

# Nuclear Nonproliferation and Safeguards Education at TAMU: Embracing Novel Teaching Practices

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## **ABSTRACT**

The Nuclear Security Science and Policy Institute (NSSPI) has established a Nuclear Nonproliferation specialization for the Master of Science degree within the Nuclear Engineering Department at Texas A&M University (TAMU). Since 2004, twenty-six students have received MS degrees in this area and over 200 (technical and political) students have taken classes offered by NSSPI at TAMU. If not currently pursuing doctoral degrees, graduates of the program have since begun careers at national laboratories, private industry, the intelligence community, power utilities, and academia. Further, the model for educating safeguards and security experts is being changed at TAMU. Beyond conventional classroom lectures, NSSPI has been developing alternative educational models based on practical experience, asynchronous learning portals, and virtual courses. Due to the experimental and practical past experiences of NSSPI staff and faculty, a heavy hands-on component has been implemented for TAMU nuclear engineering graduate students: hands-on education at Oak Ridge National Laboratory, visiting nuclear installations in other countries to discuss applied safeguards, and summer internships at several national laboratories. In an effort to disseminate basic nuclear education for professionals and students around the globe, NSSPI has developed a publically-available online resource that offers self-paced, independent course modules in basic safeguards education: the Nuclear Safeguards Education Portal. Current modules (including Basic Nuclear Physics, The Nuclear Fuel Cycle, Radiation Detection, and Statistics) consist of reading materials, supporting video from TAMU professors and subject matter experts from the national labs and industry, along with links to additional resources. Another venture utilized by NSSPI is using a virtual TAMU campus in Second Life to hold classes for students. Recently, MS-level students taking a critical analysis of nuclear security data course created Second Life avatars and attended courses online from their home computers. This endeavor is currently being pursued as a surrogate for distance education lectures and, ultimately, to incorporate practical/experimental training. NSSPI is building upon a successful academic program by embracing new educational means. This paper describes the current efforts NSSPI and TAMU have undertaken in strengthening the nuclear nonproliferation and safeguards human resource capacity domestically and internationally and the lessons learned from these efforts.

## **1. Introduction**

It is in the general interests of mankind and the specific interests of the United States government to detect, prevent, and reverse the proliferation of weapons of mass destruction materials, technology, and expertise and control existing arms stockpiles. To help achieve this goal, Texas A&M University (TAMU) has been developing the next generation of nuclear nonproliferation and material safeguards experts through the Nuclear Security Science and Policy Institute (NSSPI) using technical and policy education. Since 2004, NSSPI has offered a Master's of Science degree with a Nuclear Nonproliferation Specialization within the Nuclear Engineering department (MS-NNP) at TAMU to satisfy the growing need of safeguards and security experts worldwide. During this period, TAMU has graduated 26 students with MS degrees with the nonproliferation specialization and educated more than 200 students via the courses taught at TAMU.

In light of the development of nuclear security science education at national laboratories around the world, a small number of universities have begun offering courses, certificates, and degrees in these areas to assist the new network of nuclear security experts. To complement the number of political and social science academic programs within this field, the TAMU program focused primarily on a technical orientation in the nuclear security sciences with policy as a supporting element to help

students understand the policy implication of new technologies. Education of this kind is achievable only through a combination of theoretical and practical education curricula and a heavy focus on technical research on how to meet the expectations dictated by the policies of the safeguards and nonproliferation regimes.

