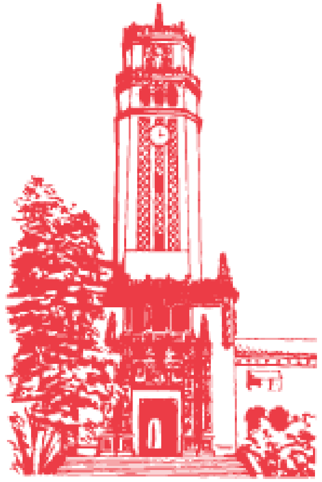
Scope of Nuclear Physics Teaching & Research at UPR: Opportunities & Obstacles

Ratnakar Palai
Department of Physics
University of Puerto Rico, San Juan, PR



Brookhaven National Laboratory

Exploring Collaboration with MSIs in Nuclear and Particle Physics
July 18-19, 2023

UNIVERSIDAD DE PUERTO RICO • RECINTO DE RÍO PIEDRAS • 1903 •

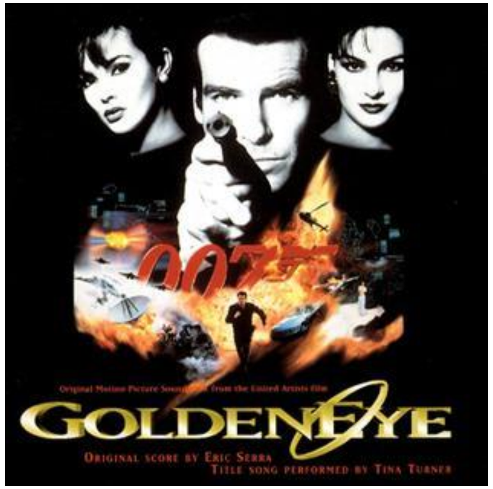
Outline

- Brief Introduction to PR & UPR
- Current research & traineeship opportunities and outcomes in NP research
- Research Facilities & Results
- Teaching efforts-Nuclear Physics
- Summary: Opportunities & Obstacles

PUERTO RICO: ISLA DEL ENCANTO

ARECIBO OBSERVATORY

Arecibo Observatory: Used to the BIGGEST (1000 ft) radio telescope in the World! Collapsed on 1st December 2020!



1995 James Bond movie **Goldeneye** with Pierce Brosnan

1997 Jodie Foster movie **Contact**

CASA BACARDI

Bacardi Rum main factory in Catanio

Culebra Beach

Flamenco Beach (Ranked #2 in the top 10 most exotic beaches in the world)!

CAVEs & UNDERGROUND RIVER

Stalactites,
Stalagmite
(CaCo3)

Camuy River Cave (700 ft length, 215 ft high) National Park. **Third-largest underground River in the world!**

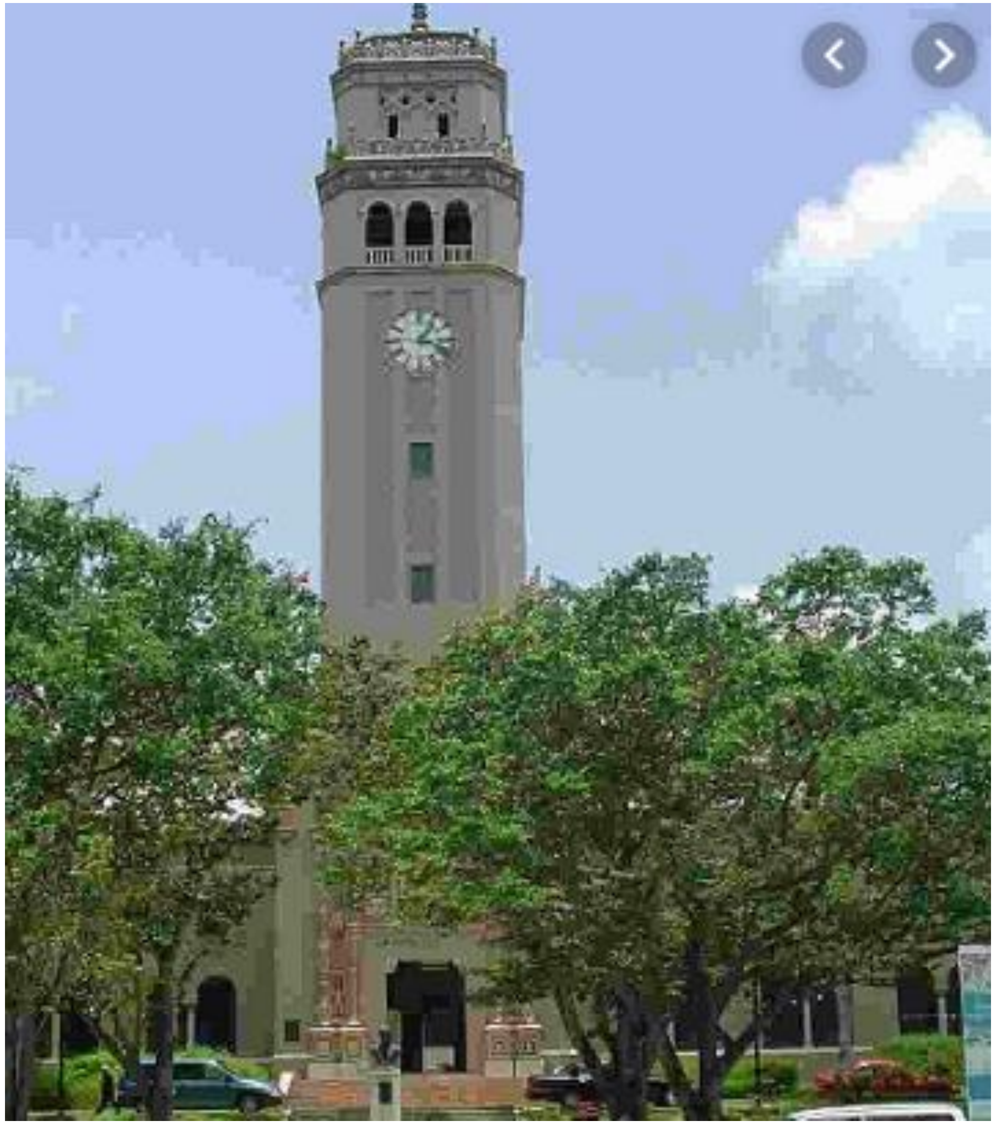
THE RAIN FOREST: EL YUNQUE

The El Yunque National Forest is the **sole tropical rain forest in the U.S. National Forest System**. Area 28, 516 acre, Luquillo Mountatin- 3,533 ft. Rainfall- 508 cm/annum.

UPR Rio Piedras Campus (UPRRP) in San Juan

UPR-RP SAN JUAN

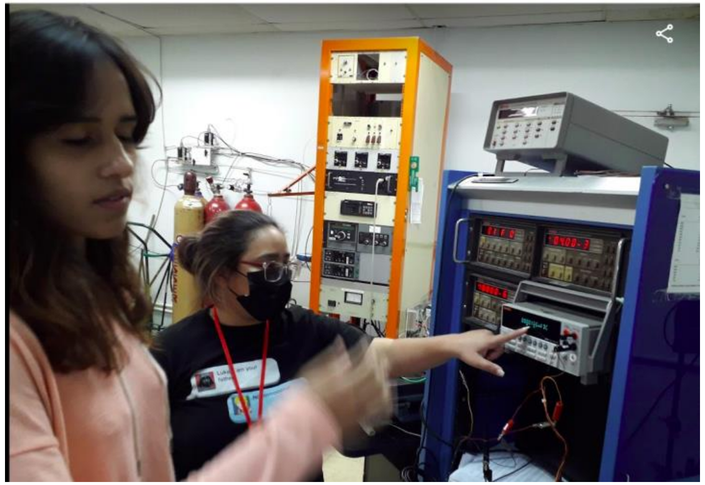
UPR-RP is the oldest (Est. 1903) and biggest public educational institute in PR located in the capitol city of San Juan. It serves about **20,000 students**, of which 20% are graduate students (MS/PhD). It is recognized by the Carnegie Foundation for the Advancement of Teaching (CFAT) is a US based education policy and research center as a research university **"high research activity" (RU/H).** Its academic offerings range from the bachelorette to the doctoral degree, through **70 undergraduate programs** and **19 graduate (MS/PhD) degrees** with 71 specializations in the basic disciplines and professional fields.



