ACCELERATING THE DEVELOPMENT OF NUCLEAR NONPROLIFERATION PROFESSIONALS IN THE UNITED STATES

ABSTRACT

Human capital development is a critical issue for the nuclear nonproliferation enterprise because projections indicate that 40% of the workforce is now eligible for retirement. Moreover, legacy and emerging issues (e.g., uranium processing and advanced reactors) abound that require a need to sustain a rich human capital to support the workforce. Consequently, aggressive efforts are needed to attract, prepare, and sustain the next generation of nuclear nonproliferation professionals. One way the United States is addressing this problem is through collaborative efforts between universities and the US Department of Energy's (DOE's) national laboratories. There are many examples of educational pathways and professional development programs at the national laboratories and at universities, which may be leveraged or used as models to advance human capital development for the nonproliferation enterprise. Nevertheless, it is necessary to continue to discover impactful strategies and tactics that also attract groups that are traditionally underrepresented in nuclear science and engineering. Thus, the intent of this paper is to offer ideas that may advance and accelerate the transition from students to nuclear nonproliferation subject matter experts (SMEs) or research scientists, as well as help attract and influence underrepresented groups to consider careers in the nonproliferation mission space.

INTRODUCTION

Human capital development is a critical issue for the nuclear nonproliferation (NN) enterprise. This is especially true because 40% of the NN workforce is retirement eligible. Thus, aggressive efforts are needed to attract, prepare, and sustain the next generation of nuclear nonproliferation professionals.

The US Department of Energy's National Nuclear Security Administration (DOE/NNSA), Office of Defense Nonproliferation (DNN) University Programs is addressing this critical issue by establishing university research consortiums. There are currently three active DNN-funded consortiums, and a fourth will begin implementation in 2023. The concept of the DNN consortiums is illustrated in Figure 1.

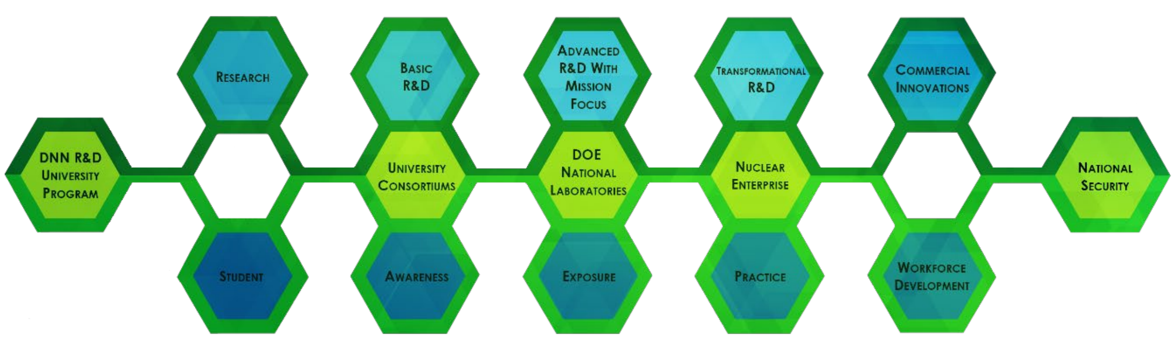

Figure 1. A Description of the DOE/NNSA DNN Consortium Model

The DNN-funded consortiums include a lead university and partnerships with other universities and national laboratories. In addition to the research, another key outcome of the consortiums is the development of the NN R&D workforce for the DOE/NNSA national laboratories. Workforce development includes both campus-based research guided by university faculty and mentoring of students by research scientists at the national laboratories. Such mentoring may include activities that range from consultation with national laboratories' SMEs, to access to user facilities at the national laboratories that may enhance or advance the campus-based research, and to participation in paid internships at the national laboratories.