NSSPI and TAMU have been implementing the MS-NNP program for five years and have seen a number of successes and learned a number of lessons. Various methods have been tried, and some have continued to be utilized by the faculty in effectively teaching the various topics offered by the nuclear engineering department at TAMU. This program has converged into using the following program elements to provide an exceptional education experience:

1. Nuclear engineering core discipline courses to provide the fundamental technical background
2. Nonproliferation, safeguards, and security specific technical courses to provide technical details of direct relevance to the mission area
3. Elective courses to provide increased breadth of knowledge into several areas of application to the mission (e.g., courses on national security policy) or deep technical knowledge into a single area (e.g., a course on nuclear forensics inverse analyses)
4. Technical research applied specifically to the mission area
5. Practical experience via training sessions at national laboratories, summer internships at national laboratories, and visits to commercial fuel cycle facilities
6. Prerequisite course material via asynchronous distance learning modules
7. Course implementation via real-time, fully-immersive distance education via the 3D virtual world Second Life
8. Extracurricular learning opportunities via the TAMU student chapter of INMM

Details for these program elements will be presented in the subsequent sections of this paper after a brief overview is presented on the current status of the MS program.

## **2. Current Nonproliferation Curriculum and Education at TAMU**

TAMU faculty and students have been active in the research fields of nuclear nonproliferation, nuclear material safeguards, and international security for many years. Activities have included scientific and engineering research projects with Los Alamos, Sandia, Oak Ridge, Lawrence Livermore, Savannah River, Idaho, and Pacific Northwest National Laboratories. Among others areas, research has included proliferation resistant nuclear fuel designs, proliferation resistance assessments for fuel cycles, nuclear material safeguards development and analysis, development of portal monitors for detecting the illicit trafficking of nuclear materials, modeling of nuclear smuggling routes, post-event nuclear material attribution, compilation of reactor data for international safeguards and safety purposes, and studying nuclear terrorism pathways.

Additionally, the MS-NNP program is based off the MS degree in Nuclear Engineering. Several courses rooted in nuclear engineering basics are included in the program for the belief that students should understand the grand scheme of how safeguards and nonproliferation is applied to the broader nuclear fuel cycle. This degree program develops a student's understanding in the area of global nuclear security through research and classroom activities which fosters their creativity in solving complex problems with a solid technical focus.

The degree program is designed as a 1½ to 2 year program consisting of nine formal courses. Of these formal courses, seven are required courses and two must be selected from a set of possible electives. As a Master of Science degree the students will also complete research of fundamental interest to the field and write a corresponding thesis detailing their research. The outline of the Master of Science in Nuclear Engineering with Nuclear Nonproliferation Specialization (MS- NNP) is shown in Table I.

**Table 1. MS-NNP Degree Curriculum**

	<b>Course Designation and Title</b>	<b>Credit Hours</b>
<b>Fall Year 1</b>	NUEN 601 Nuclear Reactor Theory	3
	NUEN 605 Radiation Detection and Nuclear Materials Measurement	3
	NUEN 650 Nuclear Nonproliferation and Arms Control	3
	NUEN 681 Seminar in Nuclear Engineering	1
	NUEN 685 Independent Study	2
<b>Spring Year 1</b>	NUEN 604 Nuclear Radiation Shielding	3
	NUEN 606 Nuclear Reactor Analysis and Experimentation	4
	NUEN 651 Nuclear Fuel Cycles and Safeguards Systems	3
	NUEN 691 Research	2
<b>Fall Year 2</b>	NUEN 656 Critical Analysis of Nuclear Security Data	4
	Technical Elective	3
	Technical Elective	3
	NUEN 691 Research	2

Elective courses are selected from a set of various courses offered in relevant areas and provided by other faculty elsewhere at TAMU including:

1. NUEN 489 Design of Nuclear Facility Security Systems (Nuclear Engineering Department)
2. CHEM 681 Radiochemistry and Nuclear Forensics (Chemistry Department)
3. MATH 644 Inverse Problems in Nuclear Forensics (Mathematics Department)
4. INTA 620 International Security (Bush School of Government and Public Service)
5. INTA 617 Deterrence (Bush School of Government and Public Service)
6. INTA 657 Terrorism in Today's World (Bush School of Government and Public Service)

These courses are intended to give the student's education a particular focus on several issues of interest to the field and provide some diversity for the student's degree program.

