Building a Nuclear Forensic Analysis Capability in South Africa

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Abstract. The threat of nuclear proliferation requires international co-operation and the development of improved measures for the prevention and detection of and response to any incidents of illicit trafficking of nuclear and/or radiological materials. No single country or nation-state can effectively address this critical 21st century problem in isolation, even on a local scale, without global engagement. To meet this need, the Confidence Building Measures (CBM) Program within NNSA's Office of Nonproliferation and International Security promotes international engagement efforts to assist partner countries develop and strengthen indigenous capabilities in nuclear forensics. Beginning in 2013, Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laborator (LANL) and the South African Nuclear Energy Corporation (Necsa) committed to a program of mutual cooperation and assistance to enhance nuclear forensic analysis capabilities in South Africa. This paper reviews the important steps, discusses the current status and points the way to future developments both in South Africa and with other partner countries.

1. Introduction and Initial Steps

The threat of nuclear proliferation requires international co-operation and the development of improved measures for the prevention and detection of and response to any incidents of illicit trafficking of nuclear and/or radiological material. No single country or nation-state can effectively address this critical 21st century problem in isolation, even on a local scale, without global engagement. To meet this need, the Confidence Building Measures (CBM) Program within NNSA's Office of Nonproliferation and International Security promotes international engagement efforts to assist partner countries develop and strengthen indigenous capabilities in nuclear forensics. Beginning in 2013, Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory

(LANL) and the South African Nuclear Energy Corporation (Necsa) committed to a program of mutual cooperation and assistance to enhance nuclear forensic analysis capabilities in South Africa. This paper reviews the important steps, discusses the current status and points the way to future developments both in South Africa and with other partner countries.

The first important step occurred in April 2011 when Necsa hosted a meeting at Pelindaba, South Africa to discuss how the United States and South Africa could best cooperate to improve South Africa's nascent nuclear forensics capabilities and infrastructure. All parties agreed on the need for a Memorandum of Understanding (MOU) discussing critical needs and important milestones and establishing a time frame for future activities. The MOU was drafted over the next four months and the final version signed in July 2011.

The MOU identifies activities to be conducted jointly between the United States and South Africa to enhance scientist-to-scientist engagement including:

1. Organize and conduct a training course in nuclear forensic analysis for Necsa staff to be given by LANL and LLNL;

2. Organize a visiting scholars program to allow senior staff from both countries to visit for an extended period and participate in daily nuclear forensic activities;

3. Assist South Africa improve their nuclear forensic analysis capabilities, specifically to construct and equip a clean room for trace element and isotope analysis of uranium-rich materials (primarily uranium ore concentrate; UOC);

4. Assist South Africa develop and maintain a nuclear forensic database containing information on U-rich materials produced or stored within South Africa;

5. Organize and execute a regular sample exchange and analysis program in which U-rich materials produced in the two countries are exchanged and analyzed independently as part of a round robin exercise program; and

6. Hold a meeting of nuclear forensic experts from Necsa, LANL and LLNL at least every two years to review the results of the round robin exercises, create a lessons learned list and review the current status of activities in both countries.

The initial step in this cooperative program was executed in January-February 2012 when LLNL and LANL held a two-week ourse at LLNL in nuclear forensic analysis focusing on trace element analysis of UOC; six staff scientists from Necsa attended the training course. The course provided an introduction to nuclear forensics followed by a series of lectures discussing techniques receiving and sampling UOC in a clean room environment and the primary techniques used for UOC characterization–microscopy, x-ray diffraction, x-ray fluorescence and inductively-coupled plasma mass spectrometry (ICP-MS) for trace elements. The course also provided an introduction to geochemistry and trace element behavior and uranium ore bodies. Approximately two-thirds of the course was devoted to hands-on work in the nuclear forensic laboratories at LLNL. The course concluded with an introduction to data analysis,and interpretation.

Staff from LANL and LLNL have worked with Necsa since late 2012 to design and construct a new clean room facility at Necsa to process U-rich samples. Information sharing developed through the collaboration allowed the U.S. team to provide Necsa with a state-of the-art design for a clean room facility and to assist with the procurement of air handling and clean room equipment as well as a new ICP-MS. Staff from LANL visited Necsa in Sept. 2012 to review progress on construction of the new cleanroom and discuss important next steps.

The second Experts Meeting was held at LLNL in July 2013. Both sides stated their commitment to the partnership and discussed plans for Kobus Hancke to visit LLNL a part of the Visiting Scholars program and to hold the first joint exercise involving the analysis of UOC. Necsa also expressed a desire for advanced training in nuclear forensic databases.

In 2014 Necsa received a new ICP-MS, which is now installed in the new clean room facility. Staff from LLNL and LANL will travel to Necsa in Sept. 2014 to provide advanced training in ICP-MS analysis of trace elements in UOC, review the status of the clean room, provide training in nuclear forensic databases and search/geolocation algorithms and review the analysis of the UOC sample interdicted in Durban, South Africa in November 2013 (see companion paper by Borg et al.). Plans for the first round robin excise with UOC will also be discussed, as will the next steps in the Visiting Scholar program.

In summary, over the past 3 years the United States and South Africa have developed a very effective partnership in nuclear forensics. This partnership represents a significant advance in scientist-to-scientist engagement and international nuclear nonproliferation and we anticipate many years of fruitful partnership. Both South Africa and the United States are very pleased with the substantial progress made by South Africa since the signing of the Memorandum of Understanding and appreciates the opportunity to work closely with Necsa to expand cooperation in forensics.

