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Application Summary

Competition Details

Competition Title:	2022 Program for Advancing Collaborative Teams (PACT)
Category:	
Cycle:	
Submission Deadline:	06/30/2022 11:59 PM

Application Information

Submitted By:	Yuri Kamyshkov
Application ID:	3257
Application Title:	Development of a Program for New Oscillation Physics Search with Cold Neutrons
Date Submitted:	06/30/2022 4:23 PM

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Amount Requested:	168,515

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Application Details

Proposal Title

Development of a Program for New Oscillation Physics Search with Cold Neutrons

Acknowledgment

Applicant Acknowledgement

[Acknowledged] **By checking the box and clicking Submit Application, the Applicant acknowledges the requirements for participation in the PACT program, including but not limited to budgetary restrictions, expected outcomes and timelines. Further, the Applicant acknowledges that any unused funds will be returned to the Science Alliance at the conclusion of the project.**

Note: In order to be able to select the Save as Draft button, this box must be checked, however, your final application will not be fully submitted until you click the Submit Application button.

June 30, 2022

PACT Proposal

Development of a Program for New Oscillation Physics Search with Cold Neutrons

Yuri Kamyshkov-PI, Professor of Physics, UTK
Matthew Frost-PI, Research Scientist, Neutron Optics and Instrument Development, ORNL

Michael Fitzsimmons-Co-PI, Distinguished R&D Staff and Professor of Physics, ORNL/UTK
Lawrence Heilbronn-Co-PI, Professor of Nuclear Engineering, UTK

(see * footnote below)

(*) Several members of UT-ORNL collaboration from ORNL side will join this proposal pending the approval of their participation in the research program from ORNL Directorate.

June 30,2022

PACT Proposal:

Development of a Program for New Oscillation Physics Search with Cold Neutrons

Yuri Kamyshkov-PI/UTK, Matthew Frost-PI/ORNL

Michael Fitzsimmons-Co-PI/UTK/ORNL, Lawrence Heilbronn-Co-PI/UTK

Project Summary

Our collaboration between UT and ORNL is pursuing development of a long-term experimental program to search for new neutron oscillation physics. The program explores the concept of matter-antimatter transformation and a new concept of the existence of a parallel "mirror" sector that can be part of the mysterious Dark Matter in the universe. Detecting such a new physics would be fundamental discovery that can change the field of particle physics and cosmology. This program will include a series of small-scale experiments performed within the ORNL General User Program using the GP-SANS instrument at the HFIR reactor in 2023-2027 and will be followed by higher sensitivity experiments based on our ideas and performed with our participation by international NNbar/HIBEAM collaboration at the European Spallation Source in 2027-2035. Key for the success of the program will be a support for full-time UT postdoc and students working on the program development and experiments.

Description of Proposed Research

Why is there only matter, but virtually no antimatter, in the universe? Since we expect equal amounts of matter and antimatter should have been created in the universe, there must be some physics processes that result in an excess of matter. However, no process resulting in a change of the amount of matter or antimatter (called Baryon Number B) has ever been experimentally detected. The question of violation of Baryon Number has motivated a worldwide program of high-sensitivity searches, including searches for proton decay, Majorana neutrinos, and neutron-antineutron oscillation searches [1]. A possibly related question of the nature of the mysterious dark matter that makes up 85% of the whole matter in the universe, has also motivated many ideas of the possible dark matter particle candidates and experimental searches for those. Despite decades of these searches, the particle nature of dark matter remains unknown. The particle physics community has highlighted the importance of pursuing all feasible avenues for searches for candidates for dark matter based on a number of unanswered questions in physics [2]. Our proposal explores a new approach to these fundamental physics puzzles.

Searches for neutron-antineutron oscillations, a ΔB=2 process, provides one of the most well-motivated avenues for discovery of Baryon Number Violation, and new facilities and technologies create the opportunity for tremendous improvement in sensitivity in the next generation of searches [3]. The possibility that the neutron can oscillate into a dark matter neutron state is only weakly constrained [4]. If discovered, this process would be evidence of violation of baryon number by ΔB=1 [5]. It also could explain the persistent 4-sigma disagreement between appearance vs. disappearance-based neutron lifetime measurement techniques [6] and would offer a clue as to the particle nature of dark matter. Prior limits on neutron oscillations into dark, "mirror" neutrons have been obtained exclusively from ultracold neutrons experiments, where some significant but controversial anomalous results have been reported [4].

Our collaboration between UTK and ORNL has developed a novel approach using cold neutrons to search for neutron oscillations into the hidden sector, by using neutron regeneration method [6 - 10]. In this approach, neutrons transition into mirror neutrons, which pass through a wall (since they are non-interacting dark matter), then transition back into detectable neutrons, where the probability of transition is enhanced by manipulating the magnetic field environment. A first search [11] performed at the Spallation Neutron Source (SNS) by our collaboration generated significant media attention (see ORNL press release June 28, 2022 [12]). This experiment [11] completely excluded one possible "non-degenerated mechanism" in mirror matter where neutrons oscillating into mirror neutrons might be the source of the neutron lifetime anomaly [13]. Having successfully demonstrated the experimental search technique, more sensitive searches for other mechanisms are possible by utilizing the high intensity neutron beam and large area, low background neutron detector of the General Purpose – Small Angle Neutron Scattering (GP-SANS) instrument at the High Flux Isotope Reactor (HFIR) (see Figure 1) in collaboration with the instrument scientists. These experiments can be performed in stages of increasing complexity, concluding with a search for neutrons oscillating into mirror neutrons, then oscillating back into antineutrons [12]. This final experiment will not only provide important input on how the matter-antimatter asymmetry could have arisen, but also will provide critical R&D opportunities for future, very high sensitivity searches for neutron-antineutron oscillation searches and possible resolution of the matter-antimatter asymmetry of the universe [5].

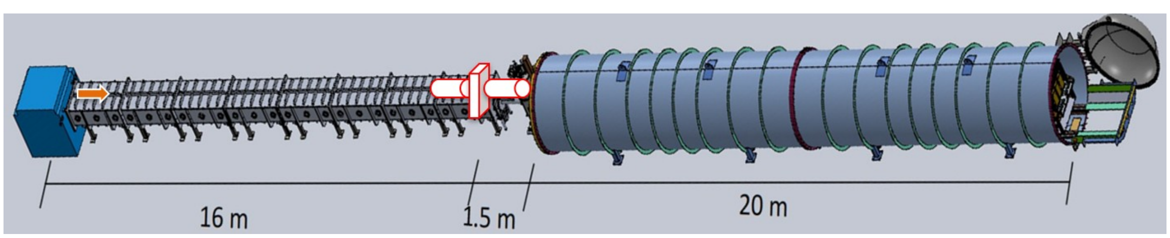

Figure 1. Schematic of one of the first experiments (modifications are shown) in the proposed program that will be performed at GP-SANS instrument at HFIR reactor.

