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Dear Professor Balabekyan,

Please find enclosed my opinion of the dissertation of Susanna V. Gaginyan.

**O P I N I O N**
**on the dissertation of Susanna V. Gaginyan**
**"Study of Nuclear Reaction Mechanisms in Heavy Nuclei under High-Energy Light Particle Irradiation"**
**submitted for the degree of Candidate of Physical and Mathematical Sciences**
**in the specialty 01.04.16 – Nuclear, Elementary Particle and Cosmic Ray Physics**

The Candidate dissertation entitled "Study of Nuclear Reaction Mechanisms in Heavy Nuclei under High-Energy Light Particle Irradiation" is devoted to the experimental study of nuclear reaction mechanisms in heavy nuclei under irradiation by high-energy light particles. The dissertation deals with important and relevant questions of modern experimental nuclear physics concerning the study of spallation, fission, fragmentation and multifragmentation phenomena, as well as the study of isotopic effects in reactions induced by high-energy deuterons on isotopically enriched lead targets.
The relevance of the dissertation topic is well justified. Studies of high-energy nuclear reactions on heavy targets are of considerable interest both for fundamental nuclear physics and for applied problems of nuclear technology, including accelerator-driven systems, radioactive waste transmutation, radiation damage studies, and advanced nuclear reactors based on lead and lead-bismuth coolants. In this regard, reliable experimental data on residual nuclide production, isotopic yields, and reaction mechanisms are necessary for the development and validation of modern theoretical and transport models.

The dissertation consists of an introduction, three chapters, a conclusion, the list of publications, and bibliography. The volume of the dissertation is 107 pages, which include numerous figures and tables demonstrating the experimental results and their interpretation.

In the **introduction**, the author explains the significance of the research topic, formulates the aim and the main objectives of the work, defines the scientific novelty and practical value of the results obtained, and formulates the major results included in the dissertation.

The **first chapter** is dedicated to the experimental methods and experimental setup for measuring the production cross-sections of residual nuclei in reactions induced by 4.4 GeV deuterons on isotopically enriched lead targets. The author describes in detail the induced activity technique, measuring gamma-spectra with the help of HPGe detectors, the procedure of detector efficiency calibration, beam intensity measurement, and the method of determining production cross-sections of the residual radioactive nuclei.

In the **second chapter**, the results of experimental measurements of production cross-sections of residual nuclei and the analysis of mechanisms of deuteron-induced nuclear reactions on lead isotopes are presented. The mass yield distributions, charge distributions, total isobaric cross-sections are analyzed, and the obtained experimental data are compared to theoretical model calculations. Particular attention is paid to the analysis of mechanisms of nuclear reactions in various mass ranges, as well as to the comparison between the results of experiments and predictions of modern transport models. As a result of this analysis, it was possible to make conclusions on the significance of particular reaction mechanisms, and estimate the applicability limits of current theoretical models in fragment production, especially in the range of light and intermediate mass fragments.

The **third chapter** is dedicated to the study of isotopic effects and isoscaling in reactions induced by deuterons on isotopically enriched lead isotopes. The author determines isoscaling parameters for residual nuclei in various mass ranges, and calculates the symmetry energy coefficient using the obtained experimental data. This work is relevant from the point of view of studying isospin-dependent effects in nuclear reactions and for studying the symmetry energy term of the nuclear equation of state under conditions of highly excited nuclear systems.
The scientific novelty of the dissertation can be characterized as follows:

- For the first time, high-energy deuteron-induced nuclear reactions on the isotopically enriched target $^{204}$Pb have been studied experimentally.
- A systematic comparison of residual nucleus production cross sections for deuteron-induced reactions on isotopically enriched lead isotopes has been carried out under identical irradiation conditions.
- New experimental data have been obtained which can be used as benchmark data for testing and improving modern theoretical and transport models describing high-energy nuclear reactions in heavy nuclei.

The practical significance of the work is related to the possibility of using the obtained experimental data for the validation and improvement of nuclear reaction models used in accelerator-driven systems, activation analysis, radiation studies, and advanced nuclear reactor technologies based on lead and lead-bismuth materials.

The results of the dissertation have been successfully presented at international conferences and published in scientific journals; this shows the scientific validity and reliability of obtained results.

**Remarks and shortcomings:**

1. This dissertation addresses reactions of enriched isotopic targets of Pb with deuterons. The aim is to interpret the results of various processes with high energy deuterons on heavy nuclei for theoretical transport models. The experimental approach is irradiation and subsequent measurements with HPGe detectors to distinguish spallation, fission, and fragmentation effects that are triggered by the deuteron beams. Several places in the text, the beam is referred to as 4.4 GeV d or 2.2 GeV/nucleon d. It would be best to be consistent throughout the dissertation.
2. In the introduction chapter, claims are made for the relevance of the work to modular reactors. It might be better to narrow the scope to "benchmarking high-energy reaction models of relevance to spallation"
3. Claims are made that the work with 204Pb is being measured for the first time, there should be citations provided that justify the case.
4. Also, a table of existing data sets and results from this work would be helpful. Similarly, a table with proton beam irradiation might be interesting in comparison.
5. There was discussion of calibrations for efficiency, deadtime, and self-absorption. A section on calibrations would have been useful.
6. MCNP is used, which version?
7. Agreement is indicated as «best agreement» but no chi-square or RMS value is presented.
8. Some discussion of intramolecular cascades versus reactions at lower energies would be useful.
9. Also, Is there some applicability of this work to nuclear energy in Armenia?

Despite the remarks mentioned above, the Candidate dissertation of Susanna Gaginyan represents a completed scientific work devoted to an important problem of modern experimental nuclear physics. The dissertation contains new experimental results of scientific and practical importance, and the conclusions drawn by the author are well justified.

The dissertation meets the requirements for Candidate of Physical and Mathematical Sciences theses, and its author, Susanna V. Gaginyan, deserves to be awarded the degree of Candidate of Physical and Mathematical Sciences in the specialty 01.04.16 – Nuclear, Elementary Particle and Cosmic Ray Physics.

Sincerely,

**Professor Ani Aprahamian**
**Frank M. Freimann Professor of Physics & Astronomy**
**and**
**Concurrent Professor of Chemistry & Biochemistry**
University of Notre Dame