### **3. Brief Course Descriptions**

In this section, a brief description of the required courses involved in this degree program is given. This gives a general overview of the details to these courses and how the overall degree program provides education of the next generation of experts in this field. It should be noted that the design of this program was intended to build upon the general fundamentals of a nuclear engineering Master of Science degree. Thus, many of the courses are fundamental nuclear engineering courses which would exist to some degree at nearly any nuclear engineering program.

#### **3.1. Nuclear Nonproliferation and Arms Control**

This course gives a basic overview of topics learned in the degree program and introduces the student to the political and technological issues associated with nuclear nonproliferation. This course studies the political and technological issues associated with nuclear nonproliferation and arms control. Topics studied include the history of arms control, descriptions and effects of weapons of mass destruction, introduction to the technology of nuclear weapons, details of various arms control treaties and efforts, proliferation pathways in the nuclear fuel cycle, international and domestic safeguards, proliferation resistance in the nuclear fuel cycle, nonproliferation strategies, treaty verification regimes, nuclear terrorism, verifying the elimination of weapons programs, safeguards measurement techniques for material accountancy programs, containment and surveillance, and physical protection mechanisms. Lecture material is supplemented by homework assignments that will require written analysis to reinforce material understanding. Students also perform two simulation exercises based on a hypothetical global security scenario. These simulations require the student to synthesize content from throughout the course to generate and evaluate solutions to the proposed scenario.

### **3.2. Nuclear Reactor Theory**

This course discusses fundamental nuclear reactor theory. The course focus is on calculations of nuclear reactor material production, reactor criticality, and reactor neutron fluxes. The student will learn the physics of nuclear systems including neutron-nucleus interactions; neutron energy spectra; transport and diffusion theory; multigroup approximation; criticality calculations; cross-section processing; buildup and depletion calculations; and modern reactor analysis methods and codes.

### **3.3. Nuclear Radiation Shielding**

The basic principles of radiation interactions and transport, especially as related to the design of radiation shields are studied in this course. Radiation sources, nuclear reactions, radiant transport, photon interaction, dosimetry, buildup factors and fast neutron shielding are covered in detail and the students is expected to develop a complete understanding of these topics.

### **3.4. Nuclear Fuel Cycles and Safeguards Systems**

This course educates students on the design and implementation of nuclear material safeguards systems for nuclear fuel cycle systems. A description of the civilian and military nuclear fuel cycles is given including the physics of the fundamental components of the fuel cycle (including enrichment, fuel fabrication, reactors, and reprocessing). The student learns methods for analysis of these cycles. Topics include the nuclear fuel resources, mining, and metallurgy; enrichment and conversion; reactor fuel design and fabrication; in-core fuel management; reprocessing and recycling; fuel cycle economics and analysis; heavy water and tritium production; and high level waste management. The course also details the fundamentals of nuclear material safeguards. This includes material protection, control, and accounting practices and the IAEA system of safeguards. The course also covers statistics applied to safeguards; the additional protocol; strengthened and integrated safeguards; environmental sampling; remote monitoring; application of NDA and DA to safeguards; and application of measurement techniques to reactors, fuel fabrication facilities, reprocessing plants, enrichment plants, and critical assemblies.

### **3.5. Radiation Detection and Nuclear Material Measurements**

This course educates students on methods and instruments used for quantitative measurements of nuclear and radiological materials. This course begins with the fundamentals of radiation emission and detection. The focus is on neutron and gamma-ray radiation detection including the use of gas-filled detectors, scintillation detectors, and semi-conductor detectors. Topics include gamma-ray interactions with matter; gamma-ray detectors, gamma-ray spectroscopy, and passive gamma-ray detection; measurement of uranium enrichment; measurement of plutonium isotopic compositions; neutron interactions with matter; neutron detectors; total neutron counting; neutron coincidence counting; active neutron interrogation; irradiated fuel measurements; perimeter radiation monitors; calorimetry; and holdup measurements.

