Building a Diverse Nuclear Energy Workforce: Hunter College/Brookhaven Partnership to Investigate Technetium-99 and Rhenium Speciation in Molten Salts

Dr. Lynn C. Francesconi[1], Professor
Co-PIs: Dr. James F. Wishart[2], Dr. Donna McGregor[3], Benjamin P. Burton-Pye[3],
Dr. Anatoly I. Frenkel[2], Dr. Gustavo E. Lopez[3]

1: Hunter College of the City University of New York, New York City, NY 10065
2: Brookhaven National Laboratory, Upton, NY 11973
3: Lehman College of the City University of New York, Bronx, NY 10468

This project investigates the chemistry of technetium-99 (Tc) in molten salts (MS), which is important to future U.S. clean energy. Molten salt reactors (MSRs) are an emerging nuclear reactor technology where the fissile nuclear fuel is dissolved in a molten salt that also acts as a coolant. As the reactor operates, the fuel salt composition will change due to the accumulation of fission products, which negatively affect reactor performance. Removing the fission products is challenging, therefore understanding what chemical forms the fission products take is key to designing effective separation systems. Studies on the very important fission product technetium-99 in MS are lacking, and that is the gap that this project intends to fill as it trains the next, diverse generation of radiochemists and molten salt chemists. *The overall hypothesis* of this research is that Tc in MS occupies a range of local environments, charge states and coordination states that depend on temperature and the composition of the salt. Rhenium (Re), the third-row congener of Tc, is used as a non-radioactive surrogate to develop the skills of trainees and validate experimental systems and methodologies before studying the Tc analogs. This project focuses on chloride-based systems because they pose significant scientific questions while being easier to handle and thus better suited for training purposes than fluorides.

The research hypothesis will be addressed by objectives 1-3: *Objective 1. Understand Tc-Cl complex speciation in low-melting chloride salts (ionic liquids, ILs).* Chloride ILs are good proxies for examining the speciation (coordination and electron transfer properties) of various Tc and Re valence states because they offer only chloride ions for coordination to the metal ions. Chloride ILs allow characterization of Tc speciation in ambient conditions convenient for training and skill development. *Objective 2. Elucidate the effects of molten salts' strong cation-anion interactions on Tc and Re speciation using pure molten $ZnCl_2$.* Here Tc and Re speciation in molten $ZnCl_2$ (m.p. 290 °C) is investigated with optical spectroscopy, synchrotron and radiolysis experiments at temperatures up to 400-450°C. The goal is to understand how the cation-anion interactions intrinsic to $ZnCl_2$ control the Tc–solvent (salt) interactions. *Objective 3. Interpret the speciation and redox chemistry of Tc and Re in $ZnCl_2$-KCl, a complex, tunable salt system*. Building on the characterization in molten $ZnCl_2$, $ZnCl_2$-KCl mixtures are used to explore how Tc and Re speciation can be controlled by tuning mixture composition over temperatures up to 700 °C. *Objective 4 is cross-cutting* and involves an examination of the advantages and limitations of X-ray absorption fine structure spectroscopy for Tc and Re speciation in ILs and MS. *Objective 5 is also cross-cutting* and includes targeted recruitment, mentoring, and retention of groups underrepresented in science. A hallmark of this BES-RENEW project will be internships at BNL (3-4 mo/yr). These will provide training in a rich science environment by world class scientists employing the unique facilities of a national laboratory.

This research was selected for funding by the Office of Basic Energy Sciences

Partnership for Fostering Graduate Training in Atmospheric Sciences at Texas Southern University

Dr. Daniel Vrinceanu[1], Professor
Co-PIs: Bruce Prince[1], Mark Harvey[1], Maria Zawadowich[2], Michael Jensen[2], and Chongai Kuang[2]

1: Texas Southern University (TSU), Houston, TX 77004
2: Brookhaven National Laboratory (BNL), Upton NY 11973

