2020 LLNL Nuclear Science and Security Summer Internship Program

Glenn T. Seaborg Institute
Lawrence Livermore National Laboratory
Physical and Life Sciences Directorate
Livermore, CA 94550

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Sponsors:
Defense Threat Reduction Agency, Department of Defense
Glenn T. Seaborg Institute, Physical and Life Sciences Directorate, Lawrence Livermore National Laboratory

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LLNL-TR-816400

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2020 LLNL Nuclear Science and Security Summer Internship Program

The Lawrence Livermore National Laboratory (LLNL) Nuclear Science and Security Summer Internship Program (NS^3IP) is designed to give graduate students an opportunity to come to LLNL for 8–10 weeks of hands-on research. Students conduct research under the supervision of a staff scientist, attend a weekly lecture series, interact with other students, and present their work in poster format at the end of the program. Students also have the opportunity to meet staff scientists one-on-one, participate in LLNL facility tours (e.g., the National Ignition Facility and Center for Accelerator Mass Spectrometry), and gain a better understanding of the various science programs at LLNL. Due to the travel and access restrictions imposed by the COVID-19 pandemic, the 2020 NS^3IP was organized as an "all-virtual" internship program. With LLNL's extensive institutional support, students accessed the laboratory's cyberinfrastructure through a secure virtual desktop environment and all seminars, mentor interactions, summer presentations, and laboratory tours were performed remotely. While this virtual internship format did not allow for hands-on laboratory research projects, both the interns and their mentors constructed creative research projects that maximized student exposure to nuclear science research that is relevant to DTRA and LLNL interests in nuclear security.

Currently titled the Nuclear Science and Security Summer Internship Program, this program began over 20 years ago as the Actinide Sciences Summer Program. The program is run by the Glenn T. Seaborg Institute in the Physical and Life Sciences Directorate at LLNL. The goal of the NS^3IP is to facilitate the training of next generation nuclear scientists and engineers to solve critical national security problems in the field of nuclear science and nuclear security. Students are selected from the fields of physics, chemistry, geology, mathematics, nuclear engineering, chemical engineering and environmental sciences. Students engage in research projects in the disciplines of actinide chemistry, radiochemistry, isotopic analysis, computation, radiation detection, and nuclear engineering. This Internship Program is supported by the Defense Threat Reduction Agency (DTRA) which enables the Department of Defense and the U.S. Government to prepare for and combat weapons of mass destruction and improvised threats and to ensure nuclear deterrence. The internship program is intended to strengthen the "pipeline" for future scientific disciplines critical to DTRA and DOE.

The NS^3IP is highly competitive, with over 150 applications received in 2020 for the 7-8 available slots. Additional students funded through paid internships and fellowships from NNSA and DOE are invited to participate in the summer lecture series. All students participate in the LLNL summer event that showcases summer internship projects. In past years, the showcase took the form of a poster session. This year, the showcase took the form of an online Student SLAM! event that emulated the short presentation format pioneered by the TED talk series. The NS^3IP hosted students from 5 universities (see Table 1) across the United States (Figure 1). The NS^3IP students conducted research on such diverse topics as field portable resonance ionization mass spectrometry, nuclear battery development, pre- and post-detonation mass spectrometry, and nuclear signatures development (see Table 2 for research topics). Continued research collaboration between the graduate student, faculty advisor, and LLNL mentors is strongly encouraged. In many cases, NS^3IP research evolves into a significant component of the students' graduate theses. For example, two graduates of the 2019 NS^3IP (Michael Klosterman and Meena Said) returned in 2020 and are continuing their collaboration with LLNL staff and incorporating their summer projects into their PhD research. Meena Said recently applied for a post-doctoral fellowship at LLNL to continue her career in nuclear science.

In addition to hands-on training, students attend a weekly lecture series on topics applicable to the field of nuclear science (Table 3). Speakers are selected to represent the breadth of expertise that is required for nuclear science research. Speakers discuss the importance of their work in the context of national and international nuclear security efforts.

Graduate and undergraduate students on fellowships such as the Nuclear Safeguards internship program and Nuclear Science and Security Consortium, are invited to join our summer internship activities. This year, the Seaborg institute hosted 5 students from Washington State University, Georgia Tech, UC Berkeley, Ohio State University and Oregon State University through nuclear science fellowships and programmatic funding. Our summer program is providing a nuclear science pipeline of top-quality students from universities across the United States. Since 2002, 25% have returned to conduct their graduate research at LLNL. In total:

- 41 interns continued their graduate work at LLNL
- 26 became postdoctoral fellows at LLNL
- 16 became postdoctoral fellows at other national labs
- 16 were hired as career scientists at LLNL
- 19 were hired as career scientists at other national labs
- 21 were hired at other government institutions
- 22 were hired at universities
- 45 transitioned to the private sector

A big factor in the success of this program is the dedication of the staff scientists (predominantly DTRA funded) who volunteer to mentor the summer students. Four of our 2020 mentors are, in fact, alumni of the Seaborg Institute summer internship programs. The mentors develop summer projects for their students, oversee necessary safety training, and dedicate time to helping the interns and students maximize their productivity and scientific potential. This internship program would not be possible without the mentors' dedication. The PowerPoint presentations summarizing the 2020 NS^3IP student research projects were presented at the virtual summer student SLAM! event and are included at the end of this report. The recorded video presentations will be available on the Seaborg Institute website (www.seabort.llnl.gov).

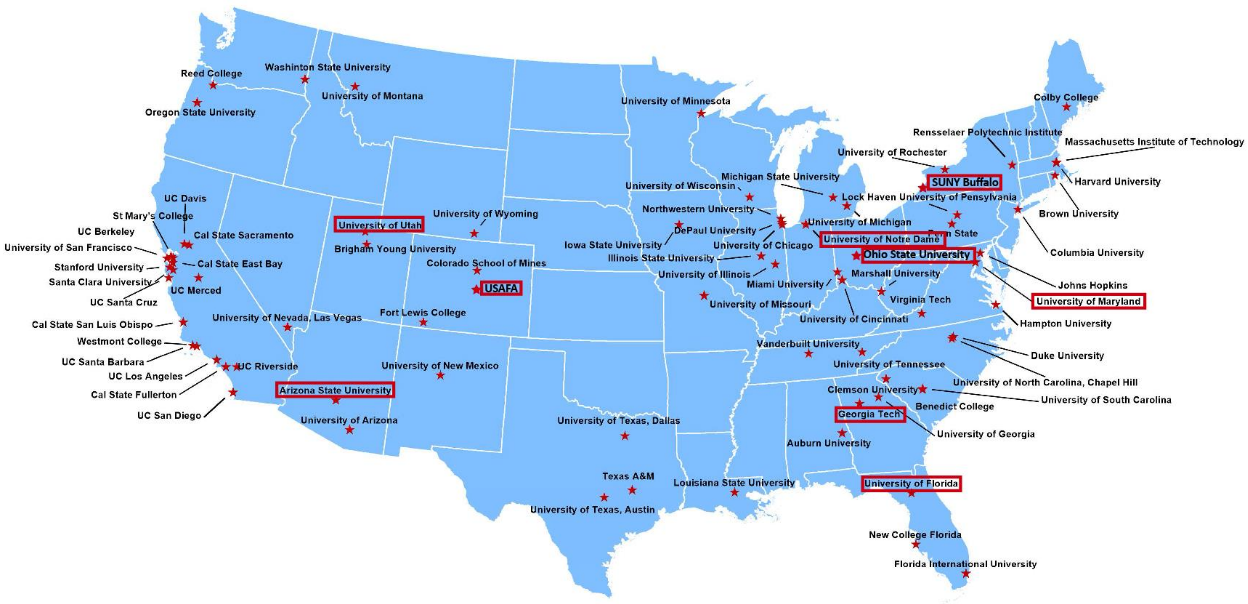


Figure 1. The Seaborg Institute summer interns come from universities from across the United States. Universities associated with the 2020 Nuclear Science and Security Summer Internship program are highlighted with a red outline.

Table 1. 2020 Nuclear Science and Security Summer Internship Program Students

Student	Major	University	Year
Mike Klosterman	Environmental Engineering	University of Utah	Graduate
James Totten[1]	Nuclear Engineering	University of Florida	Graduate
Dan Sullivan[1]	Geology/Geochemistry	Arizona State University	Graduate
Sarah Azhar[1]	Mechanical Engineering	Georgia Tech	Undergraduate
Meena Said	Earth Sciences	University of Notre Dame	Graduate
Neil Taylor	Nuclear Engineering	Ohio State University	Graduate
Christopher Brais	Analytical Chemistry	State University of New York, Buffalo	Graduate
Frederick Delawie[2]	Aerospace Engineering	University of Maryland	Undergraduate
Nicholas Parham[3]	Operations Research	USAFA, CO CS-31 Grim Reapers	Undergraduate

[1] Could not participate due to virtual format; will be considered for 2021.
[2] Funded at 50% by DTRA.
[3] Supported through a collaboration with the MARA program.

Table 2. 2020 Nuclear Science and Security Summer Internship Program Student Projects and Mentors

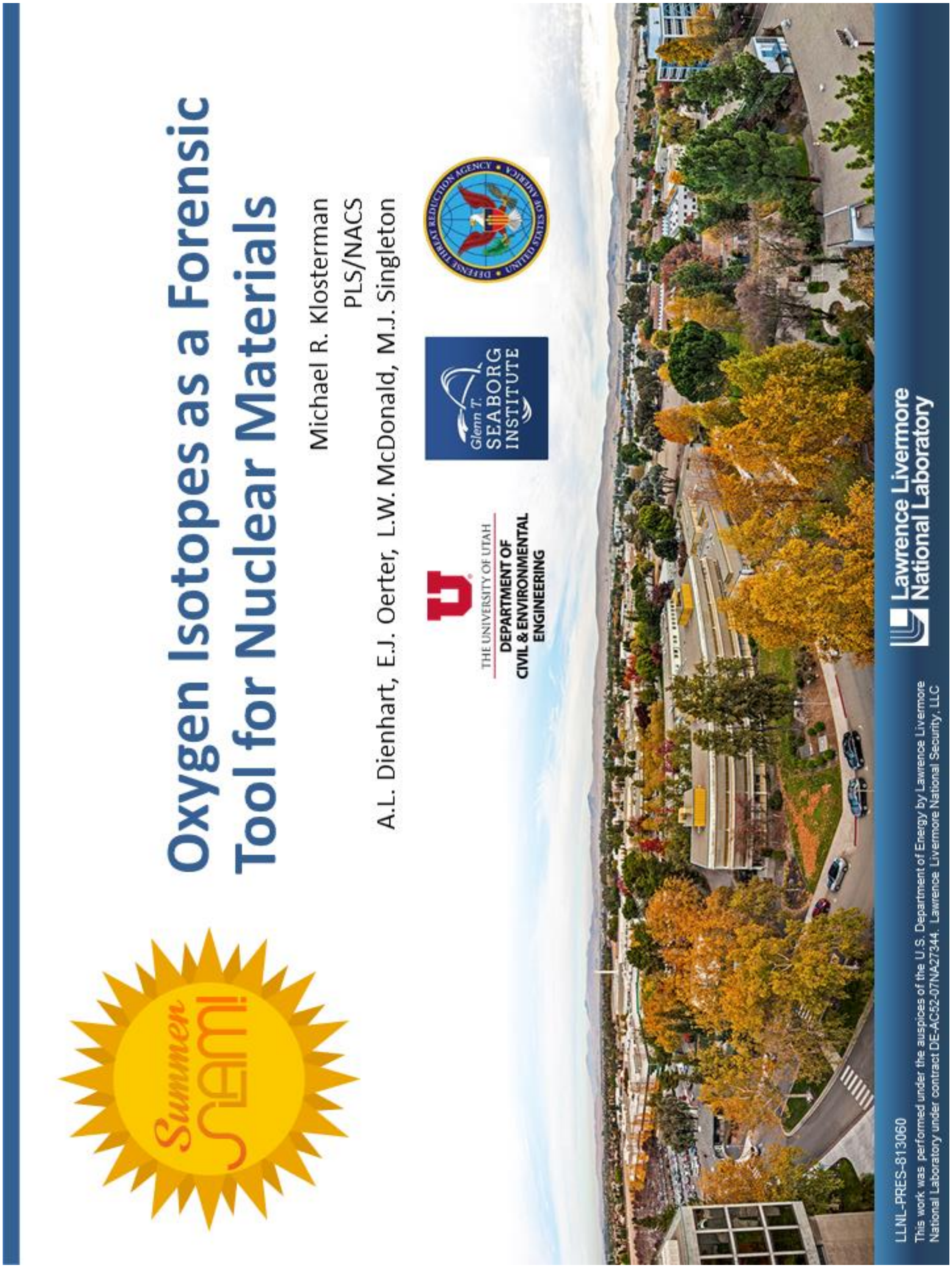
Student	Mentor	Project Poster Title
Mike Klosterman	Mike Singleton	Oxygen Isotope Signatures in Uranium Oxides
James Totten[1]	Chad Durrant	Using Laser Driven Hydrothermal Processing (LDHP) to Accelerate Dissolution of Geological Samples
Dan Sullivan[1]	Greg Brennecka	Re and Hg Osotopics in Yellowcake
Sarah Azhar[1]	Tashi Parsons-Davis and Keenan Thomas	Gamma Coincidence Data Processing
Meena Said	Naomi Marks	Uranium Fuel Pellet Signature Characterization
Neil Taylor	Joshua Jarrell	Nuclear Battery Development
Christopher Brais	Mike Savina	Automated Laser Operation, Beam Steering, and Power Control for Mobile RIMS Instrument
Frederick Delawie[2]	Joshua Jarrell	Atomic Battery Case Design
Nicholas Parham[3]	Mavrik Zavarin	Surface Complexation Database Converter Tool

[1] Could not participate due to virtual format; will be considered for 2021.
[2] Funded at 50% by DTRA.
[3] Supported through a collaboration with the MARA program.

