Lessons Learned from Developing the Graduate Nuclear Security Curriculum at the Kyiv Polytechnic Institute Primary

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Abstract. As nuclear fuel cycle activities grow and the amount nuclear material increases worldwide, there will be a similar increasing need to more deeply incorporate nuclear security knowledge, skills, and abilities into nuclear energy workforces across the globe. To address this need, the International Atomic Energy Agency (IAEA) has provided NSS No. 12—Education Programme in Nuclear Security—as a technical guidance document and has created the International Nuclear Security Education Network (INSEN) to facilitate development and implementation of such programs. While both this best international guidance and voluntary engagement network establish a strong foundation for creating an educational capability in nuclear security, each individual nation is responsible for crafting such programs that both meet their specific needs and align with their national educational systems.

In response, the Ministry of Energy and Coal Industry of Ukraine has partnered with the U.S. National Nuclear Security Administration's International Nuclear Security (NNSA/INS) program to develop a graduate curriculum in nuclear security at the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" (KPI). The main criterion of the choice of KPI is the availability of a laboratory base in Kyiv (in the center named after George Kuzmich) and the research reactor BVV-M at the Institute of Nuclear Research of the National Academy of Sciences of Ukraine, which can be used to prepare students. The Ukrainian government also agreed with this approach. Over the past several years, KPI professors have interacted with subject matter experts in multiple nuclear security-related topic areas from both NNSA/INS and Sandia National Laboratories (Sandia) to discuss how to build, implement, and maintain a nuclear security education program. These discussions have leveraged both IAEA-based guidance, Sandia expertise, and KPI's education mandate to identify and develop courses in nuclear security-related topics to help meet the needs of Ukraine's nuclear energy sector. With the support of their various governmental stakeholders, the KPI professors have diligently and effectively crafted a nuclear security curriculum that meets academic requirements across a variety of traditional disciplines, including engineering, physics, chemistry, and political science. Officially launched in the Fall semester of 2019, the KPI graduate program in nuclear security will provide a sustained source of human capacity development and education to meet national and regional nuclear security needs.

This paper will first review the history of collaboration between KPI and NNSA/INS and introduce how these engagements helped shape the progression of the curriculum and the professional development of the program's professors. Next, the structure and description of KPI's nuclear security program will be described, including a summary description of each course and how the learning objectives of each course correspond to the overall goals of the program. Lastly, the paper will provide several lessons learned—from both development process and from the initial implementation stages of KPI's curriculum—to inform (and, hopefully) assist other nations embarking on developing nuclear security education programs.

Key Words: Nuclear security, education, INSEN, professional development

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1. Introduction

Terrorist activity during the late 20th and early 21st centuries went beyond the borders of individual countries and gained international character, moreover, states that were recognized as terrorists by the international community appeared on the map of the globe. Terrorist organizations, first and foremost international ones, seek to obtain weapons of mass destruction, including nuclear weapons. After September 11, 2001, no one should have any doubt that having received such a weapon would be used by terrorists. Almost daily, the mass media report about terrorist acts in one country or another, or terrorist acts at the same time in several different countries. Of great concern to the international community is the possibility of sabotage of nuclear installations and other radiation-hazardous objects, followed by the release into the environment of large quantities of radioactive materials, which will be accompanied by significant exposure of personnel, the public and radioactive contamination. Terrorists can seize separate nuclear facilities and hostages in order to induce the state or individual public authorities to take some action in their interest.

Considering these challenges, provision of education, retraining and advanced training of personnel in the field of nuclear security is of fundamental importance for Ukraine. Preparing the next generation of Ukrainian nuclear security is uniquely important considering:

- Ukraine has recently experienced terrorism operations, resulting in significant amounts of uncontrolled armament in/through the country;
- Ukraine has 15 nuclear power reactors, 1 research reactor, and spent fuel from 13 VVER-1000 reactors stored on its territory;
- There is damaged unit #4 of the Chernobyl Nuclear Power Plant (NPP), with spent fuel of Units 1, 2, 3, and 4 and tremendous amounts of other radioactive wastes from the accident stored in the northern part of the country;
- Radioactive Ionizing Sources are widely used in the industry, medicine, geology and scientific researches that produce significant amount of radioactive wastes too;
- Territory of the Ukraine is used for transportation of radioactive materials, including transit of both fresh and spent nuclear fuel; and,
- Universities did not provide the education of the experts in area of nuclear security.

