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Sandia National Laboratories Early Career University Faculty Mentoring Program in International Safeguards

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ABSTRACT

An international safeguards mentoring program was established by Sandia National Laboratories (SNL) for early career university faculty. The inaugural year of the program focused on course material development and connecting faculty to experts at national laboratories. Two faculty members were selected for participation; one developed a safeguards-by-design course, and the other created lecture material related to unmanned robotic systems in safeguards for integration in existing courses. Faculty members were paired with SNL subject matter experts based on the topic of their individual projects. The program also included a two week visit to SNL. The structure of this program not only supported the development of new course material, but also provided junior faculty members with an opportunity to make connections and build collaborations in the field of international safeguards. Programs like this are important for professional development of faculty members and to help strengthen connections between universities and the national laboratories.

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ACRONYMS AND DEFINITIONS

Abbreviation	Definition
SBD	Safeguards By Design
SNL	Sandia National Laboratories
SME	Subject Matter Experts
VCU	Virginia Commonwealth University
PSU	Penn State University
TTE	Table Top Exercise

1. INTRODUCTION

The education of the next generation of nuclear safeguards experts is essential to the prevention of nuclear weapons proliferation. University professors are an integral component of the training pipeline, but opportunities for advanced and continuing nuclear safeguards education for early career faculty are limited. The most prevalent programs are specific to students, postdoctoral researchers, and early career scientists within national laboratories. Faculty also face the challenge of being able to travel for courses and obtaining funding; university resources for travel and training are typically focused on student opportunities, and research grants are not focused on education related travel. Thus, there is a lack of resources available to new professors to assist them with continuing education, course development, professional networking, and proposal writing.

Retention of early career faculty in nuclear safeguards related areas requires the development of a support structure. While most universities have an established mentoring plan, the mentors are typically senior faculty who can assist with the day-to-day navigation of academia, but are not safeguards, or in some cases even nuclear science, subject matter experts (SMEs). This void in intensive continuing education opportunities for faculty resulted in the development of a Sandia National Laboratories (SNL) led, nuclear safeguards focused, mentorship program for early career professors. Two faculty members, one from Penn State University (PSU), Azaree Lintereur, and one from Virginia Commonwealth University (VCU), Braden Goddard, were selected as the participants for the first cohort. The first year of the program was focused on pairing faculty with SMEs at SNL to produce safeguards related education materials and to establish connections for future work in the field of nuclear safeguards. The faculty members are shown in Figure 1 with two of the SNL mentors at the 60th Annual Institute of Nuclear Materials Management Meeting.

Figure 1. Pictures of the faculty members and two SNL mentors at the 60th Annual Institute of Nuclear Materials Management Meeting. *Left: Natacha Peter-Stein, left-middle: Braden Goddard, right-middle: Azaree Lintereur, right: Alexander Solodov.*

There are three common metrics used to assess faculty tenure applications: education, research and service. The education metric includes the modification of existing courses and the development of new courses. The development of educational material also provides faculty the opportunity to introduce courses or topics that are not currently available and are of specific interest or are related to their research areas. Thus, the PSU faculty member decided to use this opportunity to create a graduate level technical elective focused on Safeguards by Design (SBD). The VCU faculty member used the opportunity to develop curriculum on the use of unmanned robotic systems for safeguards and related applications. Instead of using this curriculum to develop a new course, it will be integrated into multiple existing undergraduate and graduate level courses. Research, sometimes referred to as scholarly activity, encompasses the development of a sustainable program, including metrics such as funding obtained and publications. The PSU faculty member is targeting potential research collaboration opportunities with SNL related to SBD, specifically SBD for Molten Salt Reactors and Small Modular Reactors. The VCU faculty member has written two proposals related to radiation measurements using unmanned systems with collaborators at SNL since the start of this program. In addition, both faculty members submitted research proposals to the 2019 Department of State Bureau of Arms Control, Verification and Compliance Broad Agency Announcement as a result of being made aware of the opportunity through this mentoring program. Service requirements are typically assigned based on institutional needs and are generally not technical in nature. Thus, the service metric was not a focus of this program.

Presented here is a summary of the activities which occurred at SNL and the educational materials developed as part of this program.