Table 3. 2020 Nuclear Science and Security Summer Internship Program Seminar Schedule

Date	Speaker	Topic
6/17/20	Naomi Marks *Staff Scientist, Chemical & Isotopic Signatures* *Nuclear and Chemical Sciences Division*	The Fascinating Field of Nuclear Forensics: How A Scientific Subdiscipline Captured My Heart
6/25/20	John Murphy *Staff Scientist* *Materials Engineering Division*	Radioisotope Batteries – An Overview on Historical Developments and Current Work at LLNL
7/2/20	Dawn Shaughnessy *Group Leader, Stockpile Radiochemistry* *Nuclear and Chemical Sciences Division*	Nuclear Science at the National Ignition Facility
7/9/20	Mike Savina *Staff Scientist, Chemical & Isotopic Signatures* *Nuclear and Chemical Sciences Division*	Nuclear Astrophysics for Fun & Profit: Moonlighting in the Nonproliferation Gig Economy
7/16/20	Gauthier Deblonde *Staff Scientist, Chemical & Isotopic Signatures* *Nuclear and Chemical Sciences Division*	Actinide Science: From Nuclear Reactors to Cancer Therapy Drugs
7/23/20	Mike Singleton *Staff Scientist, Chemical & Isotopic Signatures* *Nuclear and Chemical Sciences Division*	Forensic Applications of Light Stable Isotopes
7/30/20	Jutta Escher *Staff Scientist, Nuclear Data & Theory* *Nuclear and Chemical Sciences Division*	Nuclear Reaction Research for Astrophysics and Lab Applications