Although the consortium model is an effective pipeline for cultivating the next generation of NN professionals, the throughput of the pipeline needs to be increased, especially for underrepresented groups. Thus, it is necessary to consider ways to enhance or expand the consortium model with additional, and effective, throughput mechanisms. Such throughput mechanisms should help accelerate the production of students' research (e.g., dissertations, theses, and perhaps capstone/practicum projects) required for their academic degrees. In addition, such throughput mechanisms should help accelerate production of the workforce needed to meet the demands of the NN enterprise.

Workforce acceleration should be based on ensuring the continued evolution of a world-class NN workforce. Such a workforce should be prepared to address both legacy and emerging NN issues. Thus, it is necessary to ensure America sustains a world-class NN workforce including readiness, stability, competence, and international leadership. With the increase in the global use of nuclear power, nuclear medicine, and other peaceful uses of nuclear and radiological materials, and given the need for arms control of nuclear materials to monitor, detect, and verify state's nuclear weapons arsenals, sustaining the NN workforce is considered a matter of national and global security.

PURPOSE

The purpose of this assessment is to offer recommendations for sustaining America's NN workforce by expanding the DOE/NNSA DNN consortium model (Figure 1).

This white paper is based on examples of other workforce and professional development initiatives across national laboratories, academia, and industry (see Recommendation 1). However, the NN workforce is a very complex enterprise. There are legacy and emerging problems that require a diversity of skills and talents in a variety of disciplines across science, technology, engineering, and math (STEM) areas and non-STEM areas (i.e., international law, political science, psychology, data sciences). For the NN R&D enterprise, the academic requirements will likely continue to evolve as the need to address a plethora of challenges in nuclear security, safety, and safeguards increase due to advances in technologies and proliferation schemes as well as changes in international supply chains, policies, and governances. Because of the complexity in the NN enterprise, ideas are presented under Recommendation 2 for expanding the R&D workforce sector by broadening collaborations between consortium universities and the national laboratories. Beyond these two recommendations presented, this paper suggests the need for the development and application of data analytics models that may provide insights to better understand the issues related to the NN workforce and identify approaches that can address those issues (see Recommendation 3). Data analytics can be a viable tool to forecast workforce attrition and gaps as well as analyze the effectiveness of proposed workforce development strategies to meet forecasted demands.

CLARIFYING THE NEED TO GROW THE NUCLEAR NONPROLIFERATION WORKFORCE

There is certainly a critical need to address the projected retirement of 40% of the NN workforce. However, given the breadth of the NN workforce, there is a greater need to clarify the impacts of projected retirements across the NN domains. Having this information would aid in better understanding the components of NN needing the greatest attention and those needing the least attention.

Figure 2 and Table 1 are presented to help illustrate the breadth and depth of the NN profession. These images are relatively preliminary and are based on perceptions instead of the results of actual data collection. Yet they may help clarify the scope of the NN workforce.

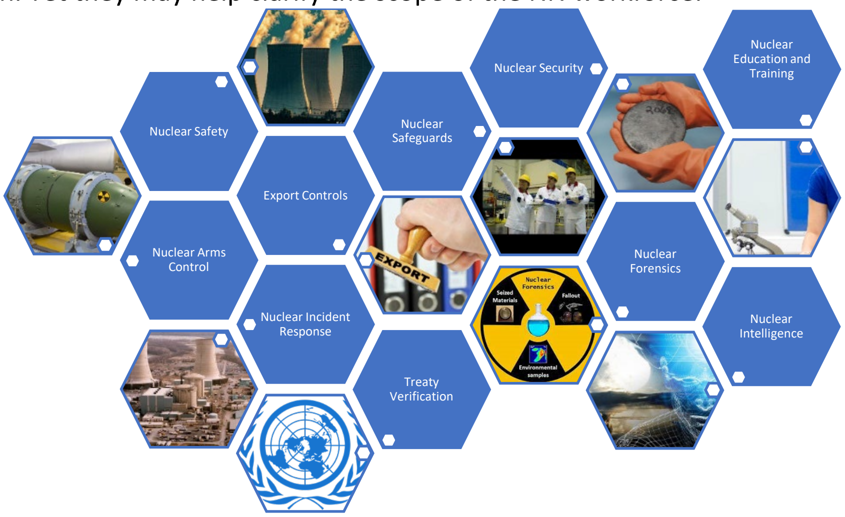

Figure 2. Some of the key components of the nuclear nonproliferation (NN) workforce