Texas Southern University (TSU), a Carnegie R2 research institution and one of the largest Historically Black Colleges and Universities (HBCUs) in the nation builds a long-term and sustainable research partnership with the Brookhaven National Laboratory (BNL) to train graduate students in Atmospheric Sciences. Through the ongoing engagement with research activities in the DOE Science Focus Area (SFA) project "PASCCALS: Process-level Advancements of Climate through Cloud and Aerosol Lifecycle Studies" (https://asr.science.energy.gov/projects/15588), this project aims to expand existing research programs, develop new capacities at TSU, and provide additional exciting opportunities for research and hands-on training for underrepresented and underserved graduate and undergraduate students. The main goal of the proposed program is the creation of a positive and inclusive learning and research environment that will nurture the next generation of a scientifically and technologically savvy, globally competitive energy workforce. Towards this end, the project sets the following objectives: 1. Provide experiential training to graduate students from the Department of Physics, Department of Chemistry and Department of Environmental and Interdisciplinary Sciences (EIS) at TSU by leveraging existing collaborations with staff scientists in the Environmental and Climate Sciences Department at BNL, and through broadening mentoring, science and immersion opportunities coupled with curricular development. 2. Enhance research capabilities at TSU by fostering a sustainable partnership with the BNL research group with the goal of developing both theoretical physical models and computational chemistry models of particulate reaction formation and its interaction to the formation of cloud condensation nuclei (CCN). 3. Leverage the Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) Facility by actively partnering on analyzing data from the Tracking Aerosol Convection Interactions Experiment (TRACER) campaign, and other ARM deployments, towards creating predictive models of critical aerosol formation and convective interactions in cloud processes, in conjunction with empirical statistical analysis methods.

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Co-designing Foundational Capabilities to Diversify the Scientific Workforce

Dr. Joseph Wilkins[1], Assistant Professor
Co-PIs: Samson Hagos[2] and John Hill[3]
1: Howard University (HU), Washington DC 20060
2: Pacific Northwest National Laboratory (PNNL), Richland, WA 99354
3: Brookhaven National Laboratory (BNL), Upton NY 11973

As the United States (US) population diversifies, the environmental science workforce lags the inclusion of historically underrepresented minorities (URM). To address the scope and scale of the dual environmental crisis faced by people and nature, this project seeks to ambitiously transform the understanding of climate-relevant processes while increasing workforce-ready URMs inclusion in climate science. By creating a foundationally solid URM pipeline through effective mentorship, the project will increase diversity and chances of understanding the urban-rural impacts due to climate change in the US most populated cities, which is critical to preparing and protecting Earth from future hazardous scenarios. This proposed Office of Biological & Environmental Research Reaching a New Energy Sciences Workforce (BER RENEW) project is designed to create a Promote Inclusive and Equitable Research (PIER) plan that catalyzes partnerships with the Department of Energy (DOE) Earth and Environmental Systems Sciences Division (EESSD) Offices address identified solvable historically black colleges and universities (HBCU) barriers. The project will accelerate inclusion and diversity of the US science and technology ecosystem to increase the future pool of young scientists with critical skills and expertise. In the long term, the overall goal of this project's motivation is for DOE labs to accelerate the ability to hire students out of these workforce ready programs which would further diversity DOE staff. The Program will be centered around Student First development and Student chosen research. By selecting a cohort of at least 3 students to be mentored in the development of DOE emerging and Critical Science Questions e.g., a required predictive capability as it is hindered by the strong heterogeneity of urban terrain, and the wide range of scales and processes that dictate how urban systems interact with the surrounding Earth system -- DOE need for the Urban Integrated Field Laboratories. The project objectives are to: i) broaden existing institutional capabilities, (ii) develop competitive advantages for experiential training opportunities, (iii) increase workforce ready URMs through effective individualized mentorship plans and PIERs. HBCU Barriers to funding will be addressed to bridge these gaps over the three-year term with in-person (tri-quarterly) and virtual (monthly) meetings with strong mentoring to accelerate workforce development. The project aims to educate and integrate URMs into DOE science with intentional inclusion in an equitable manor, through RENEW team members visiting each other's facilities (host site tours) to share science communications (oral and posters) that result in co-developed competitive proposals. Beneficial outcomes of this project will be new fundamentally inclusive partnerships with DOE and HU tasked to understand the urban-rural impacts due to climate change in the US, related to energy issues driven by heat stress and the energy cycle that can be scaled. The overall impacts of the RENEW will be in paving the way to ensure the inclusion of diverse voices to increase climate resilience with a transdisciplinary partnership that will minimize impacts on the most vulnerable communities while constraining barriers to HBCUs and URMs.