2020 NS^{3}IP PowerPoint Presentations from Student SLAM! Event


Oxygen Isotopes as a Forensic Tool for Nuclear Materials
Michael R. Klosterman
PLS/NACS
A.L. Dienhart, E.J. Oerter, L.W. McDonald, M.J. Singleton
THE UNIVERSITY OF UTAH
DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING
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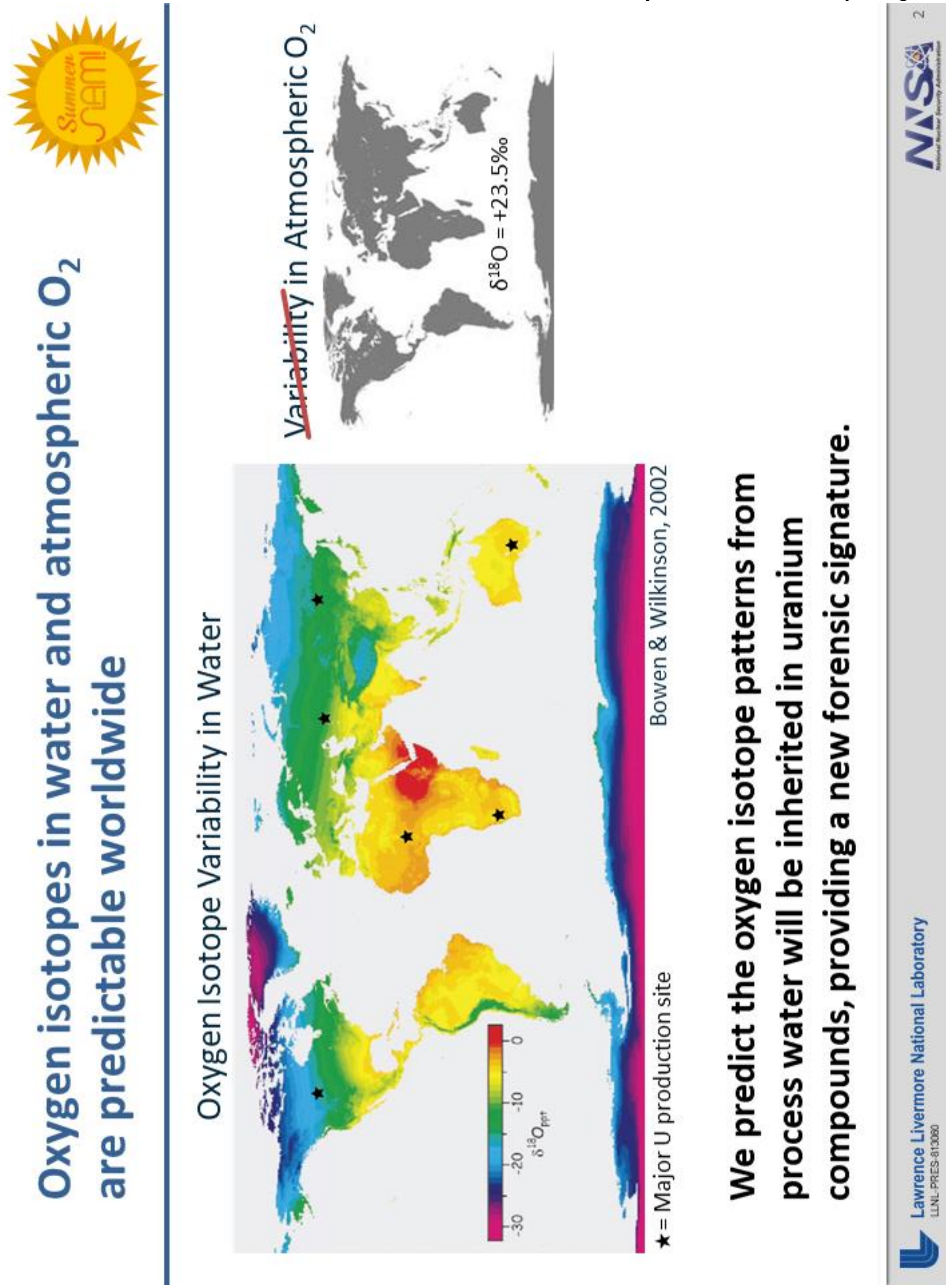
Oxygen isotopes in water and atmospheric O_2 are predictable worldwide
Oxygen Isotope Variability in Water
-30
-20
-10
0
$\delta^{18}O_{ppt}$
★ = Major U production site
Bowen & Wilkinson, 2002
Variability in Atmospheric O_2
$\delta^{18}O$ = +23.5‰
We predict the oxygen isotope patterns from process water will be inherited in uranium compounds, providing a new forensic signature.
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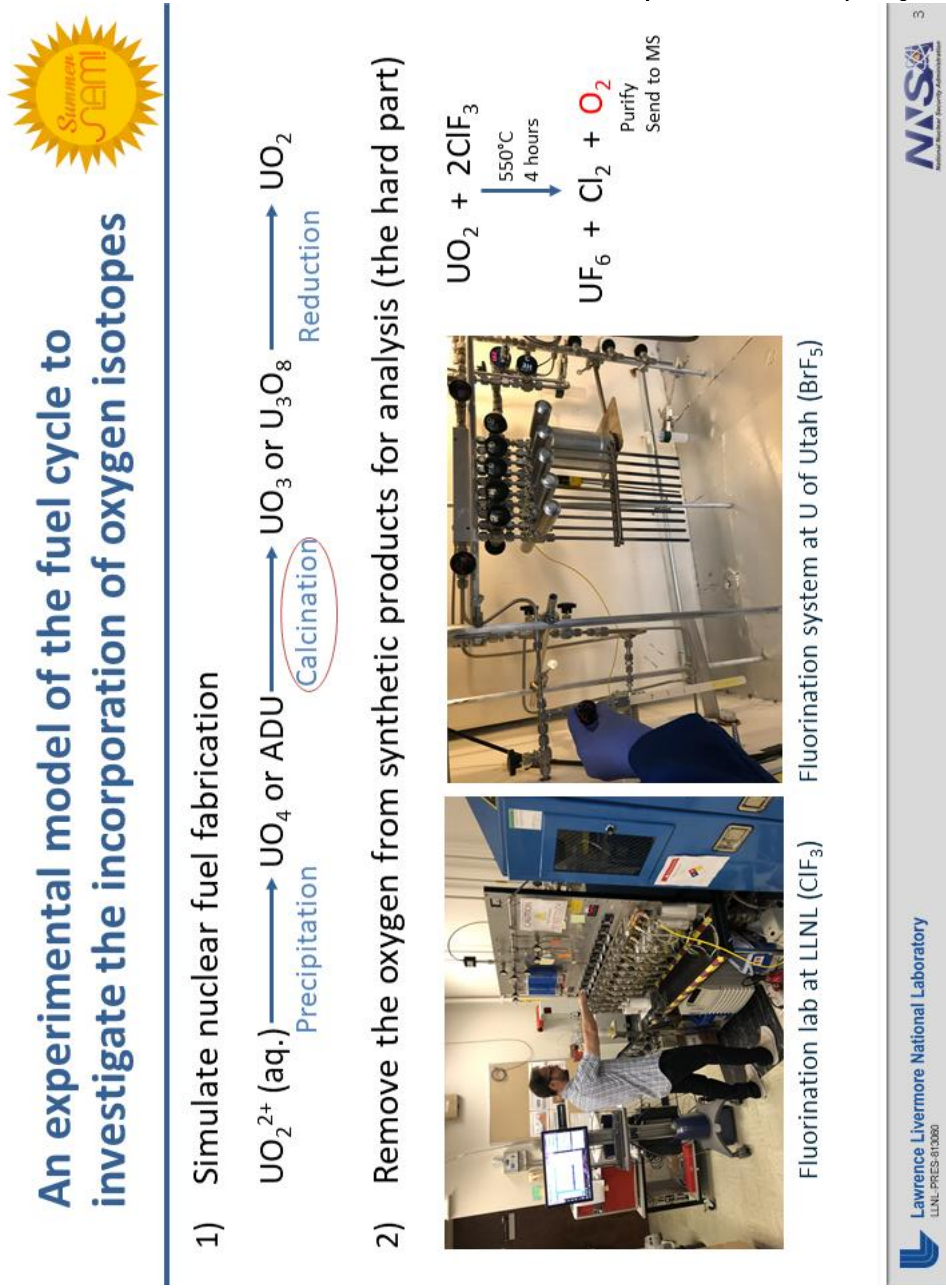
An experimental model of the fuel cycle to investigate the incorporation of oxygen isotopes
1) Simulate nuclear fuel fabrication
UO_2^{2+} (aq.) → UO_4 or ADU → UO_3 or U_3O_8 → UO_2
Precipitation
Calcination
Reduction
2) Remove the oxygen from synthetic products for analysis (the hard part)
$UO_2 + 2ClF_3$
550°C
4 hours
$UF_6 + Cl_2 + O_2$
Purify
Send to MS
Fluorination lab at LLNL (ClF_3)
Fluorination system at U of Utah (BrF_5)
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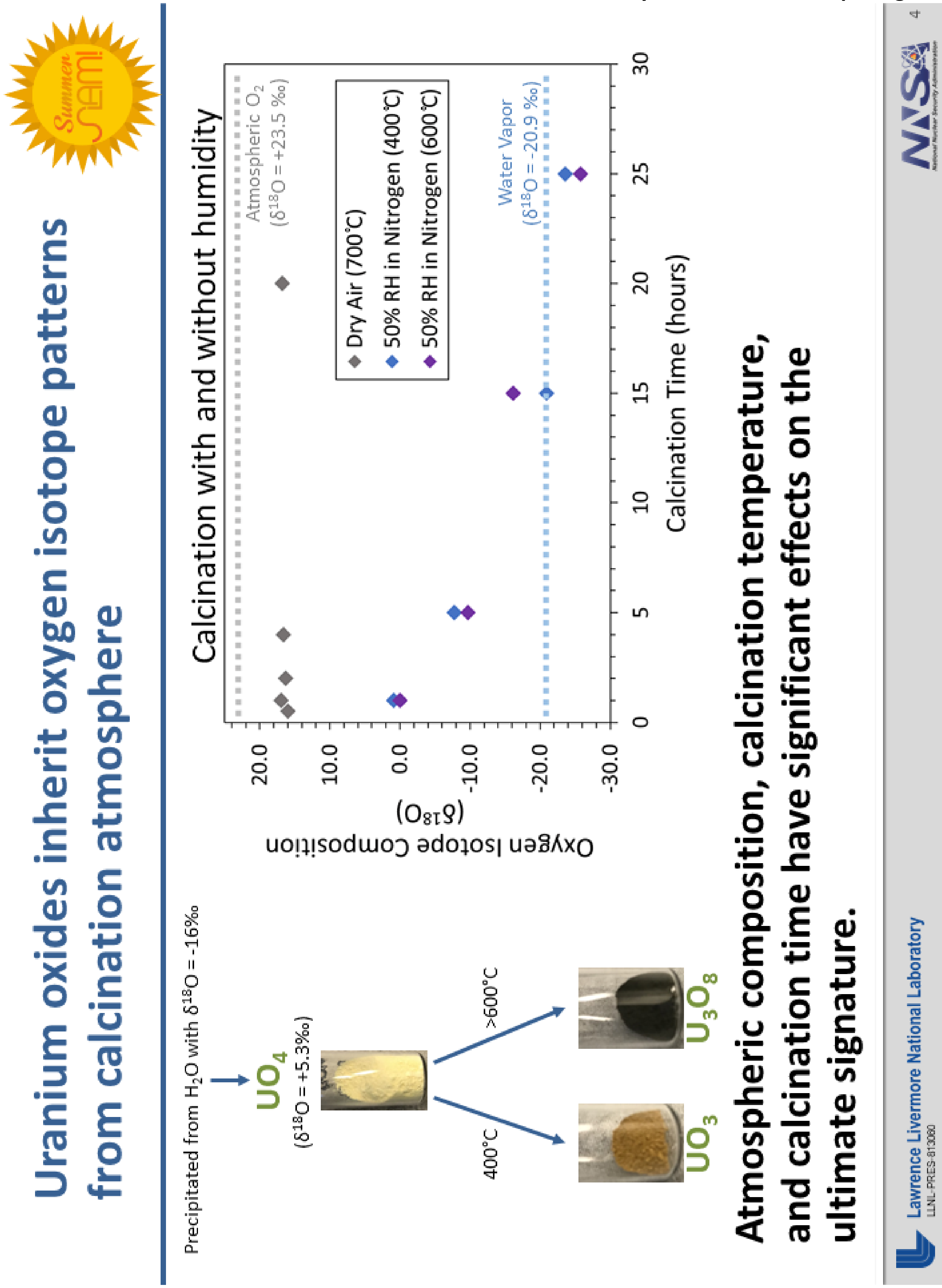
Uranium oxides inherit oxygen isotope patterns from calcination atmosphere
Precipitated from H_2O with $\delta^{18}O$ = -16‰
UO_4
($\delta^{18}O$ = +5.3‰)
400°C
>600°C
UO_3
U_3O_8
Calcination with and without humidity
