STU FEI
SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA
FACULTY OF ELECTRICAL ENGINEERING AND INFORMATION TECHNOLOGY
INSTITUTE OF NUCLEAR AND PHYSICAL ENGINEERING

Opponent Review of Doctoral Dissertation

Applicant: **Anhelina Tanchak**

Title of Dissertation: **Investigation of Pu-239 Transmutation for Accelerator Driven Subcritical Reactors**

Opponent: **Prof. Ing. Vladimír Nečas, PhD.**

In accordance with the Study and Examination Rules of BUT, in his/her review the opponent will mainly comment on:
a) the topicality of the dissertation,
b) whether the dissertation achieved its given objective,
c) the problem-solving procedure and the results of the dissertation along with the concrete contribution of the doctoral student,
d) the significance for practical application or the progress in the field,
e) formal and language qualities of the dissertation,
f) whether the dissertation fulfils the conditions of Section 47 (4) of the Act,
g) whether the student proved his/her creative abilities in the given research field and whether the work does or does not comply with the standard requirements placed on the dissertations in the given field. The review is not valid without this conclusion.
It is necessary to add a concise commentary to each of the points below.

Ad a) Topicality of the dissertation

The topic of the dissertation is very topical.
Comment:

Spent nuclear fuel (SNF) contains dangerous radionuclides and its amount is constantly increasing in the world in interim storages. Since some radionuclides of transuranic elements and fission products in SNF have a half-life of up to millions of years, it is necessary to take advantage of the prospective possibility of their disposal by transmutation using the proposed subcritical reactor system (transmutor) – accelerator driven system (ADS). Although this principle has been known for several decades, it has not yet been introduced into industrial practice. Research into transmutation technologies is constantly receiving attention in the world and new supplemented and refined data and knowledge are being obtained. This dissertation topic is currently still a current area of research on transmutation technologies. It is an area of the issue of the spallation target, which was irradiated by beams of high-energy protons at the experimental facility Phasotron at the SUJV Dubna within the framework of the still pre-war (i.e. until February 2022) international cooperation. From this point of view, the topic of the dissertation is certainly highly topical.

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Ad b) Objective of the dissertation

The objective of the dissertation was achieved.
Comment:

The main objective was to investigate through simulations and experimentally spallation and fission reactions, including emerging products in target $^{239}PuO_2$ bombarded with protons with an energy of 660 MeV. At the same time, the aim was to demonstrate the feasibility and effectiveness of the transmutation process, eventually contributing to a better understanding of these nuclear reactions. The dissertation thesis aimed to bring new information about transmutation processes related to systems controlled by accelerators, which can significantly contribute in the future in the disposal of long-lived nuclides from spent nuclear fuel. All set objectives of the dissertation have been met.

Ad c) Problem-solving procedure and the results of the dissertation and the concrete contribution of the doctoral student

The problem-solving procedure and the results of the dissertation are excellent.
Comment:

The dissertation is basically divided as if into two parts. The first theoretical part (first 4 chapters) describes the principles and details related to the ADS system, transmutation, spallation and fission process. Methods for the determination of spallation reaction products, information on the properties of semiconductor HPGe detectors, information on determining reaction rates and effective cross-sections of residual radionuclides are presented here. Attention is also paid to various corrections used to increase the accuracy and correctness of the measured data. This section also contains methodologies for processing and interpretation of gamma spectra. There are information on software packages used to evaluate gamma spectra, calculate nuclear reactions and production rates of radionuclides produced in the target, as well as descriptions of simulation codes suitable for spallation reactions (MCNP, FLUKA, PHITS).
The second experimental part (has 2 chapters) is focused on experiments with plutonium target ($^{239}PuO_2$) and comparisons of its results with simulations. The experiments were aimed at determining the radionuclides produced in the target. The main contribution of the dissertation thesis is the evaluation of obtained experimental data, determination of the overall effective cross-sections of nuclear reactions, where the method of direct kinematics was used, as well as determination of residual reaction products in the target, which were detected by gamma- and mass spectrometry. The contribution of the PhD student is also the presentation of a number of spallation reactions including, multifragmentation, evaporation, fission and other inelastic reaction products. In total, 66 total effective cross-sections of residual nuclides were determined, for which 130 gamma lines were detected. Through these, short-lived radionuclides with half-life ranging from approximately 18 minutes to 18 days, were identified.

