International Journal of Nuclear Security

Volume 2
Number 1 *Education and Training Issue*

Article 9

11-22-2016

Building the Education and Training Pillar of the University of Tennessee's Institute for Nuclear Security

Howard Lewis Hall

International Journal of Nuclear Security, Vol. 2, No. 1, 2016

Building the Education and Training Pillar of the University of Tennessee's Institute for Nuclear Security

Howard L. Hall
Institute for Nuclear Security, University of Tennessee, Knoxville, Tennessee, USA

Abstract

The University of Tennessee (UT) developed its first formal and coordinated efforts in nuclear security education in 2008-2009 with its graduate certificate program in nuclear security in the Department of Nuclear Engineering. Building on this work, in 2011 UT established the UT Institute for Nuclear Security (INS) as a collaborative center at the university to expand its curricular impact as well as foster research and partnerships with nearby major governmental facilities engaged in nuclear security work. Oak Ridge National Laboratory (ORNL), the Y-12 National Security Complex (Y-12), and Oak Ridge Associated Universities (ORAU) have joined with UT as charter members of INS. The institute has successfully fostered the development of a near-comprehensive nuclear security curriculum within multiple academic units. In addition to traditional academic offering, INS is developing a comprehensive strategy for a professional development short-course series that facilitates postgraduate entry into the nuclear security field and continuing education.

I. Introduction

In both the United States and internationally, the ability to sustain efforts in nuclear security is eroding as the population of skilled scientists and engineers in this field declines. For example, Wogman *et al.* noted as early as 2004 that 75% of the nuclear personnel in the US Department of Energy national laboratories would be eligible to retire by 2010 **[*1*]**. This decline is exacerbated by the contraction of programs and facilities wherein hands-on experience with security-significant quantities of nuclear material and its related processing can occur and the concomitant spiraling expense of academic experimental facilities that handle radioactive materials. Similar "megatrends" are affecting the international nuclear security community **[*2*]** and key international organizations such as the International Atomic Energy Agency (IAEA). As an example, a recent study of nuclear and radiochemists found similar losses in both the population of this skill set as well as the capacity to produce them **[*3*]**.

At the same time, challenges to international nuclear security regimes (such as the Non-Proliferation Treaty) are mounting from various nation-states – Pakistan **[*4*]** and North Korea **[*5–7*]** have openly tested nuclear weapons in the last decade, and other suspected proliferant states (such as Iran and Syria) **[*4, 8*]**

are or have recently been the subjects of grave concern over their nuclear intentions. The recent conclusion of the Joint Comprehensive Plan of Action **[*9*]** between the Islamic Republic of Iran and the "P5+1" countries (the United States, United Kingdom, France, China, Russia, and Germany) regarding Iran's nuclear program has created significant new demand for IAEA safeguards inspectors, and especially IAEA safeguards inspectors from countries other than the P5+1 states **[*10*]**. Terrorist groups such as al-Qaeda are on record **[*11*]** as seeking nuclear capabilities, and Daesh has raised troubling concerns about a possible nuclear nexus for its targets **[*12, 13*]**.

It is recognized that these challenges due to a graying workforce and inadequate pipeline of new talent are troubling at best, and a threat to global security at the extreme. Replacement personnel, when available, are typically educated in an academic environment that does not address the unique and critical problems that make nuclear security or safeguards challenging. Furthermore, access to experimental or operational nuclear facilities and reactors is increasingly limited **[*3*]**, reducing the experiential knowledgebase of new graduates to "academic exercises" or models and simulation.

Furthermore, the increased interest in nuclear power as a carbon-free energy source will lead to new national and international enrichment facilities and fuel cycle processing facilities – increasing the demand (and competition) for nuclear scientists and engineers. Other non-nuclear industries also compete for nuclear engineering graduates. Despite the 2011 nuclear accident at Fukushima **[*14–16*]**, there does not appear to be an appreciable slowing of the expansion of nuclear power programs overall in the global energy market.

Some government initiatives are being undertaken to address these issues – for example, the US National Nuclear Security Administration's Next Generation Safeguards Initiative has a human capital development component for safeguards specialists. Additionally, recently-issued studies highlight the need for investment in nuclear forensics science, including personnel education and development **[*17, 18*]**.

To address the broader problem of sustainable education of the next generation of experts in nuclear sciences, an integrated program, with roots in academia, is needed. This paper describes the strategies that the University of Tennessee has taken to develop a robust educational program to meet the challenge of educating the future generations of global experts in nuclear security, including a deliberate expansion of its nuclear engineering program to include the development of a specific line of instruction and research in nuclear security in 2009 **[*19*]**, and a broadening of that effort to the whole of the university under the auspices of the UT Institute for Nuclear Security in 2012.