BNL-MSI PREP-NPT, 2021-2023- UPR

Program for Research Excellence and Preparation via Nuclear Physics Traineeships

- **BNL** (**Lead**-NP groups and Office of Educational Programs), **Univ. Puerto Rico (UPR), Florida A&M, Howard, Morgan St, Texas Southern.**
- **Goals:** Provide research opportunities to UPR students & Faculty at BNL and support underrepresented Hispanic students to pursue career in NP.
- Trainees: Total # 4 students, (2-graduated, 2-working)
- **Results:** 2 in graduate schools (1 MSU-PhD, 1 UPR-MS, **2 continuing undergrads**)



Julio Alejandro Joniel Mendez

BNL summer Internship-2023

BNL-MSI PREP-NPT, 2021-2023- UPR

Program for Research Excellence and Preparation via Nuclear Physics Traineeships

Luca Cultrera

Scientist at Brookhaven National Laboratory

5th North American Particle Accel. Conf. NAPAC2022, Albuquerque, NM, USA JACoW Publishing
ISBN: 978-3-95450-232-5 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2022-MOYE6

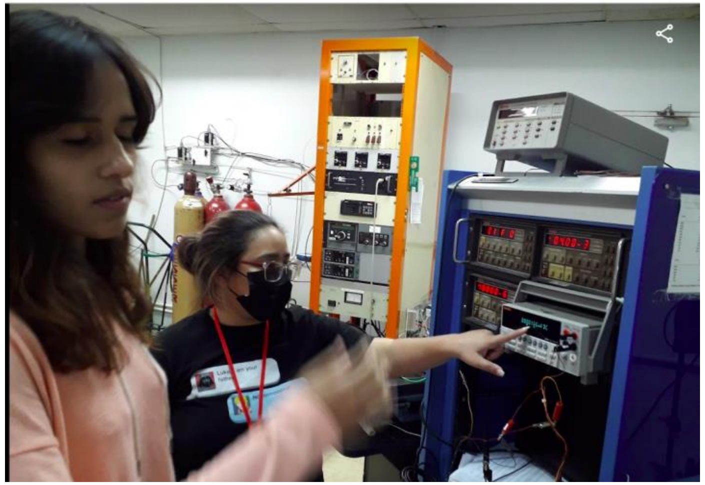
SPIN POLARIZED ELECTRON PHOTOEMISSION AND DETECTION STUDIES

A. C. Rodriguez Alicea, University of Puerto Rico - Mayaguez, Mayaguez, PR, USA
O. Chubenko, S. Karkare, Arizona State University, Tempe, AZ, USA
R. Palai, University of Puerto Rico - Rio Piedras, San Juan, PR, USA
L. Cultrera, Brookhaven National Laboratory, Upton, NY, USA

Abstract

The experimental investigation of new photocathode materials is time-consuming, expensive, and difficult to accomplish. Computational modelling offers fast and inexpensive ways to explore new materials, and operating conditions, that could potentially enhance the efficiency of polarized electron beam photocathodes. We report on Monte-Carlo simulation of electron spin polarization (ESP) and quantum efficiency (QE) of bulk GaAs at 2, 77, and 300 K using the data obtained from Density Functional Theory (DFT) cal-

band structures can be used to provide inputs to a Monte Carlo (MC) simulations, that have successfully reproduced experimental observations of QE and ESP in bulk GaAs [6], in order to predicts the photoemission from novel materials. The QE and ESP strongly depend on the experimental conditions such as, photon energy and temperature. The present work investigate how these parameters can change with temperature for bulk GaAs and compare the results with experimental observations from Liu *et al*. [7]. Once the framework has been completed for this material, we can



Julio Alejandro Joniel Mendez

BNL summer Internship-2023

Joniel- Summer 2023 Project: *Effect of strain on spin polarized electron in GaAs semiconductor thin films*.

UPR-BNL Collaboration

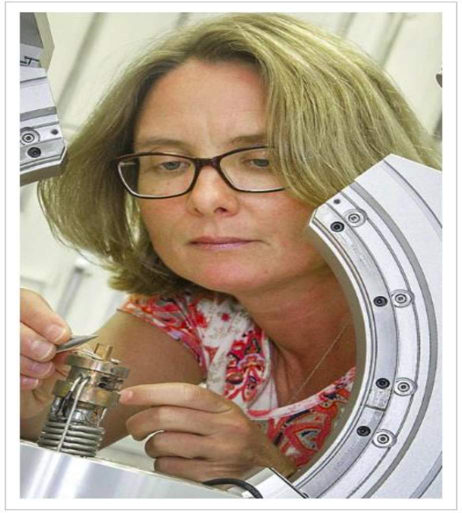
Department of Energy (DOE)
Office of Science (SC)

FY 2023 Funding for Accelerated, Inclusive Research (FAIR)

Funding Opportunity Announcement (FOA) Number:
DE-FOA-0002931

FOA Type: Initial
CFDA Number: 81.049

Luca Cultrera



Christie Nelson

Scholarly Partnership in Nuclear Security (SPINS) Consortium

NAVAJO TECHNICAL UNIVERSITY

Alabama A&M UNIVERSITY

UPRRP

SPINS

Scholarly Partnership in Nuclear Security

Savannah River National Laboratory

Los Alamos NATIONAL LABORATORY

BROOKHAVEN NATIONAL LABORATORY

NNSA National Nuclear Security Administration

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

U.S. DEPARTMENT OF ENERGY

Grant No. DE-NA0003980

SPINS Consortium: Nuclear Detection

PROJECT OBJECTIVES

The overall goal of this consortium is to develop the state-of-the-art research in nuclear security, radiation detection systems, and nuclear nonproliferation.

1. Improve radiological and nuclear detectors capable of remote deployment and operations at room temperature without cryogenic cooling.

2. Develop highly skilled next-generation technical workforce for DoE/NNSA.

3. Build STEM capacity and lasting collaborations with DoE/NNSA facilities/labs

Overview of SPINS Research at UPR- 2023


Alexis Acevedo
(PhD Student)


Dinorah Martinez
(PhD Student)


Rosemary Cortes
(MS Student)


Vincent Merrero
(MS Student)

Undergraduate Research Students


Julio Alejandro

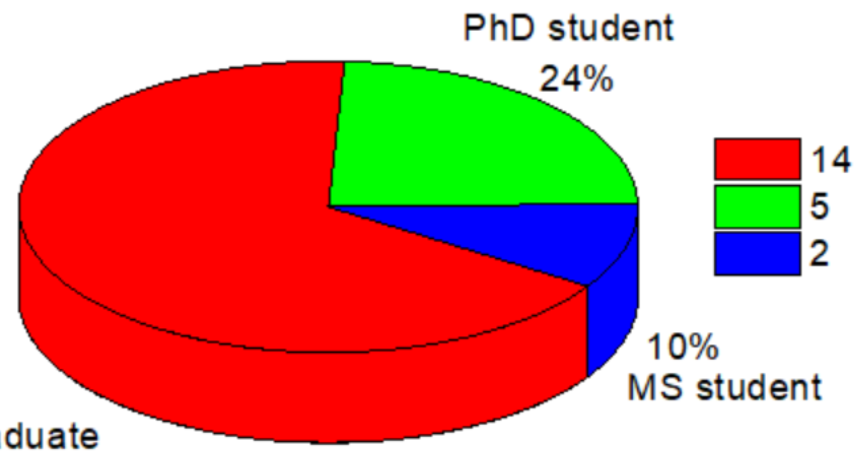

Joniel Mendez


Alejandro Soledad


Jeansel Johnson


Jaileen Caicedo

Students trained in Nuclear Physics Research (2020-2023)



Trainiship offered to UPR students (2020-2023)

UPR students at BNL-March 2023

Julio Alejandro

SPINS+NPT

Joniel Mendez

SPINS+NPT

Jaileen Caicedo

SPINS+SULI

Radiation Detection & Bioremediation

- Growth and characterization of **Al-doped ZnO** thin films for radiation detection
- Calculation of bandstructure and optical properties by DFT

R. Palai

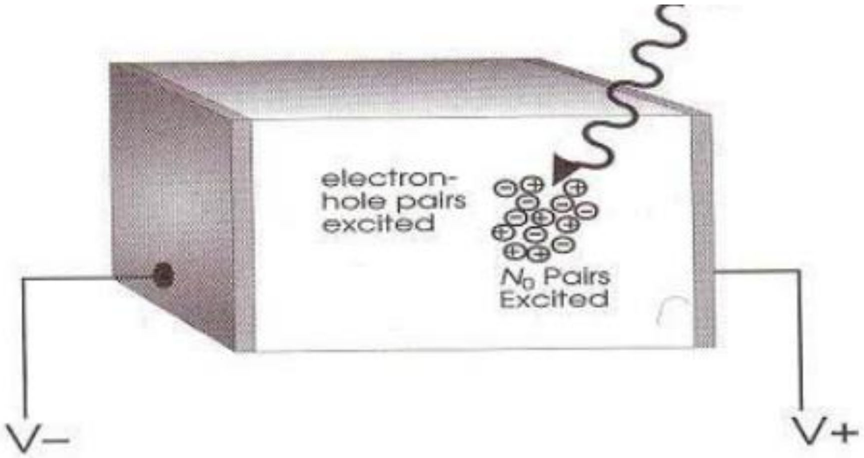
- Electrochemical Bioremediation of Uranium (VI) Using *Geobacter sulfurreducens* on Boron-Doped Diamond Electrode Surface
- Uranium Uptake Using Nano Zerovalent Iron (nZVI) Particles for Environmental Remediation Applications

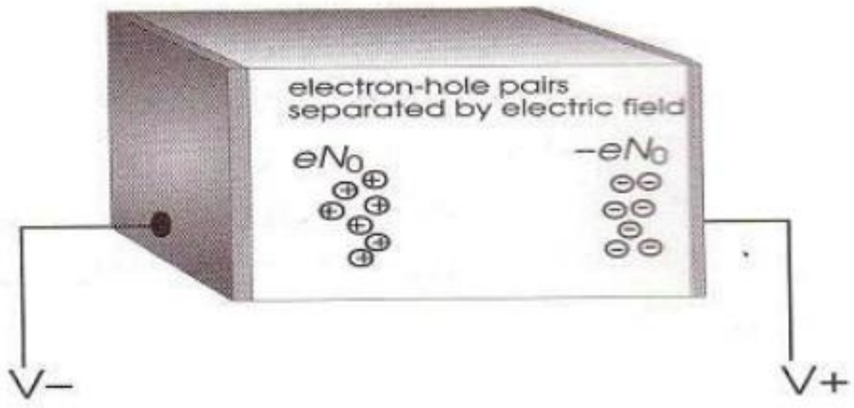
C. Cabrera

Semiconductor Radiation detections

- On semiconductor detectors, incoming ionizing radiation produce electron-hole pairs that are collected on the ohmic contacts.

