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Proceedings for the Workshop on Applied Nuclear Data Activities 2026

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EXECUTIVE SUMMARY

The annual Workshop for Applied Nuclear Data Activities (WANDA) connects different communities that invest in nuclear data and have their own unique needs for the purposes of sharing information, identifying cross-cutting needs and capabilities, and fostering collaboration. The attendance of federal program managers at these workshops is essential in creating awareness of the needs of their respective communities and in providing information to better guide funding investments.

The 2026 Workshop for Applied Nuclear Data Activities (WANDA) covered five topic areas in nuclear data: Nonproliferation and Safeguards for Advanced Reactors, Creating an Inventory Sub-Library, Mapping out the Path to the Next-Generation of Fission Data, Artificial Intelligence/Machine Learning (AI/ML) for Nuclear Data: Opportunities and Challenges, and Instrumentation and Facilities for Nuclear Data. In each of these topical sessions, a general description of the nuclear data needs and capabilities was presented, along with discussions of existing capabilities that could be leveraged, potential synergistic needs or resources, and challenges that must be overcome for the application space to progress.

A common theme across all sessions was increasing the availability, accuracy, and transparency of nuclear data to include better quantification of uncertainties and a more robust validation pipeline. Many subject areas had overlap in the types of data that they use (e.g. fission product yields, integral experiments), and the instrumentation and facilities session highlighted the variety of ways in which communities obtain this data. The use of AI/ML was a continuing cross-cutting capability identified to improve the nuclear data pipeline, including reducing time for data to get to end users and to increase data quality and quantity.

The main needs identified through this workshop are summarized below, many of which are common themes and would benefit multiple WANDA topic areas.

1. **Workforce Development**:
    - Continuous learning and training programs to keep up with new technologies and methodologies.
    - Importance of maintaining a robust pipeline of talent, including early-career scientists and interdisciplinary multiphysics teams.
    - Collaboration between nuclear scientists and machine learning researchers to maximize impact.
2. **Infrastructure and Experimental Design**:
    - Expanded and improved experimental facilities and detector systems to provide high-quality data to improve predictive model capabilities and reduce uncertainties.
    - Coordination between experimental design and computational modeling to ensure data relevance and quality for every application.
3. **Validation and Benchmarking**:
    - Systematic verification, validation, and benchmarking of data and models to ensure reliability and traceability.
    - Development of common standards, practices, and tools to facilitate data sharing and usage across the community.
4. **Uncertainty Quantification**:

    - Importance of quantifying uncertainties in both experimental data and models to improve predictions and decision-making.
    - Development of tools and workflows for systematic uncertainty quantification and propagation.

5. **Transparent Data and Data Availability**:
    - Ensuring data are accessible and transparent to support collaboration and reuse.
    - Standardizing data formats, forms, and metadata to improve interoperability and ML-readiness.
6. **AI/ML to Enhance the Data Pipeline**:
    - Utilizing AI/ML to streamline and accelerate the nuclear data pipeline while preserving data quality.
    - Leveraging AI/ML to improve data quality, model predictions, and decision-making.
    - Development of multiphysics-aware AI models and data curation practices to enhance productivity.

These themes highlight the importance of a coordinated effort to address the complex challenges in nuclear data, emphasizing the need for continuous improvement in data infrastructure, experimental design, and computational modelling capabilities.

1 Introduction

Nuclear data provide fundamental characterization of nuclear reactions and decays that are required to accurately model applications, including medical imaging and treatment; food safety; stellar phenomena; fission and fusion reactors; nuclear security; and particle accelerator facilities. The measurements and evaluation models employed to generate nuclear data for application libraries all have some inherent uncertainties, such as statistical and systematic uncertainties on measurements and some number of parameters or theoretical inputs to the models. These intrinsic uncertainties are propagated through the evaluation process to produce the evaluated nuclear data libraries. They are then incorporated into the application-specific simulation codes that rely on those nuclear data. On a nuclide-by-nuclide basis, nuclear data currently available in the various libraries have varying levels of quality based on the time and funding devoted to improving those data. New applications requiring nuclear data for materials not commonly used in nuclear applications to date may have large uncertainties because the appropriate nuclear data are not well measured or unavailable. In the same way, new applications requiring nuclear data for commonly used materials at different energies or in poorly studied reaction channels may also be unavailable or have large modeling uncertainties. The US government and private companies based in the US have several new and ongoing mission spaces that require accurate radiation transport modeling and precise modeling of application uncertainties. The annual Workshop for Applied Nuclear Data Activities (WANDA) connects different communities that invest in nuclear data and have their own unique needs for the purposes of sharing information, identifying cross-cutting needs and capabilities, and fostering collaboration. To facilitate this discussion and plan the annual workshop, the Nuclear Data Working Group (NDWG) was formed among research staff. Similarly, the Nuclear Data InterAgency Working Group (NDIAWG) was formed among federal program managers. Both groups are further described in the remainder of this section.

