Advanced Nuclear Security Engineering at the University of New Mexico

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Abstract: With support from Sandia National Laboratories (Sandia), Los Alamos National Laboratory (LANL) and sponsorship from the National Nuclear Security Administration's Office of International Nuclear Security (NNSA/INS), an Advanced Nuclear Security Program is being piloted at the University of New Mexico (UNM). This program focuses on educational foundations, research opportunities and professional development opportunities within the nuclear security discipline. This effort is based on the need for a dedicated program to educate the next generation of nuclear security experts to meet obligations for both domestic and international nuclear security enterprises and expand engineering design principles to the design and implementation of nuclear security systems. This program aims to address a lack of structured nuclear security disciplines and fill a gap facing those now finishing post-secondary education. Current program plans are structured on the foundation of several core courses—including the theory and practice behind international and domestic nuclear security, the design principles behind nuclear security systems, and a hands-on, practical course aimed to provide experience implementing technologies and practices in nuclear security systems. Completion of this program will also include additional, elective courses that may be aligned with an element of nuclear security, including but not limited to: cybersecurity, nuclear power plant safety, weapons of mass destruction and nonproliferation, nuclear materials accounting and control, and more. In addition, this program will also focus on academic-quality research and development across the various elements within the discipline of nuclear security. For example, this education and R&D nexus can support such research in fundamental areas of nuclear security as novel approaches to insider threat mitigation, optimizing the relationship between nuclear security and safety, and incorporating security into advanced reactor designs. This program will also be unique in its structure with the addition of a professional development course—modeled after intensive, in-residence, executive style programs and intended to serve a wider audience of non-traditional students—offered during summer sessions. This Advanced Nuclear Security Program is focused on educating the next generation of nuclear security experts through the fundamental principles of nuclear security.

This paper will describe the structure of the piloted Advanced Nuclear Security Program at UNM. This paper will then illustrate the three pillars of the program and how they help meet a variety of stakeholder objectives. Lastly, this paper will discuss current implementation efforts under each pillar, lessons learned at this stage of the program, and implications for the program's future evolution.

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Introduction

Nuclear facilities are facing an evolving and dynamic threat environment, which creates an increasing and timely need for experts in the field. For example, the International Atomic Energy Agency has offered guidance on crafting educational programs in nuclear security since 2010(1). In response, Sandia National Laboratories (Sandia) in collaboration with Los Alamos National Laboratory (LANL), and funding from the Office of International Nuclear Security (INS) has partnered with the University of New Mexico (UNM) to develop a unique nuclear security engineering program. From its origins, this program will create a pipeline of credentialed students into nuclear security professions; provide university-based options for onboarding or on-the-job training; advance technical and socio-technical solutions for nuclear security; and, each stakeholder in meeting their respective nuclear security missions.

Program Framework Overview

This program has been developed on three key design principles: local, strategic, and collaborative. The first design principle, ***local***, indicates that this program will focus on high-quality, in-residence education and professional development that best leverages close proximity to the technical and research capabilities of Sandia and the partner university. The second design principle, ***strategic***, indicates that this program will make decisions centered on ensuring that the program is "demand-driven" by students, and nuclear security professionals, and self-sustaining within five years. Lastly, the third design principles, ***collaborative***, indicates that initiating and shepherding program success is predicated on sharing financial, human capital, and intellectual content resource burdens to maximize strengths of each stakeholder. Taken together—based on previous experiences—these design principles provide a navigational guide to help orient and align the program with the needs of the nuclear security profession (3).

In addition, these design principles also help coordinate the objectives of the program's stakeholders. To steer the program toward success, clear and coordinated roles and responsibilities have been identified for each stakeholder. For example, Sandia and LANL as co-implementers, have such responsibilities as: providing dedicated staff for program management and development, developing curriculum, delivering courses, leading/supporting research, advising graduate students, negotiating engagement with/participation from U.S. government entities, and championing all elements of the program with various stakeholders (e.g., domestic and international agencies). Similarly, the partner university as a co-implementer, has such responsibilities: providing a dedicated faculty member for program management and development, developing curriculum, integrating this program other areas of study, delivering courses, leading/supporting research, advising graduate students, championing all elements of the program with various university-related groups (e.g., faculty and students), and exploring university-specific funding opportunities. Lastly, NNSA/INS as a primary sponsor, has such responsibilities as: providing sustained financial and programmatic support and advising on program development. In return, NNSA/INS gains tools to meet its engagement mission and internal staffing needs, as well as potential international academic outreach and support.

