Review of PhD Thesis

Candidate: Jakob Sierchuła, MSc.

Title of doctoral thesis: Determination of the liquid eutectic metal fuel Dual Fluid Reactor design

Evaluator/Reviewer: Rafael Macian-Juan, Prof. PhD, Technische Universität München (TUM)

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1. Goals and scope of the thesis / State of the art in the subject matter

The thesis of Mr. Sierchuła represents an extensive steady-state evaluation of the neutronic characteristics of a new concept of nuclear reactor, the DFRm. This design, unlike most of the reactors currently in operation or in the development phases, contains a molten core instead of a solid one, which is cooled by molten lead in a configuration known as a dual fluid reactor. Although the concept of a molten core reactor is not new, as it was developed in the USA with the MSR type in the 1960's and has become one of the Gen IV designs, the concept analyzed by the author constitutes an innovation in the use of a fast neutron spectrum, a molten core made or a metallic eutectic mixture of Uranium and Chromium, and the use of an integrated cooling circuit with molten lead. The combination of these characteristics is what makes the DFRm unique, and as such it has been patented by their creators, the IFK in Berlin.

The thesis reviews in Chapter 1 the landscape of current and advanced designs explaining convincingly the reasons why the DFRm design could potentially surpass then in terms of fuel resource utilization, high temperatures achieved, and the destruction of minor actinides in its own fuel and in that of more conventional thermal reactor designs.

As the author correctly notes, in order for the DFRm to become a reality, a series of important developmental stages will have to be completed. The thesis addresses a fundamental one, namely the determination of whether the design can, in fact, become critical and with which basic combination of fuel, coolant, and structural materials this is achievable. In addition, the author expands his analysis to include also evaluations of basic neutronic dynamic parameters that will later be important in the analysis of operational conditions and transients. Finally, the influence of the depletion in the maximum burn-up achievable is also addressed. This latter study can provide information in the future for the design of isotope extraction strategies, as well as, for the determination of the process of adding minor actinides from other reactors for destruction and the extraction of bred fuel, were this to become a desired mode of operation.

The goals are clearly set in Chapter 1 and the work reported in several well-structured chapters.

2. Innovation, originality, and relevance

As previously commented, the work reported in the thesis is completely original. Although it follows a well-known procedure, necessary to neutronically characterize a nuclear reactor core design, because of the special and innovative characteristics of the DFRm design, the procedures followed by Mr. Sierchuła and the interpretation of the results, together with the sensitivity-based design steps taken, are all original and innovative, as they are applied to a new core never before analyzed, such as the U-Cr molten eutectic. Previous analyses of another variant of the DFR, the one with a molten salt core, also followed a similar process of calculation, but the conditions studied were different and the conclusions also different.

As the author emphasizes in the last chapter when discussing the overall thesis conclusions, the results of the thesis work are a first, and necessary, step, which will be followed by many more needed studies to prove the operational capabilities, design the operation procedures, and prove the safety of the DFRm design.

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3. Suitability of the Methods Employed

The neutronic calculations in steady-state have been carried out by using two Monte-Carlo based codes, namely SERPENT and SCALE (KENO-VI). The choice is the appropriate one. These codes can provide very detailed neutronic calculations of complex systems, such as the core of the DFRm. Used together, their results can be compared and serve as a test of the correctness of the results when they are consistent. Also, the use of the two neutronic libraries, ENDF/B-VII and JEFF 3.1.1, allows the comparison of the results, in this case as a function of cross section data. This is important when considering the large number of fission products and minor actinides considered, especially in the case of the studies on burn-up in Chapter 6 and transmutation in Chapter 8.

The model development shown in Chapter 4 depicts a detailed description of the core of the DFRm, both in geometric and materials aspects, with a special care placed on the fuel tubes and their ceramic structure. The detail in the model, allows for further parametric studies in the determination of neutronic core parameters in Chapter 5 such as flux distributions and spectra, dynamic parameters, and the multiplication factor. The systematic manner in which the author carries out these studies is remarkable for its scope and provides very interesting information on the core of the DFRm.

Regarding the burn-up analysis, the degree of detail is excellent and the use of two methods, CRAM and TTA, suitable to assess the consistency and quality of the results, as is clearly shown in section 6.5.

The study is completed with a static safety analysis based correctly on the determination of the most important reactivity coefficients, especially the temperature coefficient, which is shown to be negative, as are the others. An important safety result of the thesis is the property of the reactor as designed to increase this negativity as the burn-up increases, which guarantees a stable and safe operation, from the point of view of reactivity changes.

Finally, the analysis of the operation of the reactor as a minor actinide burner, although preliminary, as the author indicates, is performed systematically for a small set of compositions, but its results are very valuable, since they show the large potential of the DFRm to carry out this task very efficiently.

4. Quality of the results and Perspectives for utilization

As summary of the comments in previous sections, the overall set of results for the quite comprehensive series of neutronic analyses are well founded on both methodology and on the data and models used. Therefore they can be considered as representative of the DFRm, and they will be the basis for further optimization and safety analyses. The results shown in the thesis show a feasible reactor, with very safe operation due to the large negative reactivity coefficients during the entire burn-up considered. The DFRm is shown to be reactor that can operate for many years and can, during such a long operating time, breed fuel as well as destroy minor actinides. Therefore, these results can be used as a basis to establish the DFRm as a future G-IV reactor design.

5. Structure and Style

The thesis is excellently written and structured. The main types of analyses have been carried out in four logically placed and mutually supporting sections, together with an initial description in Chapter 4 of the design proposed. In each section, a series of calculations are carried out to fulfil the goals of the work. They are very well presented and comprehensive to explain what is considered as most relevant for the understanding of the entire thesis. Thus, the first part offers a particularly good introduction to the DFRm main characteristics, which helps to appreciate the complexity of the modelling process and the need for the sophisticated codes used. It closes with a good explanation of the need for a new fuel in view of the restrictions imposed on the maximum Uranium enrichment allowed today and it then describes very informatively the methodology that the author wants to develop and use.

The section on the theory, Chapter 3, contains all the information and references to the literature necessary to understand the fundamental basis of the way the codes selected will perform their calculations. The description of the codes is useful and gives more than enough information to understand their capabilities and applicability to the types of reactor analyses they will be used for in the next chapters. The theoretical sections added in each chapter that deals with parametric analyses, material comparisons, methods comparison, and geometric selections, the results are presented complete, and the discrepancies observed, if any, are well explained. And argued. Such a systematic study on the neutronic analysis is clear and will support future submission of reactor transient studies needed for licensing applications for the DFRm.

Finally, the conclusions, together with the suggestions for future work, are summarized excellently and the main achievements are clearly identified, so that the reader can realize how the initial goas introduced in Section 1 have been fulfilled.

6. Grading

No modifications to the thesis are needed and no further clarifications of the content of the thesis are qrequired.

I recommend continuation of the dissertation examination procedure by Mr. Sierchuła. I grade the thesis as:

Excellent with Honors ("wyróżnienie").

because of the quality and difficulty of the work and the successful analysis of a novel reactor design.

In conclusion, the thesis fulfils requirements which are necessary to present for the doctoral degree so that I recommend the admittance of Mr. Sierchuła for the defence of his thesis.

Garching 20.06.2021
Place, date

Signature