Oxygen Isotope Composition ($\delta^{18}O$)
20.0
10.0
0.0
-10.0
-20.0
-30.0
0
5
10
15
20
25
30
Calcination Time (hours)
Atmospheric O_2 ($\delta^{18}O$ = +23.5 ‰)
Dry Air (700℃)
50% RH in Nitrogen (400℃)
50% RH in Nitrogen (600℃)
Water Vapor ($\delta^{18}O$ = -20.9 ‰)
Atmospheric composition, calcination temperature, and calcination time have significant effects on the ultimate signature.
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DEFENSE THREAT REDUCTION AGENCY • UNITED STATES OF AMERICA
THE UNIVERSITY OF UTAH
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ENGINEERING
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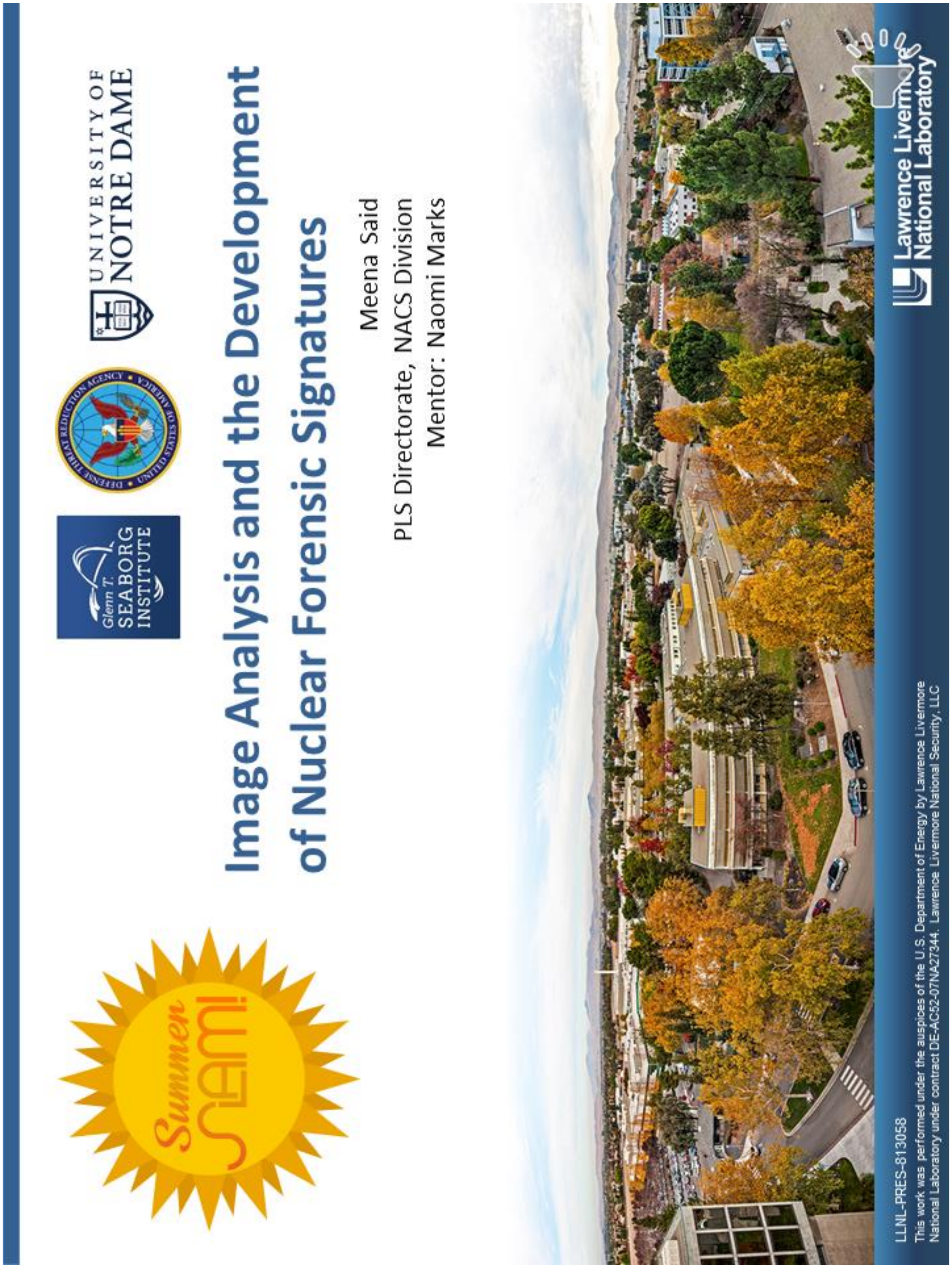
Summer NSSP!
Glenn T. SEABORG INSTITUTE
DEFENSE THREAT REDUCTION AGENCY • UNITED STATES OF AMERICA
UNIVERSITY OF NOTRE DAME
Image Analysis and the Development of Nuclear Forensic Signatures
Meena Said
PLS Directorate, NACS Division
Mentor: Naomi Marks
LLNL-PRES-813058
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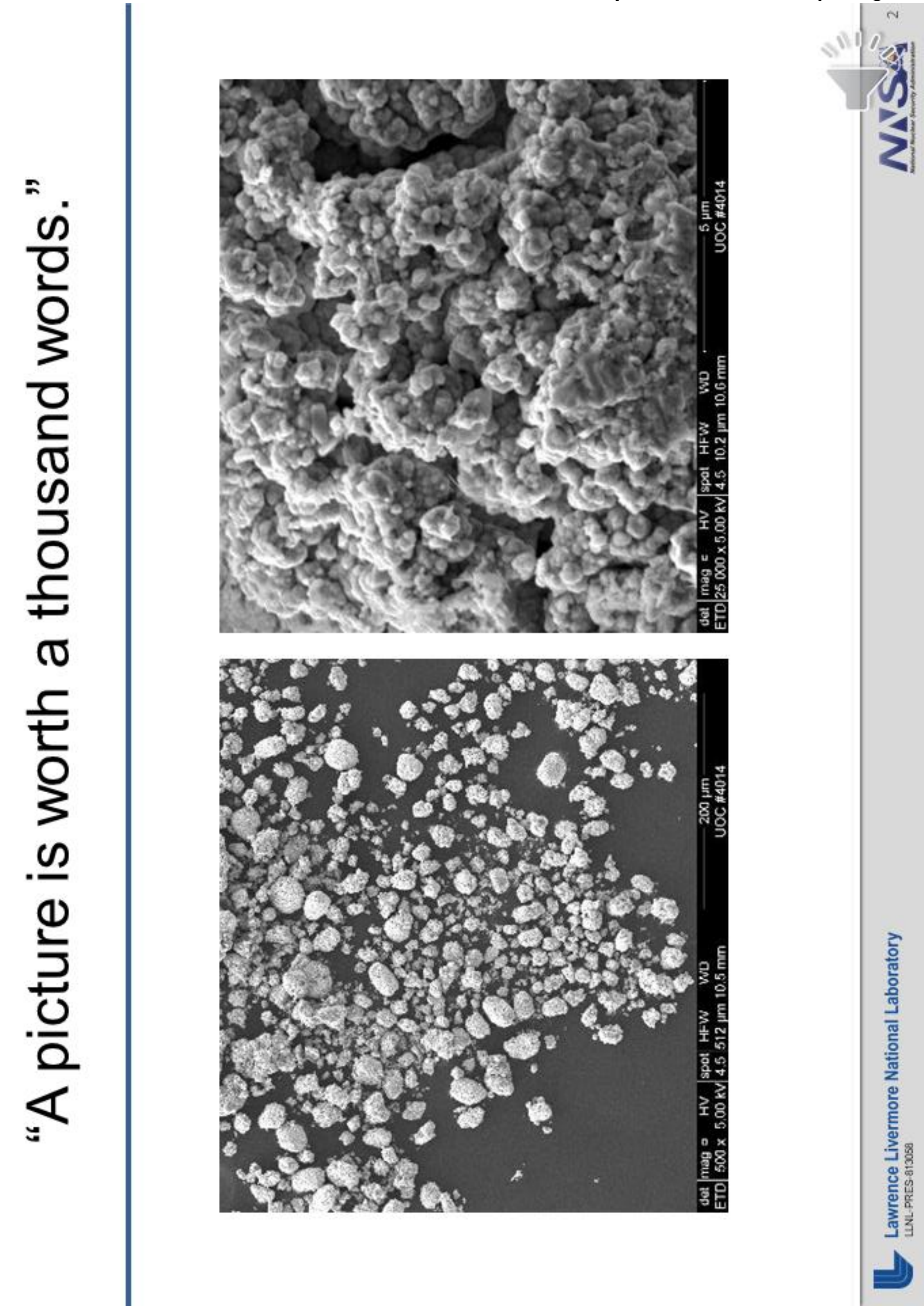
"A picture is worth a thousand words."
det mag HV spot HFW WD 200 µm
ETD 500 x 5.00 kV 4.5 512 µm 10.5 mm UOC #4014
det mag HV spot HFW WD 5 µm
ETD 25 000 x 5.00 kV 4.5 10.2 µm 10.6 mm UOC #4014
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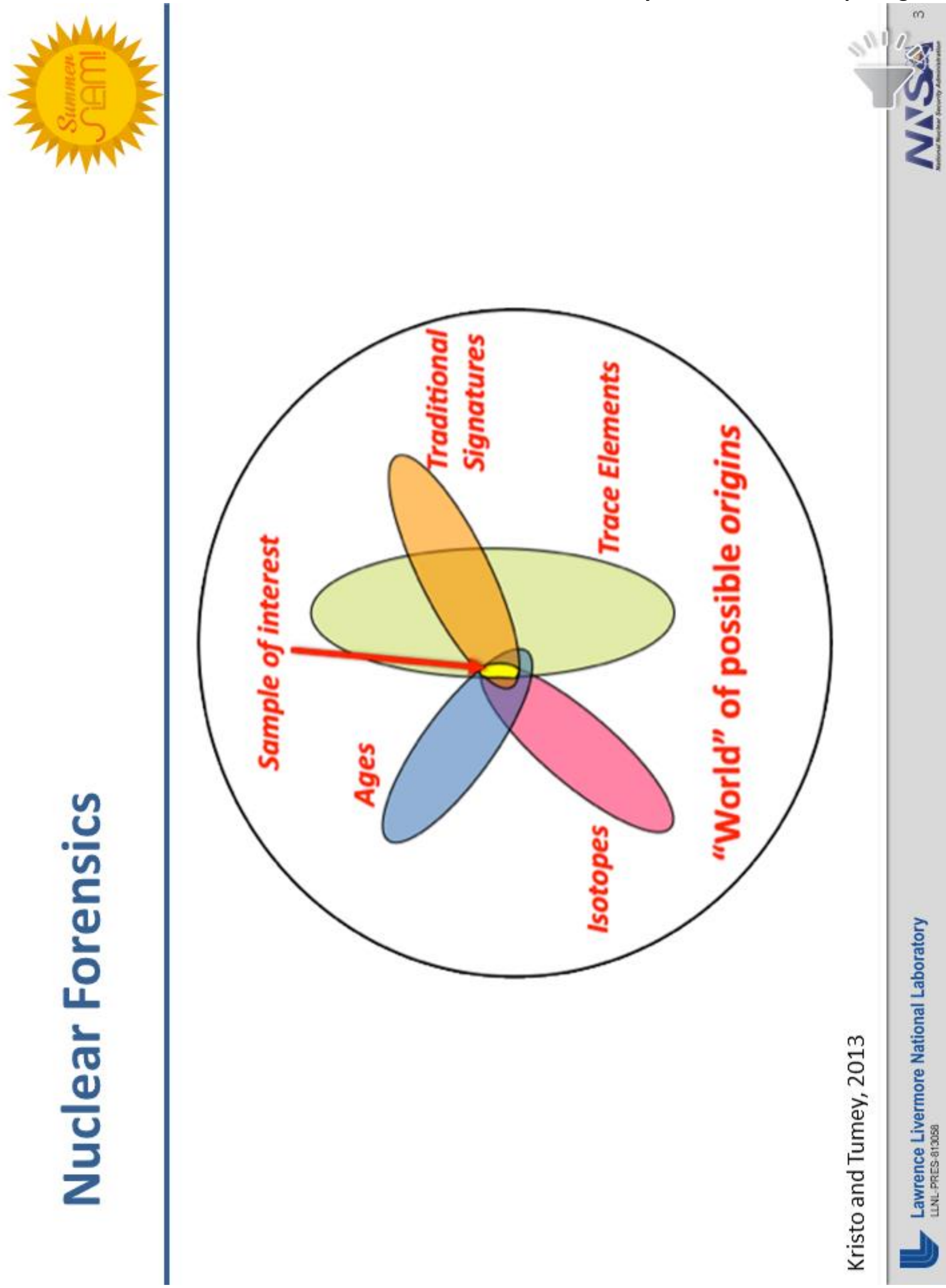
Nuclear Forensics
Traditional Signatures
Trace Elements
Sample of interest
Ages
Isotopes
"World" of possible origins
Kristo and Tumey, 2013
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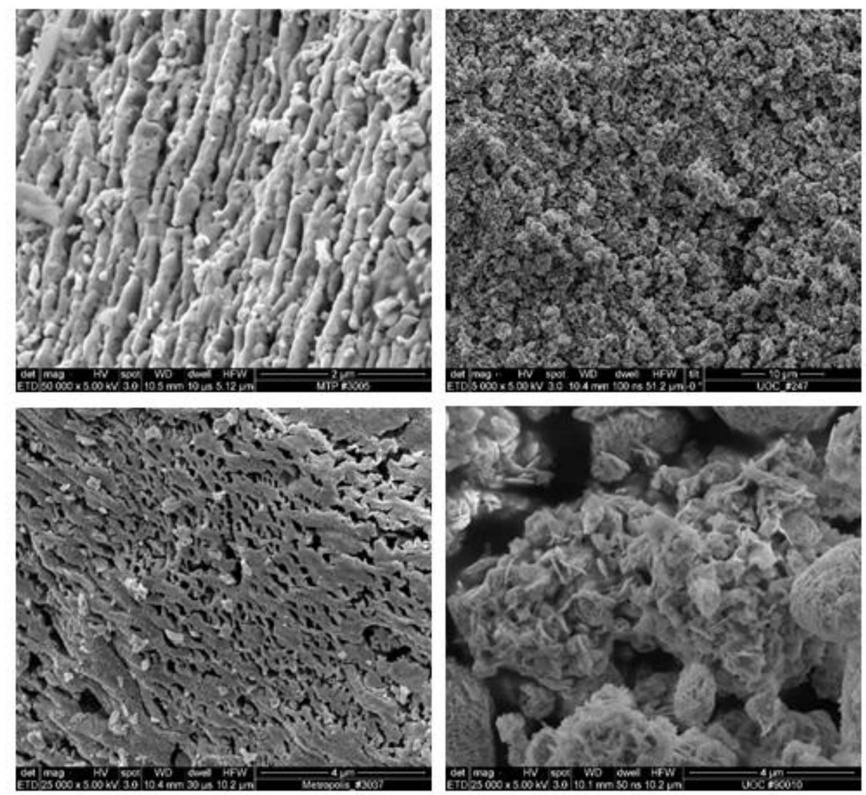
Scanning Electron Microscopy for Nuclear Forensics Research

