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Summary Report of Summer 2009 NGSI Human Capital Development Efforts at Lawrence Livermore National Laboratory

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Summer 2009 NGSI Human Capital Development Efforts at Lawrence Livermore National Laboratory

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1. Introduction

In 2009, Lawrence Livermore National Laboratory (LLNL) engaged in several activities to support NA-24's Next Generation Safeguards Initiative (NGSI). This report outlines LLNL's efforts to support Human Capital Development (HCD), one of five key components of NGSI managed by Dunbar Lockwood in the Office of International Regimes and Agreements (NA-243). There were five main LLNL summer safeguards HCD efforts sponsored by NGSI:

1. A joint Monterey Institute of International Studies/Center for Nonproliferation Studies-LLNL International Safeguards Policy and Information Analysis Course
2. A Summer Safeguards Policy Internship Program at LLNL
3. A Training in Environmental Sample Analysis for IAEA Safeguards Internship
4. Safeguards Technology Internships
5. A joint LLNL-INL Summer Safeguards Lecture Series

In this report, we provide an overview of these five initiatives, an analysis of lessons learned, an update on the NGSI FY09 post-doc, and an update on students who participated in previous NGSI-sponsored LLNL safeguards HCD efforts.

2. CNS-LLNL International Safeguards Policy and Information Analysis Course

LLNL and the James Martin Center for Nonproliferation Studies (CNS) held a week-long intensive safeguards analysis course for thirty graduate students and young professionals at the Monterey Institute of International Studies (MIIS). The course featured experts from LLNL, CNS, other U.S. national laboratories, and the IAEA to lecture on the origin, evolution, and application of international safeguards. Instructors encouraged active student discussion of safeguards challenges, and the course culminated in student presentations of mock IAEA State Evaluation Reports to a panel of experts.

2.1. Changes from the 2008 Course

The 2009 course made several changes to incorporate lessons learned from the 2008 pilot:

- 30 students participated, a doubling of the size of the 2008 pilot.
- The ratio of American to foreign national students was increased in order to include a diverse set of viewpoints offered by a culturally diverse class.
- Course duration was shortened to one week without sacrificing course material. This made the course more attractive to students with busy summer schedules and increased the cost effectiveness of the course.
- An online introductory module was created to ensure that students came prepared with some basic safeguards knowledge. This module featured required and recommended readings, video presentations, and mandatory quizzes to ensure student comprehension.

2.2. Course Design

The course consisted of a combination of lectures, discussion, and exercises. Each day the course began with a review of the previous day's lesson, along with discussion questions posed to the students to highlight important safeguards concepts or challenges. Students worked on two exercises during the course. First, there was a brief open-source information analysis exercise where students were asked to investigate the validity of a piece of information by corroborating it with other evidence. Second, the students, after being split into three groups, spent most afternoons researching and preparing a mock state evaluation report. This exercise familiarized students with the process of investigating the credibility of a state's safeguards declaration by evaluating public information about that state. At the end of the course, students presented their reports, along with recommendations for further IAEA action, to a panel of course instructors.

Lecture topics for this course included:

- Origins of International Safeguards – Fred Wehling, MIIS
- Foundations of International Safeguards through Information Circular 153 – Fred Wehling, MIIS
- Safeguards Approaches and Practices – Richard Hooper, Wind River Consulting
- The State Evaluation Process – Richard Wallace, Los Alamos National Laboratory (LANL)
- Introduction of Course Exercise: Developing a State Evaluation Report – Richard Wallace, LANL
- Safeguards Implementation at Declared Facilities: Practical Aspects and Procedures – Brian Boyer, LANL
- Safeguards Technology and Instrumentation: An Introduction to Technical Verification – Brian Boyer, LANL
- Case Study: Iraq – Richard Hooper, Wind River Consulting
- Case Study: North Korea – George Anzelon, LLNL
- Strengthened Safeguards – Lisa Owens Davis, LLNL
- Technologies for Detection and Investigation of Undeclared Facilities – Rick Wallace, LANL
- Case Study: Iran – Chris Carson, LLNL
- Open-source Information Analysis – Jonathan Essner, LLNL
- Export Controls and International Safeguards – Stephanie Lieggi, Center for Nonproliferation Studies
- Current Challenges: Legal and Political Issues – Laura Rockwood, International Atomic Energy Agency (IAEA)
- Future of International Safeguards – Thomas Shea, Pacific Northwest National Laboratory (PNNL)