ACKNOWLEDGEMENTS

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Educating Policy Students in Nuclear Forensics

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Abstract. Nuclear forensics has received a significant amount of attention and funding in a number of States and in the international arena. Accompanying this attention has been an increased level of activity in awareness training that has targeted decision makers, the scientific community, and the diplomatic, security and law enforcement communities that are the potential users of the nuclear forensics process.

However, to date there has been little effort to develop curricula on nuclear forensics. Scattered coursework tends to focus on the technical aspects of nuclear forensics and the available printed materials (by IAEA and the book Nuclear Forensics by Moody, et. al.) focus on the technical community.

Based on the author's experience in teaching nuclear forensics and other technical topics to non-technical students in a Master's degree program, the paper and presentation will focus on providing education for future policy and decision makers. In addition, a proposed exemplar curriculum will be presented and the challenges of presenting nuclear forensics materials to a non-technical group of students will be discussed.

1. Introduction

The subject of nuclear forensics has only attracted significant public attention in the 21st century although its origins arguably date from the first nuclear weapons program almost seventy years ago.

Currently nuclear forensics is receiving a significant amount of attention and funding in the international community. Many states are either developing or expanding their own efforts in nuclear forensics or looking at how they might participate in multinational nuclear forensics efforts and programs. The International Atomic Energy Agency's (IAEA's) efforts in encouraging states to establish libraries of their nuclear material holdings are raising consciousness of nuclear forensics issues in decision making bodies and regulatory agencies. Accompanying this activity has been awareness training targeting the potential users of the nuclear forensics process: decision makers, the scientific community, and diplomatic, security and law enforcement communities.

In addition, educational institutions, government laboratories, and professional societies have developed academic courses, professional short programs, summer institutes, etc., many of which provide students with scholarships and hands-on experience in various fields such as transuranic elements, radiochemistry, radiation detection, etc.

However, the majority of these programs focus almost exclusively on the science aspects of nuclear forensics. To date there has been little effort to develop curricula on nuclear forensics that provide a policy overview of the subject or consider legal aspects of the field.

For example, Lawrence Livermore National Laboratory (LLNL) which has a long history in nuclear forensics, is running a "Nuclear Forensics Summer Institute Program" this summer in which 8-10 students will receive world class training in the field.[1] The program's selection criteria for students are as follows:

We select graduate students who are majoring in physics, chemistry, geology and geochemistry, nuclear engineering, chemical engineering and environmental sciences that have an interest in nuclear science and would like to do hands-on research under the guidance of a staff scientist. [2]

Similarly, degree programs and coursework in nuclear forensics tend to originate in chemistry, nuclear engineering, and sometimes physics faculties. Available teaching materials, discussed further below, are extremely limited, and those that do exist focus primarily on the technical aspects of nuclear forensics.

Where can international relations majors, nonproliferation studies majors, or anyone whose training is non-technical go to find appropriate education for policy makers in nuclear forensics?

Based on the author's experience in teaching nuclear forensics and other technical topics to non-technical students in a master's degree program, this paper will focus on providing education for future policy and decision makers. It will consider why such education is needed and discuss what subjects should be covered. An underlying but extremely necessary discussion will address the issues of how to communicate scientific information to a non-science student and the challenges of presenting nuclear forensics materials to a non-technical group of students.

Finally, a proposed exemplar curriculum will be presented.

2. Discussion

A. Why is teaching non-technical (i.e. policy) students about nuclear forensics important?

Why is the teaching of nuclear forensics to policy students important? Perhaps the answer should be obvious. However, the fact that teaching nuclear forensics to policy students is apparently only being done in a few locations may indicate that it is not considered important either by the academic community or by the students themselves.

Simply put, policy students evolve to become diplomats, politicians, and decision-makers who will ultimately influence the development of nuclear forensics primarily through the selective allocation of resources. It is important therefore that they develop an understanding of the topic at a level of detail that allows them to understand whatever scientific arguments are being made and to intelligently make policy decisions relating to nuclear forensics.

Who are policy students? Is it sufficient to address simply undergraduate and graduate students, or is the description of the educational need broader? The author would argue that a broad definition is preferable. Although the author currently teaches in a graduate program the discussion in this paper is equally applicable to the education of undergraduates and to the education of postgraduates, i.e., professionals in all levels including diplomats, members of regulatory bodies, etc. who do not possess a technical education that allows them to self-educate in the area of nuclear forensics.

So what are the typical characteristics of a "policy" student? Perhaps the most defining characteristic is that most of them come from non-technical educational backgrounds. As an undergraduate they may have studied international relations, political science, government, etc. A few policy graduate students may have technical undergraduate backgrounds. The author's course in Nuclear Forensics is an

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[1] https://www-pls.llnl.gov/?url=jobs_and_internships-internships-nuclear_forensics_sip
[2] Id.

elective in the Nonproliferation and Terrorism masters program at the Monterey Institute of International Studies. The students' backgrounds in this course to date have been approximately two thirds non-technical students. The one third of students with technical backgrounds is higher than the general student population in this masters program.

What this means in practical terms is that teaching nuclear forensics to policy students involves the teaching of the relevant science concepts. For many of the policy students a course in nuclear forensics may be the first time they have taken any type of science course since high school. Terms such as "isotope," "fission," etc. may need to be explained. Their fundamental knowledge of science may be extremely basic or essentially nonexistent. This should by no means be taken to imply that the policy students are not intelligent. However, to some extent a course in nuclear forensics, or for that matter any course in science given to policy students, must be thought of as a language course. In fact, one of the author's stated goals for the course is the students' acquisition of a vocabulary with which to speak effectively to nuclear forensics professionals.