2. PROGRAM STRUCTURE

The goal of the Office of International Nuclear Safeguards (NA-241) Human Capital Development (HCD) Program is to develop sustainable academic and technical programs that support the recruitment, education, training, and retention of a new generation of international safeguards professionals. This program has addressed several areas within the mission of the HCD subprogram. It has strengthened university academic programs with focus on international safeguards by fostering more diverse, and knowledgeable, faculty members. It also provided mentoring opportunities for young professionals in the field and knowledge transfer and retention by transferring practical experience of national laboratory staff to new faculty members, who in turn will provide this knowledge to their students.

The program started early in the fiscal year by establishing each individual faculty member's goals. Each faculty member provided information detailing what they hoped to accomplish with their mentors, and that information was used to select the appropriate SMEs at SNL. Early communication and planning focused on logistics and establishing expectations for outcomes of the program. The majority of the mentoring interactions occurred during a two week visit by the faculty members to SNL. This intensive mentorship visit allowed for focused interactions and knowledge transfer between the mentors and the mentees, as well as designated time to concentrate on the development of the education materials. In addition to mentor-mentee interactions the visit also enabled the faculty members to meet with other SMEs and tour SNL facilities relevant to their projects. SMEs in areas related to the educational materials that were developed were consulted for resources and information. Examples included experts in nuclear security table top exercises and export control. Facility tours included the Tech Area V educational and training facilities as well as the National Solar Thermal Test Facility and an Unmanned Aerial Systems (UAS) acceptance testing demonstration.

The structure of the mentoring visit enabled depth and breadth to be added to the educational material compared to what would otherwise have been produced. It further provided an opportunity for connections to be made which will be beneficial for future career development, including research and funding opportunities.

3. COURSE MATERIAL DEVELOPMENT AT SANDIA NATIONAL LABORATORIES

The two faculty members focused on different curriculum development tasks: complete course versus flexible course content. Thus, while there was some overlap in their efforts for this mentoring program, their course material creation was done individually. The material developed by each professor is described separately, below.

3.1. Safeguards by Design

International and domestic safeguards are essential for nuclear facilities. The inclusion of safeguards related considerations after facility design can lead to the need for retrofitting, and introduce measurement challenges; however, if safeguards requirements are considered during the design process it can result in facilities that are easier to safeguard. This approach is being promoted through the concept of SBD [1]. SBD is also gaining international attention as new reactor designs are being explored [2]. However, there are currently limited opportunities for students to familiarize themselves with SBD. While PSU has a strong nuclear safeguards curriculum, which covers both policy and technical aspects of safeguards, it does not emphasize SBD. Thus, the PSU faculty member created a graduate level technical elective focused on SBD which will serve both as a stand-alone course, as well as a complement to current course offerings. This course will introduce students to the benefits of incorporating safeguards considerations into facility planning. The challenges associated with SBD will also be covered, including conflicting needs and costs. The students will gain a deeper understanding of the different aspects of SBD and the need for thorough analysis, critical thinking, and flexibility. SNL is home to experts in nuclear safeguards, covering areas from technology development to model and simulation development to training and education. An example of SNL's capabilities directly relevant to SBD includes the Separation and Safeguards Performance Model (SSPM), which is a powerful tool for safeguards design for processing facilities [3]. Access to the SNL nuclear safeguards experts while creating course content resulted in a course with increased breadth and depth in the topic material compared to what would have been generated based solely on published information.

There were three primary goals associated with the development of this course: 1. provide students with a solid foundation and comprehensive knowledge of the concepts associated with SBD; 2. create a course relevant to nuclear engineering students and accessible for students in other fields of study; 3. emphasize interactive forms of learning. Achievement of the first goal will ensure students understand the challenges associated with SBD and are prepared to think critically about the various aspects which must be addressed. The second goal was selected to ensure the course is technically rigorous, but also provides an opportunity to engage with students outside of the nuclear engineering major. The creation of a course accessible to students in other departments, such as the School of International Affairs and the Department of Physics, will generate the opportunity to obtain a diverse set of view-points. Further, including students from various backgrounds will provide an introduction to the challenges and opportunities in nuclear safeguards related careers to students who may not be familiar with the topic. Finally, the third goal for the course aimed to address the fact that traditional, lecture-based courses are not

always the most effective means of promoting learning. Studies have shown that interactive learning increases retention and student interest in a topic [4, 5]. Therefore, this course was structured to be interactive, and centered around a Table Top Exercise (TTE), as described below.