The thirty students in the course represented a variety of academic levels and disciplines; most were still in school, others were early professionals. The majority of the students in the course were Master's candidates in international relations programs with a focus on nonproliferation. The second largest discipline represented was nuclear engineering. Some students had a combination technical/policy academic background. Those participants who were early professionals included staff from the national laboratories, the IAEA, NGOs, and U.S. and foreign government.

3. Safeguards Policy Internships at LLNL

Seven graduate students who attended the LLNL-CNS safeguards policy course continued to LLNL for a 10-week safeguards policy internship. During their internship, students worked with mentors on directed research projects, became familiar with various safeguards facilities at the lab, attended the INMM Annual Meeting, and participated in a group exercise with LANL where they assessed the technical and political viability of safeguards approaches in Iran. At the conclusion of their internship, students presented their research to a group of LLNL safeguards experts.

3.1. Student Research Projects

The students worked with LLNL mentors on guided research projects determined in advance of their internships by the mentors. At the end of their internship, students produced 10-15 page research papers, plus delivered a thirty-minute presentation of their research to a panel of LLNL experts. In several cases, students are pursuing publication of their research topic or using their summer project to support their graduate or doctoral research.

- Intern: Emily Cura (Harvard)
  Mentors: Roger Miller, Chris Carson
  Project Title: Case Study: Iran, Islam, the NPT and the Bomb
  Description: Examined correlations between religious decrees by Iranian and other Islamic clerics and Iran's nuclear program, to examine whether fatwas have influenced, or reflect developments in, Iranian proliferation intent.

- Intern: Sean Dunlop (MIIS)
  Mentor: Fred Mackie
  Project Title: Safeguards Implications for the Potential Export of Indian PHWRs
  Description: Developed policy recommendations to respond to safeguards challenges of Indian PHWR export.

- Intern: Sean Dunlop (MIIS)
  Mentors: Erika Burleson and Bill Domke
  Project Title: Pakistani Export Controls: Progress, Problems, and Priorities
  Description: Evaluated Pakistani progress on export control reform using existing export control metrics.

- Intern: Nicholas Gallucci (MIIS)
  Mentor: Jonathan Essner
  Project Title: Needs, Costs, and Consequences: Defining a Realistic Safeguards Budget for the 21st Century
  Description: Analyzed IAEA safeguards budget requirements needed to respond to an increased workload.
- Interns: Theodore Kalionzes (MIIS) and Sergey Moudriak (MIIS)
  Mentor: Jonathan Essner
  Project Title: 93 + 16: Critical Evaluation of IAEA Strengthened Safeguards
  Description: Evaluated the IAEA's Safeguards Program 93+2 sixteen years after its creation.
- Intern: Taissa Sobolev (MIIS)
  Mentors: Erika Ribanszky and Jared duFresne
  Project Title: Russia and the IUEC: A Path to Changing Safeguards in Nuclear Weapons States?
  Description: Examined the applicability of the multinational enrichment center in Angarsk as a model for safeguards in NWS.
- Intern: David Sweeney (TAMU)
  Mentor: George Anzelon
  Project Title: Nuclear Weapons Latency
  Description: Analyzed resource requirements of alternative proliferation pathways to inform a PhD dissertation on modeling the time needed for a state to develop a nuclear weapon. This model could inform the allocation of IAEA safeguards resources under state-level approach.

3.2. LLNL-LANL Cross-Laboratory Exercise – Safeguards in Iran

This exercise was developed directly in response to student feedback from the 2008 safeguards summer internships. Reflecting on their internship experience, the students suggested it would have been beneficial to include a joint policy-technology exercise would require interaction between both disciplines at both LLNL and Los Alamos National Laboratory.