Unfortunately our current educational method in graduate school is still mainly lecture format. A dozen students may be listening to the lecturer and perhaps only half understand what he or she is saying. In many non-technical classes statements made by a lecturer that are not understood by the students would immediately be challenged. The author's impression is that tragically this is less likely to occur when the lecture has a scientific theme. Many students feel intimidated because they may assume that they are the only one in the class who does not comprehend what is being said. This adds to the general reluctance that students may have to pose questions which they feel will disclose what they may consider to be an embarrassing lack of scientific knowledge. Sometimes the lack of understanding by a student only becomes clear when they can't perform on an examination. How to address this challenge of a communication barrier between a science background instructor and a policy student is, in the author's opinion, one of the greatest challenges in teaching to non-technical students. It is tempting for the instructor to periodically ask the students in class, "Do you understand?" or pose some question of that nature. Many of us have seen this in practice, or may have experienced it as a student. Although it demonstrates a concern by the instructor, it rarely breaks through the barrier of reluctance students may have to admit that they truly are confused.

Another challenge that becomes apparent when teaching a mixture of technical and non-technical students in a technical subject such as nuclear forensics is the students' concern about how they will be graded. Since the subject matter is technical, the non-technical students may be reluctant to even take the course for fear that they may suffer in grading with respect to the more technically competent students. The instructor must be sensitive to the realistic concerns of non-technical students that they may not be able to compete effectively with students who have a technical background. The course syllabus should clearly indicate that the focus of the course is on the policy issues of the subject and that assistance will be provided for learning the basic science concepts.

Although it is relatively easy to express some of these concerns or challenges, overcoming them is not easy in practice. One-on-one interactions with the students (which may be extremely difficult in a large class, but is achievable generally in a seminar session) may be necessary in order to allow the students to reach a comfort level where they can learn the material. As will be discussed later, some of these problems are compounded by the lack of a suitable text to use with policy students.

In summary, teaching nuclear forensics to policy students who are essentially non-technical is an important task that is not currently being fully addressed by either the science or the policy communities. There are a number of challenges in teaching nuclear forensics to non-technical students. Some of these may be overcome by adopting teaching methods that are appropriate for the students. It is not an easy task, but it is a task which is essential for the long-term viability of nuclear forensics programs on a national and international basis since the students will be future decision-makers who will deal with the future direction of nuclear forensics programs.

B. What should policy students be taught about nuclear forensics and at what level should they be taught?

Should policy students studying nuclear forensics cover the same subject matter that science students studying nuclear forensics cover? In a four credit seminar style course at the Monterey Institute, the author's description of the course is as follows in the course syllabus:

> Nuclear forensics deals with the science related to the determination of the origins of nuclear materials such as uranium and plutonium and ... read moreto the policy considerations, such as attribution, which result from determinations that can be made. In addition to science and policy considerations the course will cover the current international efforts in nuclear forensics and survey the performance of conventional forensics in the presence of radioactive material and related issues such as radioactive crime scene management and expert testimony on nuclear forensics issues. (NPTG 8656 Spring 2014)[3]

The course objectives are as follows:

Students successfully completing this course will be able to:

- Demonstrate an understanding of the basic concepts of nuclear forensics science.
- Demonstrate an understanding of the potential applications of nuclear forensics in the determination of the origin of nuclear and other radioactive materials,
- Demonstrate an understanding of the terms and definitions that are used in the field of nuclear forensics.
- Demonstrate a fundamental understanding of the international efforts to cooperate in nuclear forensics analysis.
- Demonstrate an understanding of the legal requirements for the introduction of evidence resulting from nuclear forensics analysis.
- Demonstrate an understanding of the policy implications of attribution.

By contrast, a four-day training course offered by the Radiochemistry Society[4] described the topics covered as follows:

Key Topics You'll Learn About

- Fundamental Principles of Trans-Uranium Elements
- Fundamental Principles of Fission Products
- Fundamental Principles of Rapid Screening Measurements

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[3] Note that there are a number of definitions of nuclear forensics. One of particular note is a statement in a press release by the U. S. Department of Energy's National Nuclear Security Agency (NNSA) "Nuclear forensics is the popular term for the scientific characterization and analysis of nuclear or other radiological materials, which can provide critical information on the place of origin and process history of nuclear materials. This information can help national authorities determine how and where control of material was lost and, when combined with law enforcement and intelligence information, can facilitate the prosecution of smuggling cases." http://www.nti.org/gsn/article/nnsa-iaea-offer-nuclear-forensics-training/

[4] Available at: http://www.radiochemistry.org/courses/rc_forensic.html

- Fundamental Principles of Non- Destructive Assay
- Fundamental Principles of Neutron Activation Analysis
- Fundamental Principles of Alpha Spectrometry
- Fundamental Principles of Gamma Spectrometry
- Fundamental Principles of Neutron Counting
- Fundamental Principles of Portal Counting
- Fundamental Principles of Liquid Scintillation Counting
- Fundamental Principles of Gas Flow Proportional Counting
- Best Methods and Strategies for Separation Chemistry
- Making Reliable & High Quality Measurements in Nuclear Forensic
- Fundamental Principles of Contamination Control
- Fundamental Principles of Reporting of Results
- Fundamental Principles of External Communication

The difference in focus is obvious. Policy students need to have an understanding of what the Radiochemistry Society considers to be key topics, but they need to have that understanding at an overview level. Non-technical policy students will not understand initially what a gamma ray is or what types of detectors can detect various types of radiation. It is important for them to understand the differences, but far more important to understand why those differences can be critical. They do not need us to understand the details of how a portal monitor works, but they should have some understanding of how portal monitors are used and that portal monitors may have differences in sensitivity and different detection capabilities (i.e., that some may be able to detect neutrons in addition to gamma radiation).