Table 1. Some of the Primary Disciplines Required for Key Components of the NN Workforce

	Arms Control	Export Controls	Incident Response	Intelligence	Nuclear Forensics	Nuclear Safety	Nuclear Safeguards	Nuclear Security	Training & Education	Treaty Verification
Chemistry - Analytical	√	√			√		√		√	√
Chemistry - General	√	√			√		√		√	√
Chemistry - Radiochemistry	√				√		√		√	√
Computer Science	√	√					√		√	√
Data Science	√						√		√	√
Engineering - Chemical	√	√			√		√		√	√
Engineering - Electrical	√		√	√	√		√			√
Engineering - General	√	√			√		√		√	√
Engineering - Mechanical	√		√	√	√		√			√
Engineering - Nuclear	√	√					√		√	√
Engineering - Software	√	√	√	√	√	√	√	√	√	√
Geochemistry					√					
Geology					√					
Geophysics	√		√	√		√	√	√	√	√
International Law	√	√			√		√		√	√
Materials Science	√	√			√		√		√	√
Physics – Condensed Matter	√		√	√			√		√	√
Physics - General	√				√		√		√	√
Physics - Nuclear	√						√		√	√
Political Science	√	√			√		√		√	√
Other Contributing Disciplines to NN:	**Accounting, Anthropology, Phycology, Sociology, Statistics**									
Other Contributing Factors:	**Years of Experience**									
Basic Criteria for Primary Disciplines:	**Research & Development vs Operations v s Policies & Government**									

Often an overlooked requirement for the NN workforce is years of experience, typically relative to certain technologies. Many NN jobs require skills across a broad range of disciplines, as illustrated in Table 1. In addition, job postings in the NN professions are often published with a list of primary disciplines along with the tag of “related fields,” which could be interpreted to mean many things.

To further illustrate the need to clarify the NN workforce, consider Table 2. Let's suppose there are 10,000 NN professionals in the workforce. With a projection of 40% targeted for retirement, then there is a simple estimate of replacing 4,000 NN professionals. Let's further assume that roughly 20% of these retirees are clearly recognized as SMEs, meaning they may have 20 years or more of relevant experience. Thus, the retirement impact becomes 800 persons with 16,000 years of experience departing the NN workforce.

Table 2. Simple Comparison of NN Workforce Departures due to Retirement vs. New NN Professionals

SIMPLE ILLUSTRATION OF THE RETIREMENT IMPACT ON THE NUCLEAR NONPROLIFERATION WORKFORCE								
Estimated Number of Nuclear Nonproliferation Professions in the Workforce								10000
% of NN Professionals Forecasted to be Eligible for Retirement								40%
% of Forecasted Retirees Perhaps Regarded as R&D Subject Matter Experts								20%
Average Number of Years of Experience for Retiring SMEs								20
Retirement Impact - No. of SMEs Leaving the Workforce Upon Retirement								800
Retirement Impact - Years of Experience Leaving the Workforce Upon Retirement								16000
Compare the Years of Experience Leaving the Workforce to the Years of Experience Entering the Workforce								
ESTIMATED PRODUCTIONS OF A DNN CONSORIUM AFTER 10 YEARS OF OPERATIONS								
	PHASE 1 OPERATIONS				PHASE 2 OPERATIONS			
	Labs	Industry	Academia	Total	Labs	Industry	Academia	Total
Year 1	1	0	1	2	6	2	7	15
Year 2	4	0	2	6	19	3	2	24
Year 3	8	0	9	17	22	2	3	27
Year 4	17	0	8	25	21	1	7	29
Year 5	26	0	13	39	17	0	3	20
Totals	56	0	33	89	85	8	22	115

In some regards, the DNN university research consortiums are established to address the R&D component of the NN workforce. Based on data received from one consortium, the output is typically around 100 persons prepared to enter the NN workforce after 5 years of operations. Thus, for the three existing consortiums, we may expect 300 persons to replace those retiring in a 5-year period.