- Qualitative image analysis
- Qualitative (Lexicon) → Quantitative (Machine Learning)
  - Discerning characteristics within sample
  - Connections among samples



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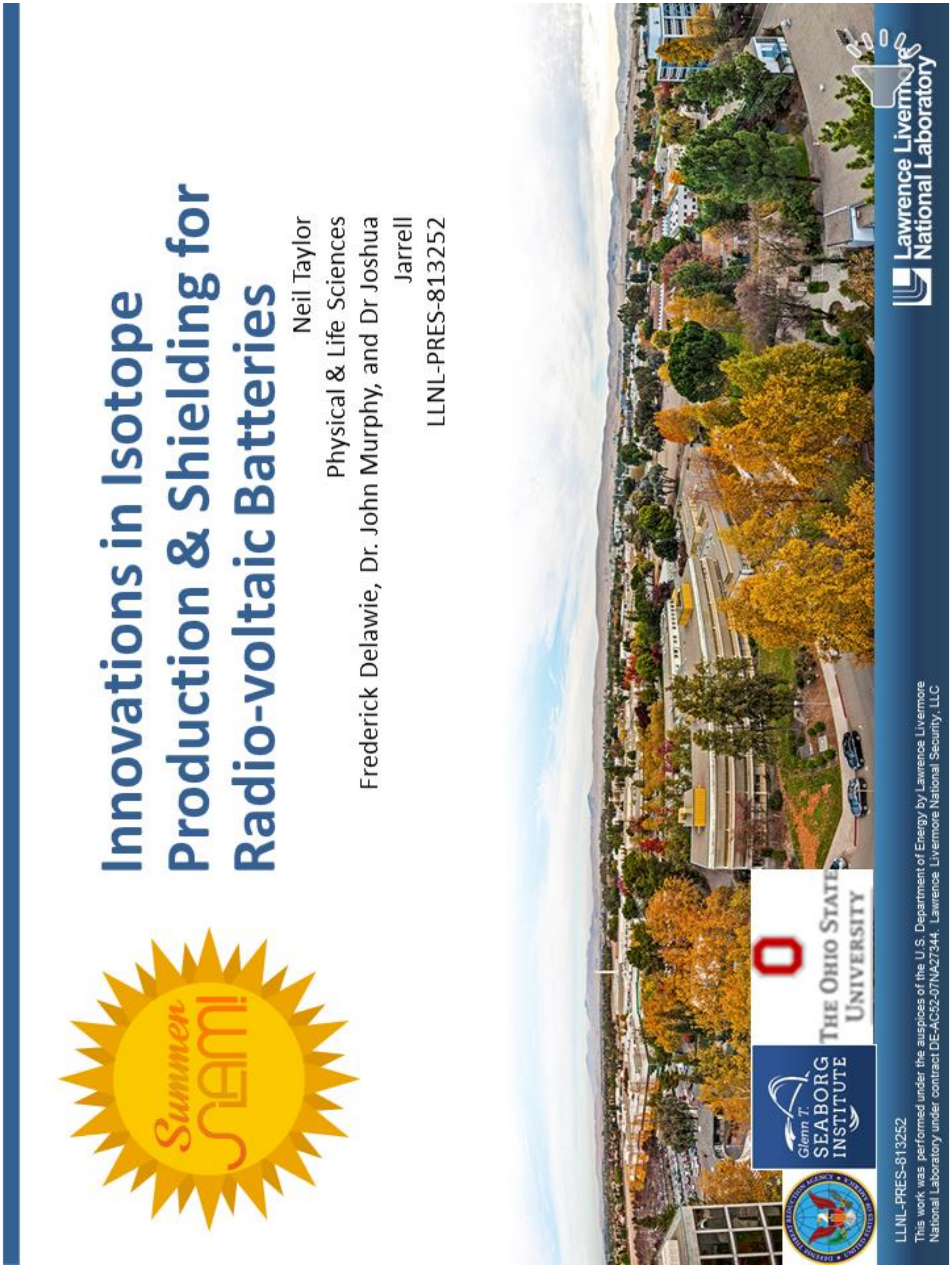
Summer
NSSIP
Innovations in Isotope Production & Shielding for Radio-voltaic Batteries
Neil Taylor
Physical & Life Sciences
Frederick Delawie, Dr. John Murphy, and Dr Joshua Jarrell
LLNL-PRES-813252
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THE OHIO STATE UNIVERSITY
LLNL-PRES-813252
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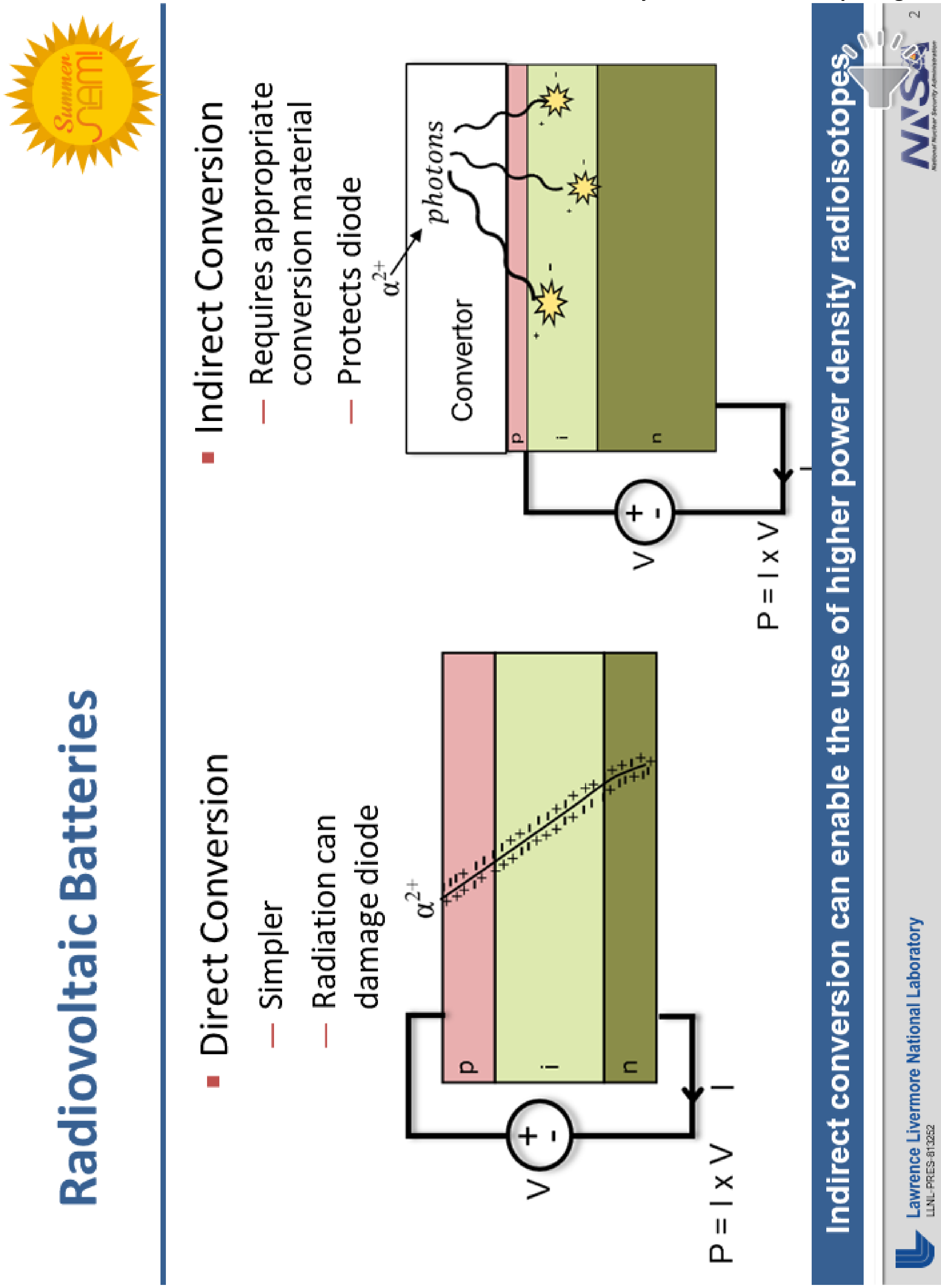
Summer Slam!
Radiovoltaic Batteries
Direct Conversion
– Simpler
– Radiation can damage diode
Indirect Conversion
– Requires appropriate conversion material
– Protects diode
α2+
p
i
n
V
I
P = I x V
Convertor
photons
Indirect conversion can enable the use of higher power density radioisotopes
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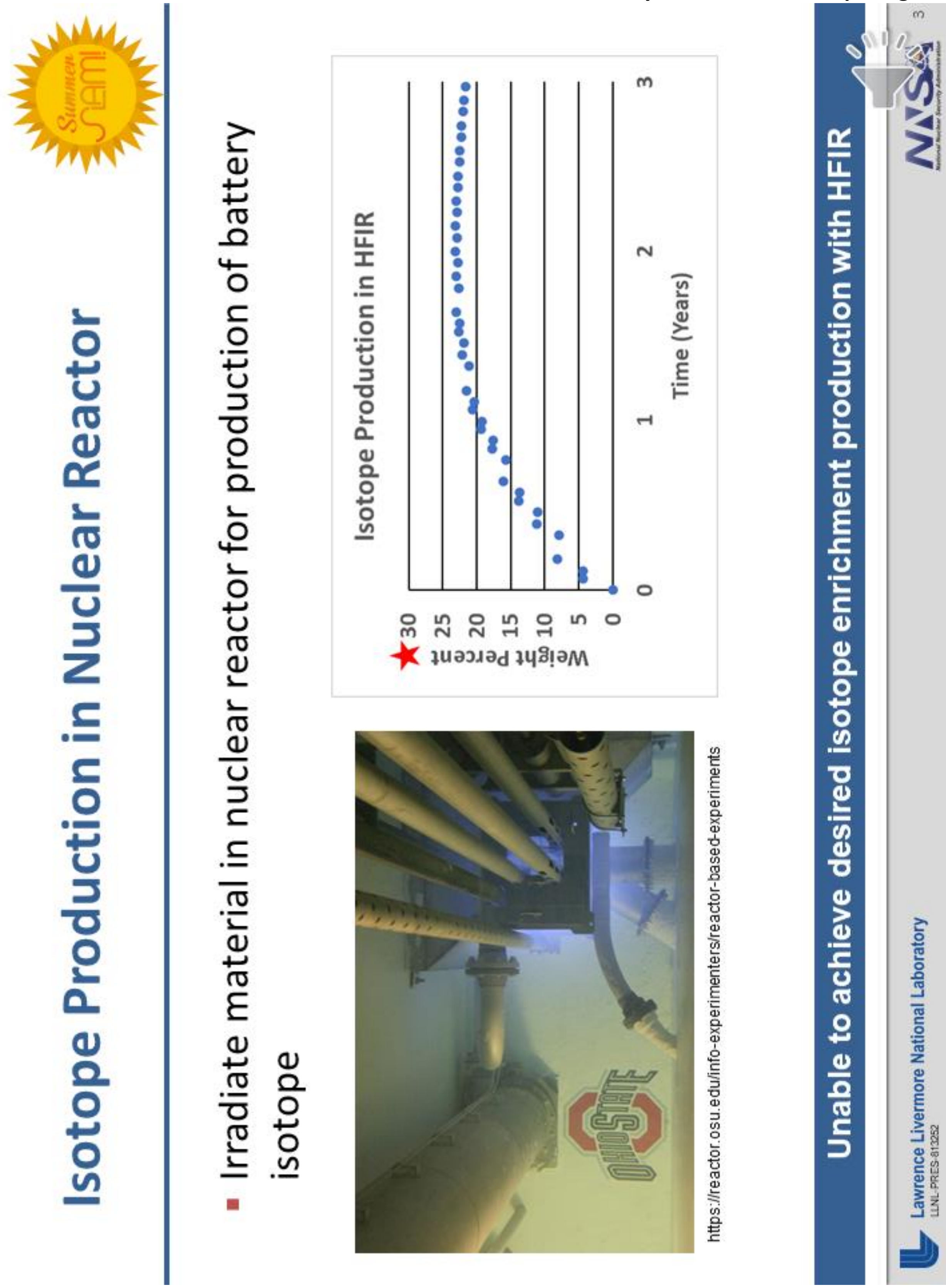
Summer SLAM!
Isotope Production in Nuclear Reactor
Irradiate material in nuclear reactor for production of battery isotope
https://reactor.osu.edu/info-experimenters/reactor-based-experiments
Isotope Production in HFIR
Weight Percent
30
25
20
15
10
5
0
0
1
2
3
Time (Years)
Unable to achieve desired isotope enrichment production with HFIR
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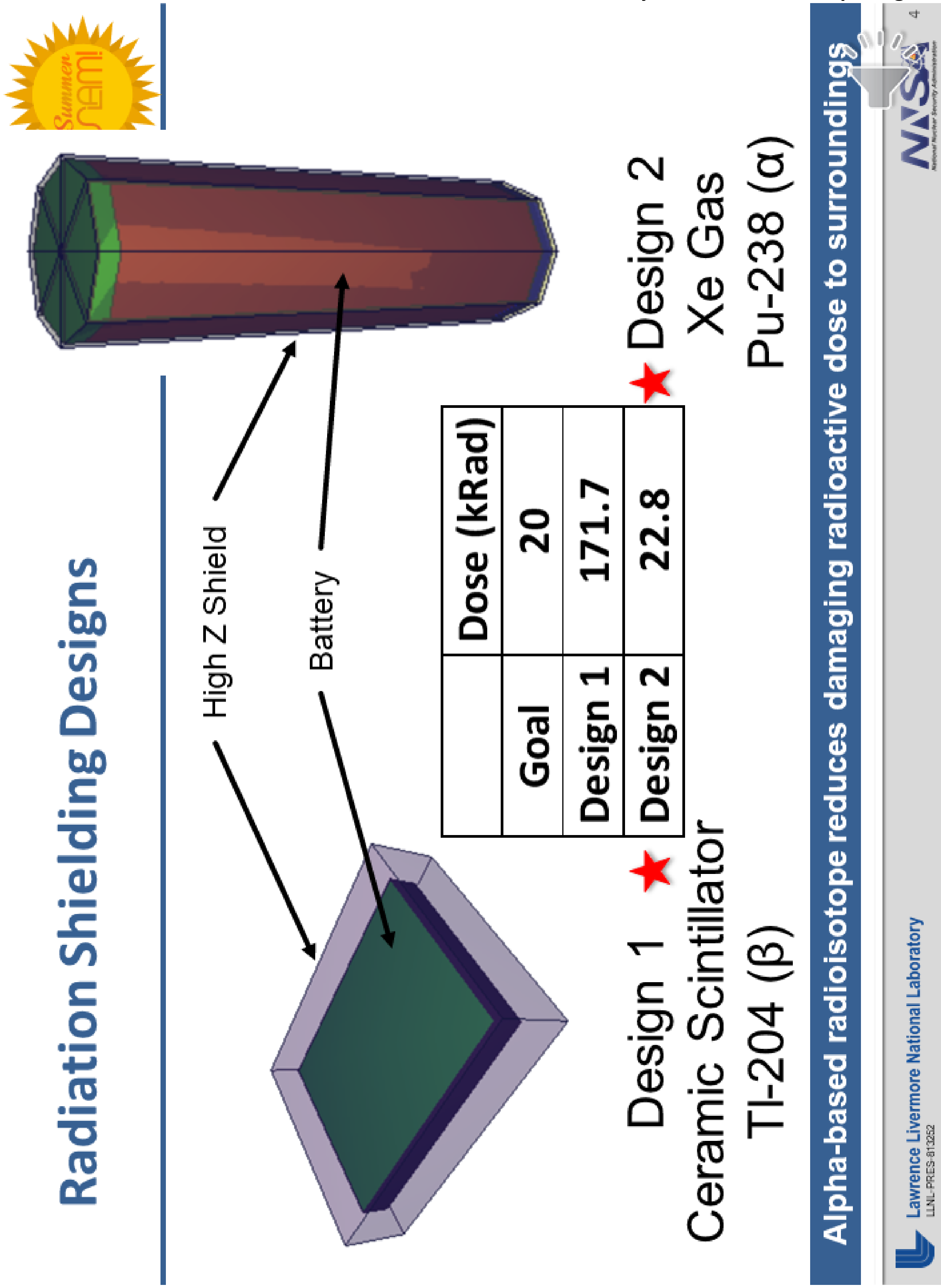
Radiation Shielding Designs
High Z Shield
Battery
Dose (kRad)
Goal 20
Design 1 171.7
Design 2 22.8
Design 1