Attached as Appendix 1 to this paper are the syllabus topics of the 16-week course on nuclear forensics taught at Monterey Institute by the author. In teaching these courses an educational concept known as "flipping the classroom" is employed to some extent. This involves the creation of short videos that further explain various topics that students found difficult to understand. Other videos provide guidance to the students on how to read and interpret some of the course materials. Educational freeware such as the iPad app “Explain Everything”[5] and simple video capture software available on any computer are typically used to produce these videos. The Monterey Institute uses Moodle as course management software, but the file size of the videos makes the use of Dropbox preferable for distributing videos to the students. Typically the PowerPoint presentations used in class are made available on Moodle shortly after the lectures are completed.

The emphasis in teaching in the author's course is on concepts, definitions, and the organizational structure of how things fit together. In other words, where do pre-and post-detonation nuclear forensics fit into a national program? What are the differences between two conceptual types of nuclear forensics, i.e,. determination or attribution with regard to nuclear or other radioactive material and performing conventional forensics in a radioactive environment or on radioactive or radioactively contaminated materials? In addition, the development of the concept of states’ nuclear materials

[5] See http://www.newschooltechnology.org/2013/02/explain-everything/. The free app is available from iTunes App Store.

libraries and their importance are significant subjects for policy students to understand. The libraries, and the IAEA's efforts in the field can give rise to significant policy issues and discussions.

Policy students are capable of understanding the importance of radiochemical separations, mass spectrometry, and a number of concepts that are important in nuclear forensics, but their understanding is at the overview level. For example, they can learn the necessity of using radiochemical separations in order to look for trace elements in radioactive samples, but they will not intuitively grasp the differences in orders of magnitude. Scientific notation will have little to no meaning to them without explanation. They are quite capable of understanding these concepts, but an instructor must be aware that they need to be educated in principles such as scientific notation and cannot assume that they have learned these somewhere in their background.

In addition to the scientific concepts of nuclear forensics the author's program in nuclear forensics places some emphasis on the legal aspects associated with expert testimony on nuclear forensics in a court of law. Policy students are interested in these concepts and how they play out. It can be a "hook" for students who are otherwise not interested in some aspects of nuclear forensics. On the other hand, it has been the author's experience that U.S. students, much less international students, have little understanding of the American legal system and in the differences between federal and state courts and the differing standards that might apply in these courts.

Finally, international efforts of cooperation in nuclear forensics (and conversely the lack of cooperation) are of great interest to policy students. Whenever possible efforts by international organizations such as the IAEA, EURATOM, INTERPOL, EUROPOL, and the United Nations Interregional Crime and Justice Research Institute (UNICRI) are discussed in the class as are efforts by the FBI, Department of Homeland Security, Department of Defense, etc. on the US domestic scene are discussed. The Nuclear Forensics International Technical Working Group (ITWG) and the efforts of professional societies such as the American Physical Society and the American Association for the Advancement of Science are also topics of discussion, particularly when, as discussed in the following section, those organizations have made policy recommendations on nuclear forensics.

In summary, policy students need to be taught the basic elements of nuclear forensics from an overview perspective. They need to understand the language of nuclear forensics in order to be able to communicate effectively on the topic and they need to understand the legal and organizational frameworks that exist on a national and international basis.

It is worth considering whether or not a "one size fits all" course is the best for policy students. At the Monterey Institute full semester courses can be either in a lecture format or a seminar format. The author's nuclear forensics course has been taught in a seminar format which allows the students to pursue their individual interests to some extent through their choice of a paper topic to satisfy the requirements of the seminar. This allows each student to find and explore a nuclear forensics topic that they find interesting. Although some may initially struggle with the topic selection, it appears that each student discovers a topic in which they are truly interested. Often, for example, international students explore their country's efforts in some aspect of nuclear forensics. The author gives students a free range of topic choice so long as it connects to the basic nuclear forensics subject.

C. What materials are available to teach policy students?

Anyone establishing a course for policy students in nuclear forensics is faced with a dilemma of what materials to use. *Nuclear Forensic Analysis* by Kenton J. Moody, Ian D. Hutcheon, and Patrick M. Grant (Moody see Figure 1 below) is virtually the only published book on the subject.

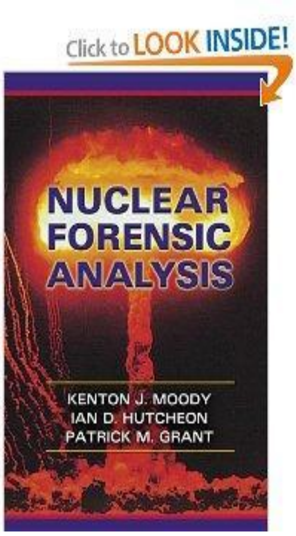

Figure 1. Cover of Moody, et. al.[6]

However, Moody is not a textbook--at least in its current edition.[7] The author uses it as a text, but it is certainly above most policy students' ability to read without significant guidance, i.e. the students need to be told what areas to ignore as to technically difficult and which to focus on. An additional difficulty with the Moody book is that like all scientific texts it is expensive, a fact that leads to an unfortunate preference by some students to use the reference copies available in our library instead of buying a copy for their professional library.[8] Certain chapters of Moody, particularly the case studies in the later part of the book are particularly good for use with the policy students as concrete demonstrations of the power and utility of nuclear forensics.

