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Angela Lousteau
Cecil Parks
Stephen Croft

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OAK RIDGE NATIONAL LABORATORY
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TECHNICAL AND PROGRAMMATIC NEEDS FOR A SUSTAINABLE NDA PROGRAM FOR THE US DEPARTMENT OF ENERGY

Angela Lousteau
Cecil Parks
Stephen Croft

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CONTENTS

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ACRONYMS

DNFSB	Defense Nuclear Facilities Safety Board
DOE	Department of Energy
DQO	data quality objective
EM	Environmental Management
LEU	low-enriched uranium
NCS	nuclear criticality safety
NCSP	Nuclear Criticality Safety Program
NDA	nondestructive assay
NNSA	National Nuclear Security Administration
TSG	Technical Support Group
UQ	uncertainty quantification

EXECUTIVE SUMMARY

Nondestructive assay (NDA) plays an integral role in the characterization of nuclear materials across various Department of Energy (DOE) programs and missions. In this role NDA is crucial to assuring effective, efficient, safe, and secure nuclear operations that comply with regulatory requirements and consensus standards. Despite the central need for NDA across the DOE complex, the preservation and advancement of NDA capabilities continues to be a challenge. With NDA playing a prominent role in such diverse areas as decommissioning, waste management, nuclear criticality safety, and material control and accountability, it is important that current NDA capabilities are sustained and, moreover, that new developments in NDA are supported to facilitate the evolving needs and challenges facing national programs now and in the future.

Defense Nuclear Facilities Safety Board Recommendation 2007-1, which was specifically related to shortcomings of in situ holdup measurements at defense nuclear facilities, identified the need for improved coordination in managing NDA challenges across the DOE complex. To identify ongoing programmatic needs, especially those that cut across multiple organizations and missions, the Nuclear Safety Research and Development Program, managed by the Office of the Chief of Defense Nuclear Safety (NA-511) within the National Nuclear Security Administration (NNSA) and with assistance from the Oak Ridge National Laboratory, organized the Workshop on the Technical and Programmatic Needs for a Sustainable NDA Program for the US Department of Energy held at Oak Ridge National Laboratory on April 10–12, 2018. A total of 42 participants representing multiple DOE organizations, including the NNSA, the Office of Environmental Management, several national laboratories, and government contractors overseeing nuclear site operations attended the workshop to provide perspectives on the utilization of NDA decommissioning activities, waste management operations, nuclear criticality safety evaluations, material control and accountability, and other disciplines. A combination of presentations and facilitated breakout sessions provided a forum for engagement and open dialogue among stakeholders in the NDA community. The workshop provided a unique opportunity for technical and programmatic stakeholders to collectively identify key NDA challenges facing various DOE programs, identify the technology needs to address current challenges or emerging opportunities for NDA utilization, and leverage synergies between DOE sites. The primary objectives of the workshop were to identify current and emerging challenges and technical gaps for NDA within the DOE complex and to recommend actions that could provide tangible benefits to current and future DOE operations and programmatic missions.

The collective findings from the workshop can be summarized into two functional areas: technical and programmatic. Many of the technical needs identified by participants were cross-cutting, affecting users and stakeholders across all programs. The following recommended actions would enhance the implementation of NDA technology:

1. Focused efforts to sustain NDA hardware and software compatibility with evolving computer operating systems
2. Standardization of the qualification and acceptance process for new measurement systems
3. Increased availability of reference nuclear materials for calibrations and system testing
4. Increased access to nuclear facilities and resources to support advancements in NDA hardware and software development

5. Research and develop active NDA systems and techniques using portable neutron generators that could replace radiation sources in active NDA systems
6. Research and implement improved techniques for data analysis, trending, and archiving to improve operational efficiency and reduce uncertainties
7. Research, develop, and implement advanced algorithms to support new measurement methodologies and techniques
8. Focused and expanded efforts to develop and use consensus standards
9. Conduct of workshops that enable operational and technology information exchange
10. Expand DOE directives related to NDA measurements to encourage consistent practice across the DOE complex

Programmatically, the workshop established a clear need for a knowledge management process and the associated mechanisms and tools that would enable information exchange. This integrated knowledge management focus could reduce the fragmented site-by-site approach to addressing operational issues and challenges and fortify staff development. Each mission area that relies on and has a vested interest in NDA-generated information would benefit from capturing and distributing lessons learned and providing a library of relevant data, publications, measurement campaign experiences, available reference nuclear materials, and available training courses and material. An increased emphasis on technical training and professional development is needed to support staff development and succession planning.

In summary, the workshop participants confirmed the proposed value of a coordinated, national NDA technical support program and identified significant benefits that such a program could provide for safety, security, operations, and mission effectiveness within the DOE complex. A formal DOE/NNSA technical support program could strengthen NDA capabilities across the complex and ensure adequate resources are sustained for response to challenges that emerge within the United States and abroad. Goals of a support program would be to facilitate coordinated strategies (e.g., technology sustainment and improvement, knowledge management, foundational training program, etc.) that would enable development of a clear and sustainable pathway to meet DOE missions efficiently and effectively. Benefits of a national support program include improved workforce development and operational efficiency through information preservation and dissemination, risk and cost reduction through adoption of modern tools and more standardized qualification and approaches, improved operational safety margins through development of new measurement techniques and processes, and creation of a focused champion for the development and use of consensus standards and/or DOE orders or directives that foster improved use of NDA methods.

DOE/NNSA organizations recognize the importance and necessity of NDA in meeting regulatory requirements; however, few organizations realize the potential for NDA technology to significantly improve operational efficiency and mitigate safety, security, and operational risk. A national program can assist sites and mission areas to achieve the full potential of NDA through a cohesive approach to addressing the current challenges and technology gaps identified within this report. In addition, a national program may assist in the development of design requirements for new facilities by helping ensure NDA considerations are included at the design onset, a vitally important element to creating technically defensible measurement programs that are effective and robust. This report provides specific details on the workshop discussions that identified challenges and needs facing the NDA community and provides recommendations that should be considered to ensure a sustainable NDA program in the US DOE complex.

1. INTRODUCTION

1.1 MOTIVATION AND BACKGROUND

Nondestructive assay (NDA) is an integral component in many US Department of Energy (DOE) programs. These techniques are heavily relied upon to support DOE safeguards and security policy requirements and to demonstrate compliance with international commitments and international safeguards agreements. In addition to providing a deterrent, NDA tools are the most important means available to directly verify that nuclear materials are accounted for and that loss, theft, or diversion has not occurred. Each DOE site and program has different strengths and weaknesses, different types of nuclear materials, different measurement instrumentation, and different missions (e.g., nuclear weapons, nonproliferation, nuclear energy, science, environmental management). These diverse programs and missions manage various material assets that require direct physical measurement.

While many customers rely on NDA measurements to ensure the safety and security of fissionable material, the preservation and advancement of NDA capabilities continues to be a challenge. The nature of the challenge itself is dynamic. There is growing recognition that although NDA is ubiquitous and essential, its overall value to operations is underappreciated, and this has resulted in long-term under-resourcing. Consequently, improved coordination in managing and addressing NDA needs across the DOE complex is necessary to ensure NDA capabilities are appropriately sustained within the US DOE complex. This need was previously highlighted in Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 2007-1 where shortcomings of in situ holdup measurements at defense nuclear facilities were identified and discussed. In response to the DNFSB Recommendation, the NDA Technical Support Group (TSG), comprised of personnel from DOE staff and contractors, was formed. The primary functions of the TSG are to provide advice and technical support to meet the needs of the DOE complex regarding in situ NDA, support the unique NDA needs of nuclear sites managed by both the Office of Environmental Management (EM) and the NNSA, and provide operational and technical expertise to the DOE through the Chief of Nuclear Safety.

The TSG tasks currently in progress include the development of guidance documentation on in situ NDA in support of nuclear criticality safety (NCS) and the development of an NDA technical infrastructure program mission and vision document, which is currently modeled after the Nuclear Criticality Safety Program (NCSP) Mission and Vision. The NCSP, executed by the Deputy Associate Administrator for Safety (NA-51), was formed with the goal of improving the criticality safety infrastructure necessary to ensure safe and efficient operations. The NCSP provides sustainable expert leadership, direction, and the technical infrastructure necessary to support safe, efficient fissionable material operations within the US DOE. It is now acknowledged that many NDA practices would benefit from a similar strategic, complex-wide approach, especially in the areas of training and education, technology development, and information preservation and dissemination. Expanding the TSG in direct support of a national-level NDA program would help strengthen many DOE programs in addition to NCS and potentially help lower overall cost associated with operations and mission area execution.