The scientific goal of our research group in the next two years is (A) to repeat the SNS experiment at GP-SANS for much higher sensitivity, and (B) to prepare for a search for a new mechanism for neutron oscillations induced by a Transition Magnetic Moment (TMM) [10] arising due to possible neutron to mirror neutron transformation. Beamtime for this experiment will be requested through the HFIR General User Program. These measurements will support a longer-term research program at HFIR (in 2023-2027) which includes several different experiment configurations at GP-SANS of increasing complexity, designed in collaboration with the instrument scientists.

The scientific goals of our research program will be pursued in (A) and (B) experiments above and in the following cold neutron beam experiments:

(C) Search for neutron disappearance using a laboratory magnetic field to compensate the “mirror magnetic field.” A positive result from this experiment would provide the first observation of Baryon number violation by one unit $|\Delta B|=1$. Also, the existence of “mirror photons” of the “mirror magnetic field” would be demonstrated [7,8]. That would be a significant step for demonstration of the existence of Mirror Matter with a structure similar to our Ordinary Matter.

(D) Search for a new process of neutron “regeneration.” [7,9] A beam of neutrons passes through a magnetic field that compensates for the mirror magnetic field effect, thus producing mirror neutrons. Neutrons will be totally absorbed by an absorber, but mirror neutrons pass through. The mirror neutrons exiting the absorber will be regenerated back to ordinary neutrons in the corresponding magnetic environment after the absorber and detected as “impossible” neutrons passing through the wall.

(E) By manipulating the magnetic environment in the experiment, it will be possible to check whether “mirror neutrons” are in fact “mirror anti-neutrons,” since the latter should have the opposite magnetic moment. Such a discovery would be important for models of baryogenesis in the universe [14].

(F) There is an untested possibility that a neutron can transformed into an antineutron as a result of a spontaneous transition through the mirror neutron state [15]. Searching for this process will require the presence of a magnetic field and can be also performed in regeneration mode. As there are no prior searches for this process, the probability of this process could be large enough even for practical purposes such as energy production. This would also be a spectacular demonstration of baryon number violation by two units $|\Delta B|=2$.

(G) A two-level quantum system, such as an oscillating system of neutron to antineutron or neutron to mirror neutron, according to a quantum-mechanical classical treatment, should lead to a reset of the oscillation phase, that is referred to as the “measurement” of the quantum-mechanical state. We include in our program a reflectometry experiment to be performed at one of the SNS instruments to study reflection from a strongly absorbing material. This experiment might allow improvements of higher sensitivity for the ultimate search for neutron-antineutron transformation planned at the ESS.

We plan to implement this research program in a series of small-size and relatively short experiments using mostly GP-SANS at HFIR as an instrument of the General User program. Several members of our ORNL-UT research group are also members of the international NNbar/HIBEAM Collaboration. HIBEAM plans to pursue a more sensitive experimental program at the ESS. This new advanced neutron source in Europe is in construction now and will provide first neutrons for experiments in 2027. The NNbar/HIBEAM neutron oscillation research program is essentially based on the ideas developed by our group for neutron-antineutron and neutron-mirror neutron searches. Y. Kamyshkov of UT is a Project Scientist of the NNbar/HIBEAM collaboration. He together with L. Broussard of ORNL are members of the Executive Committee of the NNbar Collaboration responsible for planning and developing the route to experiments at the ESS that can be performed during 2027-2035 [16,17]. Collaboration with NNbar/HIBEAM represents our future long-term plan beyond the program at ORNL for neutron oscillation searches. Advantages of using the ESS cold neutron beams in the future include higher neutron fluxes, larger available neutron flight distances, and dedicated longer beam-line time. The shorter-term program at ORNL will be essential to optimizing those future high sensitivity experiments.

Development of our neutron oscillation research program at GP-SANS will require simulation and optimization studies to understand how to calculate transition probabilities for different mechanisms in the beamline environment as well as technical studies including prototyping of how to accommodate our experimental equipment into the GP-SANS instrument. Our UT-ORNL research group, which has demonstrated its potential and capability in the experiment at SNS [11] includes scientists from ORNL: L. Broussard, L. DeBeer-Schmitt (instrument scientist of GP-SANS instrument), M. Frost (defended his PhD at UT in 2019), F. Gonzalez, E. Iverson and from UT: Physics Professors Y. Kamyshkov, M. Fitzsimmons (joint appointment with ORNL), and Nuclear Engineering Professor L. Heilbronn.

This project creates multiple opportunities for undergraduate and graduate students to participate in the research. Participating students will be exposed to the frontier of unresolved particle physics problems, they will gain familiarity with operational requirements of experiments at GP-SANS and generally of particle physics experiments, with the analytical approaches and simulation software used in particle physics and will contribute to preparation of physics results which can be presented at the conferences and published in peer-reviewed journals. In our initial experiment published in PRL [11] several unsupported graduate and undergraduate students from UT have participated. They were motivated by their interest in new physics and by the possibility to make contributions to a live experiment. We regret that we had no funding to support any graduate students for a PhD thesis in that experiment.

Scientifically, these proposed measurements and studies will not only provide insight on the violation of baryon number, on the source of the discrepancy between neutron lifetime measurements and on the composition of dark matter but will also provide important experience in conducting searches for rare transitions of the neutron using cold beams. This experience will be critical for designing future stages of searches for neutron transitions at HFIR, leading also to R&D opportunities that can pave a path to a high sensitivity search for neutron-antineutron and mirror neutron oscillations at the European Spallation Source [5]. We hope that PACT program will support development of our long-range program between UT and ORNL for fundamental neutron research at HFIR/ORNL with future growth to an international experimental program at ESS. Critical for the development of our proposed program is dedicated work of a UT-based postdoc and graduate students.

Description of funding opportunities

Our proposed program is for the search of neutron transformations to mirror neutrons and to antineutrons with a suite of small cold-neutron beam experiments at the ORNL GP-SANS HFIR instrument. This program addresses two fundamental problems that the High-Energy Program Advisory Panel has identified [18] as outstanding problems in particle physics, requiring discovery of the mechanism of matter-antimatter asymmetry of the universe and establishing the nature of dark matter. However, HEP Office of DOE is not yet accommodated in its funded scope the physics with low-energy neutrons. There are couple of groups in Europe that are trying to address the same physics with Ultra-Cold Neutrons. As we know, so far, we have no competition in US. The community-planning “Snowmass” process going this year in US should clarify for DOE the scope and status of our research [1,2].

We recently received a grant from DOE Office of Nuclear Physics for support of the initial steps in a neutron to mirror neutron oscillation research at ORNL [20] (experiments A and B above). This two-year grant will provide $150K funding for the UT group that will allow support of one graduate PhD student and one month of summer salary for the UT PI. This grant also provided $50K for the ORNL group to support initial experiments at GP-SANS and HFIR.