In addition to Moody, the IAEA's Nuclear Security Series publication on nuclear forensics, Nuclear Forensics Support[9] (see Figure 2 below) is a useful reference.

[6] http://ecx.images-amazon.com/images/I/51JGfJ9wQiL._BO2,204,203,200_PIsitb-sticker-arrow-click,TopRight,35,-76_AA300_SH20_OU01_.jpg

[7] Note that in 2013 when students attempted to purchase the Moody book through Amazon they were advised that a new edition would be forthcoming. To the author's knowledge that has not happened yet and the warning has been removed from Amazon. CRC Press indicates that a Second Edition will be published in November 2014 (See www.crcpress.com/product/isbn/9781439880616). Hopefully the newer addition of Moody will retain its scientific merit while transitioning to more of a textbook format.

[8] It should be noted that Amazon offers Kindle versions of Moody and also may offer semester rental options. These options vary from time to time and may offer better affordability for the students.

[9] Available for download as a .pdf document at:
http://www-pub.iaea.org/MTCD/publications/PDF/Pub1241_web.pdf

Figure 2. Cover of Nuclear Forensics Support--IAEA Nuclear Security Series No. 2

Although the Nuclear Security Series publication is in revision it is still useful as a reference and it can also be quite useful in explaining to students the operations of the IAEA in general and specifically with regard to nuclear forensics.

In addition to these more book or book-like publications, a nuclear forensics course for policy students must of necessity use materials available from the Internet including articles of topical interest. The author has found several national laboratory publications as well as professional society publications to be of utility in his nuclear forensics course.[10]

It should also be noted that the IAEA has developed a Master's degree level program in nuclear security that is set out in Nuclear Security Series No. 12.[11] One of the elective courses is NS19, "Nuclear forensics and attributions." The International Nuclear Security Education Network (INSEN)[12] has undertaken through its subcommittees to develop course materials in support of the IAEA's program, but to date there is no product available that supports NS19.

In summary, there does not appear to be a text which will be usable in the foreseeable future for policy students. INSEN or a private publisher may develop development a suitable text, but it appears that for the foreseeable future the teaching of nuclear forensics to policy students will need to rely on Moody (the original version or its second edition edition), much as the author has done in the nuclear forensics course taught at the Monterey Institute.

D. What should to be done to improve the situation?

An obvious way of improving the ability to teach policy students about nuclear forensics would be to develop a text which targets various levels of background in science.

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[10] In particular, "Nuclear Forensics Role, State of the Art, and Program Needs," by a Joint Working Group of the American Physical Society and the American Association for the Advancement of Science available at: http://www.aaas.org/report/nuclear-forensics-role-state-art-program-needs is a useful publication. This has been presented to policy students late in the course in order to demonstrate to them their mastery of the concepts discussed in the study.
[11] "Educational Programme in Nuclear Security" available for download as a .pdf at: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1439_web.pdf
[12] See the report of INSEN's August 2013 meeting available at: http://www-ns.iaea.org/downloads/security/annual-iinsens-meeting-2013-chairman-report.pdf

However, a text focused totally on students with a non-technical background might not be a viable commercial option. Integration of the underlying fundamental science background with policy and legal aspects of nuclear forensics could be developed into a viable text that would be useful at the undergraduate and graduate level for students with a non-technical background and for a broader non-technical audience. If creatively written, such a text would also be suitable for students with a technical background who want to learn something about the technical aspects of nuclear forensics but are not interested in delving into detailed technical issues. In addition to an overview of the subject matter, a student with a technical background should find such a text provides a gateway to learning something about the legal and policy aspects of nuclear forensics.

Development of such a text would be a useful contribution to the long-term health of nuclear forensics and therefore to the long-term health and sustainability of the global nuclear security regime.

Appendix 1: Syllabus Topics from MIIS course NPTG 8656 Spring 2014

Week 1 Topic: Course Introduction and Overview—What is Nuclear Forensics?

Week 2 Topic: Nuclear Explosive Devices

Week 3 Topic: Scientific Basis for Nuclear Forensics

Week 4 Topic: Scientific Basis for Nuclear Forensics (continued)

Week 5 Topic: Chronometry

Week 6 Topic: Analysis Techniques

Week 7 Topic: Analysis Techniques (continued). Begin selection of paper topics for class presentation and final paper

Week 8 Topic: **Spring Break no class**

Week 9 Topic: Analysis Techniques (continued) **and** Case Studies

Week 10 Topic: **Midterm Examination**

Week 11 Topic: Case Studies

a) Assigned Reading: Moody Chapters 20 to 25

Week 12 Topic: Nuclear Forensics on the International Scene (possible guest speaker)

Week 13-16 Discussion of students' paper topics, each student presents their paper, plus outside speakers. There is no final examination. Student papers are ~20 pages in length and presentations are 20-30 minutes in length.

Nuclear Forensics Expertise Development: Transferring Knowledge to the Next Generation

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Abstract. Since 2008, the National Nuclear Forensics Expertise Development Program (NNFEDP) has served as the comprehensive U.S. Government effort to grow and sustain the uniquely qualified technical expertise required to execute the nation's nuclear forensics mission. The NNFEDP has created a vibrant academic pathway over the past six years from undergraduate to post-doctorate study in nuclear and geochemical sciences directly relevant to nuclear forensics, supporting over 300 students and faculty in partnership with 11 U.S. National Laboratories and 23 universities. Through its fellowship, scholarship, junior faculty, and education development initiatives, the program links next generation scientists with technical experts at the Laboratories for practical research experiences and individual mentoring to facilitate critical knowledge transfer and to establish a seamless pipeline from academia into an attractive career in nuclear forensics. The NNFEDP provides an active and practical example of how to transfer and sustain nuclear forensics knowledge and expertise to the next generation of scientists – a major challenge facing the international nuclear security community today.