In the most simple case, if the 40% retirement factor is viewed over spans of 5 years, then the production of three DNN university consortiums (based on data from one consortium) is roughly 300 new entry-level personnel after 5 years who have roughly 3 years of experience (based on academic research and access to internships and fellowships) yielding an entry of 300 persons with 900 years of experience to replace 800 persons with 16,000 years of experience over spans of 5 years.

This simple ad hoc analysis is certainly not accurate but is designed to help clarify the 40% projected retirement of the NN workforce. But perhaps what is most important is that there are no indicators discovered relative to the spread of the retirement projections across components of the NN workforce. Having this sort of information could set a precedence for the types of university consortiums to be established in the future.

The above simple ad hoc analysis suggests the following: (1) the NN workforce problem is real and critical; (2) strategies are needed to sustain and increase the pool and the experiences of those entering the NN workforce; and (3) sound research and creditable workforce data are needed to truly understand and to better address workforce development needs for the NN profession. The recommendations that follow are intended to address these things.

RECOMMENDATION 1: LEVERAGE BEST PRACTICES FROM EXISTING WORKFORCE AND PROFESSIONAL DEVELOPMENT PROGRAMS TO DEVELOP MORE FOCUSED PATHWAYS TO NN

Robert Keepin Nonproliferation Science Summer Program at LANL

In 2017, Los Alamos National Laboratory (LANL) and the NNSA DNN-funded Nuclear Science and Security Consortium (NSSC) jointly established the G. Robert Keepin Nonproliferation Science Summer Program (https://newmexicoconsortium.org/apply-now-to-the-dr-g-robert-keepin-nonproliferation-science-summer-program/). The program is named in honor of the father of nuclear safeguards and was established as a component of NSSC.

An objective of the NSSC is to train the next generation of nuclear scientists and engineers while engaging in research and development that supports the nation's nuclear security and nonproliferation mission. In general, all NSSC fellows are connected with a mentor at a DOE national laboratory whom the students work with throughout their academic careers. The NSSC also organizes projects and summer programs (such as Keepin) that allow students to work on-site at the national laboratories.

The Keepin Program is an intensive 8-week program that introduces participants to the world of nonproliferation and nuclear security in concert with the mission of LANL. The program consists of hands-on training, complete with weekly seminars and tours as well as a research internship where students work in small groups on a research project. The program provides a survey of the national laboratory activities and mission space, focused research projects with a strong connection to nonproliferation science and technology, and a companion symposium series linking nuclear security science, technology, and policy. The Keepin Program is designed to encourage students to consider a career in nonproliferation and nuclear security at the national laboratories, particularly at LANL.

Typically, the program is designed to bring together 20–25 of the best university students and a handful of experts in the nonproliferation world, exposing everyone to the unique facilities that LANL has to offer. Students receive broad exposure to LANL, access to mentors from LANL (and also Sandia National Laboratories), and opportunities for lab-directed research in physics, nuclear engineering and nonproliferation, intelligence and space research, international and applied technology, applied physics, national security, and more. The goals of the program are to create working relationships between NSSC students and LANL scientists, increase the number of students performing lab-directed research with LANL, and to turn research and training into careers at the national laboratories. A total of 79 undergraduate and graduate students have participated in the Keepin program since it was established in 2017—nearly 40% of whom have continued their careers at LANL. The program has a reputation for excellence and for strengthening the pipeline of students interested in contributing to the nonproliferation mission space.

National School on Neutron and X-ray Scattering (NXS) at ORNL

The National School on Neutron and X-ray Scattering (https://neutrons.ornl.gov/nxs) held its 24th annual session on July 10–22, 2022. The annual session includes 1 week of lectures and hands-on activities at ORNL followed by another week of lectures and hands-on activities at Argonne National Laboratory.