- The number of electron-hole pairs are proportional to the energy of the ionizing radiation and also encode information about its intensity.

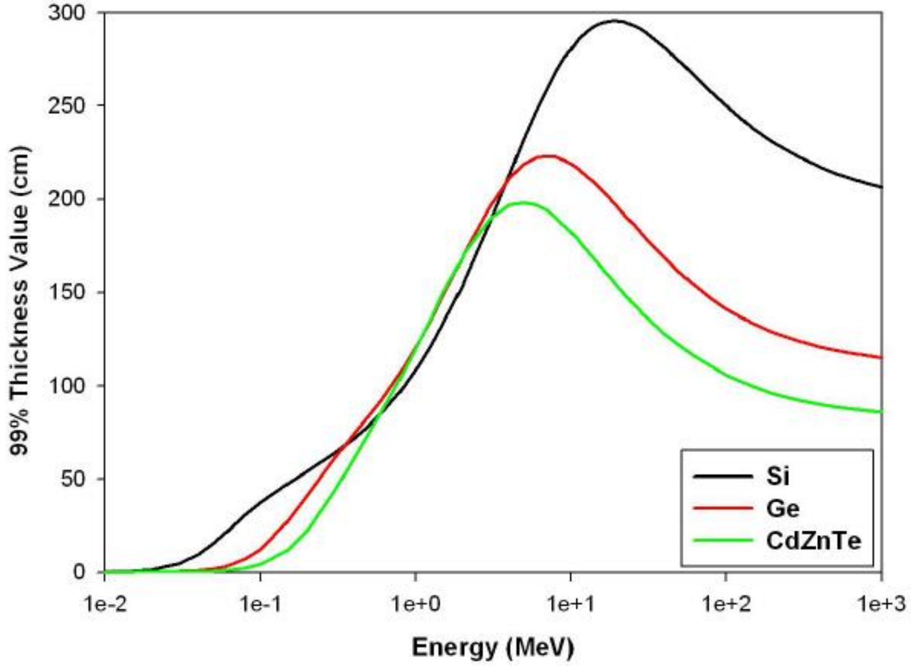




Semiconductor Radiation detectors

At present silicon and germanium detectors are the preferred detectors for X-ray and γ-rays and provide the highest achievable energy resolution. Although both provide excellent energy resolutions both have disadvantages; silicon only proves efficient for the detection of charged particles and low energy γ-rays while germanium requires significant cooling to perform well.

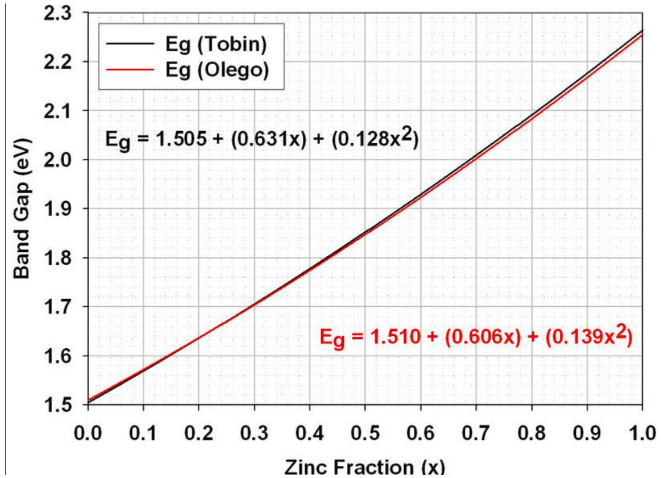
The major drawback of germanium (**HPGe**) detectors is that they must be cooled to liquid nitrogen temperatures to produce spectroscopic data.

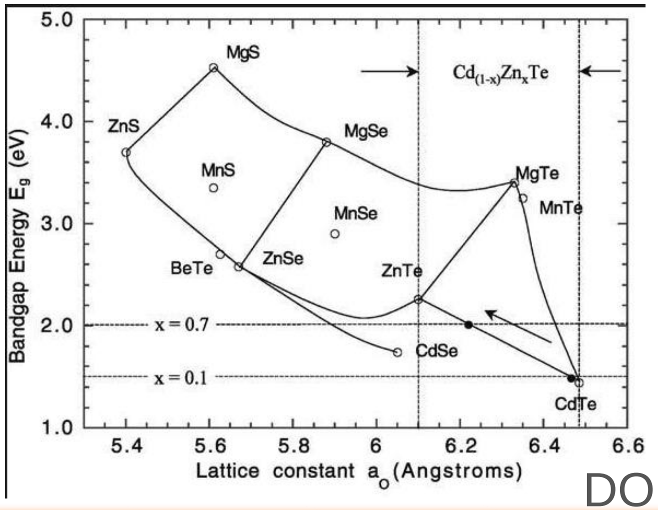


The thickness of material required to reduce the intensity of typical gamma rays to 1% of the original value.

CdZnTe Radiation detectors

Material	$Cd_{0.9}Zn_{0.1}Te$	CdTe	Ge	Si
Atomic Number	49.1	50	32	14
Density (gcm^{-3})	5.78	5.85	5.33	2.33
Bandgap E_g (eV)	1.57	1.50	0.67	1.12
Pair Creation Energy W (eV)	4.6	4.4	3.0	3.6
Resistivity ρ (Ωcm)	10^{10}	10^{9}	50	$<10^{4}$
Electron Mobility μ_e ($cm^2V^{-1}s^{-1}$)	1000	1100	3900	1400
Electron Lifetime τ_e (s)	$3x10^{-6}$	$3x10^{-6}$	$>10^{-3}$	$>10^{-3}$
Hole Mobility μ_h ($cm^2V^{-1}s^{-1}$)	10-80	100	1900	480
Hole Lifetime τ_h (s)	10^{-6}	$2x10^{-6}$	10^{-3}	$2x10^{-3}$





DOI:10.13140/RG.2.2.22915.3024

ZnO:Al contacts on CdZnTe detectors

- CdZnTe (CZT) detectors have been used as the primary candidates for **x-ray and gamma detection** in the fields of nonproliferation, national security and medical imaging, making the study of them of high importance. Despite the various advances made, the stability of the metal contact to CZT needs improvement to better the match of thermo-physical properties in the interfacial region.

- CdZnTe detectors can operate close to room temperature. They have long term durability problems due to the **incompatibility of the ohmic contacts.**

- ZnO:Al contacts have better compatibility with CdZnTe solving the compatibility issue.

CdZnTe detector with conventional Au contacts.
Ref: Baltic Scientific Instruments.

ZnO:Al contacts on CdZnTe detectors

Recently it has been found that Al-doped ZnO (ZnO:Al) can replace **gold contacts** in CdZnTe (CZT) detectors. AZO can be used as an electrode material because its matching of the thermal expansion coefficient to that of CZT. This decreases the thermal stress at the interface, causing an increase in the adhesion and decrease in the degradation of the detector. Doping ZnO with Al increase its thermal stability, reduces the resistivity, and increases the carrier concentration and conductivity.

CdZnTe detector with conventional Au contacts.
Ref: Baltic Scientific Instruments.

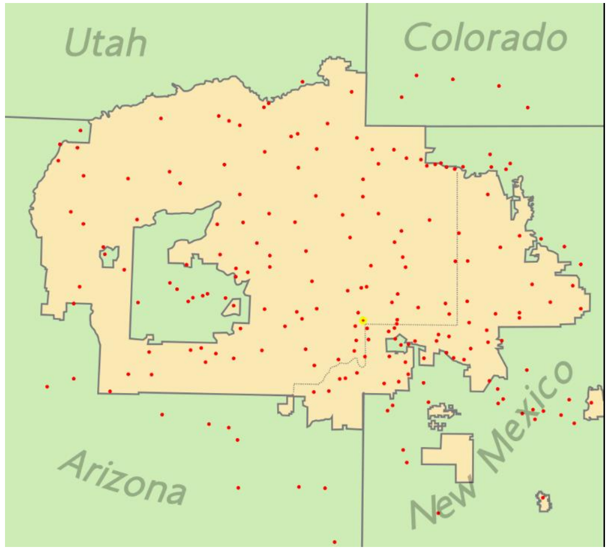
https://link.springer.com/article/10.1007/s11164-018-03729-5/figures/5

Radiation Detectors

From 1944 to 1986, nearly 30 million tons of uranium ore were extracted from Navajo lands under leases with the Navajo Nation.

Navajo Nation has about 500 abandoned uranium mines (AUMs).

Potential health effects include lung cancer from inhalation of radioactive particles, as well as bone cancer and **impaired kidney** function from exposure to radionuclides in drinking water.