This paper begins by taking a step back and defining – broadly – what UT means by the term *nuclear security*, describes the origins and rationale for establishing a campus-wide Institute to help promote education and graduate research training in this inherently interdisciplinary field, provides a detailed summary of the curriculum developed and deployed, and concludes with a brief summary of UT efforts to share and support international academic engagement in nuclear security education. To some extent, the UT experience can serve to inform other programs on development and sustainability of such efforts.

II. Defining Nuclear Security

Within the UT program, we take a very broad view of the span of activities that fall under the term *nuclear security*. In our usage, we mean it as a field of education and research that encompasses all the activities that support the following objectives:

- Beneficial applications of nuclear or radiological materials and devices are not diverted to illicit or malicious purposes. Potential threat materials are secured or replaced where feasible so as to reduce opportunities for malicious use.

- Nuclear weapons and related technology are appropriately controlled and monitored. Nuclear arms control and reduction priorities are supported and enabled.
- The proliferation of nuclear weapons or other nuclear/radiological threats is discouraged, detected, and/or dissuaded. Systems that support the peaceful uses of nuclear energy are increasingly proliferation resistant.
- Efforts to acquire or use nuclear/radiological threats by malefactors are anticipated, stopped, investigated, and effectively countered.
- Consequences of radiological or nuclear incidents, including attacks, are mitigated or minimized through prior planning and engineering, as well as effective response, emergency management, and remediation.

Explicitly, our use of the term *nuclear security* is best understood in the context of the "3S" strategy (Safety, Security, and Safeguards) that has gained recent prominence in the community. Technical aspects of nuclear safety within our curriculum are already well-established in the UT Department of Nuclear Engineering, and serve as a base on which our security and safeguards interests can draw as needed.

Many applications in nuclear security are found at the intersection of traditional academic disciplines, and do not rest easily within the normal stovepipes of existing academic departments. For example, the negotiations of new treaties require the implementation of verification and inspection regimes. These negotiations require advice about technology to inform the agreed frameworks, and the agreements also define research and development activities to improve the effectiveness of inspection and verification activities. Likewise, the evolution of new technology for supporting law enforcement efforts creates new frontiers in policy and law **[*20*]**, including, notably, laws that include strategic trade controls that can be both highly technical as well as legally complex.

III. The Structure of the UT Institute for Nuclear Security

The Institute for Nuclear Security is organizationally located within the UT Howard H. Baker Jr. Center for Public Policy ("Baker Center"), and reaches across the many UT disciplines and academic departments that can contribute to the nuclear security field. The Baker Center is a campus-wide entity answerable directly to the chancellor of the university. The placement of INS in the Baker Center was deliberate, to allow the institute to function outside the traditional academic units of the university so as to encourage cross-departmental collaboration and cooperation. Over the four years since INS was established, we have expanded UT's contributions to nuclear security from the original nucleus of activities in the Department of Nuclear Engineering to a much broader, multidisciplinary base in which many academic units both contribute to the global challenges but also develop distinctive and successful programs within each unit.

As UT is a research-intensive university with aspirations of even greater research productivity and impact, the development of a robust and impactful research portfolio is an important success metric for INS. The university is also the state of Tennessee's land grant university **[*21*]**, and hence has a institutional commitment to teaching, research, and service across the university. Supporting this university mission, INS fosters research, development, service, teaching, and related scholarly activities across the university as well as with our external partners.

In particular, INS focuses on those activities that capitalize on partnership and collaboration as well as interdisciplinary needs and challenges that the university can address. The institute also supports the development of enhanced educational capabilities for nuclear security within the academic units of the UT, and more broadly through a variety of means. A large number of professional staff from INS's partners are also engaged with the institute, including some that are now fully embedded with INS on the UT campus.

The institute focuses its efforts in five principal areas, which are referred to as the "pillars" of INS: 1) policy, law, and diplomacy; 2) education and training; 3) science and technology; 4) operational and intelligence capability building; and 5) "real-world" missions and applications. Our concept of a systems approach to nuclear security is designed specifically to encourage crosscutting efforts and collaborations between academia, government, the private sector, and the public. The institute is fostering a long-term comprehensive approach in its work that is informed by the "whole of government" **[*22*]** and "whole of society" **[*23*]** concepts advanced for addressing nuclear security concerns.