To assess the value of a nationally supported NDA program and capture the technical and programmatic NDA needs across the US DOE complex, the Nuclear Safety Research and Development Program and Oak Ridge National Laboratory organized the Workshop on the Technical and Programmatic Needs for a

Sustainable NDA Program for the US Department of Energy. The overarching goal of the workshop was to broaden the ongoing NDA efforts focused on NCS to include the NDA community across the US DOE complex.

1.2 WORKSHOP ORGANIZATION

The Workshop on the Technical and Programmatic Needs for a Sustainable NDA Program for the US Department of Energy was hosted at Oak Ridge National Laboratory from April 10 to 12, 2018. A total of 42 attendees (Figure 1) from various DOE sites, programs, and offices participated in the technical and programmatic discussions on NDA challenges. A list of attendees and affiliations is provided in Appendix A. The workshop was organized around a combination of presentations outlining NDA challenges and facilitated breakout sessions identifying needs and recommended actions. The presentation and discussions provided a forum for engagement and open dialogue among stakeholders in the NDA community. The primary objectives of the workshop were to identify key challenges and technical gaps for NDA across the DOE complex and identify the tangible benefits that can be recognized by various program missions through improved coordination addressing these challenges.

Figure 1. NDA workshop participants.

The workshop opened with an introductory overview outlining the motivation for the workshop followed by a presentation providing background on the DNFSB Recommendation 2007-1, which served as a primary driver for this workshop. Background about the importance of NDA to the NCS field and a review of the current NDA activities within the NCSP were presented with a short overview of NDA gaps and shortcomings. These opening presentations provided context for the principal question posed: *Is there value in establishing a national NDA program for the US DOE?* The role of the NCSP and its programmatic elements were further discussed to outline and provide input about what form an NDA program might take.

The plenary introduction posed the following programmatic questions for the participants to consider throughout the workshop:

1. Is there value in an NDA program at the DOE or NNSA level?
2. What are the critical elements of an NDA program?
3. How should such a program be organized to meet cross-cutting needs?

The plenary continued with presentations from five invited speakers whose purpose was to outline the grand challenges in NDA as seen from the following diverse perspectives: EM decommissioning activities, site operations and safety, international safeguards and nonproliferation, and regulations and standards. These speakers came from the Portsmouth Paducah Project Office (Office of Environmental Management), Materials Control and Accountability Program (Office of Defense Nuclear Security), Safeguards Technology Development Program (Office of Nonproliferation and Arms Control), Office of Nuclear Safety Services, and Office of Security Assistance. Small group discussions were then held to identify additional challenges (e.g., site-specific issues) not discussed in the invited plenary presentations. Once the general questions were posed and the key challenges were established by the plenary speakers, workshop participants were tasked with identifying the gaps and needs required to address those challenges.

Gaps, needs, and recommendations were identified through facilitation of eight technical breakout sessions: (1) Hardware/Software Development; (2) Algorithm Development; (3) Uncertainty; (4) Nuclear Materials; (5) Staffing, Personnel, and Training; (6) Data Management; (7) Rules and Regulations; and (8) Standards and Best Practices. The attendees had the opportunity to participate in a total of four sessions throughout the second and third day of the workshop. Throughout all eight breakout sessions, two important programmatic needs consistently emerged:

1. Coordinated management and communication of all the information, efforts, capabilities, and needs that exist across the complex in a manner that assists ongoing and planned operations
2. Adequate training for the workforce and sustaining the expertise and experience needed to address current and emerging technical challenges

At the end of the workshop, the facilitators presented the gaps and needs identified by the groups. The agenda for the workshop is provided in Appendix B. The following section outlines the programmatic challenges identified during the opening presentations. They are organized by mission area and provided the basis for the breakout session discussions. Section 3 provides a summary of the needs and recommended actions identified in the technical breakout sessions.

2. NDA CHALLENGES

NDA is an invaluable tool used to meet regulatory requirements for the measurement of nuclear materials at most DOE sites. While NDA methods can produce very accurate and precise measured values for the mass of nuclear material, the NDA measurements are only as good as the assumptions and models used for the given measurement. Poor measurement results can almost always be attributed to poor assumptions related to the material composition or matrix, item geometry, system environment, or models used for calibrations and/or analysis. Poor physical inventory execution, inadvertent accumulations of holdup deposits, and the large amount of rework (remeasurement) that have had to be performed at some sites are indicators that the NDA community could clearly benefit from improved coordination of NDA efforts across the DOE complex. Identifying current and upcoming challenges is a first step in achieving better coordination.

Many perspectives on the uses of NDA and the current challenges faced by the user community and various stakeholders were presented at the workshop. For example, NDA has the following positive attributes:

- Nonintrusive nature of the measurement techniques
- Adaptability to many measurement situations, including in situ, in-field, and fixed-location measurements
- Ability to measure entire items, thus minimizing or eliminating sample error
- Adaptability to measurement needs (e.g., locations, count times, uncertainty goals)
- Large range of tools and techniques, from those that scan for presence of an item to those that provide very precise and accurate measurements
- Availability of consensus standards for most of the basic systems

Still, there are some serious limitations hindering the performance of many NDA techniques when applied under actual field conditions:

- Large uncertainties that are difficult to quantify
- Potential for nonconservative (underestimated) measurement results due to lack of information, geometries, attenuation corrections, etc.
- Potential for overconservative (overestimated) measurement results due to “worst case” assumptions, especially for large pieces of equipment like compressors and valves
- Sensitivity of some techniques to chemical and isotopic compositions
- Lack of standardization (consensus standards) for more complex methodologies
- Obsolescence of equipment and decaying infrastructure (e.g., calibration and/or test facilities)

It is evident that NDA is a critical element in many DOE programs, but it is also evident that a champion is needed to support, sustain, and revitalize the NDA capabilities and workforce to maintain efficient and effective implementation across DOE’s diverse operations and infrastructure.

Although some sites and/or programs experience unique site-specific issues, many of the challenges identified throughout the workshop were widespread across the complex. Overarching commonalities even between vastly different programs and sites included the absence of communication and information sharing, lack of standardized training and/or a nationally recognized certification process for NDA practitioners, and lack of availability of critical resources such as instrumentation and standards for calibration and control measurements. Many of the common problems posing challenges across the complex are currently addressed on a site-by-site or program-by-program basis with little coordination or communication. Improved coordination and focus on such NDA challenges, through a national NDA program for example, would help to appropriately steer and unify NDA processes and approaches to address challenges before they become issues. A national NDA program could serve to reduce duplication of effort, improve overall efficiency of NDA operations, and ensure lessons learned are effectively disseminated between sites and programs.

The following subsections detail the specific NDA challenges presented in the following mission and programmatic areas: production and operations, safety, decommissioning and decontamination, international safeguards, and regulations. Duplication across the different mission areas is evident.

2.1 PRODUCTION AND OPERATIONS

NDA measurements provide both quantitative and qualitative data about nuclear materials for accounting, inventories, and transfers. They are used to obtain nuclear material mass values for inventories and transactions (accountability measurements), validate previously documented material values (verification measurements), and confirm the presence of a material attribute (confirmation measurement). In addition, they can provide information about the material process (e.g., fingerprinting, spatial distribution, fill height, containerization, etc.). While NDA measurements play a crucial role in detecting theft and diversion of nuclear materials, these measurement programs are not without their challenges.