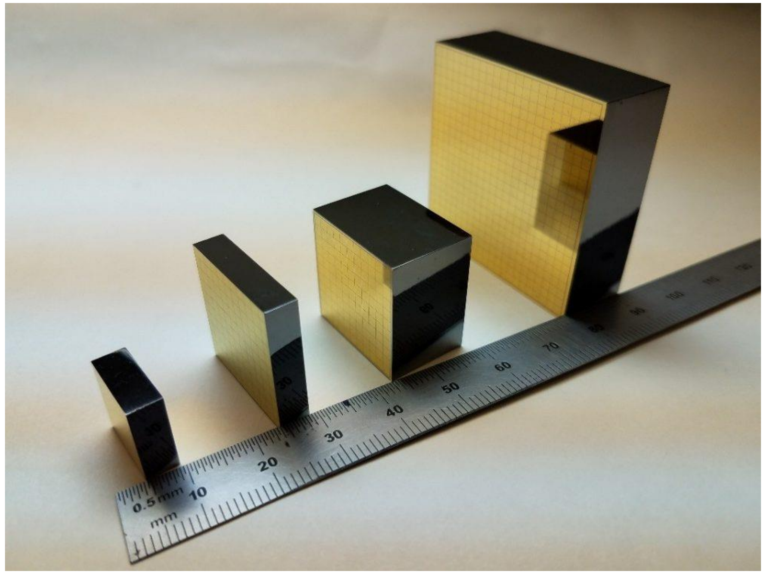


The federal government is cleaning up a long legacy of uranium mining within the Navajo Nation — some 27,000 square miles spread across Utah, New Mexico and Arizona that is home to more than 250,000 people.

https://www.npr.org

CZT Radiation Detectors

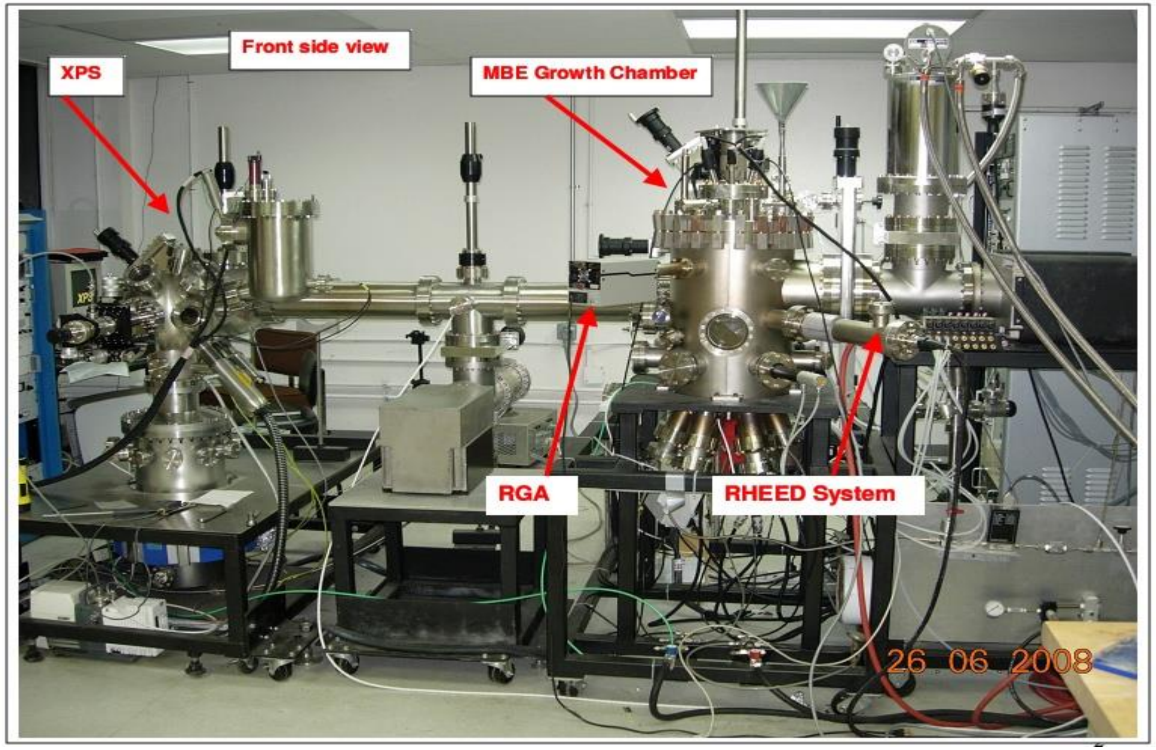
A 1 cm^3 CZT crystal has a sensitivity range of 30 keV to 3 MeV with a 2.5% FWHM energy resolution at 662 keV. Pixelated CZT with a volume of 6 cm^3 can achieve 0.71% FWHM energy resolution at 662 keV and perform Compton imaging.

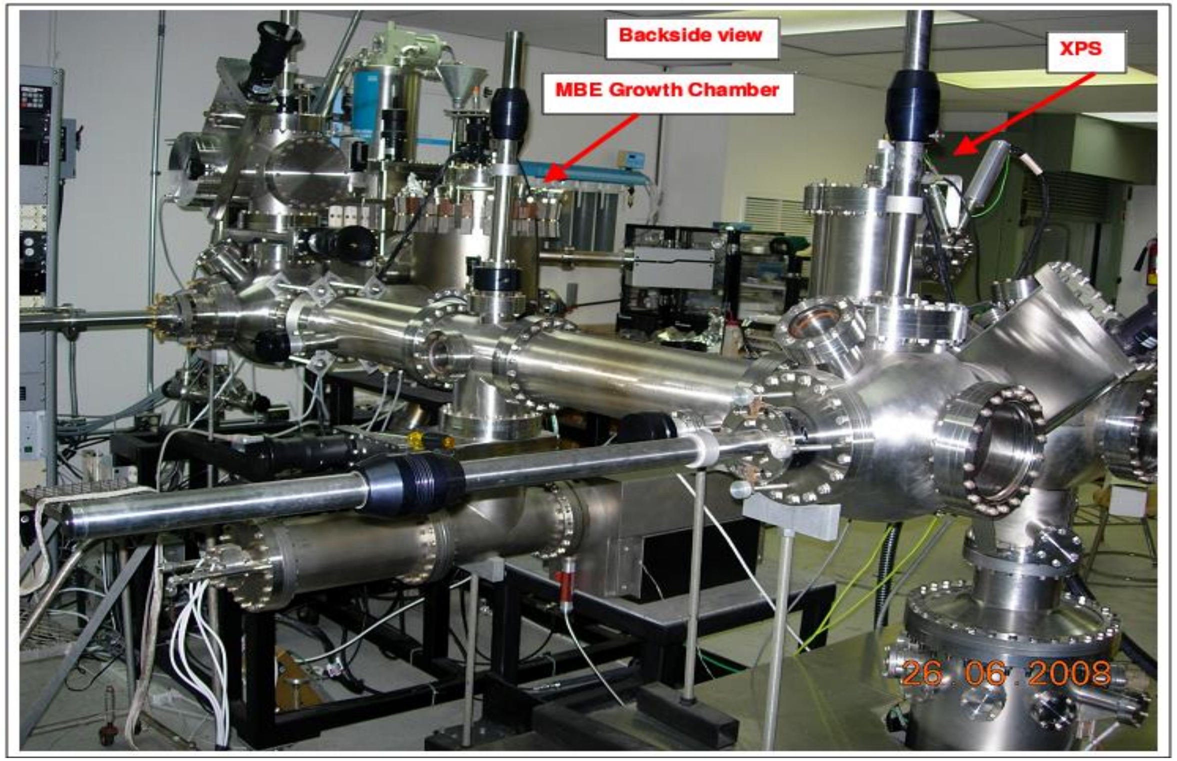


Kromek monolithic CZT detector.

A YanDavos radiation sensor system based on a 1 cm^3 CZT crystal, deployed on a Boston Dynamics Spot quadruped robot for radiation mapping in the Chernobyl Exclusion Zone.

Molecular Beam Epitaxy (MBE)





- Plasma assisted MBE
- Six effusion cells : Ga, In, Al, N, (Two dopant cells- Gd, Yb)
- In situ reflection high energy electron diffraction (RHEED)
- RGA- Residual gas analyzer
- XPS- X-ray photoelectron spectrometer

SPINS Project:

$In_{1-x}Ga_xN$:Gd,

Direct Bandgap

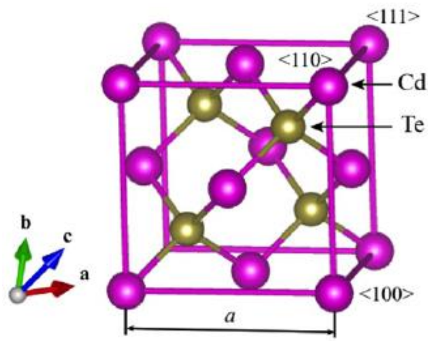
N-type & P-type

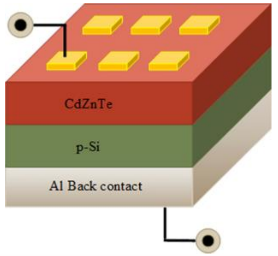
$E_g = 1.5$ eV

Pulsed Laser Deposition (PLD)

