REFEREE COMMENTS

The Long History of Promises by Accelerator-driven Systems

Friederike Frieß, Björn Steigerwald, and Yannick Vogt

General comments

This interesting review of the history and current state of ADS technologies provides a valuable view to assess recently re-appearing concepts that promise to solve the nuclear waste issue and at the generate economical profit. The authors convincingly discuss how technological and economical challenges have been there for quite some time and will remain, and that claims from new projects should be taken with caution. They further illustrate this conclusion with a clearly presented case study, in which the authors assess the claim that including radionuclide production to ADS could improve their economics and conclude that such claims are unlikely to materialize – an important conclusion in the discussion of the nuclear waste management that will still keep us busy for quite some time.

Specific comments

The paper is well structured, the contents are clear and well selected and the argumentation is convincing. At some points, however, I think that the overall readability could be improved to help the reader grasp the arguments a bit faster – in the following, most of the suggestions refer to this matter. I believe that most of the questions I had (also below) might be answered quickly by adjusting the language a little or adding an example.

Abstract

- 1f: suggest […] has recently re-gained attention **with appearances of new ideas in the startup sphere** […] - (if that is correct?) Suggest to leave a hint what discussions you are referring to.
- 3f: […] offering greater flexibility in fuel composition **compared to critical reactors**. - suggest to add for clarity

1 Introduction

- 23: […] via spallation reactions. - suggest to mention the particle accelerator as part of the system already here
- 28: […] use of fuels – suggest to explicitly mention that this is typically the separated spent fuel (or explain elsewhere, where the waste is actually transmuted;

in the core, or could you also extract protons to irradiate outside of the neutron-multiplying core?)

- 28: suggest to remove paragraph break
- 29: […] some design studies – suggest to add reference
- 22-30: maybe include information on typical neutron spectra (typically fast?) and typical transmutation efficiencies (and/or information about transmuted waste composition)
- 32: […] persistence of underlying design assumptions […] - what does this mean? Maybe give an example?
- 33: suggest to remove paragraph break
- 38: […] as a case study, […] - maybe mention already here that this study talks about the Transmutex START project
- Figure 1: Suggest to include information about electricity generation its usage for the facility to the text

2 History of ADS

I found this section especially hard to follow because I did not really get the structure here – is it sorted by time (not always it seems?), or technologies, or project goals? Maybe you could more explicitly highlight the limits of each specific technological development/project, and then explain how the following tried to solve it (this also refers to some questions in the following list)

- 43f: […] three possible ways […] - suggest to remove that it was three ways (or is it important?)
- 51: […] achievable destruction rates […] - suggest to add some (ballpark) numbers or quantify somehow if possible
- 52: was the ATW program purely calculations or did they build a prototype?
- 54: […] high overall destruction fractions […] - suggest to add some (ballpark) numbers or quantify somehow if possible
- 55: […] under multiple recycling themes […] - what is a recycling theme?
- 57: what did the roadmap include/suggest?
- 58: what does the NRC conclude about the “expense and additional operational risk”? (and why did the US come to a different conclusion? Can we understand this?)
- 62: so the ATW and everything before was thermal? Is this shift a reaction to issues before? (what issues? Didn’t they say they had high destruction fractions already l.54?)

- 63: where criticality accidents an issue with designs before?
- 68f: This can be considered in relation to … - could you clarify what this sentence means?
- 87: […] suggests a considerable degree of continuity in the central design logic of ADS, namely the combination of a high-power accelerator, a spallation target, and a subcritical multiplying system […] - isn't this just the definition of an ADS system, so it makes sense that this is a continuity in the logic of ADS? Or what do you mean here?
- 87f: Suggest to more clearly summarize here what the continuities were, and how it converged (or not?) - is it always fast reactors today? Always metal-cooled? What are the continuities, what different designs exist next to each other? 90f: suggest to explicitly state the challenges identified in early studies

3 Current State of Development

- General: Did the US, other EU states, Russia, all abandon ADS studies (or never did)? Suggest to introduce Transmutex and Emerald Horizon (maybe specifically startup sphere?) here as well (185f)
- 96: maybe discuss megawatt spallation targets, advanced fuels in history section (briefly?) - how have they been developed, what issues appeared and have they been fixed? What are the complications with those?
- 97: maybe include explanation what "fully integrated" transmutation plant means
- 103: suggest to remove paragraph break
- 108f: if accelerator is bottleneck, suggest to explain why (maybe in Sec. 2, if this issue belongs to the history of development)
- 112f: suggest this paragraph to the first mention of MYRRHA