This academic program is designed to be built on three pillars and can be seen in Figure 1.

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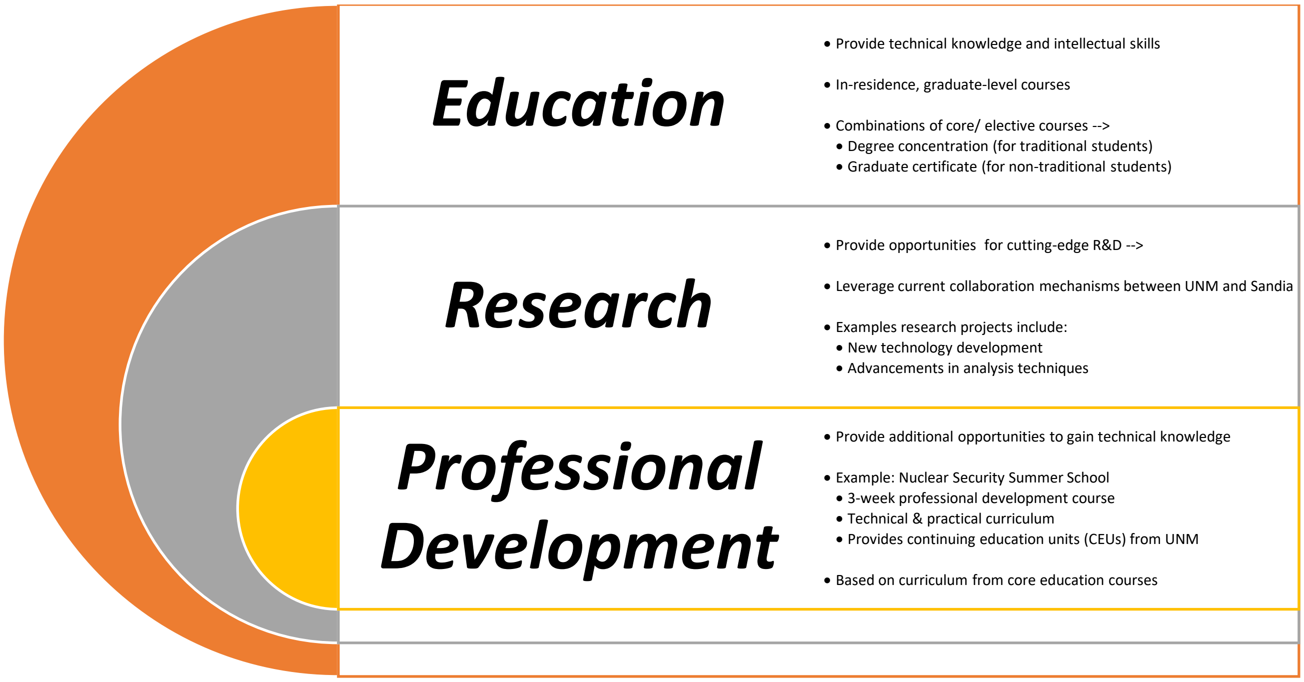

Figure 1 Three Key Pillars

Education Pillar

The primary focus of the educational pillar has been the development and instruction of two core courses. The "Nuclear Security Theory & Practice" course is the fundamental core course under this program and was piloted in the Spring of 2020. The "Advanced Nuclear Security System Design and Analysis" course was piloted in the Spring of 2021.

This program focuses on creating credentialed students at the end of their graduate career. A credential would include students earning credits in two core courses and two elective courses to gain a graduate credential. This can be seen in the figure below.

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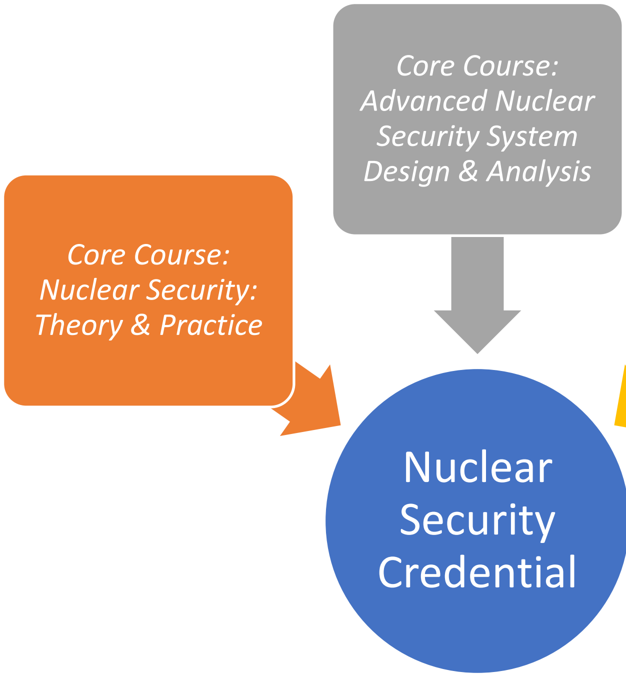