The main purpose of NXS is to educate graduate students in the use of major neutron and x-ray facilities. Lectures, presented by researchers from academia, industry, and national laboratories, include basic tutorials on the principles of scattering theory and the characteristics of the sources, as well as seminars on the application of scattering methods to a variety of scientific subjects. Students get hands-on experience using neutron and synchrotron sources by conducting short experiments at Argonne's Advanced Photon Source and at ORNL's Spallation Neutron Source and High Flux Isotope Reactor.

NXS is open to graduate students attending universities in North America majoring in physics, chemistry, materials science, geosciences, engineering or related fields, as well as to researchers with similar backgrounds who frequently use physical analysis techniques. Because NXS is highly competitive and often oversubscribed, priority is given to students who are expected to use multiple neutron and x-ray experimental techniques and who have already started their graduate research work.

NXS is jointly conducted by research scientists at ORNL's Neutron Sciences Directorate and Materials Science and Technology Division and at Argonne's Advanced Photon Source and Materials Science Division.

Trailblazers in Engineering Program at Purdue University

Trailblazers in Engineering (https://engineering.purdue.edu/Engr/Trailblazers) are workshops sponsored and coordinated by Purdue University. The workshops' objectives are to prepare future trailblazing faculty in engineering to become outstanding scholars and to equip them to commit to increasing the success of underrepresented communities of engineers. Trailblazers in Engineering fellows are selected not only for their outstanding scholarly achievements but also for their potential impact in expanding representation and diversity in engineering.

The workshop provides fellows the ability to network with leading faculty in engineering, thought leaders, program managers at key federal funding agencies, Purdue engineering heads, and of course, each other. Participants also meet current trailblazers and benefit from their keynote talks.

World Nuclear University Summer Institute

The World Nuclear Association (WNU) is the nuclear industry's leading professional development organization. Its mission is to provide comprehensive leadership, communications, and technical training to support the next generation of nuclear leaders.

One of WNU's professional development programs is the WNU Summer Institute (https://www.world-nuclear-university.org/programmes/summer-institute). This program is an immersive, 5-week nuclear leadership and professional development program for future leaders in the nuclear industry. Fellows of the institute come from around the world and are mentored by distinguished and renowned professionals across the nuclear enterprise.

The agenda for the Summer Institute include plenary topics about leadership, management, legal issues, communications, and diversity; non-power applications, including climate change, energy markets, economics, and the supply chain; safety, security, safeguards; as well as small modular reactors radiation protection, new plants, the fuel cycle (mining through disposal), plant optimization, long-term operations, and decommissioning. In addition, fellows are given technical tours of different nuclear power plants while engaging in special events that influence professional and cultural interactions and exchanges. There are numerous lessons that can be learned from the WNU Summer Institute that should help enhance existing NN professional development programs.

RECOMMENDATION 2: EXPAND COLLABORATIONS WITH THE DNN UNIVERSITY CONSORTIUMS

The examples of professional development initiatives presented under Recommendation 1 are representative of efforts that may be leveraged to enhance and to accelerate the development of the next generation of NN professionals through partnerships with the DNN consortiums. A version of the Robert

Keepin Nonproliferation Science Summer Program at LANL can be implemented across collaborating entities, as the NXS is conducted between Oak Ridge National Laboratory and Argonne National Laboratory. The Trailblazer in Engineering Program at Purdue University and the WNU Summer Institute offer insights for a broad range of ideas for professional development including ideas for programs targeted for minorities and underrepresented groups. On the other hand, many internship programs already include aspects of these examples. Undergraduate and graduate internships at the DOE national laboratories provide a range of experiences that include hands-on research projects, access to and tours of research facilities, and participation in a host of lectures and seminars. Thus, the challenge is leveraging these existing programs to establish programs that are targeted to the NN workforce.