The following key challenges were presented from a site operations and material control and accountability perspective:

- Lack of adequate and cost-effective training needed to develop qualified measurement personnel
- Obtaining quality measurements in complex operational environments where the application of NDA best practices is nearly impossible (due to accessibility and environmental constraints)
- Establishing and sustaining high measurement throughput
- Meeting various data quality objectives (DQOs) for different programs (e.g., material control and accountability, NCS, waste management, etc.)
- Dealing with unusual, unique, or off-normal situations (variations in process/waste stream materials, containerization, etc.), where generally accepted practices are invalid or do not exist
- Implementing best practices because the time or resources involved are often viewed as an impedance to ongoing operations
- Obtaining certified reference materials to calibrate and validate measurement systems

2.2 SAFETY

Nondestructive assay measurements are of the utmost importance to ensure effective and efficient operations involving fissionable material. The measurement results help ensure safety margins are maintained to protect the workers, the public, and the site. One of the most difficult NDA challenges encountered today is the in situ measurement of nuclear materials. These in situ, or holdup, measurements are essentially "blind" measurements that are often further complicated by restricted physical access of measurement locations, poor or wrong assumptions regarding material deposits, and/or weak peer review processes. There are inherent risks in both under- and overestimating the quantity of fissile material. Underestimations lead to a reduction in the safety margin and increase the likelihood of violating NCS limits, whereas overestimations undermine the ability to ensure material is not diverted or stolen and reduce operational flexibility. The DQOs vary widely from program to program, making it difficult to achieve consistency. Since NDA measurements serve many programs with different missions, there could be significant value in aligning the DQOs across the complex.

The following NDA challenges related to safety applications were identified:

- Lack of complex-wide standardized requirements for holdup measurements
- Lack of measurement considerations during the development of design requirements for new facilities
- Inadequate research and development efforts targeting holdup measurements (Updates to holdup measurement approaches and associated analysis have not been performed in nearly 20 years. The Generalized Geometry Holdup methodology overly simplifies holdup deposits and is inadequate for volumetric deposits (e.g., filters, valves) and solution tanks. More robust algorithms are needed to encompass these difficult scenarios and to deal with contaminants and interferences, low-enriched uranium, and other material types.)
- Insufficient historical or trend analysis capabilities to better support assessments and recognition of change-of-condition
- Inadequate approaches for the confirmation and validation of measurement data
- Lack of communication between programs (e.g., facility operations and nuclear criticality safety) that utilize and rely on NDA measurements in given conditions

2.3 DECONTAMINATION AND DECOMISSIONING

The greatest challenge conveyed from the decontamination and decommissioning (D&D) perspective is ensuring the quality of NDA measurements. The difficulty arises primarily from a lack of documented requirements (e.g., DOE directives and Code of Federal Regulations) associated with NDA at the DOE or NNSA level. This concern was specifically identified in the DNFSB Recommendation 2007-1 with respect to in situ measurements. Most DOE-EM programs are not recognizing the overall value (improved operational efficiency, avoidance of incidents that stop work, etc.) that can be gained from a rigorous NDA program and, therefore, only support tasks that meet and fulfill the minimum requirements of the regulations or DOE order. However, for many operations, this approach is inconsistent with expected DOE good practices that call for constant vigilance and an environment of continual improvement. Inattention to good practice principles can lead to increased errors in the implementation of NDA systems and characterization methods (including poorly estimated uncertainties, unconfirmed assumptions associated with self-shielding and material configuration, and inadequate testing of deployed systems) resulting in delayed schedules and ultimately increased costs.

The unique nature of many D&D operations is perhaps a deterrent to providing general requirements, since it could be inferred that such requirements could lead to non-beneficial measurements performed only to maintain compliance. In any case, very few documented requirements exist for operations at the

DOE-EM sites. Consensus standards help standardize some aspects of select NDA systems and applications, however, they are often considered best practices and not necessarily essential to meeting requirements. Consensus standards are also limited to the most basic NDA equipment and techniques and do not cover many of the NDA approaches that might be necessary. Without consistent requirements, oversight assessments and evaluations are subjective and often inconsistent.

Since there are no clear requirements related to the expectations on NDA measurement values, there is little support for advances that would improve operations; indeed, the lack of clear requirements encourages stagnation. The workshop participants expressed a firm belief that better guidance and more defined requirements would help support stronger, more defensible measurement programs resulting in long-term cost savings, improved effectiveness and efficiency of a measurements program, and improve the quality of NDA measurements.

Additional D&D challenges include:

- Lack of coordination and technical exchanges between different sites that could enhance best practices on similar measurement activities
- Characterization of facilities that were not designed to facilitate NDA measurements (e.g., poor signal-to-noise ratios, large equipment and closely spaced piping, lack of support structures limit access to given areas)
- Poorly written DQOs
- Cost-driven programs that limit innovation
- Lack of adequately trained and knowledgeable staff and/or difficulty retaining staff

2.4 INTERNATIONAL SAFEGUARDS

International safeguards are a key element of the global nuclear nonproliferation regime. These NNSA programs support the development and implementation of NDA tools, technologies, and techniques that support and sustain the international safeguards system through improved inspectorate effectiveness and efficiency with minimal intrusiveness to the facility. The nature of international safeguards programs (e.g., verifying or confirming the absence of nuclear material or nuclear activities) is in and of itself a challenge.

The number of facilities and quantities of nuclear materials subject to safeguards continues to grow annually. Since 2013, the number of facilities has grown ~3% and the number of significant quantities of safeguarded nuclear material has grown ~11% based on reported IAEA Safeguards Key Facts. In addition, the International Atomic Energy Agency is challenged by designing, developing, and implementing safeguards approaches for new types of nuclear facilities that have never before been subject to nuclear safeguards. There is also an increased number of nuclear facilities being decommissioned, and issues related to the termination of safeguards are coming to the forefront as legacy facilities are being dismantled. There is also a growing interest in safeguards for geological repositories. Reduced budgets, increasing attrition among safeguards professionals both internationally and domestically, and the loss of critical facilities and infrastructure increase the difficulty in addressing this evolving international landscape.

The following NDA challenges and needs within the international safeguards regime were identified:

- Availability and readiness of efficient and effective tools to verify ^{235}U in fresh low-enriched uranium (LEU) fuels
- Spent fuel verification methods to detect partial or single pin defect with high detection probability
- Modern, high-precision instrumentation with reliable, well-understood technology that is implemented in a versatile, rugged, user-friendly platform with a long battery life for improved field use
- New detector types with better signal discrimination
- Improved active neutron techniques that leverage neutron generators as replacements for physical radiation sources
- Expanded use of hypothesis testing to complement quantification methodologies
- Additional benchmark measurements to validate models and simulations and improve estimates of their contribution to overall measurement uncertainty
- Lack of methods or procedures that help establish confidence in joint-use equipment
- Lack of information and capabilities to adequately model new processes and facilities
- Improved ability to analyze large data sets with associated data visualization (more data are being collected without a robust data management architecture in place to process it effectively)
- Improved processes for quantification of uncertainty
- Expertise and knowledge to address anomaly resolution and special evaluations of one-off situations
- Improved imaging systems for new safeguards applications
- Constraints caused by the restrictions on wireless communications in facilities
- Reliable mechanisms to authenticate, encrypt, and exfiltrate data back to the International Atomic Energy Agency

2.5 REGULATIONS AND STANDARDS

Nondestructive assay methods are used to measure nuclear materials in large and small containers, various chemical and physical forms, fresh and spent fuel, etc. The NDA measurements are often performed at multiple locations and at various stages in material processing (e.g., in-process monitoring, transfers between material balance areas and sites, during physical inventories, item confirmations, and at disposition). The specific measurement technique must be chosen based on several factors including the type of material, quantity, and configuration to be measured. The selection and qualification process for NDA systems is not consistent throughout the complex. Currently, there are no performance requirements for the measurements. They only must be sufficient to detect theft or diversion, and the definition of "sufficient" can vary significantly from application to application.

Notably, the Office of Security (AU-50) previously had a Technology Development Program for Domestic Safeguards that assisted and supported implementation of DOE safeguards and security policy requirements. This program provided support for identification and testing of commercially available techniques and equipment for applicability and use in DOE operational environments and assisted program offices and sites with validating commercial products in a cost-effective manner (i.e., serving as a clearinghouse). These (perhaps) forgotten activities now define an enormous gap.