Our NSF proposal [21] is still pending the resolution of the agency. This proposal is focusing on involvement of groups from the Indiana University and the University of Kentucky who are seeking support for participation in our research experiments (B) and (C). The NSF proposal is seeking support for a UT graduate student and small support for materials for construction of experiment (B).

In May 2022 we also applied for UT SA StART funding seeking the support for one PhD graduate student working on experiment (A) and (B). This proposal is still pending.

In 2019 we started our first set of small experiments which did not require the construction of new equipment. These experiments were performed within the infrastructure provided by the User Program of the ORNL Neutron Science facilities. UT graduate and undergraduate students participated in this research. They worked without support on the experiment preparation and data analysis. Now, the paper with analysis of the first experiment performed in 2019 at SNS is published in Physical Review Letters and these students are included as authors of the paper. The data of the second experiment performed at SNS in 2020 are in the final stages of analysis despite lacking student workforce. With availability of new funding and a postdoc and student’s participation, we will be able to make initial steps in the development and realization of our experimental program and will again submit a proposal to DOE-NP and to NSF for the continuing support of the next steps of our research program with the goal of converting our activities into the self-sustaining funding from DOE/NP and/or NSF.

Description of prior affiliations, collaborations, and publications with ORNL

The UT PI Y. K. in 1991-1999 had a joint UT- ORNL appointment and in this affiliation participated in following research projects with ORNL: L3 experiment at LEP collider at CERN, development of L^{*} and GEM experiments for SSC, PHENIX experiment at RHIC, development of ORLaND neutrino project for SNS, and the KamLAND neutrino experiment in Japan. He was co-author of 150 papers on these research activities under ORNL affiliation. At ORNL, UT PI had developed a new concept of an experiment to search for neutron-antineutron oscillations $n \rightarrow \bar{n}$ for the Advanced Neutron Source (ANS) reactor which was a main construction project at ORNL before the SNS. In 1996 the PI with ORNL has organized an International Workshop at Oak Ridge [22] on the physics for baryon number violation trying to attract the attention of physics community to the possibility of a search for fundamental physics with neutrons. Following the destiny of SSC, the ANS project was closed by the federal government. The idea of $n \rightarrow \bar{n}$ search experiment came ahead of its time. It was only after 2014 that the idea of such a large-scale experiment was adopted and is now being developed with participation of PI by the NNbar/HIBEAM Collaboration in Europe for the ESS.

Co-PI professor of Nuclear Engineering Department Lawrence Heilbronn contributing his expertise in simulation and understanding of radiation backgrounds.

Co-Pi professor of Physics Michael Fitzsimmons (joint UT-ORNL appointment) is contributing his expertise in neutron beams, including polarized neutron beams, detectors, neutron scattering instrumentation, and magnetic materials.

Our current UT-ORNL Collaboration named "NN'" was developed in 2016 based on the common interest to the unresolved problems of fundamental physics that can be explored with neutrons. Driven by the interests of the collaboration members have published papers [7,8,9,10,11,17,23] and participated in writing large review papers [1,2,3,5].

The research program for ORNL discussed in this proposal, although having some similarities with this large $n \rightarrow \bar{n}$ experiment pursued at ESS, is motivated by the arguably different phenomenon of nature: the Dark Mirror Matter. Our program is based on yet unexplored physics mechanisms and requires for observation a new method of neutron regeneration under specific environmental conditions (magnetic field). All experiments envisaged in our research program are small-size and small-cost as compared to the other Dark Matter search projects pursued by DOE/HEP mission. Our experiments have, however, a potential to make a major discovery by observing the effects identifying the nature of Dark Matter as Mirror Matter. These observations, if confirmed, might be transformational for the fields of particles physics and cosmology.

Description of expected extended collaborations with ORNL colleagues

The UT-ORNL NN'- group has developed a comprehensive long-range research program of Mirror Matter searches with neutrons that includes several experiments. The mechanisms that will be explored are not excluding each other but addressing different possible properties and interactions of Mirror Matter that should provide a controlled approach to observation of the elusive Mirror Dark Matter. This exploratory high-risk high-reward program, when supported by funding agencies, will require 5-6 years for execution during 2023-2027 at the GP-SANS instrument operating within HFIR General User's program and for higher search sensitivity it will be extended to a larger effort for experiments at the European Spallation Source [5] in 2027-2035. Within these years we expect as a Collaboration to produce many journal publications on technical development topics and on the results of experiments. Several other institutions in the US express interest in joining our UT- ORNL collaboration and research at ORNL including Indiana University and University of Kentucky [21]. Researchers from Stockholm University and from the European Spallation Source intend to join our ORNL research for experiments (B) – (G) to gain experience and to train their students and postdocs in this new type of neutron physics research. Together with these institutions we plan to continue exploration of the new physics of neutron oscillations at the ESS during 2027-2035. We expect that UT-ORNL collaboration will play a leading role in this research at ESS. Our Collaboration is already enjoying the benefits of joint faculty appointment. We hope that with the development of our unique program and with the progress of neutron-mirror neutron and neutron-antineutron search experiments, and also with sustainable support of funding agencies supporting our research from ORNL and UT sides, our research group can grow including new faculty and new joint faculty positions.

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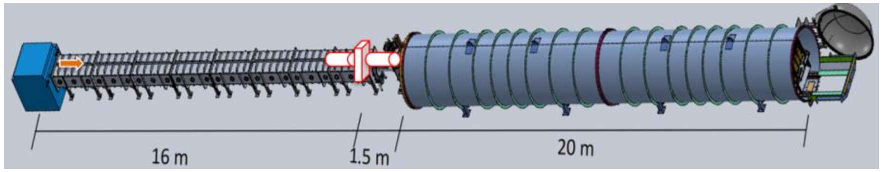
Development of a Program for New Oscillation Physics Search with Cold Neutrons

Yuri Kamyshkov-PI/UTK, Matthew Frost-PI/ORNL, Michael Fitzsimmons-Co-PI/UTK/ORNL, Lawrence Heilbronn-Co-PI/UTK

Objective

Pursue the development of the experimental program to search for the new neutron oscillation physics. This long-range program will initially include a series of small experiments performed at HFIR/ORNL reactor in 2023-2027 and will be followed by higher sensitivity experiments performed at the European Spallation Source is 2027-2035.



Schematic of one of the initial experiments (modifications are shown) in the proposed program that will be performed at GP-SANS instrument at HFIR reactor

Our **NN′ Collaboration** started by the UT- ORNL research group now includes the University of Indiana and the University of Kentucky. The Collaboration is also part of the **NNbar Collaboration** with the groups of ESS and Stockholm University in Sweden which pursues the experiments proposed by us to be performed at the new-constructed ESS facility that will start producing neutrons in 2027.