Nevertheless, the focus of this paper is accelerating the production of the consortiums to meet the demand of the national laboratories as they face NN workforce challenges due to retirements and increasing workload requirements. Ideally, multiple students in the pipeline would be available to succeed scientists and researchers at the DOE national laboratories as they transition out of the NN workforce. An ideal case of succession planning would be a seamless transfer of roles and responsibilities. Consequently, we offer programmatic recommendations to help accelerate the production of NN professionals.

Program A: Apprenticeship—Include 40 Hours of Training for Consortium Students on the Relevance/Impact of NN R&D during a Conventional 10-Week Summer Internship (Target: BS and MS Students)

For consortium students participating in a conventional 10-week summer internship assignment, their internship should include approximately 36 hours per week of research activities and 4 hours per week of learning about the relevance and impact of NN R&D. Over 10 weeks, interns would be exposed to 40 hours of training to inspire them to continue pursuing careers as NN professionals. During this training, students should gain an interest in NN R&D by learning about (1) the importance and the impact of NN R&D; (2) the complexities and the challenges of NN; (3) the unique capabilities at the national laboratories to address NN challenges; and (4) the broad range of NN career opportunities at the national laboratories and at other federal agencies. The 40 hours of training may include motivational talks by NN research scientists and managers, technical lectures/seminars, hands-on experiences/activities, and tours of facilities and capabilities that support the NN R&D activities. Ultimately, the intent of this training is to help students become indoctrinated in NN R&D by developing networks of colleagues among subject matter experts and fellows across all NNSA consortiums. With regards to indoctrination, students should exit their internships with a better understanding of the applications of their disciplines to NN R&D and a broader awareness of courses outside their disciplines that may broaden their insights and views. With respect to implementation, an appropriate internship portal should be designated with terms and conditions that align as much as possible with the consortiums' goals and objectives for collaborative partnerships with the national laboratories. Also, it is proposed that the 40 hours of training be implemented across the 10 weeks in the same 4-hour block on the same day of the week.

Program B: Coaching—Provide at Least 40 Hours of NN Professional Development to Consortium Students in Residence under a NN SME for an Extended Period (more than 3 consecutive months) to Accelerate and Advance the Development, Relevance, and Impact of their Graduate Research (Target: Master's and Doctoral Students)

Consortium graduate students may be in residence (or on-site) at a national laboratory for extended periods to work with SMEs to help accelerate and advance the scope of their thesis and dissertation research. In some instances, such extended periods may be frequent visits (typically for a week or less at a time) to conduct experiments and to collaborate with national laboratory SMEs before returning to their universities to continue their research. On the other hand, an extended period might be a consecutive length of time beyond 3 months but not exceeding 18–24 months. For consortium students performing graduate research at a national laboratory for a significant consecutive period of time (lasting 3 months or more), there is a commitment required of an SME to mentor and supervise the students' research. Under this arrangement, the SMEs should also commit to facilitating 40 hours of NN professional development for their students.

For this program to be effective, a NN professional development plan should be developed by the national laboratory SME before the student comes onboard. The plan should be agreed upon by the consortium student, his/her faculty research advisor (or committee as appropriate), and by the SME serving as the student's mentor while in residence at the national laboratory. A professional development plan should consist of at least 40 hours of NN skills development for the student that is to be completed during his/her in-residence tenure. The plan may include more than 40 hours based on the length of time the student will be in residence at the national laboratory. At minimum, the plan should include (1) skill sets the student will develop that are pertinent to the student becoming a SME; (2) opportunities to collaborate with recognized SMEs across the national laboratories and at an operational site; (3) experiences that increase the student's understanding of key issues which his/her research may address; (4) lectures, seminars, and workshops, which students may likely participate in as bystanders, presenters, facilitators, and organizers to help advance their professional development; and (5) an overview of human reliability programs and security requirements for NN professionals.