Ceramic Scintillator
Tl-204 (β)
Design 2
Xe Gas
Pu-238 (α)
Alpha-based radioisotope reduces damaging radioactive dose to surroundings
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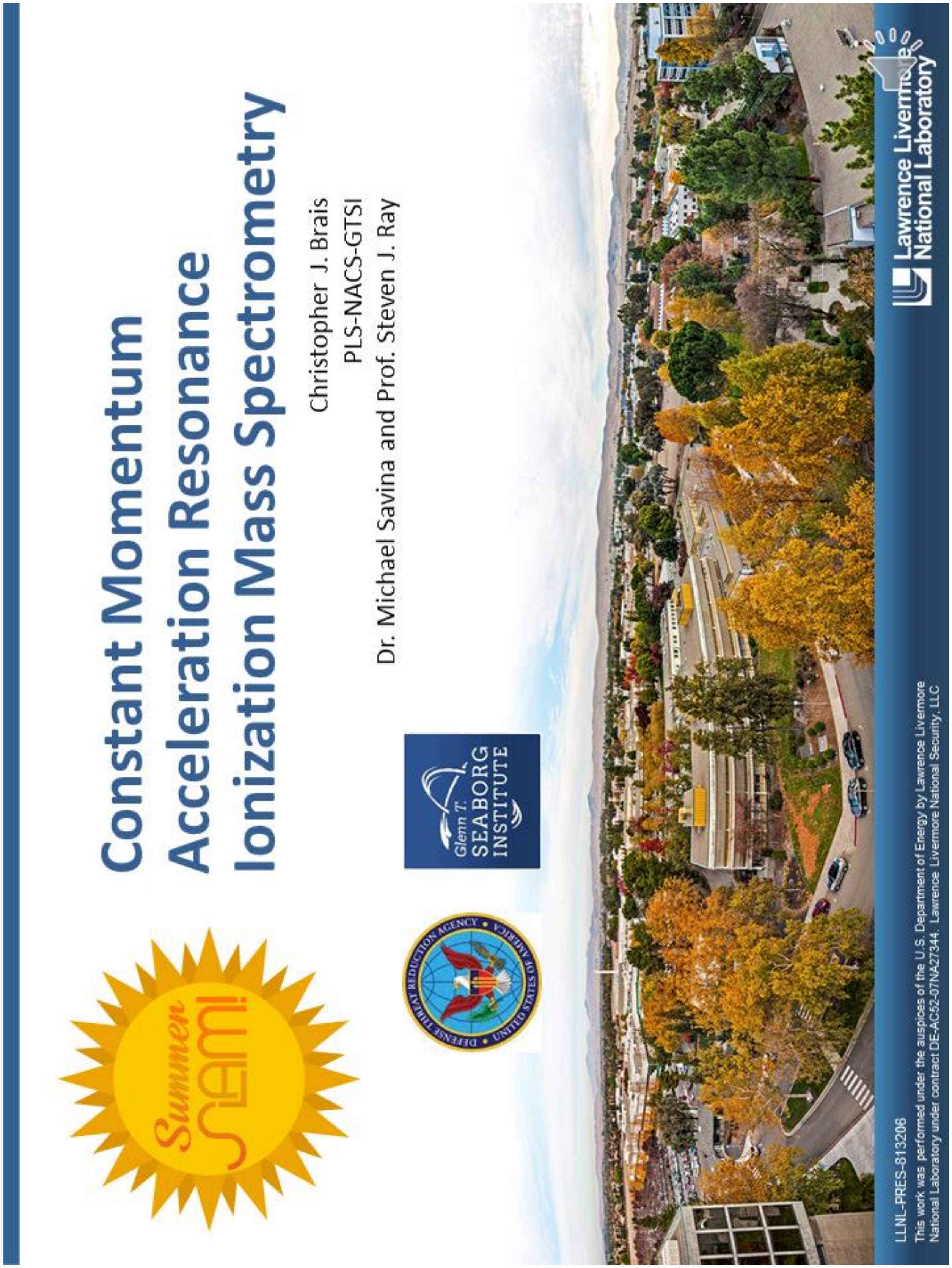
Summer Slam!
Constant Momentum
Acceleration Resonance
Ionization Mass Spectrometry
Christopher J. Brais
PLS-NACS-GTSI
Dr. Michael Savina and Prof. Steven J. Ray
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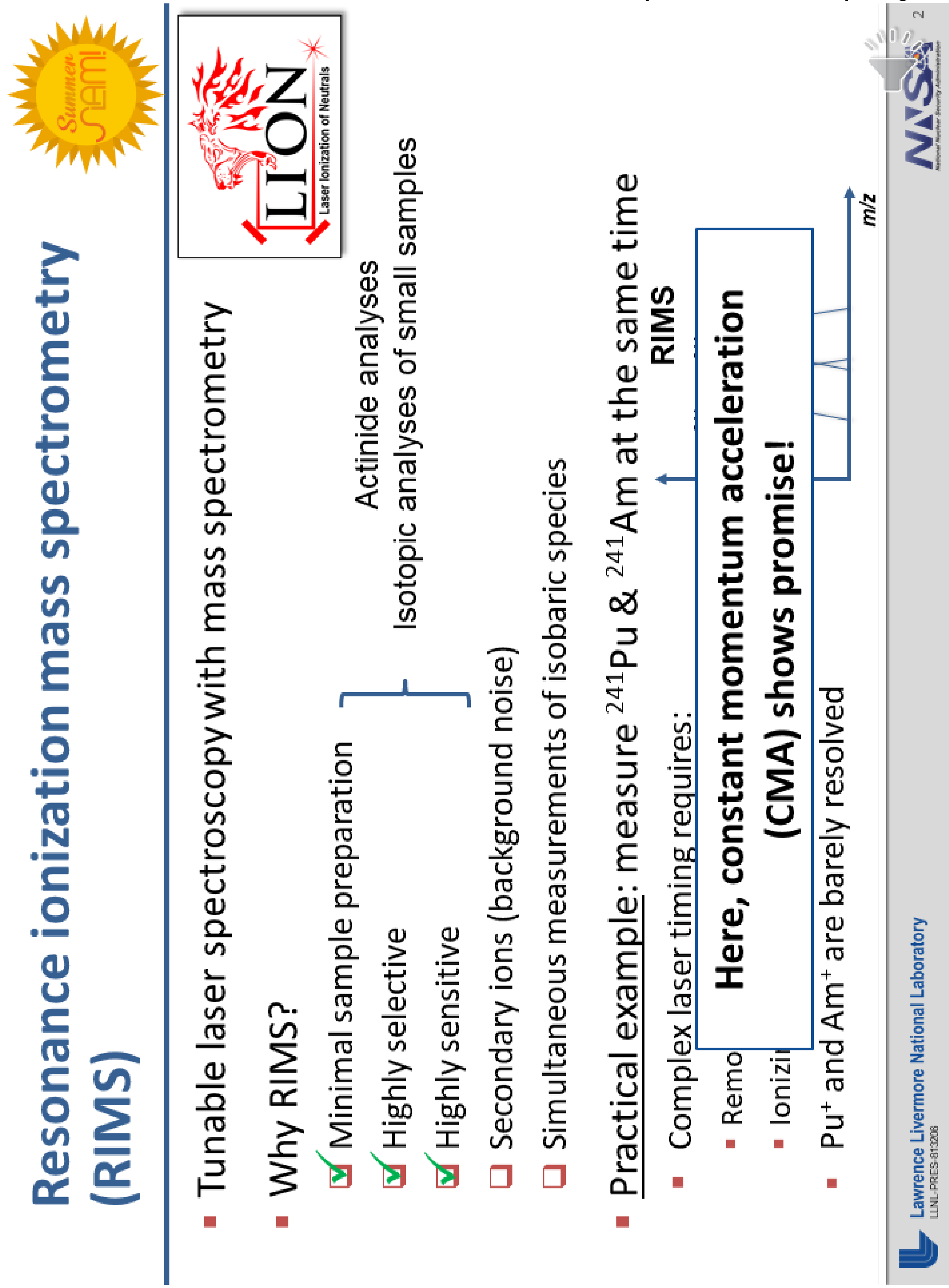
Resonance ionization mass spectrometry (RIMS)
LION
Laser Ionization of Neutrals
Tunable laser spectroscopy with mass spectrometry
Why RIMS?
Minimal sample preparation
Highly selective
Highly sensitive
Actinide analyses
Isotopic analyses of small samples
Secondary ions (background noise)
Simultaneous measurements of isobaric species
Practical example: measure 241Pu & 241Am at the same time
Complex laser timing requires:
Remo
Ionizi
Pu+ and Am+ are barely resolved
RIMS
Here, constant momentum acceleration (CMA) shows promise!
m/z
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Constant Momentum Acceleration (CMA)
CMA is alternative method that imparts a different energy to each ion of interest: small differences in ion birth times result in large differences in energy – easy separation!
Simplifies laser timing sequences
Secondary ions are removed automatically, 'on-the-fly'
Requires no new hardware
Extract ions to constant momentum
CMA-RIMS
^{241}Am
^{241}Pu
Intensity
m/z
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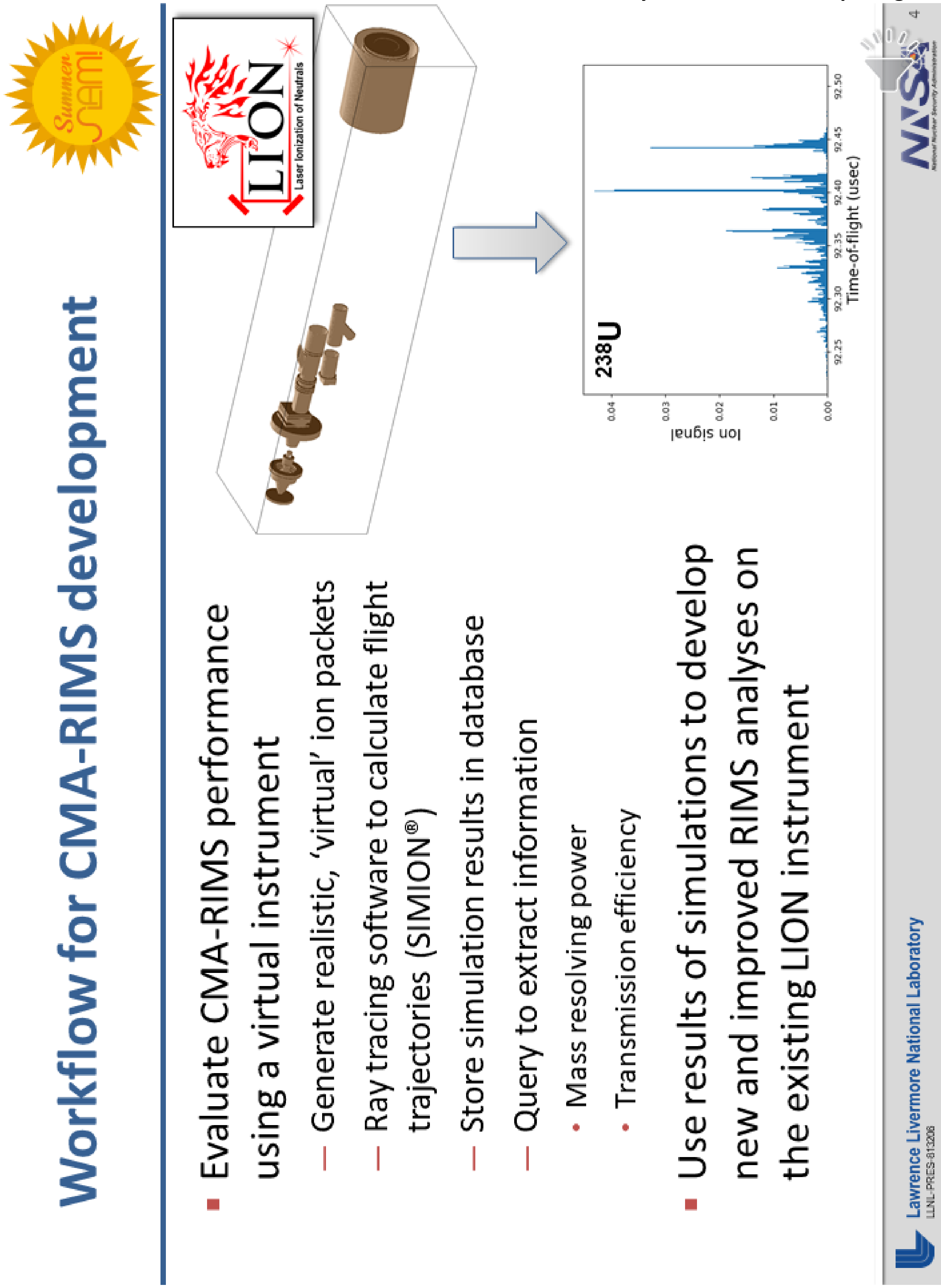
3