Innovation

- Experimental search for neutron oscillations to mirror neutrons and to antineutrons might resolve two monumental puzzles of physics: absence of antimatter in the universe and the nature of Dark Matter.
- These puzzles have been unsuccessfully probed in many expensive, state-of-the-art experiments, including direct Dark Matter searches and at LHC.
- Practically unexplored field addressed by our new program starts with a suite of several small-scale experiments to be performed at ORNL. Higher sensitivity search for transformations to mirror neutrons and to antineutrons will be performed within international NNbar collaboration at the European Spallation Source (ESS) in Sweden.

Research Impact

- Proposed high-risk high-impact program might lead to fundamental discoveries that will change the field and reformulate the scope of research in particle physics and cosmology.
- Nature of Dark Matter can be established as being Mirror Matter.
- Transformations of neutrons to mirror neutrons can explain several existing experimental anomalies observed with ultracold neutrons.
- Discovery of neutron to antineutron transformation would point out the direction of resolution of antimatter asymmetry of universe.
- Our research program was originated by the UT- ORNL group in collaboration with theory colleagues who continue to generate new ideas for observable Mirror Matter. This program is unique and has no peers in the world.
- Research topic is attracting significant interest of the best undergraduate majors. Small duration and low cost of experiments of the program allows many PhD students to be trained.
- Key for the program development will be postdoc working 100% on the preparation of experiments at ORNL and on program development.

Potential Applications

- Proposed program will explore several effects related to various possible manifestations of Mirror Matter. One such possible effect is transformation of neutron to antineutron through regeneration from mirror state, that can be enhanced by the magnetic field. This transformation of matter to antimatter that potentially can lead to the new sources of energy.
- The program aims to strengthen leadership of UTK and ORNL as a leading institutions for the new fundamental neutron physics.
- This program aims to increase the rating and scientific prestige of UT Physics in the country.
- The program aims for education of undergraduate and graduate students for future work on developing neutron technology and fundamental physics.

Funding Agency:	UTK/PACT		TCE 001 (Rev 1-24-2020)
PI Name(s):	Yuri Kamyshko, Michael Fitzsimmons, Lawrence Heilbronn		
Project Title:	Development of a Program for New Oscillation Physics Search with Cold Neutrons		
Project Start Date:	8/1/2022	Project End Date:	7/31/2023

Salaries Inflation Rate **(UTK)**	3.00%
Salaries Inflation Rate **(JFO)**	4.10%
GRA Insurance Inflation Rate	6.00%
Tuition Inflation Rate	2.00%

	A. Senior Personnel	UTK or JFO	Base Annual Salary	Appt. Type	Person Months Year 1	Person Months Year 2	Person Months Year 3	Person Months Year 4	Person Months Year 5	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
Yes	Yuri Kamyshko	UTK	133,742	9	0.28430					4,225	-	-	-	-	4,225
Yes	Michael Fitzsimmons	JFO	210,153	12	0.18892					3,309	-	-	-	-	3,309
Yes	Lawrence Heilbronn	UTK	178,007	9	0.20059					3,967	-	-	-	-	3,967
Yes		UTK								-	-	-	-	-	-
Yes		UTK								-	-	-	-	-	-
Yes		UTK								-	-	-	-	-	-
Yes		UTK								-	-	-	-	-	-
Yes		UTK								-	-	-	-	-	-
Yes		UTK								-	-	-	-	-	-
Yes		UTK								-	-	-	-	-	-
									Subtotal Senior Personnel	*11,501*	-	-	-	-	*11,501*

	B. Other Personnel	Base Monthly Salary	#	Person Months Year 1	Person Months Year 2	Person Months Year 3	Person Months Year 4	Person Months Year 5	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
Yes	Post Doc(s)	5,208.33	1	12.0000					62,500	-	-	-	-	62,500
Yes	Post Doc(s)								-	-	-	-	-	-
Yes	Post Doc(s)								-	-	-	-	-	-
Yes	Other Professional								-	-	-	-	-	-
Yes	Other Professional								-	-	-	-	-	-
Yes	Other Professional								-	-	-	-	-	-
Yes	GRA(s)	2,495.37	1	12.0000					29,944	-	-	-	-	29,944
Yes	GRA(s)								-	-	-	-	-	-
Yes	GRA(s)								-	-	-	-	-	-
Yes	GRA(s)								-	-	-	-	-	-
Yes	Undergraduate Researcher(s)	578.57	2	7.0000					8,100	-	-	-	-	8,100
Yes	Secretarial/Clerical								-	-	-	-	-	-
Yes	Other								-	-	-	-	-	-
								Subtotal Other Personnel	*100,544*	-	-	-	-	*100,544*
	Total Salaries & Wages								**112,045**	**-**	**-**	**-**	**-**	**112,045**

C.	**Fringe Benefits**		Year 1	Year 2	Year 3	Year 4	Year 5	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
	Yuri Kamyshko	UTK	18.35%	18.35%	18.35%	18.35%	18.35%	775	-	-	-	-	775
	Michael Fitzsimmons	JFO	51.10%	51.00%	51.00%	51.00%	51.00%	1,688	-	-	-	-	1,688
	Lawrence Heilbronn	UTK	26.03%	26.00%	26.00%	26.00%	26.00%	1,033	-	-	-	-	1,033
	0	UTK	33.00%	33.00%	33.00%	33.00%	33.00%	-	-	-	-	-	-
	0	UTK	33.00%	33.00%	33.00%	33.00%	33.00%	-	-	-	-	-	-
	0	UTK	33.00%	33.00%	33.00%	33.00%	33.00%	-	-	-	-	-	-
	0	UTK	33.00%	33.00%	33.00%	33.00%	33.00%	-	-	-	-	-	-
	0	UTK	33.00%	33.00%	33.00%	33.00%	33.00%	-	-	-	-	-	-
	0	UTK	33.00%	33.00%	33.00%	33.00%	33.00%	-	-	-	-	-	-
	0	UTK	33.00%	33.00%	33.00%	33.00%	33.00%	-	-	-	-	-	-
	Post Doc(s)		28.88%	29.00%	29.00%	29.00%	29.00%	18,050	-	-	-	-	18,050
	Post Doc(s)		53.81%	54.00%	54.00%	54.00%	54.00%	-	-	-	-	-	-
	Post Doc(s)		53.81%	54.00%	54.00%	54.00%	54.00%	-	-	-	-	-	-
	Other Professional		33.00%	33.00%	33.00%	33.00%	33.00%	-	-	-	-	-	-
	Other Professional		33.00%	33.00%	33.00%	33.00%	33.00%	-	-	-	-	-	-
	Other Professional		33.00%	33.00%	33.00%	33.00%	33.00%	-	-	-	-	-	-
	Undergraduate Researcher(s)		8.00%	8.00%	8.00%	8.00%	8.00%	648	-	-	-	-	648
	Secretarial/Clerical		33.00%	33.00%	33.00%	33.00%	33.00%	-	-	-	-	-	-
	Other		33.00%	33.00%	33.00%	33.00%	33.00%	-	-	-	-	-	-
	GRA Health Insurance (per MONTH each GRA)		Year 1	Year 2	Year 3	Year 4	Year 5						
			212.00	224.72	238.20	252.49	267.64	2,544	-	-	-	-	2,544
	Total Fringe Benefits							24,741	-	-	-	-	24,741
	Total Salaries & Benefits							**136,786**	**-**	**-**	**-**	**-**	**136,786**

		Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
D.	**Equipment** (Itemize Equipment with cost of $5,000 or greater)						
1.		-	-	-	-	-	-
2.		-	-	-	-	-	-
3.		-	-	-	-	-	-
4.		-	-	-	-	-	-
5.		-	-	-	-	-	-
	Total Equipment	-	-	-	-	-	-
E.	**Travel** (Complete the TRAVEL Sheet Tab) *Domestic*	1,121	-	-	-	-	1,121
	Foreign	-	-	-	-	-	-
	Total Travel	1,121	-	-	-	-	1,121
F.	**Participant Support Costs** (Complete the PARTICIPANT SUPPORT Sheet Tab, if applicable)	-	-	-	-	-	-
G.	**Other Direct Costs**						
	Supplies (Complete the SUPPLIES Sheet Tab)	15,000	-	-	-	-	15,000
	Publication	-	-	-	-	-	-
	Shipping & Postage	-	-	-	-	-	-
	Maintenance & Repairs	-	-	-	-	-	-
	Consultant Services	-	-	-	-	-	-
	Computer Services	-	-	-	-	-	-
	Subcontracts (Complete the SUBCONTRACTS Sheet Tab, if applicable)	-	-	-	-	-	-
	Contractual Services	-	-	-	-	-	-
	User Facility Fees	-	-	-	-	-	-
	Other: <please specify here>	-	-	-	-	-	-

Graduate Student Tuition (per YEAR each GRA)	Year 1	Year 2	Year 3	Year 4	Year 5
	15,608	15,920	16,238	16,563	16,894

		Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
	Graduate Student Tuition	15,608	-	-	-	-	15,608
	Total Other Direct Costs	30,608	-	-	-	-	30,608
H.	**Total Direct Costs**	168,515	-	-	-	-	168,515
I.	**F&A Base Type** (click B97 and select from dropdown): **Modified Total Direct Costs** — *Base*	152,907	-	-	-	-	152,907
	F&A Rate Type: **Sponsor does not allow F&A (0%)** — *Applied F&A Rate*	*0.000%*	*0.000%*	*0.000%*	*0.000%*	*0.000%*	
J.	**F&A Costs** (click F99 and select from dropdown)	-	-	-	-	-	-
K.	**Total Costs**	$ 168,515	$ -	$ -	$ -	$ -	$ 168,515

YEAR 1

Purpose of Travel	Depart From	Destination (if known)	No. of Days	No. of Travelers	Conference Reg. Fees	Airfare	Additional Costs (per Traveler)	Lodging (per night)	Per Diem	Total	Details (examples of conferences, mileage calculations, etc.)
Domestic Travel					*Contractual Svcs (446000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*		
For presentation to funding agencies	Knoxville	Washington, DC	2	1	$0	$447	$0	$258	$79	$1,121	
										$0	
										$0	
										$0	
										$0	
										$0	
										$0	
										$0	
Domestic Travel subtotal					*$0*	*$447*	*$0*	*$516*	*$158*	*$1,121*	
Foreign Travel					*Contractual Svcs (446000)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*		
	Knoxville	TBD			$0	$0	$0	$0	$0	$0	
										$0	
										$0	
										$0	
Foreign Travel subtotal					*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	
Year 1 Total					**$0**	**$447**	**$0**	**$516**	**$158**	**$1,121**	

YEAR 2

Purpose of Travel	Depart From	Destination (if known)	No. of Days	No. of Travelers	Conference Reg. Fees	Airfare	Additional Costs (per Traveler)	Lodging (per night)	Per Diem	Total	Details (examples of conferences, mileage calculations, etc.)
Domestic Travel					*Contractual Svcs (446000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*		
	Knoxville	TBD			$0	$0	$0	$0	$0	$0	
										$0	
										$0	
										$0	
										$0	
										$0	
										$0	
Domestic Travel subtotal					*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	
Foreign Travel					*Contractual Svcs (446000)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*		
	Knoxville	TBD			$0	$0	$0	$0	$0	$0	
										$0	
										$0	
										$0	
Foreign Travel subtotal					*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	
Year 2 Total					**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	

YEAR 3

Purpose of Travel	Depart From	Destination (if known)	No. of Days	No. of Travelers	Conference Reg. Fees	Airfare	Additional Costs (per Traveler)	Lodging (per night)	Per Diem	Total	Details (examples of conferences, mileage calculations, etc.)
Domestic Travel					*Contractual Svcs (446000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*		
	Knoxville	TBD			$0	$0	$0	$0	$0	$0	
										$0	
										$0	
										$0	
										$0	
										$0	
										$0	
Domestic Travel subtotal					*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	
Foreign Travel					*Contractual Svcs (446000)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*		
	Knoxville	TBD			$0	$0	$0	$0	$0	$0	
										$0	
										$0	
										$0	
Foreign Travel subtotal					*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	
Year 3 Total					**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	

YEAR 4

Purpose of Travel	Depart From	Destination (if known)	No. of Days	No. of Travelers	Conference Reg. Fees	Airfare	Additional Costs (per Traveler)	Lodging (per night)	Per Diem	Total	Details (examples of conferences, mileage calculations, etc.)
Domestic Travel					*Contractual Svcs (446000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*		
	Knoxville	TBD			$0	$0	$0	$0	$0	$0	
										$0	
										$0	
										$0	
										$0	
										$0	
										$0	
Domestic Travel subtotal					*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	
Foreign Travel					*Contractual Svcs (446000)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*		
	Knoxville	TBD			$0	$0	$0	$0	$0	$0	
										$0	
										$0	
										$0	
Foreign Travel subtotal					*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	
Year 4 Total					**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	

YEAR 5

Purpose of Travel	Depart From	Destination (if known)	No. of Days	No. of Travelers	Conference Reg. Fees	Airfare	Additional Costs (per Traveler)	Lodging (per night)	Per Diem	Total	**Details** (examples of conferences, mileage calculations, etc.)
Domestic Travel					*Contractual Svcs (446000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*	*Travel Domestic (431000)*		
	Knoxville	TBD			$0	$0	$0	$0	$0	$0	
										$0	
										$0	
										$0	
										$0	
										$0	
										$0	
Domestic Travel subtotal					*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	
Foreign Travel					*Contractual Svcs (446000)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*	*Travel Foreign (431500)*		
	Knoxville	TBD			$0	$0	$0	$0	$0	$0	
										$0	
										$0	
										$0	
Foreign Travel subtotal					*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	
Year 5 Total					**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	
CUMULATIVE TOTALS					**$0**	**$447**	**$0**	**$516**	**$158**	**$1,121**	

Additional Explanations/Comments (as necessary)
Travel is based on CONUS rates.