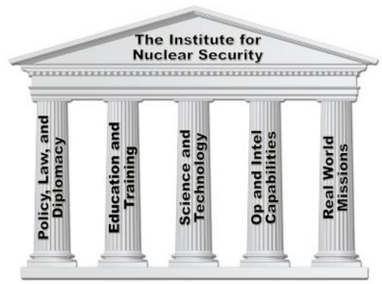

Figure 1: The thematic "pillars" of INS

While INS has made significant progress in developing its programs and capabilities in all of these pillars, this paper will confine itself to the Education and Training Pillar. Work in the educational/training front has been quite active, resulting in the development of a considerably extended curriculum, both in terms of coursework and in number of academic departments involved.

Other participants in INS include the charter partners – Oak Ridge National Laboratory (ORNL), the Y-12 National Security Complex (Y-12), and Oak Ridge Associated Universities (ORAU) – and each of these partners have contributed expertise, facilities, and research partnership opportunities that have strongly contributed to the success of the UT program. For example, ORNL makes available their Safeguards Laboratory **[*24*]** for student measurements with plutonium and highly enriched uranium and Y-12 staff in their Alarm Response Training program **[*25*]** collaborate with students in developing and testing physical security exercises for hypothetical nuclear facilities.

Equally importantly, the engagement of these partners along with others in industry, military, civilian, and international organizations helps UT keep the educational focus of its program relevant and informed about current challenges and needs.

IV. UT's Nuclear Security Curriculum

A. Building on the History of the UT program in Nuclear Engineering

Sean F. Johnston's review of the development of the field of nuclear engineering (comparing the development of the field in the United States and the United Kingdom) describes the academic program as an early postwar outgrowth of the Manhattan Project, and notes that nuclear engineering largely grew out of programs at what are now Oak Ridge National Laboratory and Argonne National Laboratory **[*26*]**. The objective of these programs was to transfer knowledge gained in developing the nuclear fuel cycle and nuclear reactors for weapons production to applications in nuclear power generation (initially for military purposes, and subsequently for civilian applications). Oak Ridge worked with the nearby University of Tennessee and the Massachusetts Institute of Technology to establish the series of educational initiatives, including the somewhat whimsically nicknamed "Clinch College of Nuclear

Knowledge," as the Clinton Training School (established in 1946) was known. Famous alumni of this program include Admiral Hyman Rickover, who lead the development of the US nuclear navy, and Admiral James Watkins, US Secretary of Energy from 1989 through 1993.

Subsequent efforts in Oak Ridge included the Oak Ridge Institute of Nuclear Studies, which focused on biological applications of nuclear science, and the Oak Ridge School of Reactor Technology, which addressed classified military applications of nuclear power.
As Johnston notes, essentially all the current US academic programs grew out of the Eisenhower Administration's Atoms for Peace initiative, which opened up much of the nuclear information and technology to the civilian sector. The Department of Nuclear Engineering at the University of Tennessee (UTNE) was founded in 1957, and is the oldest Department of Nuclear Engineering in the United States **[*27*]**.

Like many nuclear programs in the United States, UTNE saw flat or declining enrollments during the 1980's and 1990's, which mirrored broader trends in the industry. However, the last decade has seen substantial growth in the department's undergraduate enrollments and a less dramatic but still significant expansion in graduate enrollments.