Workflow for CMA-RIMS development
Evaluate CMA-RIMS performance using a virtual instrument
Generate realistic, 'virtual' ion packets
Ray tracing software to calculate flight trajectories (SIMION®)
Store simulation results in database
Query to extract information
Mass resolving power
Transmission efficiency
Use results of simulations to develop new and improved RIMS analyses on the existing LION instrument
LION
Laser Ionization of Neutrals
238U
Ion signal
Time-of-flight (usec)
0.00
0.01
0.02
0.03
0.04
92.25
92.30
92.35
92.40
92.45
92.50
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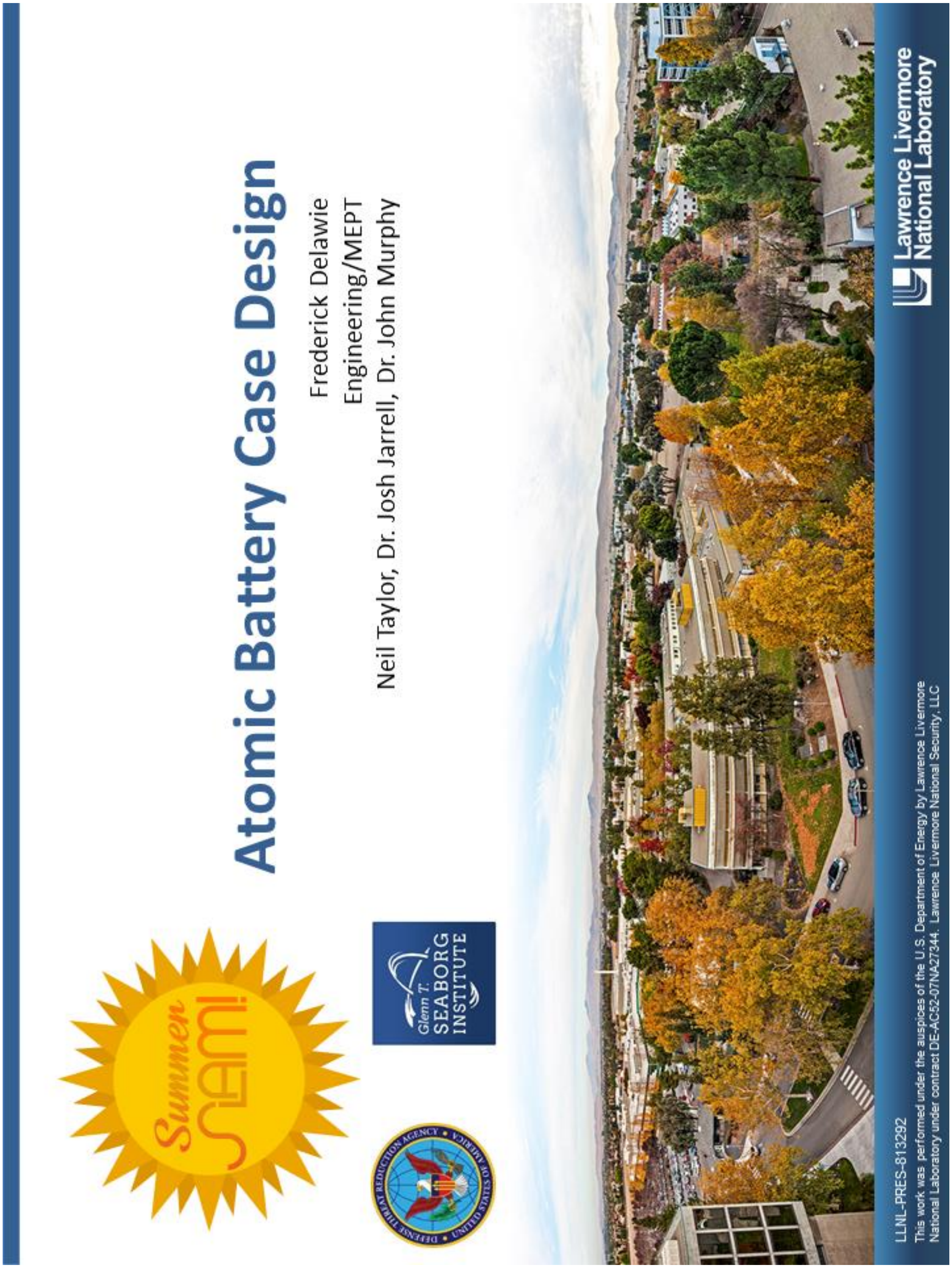
Atomic Battery Case Design
Frederick Delawie
Engineering/MEPT
Neil Taylor, Dr. Josh Jarrell, Dr. John Murphy
Summer
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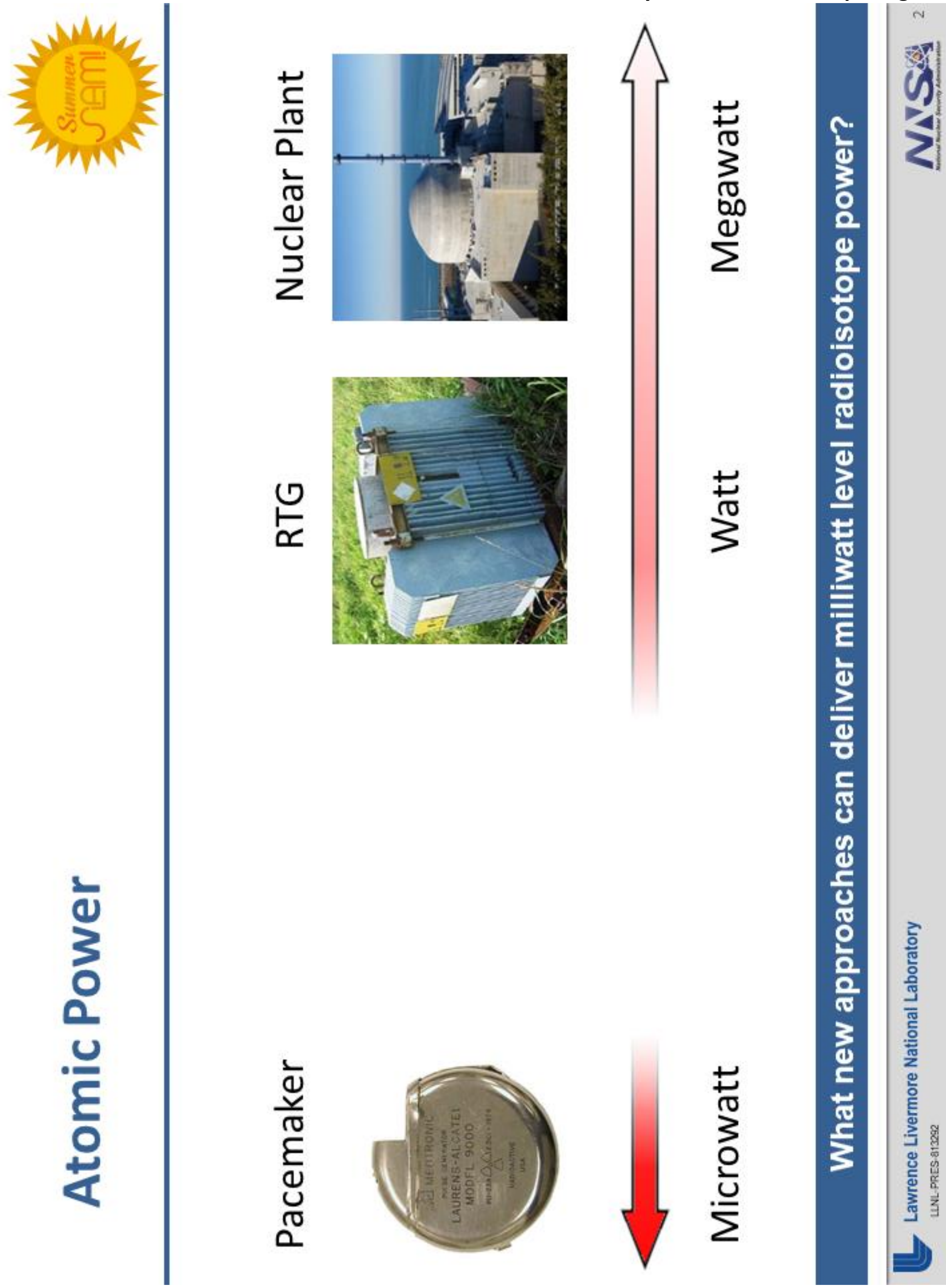
Atomic Power
Pacemaker
RTG
Nuclear Plant
Microwatt
Watt
Megawatt
What new approaches can deliver milliwatt level radioisotope power?
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LLNL's Design
The Lawrence-Livermore
Plutonium-Xenon Battery
$10.00
QUARTERS
$10.00
QUARTERS
New design, high efficiency, mW scale
Lawrence Livermore National Laboratory
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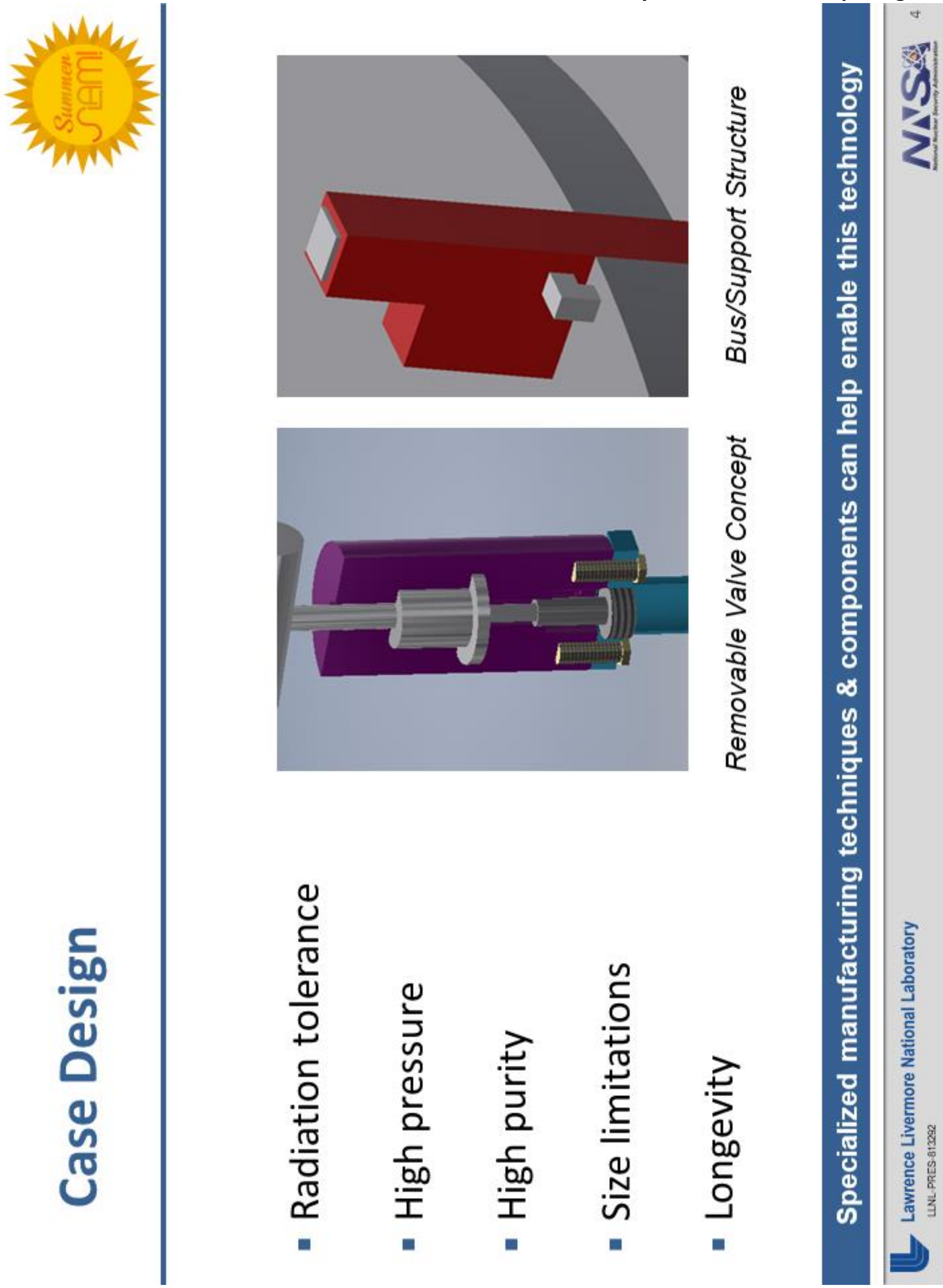
3