The NDWG currently has 47 members. NDWG representation is built from federal program manager nomination. Program offices may nominate up to two experts from the national laboratories who can represent the program or laboratory mission interest within the NDWG, ensuring that program-specific needs are communicated between the laboratories and the NDWG. In addition to the nominations by the federal program managers, each DOE and National Nuclear Security Administration (NNSA) national laboratory can nominate up to two individuals to represent their missions and communicate opportunities back to their home institution.

The NDIAWG collaborates and coordinates on funding opportunities from the WANDA and related workshop outputs. New research efforts can be started from stand-alone program funding opportunities and can include joint funding opportunities. Since 2015, these funding opportunities have started a significant number of nuclear data projects across a wide variety of application areas. Active projects are highlighted in a review session at each WANDA workshop. The 2026 review presentations can be found on the WANDA 2026 landing page [1].

The NDWG is responsible for determining the scope of the sessions held during the WANDA workshops to facilitate its goals as well as those of the program managers within the NDIAWG. The chosen topics are based on current national priorities, funding agency mission goals, and input from the greater nuclear data community. WANDA helps to gain consensus from the workshop participants on crosscutting nuclear data needs and actionable recommendations that will improve nuclear data across the application spaces. These recommendations are recorded in proceedings such as this one and are used to guide future funding opportunities. Proceedings from previous WANDA workshops can be found on the NDWG website [2]. The NDWG website also includes other publications and resources that are useful to the broader nuclear data community

This report is organized into five sections which describe the sessions held during the workshop. These sections are Nonproliferation and Safeguards for Advanced Reactors, Creating an Inventory Sub-Library, Mapping out the Path to the Next-Generation of Fission Data, AI/ML for Nuclear Data: Opportunities and Challenges, and Instrumentation and Facilities for Nuclear Data. Each section provides a summary along with intended session goals followed by the grand challenge(s) in that topic area, and new opportunities or unique capabilities. Cross-cutting needs, areas of synergy, and overall recommendations were highlighted in each section.

2 Plenary Talks

The opening morning of WANDA is a plenary session intended to engage federal program managers with a vested interest in the outcomes of the workshop as well as provide an opportunity to communicate priorities and needs from a programmatic perspective.

The plenaries featured at WANDA this year included speakers from the DOE Office of Science Office of Nuclear Physics (DOE-NP), DOE Office of Science Office of Advanced Scientific Computing Research (DOE-ASCR), the NNSA Office of Defense Nuclear Nonproliferation Research and Development (NA-22), the NNSA Office of Experimental Sciences (NA-113), the NNSA Office of Advanced Simulation and Computing & Institutional Research and Development Programs (NA-114), the NNSA Office of International Nuclear Safeguards (NA-241), the Working Party on International Nuclear Data Evaluation Co-operation (WPEC), the United States Nuclear Regularly Commission (NRC), the DOE Nuclear Criticality Safety Program (NCSP), and the DOE Office of Science on DOE Public Access and Data Management Requirements.

Many of the speakers highlighted the importance of nuclear data to their program and nuclear data related efforts they are currently funding to meet their needs. The WPEC highlighted the impact of collaborative efforts for furthering nuclear data needs internationally and how organizations can and should work together to further the field and support the community's needs. The speaker from DOE-ASCR spoke extensively about the Genesis Mission [3,4], highlighting ways in which the nuclear data community can support and benefit from it. Additionally, the DOE Office of Science provided an overview of DOE public access and data management requirements, which are essential components of all publicly dispersible data generated by the community.

3 Nonproliferation and Safeguards for Advanced Reactors

3.1 Goals

This session focused on how *nuclear data quality, uncertainty quantification (UQ), and validation* directly enable safeguards, nuclear material control and accountability (MC&A), and proliferation-resistance assessments for advanced reactors, especially designs with moving or flowing fuel (pebble-bed reactors and molten-salt reactors), nontraditional materials, and online or process-monitoring concepts.

The goals of this session were to (1) connect safeguards observables (burnup, isotopics, off-gas signatures, neutron and gamma signatures) to the nuclear data that drives uncertainty, (2) identify the highest-leverage data gaps (reaction, decay, source-term, and covariance/uncertainty products), and (3) prioritize near-term measurement, evaluation, and benchmark pathways that close the loop from experiments to evaluated libraries to validated application performance.

3.2 Grand Challenge

The most important obstacle to overcome in the next 5 years is **building a credible, end-to-end "experiment → evaluation → validation → application" pipeline for safeguards-relevant advanced-reactor regimes**, where uncertainty is transparent, defensible, and decision-contextual ("good enough" is defined quantitatively by application). This requires (a) robust uncertainty/correlation products (or clearly documented alternatives), and (b) **integral/quasi-integral benchmark testbeds** that anchor performance claims, because without validation data, suspected nuclear-data needs are hard to verify or justify.