To address this need, the International Atomic Energy Agency (IAEA) has provided Nuclear Security Series (NSS) No. 12—Education Programme in Nuclear Security—as a technical guidance document [1] and has created the International Nuclear Security Education Network (INSEN) to facilitate development and implementation of such programs. While both this best international guidance and voluntary engagement network establish a strong foundation for creating an educational capability in nuclear security, each individual nation is responsible for crafting such programs that both meet their specific needs and align with their national educational systems. This paper will first review the history of collaboration between KPI and the U.S. National Nuclear Security Administration's International Nuclear Security (NNSA/INS) and introduce how these engagements helped shape the progression of the curriculum and the professional development of the program's professors. Next, the structure and description of KPI's nuclear security program will be described, including a summary description of each course and how the learning objectives of each course correspond to the overall goals of the program. Lastly, the paper will provide several lessons learned—from both development process and from the initial implementation stages of KPI's curriculum—to inform (and, hopefully) assist other nations embarking on developing nuclear security education programs.

2. Leveraging the IAEA Approach to Nuclear Security Education

Although meeting the generic security performance goals (e.g., detection, delay, and response) is consistent across nuclear facilities, implementation will differ between nuclear fuel cycle activities, as well as between countries (or regions) in which these activities take place. The resulting wide range of related professions within nuclear infrastructures requires a similarly wide range of different academic approaches to nuclear security. When one of the authors participated in consultancy meetings to revise and update NSS-12 [1], it became clear that the needs facing the nuclear security discipline expand well beyond the traditional focus on "gates, guards, and guns." Most obvious are the security jobs related to more technical academic disciplines, like physical protection system designer or inspector; vulnerability analyst; physical protection system implementation or maintenance; or system component research and development. But, there are also a range of nuclear security–related jobs that relate to social science academic disciplines, like security policy development; security performance requirements writing; inspections; and threat assessment. Lastly, there is a need for security professionals with academic backgrounds in management, including facility security management and State-level security oversight and regulation. Figure 1, below, illustrates some common academic discipline-to-career field pathways related to nuclear security.

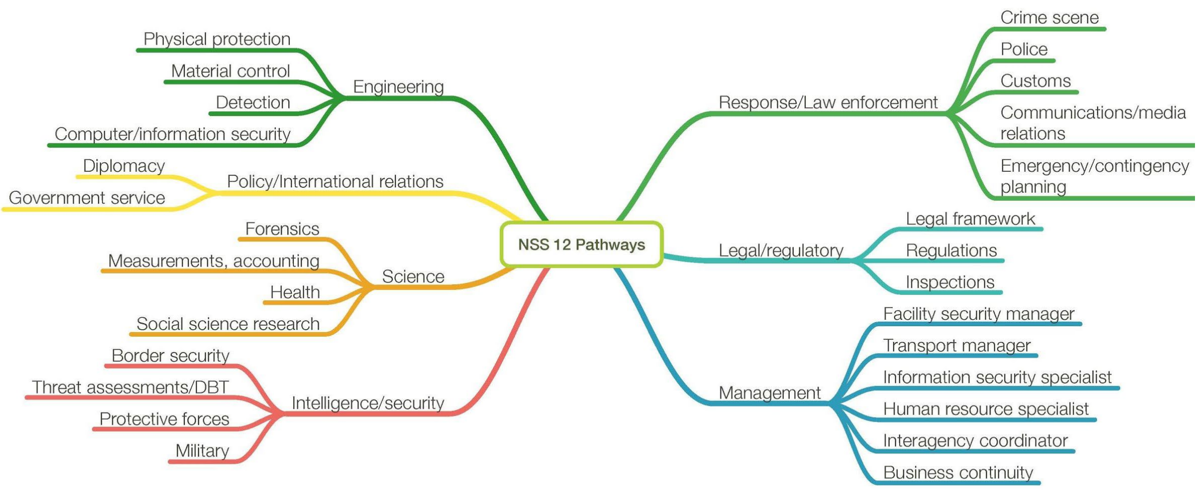

FIG. 1.Potential pathways from academic disciplines to nuclear security careers.[2]

To help meet these professional needs, nuclear security education should emphasize mastery of foundational concepts, basic principles, and underlying theory to understand nuclear security operations. To better appreciate the "why" of nuclear security, educational efforts typically involve a curriculum that provides a logical pathway for meeting high-level learning objectives. Traditional education addresses academic disciplines in depth but is not typically set up to handle cross-disciplinary organizations or functions. The evolution of education has left the practical application of these disciplines to industry, requiring early career professionals to make sense of the integration and how they work in a systematic manner.[2] In response, the IAEA has recommended nuclear security curriculum for a master's of science degree in nuclear security [1] that is currently being implemented at Brandenburg University of Applied Science's Institute for Security and Safety. Although an update to this Nuclear Security Series document is yet to be published, the recommended courses are shown in Figure 2. The International Nuclear Security Education Network (INSEN), formed with the support of the IAEA Department of Nuclear Security, assists in creating, sharing, and distributing curricula recommended in this figure and leave the implementation and scope of programs up to individual universities to use as they see appropriate.