This exercise asked the students to evaluate options for negotiating and verifying meaningful restraints on Iran's nuclear program if complete abandonment of the enrichment program continues to be unattainable. After reading extensive background material, LLNL students developed a list of hypothetical restraints and corresponding verification measures, and then worked to prioritize them in terms of their potential acceptability to Iran, their verifiability, and their significance as a barrier to diversion, undeclared activities, and breakout. LLNL students prepared an initial menu of options and evaluated them for their salience and political feasibility. Then, in a joint video-teleconference, LLNL and LANL technical interns worked together to select which options had the best combination of technical feasibility and political acceptability.

The exercise had several educational benefits for the interns:

1. It focused their thinking on safeguards by demonstrating safeguards challenges through a real-world case study.

2. It enabled the interns to understand the interdisciplinary nature of safeguards first-hand by presenting them with a situation where politically feasible options were often technically infeasible or technically irrelevant, and technically feasible or relevant options were often politically unfeasible.
3. It provided the students a networking opportunity.

Materials prepared for and produced by this exercise include the following:

1. Exercise instructions and reading list prepared by LLNL intern mentors.
2. List of safeguards goals and menu of safeguards options prepared by LLNL interns.
3. Exercise outcome report, including safeguards conclusions, prepared by LLNL interns and based on the results of the VTC with LANL.

There were several lessons learned from this initial trial. Most importantly, closer coordination between the two labs will help to enrich the experience. Also, despite the difficulty in separating the technical and political components of safeguards options, deeper analysis of political and technical barriers by the respective lab teams could have enriched discussion. Finally, a third round of activity, where the technical team sought technical solutions to political problems and the political team sought political solutions to technical problems, could have enriched the discussion.

3.3. Other Activities:

As part of their experience, LLNL safeguards policy interns traveled to the 2009 Annual Meeting of INMM. This experience allowed them to network with similarly interested individuals in addition to the educational value of listening to the various INMM presentations. Students gained exposure to the broader safeguards/nuclear community, allowing them to contextualize their internship experience and observe other DOE/NNSA safeguards efforts.

LLNL interns also gained experience by visiting facilities at LLNL. These facilities included the Center for Advanced Mass Spectrometry, the Nuclear Counting Facility, the National Ignition Facility, the High Explosive Applications Facility and others.

Where possible, LLNL mentors advised the interns on pursuing careers in nonproliferation or safeguards. This included discussions on pathways to NNSA or National Lab employment, including the Nonproliferation Graduate Fellowship.

4. Training in Environmental Sample Analysis for IAEA Safeguards at LLNL

This eight-week program was developed in response to the NGSI human capital development objective of increasing the number of well-qualified candidates for international safeguards positions at U.S. national laboratories and at the IAEA. Students worked under the aegis of the Glenn T. Seaborg Institute in the Physical and Life Sciences Directorate at LLNL; Ross Williams and Amy Gaffney served as the primary mentors for this internship. For his efforts, Ross was awarded the DOE Outstanding Mentor award.

4.1. Laboratory Training

Over the course of the summer, students were trained in the analysis of bulk environmental samples for safeguards. This included hands-on experience working in a clean laboratory, separating and purifying actinides from bulk samples, measuring U and Pu isotopic ratios through mass spectrometry, and reducing the data and interpreting the results. This training is an important supplement to university training because it exposes students to specialized techniques that are useful for safeguards applications, but typically neglected in university training. Students were also taught the history and theory behind the various techniques that they used in the laboratory.

Students also worked on independent projects with environmental applications. This year, students used the techniques they learned in the internship to identify the presence of fallout nuclides in sediment from a lake in California's Sierra Nevada. Among other findings, students were able to show that fallout levels in this lake sediment were likely affected by California's proximity to the Nevada Test Site. A report of the students' findings will be presented by their mentor at the Asia-Pacific Symposium on Radiochemistry '09 in Napa, California November 29 to December 4.