This proposed program for consortium graduate students has some similarities to the DOE Office of Science Graduate Student Research Program (SCGSR). SCGSR provides supplemental funds for graduate awardees to conduct part of their doctoral research at a host DOE laboratory/facility in collaboration with a DOE laboratory scientist for 3–12 consecutive months. Under this program, candidates must provide confirmation that a national laboratory research staff member has agreed to collaborate to provide mentoring support for the doctoral student's research. Applicants must also identify a topic that is part of the program's priority research areas, which have an Office of Science mission focus.

The SCGSR is a good model to leverage for consortium graduate master's students choosing to complete a research thesis in lieu of course work and for consortium graduate doctoral students who are considered ABD, or "all but dissertation." The intent of Program B is to inspire consortium students to become NN professionals through a prescribed set of basic or fundamental NN professional development. This program should create a collaborative research partnership between the student, his/her research professor, and the national laboratories research scientists as well as an experience that extends beyond academic research. Expected results should include timely completion of the student's graduate research and a more impactful research product. In addition, because of the professional development component, the student should emerge better prepared and equipped to transition to the NN workforce with a greater interest in pursuing a long-term career in NN R&D.

For master's students, the collaboration may cover 1 year that begins in the summer as a summer intern under Program A followed by a long-term visitor status during the following fall and/or spring. For the doctoral students, the collaboration should perhaps be 1 year. During this time, the doctoral student should establish a network of collaborators and should become a candidate for early career programs including postdoctoral assignments and distinguished-named research fellowships. Under Program B, the students should become fully indoctrinated to the point of becoming capable to help develop a younger generation of NN professionals. As efforts are made to indoctrinate consortium fellows into becoming NN professionals, there should be an effort (like the Trailblazers in Engineering Program at Purdue) to develop them as NN professionals who are also interested in growing as mentors and as scholars. Thus, avenues should be developed to recognize and reward the performances of consortium fellows under Program B based on the impact of their research products and their professional development tracks. In addition, incentives are recommended for mentors for developing effective professional development tracks for consortium fellows. These incentives might include coverage for labor as well as special merit awards and recognitions.

Program C: Diversity—Increase Awareness of, and Exposure to, NN Careers among Underrepresented Groups (Target: Undergraduates and Minority-Serving Institutions [MSIs])

It is recognized that there is disparity of underrepresented groups in the NN profession. Moreover, minority serving institutions (MSIs) produce a large portion of underrepresented groups in disciplines relevant to NN. Hence, a concerted effort is needed to promote awareness and exposure about the NN profession and about career opportunities at the national laboratories.

In addition, more aggressive efforts are encouraged to promote awareness and exposure among underrepresented groups about professional careers in NN. Efforts should be made to promote awareness among HBCUs, Hispanic serving institutions, and Asian Americans and Native American Pacific-Islander Serving Institutions. To this end, it is necessary to seek opportunities to invite MSIs to participate in seminars and organizations to provide them with information about NN professions and careers. In addition, the DOE national laboratories should consider participation in events sponsored by STEM programs and by student programs at MSIs to help increase awareness among underrepresented groups about NN opportunities and careers.

Efforts to promote and advance NN among MSIs will require more than conventional methods. Thus, additional strategies and tactics are needed to help produce sustainable relationships, partnerships, collaborations, and alliances with MSIs to expand the pool of NN candidates. It is also necessary to collaborate with a sample set of MSIs to better understand their landscape of challenges and opportunities. To be effective, this would most likely require site visits to campuses as well as site visits by the MSIs to federal agencies and to the DOE national laboratories to learn about their NN missions and programs. Both visits will help the MSIs expand awareness and interests and may encourage efforts to develop educational and training curricula and programs that aid in (1) increasing the pool of underrepresented groups and (2) advancing the capabilities of both underrepresented groups and MSIs to support the nation’s NN initiatives.