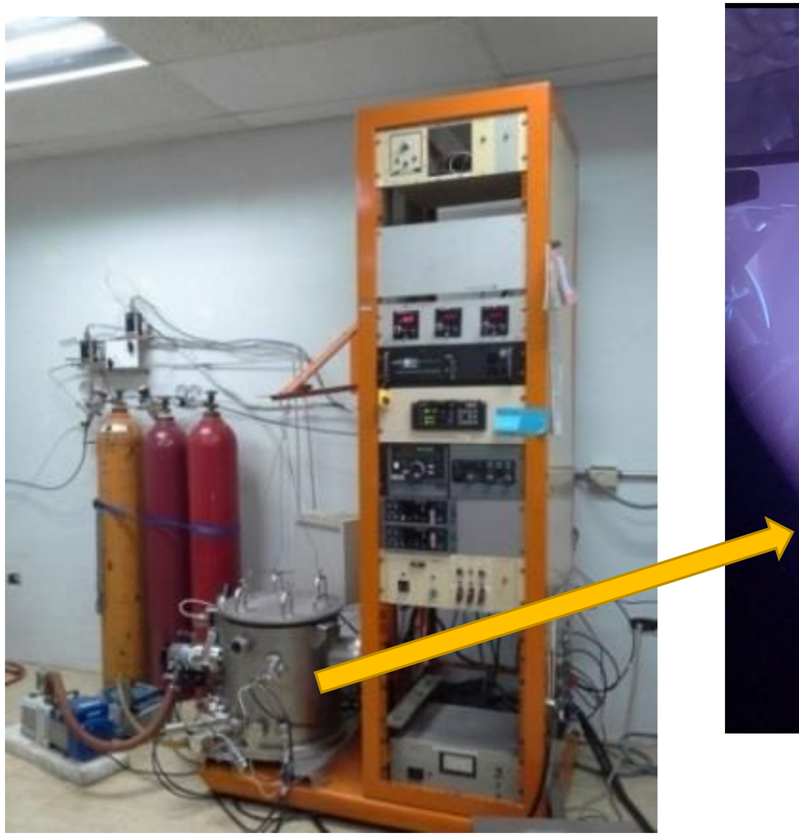
SPINS Project: PLD

- Growth of oxide buffer layers
- CdZnTe detector electrodes

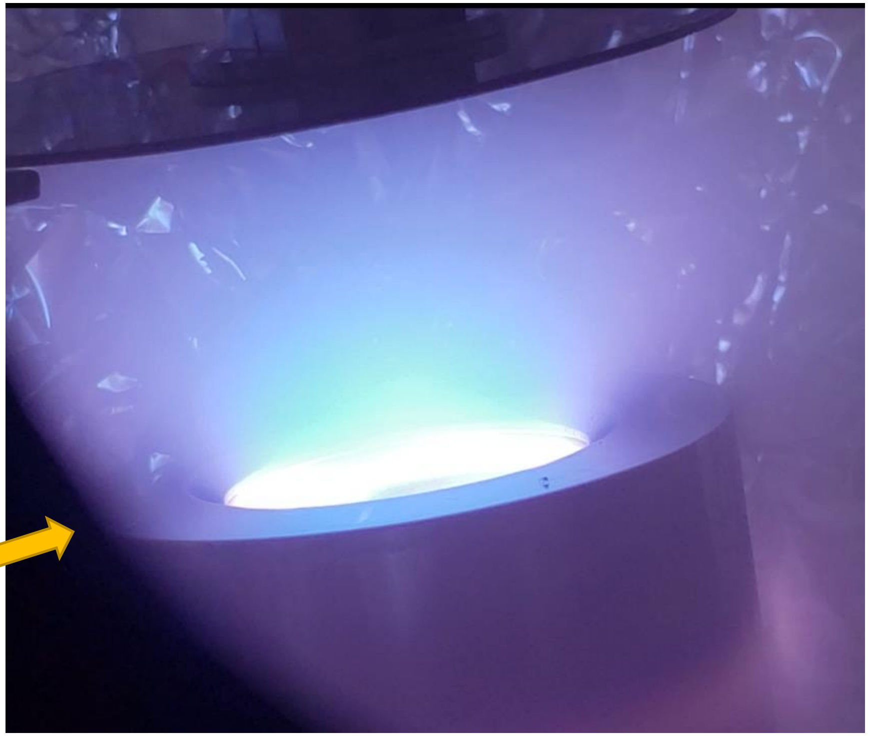




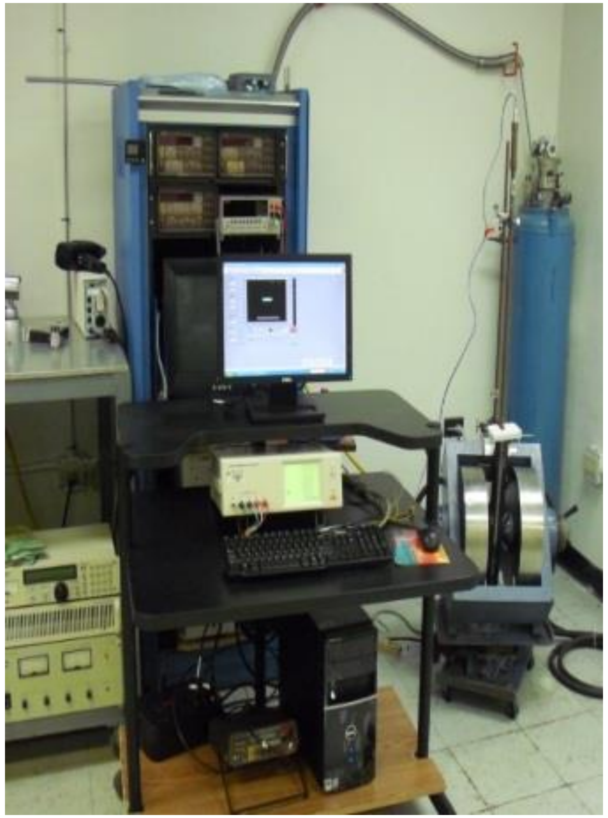
Thin Film Growth: Sputtering



RF & DC Sputtering system



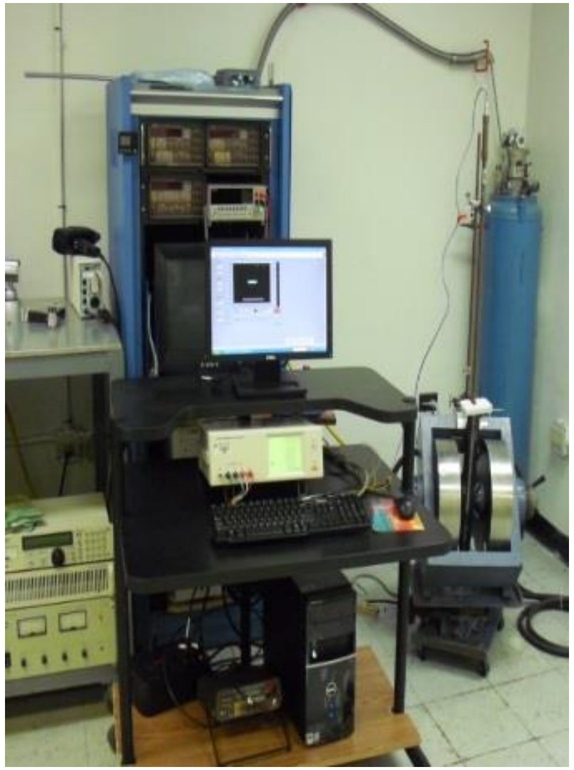
- RF Sputtering
- Inert gas: Argon
- Power 200 W
- Target distance: 56 mm
- Base Pressure: x10^{-6} Torr
- Deposition Pressure: 6.6x10^{-2} Torr
- Deposition time: ~1.5 hr



I-V Measurement setup

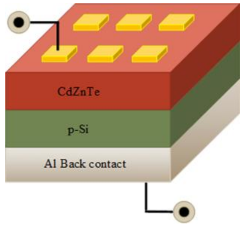
UPR Research Facilities: Sputtering & Photolithography

RF & DC Sputtering system



I-V Measurement setup

Photolithography



SPINS Project: RF & DC Sputtering

CdZnTe, CdTe, & CdGdTe Thin Films growth

Metallization- Ohmic contact & I-V measurements

Overview of SPINS Research at UPR

- Growth and characterization of **Al-doped ZnO** thin films by Sputtering on Silicon & Glass substrates
- ZnO and Al-doped ZnO (AZO) Band structure and optical properties calculation by DFT

R. Palai

- **Electrochemical Bioremediation of Uranium (VI) Using *Geobacter sulfurreducens* on Boron-Doped Diamond Electrode Surface**
- Uranium Uptake Using Nano Zerovalent Iron (nZVI) Particles for Environmental Remediation Applications.