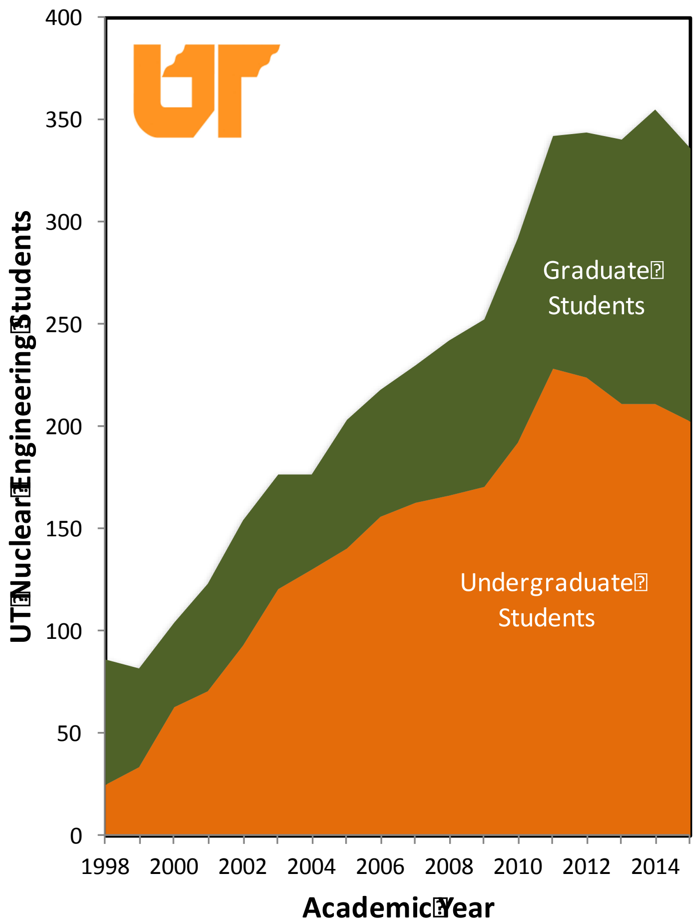

Figure 2: Aggregate enrollment in UT Nuclear Engineering program from 1998 to 2015. Numbers reflect 14-day enrollments for the fall semester of each academic year.

B. Department of Nuclear Engineering (UTNE)

In 2009, UTNE established a graduate certificate program in nuclear security science and analysis (NSSA) **[*19*]**. The program is designed primarily for technical students seeking specialization in nuclear security science and engineering. Additionally, this program prepares graduate students to engage in the research and development of new tools and processes related to nuclear security science and analysis.

The certificate requires the completion of twelve semester credit hours (SCH), and is offered in the master's of science track in the UTNE curriculum. As currently constituted, twelve credit hours in the NSSA program would constitute half of the total graduate coursework credit hours required for a student to complete their master's degree, and those credit hours can be earned in a suite of courses shown in Table 1 in the Appendix.

The selection of courses, which must be approved by the department, is determined through a student advising conference that considers the student's personal interests, academic background, and work experience. Criteria for acceptance into the NSSA certificate program are the same as for acceptance into the M.S. program in nuclear engineering. Descriptions of each course are provided in Table 1, which shows the courses that support the NSSA certificate as well as the number of student that have taken each (as of the 2015-2016 academic year [AY]).

C. Department of Political Science

Partnering with the Department of Nuclear Engineering and the Howard H. Baker Jr. Center for Public Policy, the Department of Political Science (PoliSci) has transformed their master's in public administration program into a master's in public policy and administration (MPPA) degree, with the option to tailor the curriculum into a global security studies track.

The MPPA degree is a 30-SCH program, and to fulfill the requirements of the global security track students are required to fulfill 9 SCH out of the total 30 SCH from the coursework in Table 2. The MPPA program became available for enrollment in the fall semester of 2013.

Prior to the development of the MPPA program, however, the Department of Political Science, the Baker Center, and INS collaborated to develop a special seminar (Arms Control and Treaty Negotiation) as a centerpiece course in the PoliSci global security–related curriculum. This course, co-taught by Professor Brandon Prins and previously Ambassador Thomas Graham, focuses on the strategies, contexts, and tactics associated with development of complex international treaties. The class concludes with an extended mock international negotiation, with class participants representing various nation-states in the simulation.

D. Department of Chemistry

In AY 2015, the departments of Chemistry and Nuclear Engineering collaborated to implement a joint graduate certificate program in radiochemistry. The 12-SCH certificate is earned by completing four courses as shown in Table 3. Criteria for acceptance into the program are the same as for acceptance into the graduate programs in chemistry or nuclear engineering. This new Radiochemistry Graduate Certificate is especially valuable in light of the recent study indicating the strong need for these programs **[*3*]**.

International Journal of Nuclear Security, Vol. 2, No. 1, 2016

V. Addressing the Mid-Career Entrant

Another pathway for personnel to enter into a career in nuclear security applications is via a postgraduate career transition. These entrants typically have been in the workforce for some time, and will have some level of background education, but usually no nuclear security–specific education or training. Furthermore, these individuals – and their employers – generally cannot accommodate the typical 18-24 month cycles for graduate degrees. To support these mid-career entrants, INS has developed a professional development and training effort that provides training and familiarization for new entrants, but does so in smaller increments than a typical semester-long class. These classes typically last a maximum of five days for ease of participation. These training classes ultimately lead to professional certificates for the participants, along with relevant continuing education credits for those with professional licensure requirements (such as professional engineers, attorneys, etc.).

These are not just conference room lectures. Each course contains extensive in-class interactive exercises as well as extensive experiential learning opportunities through our partners. Our emphasis in developing these courses is to make maximum use of the opportunity to see and experience real working facilities that are relevant to the topic of the course. In addition, we make extensive use of working subject matter experts drawn from all the partners of INS.

