EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Directorate G – Nuclear Safety and Security

TO WHOM IT MAY CONCERN

13 June 2023

Assessment of the doctoral thesis presented by Ms. Zuzanna Krajewska entitled "Front-end investigations of the coated particles nuclear fuel for high temperature gas cooled reactors"

Ms Zuzanna Krajewska is known to me since January 2020 when we met in the frame of a technical visit of a TAURON power plant in Poland, organized by the Horizon 2020 GEMINI+ project on High Temperature Gas-cooled Reactors. Since the beginning of her PhD work we had regular contact. I was able to provide her with the specimens that she used in her research and will deliver further specimens in the next few months.

As described on page 10, Ms. Krajewska has based her dissertation on 5 earlier journal publications and 2 conference papers produced during her productive PhD work. Her 108-page dissertation is well structured comprising a detailed introduction to the problem and the context for it. Starting from macroscopic aspects (nuclear reactor and fuel factory) she explains in a very didactic manner important aspects of the fuel containing the TRISO fuel particles down to the individual coatings of this fuel at the sub-millimeter scale and the expected physical damages of these coatings under irradiation.

In the following section, the thesis describes various quality assurance techniques for virgin TRISO fuel. Having learned from earlier experience of other researchers, she compared different specimen preparation techniques and, based on her own test results and clear criteria, selected ion polishing as the best option for her purposes.

Ms. Krajewska then discusses the performance of different possible characterization techniques, namely Scanning Electron Microscopy, Confocal Laser Scanning Microscopy, and Raman Spectroscopy as tools to appreciate the quality and specific characteristics of as-fabricated TRISO fuel.

Apart from quality assurance of un-irradiated TRISO fuel, simulation of possible irradiation defects and examination of irradiated TRISO fuel is a subject of this dissertation. For sample availability, time, budgetary and transport reasons, in-pile experiments of real TRISO fuel particles followed by post-irradiation examinations in hot cells had to remain beyond the scope of this thesis. Instead, Ms. Krajewska used some similarities between ion implantation and neutron irradiation to simulate damage by neutron irradiation during the fuel service life in an HTGR reactor for 1, 3, and 5 years. She did this first analytically using specific computer codes to determine the required experimental conditions followed by the experiments themselves, in which the available fuel particle samples were implanted with ions of different types (He, Ne), energies and fluences.

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Un-irradiated and ion-implanted particle samples then underwent a series of examinations. The dissertation finishes with the analysis and interpretation of the collected data in view of using these techniques for quality assurance purposes in a future TRISO fabrication facility.

It can be concluded that the performed research work is systematic and ambitious. The attempt to simulate neutron irradiation of TRISO fuel by ion implantation is quite innovative, but despite Ms. Krajewska's effort still relatively experimental requiring in the future comparison with neutron-irradiated samples on a statistically relevant basis, which is obviously a very tedious, expensive and time consuming endeavor.

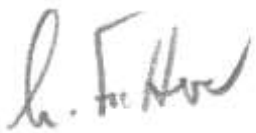
Ms. Krajewska's dissertation is timely and important considering the nuclear ambitions in Poland. Her investment in the subject matter is fundamental for achieving the goals of developing TRISO fuel fabrication and quality assurance capacity in the country.

The research performed is a useful mix of analytical and experimental work, well fitted together. It puts in fact more emphasis on qualification of the examination techniques than on the results achieved on ion-implanted, not fully representative TRISO particles. All along her scientific work, Ms. Krajewska has demonstrated scientific rigor and vigor, initiative, good networking skills as well as the ability to employ and combine very different disciplines. The dissertation is also witness to a high degree of ease in international collaboration.

Some of the more general state-of-the art review sections, especially Sections 2 and 3, would have benefited from an early expert review to avoid a number of imprecisions, gaps and potential misunderstandings. Certain references seem to be outdated while other important ones were not quoted. As the equivalence of ion vs. neutron irradiation has been debated for about half a decade, it would have been appropriate to include in the thesis a more detailed discussion on the opportunities and limits of ion implantation vs. neutron irradiation, if only for corroborating the meaningfulness of Ms. Krajewska's approach.

Overall, the dissertation represents a piece of convincing research with insightful findings that are plausible and verifiable, and can be used as a technological cornerstone for NCBJ's HTGR fuel laboratory plans. During her research work, the candidate has been able to develop a high degree of methodological meticulousness, scientific expertise, resilience and creativity.

Ms. Krajewska's solid contributions to this area of research are clearly visible, be it in the experimental or analytical part or in the interpretation and discussion of her results. In conclusion and in view of the high quality of her work, I believe that the submitted dissertation of Ms. Zuzanna Krajewska easily meets the requirements for a doctorate degree in Physical Sciences, which I propose to grant her with distinction.



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