Additional NDA-related challenges and needs are listed here:

- Effective communication of site-specific and complex-wide needs
- Large variety of material assets that must be measured
- Changing and evolving material streams
- Lack of a standardized qualification process for new and existing NDA measurement methods
- Availability of certified nuclear material measurement standards
- Lack of consistent uncertainty analysis processes across the complex
- Inadequate communications and technical information exchanges that could support improved interpretation and use of NDA results across disciplines
- Understanding and supporting a large array of NDA methods to address decommissioning activities, waste stream monitoring, measurements on new forms of nuclear fuel, spent nuclear fuel, nuclear materials holdup, and termination of safeguards
- Aging workforce and loss of NDA expertise
- Analyzing and managing large data sets

3. NDA GAPS, NEEDS, AND RECOMMENDATIONS

The gaps, needs, and recommendations identified during the technical breakout sessions are presented in the following subsections. The summarized output from each session is presented independently to maintain the integrity of the discussions. As a result, there is some duplication and overlapping recommendations from each of the breakout sessions. Table 1 at the end of the section provides a summary of these needs and the recommended actions necessary to address them.

All organizations represented at the workshop expressed a strong desire for more effective information sharing—an issue already noted in Section 2. The need for a knowledge management tool was cited throughout the entire workshop as a cross-cutting need. There was consensus that an actively maintained mechanism to capture lessons learned, best practices, problems with implemented solutions (shared experiences), references to technical literature and specialist documentation, resources available for use (e.g., reference nuclear material or equipment), relevant nuclear data, raw measurement data, etc. would support technology development across the community and would likely substantially reduce duplicated efforts, cost, and time associated with NDA measurements and data processing.

3.1 HARDWARE/SOFTWARE

The Hardware/Software breakout sessions were intended to identify the needs related to NDA hardware and software, although various interrelated issues were also raised reflecting the high degree of connectivity between different facets of all measurement programs. Apparent from the discussions was that many of the hardware and software needs across the complex are specific to the site or mission for which they are used. Still, there are commonalities among the different missions: all are interested in more efficient detectors, medium resolution spectrometry, and easy-to-deploy tools. Most, if not all, have trouble with compatibility between existing hardware/software and new computer operating systems that are becoming commonplace. All programs would benefit from more accurate nuclear data parameters. An information and equipment exchange would potentially reduce overall costs associated with research and development of "single-use" hardware and software packages (i.e., those developed to address a single issue and are therefore not useful for "other" applications) and hopefully eliminate duplicate efforts from site to site. A national technical support program could provide a structured approach to information and hardware sharing that would complement and support individual task-driven projects.

A standardized measurement system qualification process would also greatly benefit the DOE complex. Currently, each site is required to perform a formal system qualification for each NDA system or technique used for reported measurement results. This exercise is an extremely time-consuming and expensive effort, and it sometimes precludes the use of the best instrument for a given job. Standardization of the qualification process and acceptance at a national level would allow sites to "piggy back" on the qualification performed at other sites, saving time and reducing costs associated with the implementation of new NDA equipment/systems. Nonprescriptive guidance and performance demonstration testing that could be widely adopted across sites would help enable this transition.

Holdup measurements are another area of significant concern for many sites. One of the biggest issues is effectively locating holdup deposits in large process items and equipment. Reliably identifying holdup deposit locations is a significant challenge for D&D and operating process facilities that must avoid inadvertent accumulations. Many sites have instituted scanning programs designed to identify areas where material holdup is located and implement approaches to identify changes in the deposit. But these efforts are often implemented for safety or operational reasons, and the data are rarely tied into the existing holdup measurement systems focused on nuclear material accounting. A more integrated approach or advanced process monitoring applications might increase the efficiency of these scanning programs and allow for better coverage of the equipment and areas. Subsequently, findings should be shared and used to inform process accumulation models.

Integration of environmental sensors into measurement algorithms would support the identification and correction of potential degradation of detector performance such as gain drift and electronic noise. Such algorithm upgrades are especially important with the implementation of new detector technologies where longevity and stability in various conditions are less well established (e.g., pulse-shape discriminator scintillators). This approach may also provide a mechanism to reduce or better quantify the impact of external interferences such as cosmic-ray induced backgrounds.

3.2 ALGORITHM DEVELOPMENT

The Algorithm Development breakout sessions identified many technology gaps and needs related to the software and algorithms used within the NDA community. Identifying current user needs and requirements upfront may help streamline algorithm development by increasing the practicality and utility of algorithms/software and reducing duplication of efforts across the complex. Algorithms for the following topical areas are particularly outdated or underdeveloped: neutron multiplicity and other active neutron counting techniques, isotopic determination, segmented gamma scanner, and holdup measurements. In addition, general improvements to gamma-ray spectrum analysis would benefit many aspects of NDA measurements.

Neutron multiplicity is an important technique that provides a mechanism for measuring challenging objects not conducive to more common gamma techniques. While multiplicity counting has numerous advantages in these situations, its use is limited by current algorithms. To take full advantage of neutron multiplicity counting, extensions to the fundamental point model, updates to dead-time corrections for fast counting, exploration of cross-correlation between detector banks, and improved list mode processing algorithms are needed. Additionally, active neutron techniques, which are heavily relied on to measure bulk material, historically rely on the use of radioactive sources (e.g., AmLi and ^{252}Cf) to produce the interrogation flux. Because of rising costs and reduced availability of those sources, more emphasis should be put on the use of neutron generators. Adaptation of existing systems to use neutron generators will require some modification to analysis algorithms.

Software packages for isotopic determination are generally well developed; however, there is little support for software maintenance and improvement. Some codes are actively updated to maintain compatibility with newer operating systems, incorporate new algorithms to deal with interferences, measurement corrections, detectors, etc., but they lack formal verification and validation for most applications. Other codes are maintained ad hoc by independent code developers with no succession plan for maintenance or sustainability in the outyears. Implementation of configuration control under a software quality assurance process will ensure consistent and reliable methodologies are available for interpretation of quantitative data from physical inventory and other confirmatory measurements.

The Segmented Gamma Scanner, a heavily employed quantitative measurement system, uses commercial-off-the-shelf software that does not integrate current best practices and has not been updated in decades (e.g., end-effects are not included). Algorithm corrections for end-effects and lumps need to be implemented into a modernized software package. Enhanced gamma-ray spectrum analyses are also needed to address difficult and unique measurement challenges encountered at various sites. Better algorithms for LEU applications, advanced continuum analysis to extract additional information on the physical properties of the item of interest, improved fitting techniques for "medium" resolution detectors like $LaBr_3$, and expansion of the Generalized Geometry Holdup algorithms to include volumetric analyses (for solution tanks) are all topics that need to be addressed.

Software quality assurance for new algorithms and software packages is also challenging because there is a time and cost burden that must be initially addressed. However, decades of experience have shown that properly implemented software quality assurance provides tremendous efficiencies in the long run and improves reliability for both new and legacy software. Inter-comparison exercises can help identify poor assumptions, errors, or both in software and provide significant value as additional algorithms and software packages evolve and enter use in the community. These round robin measurement campaigns strengthen and enhance the verification and validation of new algorithms and measurement techniques to demonstrate that an algorithm is fit for purpose. Alternatively, improvements and upgrades to the nuclear infrastructure within the complex could support the implementation of NDA system test beds, which could serve as the foundation for verification, validation, and qualification of a new algorithm. Consolidation and standardization of this process would ultimately reduce the costs of implementing new algorithms and software packages.

Lastly, a supported, controlled mechanism for distributing and sharing algorithms between sites would be of tremendous value to the community of users. Common resources—such as a collection of basic Monte Carlo N-Particle (MCNP) input decks; a library of key nuclear data; and raw measurement data—could be made accessible and could be used to support validation tests, case study development, data analyses, or uncertainty evaluations.

3.3 UNCERTAINTY ANALYSIS

The breakout session on Uncertainty Analysis examined the current methodologies for estimating measurement uncertainty. Proper uncertainty analysis is a major challenge as there are no overarching requirements or standards defining the process. Across the complex, there is not a consistent methodology used for uncertainty quantification (UQ). Uncertainty analysis is rarely incorporated into NDA analysis software in a comprehensive and technically defensible way (generally only counting statistics are reported). Even the definitions and terms used in conjunction with UQ vary among sites and programs. Therefore, it is even more difficult to qualify measurement methods as *fit for purpose*. UQ methods are still validated on a case-by-case basis. Users often develop uncertainty models differently based on whether an item is being measured for accountancy or for criticality safety, and a focus on aggregate values introduces a different emphasis. Random uncertainties and systematic uncertainties can have different meanings depending on the user. Asymmetric uncertainties and full probability density distributions are not supported by current reporting databases. These issues highlight a need for a consistent uncertainty quantification approach designed to meet the needs of all the different stakeholders.