RECOMMENDATION 3: APPLY DATA ANALYTICS R&D TO BETTER UNDERSTAND THE NN WORKFORCE

Sustaining the NN workforce is a complex human resource problem as well as a complex national and global security problem. Because of its complexity, more research is needed to better understand how to sustain a skilled workforce in this mission space. Thus, the application of data analytics tools, used where most possible and feasible, should help with discovery of new and enhanced approaches to building a strong NN workforce. Data analytics is a force multiplier for complex problems and has become a tool for addressing technical issues in nonproliferation and arms control. There appears to be no published efforts to apply data analytics to matters related to the NN workforce.

Advances in computing, algorithms, and new data sources often justify the use and development of cutting-edge data analytics approaches for nonproliferation and arms controls. These techniques are typically applicable to decision makers in developing policies and enhancing security, safety, and safeguards operations in terms of monitoring, detection, and verification measures. Thus, it is reasonable to consider the viability of data analytics to address issues relative to the NN workforce.

As we understand, the DNN consortiums are designed to produce a workforce for the NN enterprise with particular emphasis on the production of research scientists for the DOE/NNSA national laboratories. At present, the production has been successful, but it is unknown if there are metrics relative to addressing the national laboratories' nuclear nonproliferation workforce needs. Nevertheless, what if there were an alignment between the needs of the national laboratories and the human capital products of the consortiums' universities? What if the attritions by the national laboratories were accommodated by the human capital outputs of the consortiums? What if a workforce balance were sustained by the relationships, partnerships, and collaborations between the national laboratories and the consortiums? What if a way to predict emerging workforce trends and gaps in the NN enterprise and at the national laboratories existed? On the other hand, what if the consortiums' universities and the national laboratories could better address diversity issues by increasing the number of underrepresented groups in the pipeline? And, what if there was a way to examine demographic trends and gaps to maximize acquisition of all possible pipelines to build a stronger NN workforce? These are just a few workforce development issues for which data analytics may provide support to decision makers in the NN workforce.

We envision the development of NN data analytics workforce tools that support the consortiums in determining what types of disciplines and skills to emphasize to meet the NN workforce future requirements. We also envision the development of similar tools that support the national laboratories in sustaining their expertise. Moreover, we anticipate such tools will aid DNN in developing criteria for future consortiums to address the workforce development needs of the national laboratories as well as the NN enterprise. Furthermore, it is probable that such NN data analytic tools may become a force multiplier for universities to support the development of new education curricula and training programs that are structurally relevant to the NN enterprise.

The development of data analytics methods is expected to provide insights to better understand key issues related to the NN workforce and identify solutions that can address those issues. Moreover, such tools may help provide more effective collaborative partnerships between the national laboratories and the consortiums in cultivating the next generation of NN professionals.

SUMMARY

This paper has presented ideas to increase and advance the next generation NN workforce, especially for the DOE/NNSA national laboratories. The NN workforce is facing a significant attribution problem as 40% of the workforce being eligible for retirement. As legacy and emerging issues abound for the nuclear industry, so does the need to sustain America's rich human capital in NN to support global nuclear initiatives.

The DNN university consortiums are designed to help address the NN human capital problem, especially for the national laboratories. The outputs of the consortia have proven to be significant. Yet, it remains a constant challenge to discover strategies and tactics that may help increase and accelerate their productions to meet the future demands and the challenges of the nation's NN missions. Thus, it is necessary to engage the consortiums in addressing the workforce requirements for the next generation of NN professionals. By doing so, the products of the consortiums—and of other universities—will likely better align with the retirement and attrition timelines/forecasts for the nuclear enterprise, especially with respect to the national laboratories.

Data analytics tools should be developed to help decision makers understand the pipeline and the human capital landscape. These tools should aid in better clarifying the NN human capital products needed for the future.

Many examples of internships and professional development programs already exist at the national laboratories and at universities and can be leveraged or used as models to further advance human capital development for the NN enterprise. Nevertheless, it is necessary to continue to discover impactful strategies and tactics to attract underrepresented groups. Consequently, the intent of this paper has been to offer ideas that may help accelerate workforce development (and security) for the next generation of NN experts and scientists for the nation.

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