At the conclusion of this the sequence of training courses of the program, successful participants receive a certificate from INS along with the necessary documentation to claim their continuing education credits.

Over the last few years, INS has developed and provided a number of courses and workshops on nuclear security. In many cases, these workshops have been supported by the US National Nuclear Security Administration or the US Department of State. These workshops have focused on developing an awareness of nuclear security isues and practices, insider threat issues, physical security issues, and various strategies for teaching and training others ("train-the-trainer" approaches). In many cases these workshops are presented with our partners from ORNL, the Y-12 Nuclear Security Complex, the UT Law Enforcement Innovation Center, and other universities as appropriate.

VI. Supporting the Academic Nuclear Security Global Community of Interest

The scale of the worldwide need for expertise in nuclear security is, of course, well beyond the capability of UT to address alone. Therefore, INS also engages and supports the dissemination of nuclear security curricula worldwide. Part of this dissemination effort includes sharing curricula and part includes supporting new faculty interested in teaching nuclear security in their home institution.

One of the major vehicles that supports this international engagement is the International Atomic Energy Agency (IAEA) and its support for the International Nuclear Security Education Network (INSEN), a voluntary network of universities and related entities from around the world. This network shares curricular materials and best practices, enables inter-university collaborations, and encourages faculty development among the emerging global network of nuclear security educational programs. The University of Tennessee has participated in INSEN since its inception, and has supplied curricular materials in nuclear forensics and human reliability as well as supporting the development of INSEN and IAEA guides and working group functions. Through INSEN working groups, the need for faculty to be able to publish research in nuclear security was identified, as was the lack of an appropriate peer-reviewed vehicle for such work. That realization led to the INS decision to sponsor the development of this journal, the *International Journal of Nuclear Security* **[*28*]**.

International Journal of Nuclear Security, Vol. 2, No. 1, 2016

Additionally, UT has supported several extended faculty visits from international universities interested in expanding their nuclear security curricula, ranging from short visits/study tours to hosting extended faculty visits of several months. Over the last few years, UT has hosted faculty visits from Indonesia, Jordan, Brazil, South Africa, Nigeria, Algeria, Morocco, Ghana, and Brazil. These visits are frequently supported by the US Department of State, the US National Nuclear Security Administration, and the IAEA.

The Institute of Nuclear Security has worked bilaterally with a number of international educational programs through US National Nuclear Security Administration and US State Department efforts as well as direct connections with international stakeholders, such as IAEA's International Nuclear Security Educational Network (INSEN). This has included dispatching UT faculty and staff to support in-country development of curricula, program reviews, and other academic support activities.

VII. Conclusions

The University of Tennessee has established and continues to refine a robust interdisciplinary nuclear security curriculum, building off an initial base in the Nuclear Engineering Department but expanding organically into other academic units as well. The university is partnering with key laboratories and facilities in the region to ensure that UT students have an educational experience that is highly relevant to the needs of the nuclear security community, as well as gaining access to unique facilities and materials.

The university has also developed the early beginnings of a curricula of short courses and workshops to support the competency development of mid-career entrants into the field of nuclear security. This work continues to mature.

Another major focus for INS in its early implementation has been developing connectivity between the UT academic program and the international nuclear security community. In this period, INS has worked bilaterally and multilaterally with a number of international educational programs through direct connections and through international collaborations such as INSEN.

The establishment of INS within UT has been an important step forward, formalizing partnerships and serving as a vehicle for promoting nuclear security across the university's missions in teaching, research, and public service. Under the auspices of INS, UT has continued to expand its academic curriculum and student engagement as well as undertake an important effort in addressing the needs of mid-career entrants into the field.

VIII. Appendix: Coursework Tables

Table 1. Coursework qualifying for the UTNE NSSA certificate

Course Number	***Course Title and Description***	***# of Students since (Inception/Upgrade) as of AY 2016***
NE 530	Nuclear Security Science and Analysis – *Understanding nuclear threats and the evolution of nuclear threats to present day.* ***(This course is required)***	120 (2009)
NE 531	Global Nuclear Security Culture – *Principles and best practices in nuclear security, nuclear safety, and nuclear materials safeguards ("3S") culture with an emphasis on developing and expanding nuclear power-producing states*	17 (2014)