Case Design
Radiation tolerance
High pressure
High purity
Size limitations
Longevity
Removable Valve Concept
Bus/Support Structure
Specialized manufacturing techniques & components can help enable this technology
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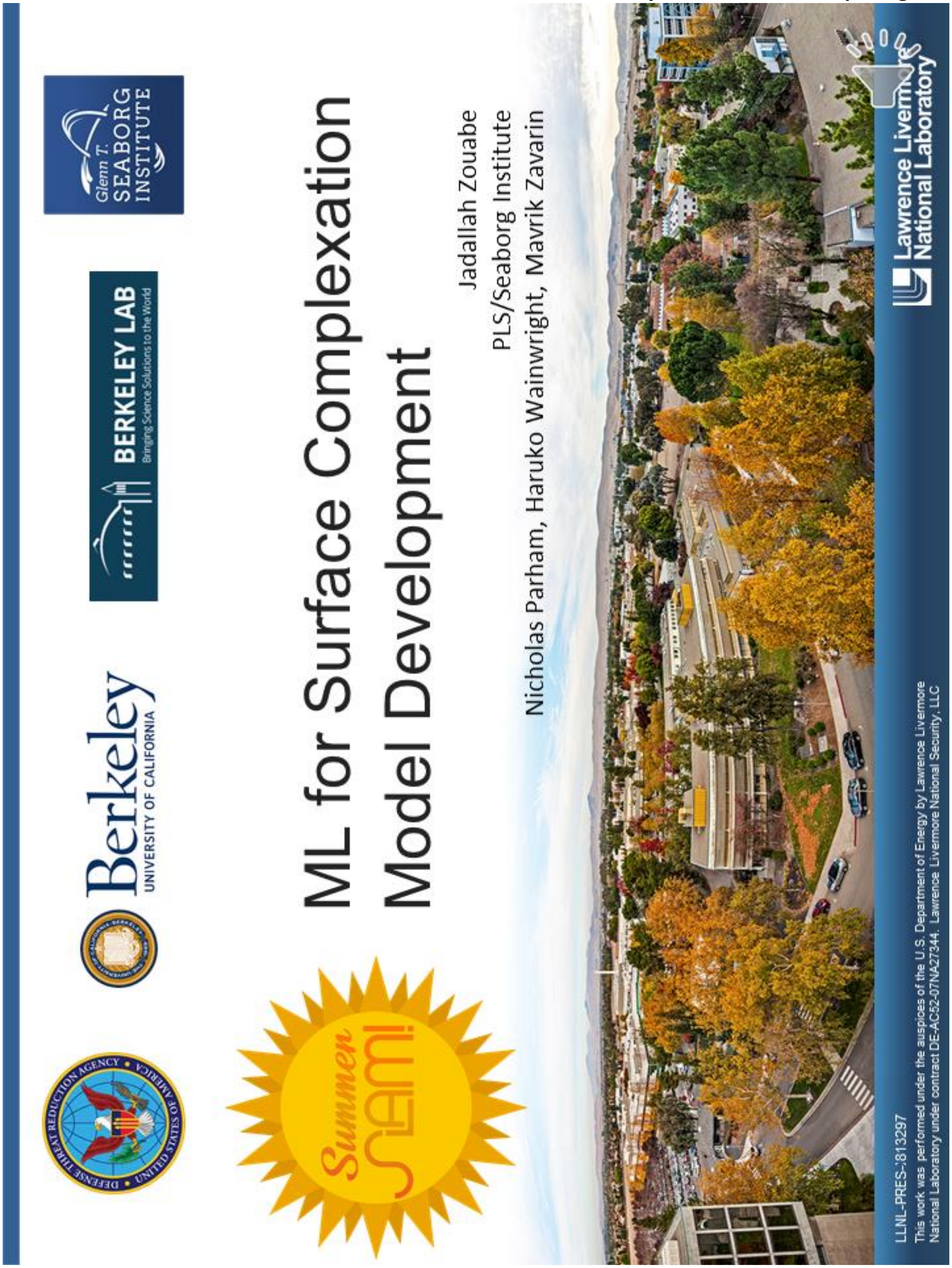
Berkeley
UNIVERSITY OF CALIFORNIA
BERKELEY LAB
Bringing Science Solutions to the World
Glenn T. SEABORG INSTITUTE
ML for Surface Complexation Model Development
Jadallah Zouabe
PLS/Seaborg Institute
Nicholas Parham, Haruko Wainwright, Mavrik Zavarin
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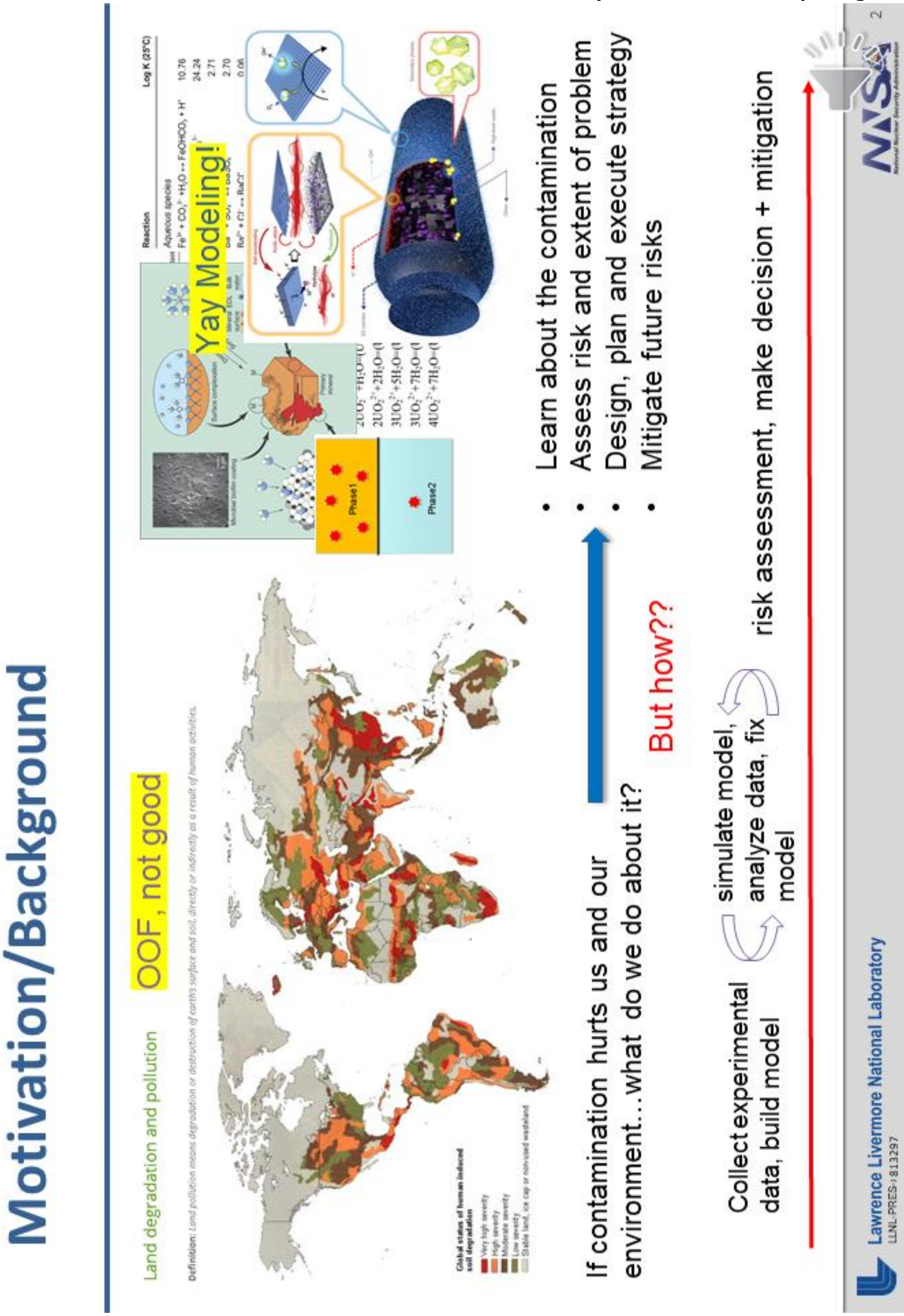
Motivation/Background
Land degradation and pollution
OOF, not good
Definition: Land pollution means degradation or destruction of earth's surface and soil, directly or indirectly as a result of human activities.
Global status of human induced soil degradation
Very high severity
High severity
Moderate severity
Low severity
Stable land, ice cap or non-used wasteland
Yay Modeling!
Phase1
Phase2
If contamination hurts us and our environment…what do we do about it?
But how??
Learn about the contamination
Assess risk and extent of problem
Design, plan and execute strategy
Mitigate future risks
Collect experimental data, build model
simulate model, analyze data, fix model
risk assessment, make decision + mitigation
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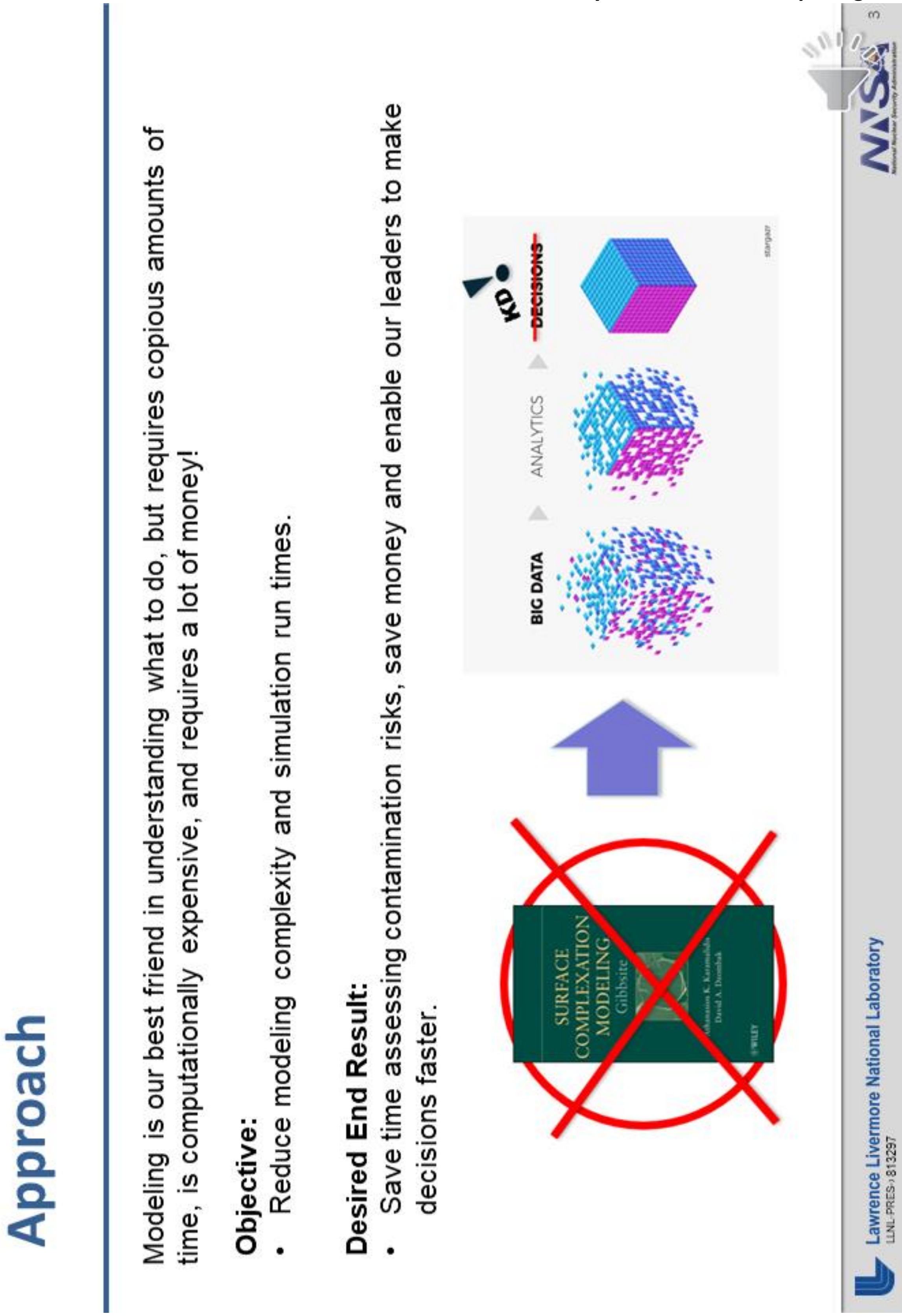
Approach
Modeling is our best friend in understanding what to do, but requires copious amounts of time, is computationally expensive, and requires a lot of money!
Objective:
• Reduce modeling complexity and simulation run times.
Desired End Result:
• Save time assessing contamination risks, save money and enable our leaders to make decisions faster.
SURFACE COMPLEXATION MODELING
Gibbsite
BIG DATA
ANALYTICS
DECISIONS
KD
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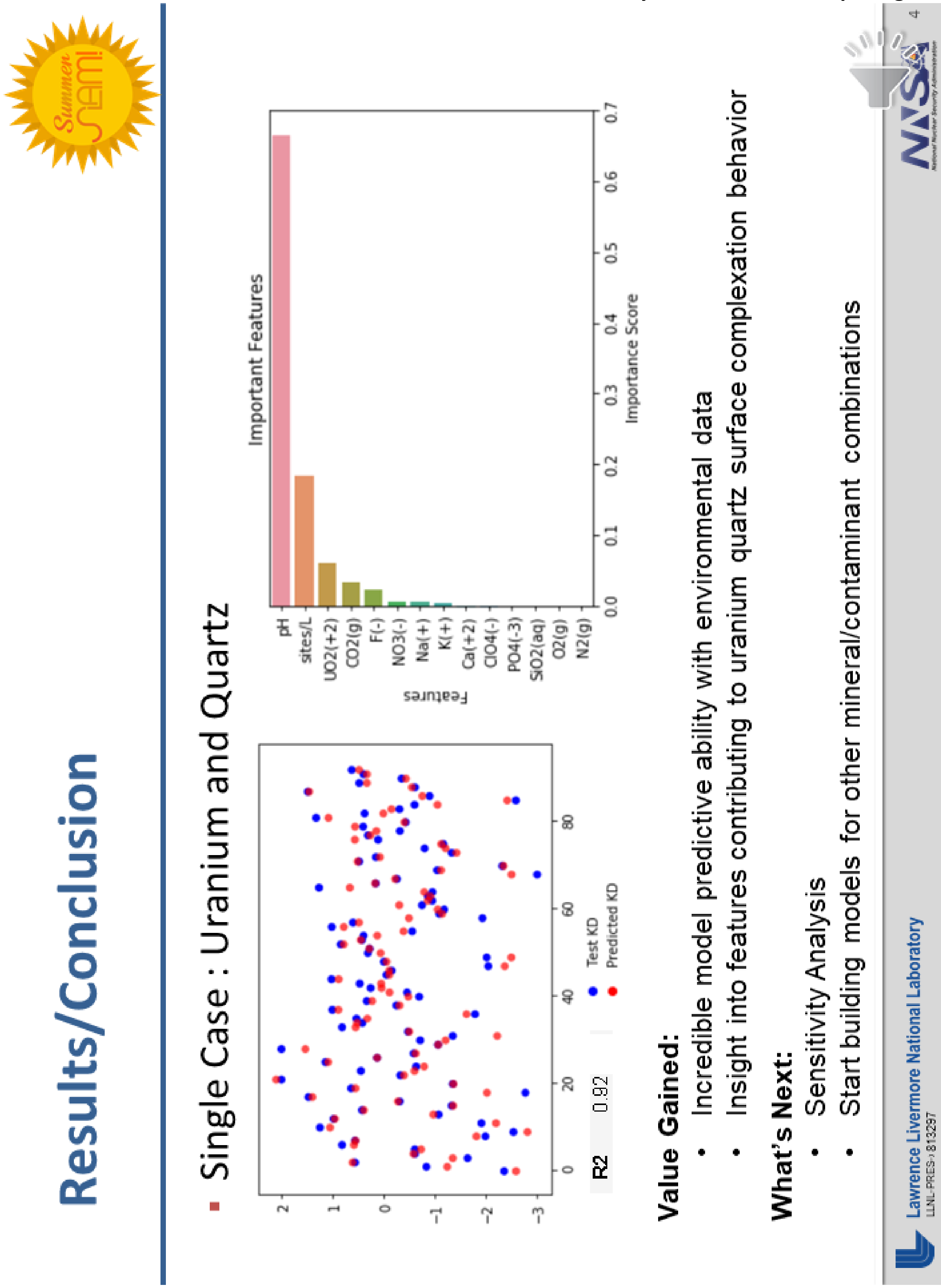
Summer SLAM!
Results/Conclusion
Single Case : Uranium and Quartz
R2 0.92
Test KD
Predicted KD
Important Features
Features
pH
sites/L
UO2(+2)
CO2(g)
F(-)
NO3(-)
Na(+)
K(+)
Ca(+2)
ClO4(-)
PO4(-3)
SiO2(aq)
O2(g)
N2(g)
Importance Score
Value Gained:
• Incredible model predictive ability with environmental data
• Insight into features contributing to uranium quartz surface complexation behavior
What's Next:
• Sensitivity Analysis
• Start building models for other mineral/contaminant combinations
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Thank You for Listening!
Thank You!
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