The PSU faculty member had prior experience with course development, but creating this course under the guidance of an SNL mentor with expertise in SBD provided invaluable insight into the essential topics. The mentoring also included input on the best methods of material presentation, contributing to a stronger course. The influence of the mentor's input on the course development is illustrated through the evolution of topics included in the course syllabus, as shown in Table 1. As can be seen by comparing the early version of the syllabus (center column - Topics (Initial)) and the working version at the end of the faculty member's time at SNL (right column - Topics (Final)) the course topics were expanded and the concepts to be covered became more concrete. The SNL mentor was also able to provide resources, such as references and content for lectures. These contributions provided a broader, more comprehensive base for the course. The tangible effect of the additional resources is evident in the updated course topics. The most important changes to note are the addition of more technical topics, such as statistics and material unaccounted for (MUF) calculations, and the inclusion of current SBD issues of interest, such as cyber security. The technical topics will increase the students' understanding of the challenges associated with safeguards related measurements, which will be essential whether their careers take them into technical or policy related fields. The addition of a module on current topics will ensure the course remains relevant, and that students are introduced to the challenges associated with emerging safeguards related threats.

Week Starting	Topics (Initial)	Topics (Final)
20-Aug	Introduction, Safeguards vs. Security	Introduction, Safeguards vs. Security
27-Aug	Policy and Facilities	Policy and Facilities
03-Sep	Labor Day. Safeguards Technology	Labor Day. Safeguards Technology
10-Sep	Safeguards Technology	Statistics, Process Monitoring
17-Sep	Safeguards by Design, Case Study	Process Monitoring Example, MUF Calculations
24-Sep	TTE	SBD, Exam 1
01-Oct	TTE	TTE Introduction, SBD Case Study
08-Oct	TTE	TTE, TTE, Economics
15-Oct	Project Introduction	TTE, Simulations, Simulations Example
22-Oct	Safeguards for Nontraditional Manufacturing	TTE, TTE, Advanced Facilities (SMR, Molten Salt)
29-Oct	Advanced (Future) Facilities	TTE, Safeguards for Advanced Facilities
05-Nov	Safeguards for Advanced Facilities	TTE, TTE Conclusion, Safeguards and Cyber Security
12-Nov	Project Updates, Exam 2	Cyber Case Study, Exam 2
19-Nov	Thanksgiving Holiday	Thanksgiving Holiday
26-Nov	Projects	Assessment of TTE
03-Dec	Project Presentations	Final Topics

Table 1. Initial and final course schedule for the SBD class developed as part of the mentoring program.

In addition to guidance on the course topics the SNL mentor also facilitated meetings with other experts relevant to the course development. This included meetings with experts in TTEs and cyber security. As a result of these meetings the TTE was expanded and additional case studies and interactive components were added. The original course structure included one case study. The course currently includes four case studies (including one specific to cyber security) which will be used as in class analysis exercises. Student engagement and active learning opportunities were course priorities from the outset of planning but translating those priorities into tangible course components was challenging. The input from SMEs at SNL directly resulted in the inclusion of interactive process monitoring examples, the addition of a treaty negotiation exercise, and the development of the TTE. The treaty negotiation exercise was added to help students understand the benefits and limitations of treaties, and the challenges associated with their negotiation. While the TTE was always planned to be included, at the beginning of the professor's two weeks at SNL it was a concept without concrete structure. It was developed and modified as a result of meetings and knowledge gained at SNL into a project which will be the focal point of the course.

An overview of the TTE is shown in Figure 2. This exercise will span the second half of the semester and will provide students with the opportunity to apply what they have learned from lectures and other exercises. There will be two teams (two sets of two if warranted by the class size) acting as two different parties in the implementation of safeguards for a specified (fictitious) facility. One team will be given an ulterior objective, which they will need to achieve without detection. The exercise will cumulate with an individual assessment of the teams' plans and results. The exercise will produce guided and independent learning opportunities related to

both policy and technical considerations, which will enable students to actively participate in the course.