Figure 2 Education Pillar

Nuclear Security Theory & Practice

Each meeting of this seminar-style course is divided equally into three sections. In the first section, one of the primary instructors provided a comprehensive overview of the weekly topic, which often included historical context, analytical foundations/assumptions, current capabilities/ applications, and gaps/areas for growth. In the second section, students actively discussed topical readings—which included relevant academic journal papers, laboratory publications, and open-source news articles which were read *before* class—which provided the students with insights into new and developing research in the weekly topic, advancements and current applications of the topic, and served to enhance the technical understanding of each weekly topic. In the final section of each class, a Subject Matter Expert (SME) provided a guest lecture on some element of the weekly topic. This course began by building a foundation for nuclear security based on historical connections to nuclear safety, different philosophies underlying security, and on understanding/assessing threats to nuclear facilities. Given the importance of non-technical aspects influencing technical security requirements, this seminar also introduced students to the international recommendations and domestic regulations that guide security design and operations at nuclear facilities. The course then transitioned into more traditional, technical approaches to nuclear security to help establish the current "state of the art." Once established, the conversation naturally turned toward what capabilities or operations aspects challenge the efficacy and efficiency of these current state of the art approaches. Finally, the course ended with several discussions on how options for evolving current state of the art of practices to better mitigate these new challenges.

Table 1 Nuclear Security Theory & Practice Topics.

Course Theme	Class	Topic
Core Concepts for Nuclear Security	1	Introduction to Nuclear Security: From "theory" to practice
	2	Threats to Nuclear Security: The Identification, Assessment, Mitigation Loop
	3	Nuclear Security: Gates, Guards, & Guns

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Policies & Best Practices in Nuclear Security	4	International Best Practices for Nuclear Security: Challenges & Opportunities
	5	US Best Practices for Nuclear Security: Comparing DOE & NRC perspectives
	6	Nuclear Security Case Studies
Current Context & Capabilities for Nuclear Security	7	Physical Protection System Design: A DEPO-Based Perspective
	8	Nuclear Material Accounting & Control: Support for Nuclear Security
	9	Modeling and Simulation
Challenges to Current Nuclear Security Approaches	10	Unmanned Aerial Systems
	11	Cyber & Digital Challenges
	12	The Role of Humans in Nuclear Security
Future Capabilities & Needs	13	Advancements in Vulnerability Assessments
	14	Physical Protection System Design: A "beyond-DEPO" perspective

The students had a series of four assignments. The first three assignments built to the fourth assignment. This final assignment focused on students identifying vulnerabilities within a hypothetical nuclear facility and identifying methods to mitigate these vulnerabilities. These assignments prepared students to take the "Advanced Nuclear Security System Design and Analysis" course.

Course Effectiveness

To evaluate the effectiveness of this "Nuclear Security: Theory & Practice" course, Sandia generated a specific course survey to gather student opinion on course delivery, appropriateness, and applicability. Of the 18 students registered in the course, nine students answered the survey given. Of the nine answers, four students were undergraduates, three were graduate, and two were non-traditional students. The table below highlights some of these results.