3.2.1 *Needs*

High-impact data prioritization with sensitivity + UQ workflows: A foundational need is a safeguards-focused sensitivity and uncertainty (S/U) study to identify the nuclear data that most strongly influence advanced reactor monitoring and verification metrics. This effort should quantify the impact of nuclear data uncertainties on fresh fuel verification, spent fuel characterization, and sealed-core reactor monitoring applications. Priority isotopes are expected to include U-235, U-238, U-233, Pu-239, Pu-240, Pu-241, Am-241, Np-237, and key fission products used for safeguards signatures (e.g., Cs-134, Cs-137, Eu-154, Ce-144). The study should evaluate sensitivities across thermal (<0.5 eV), epithermal (0.5 eV–100 keV), and fast (>100 keV) neutron energy ranges and establish target uncertainties (<1–3% for dominant reaction channels) needed to support safeguards-relevant observables.

Advanced-reactor validation science: Integral and quasi-integral benchmark experiments are needed to validate nuclear data in advanced reactor environments that differ substantially from traditional Light Water Reactor (LWR) systems. Experiments should target thermal, epithermal, and fast neutron spectra representative of microreactors, High Temperature Gas Reactors (HTGRs), molten salt reactors, sodium-cooled fast reactors, and sealed-core reactors. Particular emphasis should be placed on materials and isotopes commonly used as moderators, reflectors, shielding, and structural components, including H-1, D-2, C-12, Be-9, O-16, F-19, Li-6, Li-7, Na-23, Fe-54/56, Cr-52, Ni-58/60, Zr-90/91/92/94, Si-28, and Pb-206/207/208. Measurements should prioritize reaction channels and energy regions where existing uncertainties exceed approximately 3–5% and significantly impact safeguards signatures or reactor-state observables.

Data and models for dynamic fuel and process monitoring: Advanced fuel cycles introduce dynamic material flows that require improved nuclear data and modeling capabilities. For flowing-salt systems, moving-fuel concepts, and online refueling reactors, priority isotopes include U-233, U-235, U-238, Th-232, Pa-233, Pu-239, Pu-241, Np-237, and selected fission products used as process-monitoring indicators. Measurements and evaluations should focus on neutron-induced reactions in thermal, epithermal, and fast energy regimes relevant to thorium and uranium fuel cycles. Target uncertainties should support predictive monitoring models with less than 5% uncertainty in key safeguards observables such as fissile inventory, breeding ratio, burnup, and material flow estimates.

Measurement science for signatures: Improved decay data are needed to fully exploit high-resolution gamma-ray spectroscopy systems, including HPGe gamma detectors and emerging microcalorimeter technologies. Priority needs include gamma-ray branching ratios, emission probabilities, and decay schemes for uranium and plutonium isotopes, particularly U-232, U-233, U-235, U-238, Pu-238, Pu-239, Pu-240, Pu-241, and Am-241. Special emphasis should be placed on low-energy gamma emissions in the 50–250 keV region, where many safeguards-relevant signatures reside and where current decay-data uncertainties often exceed detector performance capabilities. Target uncertainties below 1% for key branching ratios and emission probabilities would enable substantial improvements in isotopic analysis, age dating, and material attribution measurements.

3.2.2 *Overarching Themes*

This session topic clearly tied nuclear data research and development (R&D) to mission-level outcomes: **credible prediction of inventories/signatures**, **validated modeling tools**, and **risk-informed verification/anomaly detection** for emerging reactors and fuel cycle deployments. Digital-twin ambitions are constrained by benchmark scarcity and incomplete multiphysics and nuclear data uncertainty integration – making validation and UQ foundational grand challenges, not "nice-to-haves."

3.3 Path Forward and Recommendations

3.3.1 *New opportunities nuclear data research should capitalize on*

Microcalorimeter gamma spectroscopy at user-facility technical readiness level (TRL ~7–8) creates an immediate opportunity: detector capability is now strong enough that **gamma and x-ray branching ratios** become a dominant limit. As a result, targeted nuclear data improvements translate directly into better nondestructive assay (NDA) capabilities and safeguards.

Automated nuclear data performance assessment workflows (e.g., automated library generation + validation suites) make it feasible to track "no regressions" and quantify where new evaluations help/hurt applications.

Safeguards-relevant digital twins (physics, sensors, and AI/ML) are emerging as an analytical backbone for monitoring/verification; this opens nuclear data opportunities in NDA-relevant evaluated products, uncertainty propagation, and benchmark datasets tailored to diversion/misuse observables.

3.3.2 *Capabilities to capitalize on before they are gone/irrelevant*

Reconfigurable testbeds and flexible integral assemblies/benchmarks (including those aimed at intermediate spectra and nontraditional materials) enable validation anchors that were repeatedly requested by the safeguards and nuclear energy communities.

Cross-lab, round-robin measurement campaigns (microcalorimetry + evaluators + users) are already positioned to convert capability into published evaluated improvements; this is a high-leverage model worth scaling.

3.3.3 *Recommendations that benefit other nuclear data grand challenges*

Benchmarks beyond criticality: shielding/structural-material validation (Fe/stainless steels) strengthens not only safeguards but also reactor physics, radiation protection, and transport verification broadly.