1. Introduction

The National Nuclear Forensics Expertise Development Program (NNFEDP) serves as the comprehensive U.S. Government (USG) effort to grow and sustain the uniquely qualified technical expertise required to execute the nation's nuclear forensics mission. The U.S. Department of Homeland Security (DHS) launched the NNFEDP in 2008, and President Obama supported the effort when he signed the Nuclear Forensics and Attribution Act into law in 2010 [1]. The primary program objective is to create a vibrant and enduring academic pathway from undergraduate to post-doctorate study in nuclear and geochemical sciences directly relevant to nuclear forensics, including radiochemistry, geochemistry, nuclear physics, nuclear engineering, materials science, and analytical chemistry. Through its fellowship, scholarship, junior faculty, and education development initiatives, the NNFEDP links next generation scientists with technical experts at the U.S. Department of Energy (DOE) National Laboratories for practical research experiences and individual mentoring to facilitate critical knowledge transfer and to establish a seamless pipeline from academia into an attractive career in nuclear forensics.

Over the past six years, the NNFEDP has supported over 300 students and faculty in partnership with 11 U.S. National Laboratories and 23 universities. This program provides an active and practical example of how to transfer and sustain nuclear forensics knowledge and expertise to the next generation – a major challenge facing the global nuclear security community today.

2. The Workforce Challenge and the U.S. Approach

In the early 2000s, a number of expert groups published studies recognizing that the cadre of experienced nuclear forensics experts at U.S. National Laboratories and in academia had been rapidly diminishing since the end of the Cold War, and the outlook for replacing them was grim. A 2004 DOE National Science Foundation Nuclear Science Advisory Committee report assessed that within ten years, "more than three quarters of the workforce in nuclear engineering and at the National Laboratories will reach retirement age" [4]. At the same time, the decline in U.S. academic programs in technical areas directly relevant to nuclear forensics, such as radio- and nuclear chemistry, had reached alarmingly low levels. Few universities still offered graduate programs in radiochemistry, and in most of these, only one faculty member remained. By 2008, the total number of Ph.Ds. awarded nationwide had decreased to fewer than six per year. The National Academy of Sciences, a Joint Working Group of the American Association for the Advancement of Science and the American Physical Society, and the U.S. Government Accountability Office all highlighted these gaps as a crisis and recommended they be addressed in a swift, targeted manner [2, 3, 5].

In the face of a dire situation both at the National Laboratories and in academia, the USG established the NNFEDP to reverse declining trends and develop the next generation of nuclear forensic scientists in the United States. The NNFEDP promotes an interdisciplinary approach emphasizing collaboration among students, academic departments, universities, and National Laboratories. It is unique compared to broader science and technology federal education programs in its deliberately narrow focus on addressing highly specific, identified technical needs within the nuclear forensics field. All efforts are integrated, aligned, and inextricably linked to USG nuclear forensics priorities, projects, and the cadre of expert nuclear scientists at the National Laboratories. This is accomplished through one-on-one mentoring, practical internships, and focused collaborative applied research.

3. Establishing an Academic Pathway to a Nuclear Forensics Career

Key components of this holistic program aim to create a seamless pipeline from academia into a career in nuclear forensics at the national level [Fig. 1]. NNFEDP initiatives include graduate and undergraduate scholarships, fellowships, internships and mentoring, post-doctoral fellowships, and university and junior faculty awards for studies and research in nuclear forensics-related disciplines.