Measurement techniques are qualified over a specified set of parameters and for a given set of assumptions; however, determining the validity of those assumptions is challenging. Models and simulations are often used to predict measurement results but face the same challenges: Are the models used good enough? What is the uncertainty in the assumptions that are made? How well is the underlying nuclear data known? Again, the real complications come in validating these models.

Material recovery and validation (e.g., material balance before and after clean out compared to the amount recovered) is crucial for measurement confirmation and the development of good measurement uncertainty practices. The ability to validate NDA measurement techniques, especially for in situ measurements is recognized as being very difficult and often expensive. However, there is not a better way to provide confidence in a measurement technique. Performing destructive analysis on more items or systems could also help reduce uncertainties associated with assumptions based on process knowledge or other acceptable knowledge made during the measurement process. The process for including human error or human factors is not defined and thus not often incorporated into the total measurement uncertainties. Current regulations do not mention bias corrections, or lack thereof, for UQ.

3.4 NUCLEAR MATERIALS

The discussions in the Nuclear Materials breakout session focused on both the lack of reference nuclear materials available and on the need for measurement capability of difficult-to-measure nuclear materials. Suitable reference standards are necessary to confirm the quality of measurement results obtained by an NDA system and ensure an overall quality measurement program is maintained. There is a complex-wide need for representative, traceable standards (e.g., geometry, composition, density) to support calibration and validation of measurement systems, support hands-on relevant training of NDA professionals, help benchmark Monte Carlo simulations, validate measurement assumptions including those used in the uncertainty analysis, and ultimately reduce measurement uncertainties. Maintaining certified reference nuclear materials is an ongoing, yet necessary, investment because even small process changes or variations in measurement configurations (e.g., holdup vs. waste drums) may suggest the development of new material standards or working reference items. Additional challenges arise in situations where representative standards are not available (e.g., holdup deposits, nuclear materials from new processes and waste streams, or unique nuclear materials). A subset of reference nuclear materials common across DOE sites would be extremely beneficial and ensure all sites can place themselves on a common absolute scale.

Suitable reference materials are needed for hardware and algorithm/software testing and evaluation. Often, NDA systems are tested with material surrogates; however, this situation adds uncertainty to the measurements and complicates performance demonstration. Further, the need for better and more formalized equipment and software testing processes was identified in the breakout session.

Specific nuclear materials necessary to improve the DOE infrastructure include material standards for both highly enriched uranium and LEU holdup measurements, uranium standards in the 5–60% enrichment range, uranium and plutonium in various matrices, and various types of fresh nuclear fuel.

Additionally, the availability of more complex nuclear materials (e.g., spent nuclear fuel) should be better communicated and made accessible to others in the DOE complex.

In general, facilities and resources within the complex should be more easily accessible to support testing and development. A repository of measured data for various reference materials would provide a mechanism to test (at least to some degree) software and algorithms. A round robin measurement campaign where various standards are sent around the complex for measurement would support many sites by providing the ability to cross-calibrate instruments, prepare working reference materials with traceability, and mine enough data to develop acceptable target values for various measurement systems. Other information sharing should include a list of reference nuclear materials available for use/measurement; identification and availability of nuclear test facilities; documented processes for developing traceable standards; and measurement needs for identified nuclear materials (e.g., LEU).

3.5 STAFFING, PERSONNEL, AND TRAINING

Participants in the Staffing, Personnel, and Training breakout session primarily considered personnel training, staff retention, and knowledge management. Staffing varies site to site: Some sites require a large workforce of measurement technicians, whereas others need mid- to senior-level NDA experts (expertise that takes years to develop) to ensure proper use of specialty equipment and interpretation of results. A national NDA program could encompass a training program aimed at identifying and meeting training requirements for NDA practitioners, scientists, and organizational managers. A clear message from participants was that on-the-job training and experience must be complemented by broader education to build well-rounded NDA professionals with the ability to think critically about "off normal" conditions and their consequences. The requirements for a well-established and effective training program are ill-defined at a national level. Some sites may provide on-the-job training, some may require a formal vendor-led training, and still others may incorporate more advanced technical training. The *ASTM C1490-14: Standard Guide for the Selection, Training, and Qualification of Nondestructive Assay (NDA) Personnel* is used by some sites to develop in-house training and qualification requirements; however, the current version could be improved to include a more detailed description of a qualification program for NDA practitioners.

The development of a nationally accepted qualification program for NDA practitioners was the most well-supported recommendation from this breakout session. A formal qualification program or DOE guidance for an adequate qualification program would support a combination of standardized on-site, off-site, and on-line training, which would reduce the cost of developing, maintaining, and implementing in-house training at each site once developed. Suggested topics to be considered for inclusion into the core curriculum include: basic math, nuclear physics, radiation detection, fundamentals of NDA, NDA techniques, and measurement statistics. These modules could be developed and implemented by a combination of vendors, national laboratories, the DOE National Training Center, or modularized at the sites. On-the-job training would then be reserved for specific NDA techniques, but could potentially be standardized for many general-use systems. Such a process should ensure that all NDA practitioners are trained with the same core curriculum and provide recognition and consistency of skills between sites. As such, some or all the training qualifications could be easily ported to other sites within the complex reducing lost startup time for staff who might transition from site to site and improving communications between practitioners.

Challenges in providing adequate training for staff is exacerbated by the high turnover and attrition rates being experienced at many sites. NDA is a small, specialized field, and unless there are opportunities for career growth and professional recognition and development, it is difficult to retain quality personnel. Knowledge retention is another significant challenge experienced by all sites due to an "aging" workforce. Often, sites cannot open a position or hire new staff until the current position is vacant. This provides little opportunity for knowledge transfer and mentorship and leaves many single points of failure. A national program cannot directly address retention issues like salary and benefits or job flexibility. However, a national program can assist sites and organizations by facilitating access to high-quality training and engagement with other professionals, stimulate an improved understanding of NDA value to management, and provide recognition for staff who excel at the core competencies. The function of the TSG might be expanded to assist sites with mentoring new staff or addressing challenges for which qualified staff are not available.

The need for a central knowledge repository was identified consistent with recommendations from other breakout sessions. Such a resource could support training efforts; effectively capture and share lessons learned, references, documents, data, and other resources; and improve communications overall. Oral histories, recorded presentations and so forth can provide an important and personal connection between new staff and the decades old facilities where they may find themselves working. Mission space, accidents, upgrades, and lessons learned from experience (good and bad) would all make suitable subjects for information preservation.

3.6 DATA MANAGEMENT

The Data Management breakout session focused on the use of NDA measurement data. NDA data are used in various ways by various organizations to address multiple technical and programmatic needs. The challenges include inconsistent data handling, inadvertent introduction of human errors, variation in reporting techniques between programs, and handling of measurement uncertainties and shipper/receiver differences. The breakout session addressed topics regarding data usage (e.g., users, information flow, handling, data transformations, and reporting), current systems and their limitations, process requirements, data archiving, and opportunities for improvement. A significant need exists for improved data management processes. Measurement data are often manually input into reporting systems and can be handled or manipulated upward of 10 times, increasing the opportunity for errors. Additionally, data transformations where raw data is manipulated to meet specific user needs are not well documented and can lead to mismatching values (for the same item) recorded in different systems. This situation typically stems from inadequate requirements on data reporting and the nonstandard mechanisms in which uncertainties are handled. More automated data acquisition and standardized reporting mechanisms are needed to reduce data manipulation errors; the emphasis should be on assisting the NDA professional rather than turning their function into a mundane task.

As with previously discussed breakout sessions, the need for better communication and knowledge sharing was discussed during this breakout session. A searchable measurement data repository (including information regarding measurement systems, calibrations, standards, etc.) to support audits, historical trend analysis, and archiving would be an invaluable asset that could be used by all the sites. The ability to quickly and easily document relevant aspects of a measurement would reduce the burden of audits and preserve measurement integrity.