### **3.6. Critical Analysis of Nuclear Security Data**

This course serves as a capstone for the MS degree program. The course requires students to synthesize content from all of their other courses to critically analyze a hypothetical nuclear security event. This is a project-based course which studies the analysis of nuclear security events, threats, and data. Students are each assigned a project which requires an analysis of data for a hypothetical case of interest to national security. The course focuses on detailed technical analysis using diverse datasets and country/organization profiles. These dataset may include overhead imagery; mass and gamma-ray spectroscopy from air, biota, soil, and water samples; press reports; watchdog group reports; historical details; seismic data; ultrasound data; nondestructive radiation measurements of materials; destructive analysis of materials; export control information; and safeguards accounting data. The students are divided into small teams and develop their analysis of their case over the semester by learning how these analyses are performed in professional environments. The students present their results on several occasions throughout the semester and the audience will serve as the "Red Team" for the analysis. Quantitative and qualitative analysis are developed. The following techniques are discussed and used where applicable: critical success factors, competitor profiling, SWOT analysis, and gap analysis. Also included are presentations on recognizing the interaction between the collection and analysis phases, methods to analyze creatively, how to employ inductive and deductive reasoning in analysis, how to recognize gaps and blind-spots and ways to determine to cease analysis. This course serves as the capstone course for the degree program.

## 4. Novel Teaching Techniques at TAMU

In addition to the coursework and curriculum outlined in Section 3, NSSPI has pioneered novel teaching techniques that are currently being implemented at TAMU to benefit students within the MS-NNP program but also internationally. This section will discuss the various methods explored and currently implemented for developing next-generation safeguards experts.

### 4.1. Graduate-Level Research

Paramount to effective education for graduate students is a rigorous research program. Staff members at NSSPI and TAMU use ties to various U.S. and international research organizations to acquire research projects for MS-NNP students in the areas of nonproliferation, safeguards, and security. Since 2004, students have been paired with project leads at the various U.S. national laboratories to work in a myriad of areas related to safeguards and nonproliferation: nondestructive assay, containment and surveillance technologies, proliferation resistance analysis, physical security science, latency analysis, attribution analysis and forensics, and others. The NSSPI students work in small teams on these research projects. These teams often include students from disciplines outside of nuclear engineering including international affairs student. These projects often include research using the unique facilities at the national laboratories (Fig. 1).



**Figure 1.** TAMU students (Dan Strohmeier and Alissa Stafford) conduct research at ORNL with TAMU professor (William Charlton) and ORNL and LANL staff (Steven Saavedra and Andrew Hoover).

### 4.2. Practical Experience

NSSPI fosters a culture of comprehensive education for the MS students that goes beyond mere theoretical education. Via the three specific activities described in the following subsections, students within the program gain an unprecedented amount of practical knowledge and experience otherwise not available to them within the classroom.

#### 4.2.1. Hands-On Laboratory Experience

Every semester, NSSPI provides the opportunity for graduate students within the MS-NNP program at TAMU to complete a week-long practical course at the Safeguards Laboratory (SL) at the Oak Ridge National Laboratory (ORNL). The course alternates between hosting undergraduate and graduate nuclear engineering students each semester. This opportunity allows students to understand and

appreciate basic material control and accounting technologies focused specifically on detecting and measuring special nuclear material using nondestructive assay (NDA) techniques. The week-long class was first developed by TAMU and ORNL SL staff in Spring 2007. It borrowed heavily from the vast experience ORNL SL staff has obtained in providing training courses on NDA techniques to professionals from various international institutions. Working closely with the ORNL staff, NSSPI coordinated this course to focus around topics the MS students learn as part of the aforementioned NUEN 605 course (Detection and Measurement of Special Nuclear Material) from Section 3.5.

The time spent at the SL for students is highly beneficial for their education and complements the theoretical education they receive while on the TAMU campus during the semester. Understandably, other universities have followed the example set forth by TAMU in this venue, and the ORNL staff has expressed the great successes of collaborating with universities within their region and beyond. This has been a fruitful collaboration for ORNL, TAMU, NSSPI, and the MS-NNP students.