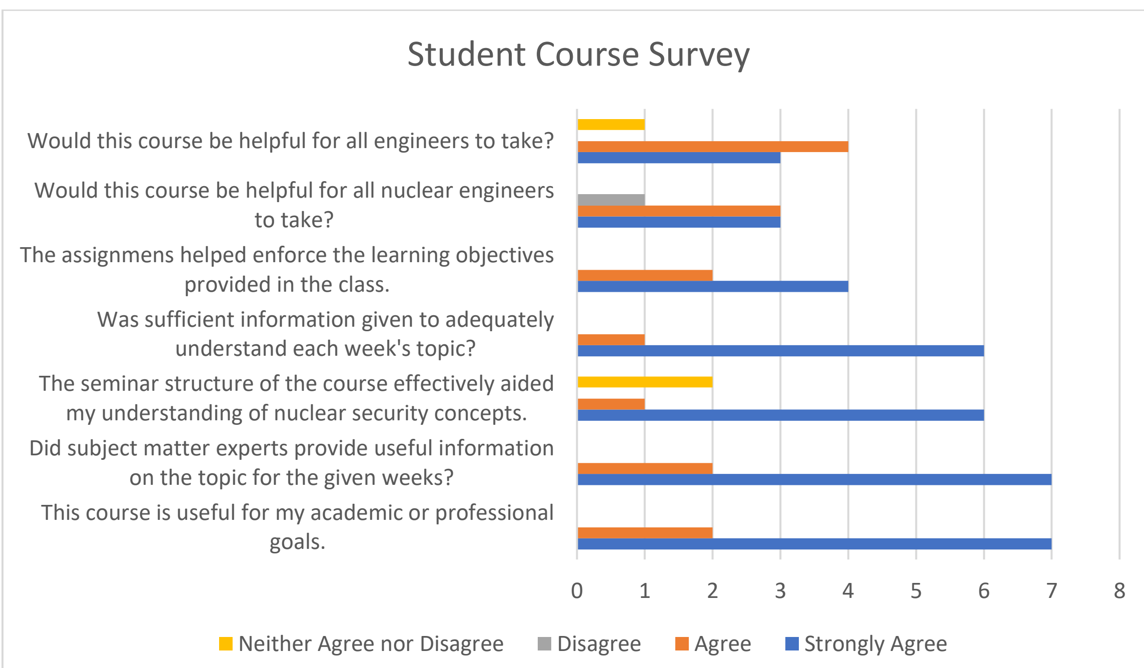

Figure 3: Student survey results.

Based on the results from the student surveys the students who took this class believed this course was beneficial to both their academic and professional goals. This shows the added benefit to students of

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improving their academic experience and created a course that lends to their success in their academic and professional careers. Students also tended to agree that both nuclear engineering students and other engineering discipline students would benefit from taking this course. Based on these results and the wide technological breadth of nuclear security, this course would be impactful to multiple engineering disciplines. Students also conveyed in their survey that the two primary instructors and the guest lecturers effectively delivered information and context that contributed to their understanding of the core nuclear concepts. Students conveyed through the survey that Modeling and Simulation and Physical Protection System Design: A "beyond-DEPO[1]" perspective were the two topics that the students would have liked more time spent on in class. In the Modeling and Simulation portion of the class, students were exposed to a variety of modeling and simulation methods and tools. Modeling and simulation tools were taught as design and analysis tools for physical protection systems. The Physical Protection System Design: A "beyond-DEPO" perspective section was designed to create critical-thinking based on the new threats that nuclear facilities face and the potential gaps in the existing DEPO methodology. Students were exposed to some solutions and new iterations of the DEPO methodology that can lead to addressing the new threats and challenges that nuclear facilities face. From these student responses, students are very interested in learning more information on tools for design and analysis, solutions and methodologies for improving security system designs, and solutions and methodologies for securing facilities against new and advanced threats that nuclear facilities face.

Advanced Nuclear Security System Design and Analysis

This course is considered one of the core courses within the developing academic nuclear security program. This course will serve as an advanced, comprehensive overview of principles, concepts, technologies, and practices used in designing and analyzing nuclear security systems. Design applications will include traditional nuclear power plants (NPPs), Small Modular Reactors (SMRs), Research Reactors, and Fuel Processing Plants, in both domestic and international contexts. This course aims to emulate a typical engineer's working environment in the nuclear security domain. Students will be exposed to interdisciplinary engineering methods to address problems with no closed-form solutions and develop nuclear security designs from an understanding of key technical, geopolitical, social and economic aspects. The course topics by week can be seen in the table below.

Course Theme	Week	Topic
Introduction & Context	1	Nuclear Security Design & Analysis: Core Concepts
	2	Nuclear Security Design & Analysis: Setting the Operational Context
	3	Nuclear Security Design & Analysis: Evaluation Techniques
Deriving Technical Performance Requirements	4	Deriving Threat-Related Requirements
	5	Designing to Meet Detection Requirements
	6	Designing to Meet Delay Requirements
	7	Designing to Meet Guard and Response Requirements
	8	Designing to Meet NMAC Requirements
	9	Addressing Performance Challenges
	10	Mid-Semester Briefs

[1] The "Design Evaluation Process Outline (DEPO)" is a security design framework developed by Sandia in the early 1980s [Mary Lynn Garcia Book]. DEPO is a globally accepted framework and serves as the de facto "standard" for nuclear security applications.