Ad d) Significance for practical application or progress in the field

The significance for practical application or progress in the field is above average.
Comment:

Experiments and simulations confirmed the formation and accumulation of a number of short-lived radionuclides in the irradiated target Pu-239 according to expected assumptions and at the same time the existence of potential systematic errors and sources of uncertainty by comparing experimental and theoretical results. The results are useful and important for better understanding and obtaining new information about the process of spallation and fission reactions or transmutation. The new and refined scientific information can be used in the future for larger research projects aimed at accelerator controlled transmutation systems. The dissertation is beneficial for practical application and progress in the field of nuclear engineering.

Ad e) Formal and language qualities of the dissertation

Formal and language qualities of the dissertation are excellent.
Comment:

The formal editing of the dissertation is at a high level, without errors and I have no major comments. The work under consideration is written in English, contains 164 pages of text, including abstracts, content of the work, figures (95), tables (28), a list of abbreviations, and 172 references. Appendices (7) on another 22 pages are attached, mostly with the results of experiments and computational simulations in the form of tables and figures.

Ad f) The dissertation fulfils the conditions of Section 47 (4) of the Act

The dissertation fulfils the conditions of Section 47 (4)*) Act No. 111/1998 Sb. Higher Education Act: YES

((4) Studies are duly finished with a doctoral state exam and dissertation defence, which prove the ability and readiness to work independently in the field of research or development, or in theoretical and creative arts. The dissertation must comprise original and published results or results accepted for publication.*

Ad g) Creative abilities of the student in the given research field. Compliance with the standard requirements placed on the dissertations in the given field.

The doctoral student did prove her creative abilities in the given research field and the work does comply with the standard requirements placed on the dissertations in the given field.
Comment:

The author demonstrated excellent theoretical knowledge, and also mastered demanding simulation calculations, evaluation of experiments and interpretation of obtained results. She has 3 and 4 records in the WOS and SCOPUS databases, she is the first author in 1 article in an indexed scientific journal, for which she records 20 citations in SCOPUS. Other records are papers in proceedings of international scientific conferences.

Overall evaluation:

The submitted dissertation is of high quality and original. In view of the above, I recommend the dissertation for defense and after successfully completing the defense, I propose to award Anhelina Tanchak the degree of Doctor of Philosophy (Ph.D.) in the study program High Current Electrical Engineering and Electrical Power Engineering.

Opponent's questions:

- In ADS systems driven by high-energy protons, there is an increase the neutron flux density in the transmutor core by 1-2 orders of magnitude compared to a conventional reactor. In the target, the spallation reaction of a high-energy proton with a heavy nucleus (e.g. Pb, U, Pu, ...) first produces a highly excited nucleus and then evaporates a certain number of its nucleons or light nuclei. An experiment in LANL (1994) with a Pb target (LANL sunnyside experiment: Study of neutron production in accelerator-driven targets | AIP Conference Proceedings | AIP Publishing), where the results for neutron yield from the spallation reaction matched perfectly with the MCNP code calculation (LAHET). Using protons with an energy of 660 MeV, the target from Pb would extract free neutrons from spallation reaction ~ 16 to one interacting proton. Since in this dissertation the target lead is replaced by much heavier plutonium, I miss one important information in the tesis. What was approximately the neutron yield from spallation for this target material and for the proton energy used at 660 MeV? What was the average kinetic energy of these evaporated neutrons?
- Have the experimental data obtained by gamma spectroscopy also been corrected for the internal conversion process? (This applies mainly to heavier nuclei.)
- Were the simulation calculations also taking into account the possible process of radiation capture of neutrons by nuclei formed radionuclides and their decay products in the target?
- Which factors most influence the differences (up to 3 orders of magnitude) of the established values of effective cross-sections of radionuclides formed after irradiation of $^{239}PuO_2$ from experiments and theoretical simulations?
- How do you see the perspective of these ADS systems for the industrial use of transmutation technologies, respectively the construction of a transmutor prototype for transmutation of dangerous radionuclides in the world?

I ☒ recommend ☐ do not recommend the dissertation for the defence.

Date: 20.05.2024

[redacted]

Signature: .....