Further, in recent courses, students from the TAMU Bush School of Government and Public Service studying nonproliferation and international security and other foreign relations areas have also been hosted in the SL course at ORNL (Fig. 2). This has provided policy students the opportunities to better understand the limitations and applications of various technologies as applied to safeguards and nuclear security and fosters enhanced communication between the future technical and policy experts. This integration of policy and technical students has been very fruitful for the students attending this course.



**Figure 2.** Group Photo (MS-NNP and Bush School students) at Oak Ridge National Laboratory

#### **4.2.2. Foreign Field Experience**

As part of the capstone course (NUEN 656) discussed in Section 3.6, MS students at TAMU have been afforded the opportunity to travel to nuclear fuel facilities in other countries to discuss safeguards applications and effects on operations. This endeavor is commonly referred to as the Foreign Field Experience (FFE) and has been conducted with two Russian universities with established Nonproliferation and International Security education programs: the Moscow Engineering and Physics Institute (MEPhI) and the Obninsk State Technical University's Institute for Nuclear Power Engineering (IATE). As of 2007, students from the three academic institutions (Fig. 3) have visited, toured, and openly discussed safeguards applications at nuclear fuel cycle facilities in France, the United Kingdom, and Switzerland. Hosting organizations have welcomed the students into their facilities and have shown candor when discussing their operations and international safeguards applications (much to the delight of the students).

The FFE is a unique opportunity for students from the United States to witness full-scale fuel facilities (ranging from reprocessing plants, fuel fabrication plants, and enrichment plants) and discuss topics they have received conceptual instruction on for the previous two years while in the MS-NNP program at TAMU. Furthermore, students from the Russian institutes, MEPhI and IATE, receive the opportunity to visit western-style facilities and gain an appreciation of applied safeguards features that benefit their future careers. Students on both sides gain the opportunity to expand their own professional networks of nuclear experts and, it is hoped, that when the students' paths cross in the future, the warmth instilled by the FFE carries through and future professionals can rely on these relationships for the benefit of the cause.



**Figure 3.** Group photo at the UK Nuclear Decommissioning Authority's Training Center. In this photo are students and professors from TAMU, MEPhI, and IATE.

#### **4.2.3. Summer Internships and Summer Safeguards Courses**

Students in the MS-NNP program are encouraged to participate in summer internships at the national laboratories where they can continue their research under the direct guidance of national laboratory experts. Students gain additional knowledge outside of the expertise at TAMU and make contacts with possible future employers. The national labs gain a cost-effective research resource, establish enduring contacts with academia, and acquire an opportunity to evaluate potential future employees.

The TAMU MS-NNP students have been prominent participants in the summer safeguards courses at the national laboratories sponsored by the Next Generation Safeguards Initiative (NGSI). These courses provide an educational opportunity to the students that would be difficult to acquire at a university. They have an opportunity to hear lectures from leading experts at the national laboratories and to participate in laboratory practicals using the advanced materials and technologies available throughout the DOE complex.

#### **4.3. Nuclear Safeguards Education Portal**

The Nuclear Safeguards Education Portal (NSEP) was launched in the spring of 2009 as an effort to provide introductory information to summer interns interested in safeguards. The Department of Energy, through the Next Generation Safeguards Initiative (NGSI), funded a large number of students to participate in internships across the laboratory complex over the past several summers. These students all participated in safeguards education initiatives being taught as summer courses. However, the participating students were from a wide variety of backgrounds with varying degrees of technical expertise. Initial summer efforts were hampered by this fact. Students with technical

backgrounds (such as nuclear engineering) were subjected to fundamental topics that were necessary for non-technical students during the introductory sessions. This led to the technical students being under-stimulated and under-challenged through the beginning of the course. Due to this, NGSI provided funding to NSSPI to develop NSEP. In 2009, the first courses were developed as required modules for students unfamiliar with the technical aspects of safeguards. Students from all over the country participated with a large degree of success. The initial modules were:

- Basic Nuclear and Atomic Physics
- The Nuclear Fuel Cycle
- Basics of Radiation Detection

While all of these modules were specifically designed for use in the summer seminars, they served to provide educational resources for students with an interest in nuclear safeguards and the security of nuclear materials anywhere in the world. All current modules are globally available regardless of enrollment at TAMU. All of the initial modules are intended to be completed in a few hours. They consist of reading materials, supporting video from professors at TAMU and subject matter experts from the national labs and industry (where appropriate), along with links to additional resources. The online, asynchronous nature of the modules provides students with the opportunity to complete the module at their own pace.