SUPPLIES						
Description	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**TOTAL**
Supplies	15,000	-	-	-	-	**15,000**
for construction of prototypes, supports, magnetic coils	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**
Annual Totals	**15,000**	**-**	**-**	**-**	**-**	**15,000**

SUBCONTRACTS										Is institution a National Lab? (see note in cell B2)	MTDC CALCULATION				
#	Institution	Technical Lead		Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL	*(Y or N)*	Year 1	Year 2	Year 3	Year 4	Year 5
1			*Total*	-	-	-	-	-	-		-	-	-	-	-
2			*Total*	-	-	-	-	-	-		-	-	-	-	-
3			*Total*	-	-	-	-	-	-		-	-	-	-	-
4			*Total*	-	-	-	-	-	-		-	-	-	-	-
5			*Total*	-	-	-	-	-	-		-	-	-	-	-
6			*Total*	-	-	-	-	-	-		-	-	-	-	-
7			*Total*	-	-	-	-	-	-		-	-	-	-	-
8			*Total*	-	-	-	-	-	-		-	-	-	-	-
9			*Total*	-	-	-	-	-	-		-	-	-	-	-
10			*Total*	-	-	-	-	-	-		-	-	-	-	-
			Totals	**-**	**-**	**-**	**-**	**-**	**-**		**-**	**-**	**-**	**-**	**-**

GL Category (DEPT/ADMIN USE ONLY)	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
Subcontracts **to** $25K *(481000)*	-	-	-	-	-	-
Subcontracts **over** $25K *(482000)*	-	-	-	-	-	-
Totals	**-**	**-**	**-**	**-**	**-**	**-**

Tuition Inflation Rate: **2%**
(from UTK Budget tab)

PARTICIPANT SUPPORT COSTS					Number of Participants per Year					
					Year 1	Year 2	Year 3	Year 4	Year 5	Total
					-	-	-	-	-	-
Costs per Participant					**TOTAL Costs per Year**					
					Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
Stipend Allowance	$0	each		Stipend Allowance	$0	$0	$0	$0	$0	$0
Travel Allowance	$0	each		Travel Allowance	$0	$0	$0	$0	$0	$0
Subsistence Allowance (meals/housing)	$0	each		Subsistence Allowance (meals/housing)	$0	$0	$0	$0	$0	$0
Tuition *(if applicable & allowable)*	$0	each		Tuition *(if applicable & allowable)*	$0	$0	$0	$0	$0	$0
Supplies *(if applicable & allowable)*	$0	each		Supplies *(if applicable & allowable)*	$0	$0	$0	$0	$0	$0
Total/Participant	**$0**	**each**		**TOTALS**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**

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June 29, 2022

To Whom it May Concern,

The application of neutrons towards the understanding of fundamental neutron physics phenomena is historically important to Oak Ridge National Laboratory (ORNL), long before the Spallation Neutron Source (SNS) and even the High Flux Isotope Reactor (HFIR) have been available to the scientific community. The proposal “Development of a Program for a New Oscillation Physics Search with Cold Neutrons” lead by The University of Tennessee-Knoxville Physics Professor Yuri Kamyshkov is a natural progression in the advancement of that same research in the 21st century.

As noted in the proposal, we have already collaborated on experiments involving cold neutron beams at SNS and HFIR and anticipate further collaboration with UTK Physics and Nuclear Engineering departments in the advancement of fundamental neutron physics, neutron scattering techniques, and neutron instrumentation technology. We are excited to host UTK professors, post-docs, students and any other researcher affiliated with this collaboration along with the caveat that access to neutron scattering resources at ORNL is contingent upon submission of a successful user proposal through the process described at neutrons.ornl.gov and dependent on the user meeting the access requirements for the facility (including badging and training). Researchers in Neutron Sciences at ORNL will provide resources limited only to that would be expected of a typical user proposal, as this is a key component of our ability to provide a free and open source for cutting edge neutron science to the United States and the entire world. That said, I assure you that this promise will enable us to provide ample support to ensure a successful and high impact science research campaign befitting the prestige of your institution.

If you have any questions about Neutron Sciences at ORNL, our ability to serve the fundamental neutron physics community or any other concerns, please do not hesitate to contact me via email.

Most Sincerely,

Matthew J. Frost, PhD.
Research Scientist, Neutron Optics and Instrument Development
Neutron Sciences Directorate

Yuri A. KAMYSHKOV
Professor, Department of Physics and Astronomy of the University of Tennessee
Office phone: (865) 974-6777, email: kamysho@utk.edu

A. Education and training

Moscow Physics and Technology Institute (MPTI)	Particle Physics	M.S.	1970
Institute for Theoretical and Experimental Physics (ITEP)	Particle Physics	Ph.D.	1978

B. Research and professional experience

1999 - present	Professor of Physics, University of Tennessee-Knoxville (tenured).
1991 - 1999	UTK Associate Professor Joint with Oak Ridge National Laboratory
1969 - 1991	senior scientific staff (latest position) at ITEP, Moscow, Russia

C. Most recent grants

02/02/2015 – 09/30/2015	$ 15K	"WATCHMAN Project", DOE-NNSA-LLNL
04/01/2015 – 03/31/2018	$ 1,100K	"Elementary Particle Interactions", DOE - HEP
04/01/2016 – 03/31/2017	$ 38K	"Suppl. Elementary Particle Interactions", DOE - HEP
06/13/2016 – 08/01/2016	$13K	"WATCHMAN Project", DOE-NNSA-LLNL
08/01/2022 – 07/31/2024	$ 150K	"Search for Hidden Sector Neutrons", DOE - NP

D. Professional Awards

Breakethrough-2016 Physics Prize for Neutrino Oscillations in KamLAND experiment (shared with KamLAND Collaboration)

E. Publications

210 published papers, 21241 citations 5 renowned papers with > 500 citations, 6 famous papers with 250-499 citations; 15 well-known papers with 100-249 citations, Hirsch index h = 60.