Figure 2. Table top exercise summary for the SBD course.

SBD Table Top Exercise Outline

Objective:
Design and implement safeguards for a facility (to be specified) in a non-nuclear weapon state.

Overview:
Exercise moderators:
Professor, TAs

1. Determine realism of measurement requests and responses
2. Provide teams with information based on requests
3. Provide feedback to both teams

Teams:

Blue Team: IAEA	White Team: State
Assess and approve safeguards plans submitted by the White Team a. Request changes b. Assess the probability of detecting a diversion	Develop plans for inclusion of safeguards during the construction phase a. Respond to Blue Team requests
Identify measurements that will be made a. Type and frequency	Evaluate cost
Establish procedures a. Operational b. Response to suspicious results	Provide requested measurement results
Evaluate response times	Provide Blue Team access as required a. Consider your rights vs safeguards and reporting obligations

Final Evaluation:
Individual exercise evaluation

The course material was developed with consideration for future modifications. Changes to the assignments, other TTEs, and updates to the lectures were all considered during the course development. There are plans to include SSPM modules for student assignments in future courses, as well as to explore the inclusion of a computer-based TTE. These future modification considerations are the direct result of the opportunities that arose as part of the SNL mentoring program.

The SNL mentoring program enabled the three initial goals for the course development to be achieved. Input from SMEs ensured the course topics covered the concepts necessary for SBD. Resources provided by the SNL mentor were leveraged to produce a technical course accessible for students with a variety of backgrounds. And finally, meetings with TTE experts were utilized to develop an interactive course with future flexibility.

3.2. Unmanned Robotic Systems for Safeguards Applications

While at SNL, the VCU faculty member developed curriculum on the use of unmanned robotic systems for safeguards and related applications. SNL has a concentration of experts regarding all types of unmanned robotic systems, including air, ground, and underwater. They have conducted research on topics such as how UAS pose a potential threat to nuclear facilities [6] as well as how they can be used to help safeguard uranium mines [7]. In addition to the depth and breadth of knowledge, SNL has advanced capabilities to fly and drive multiple types of unmanned systems of different size and applications.

Due to the fixed budget of the International Atomic Energy Agency (IAEA) and the expanded use of nuclear technology globally, there is a significant need to reduce the costs of safeguards on a per facility/country biases. The use of unattended monitoring systems and satellite imagery has already been implemented and has reduced operational costs of the IAEA [8]. Like many sectors, such as automotive manufacturing, the safeguards community is interested in the potential of unmanned robotic systems to reduce the human capital needs to safeguard a facility/country. These systems include air, ground, surface water, and underwater based locations. The curriculum also includes currently used vehicles and sensors, and the applications which they support. Examples of these applications include declared site evaluations and Design Information Verification using UAS. These systems could include high resolution and hyperspectral imagery as well as LiDAR to identify unexpected structures or components. Included in the curriculum is the capability of current sensors and analyses methods, such as image reconstruction to create a 3D model of the photographed location and the spatial resolution of the 3D model. Challenges and potential solutions to these types of measurements are also included. One such challenge is the dangers posed by UAS within a confined space, with currently available potential solutions being a collision cage around the UAS or advanced obstacle avoidance software and hardware on the UAS [9].

Another example area that the curriculum covers is environmental sampling and how unmanned robotic systems can be utilized. Air samples can be collected at different locations and altitudes using a UAS. This potential capability is compared and contrasted to air sampling done by the

Comprehensive Test Ban Treaty Organization as well as post-detonation nuclear forensics air sampling approaches. Environmental sampling can also potentially be performed by unmanned water craft and underwater systems. These systems would allow for water sampling of lakes, rivers, and other bodies of water. These samples could be collected at various locations and depths without the need to acquire a boat to carry the person doing the sampling to the various locations or water depths. Applications of this technology extend beyond safeguards and into the realm of safety and security, thus highlighting the unity of the "3S" approach to nuclear energy education [10].