3.7 REQUIREMENTS AND STANDARDS

Because of the significant overlap of identified needs and recommendations from the Rules and Regulations breakout session and the Technical Standards and Best Practices session, the results are combined in this section. The discussions on Rules and Regulations centered around the need for better requirements to strengthen the quality of NDA data. The Technical Standards and Best Practices breakout session concentrated on the potential use and integration of NDA-related consensus standards with DOE orders. Quality data are the bedrock that will help ensure the safety and security of DOE nuclear programs and minimize operational interruptions. The lack of standardized requirements and technical standards governing NDA measurement programs, however, reduces confidence in NDA measurement results.

Obtaining quality in NDA measurements starts with a core belief that measurements are important and contribute significantly to an organization. The importance of NDA and the need to better communicate that importance to various stakeholders was endorsed throughout the workshop. The consequences and repercussions of poor NDA practices must be more effectively communicated. The underlying viewpoint of many participants was that NDA is an afterthought for many sites and organizations; thus, leading NDA programs to be understaffed and underequipped to address the issues. In many situations, inadequate resourcing for NDA activities has become the accepted practice.

Without defined or required processes outlining how NDA measurements should be performed (i.e., no standardization), there is little that can be identified in an assessment or audit. More defined requirements would support oversight and provide the foundation for more robust and technically defensible NDA measurement programs. Naturally, there will be some reluctance to new or expanded requirements. Importantly, expanding NDA-related requirements does not necessarily translate into a loss of flexibility or over-prescriptive guidance. New requirements must be carefully written by NDA experts to ensure they are reasonable and achievable. The ASTM working group process could stand as an example of the needed process for adding requirements to a DOE directive.

The implementation of technical standards improves standardization of measurement techniques and analyses and increases the efficiency of a measurement program by reducing the number of technical basis documents needed. Consider a shipper/receiver difference where two sites perform measurements on the same item. There are potential inconsistencies between the two values based on the selected measurement technique and analysis routine. The justification for using one value instead of the other is often difficult to document; however, standardization of measurement techniques may simplify that process by providing a generally accepted justification.

The DOE-STD-1194-2011, *Nuclear Materials Control and Accountability*, has a small subsection related to NDA, but it only lists metrics that describe *what* needs to be done – guidance on *how* to do it is not available. Desired future requirements should set a well-defined framework for NDA measurement programs. Participants agreed that technical and consensus standards are extremely useful, but without broader development and application of the standards it will be difficult to ensure that measurements are accurate and repeatable. Standards, as such, are futile if not incorporated by the site or organization as a requirement for performance expectation.

The use of standards creates a safe harbor; provides confidence in people, processes, and results; strengthens the use and understanding of NDA (outreach and communication); and creates consistency and synergy across DOE and other organizations like the Nuclear Regulatory Commission, Environmental Protection Agency, and US Department of Transportation. This environment reduces the chance for miscommunication and misunderstanding. In response to the lack of explicit NDA measurement requirements in the DOE directives identified during the plenary, the addition of an NDA section to the DOE O 420, *Facility Safety* was proposed by the breakout participants. This addition might then identify standards to be used, include additional requirements (like those outlined in the Quality System for Nondestructive Assay Characterization used by Portsmouth and Paducah), or establish common DQOs for various programs.

New and revised standards focused on training and qualification of NDA personnel, NDA systems, in situ and process monitoring measurements, uncertainty calculation, and the use of the modeling for calibrations and measurements are needed. As identified in Section 3.5, the NDA community agrees that there is great benefit in a nationally recognized NDA training and qualification program. Expanding the existing ASTM C1490 standard might be one approach to creating consensus guidance for a training and qualification program. Consensus standards are critically important to DOE measurement programs, but participation in the writing and review committees is diminishing. Participation on standards committees and writing groups should be encouraged so that the standards remain relevant and reasonable, are subject to appropriate subject matter expert scrutiny, and remain nonpartisan.

Table 1. Summary of needs and recommendations

Need:	**Recommendations:**
Improved information exchange mechanism to support a strong and more efficient NDA community	- Form and conduct an annual NDA Users Group Meeting - Conduct topical technical workshops - Develop and support a searchable knowledge management tool (e.g., website or database) that communicates the use and benefit of NDA; shares experiences and lessons learned; provides information about available training opportunities and resources (e.g., measurement equipment, reference nuclear materials, measurement data sets, pertinent documents and references); and captures complex-wide NDA needs and input regarding technology advances and user requirements
Need:	**Recommendations:**
A searchable data archive to support algorithm testing, trend analyses, and establish a historical archive for NDA data sets	- Develop data set requirements and survey NDA community for existing and needed data sets - Develop and maintain an online database architecture to manage the storage, filtration, and retrieval of measurement data - Establish an algorithm sharing mechanism to enable users and sites to obtain and/or distribute new or updated software for testing and use
Need:	**Recommendation:**

Strengthened NDA workforce to ensure the quality of NDA measurements and results	- Explore and identify potential models, tiers and progression for nationally accepted NDA training qualifications
	    - Identify technical competencies for NDA Practitioners like the Criticality Safety Qualification Standard Reference Guide for Criticality Safety Engineers or develop a foundational curriculum like the DOE Radiological Control Technician training the that will help grow and sustain NDA expertise to support the complex
	    - Develop standardized training modules
	    - Provide resources (reference materials, measurement equipment, and facilities) to effectively execute training activities
	    - Institute a multi-lab/site “mobile” NDA training team
	- Establish a mentorship program like the Human Capital Development Program (NA-24) to support shadow training, exchanges, and knowledge retention
	- Expand ASTM Standard Guide C1490-14 on training of NDA Practitioners
	- Create and implement tools to assist analysts in recognizing off-normal conditions

Table 1. Summary of needs and recommendations (continued)

Need:	**Recommendations:**

Standardized NDA measurement system qualification processes to facilitate acceptance and use of appropriate NDA systems in a cost-effective and timely manner	- Establish a formalized (and nationally recognized) system qualification process to simplify and unify the qualification of systems already in use and introduce pertinent performance demonstration testing
	    - Identify measurement controls program requirements by site
	    - Develop a formalized verification and validation process for algorithms and software to ensure reliable, consistent, and trusted results across the community
	    - Develop a formalized performance test and validation plan for NDA systems/hardware
	    - Document and share the Performance Test and Validation Reports and Evaluations for qualification of NDA systems
	- Perform round robin measurement campaigns (between national laboratories) to promote good practice and communication between measurement teams and stimulate acceptance and trust in the applied methods and results between facilities

Need:	**Recommendations:**
Increased access to nuclear facilities that can enable empirical demonstration of new measurement systems under realistic (but known and controlled) conditions	- Provide resources to sufficiently test NDA systems (equipment, nuclear materials, mock measurements scenarios that correctly mimic attenuation properties, cosmic spallation production, etc.) to ensure deployed systems are well-understood and capable of delivering trusted and reliable results - Increase support for joint measurement campaigns and field trials such that adequate testing can be performed
Need:	**Recommendation:**
Increased access to existing reference materials to support the development, testing, calibration, and validation of NDA-related technology	- Perform a survey of existing NDA reference materials within DOE - Explore ways to facilitate acquisition and ease transfers of nuclear materials and equipment between sites (often, it is easier to dispose or excess items than to transfer them) - Support procurement of adequate nuclear materials to improve and preserve nuclear measurement capabilities
Need:	**Recommendations:**
New reference standards for validation of new NDA techniques and application to new material forms	- Perform a survey of NDA reference material needs across the DOE complex - Support the development and production of new certified reference materials

Table 1. Summary of needs and recommendations (continued)