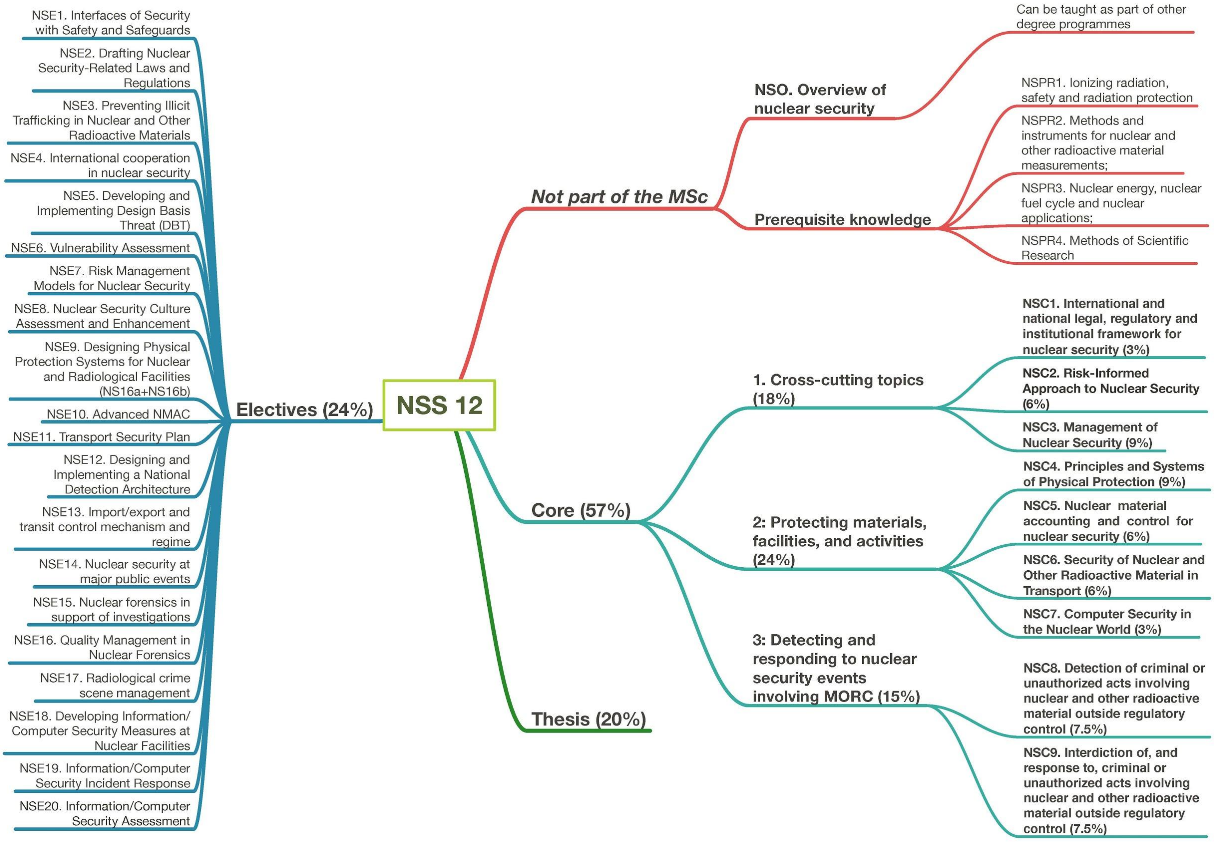

FIG. 2. IAEA recommended curriculum for master's in science in nuclear security [2]

3. Ukrainian Background for Nuclear Security Education

In the Ukrainian context, the number of nuclear security specialists under the responsibility of the Ministry of Energy and Coal Industry of Ukraine is more than 1230 people. In addition, the annual need for training specialists in higher educational institutions averages approximately 20-30 people. Yet, similar to Figure 1, the need for nuclear security expertise differs across domains. For example, the need for nuclear security specialists includes: Central executive authorities carrying out control and regulation in the field of nuclear energy (e.g., Ministry of Energy and Coal Industry of Ukraine and State Nuclear Regulatory Inspectorate of Ukraine); state law enforcement authorities and special purpose bodies (e.g., Security Service of Ukraine and State Border Guard Service of Ukraine); and, Government bodies (e.g., Cabinet of Ministers of Ukraine and National Security and Defense Council of Ukraine). In addition, there is a need for nuclear security expertise at such Ukrainian operators and licensees as:

- NNEG “Energoatom“ (including Energatom management and 4 , Ukrainian NPPs);
- State Specialized Enterprise “Chernobyl NPP”;
- Institute for Nuclear Research of National Academy of Sciences of Ukraine;
- National Science Center “Kharkov Institute of Physics and Technology of National Academy of Sciences of Ukraine;
- State Concern “Nuclear Fuel“;
- Ukrainian State Corporation “Radon“ (SSE “Donetsk SSC”, SSE “Dnipropetrovsk SISC”, SSE “Kyiv SISC”, SSE “Lviv SISC”, SSE “Odesa SISC”, SSE “Kharkiv SISC”, SSE "Complex"; Head Office);
- Ukrainian Production State Enterprise “Isotop";
- Medical facilities, which use sources of ionizing radiation.

In addition, *previously* the education of specialists in the field of Physical Protection, Accounting and Control of Nuclear Materials was carried out by Sevastopol National University of Nuclear Energy and Industry—but this university is located in the Crimea region and is currently not available to Ukraine. Thus, there was a *unique* and *significant* need to develop a nuclear security education option in Ukraine.

In response, at the request of the Ministry of Energy and Coal Industry of Ukraine—and in cooperation with the U.S. National Nuclear Security Administration’s Office for International Nuclear Security (NNSA/INS)—the James Martin Center for the Study of the Non-Proliferation "Monterey Institute of International Studies” (MIIS) identified issues and provided recommendations on the development of the educational potential in the field of nuclear security in Ukraine. This MISS report recommended National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" (KPI) as the optimal university to develop a "Nuclear Security" education program. The main criterion for this recommendation included: the availability of modern laboratory facilities in Kyiv (e.g., the George Kuzmycz Training Center for Physical Protection, Control and Accounting of Nuclear Material) and of the research nuclear reactor VVR-M at the Institute for Nuclear Research of National Academy of Sciences of Ukraine of Ukraine. KPI’s proximity to these venues indicate the potential for their regular use in teaching and training of students in nuclear security topics.

4. Development of the Graduate Nuclear Security Curriculum at KPI

The development of this nuclear security education began with a meeting of all interested stakeholders in Ukraine—including representatives of the NNEG “Energoatom“, Ministry of Energy and Coal Industry of Ukraine, State Nuclear Regulatory Inspectorate of Ukraine, Institute for Nuclear Research of National Academy of Sciences of Ukraine and KPI. As a result of this meeting, a preliminary list of courses to be developed was identified and specific KPI professors were selected to help develop this program. The next step was to further develop the nuclear security expertise within these professors via a *train the trainer* program. With the support of the NNSA/INS, a nuclear security education technical tour was organized and conducted for the KPI professors to Texas A&M University (TAMU) and Sandia National Laboratories (Sandia) from June 20 to July 15, 2016. This technical tour included lecture style briefings on various nuclear security topics; pedagogical issues and options for teaching nuclear security topics; and technical tours (for hands-on experience opportunities). The details of these activities are summarized in Table 1, below.

Table 1. Summary of Activities for KPI Professors during the 2016 Summer Nuclear Security Education Technical Tour

	Texas A&M University	Sandia National Laboratories
Tours/ Facilities	• Radiation Detection Laboratories • Disaster City (Emergency Operations Training Center) • Nuclear Science Center – TRIGA Research Reactor	• National Museum of Nuclear Science & History • Nuclear Forensics & Radiochemistry Laboratory • Sandia's Training, Technology & Demonstration Area • Test facilities at Security Equipment Performance Testing at TA-III & Access Delay Bunker • Virtual Tour of Integrated Security Facility (TA-V)
Nuclear Security Topic	• Nonproliferation & Arms Control (Course NUEN650) • Radiation detection & materials measurement (Course NUEN605) • Nuclear security system design (Course NUEN451) • Nuclear/Radiological Response and Consequence Management (Course NUEN689) • Nuclear fuel cycles and materials safeguards (Course NUEN651) • Radiochemistry & nuclear forensics (Course CHEM689) • Nuclear terrorism threat assessment & analysis (Course INTA669)	• Systems approach to nuclear security • Introduction to connections between security, safety & safeguards • International & national nuclear security obligations • Risk informed approaches to nuclear security • Radiation protection for security • Design and Evaluation Process Outline (DEPO) • Physical protection system (PPS) design • Nuclear material accountancy and inventory control for security applications • PPS evaluation and vulnerability assessment • Nuclear security culture & human factors influencing nuclear security • Insider Threat & Analysis Techniques • Security of nuclear materials in transit • Materials outside of regulatory control • Cyber security & its relationship to nuclear security • Differences in security design/analysis for different NFC facilities