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Long Island High Energy and Astrophysics Undergraduate Pathway (LEAP-UP)

Dr. John Estes[1] (Assistant Professor)
Co-Principal Investigators: Dr. Michael Kavic [1], Dr. Matthew Lippert [1] Dr. Ketevi Assamagan [2],
Dr. Mary Bishai [2], Dr. Mateus Carneiro [2], Dr. Anze Slosar [2]
1: State University of New York at Old Westbury, 223 Store Hill Rd, Old Westbury, NY 11568
2: Brookhaven National Laboratory, Upton, NY 11973

The Long Island High Energy and Astrophysics Undergraduate Pathway (LEAP-UP) program teams up the new physics program at the State University of New York at Old Westbury (OW), the most diverse SUNY campus, with the world-class research programs at Brookhaven National Laboratory (BNL). Through this partnership, OW and BNL will create a new pathway which supports students, starting with recruitment efforts at local high schools and community colleges, mentorship and support throughout the students' academic journey, an interactive research experience, and ending with support as students apply to graduate programs and beyond. This will be done along three main thrusts: Build: The project will construct an active bridge between OW and BNL by pairing the HEP theory expertise of OW faculty with the experimental expertise of BNL researchers. Once built, this bridge will continue to provide HEP experimental research opportunities to OW's diverse student population.

Accelerate: OW is launching a new physics program. This grant provides essential resources to establish a robust physics program at OW, generating diverse physics student enrollment, with higher participation in HEP research and more graduates entering the HEP workforce. Mentor: Finally, this grant will support the development of teaching and mentoring training for both OW faculty and BNL staff emphasizing diversity, equity, inclusion, and justice, with the goal of increasing success of underrepresented minority students in HEP.

Two-year traineeships will provide students with stipends and support for tuition and housing. The key element is a fully mentored research experience, involving a 10-week summer program at BNL, with continued support as trainees continue their research during the following academic year. Students will have the opportunity to work on high-energy experiments like ATLAS, DUNE, LuSEE, and BMX, as well as theoretical projects in string theory and applications of holography to quantum field theory. Collaborative experiments: ATLAS, Deep Underground Neutrino Experiment (DUNE), Lunar Surface Electromagnetic Experiment (LuSEE) – Night, Baryon Mapping eXperiment (BMX), All Sky Transient Radio Array (ASTRA).

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Developing novel high-performance SPAD detectors for HEP - creating a training and research path for minority students

Dr. Mst Shamim Ara Shawkat[1], Assistant Professor
Co-Principal Investigators: Dr. Nezih Pala[1], Dr. Andrei Nomerotski[2],
1: Florida International University, 11200 SW 8th Street Miami, Florida 33199
2: Brookhaven National Laboratory, Upton, NY 11973

For the new era of exploring physics laws, high energy physics (HEP) demands highly sensitive, fast, noise-free and radiation hard detectors. Silicon photomultipliers (SiPMs), an array of single photon avalanche diodes (SPADs), have gained popularity in recent years as single photon sensitive, solid-state alternatives to conventional photon detectors due to their compactness, low operating voltage, robustness, invulnerability to magnetic fields, and lower cost. Furthermore, SiPMs and SPAD arrays implemented in a standard complimentary metal-oxide-semiconductor (CMOS) process, as opposed to a dedicated optical process, allow the optical sensor to be integrated on the same chip with the readout electronics, resulting in scalable and high-speed detectors. These detectors with picosecond scale resolution and high throughput are much needed for registration of simultaneous single photons as in the spectrometers for optical interferometers and a variety of other applications. Also, due to the trend toward higher luminosities and, therefore, higher levels of irradiation, SiPMs/SPADs may degrade for high radiation dose environment at future particle colliders, which makes them unsuitable for some experiments due to the noise deterioration. As a solution, we propose developing low-cost, compact, and high performance SPAD arrays, specialized for HEP applications, in particular, for quantum-assisted two-photon interferometry with great impact on the cosmic frontier topics and radiation hard SPAD arrays for the energy frontier topics. Moreover, it will provide excellent educational and training opportunities for developing a diverse workforce with advanced skills in detectors, microelectronics, and data acquisition, much needed not only in HEP but in other areas of science and industry. The overall goal of this project is to broaden and diversify the HEP community by lowering academic and social barriers through cutting-edge HEP-oriented research activities with associated education, training, mentoring and support programs at the Florida International University (FIU), one of the largest minority-serving institutions in the U.S. in collaboration with Brookhaven National Laboratory (BNL). The research part of the project aims to develop novel high-performance single photon avalanche (SPAD) detector arrays for HEP applications, which will provide training and research opportunities for underrepresented communities in HEP related fields at FIU. The project will provide associated mentoring, training, and outreach activities to build a strong and diverse future workforce in HEP. The project also plans to expand FIU's capacity to conduct research on HEP projects by developing sensor design and testing facilities at FIU in collaboration with BNL. The proposed infrastructure will fill a crucial need in HEP research and education in the area of transformative photon detection systems for HEP applications.