Need:	**Recommendations:**
Advanced detector development and system integration to provide reliable and sustainable field measurement capabilities	- Implement a support program to help identify and address emerging incompatibilities between computer systems and measurement software/hardware - Survey and document user requirements for field instrumentation - Perform a study to outline acceptable communication criteria (based on power levels and frequencies) needed to engineer radio-frequency (RF), wireless, or Bluetooth communication technologies acceptable for use by NDA practitioners - Support studies utilizing emerging technologies and their impact on detection efficiency and measurement uncertainty - Facilitate deployment of smaller and more capable (multi-detector support) multichannel analyzers by developing plug and play drivers that are compatible with currently used data acquisition platforms - Formalize hardware/software testing at sites and labs prior to field tests - Establish standardized test plans - Invest in infrastructure (e.g., equipment, reference materials, etc.) to support R&D testing
Need:	**Recommendations:**
Replacements for active neutron sources used in NDA systems	- Evaluate the potential for portable neutron generators to replace physical sources in existing active NDA systems (e.g., AmLi and ^{252}Cf) - Support updates to measurement software/algorithms to integrate use of neutron generators
Need:	**Recommendations:**
System or process for locating/characterizing in situ material in large process equipment and items such that areas of material holdup can be appropriately measured	- Document and share current process monitoring methodologies used at DOE sites - Support studies on unattended and continuous monitoring capabilities to measure flows and processes, assist in material balance measurements, and provide confidence in facility operations over long periods of time - Develop advanced neutron measurement techniques to evaluate thick deposits in heavy equipment - Develop analysis techniques capable of measuring volumetric holdup deposits
Need:	**Recommendations:**
Reduction in total measurement uncertainties for NDA methods	- Identify the current methodologies used across DOE for estimating uncertainty - Identify the mechanism by which UQ methodologies are validated - Identify DQOs for each site across DOE - Establish a support group and set of case studies for different techniques - Confirm or validate NDA measurements by supporting destructive analysis on measured items

Table 1. Summary of needs and recommendations (continued)

Need:	**Recommendations:**
Improved and expanded nuclear data to support measurement analysis and algorithm development	- Survey NDA applications specialists and algorithm developers to identify nuclear data needs - Prioritize nuclear data needs based on potential reduction in measurement uncertainties - Support nuclear data projects and experiments
Need:	**Recommendations:**

Enhanced algorithms and software programs for NDA applications to increase measurement capability and reduce measurement uncertainty	- Support algorithm development and testing in the following areas:
	    - Neutron multiplicity counting, including assay and background characterization
	    - In situ measurements of volumetric sources
	    - Isotopic analyses (enrichment and composition) that build on research and development outside of the tradition nuclear spectroscopy domain
	    - Integration of end effects and lump corrections for Segmented Gamma Scanner analyses
	    - LEU analyses methods to address ^{99}Tc interferences (from recycled U)
	    - Analysis techniques for materials (e.g., LEU and new fuel types) where traditional techniques tailored around ^{235}U gamma rays are limited by self-attenuation
	    - Analysis techniques for commercial or research reactor spent nuclear fuel
	- Investigate approaches to expand software packages to handle contaminants, interferences, chunks, nonuniformities, and truly unknown items where assumptions are difficult compared to the traditional routine of developing single-purpose systems
	- Develop flexible software platforms that include trending and archiving capabilities and use a standard interface specification independent of equipment vendor

Need:	**Recommendations:**
Advanced inverse modeling techniques to better understand the assumed conditions and parameters that best fit the measured data of “unknown” items	- Evaluate the application and use of modeling and simulation to perform sensitivity analyses to better outline measurement uncertainties - Investigate the use of Bayesian logic to decide the best solution to various problems - Transition to improved application models—A national technical support program should nurture and facilitate expanded use of modern radiation transport codes such as MCNP within measurement systems to correct for attenuation, spatial, and other effects. An effort to enable and provide guidance on incorporation of these modern codes into the measurement systems would, for many cases, substantially improve measurement uncertainties and reduce reliance on incorrect assumptions

Table 1. Summary of needs and recommendations (continued)

Need:	**Recommendations:**
Standardized and improved data analysis processes to provide consistent results across the DOE complex	- Develop a formalized process to link simulations and calibrations (e.g., published case studies and guidance on reporting) - Evaluate the use of integrated data (i.e., measurement data from several NDA methods) to confirm agreement between NDA methods and instruments
Need:	**Recommendations:**
Standardized data management processes to provide consistent results across the DOE complex	- Develop standardized requirements for data transformations (e.g., calculations and reporting) to ensure data integrity is maintained - Develop standardized requirements for uncertainty reporting and handling - Support automation of data acquisition and reporting mechanisms to reduce data handling errors
Need:	**Recommendations:**

Increased participation in standard writing committees	- Perform a survey of NDA-related standards and their current status
	- Establish, maintain, and update standards for the following topics as needed:
	  - Process monitoring
	  - Use of modeling for calibrations and measurements
	  - Uncertainty determination for NDA measurements
	  - Selection and qualification of NDA Systems
	- Expand ASTM C1490–14, *Standard Guide for the Selection, Training, and Qualification of NDA Personnel* to include nationally recognized training qualifications for NDA personnel (or at least outline the framework)
	- Reestablish ASTM C1592, *Guide for Making Quality NDA Measurements*
	- Hold and support working group meetings to maintain standards

Need:	**Recommendations:**
Integration of additional technical standards into formal requirements	- Add NDA-specific chapters to DOE orders - Invoke N15.56 standard in directives 420 and perhaps 470 and 474 - Establish a working group to develop domestic target values where similar methods applied to similar nuclear materials should get similar quality results. Such information would also assist instrument selection when changes are needed, or new facilities need to be measured - To better align NDA processes, establish common DQOs for DOE, possibly modeling the Environmental Protection Agency–DQO process

4. SUMMARY

NDA measurements are an indispensable asset for all aspects of nuclear operations (i.e., production to waste disposition) and serve as the foundation supporting safety, safeguards and security, and nuclear material management. The instrumentation, software, and practices developed decades ago from the deep technical expertise following the "golden age" of nuclear technology development have served the DOE and NNSA complex well. However, emerging measurement challenges, development of new processes and nuclear materials, equipment obsolescence, long-term limited investment, and the retirement of experienced NDA professionals are all problems threatening the future of NDA in the United States. The gaps between the current state of practice, potential state-of-the-art based on current technology, and future potential are enormous. Ignoring the programmatic challenges and technology gaps in NDA will eventually impact operational effectiveness and efficiency and could be detrimental to safety and security.

The 3-day Workshop on the Technical and Programmatic Needs for a Sustainable NDA Program for the US DOE brought a representative cross-section of NDA experts, users, and other stakeholders across many disciplines together to discuss the value of a national-level NDA program that could help address some of these pressing issues. Participants provided insight into current and foreseeable challenges facing the NDA community and used technical breakout sessions to identify important technical and programmatic NDA needs and gaps across the DOE complex. While there exist some niche areas that require special attention, the workshop identified several gap areas and needs that are broad and shared across sites and stakeholders. The shared program vision included four key elements:

1. Integrated knowledge management and active communication across DOE sites and organizations
2. Investment in the NDA workforce (e.g., improving culture, supporting professional development opportunities, and establishing unified approaches to training and program qualification)
3. Strategic actions to encourage and facilitate uniformity and process standardization that provide consistency and confidence in the implementation and use of NDA measurements
4. Focused efforts to develop and integrate improved technology (e.g., improved computational methods, algorithms and data; improved compatibility of hardware and software; exploratory studies around emerging technologies)

Collectively, it was agreed that NDA is mission critical and better coordination of resources is essential to maintain current capabilities and transition toward best modern practices. An NDA program focused on cross-organization technical support for the complex could be structured along the four elements cited above and address many short- or near-term needs acknowledged during the workshop by:

- Establishing a mechanism(s) by which information is readily shared and accessible across the DOE complex
- Developing and implementing an assistance program for training and developing NDA practitioners
- Creating clear goals and objectives for successfully and consistently measuring SNM mass, to ensure all safety bases limits, criticality safety controls, and material control and accountability requirements are satisfied
- Facilitating professional development opportunities to strengthen the NDA workforce
- Improving algorithm software and access to field deployable equipment

- Encouraging and stimulating the development and use of written consensus standards
- Supporting and implementing round robin measurement campaigns to ensure continuity and consistency of implementation across the DOE on methods, standards, instruments, and uncertainty quantification

Present practices in NDA largely rest on capabilities created decades ago and are often seen as a cost to be minimized rather than an indispensable enabling asset to be continually maintained and enhanced. Thus, it is important that the central role as well as the limitations of NDA are properly understood within the broader context and that the fundamental importance of NDA to nuclear operations are widely conveyed. Future meetings or workshops that engage a spectrum of NDA practitioners, mission owners, site managers, etc. can assist efforts to further communicate the challenges currently being faced and the benefits that can be realized when the use of NDA shifts from an afterthought to a forethought, from a cost to be minimized to an investment to be treasured. Continued engagement and buy-in from all tiers involved in making NDA measurements and those that rely on the data generated is necessary.