4.2. Lectures

The bulk of student time was spent in the chemistry laboratory learning and practicing analytical techniques, and analyzing unknown environmental samples. The students also completed written problem sets assigned by the instructors. The training course had two structured lectures per week; the lecture topics were as follows:

- Introduction to LLNL: Training, safety and course overviews.
- The IAEA NWAL: What is it? Why take analyses of low-level uranium and plutonium in bulk environmental samples?
- History of the development and application of isotope ratio measurements.
- Inorganic isotope ratio mass spectrometry – Part 1: The Fundamentals
- Introduction to the LLNL mass spectrometers (IsoProbe, Nu Plasma and Triton); applications and operations
- Inorganic isotope ratio mass spectrometry – Part 2: Ion-counting and statistics
- Data reduction and sources of uncertainty in analysis; Guide to the Expression of Uncertainty in Measurement (GUM)
- Application of software for GUM
- Working with data – present results from QC samples; interpretations; troubleshoot problems with analyses and uncertainty estimates; what does it all mean?
- Gamma-ray spectrometry – an introduction and its role in safeguards
- Uranium enrichment, reactor operations and interpretation of data from bulk environmental samples

- The cutting edge in isotope ratio measurements
- Nuclear forensics and international safeguards
- Proliferation detection
- Other applications of isotope ratio analyses (biomedical, environmental, and geological)

4.3. Lessons Learned

Even though the students were all among the "best and the brightest" as judged by their academic records, their range of prior experience, and the range in their knowledge of chemistry, radiochemistry, mathematics, physics and nuclear science was quite large. Course lessons were geared to teach to the highest level, not the lowest, and most students felt intellectually challenged in one field or another. While teaching at a high level is important, mentors must be sensitive about the need to accommodate varying levels of experience.

To avoid the possibility of not recognizing when a student may feel overwhelmed, and to personalize the experience even more, a casual exam will be given next year on day one, and followed up with individual private discussions. This will help mentors to start out the summer knowing each student's learning objectives and incorporate those into our pedagogic process, which should result in a greater likelihood that the students will develop an interest in and enthusiasm for this aspect of safeguards science.

5. Safeguards Technology Internships at LLNL

In addition to the summer safeguards programs, there were several individual internships focused on working with specific technologies. These internships supported student graduate research and were funded in part by NGSI.

5.1. Student Projects and Mentors

- Student: Grant Spence
  University: TAMU
  Mentor: Dan Dietrich
  Project: Liquid Scintillator Multiplicity Counter
- Student: Erin van Erp
  University: Tufts
  Mentor: Stephen Friedrich
  Project: Comparison of Ge and Cryogenic Gamma Detectors
- Student: Andrea Robels
  University: MIT
  Mentor: Stephen Friedrich
  Project: Geant4 Modeling of Cryogenic Gamma Detectors
- Student: Brian Frisbie
  University: UC-Berkeley

Mentor: Adam Bernstein and Kareem Kazkaz
Project: Simulation of Scintillator Detectors for Safeguards Applications

- Student: Kristina Yancey
  University: TAMU
  Mentor: Adam Bernstein
  Project: Application of the DRAGON Reactor Simulation Package to Predict Antineutrino Emissions from Reactor Cores
- Student: Mike Foxe
  University: Purdue
  Mentor: Adam Bernstein
  Project: Coherent Neutrino Nuclear Scattering for Future Small Footprint Reactor Monitoring Detectors
- Student: Tenzing Joshi
  University: UC-Berkeley
  Mentor: Adam Bernstein
  Project: Coherent Neutrino Nuclear Scattering for Future Small Footprint Reactor Monitoring Detectors
- Student: Afram Kirmiz
  University: UC-Davis
  Mentor: Julie Herberg
  Project: Spectroscopic Studies of the Uranyl-Histidine Moiety

A more detailed description of select student projects, along with the future plans of the student where available is below:

Grant Spence (TAMU) worked on a project to assess the applicability of liquid scintillator based gamma/neutron detectors systems for safeguards applications. In particular, he researched techniques to discriminate between Plutonium, Californium and Curium. Grant has been producing and bench marking an MCNP model for the detector systems including safeguards appropriate geometries.

Last year, Grant participated in the TAMU-LANL-LLNL Safeguards Technology Training Pilot Course. Grant will continue his safeguards related research with LLNL while he works on his PhD at TAMU. Grant plans to return to LLNL to continue his research next summer.