As a result of this research, we expect to create new classes of single photon detectors with improved noise performance and specialized architectures that will be suitable for multiple applications within and outside of HEP. As FIU is one of the largest minority-serving universities in the nation, this project will broaden the participation of minority students and women in science and engineering, particularly in HEP. Students at all levels studying different majors will be involved, which will foster interdisciplinary interactions and will build a solid foundation for their education and future productive work. Students at FIU will have skill development opportunities through the lab visiting and training at advanced experimental facilities at BNL.

This research was selected for funding by the Office of High Energy Physics

BNL-MSI Fellowship Program for Research Excellence and Preparation in Nuclear Physics (PREP-NP)

Dr. Mickey Chiu[1], Senior Scientist
Co-PI(s): Prof. Ahay Deshpande[1,2], Prof. Marcus Alfred[3], Prof. Mark Harvey[4], Prof. Stacyann Nelson[3], Prof. Ratnakar Palai[5], Prof. Willie Rockward[6], Prof. Carol Scarlett[7]
1: Brookhaven National Laboratory, Upton, NY 11973
2: Stony Brook University, Stony Brook, NY 11794
3: Howard University, Washington, DC 20059
4: Texas Southern University, Houston, TX 77004
5: University of Puerto Rico, San Juan, PR 00925
6: Morgan State University, Baltimore, MD 21251
7: Florida A&M University, Tallahassee, FL 32307

The BNL-MSI Fellowship Program for Research Excellence and Preparation in Nuclear Physics is a partnership program between Brookhaven National Laboratory and five core Minority Serving Institution's: Florida A&M, Howard, Morgan St, Texas Southern, and the Univ. of Puerto Rico. The program was created to help place undergraduate students from under-represented populations on a path to graduate school in Nuclear Physics, thus increasing the pool of scientific talent in the US. The BNL-MSI Fellowship program achieves this goal by pairing upper-class students interested in a career in physics with Faculty Advisors and BNL Scientists to pursue a cutting-edge Nuclear Physics research project over a two-year term. The program is designed to efficiently leverage the resources at BNL, making them available for use by the students and professors at MSI's. The mentoring provided by world class scientists, and educational expertise from BNL's Office of Educational Programs work in concert to provide a supportive research experience to the student fellows. This fellowship gives them the opportunity to acquire the scientific skillsets that they need to succeed, and builds their own confidence in their future as possible scientists. The program completed a two-year pilot in mid-2023. Out of the 9 PREP-NP Fellows in the program ready for the next stage in their career, 8 are in or will be attending graduate school in physics or closely related STEM fields. In addition, strong research relationships are being developed between BNL and the professors at the MSI's, helping to improve the quality of science being done in the US. This RENEW award allows the BNL-MSI PREP-NP program to continue providing research opportunities to under-served populations, keeping this successful pipeline into graduate school going. It also furthers the nuclear physics research being done by the MSI's at BNL.

This research was selected for funding by the Office of Nuclear Physics

NuSTEAM: Nuclear Science in Texas to Enhance and Advance Minorities

Dr. Claudia Ratti[1], Professor
Co-PI(s): Rene Bellwied[1], Anthony Timmins[1], Volodymyr Vovchenko[1],
Philip Cole[2], Efrain Ferrer[3], Jorge Munoz[4], Premkumar Saganti[5]
1: University of Houston, Houston, TX 77204
2: Lamar University, Beaumont, TX 77705
3: University of Texas Rio Grande Valley, Edinburg, TX 78539
4: University of Texas El Paso, El Paso, TX 79968
5: Prairie View A&M University, Prairie View, TX 77446