Uncertainty/correlation products and standards: expanding and standardizing uncertainty reporting improves every application area that depends on propagated uncertainty (design, licensing, safeguards, experiments).

Continuous-energy fission product yields (CE FPY): repeatedly emphasized as a highest impact need, CE FPY improvements support burnup, source term, decay heat, and safeguards signature prediction across reactor types and fuel cycles.

Reactor operations & safety gain from validated inventory and decay heat predictions (and from better uncertainty accounting), which also anchor safeguards conclusions.

Security and monitoring technologies benefit when nuclear data enables more trustworthy signature models (neutron/gamma emission spectra, detector response functions), improving anomaly detection and reducing false positives in monitoring systems.

Workforce + infrastructure synergies emerge through shared testbeds, shared UQ frameworks, and shared benchmark datasets that can be used across labs, universities, vendors, and regulators.

4 Creating an Inventory Sub-Library

4.1 Session Summary

The session addressed the need for a modern, community-usable activation (inventory/transmutation/dosimetry) sub-library. This will be a collection of reaction cross sections and decay data required to model time-dependent isotopic composition and associated radiation. This library will support applications spanning fission, fusion, national security, fundamental science, and space exploration. Participants agreed that although the necessary theory, experimental capabilities, and evaluation tools exist, the absence of a coordinated and consistently maintained activation library has led to fragmented, application-specific solutions. Key challenges identified are the requirement of complete isotope and reaction coverage, ensuring consistency between reaction and decay datasets, and the need for covariance data for rigorous uncertainty quantification. Speakers highlighted that advances in automated evaluation workflows, data infrastructure, and experimental techniques provide a timely opportunity to address these gaps. Establishing a coordinated activation library with completeness, consistency, and covariances as design requirements was viewed as both achievable and strategically enabling for predictive modeling and future nuclear energy systems.

Across all talks, a consistent picture emerged: **the capabilities and basic tools exist to build a useful library, but a coordinated effort, integrated workflows and consistent funding are needed to provide and maintain a complete and high quality product.**

4.2 Grand Challenge

The session speakers identified several aspects that their respective inventory libraries are lacking; needs can be grouped in the three main categories (1) completeness (2) consistency and (3) covariance data.

4.2.1 *Completeness*

The session participants highlighted data gaps in the current ENDF/B and other libraries, which include the **energy range, isomer production cross sections as well as charged particle reactions** (see Figure 1). While the discussion focused on neutron-induced activation, there is also a need for charged particle-induced activation, especially for fusion applications, where deuterium and tritium are present as fuel and protons are produced in reactions induced by high-energy neutrons.

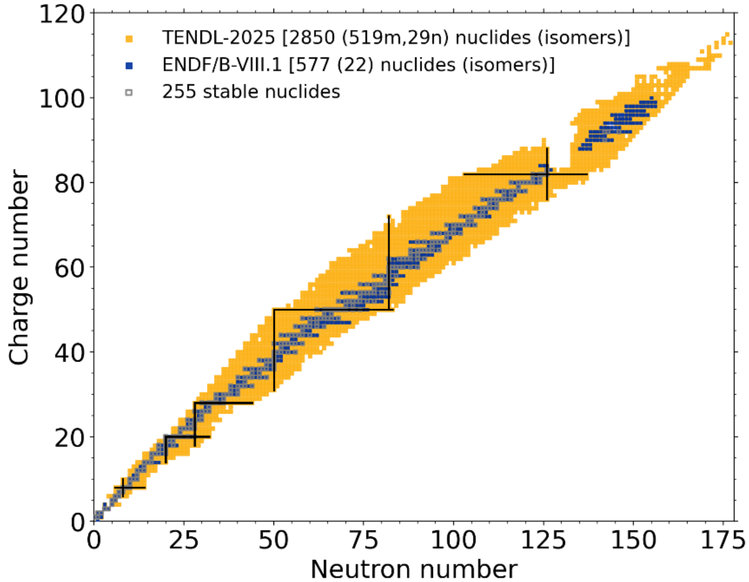

Figure 1: Scope of isotopes in the current ENDF/B library compared to the TENDL-2025 library, which is used as an activation library. Image credit: J.C. Sublet.

Reactions on fission fragments are important for nuclear fuel inventories, but the completeness of the data is a major issue. Participants pointed out that most fission fragments do not have cross sections in the ENDF/B-VIII.1 library. Inventory codes used for fuel burnup studies, such as ORIGEN, include their own library generation processes [5], which currently takes missing data from the more complete JEFF-3.3 library, which takes most data from the theory-based TENDL-2017 library.

There are several applications that require a significant extension of the considered energy range. For example, the ACTIVATE project was discussed, which aims to characterize backgrounds from cosmogenic activation for high-precision measurements such as neutrinoless double beta decay [6]. This project requires activation data up to far higher energies (~10 MeV-GeV range) than most libraries provide. The impact of cosmic rays and associated secondary particles on electronics and astronauts is also a major concern for space exploration. The need for high-energy nuclear data was also highlighted in [7], but clearly requires long-term development to be included consistently in an activation library.