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Evaluating Nuclear Security Designs	11	Path Analysis Techniques
	12	Vulnerability Assessment Processes
	13	Emerging Challenges
	14	Final Design Briefs
	15	Final Design Briefs

Course Assignments

This class provided students quizzes throughout the semester to reinforce learning objectives. The remaining of the assignments focused on the course final project. The final project for this class included a security system design, an evaluation of their system effectiveness, a budget estimate for the cost of their security system, as well as considerations for defending against emerging threats (e.g. UAS and cyber-attacks). For the final project in the course, students were allowed to site a hypothetical nuclear power plant, research reactor, or small modular reactor anywhere in the world. Students were asked to site their reactor based on expressed interest or need for their facility within that region. Students were then asked to develop the following through the design process

1. A threat assessment or design basis threat,
2. Design a security system according to regulations within the country the facility was sited,
3. Design a system that defended against the threat posed to the facility,
4. Conduct path analysis to determine probability of interruption in PathTrace©,
5. Conduct tabletop exercises to determine guard and response force effectiveness, and
6. Determine the cost for their security system design.

The final projects were then presented to a group of subject matter experts to review the work that had been completed throughout the semester.

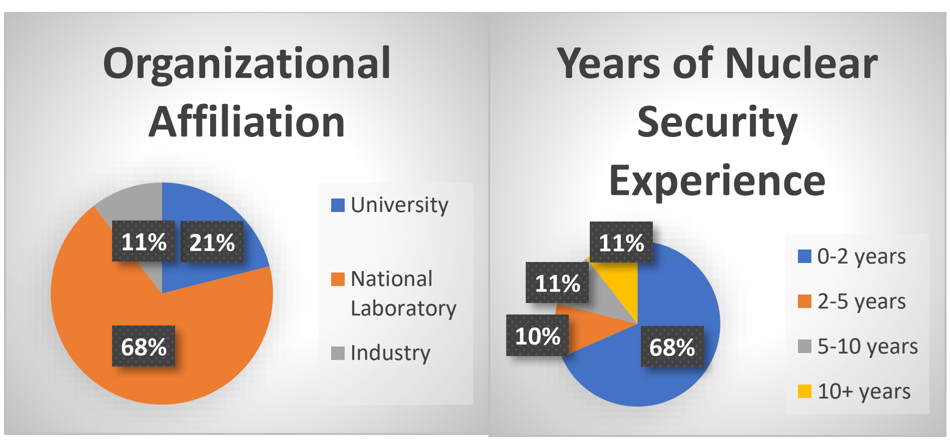

Figure 4: Student Background

Next Steps and Vision of Success

The UNM Nuclear Security Program has had many successes in the last year. To continue the success of this program, there are next steps needed to ensure the integrity of the program. These next steps focus on the three key pillar areas of the program, education, research, and professional development.

The next steps in the education pillar include, but are not limited to

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- Conducting the Nuclear Security Theory & Practice and Advanced Nuclear Security System Design and Analysis courses in following semesters to develop a proper program structure
- Conduct the Advanced Nuclear Material Accounting and Control Course in the Fall of 2021 (will be the first elective course in the program)

The professional development pillar of this program will expand in 2021 by hosting the “Nuclear Security Summer School (NSSS).” The NSSS will be a professional development-based course aimed to educate domestic and foreign academic faculty members, domestic and foreign nuclear security professionals, and professionals transitioning or interested in understanding nuclear security. The focus will be based on condensing course content from the two core educational courses into two-weeks of in-class learning, and one hands-on week of training held jointly at Sandia and LANL.

Due to the COVID-19 pandemic, the NSSS will be hosted virtually from July 19-30, 2021. The virtual delivery of the summer school will allow for professionals from the international community to easily access this professional development opportunity.

The research pillar will continue to grow over the duration of the course. Furthering the research pillar is a large goal of the program. The research pillar will focus on leveraging existing research opportunities and generating new research ideas through research webinars.

The research pillar under this program has seen success by having students in the nuclear security program be involved in research projects ongoing at Sandia. This process will be expanded upon to create research opportunities for UNM faculty and students. Leveraging existing funding sources and UNM faculty and student expertise areas will create an effective link to nuclear security related research.

Additional research webinars will be held between UNM and other national laboratories. A research webinar was held in 2020 that allowed for UNM faculty, Sandia experts, and LANL experts to understand the security related research ongoing. Many topics were discussed and explored for future collaboration. In the future, webinars are being planned between UNM and other national laboratories to expand potential research collaboration for UNM students and faculty.

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