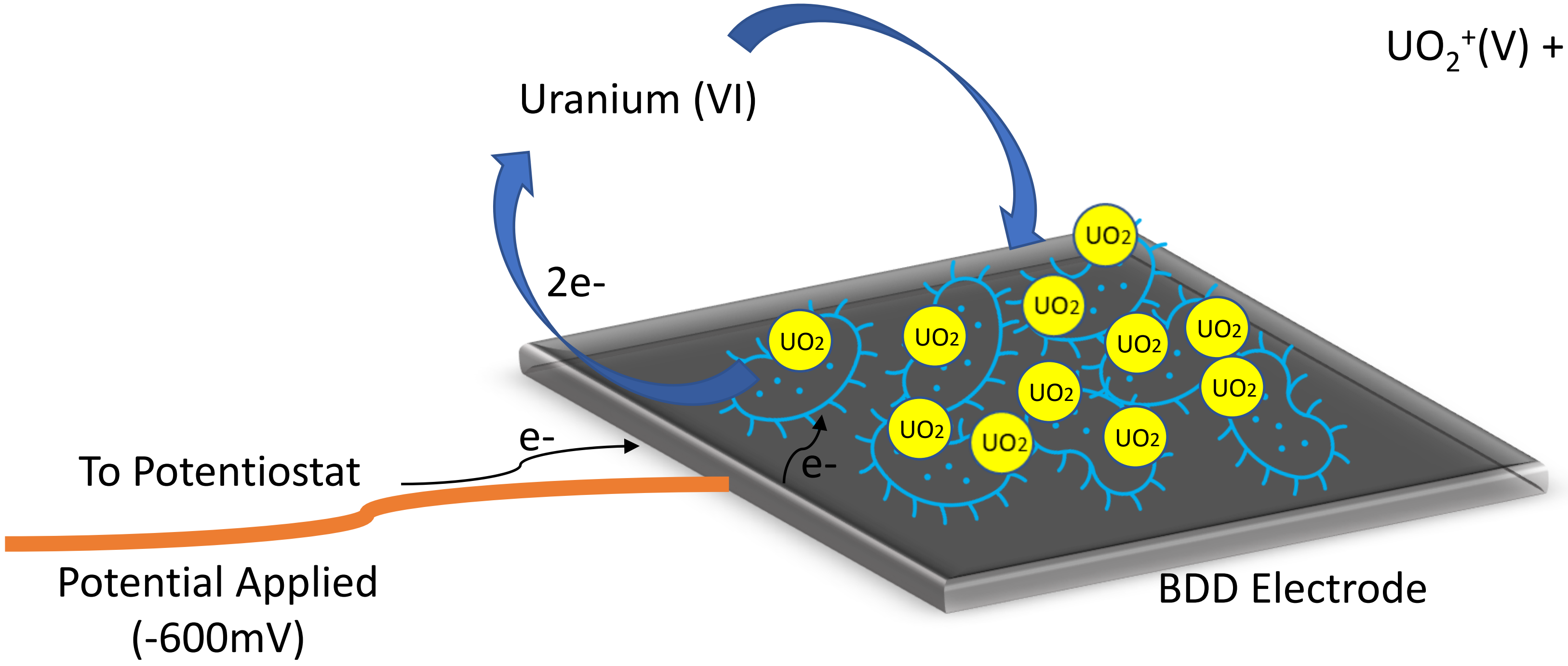
C. Cabrera

Bioremediation of Uranium

Electrochemical Reduction of Uranium (VI) with *Geobacter sulfurreducens*

$$UO_2^{+2}(VI) + e^- \longrightarrow UO_2^{+}(V)$$

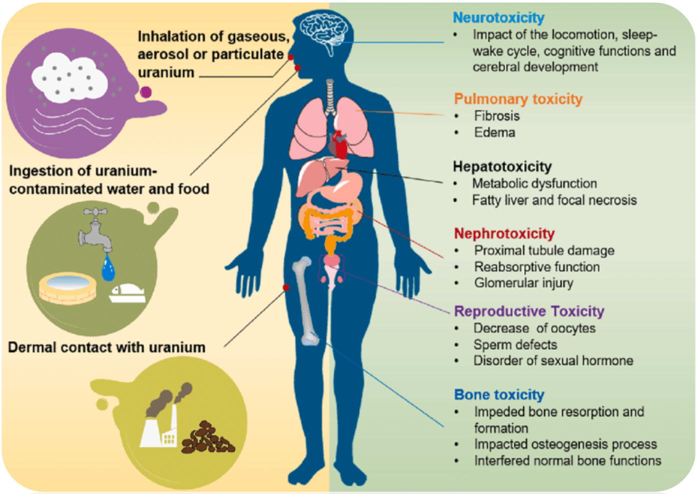
$$UO_2^{+}(V) + e^- \longrightarrow UO_2(IV)$$

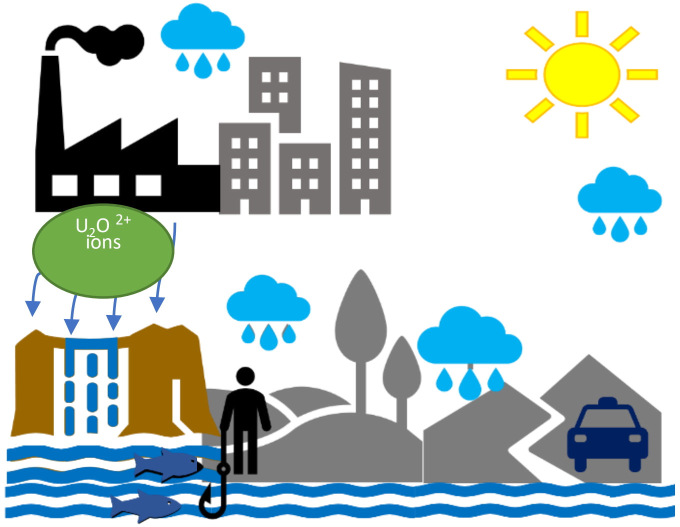


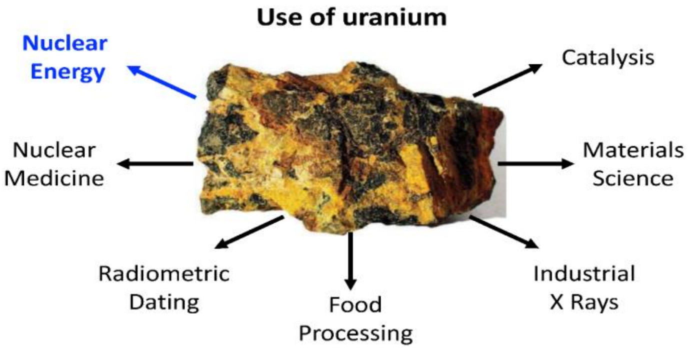
Bioremediation of Uranium

Uranium Uptake Using Nano Zerovalent Iron (nZVI) Particles for Environmental Remediation Applications

Health Effect of Uranium

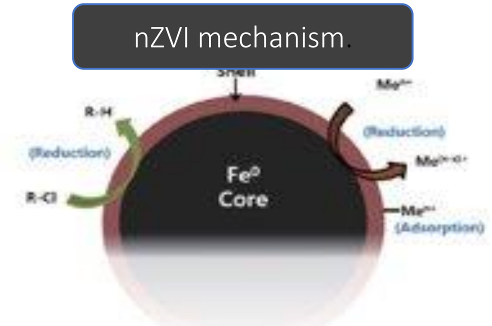






- Industrial and demographic growth in urban areas has increased uranium metal pollution.

- Uranium (U) is a toxic heavy metal that can be responsible for liver and kidney damage, anemia, infertility, and mental retardation among other consequences.



- In this study we evaluate the nZVI superficial and structural changes occurring during the U sorption process for environmental remediation applications.

Bioremediation of Uranium

Testbed

Wetlands in Puerto Rico

Pterocarpus Zone and Mangrove Zone *(Near to Yields 1-3)*

Experimental Setup:

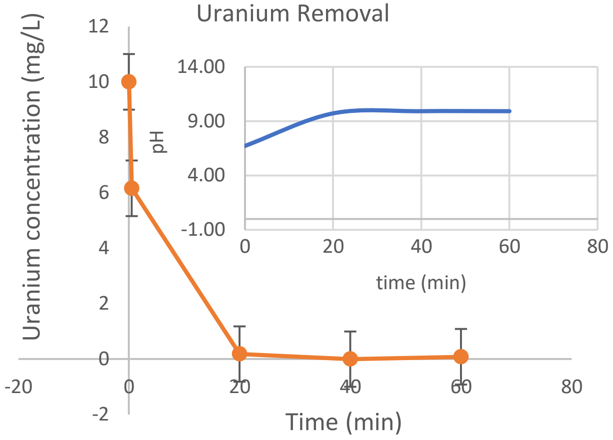
✓Simulation of wastewater concentration analysis.

Evaluate UO_2^{2+} removal efficiency at different pHs by ICP-OES analysis

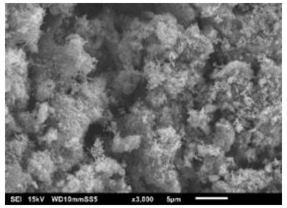
1. Prepare a 193ppm lead solutions in HNO_3 at pHs range 2-8.
2. Add the nZVI into the solution.
3. Measure initial pH. Then every 20 minutes take an alicuote and measure the pH.
4. Centrifugate the solution

Schematic illustration of UO_2^{2+} synthetic wastewater analysis.