4.2.2 *Consistency between different types of data*

Taking the JEFF-4.0 activation library as an example, the presenters have identified several consistency issues in the assignment of levels and metastable states between reaction and decay datasets. For example, there are two reaction cross sections for the population of excited states in indium-127 (^{127}In) [8]. However, there is only one state for ^{127}In in the decay library and its excitation energy does not match the reaction Q-value. These issues are likely the result of merging different libraries for building the activation library.

For fission yields, it has been pointed out that current libraries often break consistency between cumulative and independent fission yields that are connected by the decay data.

In addition to the nuclear cross sections, supporting data, including photo-atomic cross sections, KERMA (kinetic energy released per unit mass), damage/displacement cross sections (dpa) and covariances for decay data have been identified as missing, but needed for uncertainty and sensitivity analyses.

4.2.3 *Covariance data (uncertainties)*

Fusion and advanced reactor designers increasingly work under Best Estimate Plus Uncertainty (BEPU) frameworks [9], requiring formal uncertainty quantification for fuel inventories, source terms, radiation damage and shutdown dose rate among other things. In this framework, better covariances and rigorous libraries are needed for uncertainty propagation.

The reactor dosimetry community provides a concrete example of how covariance-qualified activation data are used in practice. The STAYSL PNNL [10] spectral adjustment suite employs generalized least-squares methods to combine measured activation reaction rates with prior neutron transport calculations, using evaluated cross sections and covariances to produce adjusted neutron flux spectra and associated covariance matrices. This workflow illustrates the importance of high-quality covariance data in enabling rigorous uncertainty propagation for critical applications such as reactor neutron spectrum adjustment. When covariances are missing, such workflows cannot be exercised in a defensible way. A future inventory sub-library must therefore be constructed with covariances as a design requirement. A critical part of this is the inclusion of covariance information in the published experimental work, as the libraries cannot create this information if it is not provided.

The advent of new reactor concepts with different fuel cycles, fast neutron spectra and complicated, dynamic designs, such as pebble bed reactors [11], pose new challenges for accurate modeling and nuclear data. New reactors may operate well outside the regime that has been validated over decades with thermal reactors, making reliable uncertainty quantification crucial to ensure regulatory compliance and safety of new designs. Several specific cases of missing uncertainties and covariances have been identified. For example, for key metastable nuclides relevant to reactivity and fuel cycle, such as gadolinium and samarium isotopes, ENDF/B-VIII.1 is missing evaluations or provides incomplete uncertainties.

Most of the above issues can be addressed with currently available tools and expertise and there is a consensus that a central, consistent library will avoid many pitfalls of the currently fragmented landscape of stopgap solutions implemented by user communities.

4.3 Future Opportunities for Student Engagement

Building a modern activation (inventory) library presents a compelling entry point for students into the nuclear data community. The scientific challenges include cutting-edge **reaction and nuclear structure theory** needed to model nuclei far from stability. It also requires **experimental** efforts with short-lived and rare isotopes at leading facilities such as the **Facility for Rare Isotope Beams (FRIB) and the National Ignition Facility (NIF)**, but also high-precision nuclear structure and decay data for stable and long-lived isotopes that can be obtained at smaller, **university-run facilities**. These are intellectually rich problems with direct impact on fusion energy, advanced fission systems, national security, and rare event physics, offering students opportunities to contribute to mission relevant science while working on frontier nuclear physics.

Equally important, the effort demands integrated, automated workflows across evaluation codes, transport solvers, inventory tools, and modern data formats. This will help create an environment where students develop strong programming, **data science, uncertainty quantification, and software engineering skills** which are directly transferable to careers in AI, high-performance computing, and computational science more broadly.

4.4 Unique Opportunities and New Capabilities

Several talks highlighted **new tools, capabilities, and opportunities** that can accelerate progress toward an inventory sub library if exploited now.

4.4.1 *Automated evaluation frameworks and advanced modeling*

The currently most comprehensive cross section library TENDL is generated by a fully automated state-of-the-art workflow that connects different codes, applies normalizations and provides a broad coverage with covariances for many nuclides and reactions [12]. Participants noted that automated processes are needed to produce such comprehensive libraries and the presented reaction theory framework at LANL built around CoH_3 [13] is a major step towards an integrated system for the generation of an activation library. LLNL has also established a comprehensive workflow for nuclear reaction calculations and uncertainty quantification [14]. Bringing these workflows to a level comparable to the integrated TENDL workflow, however, will require further development and long-term support. Here, emerging AI and ML tools are a promising avenue to further accelerating and improving the quality and speed of nuclear data evaluation, but the underlying nuclear theory, input data and model codes need to be kept up-to-date and streamlined for seamless integration.

