undersupply. In Figure **??**, a 2000MW buffer size has 6 time steps with undersupply, while a 8000MW buffer size has 5 time steps with undersupply. We determined that extra commissioning of multiple reactors does not justify a single time step with no undersupply. This type of logic is difficult to program into a NFC simulator, therefore, even though NFC simulators can help inform policy decisions, decision-makers must still evaluate NFC simulator results to determine if they are valid and logical. Therefore, a buffer of 4000MW and 2000MW minimizes the power undersupply for EG01-EG24 and EG01-EG30 transition scenarios, respectively.

18. Aside.Why does the manuscript have 2 inch margins? Im assuming this was prepared in LaTeX, where a4paper would have been sufficient. This doesnt have any bearing on the recommendation to publish the paper, but it just makes it harder to read. Im actually surprised NT didnt insist on the standard format prior to sending it out to reviewers. I think they have a template.

> **Solution:** I have updated the submission to follow the Nuclear Technology Latex template.

Reviewer 2

1. Comments on Content. You make no mention of the impact of the issue of dynamic fuel compositions. The commodity that the reactors are demanding and the one being supplied by the reprocessing plants is constantly in flux during a transition scenario with unlimited recycle. Other applications that use forecasting methods don't have this concern. So effectively what you need to predict isn't just the capacities needed based on the mass of SNF, but also its post-reprocessing worth. When using reprocessed fuel, the necessary fissile loading fraction of MOX or TRU in a fast reactor may be as much as 50% higher for material sourced from a MOX LWR than from a UOX LWR. This difference will significantly impact your reprocessing capacity required to supply that material.

> **Solution:** Thank you for your kind review. The statement concerning 'unmatched' fidelity has been removed entirely and the bibliography has been expanded significantly. See the responses below for more detail..

2. Pg 2. Fuel cycle options doesn't need to be capitalized.
   Pg 3. Greenhouse is one word and greenhouse gas doesn't need to be capitalized.
   Pg 3. Line 50-52. This sentence is hard to follow with nested lists and clunky grammar.
   Pg 3. Line 59 Evaluation groups doesn't need to be capitalized.
   Pg 9. This section might be easier to follow if it was an enumerated list rather than forcing a paragraph structure.
   Pg 9. You use the acronym LWR but don't define it until page 11.
   Pg 10. Please use the same indentation for both equations 4 and 5.
   Pg 12. Numbers on axes for figure 3 are small.
   Pg 13. The definition of terms in an equation shouldn't have its own equation number. Equation 7 should be a list or part of equation 6. Also, please match indentation.
   Pg 15. Please fix indentation after equation 9.
   Pg 15. The sentence after an equation does not always start a new paragraph, so it shouldn't be indented if it doesn't.
   Pg 16. Equation 12 should be a list or part of equation 11.
   Pg 16. You do not define what the "L" term is in equation 13.
   Pg 17. You do not define what the "d" or "Y" terms are in equation 14.
   Pg 18. Rather than starting the results section with a sentence 7 lines long, it would improve readability to make it into an enumerated list.
   Pg 19. You don't need to state in the caption to figure 5 that power undersupply is avoided. You state that in the preceding paragraph Pg 23. The labels and axes are too small in figure 8. You also don't need to state results in your caption that are already stated in the main text.
   Pg 24. The labels and axes are too small in figure 9. You also don't need to state results in your caption that are already stated in the main text.
   Pg 25. Why is table 7 placed on page 31, if it's only mention is here and before table 5 and 6 are referenced?
   Pg 27. The font size used for figure 10a and b is good, but does not match the rest of your figures. All figure titles and labels should use the same font and font size.
   Pg 28. Please provide a citation for "The need for commodity supply buffers is a reflection of reality in which a supply buffer is usually maintained to ensure continuity in the event of an unexpected failure in the supply chain."
   Pg 29. The axes' font is too small in figure 11 and 12.

   Solution: All these comments have been addressed and fixed.

3. Pg 5. It is unclear if d3ploy runs before the simulation or if it is doing these calculation on-the-fly. If you are only predicting the necessary capacity a single time-step in advance does that mean that there is no deployment or process times?

   Solution:

4. Pg 24. In section 3.2 you state what methods provide the best results, but why do the POLY and FFT methods perform best when they do? What is it about those methods that causes them to outperform the others so significantly?

Solution:

5. Pg 29. Figure 11b and 12b shows that facilities remain in the simulation after they are created regardless of time and need. Is this the expected behavior, and if it is, is there no facility decommissioning?

Solution:

6. Pg 29. Please include descriptions of your facilities, or at least their capacities. Showing the number of agents deployed in figure 11 and 12 doesn't have much meaning otherwise (e.g., it could be misinterpreted in figure 11 that power supplied is increasing since you are deploying significantly more reactors).

Solution:

References

[1] New DOE Nuclear Energy Chief Suggests Rethinking Spent Fuel Reprocessing - ExchangeMonitor | Page 1, July 2019. Library Catalog: www.exchangemonitor.com Section: Department of Energy.

[2] Mike Crapo. S.97 - 115th Congress (2017-2018): Nuclear Energy Innovation Capabilities Act of 2017, September 2018. Archive Location: 2017/2018 Library Catalog: www.congress.gov.

[3] Robert E. Latta. H.R.590 - 115th Congress (2017-2018): Advanced Nuclear Technology Development Act of 2017, February 2017. Archive Location: 2017/2018 Library Catalog: www.congress.gov.

[4] R Wigeland, T Taiwo, H Ludewig, M Todosow, W Halsey, J Gehin, R Jubin, J Buelt, S Stockinger, K Jenni, and B Oakley. Nuclear Fuel Cycle Evaluation and Screening – Final Report. Technical Report INL/EXT-14-31465, U.S. Department of Energy, 2014.