NE 532	Advanced Topics in Nuclear Security Science and Analysis – *Advanced topics in radiation measurement science, nondestructive assay techniques, and nuclear materials safeguards.*	24 (2010)
NE 533	Physical Security for High-Consequence Facilities – *Design criteria and performance basis that make up a physical security program for high-consequence and critical environments.*	54 (2014)
NE 534	Physical Security Vulnerability Assessment – *Evaluation of threat basis, facility characterization, and asset determination.*	31 (2014)
NE 535	Nuclear Chemistry and Radiochemistry – *Introduction to nuclear and radiochemistry. Cross-listed with UT Department of Chemistry*	7 (2014)
NE 536	Export Control and Nonproliferation – *Principles and regulatory frameworks for controlling sensitive nuclear technology*	15 (2014)
NE 537	Human Reliability in Nuclear Systems – *Methodology for assessing and managing human reliability factors in nuclear systems.*	25 (2014)
NE 542	Management of Radioactive Materials – *Technology for processing, treatment, handling and storage of radioactive nuclides. Analytical and numerical methods for evaluating environmental impact of radioactive materials. Licensing and regulation issues.*	98 (2011)
NE 550	Radiation Measurements Laboratory – *Physics and electronics associated with radiation detection and measurement, methods of data analysis. Applicability of particular detector measurements and fundamentals of radiation detection instrumentation operation.*	61 (2011)
NE 551	Radiation Protection – *Fundamental concepts and definitions used in radiation protection. Interactions of photons, neutrons and heavy charged particles with matter and mechanisms of energy loss. Chemical and biological effects of radiation. Introduction to current radiation protection standards and regulations.*	179 (2010)
NE 571	Reactor Theory and Design – *Analytical and numerical techniques for neutronics modeling of nuclear systems. Forward and adjoint Boltzmann transport equation. Multigroup diffusion theory. Core analysis methods and codes.*	125 (2011)
NE 404	Nuclear Fuel Cycle – *Mining, milling, enrichment, fuel fabrication, in-core management, nuclear reactor theory, reprocessing, waste disposal, regulatory requirements, nuclear facilities, nuclear material accountancy and physical protection. (This is a senior-level undergraduate course, and must be taken for graduate credit to qualify)*	108 (2011)
NE 433	Principles of Health Physics – *Radiation quantities, limits and risk assessment, external and internal dosimetry, biological effects of radiation, radiation detection, radiation interactions and decay, applications. (This is a senior-level undergraduate course, and must be taken for graduate credit to qualify)*	297 (2011)
NE 470	Nuclear Reactor Theory I – *Fundamentals of reactor physics relative to cross sections. (This is a senior-level undergraduate course, and must be taken for graduate credit to qualify)*	356 (2010)
PS 686	Arms Control, Deterrence and Nuclear Nonproliferation - *Challenges to US and global security created by the existence of nuclear weapons and power.*	22 (2013)
NE 635	Nuclear Forensics – *Introduction to nuclear forensics. Principles of*	29 (2013)

International Journal of Nuclear Security, Vol. 2, No. 1, 2016

isotopic signatures and their origins, ultra-trace radiochemical separations, and isotope measurements via nuclear counting and mass spectrometry.

Table 2. Courses available to fulfill the global security track in the UT MPPA degree program

Course Number	***Course Title and Description***	***# of Students since (Inception/Upgrade) as of AY 2016***
PS 556	Policy Analysis – *Strategies and techniques for identification and analysis of public problems and policy solutions.*	29 (2015)
PS 571	Foundations of Security Studies – *Theoretical and legal underpinnings to security policy.*	13 (2015)
PS 573	War, Peace, and Grand Strategy – *Issues in war, asymmetric conflict, and national/global strategies to address conflicts.*	0 (Pending first offering)
PS 580	International Relations – *Survey of literature and major aspects of international politics.*	33 (2015)
PS 682	Theory and Analysis of US Foreign Policy – *Theoretical approaches to decision making in foreign policy area and analysis of policy-making process.*	0 (Pending first offering)
PS 684	International Law – *Provides the analytical tools necessary to evaluate the legality of events under international law. Presents the law relevant to politics, such as the use of force, human rights, war crimes, international courts, principles of jurisdiction, and air, space and sea law.*	0 (Pending first offering)
PS 685	Conflict Processes – Theoretical explanations for the causes and processes of war and international disputes or crises.	15 (2015)
PS 686	Arms Control, Deterrence and Nuclear Nonproliferation - *Challenges to US and global security created by the existence of nuclear weapons and power.*	22 (2013)

Table 3. Chemistry and nuclear engineering courses available to fulfill the Radiochemistry Graduate Certificate