4.4.2 *Modern data infrastructure*

Recent developments in data infrastructure and validation capabilities provide a strong foundation for advancing activation and inventory libraries. **Participants discussed** a verification and validation (V&V) automation framework in connection with FENDL, built on a repository for curated benchmark problems (e.g., ITER relevant shielding cases).

Several new tools for interactions with nuclear data formats that have recently been developed were mentioned, including **endf-parserpy** and an updated **EXFOR web-API** for interacting with standard libraries and formats as well as **Fudge** (LLNL) for editing the new Generalized Nuclear Data Structure (GNDS) format. Updated application codes, such as **CINDER 202x** can now automatically and quickly generate the required input data from ENDF formatted libraries. Such capabilities provide a strong foundation for building a consistent activation library.

Updates to the International Reactor Dosimetry and Fusion File (IRDFF), a special-purpose activation library have recently been mapped out [15] and participants highlighted the development of an OpenMC based workflow for shutdown dose rate [16].

The inventory and radiation source term code FISPACT-II was discussed extensively and continues to serve as a multiphysics inventory, radiation, and source term code that can help delineate necessary data forms for an inventory library.

4.4.3 *New experimental capabilities for activation and validation*

The session presenters highlighted advances in experimental methods and facilities that can now be used to measure, constrain and validate the types of reactions on unstable targets needed for an activation library. **Participants discussed reactor-based experiments** with high burnup fuel radiochemical assays as benchmarks for actinide and fission product inventories [17]. Commercial reactor developers, such as Westinghouse, who regularly check the performance of new nuclear data library releases in their models also provide valuable feedback to nuclear data producers.

For fusion, benchmarks such as the JAEA FNS benchmarks (Fe, W, V, Cu, C, etc.) are valuable for validating fusion relevant cross sections and damage metrics [18] and were introduced in the session.

High neutron flux measurements at NIF enable high-flux neutron activation measurements [19] on both stable and radioactive isotopes, were also discussed as constraints with small target masses and short-lived nuclides.

The **LANSCE ICE-HOUSE** facility has a neutron beam spectrum that is very similar to that of natural cosmogenic neutrons on the Earth's surface and allows for measurements of the production rate of spallation products from high energy neutrons (up to 800 MeV).

The discussions have clearly shown that indirect measurement techniques, such as the surrogate reaction method that uses reactions like (d,p), (p,p′), and (p,d) to constrain neutron-induced cross sections [20] on radioactive targets are going to be a key element to improve nuclear data for an activation library. Recent examples include ^{157}Gd(d,p) for ^{157}Gd(n,γ), that is highly relevant for spent fuel inventories. The Oslo method [21] is another indirect approach that determines key ingredients for reaction models of radioactive compound nuclei. The indirect approaches rely on nuclear theory to interpret the measurements and developments are needed, e.g. for the treatment of deformed nuclei and multi-step reactions [22].

4.5 Synergistic Work

The creation of a modern activation (inventory) library is not a narrowly scoped nuclear data effort. It represents foundational digital infrastructure for DOE's energy, science, and national security missions.

A coordinated activation and inventory library directly supports the core priorities of the **NSAC Long Range Plan (LRP) [23]** by strengthening the nuclear data infrastructure required for predictive, uncertainty-quantified nuclear science. The LRP emphasizes the integration of experiment, theory, and computation to achieve reliable modeling across nuclear structure, reactions, astrophysics, and applications. A modern activation library advances this goal by providing consistent reaction and decay data with quantified covariances. Extending coverage to unstable isotopes and higher energies enables the library to support efforts in fundamental sciences including neutrinoless double beta decay, high-energy physics, and nuclear astrophysics. The latter will benefit immensely from a curated repository of vetted cross section data covering a wide range of isotopes.

A reliable library for inventory and activation calculations also directly underpins **multiple DOE Genesis Mission** challenges [4] by providing the structured, uncertainty-qualified nuclear data required for AI-driven digital twins, risk-aware decision systems, and simulation-ready platforms. Genesis initiatives in delivering nuclear and fusion energy, nuclear cleanup and nonproliferation, and attribution of nuclear and radiological signatures all depend on accurate activation cross sections and decay chains with quantified uncertainties; without these, digital convergence platforms and multimodal AI systems cannot produce reliable results.

The are also strong synergies with the DOE Fusion Energy Science Roadmap [24], notably that remote maintenance at plant cadence must explicitly account for **activation and dose, requiring nuclear data input found only in an activation sub-library.** At the same time, the roadmap calls out a need for *design-grade* modeling with data standards and uncertainty quantification, which has also been identified as a cornerstone for a future inventory library in this session.

The session participants concluded that a future activation library is therefore a strategic enabler: it strengthens U.S. leadership in nuclear science, accelerates clean energy deployment, enhances national security, and provides the structured nuclear data backbone required for 21st-century AI-driven scientific infrastructure for applications and discovery.