4 Assessment of Transmutation Systems

- Section title, suggest to add: […] for waste treatment
- 122: […] system-level constraints […] - suggest to add an example or explain what it means
- 129: […] the dominant limitation arises […] - limitation for what?
- 140: suggest to add the significance of this IAEA assumption (is this generally used as a benchmark for calculations? Or would you like to highlight that the claims from 1998 have not been materialized?)
- 152: […] metal-cooled subcritical systems […] - are all ADS metal-cooled subcritical systems?

- 152: […] practical feasibility of spallation targets […] - what does this mean (maybe add example?)
- 157f: what is the difference of minor actinides vs. fission products regarding the hazard/safety for a final repository? Maybe add a paragraph comparing and explaining the differences explicitly?
- 161f: Why is it bad that this is funded? (Even if it is “only” about radiotoxicity)? (What is exactly implied here?)

5 Motivations for ADS Systems

- Suggest to add to section title: **Further** motivations for ADS systems (different to transmutation discussed before)
- Suggest to swap first two paragraphs (first, transmutation, then, write about electricity production)
- 176: suggest […] as a rule of thumb […] → […] as a benchmark to estimate the cost for fast ADS, […]
- 176: (as before) are ADS always metal-cooled fast reactors?
- 179: suggest to remove paragraph break
- 185f: I think those very recent proposals are really interesting to mention before! (see general comment to section 3)
- 188f: suggest to make more explicit what you are implying – is it just a small group of people interested in these ideas? Or what does this continuity in personnel mean?

6 Production of Radionuclides

- 191-202: I think that this paragraph could (if needed) be reduced and the details about nuclide usage be omitted
- 229: Suggest: The first group of radionuclides → The radionuclides produced by irradiation of targets
- 233f: maybe further divide following cases: “normal” research reactors vs. ADS? (since paper is about ADS, people might be specifically interested in those cases?)
- 237: Originally oriented as a commercial project […], shift towards a transmutation facility […] - is a transmutation facility not also a commercial project?
- 242: […] project continues to “seek international partners and investors […] - suggest to add explicitly how you interpret this (financing is not secured?)
- 247: maybe add conclusion/interpretation from the cases (I guess: demonstration, that many have not been financing themselves without public funding?)

- 256: suggest to add: […] from this revenue stream **with a case study on the Transmutex proposal**

7 Example: Estimated Revenue from Radionuclide Production

- 262: suggest to add a summary of the table contents rather than just reference (maybe ranges?)
- 265f: why this selection of radionuclides? (compared to those listed in 260?)
- 267: what are those scenarios? (not introduced before?)
- 268: […] Given the […] quality requirements […], this revenue appears limited relative to the infrastructure scale of the proposed facilities. - what does this mean?
- 270: What is the negative scenario? (S. 267)
- 275: suggest to repeat Strontium-90 market volume here for clarity (from 224)
- 277: The financial model […] - which one? The one used by Houben et al.?
- 279: is the Transmutex plan to treat the full German HLW inventory? Or is this just for illustration?
- 290: suggest: […] under varying efficiency assumptions → for different transmutation efficiency assumptions
- 291: The authors did not explicitly consider […] - how would this change the analysis result?
- Fig. 3: Why are more reactors needed, when the transmutation efficiency is higher? (Wouldn't that mean, the better you transmute, the less you need?). What is optimized for here? (Maybe also add in text?)

8 Conclusion

- 314: […] START facility **by Transmutex**

Technical corrections

- 74: merge reference with reference from sentence before?
- 108: reference looks odd
- 182: developer → developers
- 274: radionuclide → radionuclides
- 282: which suggest → who suggest or which suggests
- 308: system-level assessments (too many blanks)

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Generally, a referee comment should be structured as follows: an initial paragraph or section evaluating the overall quality of the preprint ("general comments"), followed by a section addressing individual scientific questions/issues ("specific comments"), and by a compact listing of purely technical corrections at the very end ("technical corrections": typing errors, etc.).