Andrea Robles-Olson (MIT) worked on Monte-Carlo Simulations of superconducting ultra-high energy resolution Gamma-spectrometers for nuclear safeguards. Specifically, she worked on simulating the response function of superconducting ultra-high energy resolution microcalorimeter Gamma-detectors using the GEANT4 Monte-Carlo simulation software. The simulations were used to optimize the response function and assess the feasibility of experiments on Gamma analysis of spent nuclear fuel.

Andrea is an undergraduate student and plans to write her senior thesis on a safeguards-related topic in coordination with LLNL. She plans to apply for an IAEA fellowship after graduation and is applying to a PhD program at UC-Berkeley in nuclear engineering.

Erin van Erp (Tufts) worked on development of high-resolution Gamma-spectrometers. Specifically, she worked on setting up and calibrating a high-purity

germanium Gamma detector. Erin compared the low-energy gamma response of this detector with that from a superconducting ultra-high energy resolution microcalorimeter Gamma-detector.

Mike Foxe (Purdue) is continuing his PhD research in the safeguards-related area he worked on during his LLNL summer internship.

Tenzing Joshi (UC-Berkeley) is continuing his PhD research in the safeguards-related area he worked on during his LLNL summer internship.

5.2. Safeguards Technology Internships Lessons Learned

Two lessons were learned that will help to get the best quality work from the best possible students. First, in selecting students, prospective mentors should not rely on CVs and GPA alone; a telephone interview with students will help to ensure that the right candidates are selected. Second, those students that had a postdoctoral fellow working closely with them in the lab achieved higher scientific output due to the day-to-day guidance they received in the lab.

6. LLNL-INL Summer Safeguards Lecture Series

The LLNL-INL Summer Safeguards lecture series was held on most Tuesdays and Thursdays for eight weeks and featured 13 lectures on safeguards issues and concepts. Most lectures focused on technical issues of safeguards, while some focused on policy issues, safeguards history, and safeguards best practices. This lecture series was conceived by safeguards points-of-contact at LLNL and INL who thought their summer students would benefit from an informal series of lectures on a variety of safeguards topics. As such, these lectures were informal and unvetted and not designed to supplant the more formal lectures being developed by the LLNL-CNS and other summer safeguards courses.

LLNL and INL presented these lectures by video-teleconference to interns at nine laboratories and eventually at NNSA headquarters. On average, 45 participants sat in on the conferences, though some lectures had as many as 62 participants.

6.1. Lectures

Lectures are available on the NGSI E-Room website and by special request from the presenters. Lecture topics covered the following topics:

- Introduction to Nuclear Safeguards – Richard Metcalf, INL
- The Nuclear Fuel Cycle – Adam Bernstein, LLNL
- A Day in the Life of an Inspector – Casey Durst, INL
- International Safeguards Systems, Science & Technical Challenges – Mark Schanfein, INL
- Material Control and Accounting – Robert Bean, INL
- Destructive Analysis Methods – Mary Ademic, INL
- Nondestructive Analysis Methods – David Chichester, INL
- Passive & Active Interrogation – John Luke, LLNL

- Environmental Sampling – Ross Williams, LLNL
- Grand Challenges for Safeguards – Arden Dougan, LLNL
- Statistics and Safeguards & Basic Process Monitoring – Richard Metcalf, INL
- Integrating Safeguards and Nonproliferation – Bill Domke, LLNL
- Open-Source Information: Collection and Analysis – Jonathan Essner, LLNL

7. Update on LLNL FY09 NGSI Post-Doctoral Fellow

The FY09 NGSI post-doctoral research project is to develop and optimize the detection and analysis of fast neutrons in a liquid scintillator array for safeguard purposes. Currently, we have developed such an array and methods to assay to the 5% level quantities of non-multiplying californium and multiplying plutonium samples. The system employs fast liquid scintillator and digital pulse shape discrimination (to separate neutrons from gamma ray events in the liquid scintillator) but we have not come close to exploiting the full power of the hardware.

The post-doctoral fellowship project will be to develop and optimize the system balancing purity of the neutron signal vs. the highest efficiency and the speed of processing. A second task will be to improve the overall modeling capability of the fast neutron system in order to optimize the hardware designs for the presumed high-flux environments common in safeguards activities. Ultimately the result of this work will be the development of an optimal fast neutron detection system that can be used to assay high-flux materials and even quantify the presence of plutonium and curium in the same samples.