4.6 Path Forward and Recommendations

The session discussions converged on several **near-term steps** toward a useful inventory sub-library:

- **Reaction model codes** form the basis for most of the activation cross sections and for the basis of the interpretation of indirect measurements. Therefore, it is necessary to:
    - Develop a robust, validated predictive reaction model code base, as called for in [3] and extend the physics capabilities and maintain US-based reaction model codes.
    - Integrate the reaction model codes into automated workflows and produce a candidate library building on ENDF/B.
    - In the longer term, improve the nuclear theory concepts implemented in reaction models, e.g. to include more microscopic nuclear structure information and more predictive models.
- Due to the wide range of applications and the existence of application-specific solutions, **coordination** is key for building a useful library. The session participants recommend to:
    - Establish community-agreed rules and conventions for general-purpose activation and inventory libraries, e.g. through dedicated meetings, workshops and through cooperation with established international nuclear data efforts, such as the Working Party on International Nuclear Data Evaluation (WPEC),
    - Provide additional funding for existing nuclear data programs to build, coordinate and maintain an activation sub-library by making the activation library a part of its core mission.
- While theory and computation are a major part of an activation library, the calculations need validation and backing from **experiments**. Therefore, there is a need for:
    - Theory development for the interpretation of indirect experimental methods (e.g., surrogate method, Oslo method).
    - Theory development for integral experiments and benchmarks for reactions on unstable isotopes (e.g., irradiation at high-flux neutron sources such as NIF).

In summary, the session underscored that **creating a robust inventory sub-library is both urgent and achievable**. The major obstacles are not the lack of physics or codes, but rather fragmented efforts, outdated formats, and insufficient attention to uncertainty and consistency. The talks collectively provided a clear diagnosis of these issues and outlined concrete technical and organizational steps to address them, setting the stage for coordinated progress over the next five years.

5 Mapping out the Path to the Next-Generation of Nuclear Fission Data

5.1 Session Summary

The aim of this session was to develop a prioritized list of activities necessary to deploy predictive fission-related nuclear data, including continuous energy (CE) representations of independent fission product yields

(FPY), neutron-gamma-fragment correlations, photofission, and their covariances in representations that can be readily distributed and utilized for applications. Discussion topics included needs of the end-users, opportunities for using existing measurements or new ones that can be performed in the near term, gaps and improvements in fission theory and computational modeling, and innovations in fission data formats and evaluation pipelines.

5.2 Grand Challenge

The most important obstacle to overcome in the next 5 years is the lack of a consistent, modern CE FPY dataset with proper correlations and uncertainties that can be incorporated into an evaluated nuclear data library such as ENDF. Having these data in an application-ready format is essential for spent fuel/reactors (especially next generation reactor designs that operate with different neutron energies than conventional designs), nuclear security, burnup credit, regulatory needs, nuclear forensics, and reactor design physics. This obstacle encompasses several interconnected challenges:

- Delivering FPY and evaluation at more than three energies (thermal, fast, 14 MeV),
- Advancing the ENDF and GNDS formats to include covariances between FPYs, and
- Providing processing tools to convert the new, CE data into the energy-binned data format that some applications require.

New measurements of correlated fission observables were widely identified as essential for constraining fission theory and improving models. In particular, correlations among independent FPYs, prompt neutrons, prompt gammas, and total kinetic energy (TKE) were seen as especially valuable for constraining initial fragment properties. Improving uncertainty quantification was also emphasized. This could be supported by having experimental teams adopt the uncertainty quantification templates developed by the evaluation community. Reevaluating uncertainties in historic measurements may also be needed, especially for neutron-induced fission cross sections, where the spread in literature values often exceeds the reported uncertainties.

Delivering new FPYs will require analysis of new experimental data. Several speakers prioritized analyzing existing Triangle Universities Nuclear Laboratory (TUNL) datasets for short-lived fission products collected at multiple incident neutron energies, as these experiments have already been performed and the data are available now. New FPY evaluations should incorporate these measurements and use state-of-the-art fission modeling codes (e.g. BeoH, CGMF, FREYA, FIFRELIN, FETA, and GEF) to generate a CE evaluated FPY library. An important consideration for these evaluations is representing FPY covariances in a usable, computationally tractable form, such as covariances reported in coarsely binned energy groups.

A common sentiment throughout the discussion was that perfect should not be the enemy of good. Updated FPY evaluations should be made available for applications use even if the ENDF data format does not yet support covariances. The evaluations can always be updated to include covariances once the format is ready. Existing formats currently in use by the applications community are desirable to keep since existing workflows rely upon them. A tool which could reliably convert from GNDS to ENDF may be a solution, but there would need to be a guarantee that a single community standard tool would be developed and maintained.

Additionally, the new CE evaluations should not break applications that expect the standard three energy groups. This could be accomplished by providing a community standard tool that processes the CE evaluation to produce FPY evaluations in discrete energy groups. A standard tool would ensure a common definition for the standard energy groups (e.g. FPYs from thermal neutron on ^{235}U) for a particular evaluation. The tool could also provide FPY realizations by sampling the covariances, enabling end users to take advantage of the covariances without the overhead of implementing them in code.