Recent relevant publications :

1. J. L. Barrow, L. Broussard, J. M. Cline, B. Dev, M. Drewes, G. Elor, S. Gardner, J. Ghiglieri, J. Harz, Y. Kamyshkov, J. Klaric, L. W. Koerner, B. Laurent, R. McGehee, M. Postma, B. Shakya, R. Shrock, J. van de Vis, G. White, "Theories and Experiments for Testable Baryogenesis Mechanisms: A Snowmass White Paper", March 2022, https://arxiv.org/abs/2203.07059.
2. L. J. Broussard, J. L. Barrow, L. DeBeer-Schmitt, T. Dennis, M. R. Fitzsimmons, M. J. Frost, C. E. Gilbert, F. M. Gonzalez, L. Heilbronn, E. B. Iverson, A. Johnston, Y. Kamyshkov, M. Kline, P. Lewiz, C. Matteson, J. Ternullo, L. Varriano, S. Vavra, "Experimental Search for Neutron to Mirror Neutron Oscillations as an Explanation of the Neutron Lifetime Anomaly," March 2022, https://arxiv.org/abs/2111.05543, accepted for PRL publication.
3. Y. Kamyshkov, J. Ternullo, L. Varriano, Z. Berezhiani, "Neutron-Mirror Neutron Oscillations in Absorbing Matter", October 2021, MDPI, Symmetry 14 (2022) 2, 230.
4. K. Babu, J. Barrow, Z. Berezhiani, L. Broussard, M. Demarteau, B. Dev, J. de Vries, A. Fomin, S. Gardner, S. Girmohanta, J. Heeck, Y. Kamyshkov, B. Long, D. McKeen, R. Mohapatra, J-M. Richard, E. Rinaldi, V. Santoro, R. Shrock, W. M. Snow, M. Wagman, L. Wan, J. Wells, A. Young, "$|\Delta B|=2$: A State of the Field, and Looking Forward--A brief status report of theoretical and experimental physics opportunities", October 2020, https://arxiv.org/abs/2010.02299.
5. A. Addazi, K. Anderson, S. Ansell, K. Babu, J. Barrow, D.V. Baxter, P.M. Bentley, Z. Berezhiani, R. Bevilacqua, C. Bohm, G. Brooijmans, J. Broussard, R. Biondi, B. Dev, C. Crawford, A. Dolgov, K. Dunne, P. Fierlinger, M.R. Fitzsimmons, A. Fomin, M. Frost, S. Gardner, A. Galindo-Uribarri, E. Golubeva, S. Girmohanta, G.L. Greene, T. Greenshaw, V. Gudkov, R. Hall-Wilton, L. Heilbronn, J. Herrero-Garcia, G. Ichikawa T.M. Ito, E. Iverson, T. Johansson, L. Joensson, Y-J. Jwa, Y. Kamyshkov, K. Kanaki, et al., "New high-sensitivity searches for neutrons converting into antineutrons and/or sterile neutrons at the European Spallation Source", January 2020, J. Phys. G 48 (2021) 7, 070501, https://arxiv.org/abs/2006.04907.

Matthew J. FROST
Research Scientist, Neutron Technologies Division, Oak Ridge National Laboratory
email: frostmj@ornl.gov

A. Education and training

Kent State University	Physics	B.S.	2005
The University of Wisconsin-Madison	Nuclear Engineering	M.S.	2007
The University of Tennessee-Knoxville	Physics and Astronomy	Ph.D.	2019

B. Research and professional experience

2020 - present	Research Scientist, Neutron Technologies Division, Oak Ridge National Laboratory
2007 - 2020	Scientific Associate, Neutron Scattering Division, Oak Ridge National Laboratory
2014 - 2018	Research Assistant, Department of Physics, The University of Tennessee-Knoxville
2005 - 2007	Research Assistant, Department of Engineering Physics, UW-Madison

C. Most recent grants

None.

D. Professional Awards

None.

E. Publications

37 published papers, Hirsch index h = 13. ORCiD: 0000-0001-6821-170X

Recent relevant publications:

1. L. J. Broussard, J. L. Barrow, L. DeBeer-Schmitt, T. Dennis, M. R. Fitzsimmons, M. J. Frost, C. E. Gilbert, F. M. Gonzalez, L. Heilbronn, E. B. Iverson, A. Johnston, Y. Kamyshkov, M. Kline, P. Lewiz, C. Matteson, J. Ternullo, L. Varriano, S. Vavra, "Experimental Search for Neutron to Mirror Neutron Oscillations as an Explanation of the Neutron Lifetime Anomaly," March 2022, https://arxiv.org/abs/2111.05543, accepted for PRL publication.
2. Ehlers, G; Frost, Matthew J; Granroth, Garrett E; Huegle, Thomas; Ibberson, Richard M; Robertson, J Lee, “A Replacement Cold Neutron Guide System for HFIR (Conceptual Design Report)”, July 2020, Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States).
3. Broussard, Leah J; Bailey, Katherine M; Bailey, William B; Barrow, Joshua L; Berry, K; Blose, A; Crawford, C; Debeer-Schmitt, L; Frost, M; Galindo-Uribarri, Alfredo, “New search for mirror neutron regeneration”. EPJ Web of Conferences. EDP Sciences, 2019.
4. A. Addazi, K. Anderson, S. Ansell, K. Babu, J. Barrow, D.V. Baxter, P.M. Bentley, Z. Berezhiani, R. Bevilacqua, C. Bohm, G. Brooijmans, J. Broussard, R. Biondi, B. Dev, C. Crawford, A. Dolgov, K. Dunne, P. Fierlinger, M.R. Fitzsimmons, A. Fomin, M. Frost, S. Gardner, A. Galindo-Uribarri, E. Golubeva, S. Girmohanta, G.L. Greene, T. Greenshaw, V. Gudkov, R. Hall-Wilton, L. Heilbronn, J. Herrero-Garcia, G. Ichikawa T.M. Ito, E. Iverson, T. Johansson, L. Joensson, Y-J. Jwa, Y. Kamyshkov, K. Kanaki, et al., "New high-sensitivity searches for neutrons converting into antineutrons and/or sterile neutrons at the European Spallation Source", January 2020, J. Phys. G 48 (2021) 7, 070501, https://arxiv.org/abs/2006.04907.
5. Wu, Wei; Stoica, Alexandru D; Berry, Kevin D; Frost, Matthew J; Skorpenske, Harley D; An, Ke, “PIND: High spatial resolution by pinhole neutron diffraction”. Applied Physics Letters, 112, 25, AIP Publishing LLC, 2018.

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A. Education and training

Reed College	Physics B.A.	1982
Cornell University	Materials Science and Engineering, M.S.	1984
Cornell University	Materials Science and Engineering, Ph.D.	1988

B. Research and professional experience

2016 - present	Professor, University of Tennessee
2015 - present	Scientist, Oak Ridge National Laboratory
2015 - 2019	Group Leader, Oak Ridge National Laboratory
1993 - 2015	Scientist, Los Alamos National Laboratory
1990 - 1993	Postdoctoral Fellow, Los Alamos National Laboratory
1989 - 1990	Jr. Fulbright Fellow, Ludwig Maximilans University, Munich Germany

C. Most recent grants

10/01/2017 – 10/01/2018	$ 190k	"Turbulent Flow", ORNL-LDRD
10/01/2015 – 1001/2017	$ 596k	"Emergence", ORNL-LDRD

D. Professional Awards

2014	Fellow of the Neutron Scattering Society of America
2007	Fellow of the American Physical Society

E. Publications

150 published papers, 6300 citations, 34 in impact >7 journals, Hirsch index h = 39.