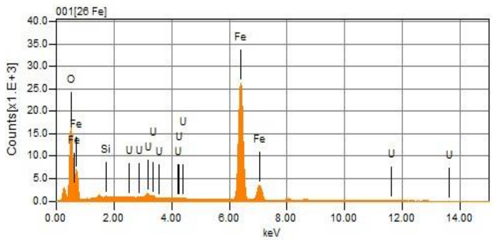
U-nZVI ICP-OES analysis



U-nZVI SEM & EDS



Element	Mass %
U	2.85
Fe	80.80
O	16.14
Si	0.21



Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) Results at "Las Cucharillas" Mash

Metal	Sample 1 (Concentration in water)	Sample 2 (Concentration in water)	Sample 3 (Concentration in water)	EPA maximum contaminant level in drinking water (concentration)
Uranium	10 ppm	2 ppm	4.7 ppm	0.2 ppm

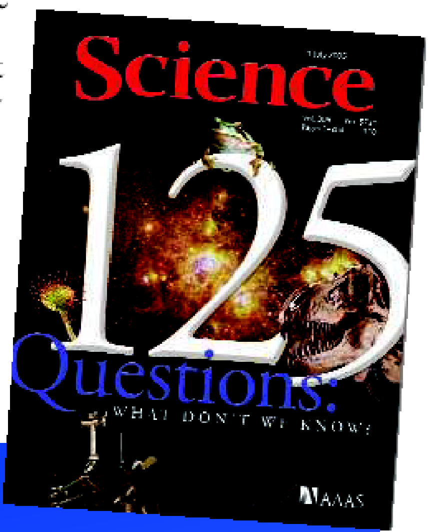
What Don't We Know?

At *Science*, we tend to get excited about new discoveries that lift the veil a little on how things work, from cells to the universe. That puts our focus firmly on what has been added to our stock of knowledge. For this anniversary issue, we decided to shift our frame of reference, to look instead at what we *don't* know: the scientific puzzles that are driving basic scientific research.

We began by asking *Science*'s Senior Editorial Board, our Board of Reviewing Editors, and our own editors and writers to suggest questions that point to critical knowledge gaps. The ground rules: Scientists should have a good shot at answering the questions over the next 25 years, or they should at least know how to go about answering them. We intended simply to choose 25 of these suggestions and turn them into a survey of the big questions facing science. But when a group of editors and writers sat down to select those big questions, we quickly realized that 25 simply wouldn't convey the grand sweep of cutting-edge research that lies behind the responses we received. So we have ended up with 125 questions, a fitting number for *Science*'s 125th anniversary.

First, a note on what this special issue is not: It is not a survey of the big societal challenges that science can help solve, nor is it a forecast of what science might achieve. Think of it instead as a survey of our scientific ignorance, a broad swath of questions that scientists themselves are asking. As Tom Siegfried puts it in his introductory essay, they are "opportunities to be exploited."

We selected 25 of the 125 questions to highlight based on several criteria: how fundamental they are, how broad-ranging, and whether their solutions will impact other scientific disciplines. Some have few immediate practical implications—the composition of the universe, for example. Others we chose because the answers will have enormous societal impact—whether an effective HIV vaccine is feasible, or how much the carbon dioxide we are pumping into the atmosphere will warm our planet, for example. Some, such as the nature of dark energy, have come to prominence only recently; others, such as the mechanism behind limb regeneration in amphibians, have



Contents >> News

WHAT DON'T WE KNOW?

WHAT DON'T WE KNOW?

Is it possible to create magnetic semiconductors that work at room temperature? P. 82

Can researchers make a perfect optical lens?
They've done it with microwaves but never with visible light.

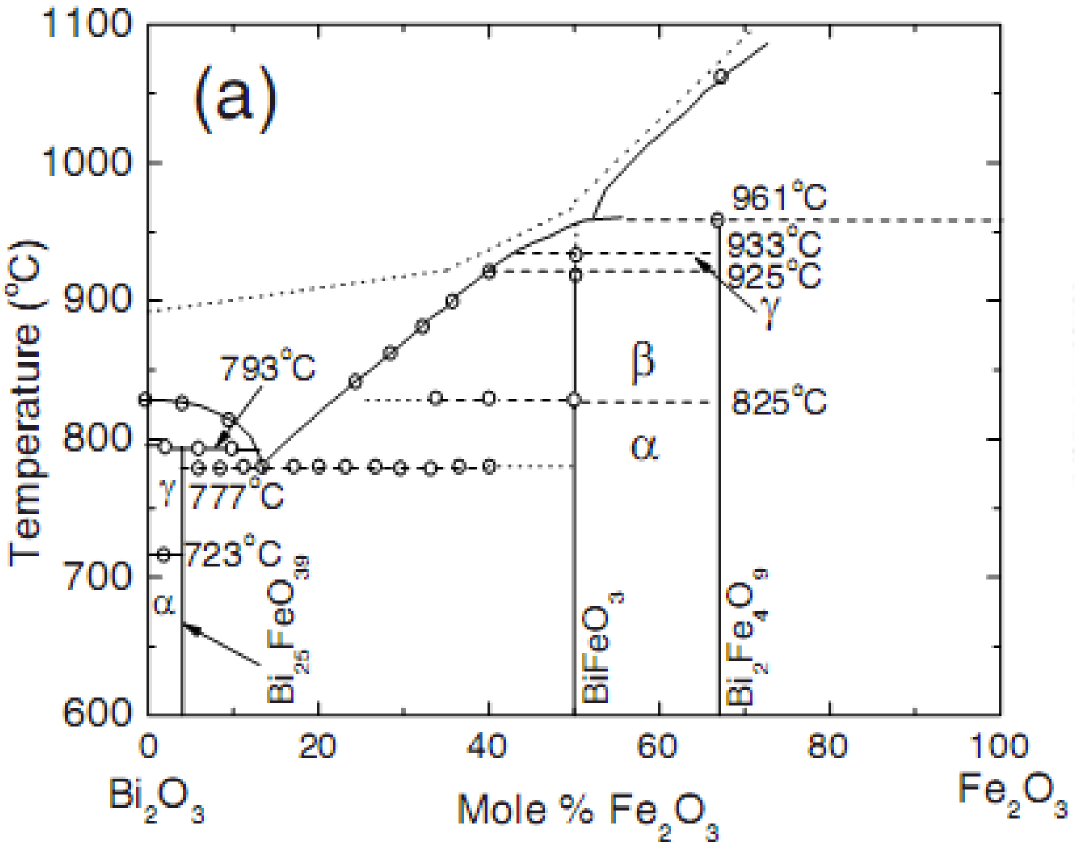
Is it possible to create magnetic semiconductors that work at room temperature?
Such devices have been demonstrated at low temperatures but not yet in a range warm enough for spintronics applications.

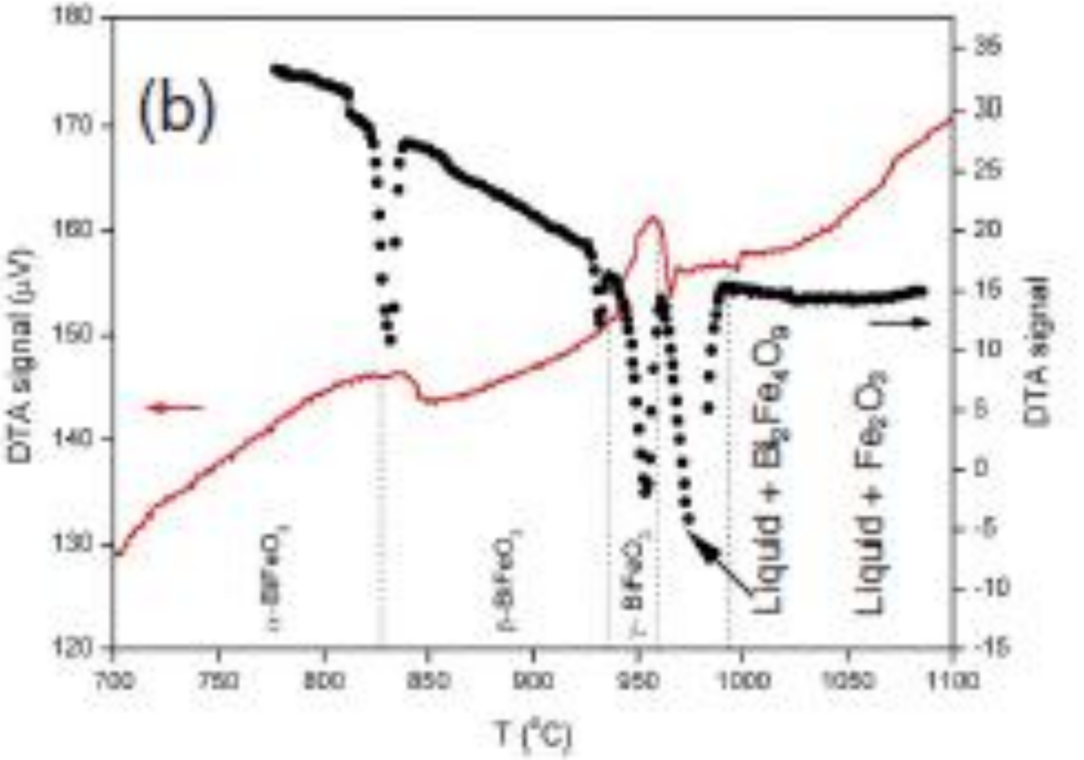
What is the pairing mechanism behind high-temperature superconductivity?
Electrons in superconductors surf together in pairs. After 2 decades of intense study, no one knows what holds them together in the complex, high-temperature materials.

Can we develop a general theory of the dynamics of turbulent flows and the motion of granular materials?
So far, such "nonequilibrium systems" defy the tool kit of statistical mechanics, and the failure leaves a gaping hole in physics.