After this summer technical tour, the collaboration between KPI, Sandia, and INS continued to support development of the curriculum. A majority of the correspondence was electronic and consisted of Sandia coordinating subject matter expert review of materials provided and answer professor questions. In addition, there were three in-person meetings in Kyiv to assess progress in detail. These in-person meetings—which included program structure development (Spring 2017), preliminary course curriculum review (June 2018), and post course development curriculum review (June 2019)—also included site visits to the campuses of both KPI and GKTC to tour several of the hands-on facilities intended to be used to support the nuclear security curriculum.

The culmination of these several years of engagements concluded the initial KPI train the trainer program coordinated the current state of the curriculum to all interested stakeholders in Ukraine. Based on experience gained during the "Kyiv Polytechnic Institute Nuclear Security Education Summer Tour" and feedback from Ukrainian stakeholders, the number of courses of the graduate nuclear security curriculum was reduced from 21 to 15 by collapsing several disciplines into one and combining several disciplines into one as separate modules. By March 2019, the plan was finalized to develop—and obtain all necessary approvals for—these new courses under the specialization "Nuclear Security."

5. KPI's Masters Program in Nuclear Security

The "Nuclear Security" masters program exists within the "Nuclear Energy" specialty within KPI's Nuclear Power Plants and Engineering Thermal Physics Department. Since KPI has a license to conduct educational activities on specialty «Nuclear energy», additional permits from the Ministry of Education and Science of Ukraine were not required. Nonetheless, in accordance with the legislation of Ukraine, it was necessary to obtain a license from State Nuclear Regulatory Inspectorate of Ukraine. Preparations for licensing began on time and on September 1, 2019 the president of the State Nuclear Regulatory Inspectorate of Ukraine officially handed over the license to university representatives.

To meet Ukrainian higher education requirements, this nuclear security specialization consists of 90 credits and is designed to be completed over two academic years. To meet these requirements, the 15 total nuclear security courses consist of nine core (#1-#9) and six elective (#10-#15) courses that span hard and soft science academic disciplines, summarized in Table 2 below. The courses themselves are composed of a mix of pedagogical approaches (e.g., lecture-based, seminar-based, and experiment-based courses) and incorporate a full range of student assessment tools (e.g., homework, quizzes, term papers, exams).

#	Title	High Level Objectives
1	Overview of nuclear security	• Introductory, standalone course • Overview of entire nuclear security field
2	International and national legal, regulatory and institutional framework for nuclear security	• understanding the prerequisites of nuclear security • general principles/concepts of developing documents/regulations • overview of the legal framework • Understanding the role of international organizations
3	Use of nuclear material accounting and control for nuclear security	• Describe NMAC functions at nuclear and radiological facilities and during transportation • Fundamental components necessary for developing/ implementing/maintaining effective detection strategies • Detailed description of radiation detection instrumentation and personal protective equipment, & emergency management
4	Developing and implementing Design Basis Threat	• Overview of threats to nuclear security • How to describe potential adversary groups, their intentions, capabilities and targets of interest • Conducting threat assessments • Developing, using and maintaining a DBT
5	Nuclear security culture	• Provide definition and history for nuclear security culture • Define the roles of States, organizations, managers, and individuals in promoting good nuclear security culture • Provide a model for elements of good nuclear security culture • Describe guidance on evaluating/improving the nuclear security culture of a facility or organization
6	Physical protection systems design and evaluation	• Discuss the fundamental principles of physical protection • Describe how to plan/implement the physical protection system (PPS) design process • Provide an understanding of the PPS and the possibilities of their application • Explain the main functions of the PPS and their interaction • Provide basic knowledge of PPS design and reliability assessment