Since June 2009, NSEP has been accessed by approximately 1100 unique users. “Basic Radiation Detection” is the module accessed most frequently, specifically the section concerning Semiconductor Detectors. The complete breakdown is as follows:

**Table 2.** Module and Number of Users for NSEP

<b>Module</b>	<b>Number of users</b>
Basic Nuclear and Atomic Physics	280
The Nuclear Fuel Cycle	300
Basic Radiation Detection	500

For comparison, a typical graduate level course covering any of these topics may have 10-20 students. Asynchronous distance education provides the opportunity to reach a considerably larger audience. While many of these users are concentrated around the U.S. national laboratories and DOE HQ, other University programs have included these modules as required assignments and a significant body of international users has been observed.

To continue in TAMU’s commitment to educating next-generation safeguards and nonproliferation experts, NSSPI staff and students are composing the second round of modules which will focus on:

- History of the Manhattan Project
- Safeguards Terminology
- Statistics as Applied to Nuclear Safeguards
- Nuclear Material Accountancy
- Physical Protection
- Containment and Surveillance

These modules will provide more profound understanding of the various aspects of the subject matter and will be available beyond the student population at TAMU. Lastly, resulting from a special request, NSSPI has implemented an evaluation portion of NSEP where students can quiz themselves and assess their understanding of the topics at hand. This can prove useful for institutes that would like to use the modules as prerequisites for their own programs.

## **5. Education Using a Virtual Environment**

NSSPI has developed courses deployed via distance technologies that benefit the students in the MS-NNP program at TAMU via virtual education. Unique among universities, TAMU has developed



and maintains a virtual campus within Second Life (a 3D virtual online realm that is open access to all TAMU students, regardless of major or level of study). Within this space, NSSPI has created a classroom and has effectively taught courses via the project to facilitate teaching where the students and professor are separated geographically. Every user interacts via a user-created avatar that literally sits in a classroom and can participate in a lecture. Furthermore, when discussing more complex topics, the avatar is able to tour the interior workings of a reactor or physically witness the interaction of a photon when striking any given medium. Voice chat and multimedia features are available to facilitate participation in individual and group activities limited only by the imagination of the world's creator.



**Figure 4.** Screen captures from NUEN 656 in Second Life

The NUEN 656 and NUEN 489 courses discussed in Section 3.6 have held classes taught in Second Life and the response was positive. As is seen in the collection of pictures in Figure 4, a white board is used to convey equations, slides are presented, lectures are provided verbally via voice chat, and students witness the interior features of an operating reactor. In the future, it is foreseeable that Second Life can be used to educate students in physical security sciences by exploiting the capabilities of the 3D realm and combining them with game play to create red team/blue team exercises among other subjects which could benefit from Second Life.

## **6. Conclusions**

The Master's of Science degree program specializing on Nuclear Nonproliferation was described, and the novel educational techniques being utilized by NSSPI staff and TAMU faculty was discussed. The general philosophy of the MS program is based on the concept that nuclear nonproliferation is an engineering problem, within a policy framework, that it includes a multi-disciplinary component and is highly dependent on practical experience and infusing state-of-the-art educational techniques. This program will continue to develop in the future with continual feedback from the primary customers: the national laboratories, government agencies, and the IAEA. Students have seen the capabilities at TAMU and NSSPI and, more so, have witnessed first-hand the benefits they receive by attending the MS degree program. Embracing state-of-the-art educational technologies is paramount to maintaining a successful educational program in the ever-evolving area of nuclear nonproliferation and safeguards.