Revitalization of NDA across the US DOE complex is long overdue. Implementation of the program vision cited above should support DOE and NNSA goals for more efficient and effective operations while reducing safety, security, and material accountancy risks. It is envisioned that an investment in such a program will pay long-term dividends by reducing the overall programmatic costs to the US government. Without a proactive, integrated approach, there appears to be little support for even incremental advances in NDA practice within the complex.

Participants of the workshop at ORNL overwhelmingly praised the value of the workshop in providing a medium for outreach and communication across the NDA community. Thus, a commitment to annual technical workshops on topics such as in situ holdup measurements, isotopic analyses, and modeling and simulation of NDA techniques would be an excellent first step toward improved communication and problem-solving across the community. The TSG may be an existing body of subject matter experts who can help advise and prioritize on a series of workshops and help in develop implementation steps for a technical support program.

The workshop and this ensuing report provide a catalog of identified needs and technology gaps as well as a set of recommendations that, if addressed, can generate cross-disciplinary benefits for numerous DOE and NNSA programs and organizations that rely on NDA. To achieve these benefits, it will be necessary to develop a sustainable NDA technical support program that casts a clear and concise mission and vision and implements a coordinated strategy to address the needs and technology gaps. While NDA plays a foundational role in ensuring material accountancy, safety, and security for DOE operations it will continue to erode without proper attention and resource investments.

APPENDIX A. WORKSHOP PARTICIPANT LIST

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Tim Aucott Savannah River National Laboratory	Angela Lousteau Oak Ridge National Laboratory
Pam Baird Four Rivers Nuclear Partnership, Inc. (Paducah)	Delis Maldonado Oak Ridge Inst. for Science & Education
Larry Berg NNSA (NA-512)	Melanie May DOE (AU-52)
Douglas Bowen Oak Ridge National Laboratory	Richard Mayer DOE EM PPPO (Portsmouth)
Chuck Britton Oak Ridge National Laboratory	David McAllister Nuclear Fuel Services
Angela Chambers NNSA (NA-511)	Bob McElroy Oak Ridge National Laboratory
Jeff Chapman Oak Ridge National Laboratory	Arielle Miller Defense Nuclear Safety Board
Cary Crawford Oak Ridge National Laboratory	Cecil Parks Oak Ridge National Laboratory
Stephen Croft Oak Ridge National Laboratory	Linda Paschal Oak Ridge National Laboratory
Amanda DeHart Fluor-BWXT Portsmouth LLC	Brandon Rasmussen Restoration Services Inc. (ETTP)
David Dolin Savannah River Site	Nathan Rowe Oak Ridge National Laboratory
Arden Dougan NNSA (NA-241)	Ralph Royce Restoration Services Inc. (ETTP)
Ernest Elliott Los Almos National Laboratory	Mark Schanfein Idaho National Laboratory
Micah Folsom Oak Ridge National Laboratory	Jason Schnackenberg Lawrence Livermore National Laboratory
Vanna Gaffney DOE OREM (EM-933)	Angela Simone Oak Ridge National Laboratory
Bill Geist Los Almos National Laboratory	Susan Smith Oak Ridge National Laboratory
Phillip Gibbs Oak Ridge National Laboratory	Sharon Steele NNSA (NA-511)
Richard Green NNSA Production Office	Christy Steen Y-12 National Security Complex
Jeff Gross Lawrence Livermore National Laboratory	Somer Stephens DOE OREM (EM-932)
Cynthia Gunn Y-12 National Security Complex	Allen Townsend Four Rivers Nuclear Partnership, Inc. (Paducah)
Jessica Halligan Lawrence Livermore National Laboratory	Ram Venkataraman Oak Ridge National Laboratory
Joe Harvill Nuclear Waste Partnership, LLC	Holly Watson Savannah River National Laboratory
Tom Hines DOE EM PPPO (Paducah)	Harold Wheat Y-12 National Security Complex
Mansie Iyer NNSA (NA-21)	Keith Wines Fluor-BWXT Portsmouth LLC
Sandi Larson Atkins Nuclear Solutions	

APPENDIX B. AGENDA

Workshop on the Technical and Programmatic Needs for a Sustainable NDA Program for the U.S. Department of Energy
April 10-12, 2018

Event contact	Angela Lousteau, 865-576-0276, lousteaula@ornl.gov Linda Paschal, 865-241-7636, paschallj@ornl.gov	
TIME	**Event**	**Lead**
Oak Ridge National Laboratory, 1 Bethel Valley Rd. Oak Ridge, TN 37831, JICS Bldg. 5100		
Day 1		
8:00 – 8:20	Arrival at JICS (5100)	Sonda Ellis
8:30 – 8:40	Welcome	Cecil Parks
8:40 – 8:50	Workshop Structure and Logistics	Angela Lousteau
8:50 – 9:00	Motivation	Angela Chambers
9:00 – 9:30	Background on DNFSB/NCSP/TSG	Doug Bowen
9:30 – 9:50	Grand Challenges: EM	Dick Mayer
9:50 – 10:10	Grand Challenges: Operations	Amy Whitworth
10:10 – 10:30	Break	
10:30 – 10:50	Grand Challenges: International Safeguards	Arden Dougan
10:50 – 11:10	Grand Challenges: Safety	Larry Berg
11:10 – 11:30	Grand Challenges: Regulations and Standards	Melanie May
11:30 – 12:00	Panel: Question & Answers	Moderator: Stephen Croft
12:00 – 1:15	Working Lunch: Expectations and topics for small group discussions	Angela Lousteau
1:15 – 2:45	Small group discussions: Facility-specific challenges	ORNL
2:45 – 3:30	Group Photo/Break	

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TIME	**Event**	**Lead**
Oak Ridge National Laboratory, 1 Bethel Valley Rd. Oak Ridge, TN 37831, JICS Bldg. 5100		
Day 1		
3:30 – 4:15	Short presentations from groups	
4:15 – 4:30	Summary and directions for Day 2	

TIME	Event	Lead
Day 2		
8:30 – 10:00	Break-out Sessions: - Hardware/Software (Rm. 134) - Algorithm development (Rm. 130) - Rules and regulations (Rm. 262) - Data management (Rm. 276)	Facilitators: Mark Schanfein Bob McElroy Dick Mayer Phil Gibbs
10:00 – 10:30	Break	
10:30 – 12:00	Break-out Sessions: - Uncertainty analysis (Rm. 130) - Nuclear materials (Rm. 276) - Staffing, personnel, and training (Rm. 262) - Standards and best practices (Rm. 134)	Facilitators: Jeff Chapman Jeff Sanders Bill Geist Jeff Gross
12:00 – 1:00	Working Lunch: Break-out Session Debrief	Angela Lousteau
1:00 – 2:30	Break-out Sessions: - Hardware/Software (Rm. 276) - Algorithm development (Rm. 130) - Staffing, personnel, and training (Rm. 262) - Standards and best practices (Rm. 134)	Facilitators: Mark Schanfein Bob McElroy Bill Geist Jeff Gross
2:30 – 3:00	Break	

TIME	Event	Lead
Day 2		
3:00 – 4:30	Break-out Sessions: - Uncertainty analysis (Rm. 130) - Nuclear materials (Rm. 276) - Rules and regulations (Rm. 262) - Data management (Rm. 134)	Facilitators: Jeff Chapman Jeff Sanders Dick Mayer Phil Gibbs

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TIME	**Event**	**Lead**
Oak Ridge National Laboratory, 1 Bethel Valley Rd. Oak Ridge, TN 37831, JICS		
Day 3		
8:30 – 8:45	Summary of break-out session topics	Angela Lousteau
8:45 – 10:00	Presentations from break-out sessions	Facilitators
10:00 – 10:30	Break	
10:30 – 11:00	Presentations from break-out sessions	Facilitators
11:00 – 11:30	Workshop summary	Stephen Croft
11:30 – 11:45	Next Steps	Cecil Parks
11:45 – 12:00	Closing Remarks	Angela Lousteau