We have found a senior postdoctoral fellow, Steven Sheets, who joined us in July and will be working with us until the end of the calendar year. His mentor is Les Nakae. Steven Sheets received his BS in physics and mathematics at Illinois Wesleyan University. He received his PhD in nuclear physics at North Carolina State University for work done studying compound nuclear reactions at Los Alamos National Laboratory. As a postdoctoral researcher at Lawrence Livermore National Laboratory Steven has worked on measuring reaction rates relevant to nuclear astrophysics, characterizing the proportionality of scintillating materials, and measurement of the half-life of the lowest known nuclear isomer.

We plan to hire a new postdoctoral fellow in FY10 to continue this work.

8. Next Steps for LLNL Summer Safeguards Programs

Based upon an internal evaluation of this year's Summer Safeguards programs, we will propose the following improvements for next year.

With respect to the CNS-LLNL safeguards course:

- We will integrate student feedback and leverage lab expertise to develop a clearer SER-based project for the students and young professionals.

- We will expand lecture topics, particularly case studies, to include safeguards-related discussions on Syria, on observations related to the new DG, etc.
- We will work with CNS to expand and improve the online-modules and read-ahead materials for the course

With respect to the summer internships:

- We will consider expanding material coverage to include deeper discussion of policy-related issues. We will link policy and technical discussions through the use of illustrative case studies and examples where technology needs were driven by policy decisions.

With respect to the LLNL-INL Lecture series

- Better internal and external coordination of the lectures. We will attempt to broaden participation to include lectures from other national laboratories. Also, we will provide early information about the lecture series to ensure that interns from HQ and the laboratories are able to participate from the beginning of the series.
- Expanded material coverage. Material coverage will be expanded to include deeper discussion of policy-related issues. Also, policy and technical discussions will be linked through the use of illustrative case studies and examples where technology needs were driven by policy decisions. We will consider the feasibility of pre-recording tours of safeguards facilities unique to individual labs.
- We will more actively engage student participants by designing a website to serve as an access point for presentation materials, to manage email distribution lists, and to facilitate online evaluations of the course. We will also attempt to distribute presentations one-week prior to delivery to encourage active student participation.
- Also for the lecture series, we will explore LLNL as lead for lectures delivered across laboratory complex and INL as lead for lectures across participating universities.

With respect to broader university outreach

- A new activity for FY10 NGSI HCD will be to initiate, in coordination with other DOE laboratories, a broader university outreach effort. Though not explicitly linked to the LLNL summer safeguards activities, this outreach effort will help to raise awareness of the safeguards learning opportunities available to students through LLNL.

9. Update on Select Students Involved in Previous Summer Safeguards Programs

Most students in this year's or last year's summer internships are still in school, and it is too early to tell if they will end up in a safeguards related career. However, several former LLNL summer interns have gone on to undertake additional safeguards-related internships or programs. Through their additional safeguards related work, these students have demonstrated a clear interest in a safeguards or nonproliferation career and are likely to be included in the "next generation of

safeguards experts." The list of below is meant to highlight some of the ways former interns have continued their safeguards work; it is by no means comprehensive.

9.1. 2008 LLNL Summer Interns

David Peranteau:

- Completed a six month internship at the IAEA
- Currently a member of the Nonproliferation Graduate Program Class of 2010, serving in NA-245 and NA-241

Bill Moore:

- Currently a member of the Nonproliferation Graduate Program Class of 2010, serving in NA-241

9.2. 2008 Safeguards Technology Training Summer Internship (TAMU-LANL-LLNL)

David Sweeney:

- Completed the 2009 CNS-LLNL International Safeguards Policy and Information Analysis course
- Completed the 2009 LLNL Safeguards Policy Internship
- Currently working on a PhD dissertation with safeguards applications

Grant Spence:

- Participated in a 2009 Safeguards Technology Internship

Karen Miller

- Completed the 2009 CNS-LLNL International Safeguards Policy and Information Analysis course
- Currently working on a PhD dissertation with safeguards applications