This project is the continuation of a successful Texas-based program under the guidelines of the NP-RENEW FOA (Nuclear Physics – Reaching a New Energy Sciences Workforce). The program is based on recruiting a diverse set of undergraduate students to be trained and do research on state-of-the-art Nuclear Physics topics, retaining some of them as graduate students, and preparing others for the nuclear workforce. Four of the largest minority-serving institutions in the United States have participated in the first phase of this collaborative program, the **Nuclear Science in Texas to Enhance and Advance Minorities (NuSTEAM)**, funded from 2021 to 2023. The initial team consisted of the University of Houston (UH), University of Texas - Rio Grande Valley (UTRGV), University of Texas - El Paso (UTEP) and Prairie View A&M University (PVAMU), with the University of Houston serving at the lead institution. For this renewal, Lamar University, joins the project starting with the summer traineeship in 2024. The University of Houston has an extensive Experimental and Theoretical Nuclear and High Energy Physics Research Program for graduate and undergraduate students and will serve as a host for the summer program of the year-long traineeship. UTRGV and UTEP have a graduate program, but not in Experimental Nuclear/High Energy Physics. Prairie View A&M and Lamar University only have undergraduate programs. All five institutions will provide minority undergraduate students to the program. After completing a six-week summer course at UH, Brookhaven National Laboratory will host the students for a two-week hands-on experience in the laboratory environment. Upon returning to their home institutions, the students will continue to be supported for the Fall and Spring semesters for 15 hours/week, while working on a research topic chosen through the traineeship program. The curriculum of the summer course focuses on developing a Nuclear Physics based skill set, which will be applicable to future professions in academia and industry within the Nuclear Physics field. Areas that will be covered in the course are low- and high-energy Nuclear Physics research, Nuclear radiation applications in Space Science and Medical Physics, Instrumentation and Detectors, Electronics, Software Development, Analysis tools, Machine Learning, and finally Networking, Presentation Skills and Career Planning. Upon completion of the UH and BNL experiences, the student, in coordination with the local supervisor and the program coordinator at UH, will receive a research project to be addressed and completed over the next two semesters at their home institutions. Possible topics will include heavy ion data analysis, phenomenological modeling of data from RHIC and LHC, radiation physics studies, machine learning applications in nuclear physics, detector and electronics development, simulation, and testing for new instruments. Retained graduate students will work on more complex problems within the same topics.

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HBCU Collider Consortium

PI: Dr. Carol Scarlett[1], Associate Professor
Co-PI's: Dr. Marcus Alfred[2], Associate Professor, Dr. Mark Harvey[3], Associate Professor
and Dr. Mickey Chiu[4], Staff Scientist
1: Florida A&M University, Tallahassee, FL 32210
2: Howard University, Washington, DC 20059
3: Texas Southern University, Austin, TX 77004
4: Brookhaven National Laboratory, Upton, NY 11973

Abstract:

The Relativistic Heavy Ion Collider (RHIC) at BNL has made many notable discoveries over the past two decades of operation, yet there are still new discoveries being made. In particular, with the upgrade of PHENIX to sPHENIX, for the first time at RHIC there will be a detector capable of high-rate data acquisition to exploit the full luminosity of a mature RHIC, and full jet reconstruction capability using hadronic calorimeters. The three HBCU's on this team proposal, Howard University, Florida A&M University (FAMU), and Texas Southern University (TSU), formed the HBCU Collider Consortium in 2019 to initiate the formation of a collaborative research group across our institutions that would join the PHENIX and sPHENIX collaborations, in order to exploit the possibility of discoveries with the two experiments. Two of the institutions in this proposal comprise 50% of all HBCU's that offer a PhD with a specialization in nuclear physics. Our group was initially funded by a small NSF EiR grant that started in 2019 and ends this fiscal year. The funding has supported the effort of 4 graduate students. Two of these students analyzed UPC J/Psi production in PHENIX for their theses, which provides valuable information about how the nuclear materials are distributed. This new proposal seeks to continue support for several graduate students as they pursue their dissertations. As well, this proposal will support crucial detector development for the sPHENIX Minimum Bias Detector during the 3 years of sPHENIX data-taking. The HBCU Collider Consortium also seeks to provide new opportunities for future graduate students and post-docs to contribute to developing detectors that can exploit the opportunities for measuring very rare isotopes in the very forward rapidities at the EIC, as well as further analyze UPC data from sPHENIX.

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