7	Non-Destructive Assay of Nuclear Materials	• Provide fundamentals, approaches, technique and equipment on NDA • Discuss the fundamentals of nuclear radiation and its detection • Explore the basics of radiation detectors, counting statistics and spectra analysis
8	Information and computer security	• Discuss computer security related to nuclear security • Explore options for protection of sensitive and secret information • Provide principles for constructing/protecting computerized control systems of technological processes at sites with nuclear and other radioactive materials
9	Nuclear security management at national and facility level	• Provides an overview of the main aspects and principles of nuclear security management • Describe the features of stakeholder cooperation – including at the local, national, and international levels
10	Legal drafting for nuclear security	• Discuss the main components and elements of comprehensive national nuclear security legislation • Provide experience and knowledge necessary to develop and draft regulations and other documents related to nuclear security
11	System of Radioactive Waste Management	• Discuss common approaches and principles for the classification of radioactive waste • Provide a general overview of radioactive waste management systems in Ukraine and abroad • Explore concepts and requirements for radioactive waste disposal facilities
12	Nuclear Facility Vulnerability Assessment and Risk Management	• Provide information about risk management • Evaluate and optimize methods for physical protection systems evaluation
13	Preventing and protecting against insider threat.	• Describe the insider threats facing nuclear organizations • Analyze the complex nature of insider threats • Describe how organizations and individuals can secure themselves against this threat
14	Physical protection technologies and equipment.	• Provide an understanding of existing technical methods, sensors and tools • Learn how to choose the right equipment to meet the requirements for various physical protection systems
15	Management of Emergency and Crisis Situations at Nuclear Facilities	• Discuss features of crisis management and crisis response in the field of nuclear security • Describe the features of stakeholder cooperation – including at the local, national, and international levels

The first course that was developed was “Overview of nuclear security”. This is the only course we decided to take at the bachelor's level at the university. Such a decision was made to ensure that all students studying at the Department of Nuclear Power Plants and Engineering Thermal Physics at KPI were acquainted with the basics of nuclear security. Due to the fact that making changes in the educational process is a very difficult task from a bureaucratic point of view. In the 2017/2018 academic year course was included as a separate module (4 lectures) in the existing Nuclear Safety Culture course. In the 2018/2019 academic year course Overview of nuclear security was included as core course for all students studying at the department.

This approach enabled students to make informed choices about studying in the new master's program Nuclear Security. In parallel with the course, representatives of the University, with the support of the Ministry of Energy of Ukraine, conducted a wide advertising campaign. This approach, during the summer introductory campaign, allowed to attract 9 full-time students and 29 part-time students to enroll in the program that officially began in September 2019—demonstrating that this program meets the target populations.

6. Conclusions, Lessons Learned, and Future Challenges

The success of KPI's nuclear security masters program is a result of leveraging international best practices and bilateral collaboration with tacit knowledge of state-level needs and related implementation complexities. For example, the IAEA's NSS-12 provided a great start for scoping the topics included in the KPI program, but still needed to be tailored to meet Ukraine's own nuclear security-related requirements. Similarly, the strong collaboration between KPI, Sandia, and NNSA/INS successfully build the foundation for strong graduate-level education program in nuclear security. In addition, this bilateral cooperation—augmented by other resources provided by global nuclear security stakeholders—was instrumental in preparing a cadre of dedicated academic faculty to provide the courses associated with this KPI graduate program. Though it is still early in the lifespan of the program, KPI's nuclear security graduate program is oriented to successfully meet the security needs of Ukraine's nuclear enterprise and to serve as a model program for emulation by other states.

During this inaugural offering of the KPI nuclear security masters degree, lessons learned and insights gained will be documented for the dual purposes of continuous improvement of the program itself and for sharing as a resources for other programs. As the KPI program matures and evolves, expected future challenges are serves as targeted opportunities for improvement. For example, for any university that considers such a graduate program must be considerate of maintaining (and managing) student throughput. At minimum, such programs must attract enough students to meet university-based course viability requirements and state-level need for graduates. Though a challenge, this *also* presents an opportunity for such programs to remain at the cutting edge of the discipline and to seek appropriate opportunities to expand to meet regional nuclear security needs—both of which the KPI program has been oriented to do. Similarly, the need to continually build the theoretical expertise and practice experience for the KPI professors in nuclear security could initiate additional regional and global cooperation to support the masters program. Lastly, the KPI program—given that its host is a national technical university—is well positioned to incorporate research and development activities beyond those included as practical exercises within individual courses. And, with its strategic partnership with GKTC, KPI is positioned to push the cutting edge of academic R&D in nuclear security. By these leveraging these opportunities, this new KPI masters program can help increase the Ukrainian voice in the international discourse on nuclear security.

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