General comments:

I appreciate this manuscript as an excellent and comprehensive contribution to the current discussion on alternative (to direct deep geological disposal) HAW treatment strategies. Although the authors definitely distrust promises of startup companies recently vehemently advertising the benefits – and even additional revenues – of ADS facilities, the manuscript stays rather impartial – also pointing out the slow progress of conventional HAW treatment and disposal efforts. Although the concept being not new at all, ADS might be an option, especially for countries with large stocks of weapon grade plutonium.

Specific comments:

The most important statement – although not new either – is on the necessity for final disposal capacities even when treating the majority of HAW in ADS machines. Those capacities might change with waste constituent separation (partitioning) and burning (transmutation) efficiencies. In this context, one aspect seems to be somewhat neglected. What about the energy costs for operating industrial scale reprocessing and transmutation target fabrication plants required to provide the fuel for the ADS fleet over many decades? What about volumes and radiotoxicity levels of all the generated secondary waste streams concentrating fission products, and process technology equipment highly activated during necessary reprocessing cycles?

Technical corrections:

I did not discover any technical errors or flaws.

SAND Paper:

Overall Comment:

Thank you very much for your contribution on this important and up to date topic. I would like to emphasize certain points before going into details.

It is general scientific standard to write in an unbiased manner. I don't see this taken into consideration in your paper. You are of course allowed to have an opinion, but is neither standard not polite to use words like "frequently, unprecedented, famous" etc. You are trying to use sources that fit well your purpose and do not take scientific standards to check both sides of your statement. Try to quantify your statements with numbers, try to use volumes /waste volumes or TRL or any other quantifiable number to strengthen your statements.

The manuscript refers at several places to the authors' previous work. While self-citation is appropriate where directly relevant, I would encourage the authors to review whether all of these references are necessary and to ensure that the discussion adequately reflects the broader literature in the field. In particular, some claims may benefit from support through independent sources in addition to the authors' own publications.

In addition, I would like to challenge the chapter 3, current state of development: I think it would be very beneficial to the work to take a more structured approach to this chapter, and value the whole chapter on the TRL, that is introduced in the first sentence. Otherwhise it remains an relative comparison, and does not reflect any proven numbers. The author could distinguish between fundamental technological stagnation and incremental engineering advances. The author could also work on the point which of the systems would be able to achieve market readiness instead of stating that the concepts are repetitive.

There is no clear separation between demonstrated laboratory efficiency and industrial scale ton – tonnage throughput reliability.

The author shows a strong opinion that none of the systems has been realized so far – please reduce the statement in the paper to a reasonable amount.

Scientific comments:

The title has a random capital letter/non capital letter choice.

15: the US has a DGR in place that is operational.

45 space missing between p. and 284

60 no "." After et

65: this paragraph does not address the history of ADS, but tries to prove a point the author would like to stress – this can go into the analysis/summary section but not in the description.

85: Please check again your argument regarding the minor actinides: Is there an imput from the reduction of minor actinides and long lived fission products? Can you quantify this? Perhaps on parameters like total decay heat generation rate or the chemical stability over time.

Text in Fig. 2 – delete last sentence, does not give any additional information.

115: I strongly question this statement: I know Chinese information is hard to get, but the research in Japan and China is strong. CIADS and the Japanese research line are examples.

128 – 130: this paragraph is unclear and needs to be rewritten.

135 – the proliferation question is coming out of the blue and is out of context of the paper. I suggest to remove this.

Also here, you jump frm ADS to reprocessing – why are you not addressing it as reprocessing. Why is it connected to ADS? Or is it again just a point you would like to emphasize to explain your disagreement with the system?

170: Buongiorno is only addressing US plant, and is not talking globally.

176: You are jumping now from an ADS system to a GEN IV system – also here I am missing the context.

205 – this is well known information, and it can be shortened.

206 misspelling of “Technetium”

215 – I am missing a source for this statement.

220 ff: Your statement poses an oversimplification regarding the major component of Sr-90 recovery from reprocessing. While the market potential is cited (e.g., Intel Market Research, 24chemicalResearch), this conclusion relies heavily on highly volatile and speculative future market absorption rates. The author fail to adequately model the risk associated with geopolitical supply disruptions or fluctuations in global medical/industrial demand for these niche isotopes.

260 – 265: The conclusion that the revenue from isotope production is "economically negligible at the facility scale" (Page 9, lines 260-265) while simultaneously highlighting $Sr-90$ as a major component creates an internal contradiction.