Course Number	*Course Title and Description*	*# of Students since (Inception/Upgrade) as of AY 2016*
CHEM 580	Radio- and Nuclear Chemistry – *Nuclear properties, structure, and models; radioactivity, decay processes; radioemission interaction with matter; radioemission detection; radioactive tracers; industrial; research and medical applications; fission; fusion; carcinogenesis; environmental radioactivity; radiation protection*	10 (2015)
NE 550	Radiation Measurements Laboratory – *Physics and electronics associated with radiation detection and measurement, methods of data analysis. Applicability of particular detector measurements and fundamentals of radiation detection instrumentation operation.*	61 (2011)
CHEM 511	Analytical Separations – *Physical principles and instrumentation of the modern methods of separation of mixtures into simpler fractions or pure compounds.*	33 (2015)
CHEM 531	Materials Inorganic Chemistry and Catalysis – *A survey of the structure properties of contemporary inorganic materials. Topics include structure and bonding, methods of synthesis and characterization, introduction to heterogeneous catalysis.*	20 (2015)
NE 433	Principles of Health Physics – *Radiation quantities, limits and risk assessment, external and internal dosimetry, biological effects of radiation, radiation detection, radiation interactions and decay, applications. (This is a senior-level undergraduate course, and must be taken for graduate credit to qualify)*	297 (2011)
NE 635	Nuclear Forensics – *Introduction to nuclear forensics. Principles of isotopic signatures and their origins, ultra-trace radiochemical separations, and isotope measurements via nuclear counting and mass spectrometry.*	29 (2013)

IX. References

1. Ned A. Wogman, Leonard J. Bond, Alan E. Waltar, and R. E. Leber, "The Nuclear Education and Staffing Challenge: Rebuilding Critical Skills in Nuclear Science and Technology," *The Journal of Radioanalytical and Nuclear Chemistry* 263 (2005): 137–143, doi: 10.1007/s10967-005-0027-z.

2. Eduard F. Kryuchkov, "Nuclear Education in Russia: Status, Peculiarities, Perspectives and International Cooperation," *Progress in Nuclear Energy* 50, no. 2 (2008): 121–125, doi: 10.1016/j.pnucene.2007.10.014.

3. National Research Council (US) Committee on Assuring a Future US-Based Nuclear Chemistry Expertise, *Assuring a Future US-Based Nuclear and Radiochemistry Expertise* (Washington, DC: National Academies Press, 2012).

4. Andy Oppenheimer, "Destructive Deals: North Korea, Pakistan and the Proliferation of Weapons of Mass Destruction," *The World Today* 60, no. 2 (2004): 26–27.

5. Sheena Chestnut, "Illicit Activity and Proliferation: North Korean Smuggling Networks," *International Security* 32, no. 1 (2007) 80–111, doi: 10.1162/isec.2007.32.1.80.

6. Richard Stone, "North Korea's Bomb: Boom or Bust?" *Science* 314, no. 5797 (2006): 233, 10.1126/science.314.5797.233.

7. William J. Perry, "Proliferation on the Peninsula: Five North Korean Nuclear Crises," *The Annals of the American Academy of Political and Social Science* 607, no. 1 (2006): 78-86, doi: 10.1177/0002716206290850.

8. Mark Fitzpatrick, "Iran and North Korea: The Proliferation Nexus," *Survival* 48, no. 1 (2006): 61–80, doi: 10.1080/00396330600594264.

9. US Department of State. *Joint Comprehensive Plan of Action* (2015) http://www.state.gov/e/eb/tfs/spi/iran/jcpoa/.

10. Willem Janssens and Howard L. Hall, "Safeguards Education and Training: Report and Follow-up of the 2015 INMM-ESARDA Meeting." *Proceedings of the 57th Annual Meeting of the Institute of Nuclear Materials Management* (2016).

11. Micah Zenko, "Intelligence Estimates of Nuclear Terrorism." *The Annals of the American Academy of Political and Social Science* 607, no.1 (2006): 87–102, doi: 10.1177/0002716206290862.

12. Matthew G. Bunn, William H. Tobey, Martin Benjamin Malin, and Nickolas James Roth, *Preventing Nuclear Terrorism: Continuous Improvement or Dangerous Decline?* (Cambridge, MA: Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard Kennedy School, March 2016), http://belfercenter.ksg.harvard.edu/publication/26400/preventing_nuclear_terrorism.html.