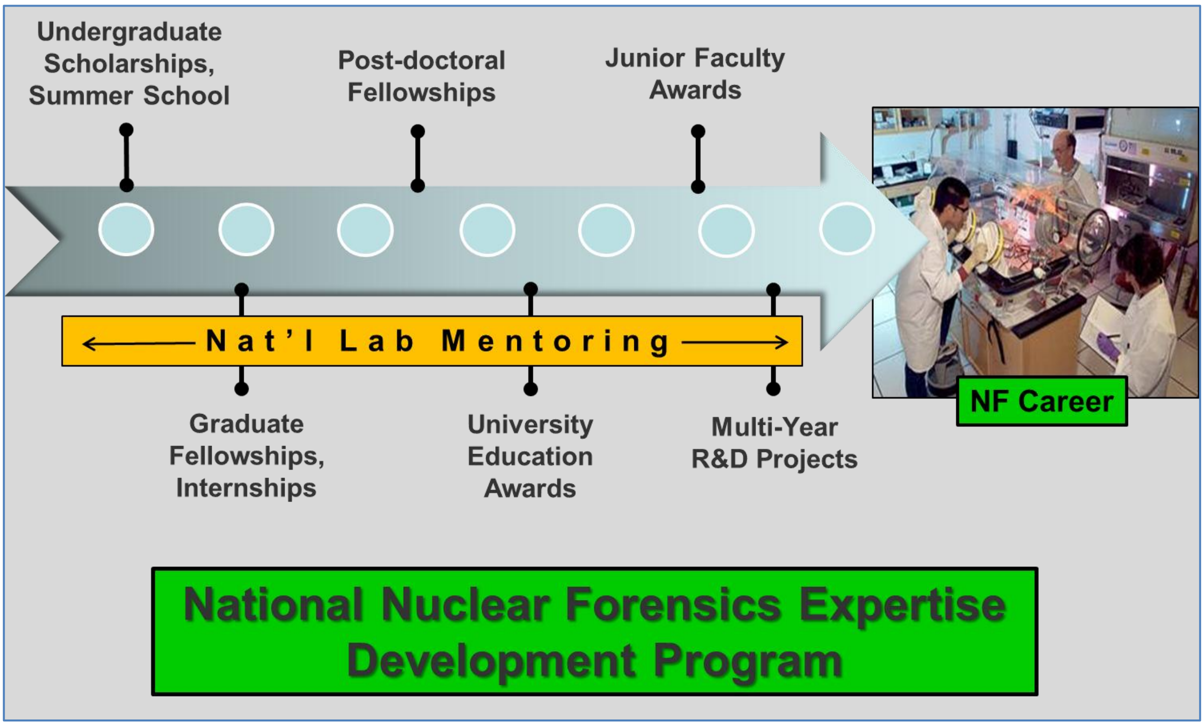

FIG. 1. Illustration of the NNFEDP: key components from the undergraduate through the post-doctoral level create a seamless pipeline from academia into a career in nuclear forensics at the national level.

3.1. Undergraduate Initiatives

The NNFEDP undergraduate-level programs are designed to introduce undergraduate students to the field of nuclear forensics as a viable career path, increase the number of qualified undergraduates pursuing graduate studies in technical fields related to nuclear forensics, develop enduring relationships between the students and National Laboratories, and foster collaborations between university partners and laboratory staff conducting nuclear forensics research. NNFEDP addresses these objectives through two primary initiatives.

3.1.1. Nuclear Forensics Undergraduate Scholarship Program

The Nuclear Forensics Undergraduate Scholarship Program aims to introduce outstanding physics, chemistry, and nuclear engineering undergraduates to nuclear forensics-related research sponsored by the USG at the National Laboratories. Participants gain hands-on experience through a nine-to-12-week summer research practicum under the guidance of a senior laboratory mentor and a university faculty advisor. Following the completion of the practicum, scholars produce a scientific report and deliver oral presentations of their research to the broader nuclear forensics community, including technical and policy experts from academia, the National Laboratories, and the Federal Government, as well as their peers.

3.1.2. Nuclear Forensics Undergraduate Summer School

The Nuclear Forensics Undergraduate Summer School provides a comprehensive, experimental, hands-on training curriculum in topics essential to nuclear forensics as a means of attracting students to pursue graduate studies in related technical fields. Students participate in a four- to six-week program, hosted by a partnership of universities and National Laboratories, that comprises a series of lectures, laboratory experiments, National Laboratory field trips, and practical exercises. The focus of this program is to introduce students to the technical and practical aspects of nuclear forensics, while providing them with a fundamental understanding of the underlying science necessary to comprehend the subject matter. The Summer School recruits undergraduate students from chemistry, physics, geology, and materials science departments at research universities across the nation, with the host school and laboratory field trip rotating each year.

3.2. Graduate Initiatives

The NNFEDP graduate-level programs encourage students to pursue advanced degrees in radiochemistry and other nuclear forensics-related disciplines and encourage universities to invest in these types of academic programs. The main objective at the graduate level is to meet the near-term USG milestone of adding 35 new Ph.D. scientists into the nuclear forensics field by 2018. The NNFEDP implements two primary initiatives in this area.

3.2.1. Nuclear Forensics Graduate Fellowship Program

As a key component of the broader NNFEDP, the Nuclear Forensics Graduate Fellowship Program enables students to gain unique, hands-on experience through laboratory practicums and close interaction with technical and policy experts throughout the nuclear forensics community. The program encourages these students to seek advanced education in technical areas related to nuclear forensics and provides incentives for universities to invest in and further develop radiochemistry and other related academic programs.

Fellowship appointments provide tuition and a 12-month stipend at an approved university, renewable for up to 60 months, for outstanding graduate students pursuing doctoral degrees in nuclear, geochemical, and related scientific disciplines. Universities selected to participate in the program have demonstrated a commitment to building a sustainable academic program in these core disciplines. Fellows must earn their degrees with a consistently high level of academic standing and complete at least two ten-week-minimum practicums at a National Laboratory or federal agency conducting nuclear forensics research. Upon graduation, fellows must serve for two years in a post-doctoral or other staff position at a National Laboratory or federal agency in a nuclear forensics-related area. Ultimately, this program gives highly motivated students an exceptional opportunity to apply their knowledge to enhance U.S. national security.

3.2.2. Glen T. Seaborg Institute Nuclear Science Summer Internship Program

The USG also sponsors graduate and outstanding undergraduate students as interns at Lawrence Livermore National Laboratory and Los Alamos National Laboratory each summer through the well-established Glen T. Seaborg Institute Nuclear Science Summer Internship Program. Most interns are graduate students with expertise in nuclear engineering, radiochemistry, math, physics, and the earth sciences. The Seaborg Institute facilitates student research in a variety of different areas; however, NNFEDP students work on projects directly related to nuclear forensics. Interns also have the opportunity to participate in a seminar series at their respective laboratories to interact with their peers and more senior experts and to learn about important topics in the nuclear sciences.

3.3. Post-Graduate Initiatives

The NNFEDP Post-Doctoral Fellowship Program encourages recent Ph.D. graduates with relevant technical expertise to enter the forensics workforce and provides a career track for nuclear forensics graduate fellows. During these three-year appointments, post-docs work on nuclear forensics research projects at a National Laboratory and have the opportunity to engage with experts across the USG nuclear forensics community. The ultimate goal is to help facilitate the successful transition of these fellows at the end of their appointments to permanent staff positions at the National Laboratories.