Recent relevant publications :

1. L. J. Broussard, J. L. Barrow, L. DeBeer-Schmitt, T. Dennis, M. R. Fitzsimmons, M. J. Frost, C. E. Gilbert, F. M. Gonzalez, L. Heilbronn, E. B. Iverson, A. Johnston, Y. Kamyshkov, M. Kline, P. Lewiz, C. Matteson, J. Ternullo, L. Varriano, S. Vavra, "Experimental Search for Neutron to Mirror Neutron Oscillations as an Explanation of the Neutron Lifetime Anomaly," March 2022, https://arxiv.org/abs/2111.05543, accepted for PRL publication.
2. A. Addazi, K. Anderson, S. Ansell, K. Babu, J. Barrow, D.V. Baxter, P.M. Bentley, Z. Berezhiani, R. Bevilacqua, C. Bohm, G. Brooijmans, J. Broussard, R. Biondi, B. Dev, C. Crawford, A. Dolgov, K. Dunne, P. Fierlinger, M.R. Fitzsimmons, A. Fomin, M. Frost, S. Gardner, A. Galindo-Uribarri, E. Golubeva, S. Girmohanta, G.L. Greene, T. Greenshaw, V. Gudkov, R. Hall-Wilton, L. Heilbronn, J. Herrero-Garcia, G. Ichikawa T.M. Ito, E. Iverson, T. Johansson, L. Joensson, Y-J. Jwa, Y. Kamyshkov, K. Kanaki, et al., "New high-sensitivity searches for neutrons converting into antineutrons and/or sterile neutrons at the European Spallation Source", January 2020, J. Phys. G 48 (2021) 7, 070501, https://arxiv.org/abs/2006.04907.
3. M.R. Fitzsimmons and T.R. Charlton, Strategies to minimize the influence of instrumental bias in neutron scattering, *Nuclear Instrumentation and Methods A* 941, 162330 (2019).
4. Roger Pynn, M.R. Fitzsimmons, W.T. Lee, P. Stonaha, V.R. Shah, A.L. Washington, B.J. Kirby, C.F. Majkrzak, B.B. Maranville, Birefringent neutron prisms for spin echo scattering angle measurement, *Physica B* 404, 2582 (2009).
5. R. Pynn, M.R. Fitzsimmons, H. Fritzsche, M. Gierlings, J. Major, A. Jason, Neutron spin echo scattering angle measurement (SESAME), *Rev. of Sci. Instr.* 76, 1 (2005).

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A. Education and training

Michigan State University	Ph.D.	Nuclear Physics	1991
University of Illinois	M.S.	Physics	1984
University of Montana	B.A.	Physics	1982

B. Research and professional experience

2020 – present	John D. Tickle Professor, Nuclear Engineering Department, UTK
2014 – 2020	Associate Professor, Nuclear Engineering Department, U. Tennessee-Knoxville
2008 – 2014	Assistant Professor, Nuclear Engineering Department University of Tennessee-Knoxville
1993 – 2008	Staff Scientist, Lawrence Berkeley National Laboratory
1991 – 1993	Postdoctoral Fellow, Lawrence Berkeley National Laboratory

C. Most recent grants (current)

08/2019 – 07/2022	$232K	"Novel Methods 229Th Production, DOE-NP
08/2019 – 12/2022	$931K	"MRI: Development of Neutron Detector", NSF
03/2019 – 03/2023	$152K	"Nuclear Thermal Propulsion Test Device", ORNL
02/2019 – 12/2022	$150K	"Salt Thermochemical Measurement", ORNL

D. Professional Awards

2022 – TennACADA Faculty Advisor Award
2015 – Chancellor's Research and Creative Achievement – Professional Promise Award
2015 – College of Engineering Professional Promise in Research Award
1996, 2002 – Outstanding Performance Award, Lawrence Berkeley National Laboratory

E. Publications

267 publications, H-index 33
Recent relevant publications:

1. L. J. Broussard, J. L. Barrow, L. DeBeer-Schmitt, T. Dennis, M. R. Fitzsimmons, M. J. Frost, C. E. Gilbert, F. M. Gonzalez, L. Heilbronn, E. B. Iverson, A. Johnston, Y. Kamyshkov, M. Kline, P. Lewiz, C. Matteson, J. Ternullo, L. Varriano, and S. Vavra, "Experimental Search for Neutron to Mirror Neutron Oscillations as an Explanation of the Neutron Lifetime Anomaly", Phys. Rev. Lett. 128, 212503 (2022).
2. S. Neupanea, J. Heideman, R. Grzywacz, J. Hooker, K.L. Jones, N. Kitamura, C.R. Thornsberry,L.H. Heilbronn, M.M. Rajabali, Y. Alberty-Jones, J. Derkin, T. Massey, D. Soltesz, "Neutron detection efficiency of the Neutron dEtector with Xn Tracking (NEXT)", Nucl. Instrum. Meth. A, vol. 1020, 165881 (2021) https://doi.org/10.1016/j.nima.2021.165881.
3. N. Burahmah, J. W. Griswold, L. Heilbronn, and S. Mirzadeh, "Transport Model Predictions of 225Ac Production Cross Sections via Energetic p, d and 4He Irradiation of 232Th Targets", Applied Radiation and Isotopes 2021 March 3, 172: 109676.
4. A. Addazi, K. Anderson, S. Ansell, K. Babu, J. Barrow, D.V. Baxter, P.M. Bentley, Z. Berezhiani, R. Bevilacqua, C. Bohm, G. Brooijmans, J. Broussard, R. Biondi, B. Dev, C. Crawford, A. Dolgov, K. Dunne, P. Fierlinger, M.R. Fitzsimmons, A. Fomin, M. Frost, S. Gardner, A. Galindo-Uribarri, E. Golubeva, S. Girmohanta, G.L. Greene, T. Greenshaw, V. Gudkov, R. Hall-Wilton, L. Heilbronn, J. Herrero-Garcia, G. Ichikawa T.M. Ito, E. Iverson, T. Johansson, L. Joensson, Y-J. Jwa, Y. Kamyshkov, K. Kanaki, et al., "New high-sensitivity searches for neutrons converting into antineutrons and/or sterile neutrons at the European Spallation Source", January 2020, J. Phys. G 48 (2021) 7, 070501, https://arxiv.org/abs/2006.04907.
5. L. Heilbronn and Y. Iwata, "Secondary Neutron Production Cross Section Measurements from Heavy-Mass Targets at HIMAC", Radioisotopes 68, Issue 8, pp. 553-557 (2019) DOI: 10.3769/radioisotopes.68.553

Statement of compliance with existing guidelines based on COVID19 restrictions

Authors of the current proposal are aware of the system of COVID-19 regulations and restrictions as provided by guidelines of CDC, UTK, and ORNL and will comply with these rules and restriction in existing or updated form. To minimize interactions between members of collaboration, ORNL, UT staff, and students most of the meetings and discussions will be performed in remote format via Zoom.