The primary focus of the developed curriculum was to educate both graduate and undergraduate students about the current technology of unmanned robotic systems and their potential applications to safeguards. Due to the diverse use of unmanned robotic system, the developed curriculum has broad appeal to many disciplines thus broadening the number of currently taught courses that this curriculum can be integrated into. The technology in this curriculum also has applications to nuclear safety, security, and forensics, thus further broadening the number of courses that can benefit from this curriculum development. The current list of courses within the Department of Mechanical and Nuclear Engineering at VCU which could benefit from the developed curriculum include:

- EGMN 355 – Radiation Safety and Shielding
- EGMN 491 – Radiation Measurement Laboratory
- EGMN 574 – Nuclear Safeguards, Security and Nonproliferation
- EGMN 591 – Nuclear Nonproliferation
- EGMN 591 – Nuclear Safeguards Measurements and Simulation
- EGMN 591 – Security Science

It should be noted that while many published references where used in the develop of this curriculum, the work of A. Hackett and J. Hayward [9] and L. Boldon et al. [11] were of most relevance.

4. FACILITY TOURS AND MEETINGS WITH SMES

In support of the program goals, three SNL facility tours were organized for the faculty members. These tours were designed to build potential collaborations and provide real-world examples of safeguards and related technologies in practice.

Tech Area V was the first facility to be toured. Several training facilities, including shipping/receiving, control room, and processing facility, were included in the tour. The Tech Area V training is focused on security systems, but discussions for how they could be synergistically used to support safeguards took place, as well as conversations about future training opportunities. The tour also included discussions about considerations and lessons learned for active training implementation. In addition to providing insight into training development, the tour also sparked conversations about the possibility for future student tours and educational opportunities.

The next facility to be toured was the Technology Training and Demonstration center. This facility houses real-life systems developed by SNL to combat chemical, biological, radiological, and nuclear proliferation and terrorism. Several of the more nuclear focused systems are included in the developed curriculum and offered the faculty a hands-on experience to better describe the theoretical and practical use of these technologies. The technical expert guiding the tour provided information and answered questions about system use, practicalities of fielding technology, and policies.

The last facility that was toured at SNL was The National Solar Thermal Test Facility, shown in Figure 3. At this location, the faculty learned about the needs of carbon free sources of energy, the size of industrial solar facilities, and the challenges associated with operations at industrial sized facilities. Of particular interest was the use of UAS at this facility to improve operation efficiency and reduce costs. Benefits and concerns with the use of UAS at this facility were studied and experienced first-hand to better understand their potential safeguards use at nuclear sites. Information from this tour was directly implemented into the curriculum on the use of unmanned robotic systems.

Figure 3. Pictures of the faculty members and two SNL mentors at the SNL National Solar Thermal Test Facility. *Left: Alexander Solodov, left-middle: Natacha Peter-Stein, right-middle: Azaree Lintereur, right: Braden Goddard.*

5. FUTURE COLLABORATION

In addition to the opportunity to develop curriculum, this program also had the benefit of expanding each faculty members' safeguards knowledge and broadening the safeguards knowledgeable contacts they have at SNL. These contacts will be vital for safeguards related educational projects, as well as future research projects. As a result of the connections made through this program, the faculty have written two joint proposals with SNL and are in the process of developing a third. These projects, if funded, will not only expand safeguards capabilities and related applications, but will also help support a pipeline of safeguards knowledgeable graduate and undergraduate students to fill personnel needs. Finally, in addition to strengthening the relationship between the universities and SNL, this program also produced a stronger connection between the PSU and VCU faculty members. There are immediate plans for joint educational opportunities, including an INMM student chapter workshop in 2020 and student nuclear facility tours in 2020 and 2021.

SUMMARY

This program was an incredibly valuable experience for the faculty, both of whom are from universities without an established mentoring program in the field of international safeguards. This program offers these faculty an opportunity to expand not only their teaching curriculum, but also their own knowledge in international safeguards and their network of potential collaborators. The flexibility to develop a full course or a module to be applied to multiple courses was appreciated by the faculty members, and helped them meet their own institutional needs. The educational content that was produced as part of this program is stronger than what would have been generated by the individual faculty, which will benefit the students who take the courses that contain this material. It is the recommendation of the faculty members that this program continue to be funded to support junior faculty without established international safeguards mentoring programs. Future expansion of this program to include specific mentoring in the other tenure metric areas, such as proposal writing and research program development, would also be highly beneficial to the success of faculty who focus on international safeguards.

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