13. Steven Mufson, "Brussels Attacks Stoke Fears About Security of Belgian Nuclear Facilities," *Washington Post*, March 25, https://www.washingtonpost.com/world/europe/brussels-attacks-stoke-fears-about-security-of-belgian-nuclear-facilities/2016/03/25/7e370148-f295-11e5-a61f-e9c95c06edca_story.html.

14. Kyoshi Kurokawa, Katsuhiko Ishibashi, Kenzo Oshima, Hisako Sakiyama, Masafumi Sakurai, Koichi Tanaka, Mitsuhiko Tanaka, Shuya Nomura, Reiko Hachisuka, and Yoshinori Yokoyama, "The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission." *The National Diet of Japan* (2012).

15. International Atomic Energy Agency, ed., *The Fukushima Daiichi Accident* (Vienna: International Atomic Energy Agency, 2015).

16. Howard L. Hall, "Fukushima Daiichi: Implications For Carbon-Free Energy, Nuclear Nonproliferation, and Community Resilience." *Integrated Environmental Assessment and Management* 7, no. 3 (2011): 406-408, doi: 10.1002/ieam.225.

17. Michael May, chair. *Nuclear Forensics: Role, State of the Art, Program Needs* Washington, DC: Joint Working Group of the American Physical Society and the American Association for the Advancement of Science, 2008).

International Journal of Nuclear Security, Vol. 2, No. 1, 2016

18. Gene Aloise, *Nuclear Forensics: Comprehensive Interagency Plan Needed to Address Human Capital Issues* (Washington, DC: United States Government Accountability Office, DIANE Publishing, 2010).

19. Howard L. Hall, H. L. Dodds, Jr., Jayson Hayward, Lawrence Heilbronn, J. Wesley Hines, Haitao Liao, G. Ivan Maldonado, Laurence F. Miller, Ronald E. Pevey, Arthur E. Ruggles, Lawrence W. Townsend, Belle R. Uphadhyaya, (2010) "Nuclear Engineering and Nuclear security: A Growing Emphasis at the University of Tennessee," *Proceedings of the Pacific Northwest International Conference on Global Nuclear Security – The Decade Ahead* (Institute of Nuclear Materials Management, 2010), http://www.inmm.org/PNNL_Conference_Papers.htm.

20. Don Prosnitz, "WMD Sensors: Search and Seizure." *Science* 310, no. 5750 (2005): 978-978, doi: 10.1126/science.1115536

21. Gordon G. Lee, "The Morrill Act and Education," *British Journal of Educational Studies* 12, no. 1 (1963): 19-40, doi: 10.2307/3118919.

22. Barak Obama, *National Security Strategy of the United States* (Washington, DC: The White House, 2010), www.whitehouse.gov/sites/default/files/rss_viewer/national_security_strategy.pdf).

23. Brian Finlay, "A 'Whole of Society' Approach," *Courier* 73 (2011), http://www.stanleyfoundation.org/articles.cfm?id=711.

24. "Research Facilities: Safeguards Laboratory." Oak Ridge National Labratories, http://web.ornl.gov/sci/ees/gnstd/facilities.shtml.

25. "Alarm Response Training," Y-12 National Security Complex video, 02:47. http://www.y12.doe.gov/library/videos/alarm-response-training.

26. Sean F. Johnston, "Implanting a Discipline: The Academic Trajectory of Nuclear Engineering in the USA and UK," *Minerva* 47, no. 1 (2009): 51–73, doi: 10.1007/s11024-009-9114-6.

27. "2015 Program Overview: Department of Nuclear Engineering," The University of Tennessee, Knoxville (2016), http://www.engr.utk.edu/nuclear/Documents/ataglance.pdf.

28. Russel Hirst, "From the Editor's Desk," *International Journal of Nuclear Securit*y 1 (2015), doi:10.7290/V7QJ7F7F.

X. Author's Bio and Contact Information

Dr. Howard Hall is the University of Tennessee and Oak Ridge National Laboratory Governor's Chair in Nuclear Security. He is a Senior Fellow in Global Security Policy at the Howard H. Baker Jr. Center for Public Policy, where he directs the Global Security Policy Program. He also directs the UT Institute for Nuclear Security. Before joining UT, he spent 20 years at Lawrence Livermore National Laboratory. His research interests include nuclear security applications at the intersection of science, security, and public policy. Professor Hall is a member of the American Nuclear Society, the American Chemical Society, and the Institute of Nuclear Materials Management. He is a Fellow of the American Association for the Advancement of Science and the American Institute of Chemists. Contact: hhall6@utk.edu