3.4. University Initiatives

3.4.1. Nuclear Forensics Education Award Program

The Nuclear Forensics Education Award Program is designed to encourage universities to develop interdisciplinary programs in partnership with the National Laboratories. This program provides cost-shared grants, renewable for up to three years, to colleges and universities to support educational programs in analytical, geological, and radiochemistry, nuclear physics and engineering, and materials science. To ensure university commitment, an annual cost-share agreement of 50 percent matching funds is required from the institution receiving an award. Universities may use the award to develop nuclear forensics curriculum and research programs that complement ongoing research at the national laboratories, construct on-campus laboratory facilities for forensics-related work, enhance faculty member qualifications or hire new faculty, sponsor students, and/or make other improvements that align with USG mission priorities.

3.4.2. Nuclear Forensics Junior Faculty Award Program

The objective of the Nuclear Forensics Junior Faculty Award Program is to provide universities with an incentive to recruit, promote, and retain highly qualified personnel to teach within nuclear forensics-related degree programs and to contribute to associated research at universities. These awards are renewable for up to three years and can be used to support faculty salaries, facilitate research projects, purchase equipment, and provide travel to National Laboratories for technical collaboration. The award recipient must be in a tenure-track position and meet the definition of a “junior faculty member” (someone with less than six years of experience at the time of application). Partial matching funds from the university are encouraged and demonstrated collaboration with a National Laboratory is a key component of this program.

3.4.3. Nuclear Forensics Minority Serving Institution Collaboration Award Program

The Nuclear Forensics Minority Serving Institution Collaboration Award Program serves to strengthen the engineering and science programs at Minority Serving Institutions located throughout the United States and to enhance the partnerships between these institutions and other U.S. universities with established academic programs in scientific disciplines relevant to nuclear forensics. These three-year awards can be used to support faculty salaries, student scholarships and fellowships, travel, laboratory and equipment improvements, coursework, and other collaborative academic activities with university and national laboratory partners. The overarching goal of this program is to help meet USG needs for a diverse and highly trained workforce in priority technical areas for nuclear forensics research and development.

3.5. Mentoring

The Graduate and Undergraduate Mentoring Assistance Programs enable mid-to-senior-level staff scientists at U.S. laboratories to mentor students in collaboration with university professors. These programs provide dedicated funding for one-on-one mentoring, which includes training, assistance with the design, execution, and publishing of research projects, and interaction with the student’s faculty advisor and home university. The impact of this support has also extended into the development of special lectures and courses in nuclear forensics-related topics at universities, thus benefiting upper-level undergraduate and graduate students more broadly in addition to individual mentees. Scientist-student mentoring is a multi-year responsibility that helps to build a long-term collaboration among the National Laboratories, universities, and next generation of experts that is critically important to facilitating a seamless pipeline from academia into a nuclear forensics career and transferring expert knowledge to the next generation of scientists.

4. Real Progress

In close collaboration with 11 National Laboratories, the NNFEDP has supported over 300 students and faculty and 23 universities since its inception in 2008. Twenty-one students are currently pursuing their Ph.D.'s through the Nuclear Forensics Graduate Fellowship Program, along with 13 post-doctoral fellows who are at the laboratories conducting research under preeminent nuclear forensics experts. Eighteen graduates of these two programs have already entered the nuclear forensics workforce at U.S. National Laboratories and federal agencies, with four post-doctoral fellows transitioning to permanent positions at the labs in the first half of 2014 alone. Undergraduate initiatives are proving to be an effective tool for recruiting future Ph.D. candidates, with 15 new undergraduate participants each year. NNFEDP education award programs have directly sponsored nuclear forensics-related curriculum development and research partnerships at 13 universities around the country, including support to eight tenure-track junior faculty members. These university initiatives are having a broad impact in increasing the awareness and knowledge base of the next generation, with an increase of more than 50 percent since 2009 in the number of nuclear forensics-related courses and the number of students enrolled in those courses at universities with awards.

5. Continual Assessment

The USG continually evaluates the state of the workforce within the National Laboratory system relative to the U.S. nuclear forensics mission requirements in order to appropriately scale and scope the NNFEDP. In addition, DHS chairs a Nuclear Forensics Expertise Development Committee in order to ensure whole-of-government integration and participation in nuclear forensics expertise development activities. The Committee provides a forum to plan, coordinate, and execute joint program initiatives, avoiding duplication, leveraging funding, and ensuring robust national support and unity of effort. Participants include DHS, DOE, and the U.S. Departments of Defense and Justice.

6. Summary

The United States is steadily accomplishing its goal to grow and sustain the uniquely qualified technical expertise required to execute the nation's nuclear forensics mission through the implementation of the NNFEDP. The range of initiatives spanning the undergraduate to the post-doctoral level has created a pathway for students from academia to a career in nuclear forensics. Eighteen new Ph.D. scientists have now transitioned from the expertise pipeline into full-time positions in the USG nuclear forensics workforce, as the NNFEDP steadily progresses toward the near-term milestone of adding 35 new Ph.D. scientists into the field by 2018. More broadly, this program is reinvigorating the nuclear science academic community at universities across the United States – providing the strong foundation in core scientific disciplines that is needed to educate the next generation of nuclear forensics experts and enhancing the overall U.S. capacity for critical technical research. The NNFEDP is a key component in ensuring an enduring and robust nuclear forensics capability that will continue to contribute to both national and international efforts to prevent nuclear terrorism.

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