Science, 309, 78-102 (2005)

Magnetoelectric Multiferroics: BiFeO3



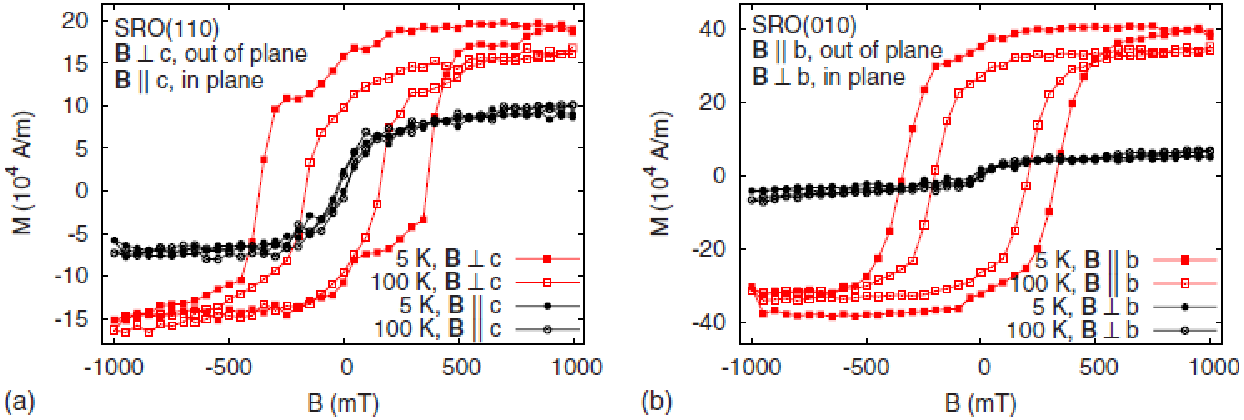


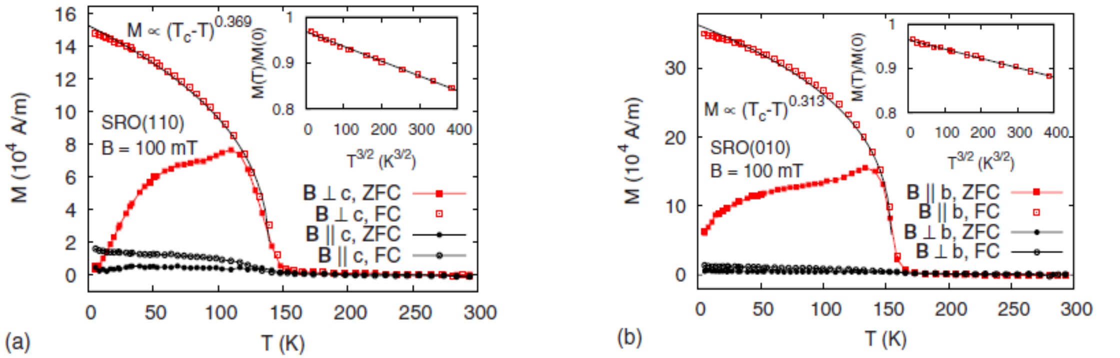
R. Palai, et al. PRB 77, 014110 (2008)

Spin-charge-lattice interactions in magnetoelectric multiferroics with ferromagnetic, ferroelectric, and ferroelastic order parameters.

β phase and $\gamma-\beta$ metal-insulator transition in multiferroic $BiFeO_3$ R Palai, RS Katiyar, H Schmid, P Tissot, SJ Clark, J Robertson, ... Physical Review B 77 (1), 014110	788	2008
Raman spectroscopy of single-domain multiferroic BiFeO 3 R Palai, H Schmid, JF Scott, RS Katiyar Physical Review B 81 (6), 064110	130	2010

Spin-glass transitions: $SrRuO_3$ Thin Films





Tc= 150K, β=0.369, 3D Heisenberg type, (theory β= 0.367)

Tc= 160K, β=0.313, 3D Ising type, (theory β= 0.326)

PHYSICAL REVIEW B **79**, 104413 (2009)

Observation of spin-glass-like behavior in $SrRuO_3$ epitaxial thin films

R. Palai,[1] H. Huhtinen,[2] J. F. Scott,[3] and R. S. Katiyar[1]
[1]*Department of Physics and Institute for Functional Nanomaterials, University of Puerto Rico, San Juan, Puerto Rico 00931-23343, USA*
[2]*Department of Physics, University of Turku, Turku FIN-20014, Finland*
[3]*Department of Earth Science, University of Cambridge, Cambridge CB2 1PZ, United Kingdom*
(Received 13 November 2008; revised manuscript received 26 January 2009; published 12 March 2009)

We report on the observation of spin-glass-like behavior and strong magnetic anisotropy in extremely smooth (~1–3 Å roughness) epitaxial (110) and (010) $SrRuO_3$ thin films. The easy axis of magnetization is always perpendicular to the plane of the film (unidirectional) irrespective of crystallographic orientation. An attempt has been made to understand the nature and origin of spin-glass behavior, which fits well with Heisenberg model.

DOI: 10.1103/PhysRevB.79.104413 PACS number(s): 75.50.Lk, 75.60.Ej, 75.70.Ak, 77.80.−e

Observation of spin-glass-like behavior in SrRuO 3 epitaxial thin films 77 2009
R Palai, H Huhtinen, JF Scott, RS Katiyar
Physical Review B 79 (10), 104413

R. Palai, et al. PRB 79, 104413 (2009)

SUPERCONDUCTIVITY: HTS

PHYSICAL REVIEW B **75**, 184524 (2007)

Effects of nanocrystalline target and columnar defects on flux pinning in pure and $BaZrO_3$-doped $YBa_2Cu_3O_{6+x}$ films in fields up to 30 T

M. Peurla,[1,2] H. Huhtinen,[1] M. A. Shakhov,[1,3] K. Traito,[1] Yu. P. Stepanov,[1,3] M. Safonchik,[1,3] P. Paturi,[1] Y. Y. Tse,[4] R. Palai,[5] and R. Laiho[1]
[1]*Wihuri Physical Laboratory, Department of Physics, University of Turku, FI-20014 Turku, Finland*
[2]*Graduate School of Materials Research, University of Turku, Turku, Finland*
[3]*A. F. Ioffe Physico-Technical Institute, St. Petersburg 194021, Russia*
[4]*School of Engineering, University of Birmingham, Birmingham B15 2TT, United Kingdom*
[5]*School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, United Kingdom*
(Received 1 February 2007; published 24 May 2007)

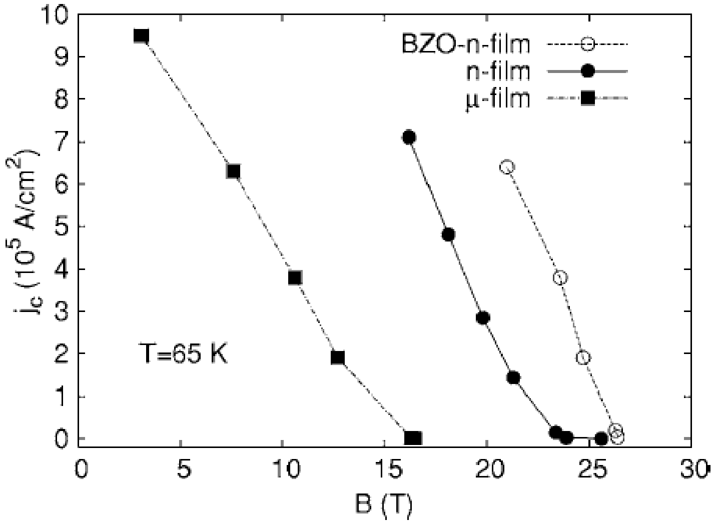


FIG. 5. Critical current densities determined at 65 K using pulsed magnetic fields. The lines are to guide the eye.

SPINS Research at UPR: HS Summer Program

Smart Materials & Their Applications

Ratnakar Palai
Department of Physics
University of Puerto Rico, San Juan, PR, USA

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Scholarly Partnership in Nuclear Security

SPINS High School Summer Program
June 06, 2023

National Nuclear Security Administration
Grant No. DE-NA0003980
U.S. DEPARTMENT OF ENERGY

Nuclear Structure: Rutherford Scattering

Ratnakar Palai
Department of Physics
University of Puerto Rico, San Juan, PR

SPINS High School Program –Summer 2023
June 12, 2023

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Grant No. DE-NA0003980
U.S. DEPARTMENT OF ENERGY

Nuclear Radiation & Its Application in Medical Science

Ratnakar Palai
Department of Physics
University of Puerto Rico, San Juan, PR

SPINS High School Summer Program
June 09, 2023

National Nuclear Security Administration
Grant No. DE-NA0003980
U.S. DEPARTMENT OF ENERGY

Summary

Opportunities:

- Having a Nuclear Physics –concentration/program in undergraduate/graduate curriculum will provide excellent opportunity to UPR students to pursue higher studies/research in NP .
- Involving underrepresented students in nuclear physics research will be provide better employment opportunity and meet the Nation's demand in nuclear workforce.

Obstacles:

- Need fellowships for Graduate students.
- Need some funding support to set up nuclear physics teaching lab.

Future Plans:

We submitted a new proposal ***"BNL-MSI Fellowship Program for Research Excellence and Preparation in Nuclear Physics"*** **PI: Mickey Chu.** If the proposal get funded, we will involve more UPR students in NP traineeship to work at BNL.