The NSAC report prioritizes developing next-generation nuclear fission reactors and finding solutions for long-term management of spent nuclear fuel [23]. In addition, the report highlights that research aimed at better understanding and modeling the neutrino energy spectrum from reactors contributes to the basic science of technologies for remotely assessing the radioactive content of a reactor core during operation. Modeling the performance of current and novel reactor designs, the burnup of the fuel, the decay heat, and the reactor antineutrino spectrum critically depend on accurate FPYs.

Improved FPYs and predictive models are essential for understanding the role of fission recycling in r-process nucleosynthesis, where superheavy nuclei far from stability (and for which there is no experimental data) undergo fission and change the distribution of r-process products.

5.2.1 *Preserving Institutional Knowledge*

A capability that exists now that we need to capitalize on before it is gone is institutional knowledge. Institutional knowledge spans both historical measurements and benchmarks, as well as state of the art nuclear theory. Many of the theory tools the community relies on for evaluation are maintained primarily by senior members of the field. In both theory and experiment, it is essential to sustain a strong pipeline for recruiting and retaining talented early-career scientists. Too often, mentorship and the transfer of institutional knowledge are treated as secondary concerns and are managed informally and inconsistently. The recent Nuclear Structure Evaluators Trainee Program, funded out of the DOE Office of Science US Nuclear Data Program, provides a model for a deliberate, structured approach to bringing new people into the field.

5.3 Future Opportunities for Student Engagement

There are opportunities to engage students in the design of novel experiments to measure correlated fission observables such as total kinetic energy (TKE), gamma multiplicities, fission products, neutron energies, etc. New facilities and detectors can be leveraged to perform high-precision correlated measurements that weren't previously possible. Such measurements could challenge state-of-the-art fission theory and provide constraints on inputs that cannot be directly measured such as fission fragment properties before neutron/gamma emission and properties of the compound nucleus.

There are also opportunities in the advancement of fission theory. There is a need for predictive fission models that can calculate observables for nuclei or incident energies that have not yet been measured. Such theoretical models are essential for predicting the fission behavior of short-lived nuclei that cannot be measured in the laboratory (e.g. ^{237}U(n,f)), of superheavy nuclei that only exist in astrophysical environments (e.g. fission recycling in r-process nucleosynthesis), and the energy dependence of FPYs and other fission observables of target nuclei for which there is currently no experimental data (e.g. minor actinides). Achieving predictive models requires theoretical approaches that accurately represent the fundamental, microscopic physics driving the complex fission process.

5.4 Path Forward and Recommendations

- There is a wealth of energy-dependent short-lived FPY data previously collected at TUNL but remains unanalyzed. This analysis should be completed and these yield data incorporated into new FPY evaluations, either continuous in energy or with more energy groups to match the data.

- State-of-the-art fission modeling reproduces many prompt fission observables well, but key physics inputs remain uncertain or unmeasured, including pre-emission fragment properties, compound nucleus multi-chance fission probabilities, and nuclear level and level density information. Improving these models will require targeted new experimental data, especially more measurements of prompt gamma-ray emissions and independent FPYs, to better constrain and benchmark predictions. There should be close coordination between experimentalists and theorists to ensure any new measurements will provide the most useful data for improving model calculations.

- A new opportunity that nuclear data research should capitalize on is emerging AI and ML capabilities, including physics-aware data compression, pattern recognition to identify and prioritize historical experimental discrepancies, surrogate modeling approaches (e.g. autoencoders) to accelerate computationally intensive fission calculations, and automated sensitivity analyses spanning a wide range of application domains.

Improved fission modeling and FPY evaluations, with usable uncertainties and correlations, benefit missions well beyond reactor analysis. For nuclear security and post-detonation forensics, better energy-dependent yields, short-lived products/isomers, and correlated prompt emissions improve early-time inventories and signatures used in debris and attribution modeling. For criticality safety, safeguards, and regulatory analysis, improved $\bar{\nu}$, PFNS, and prompt gamma-ray source terms, together with consistent processing to application-ready group structures, strengthen validation and the traceability of safety-relevant calculations, especially in intermediate-spectrum or time-dependent scenarios. More broadly, standardized formats, covariance deliverables, and common processing tools enable consistent uncertainty propagation and benchmarking across application domains, while more predictive fission models also strengthen r-process fission recycling studies and reactor antineutrino spectrum calculations.

6 AI/ML for Nuclear Data: Opportunities and Challenges

6.1 Session Summary

The goal of this session was to examine the challenges and opportunities offered by Artificial Intelligence and Machine Learning (AI/ML) in the broader area of nuclear data and its applications. Following an initial presentation giving an update on the Genesis Mission of the US Department of Energy (DOE), the session covered various topics ranging from automated nuclear data pipelines, surrogate modeling, forward and backward uncertainty quantification (UQ), Bayesian estimation, high-fidelity emulators, multi-objective reaction modeling, experimental design, radioactive beam tuning, and Large Language Models (LLM)-assisted knowledge systems.

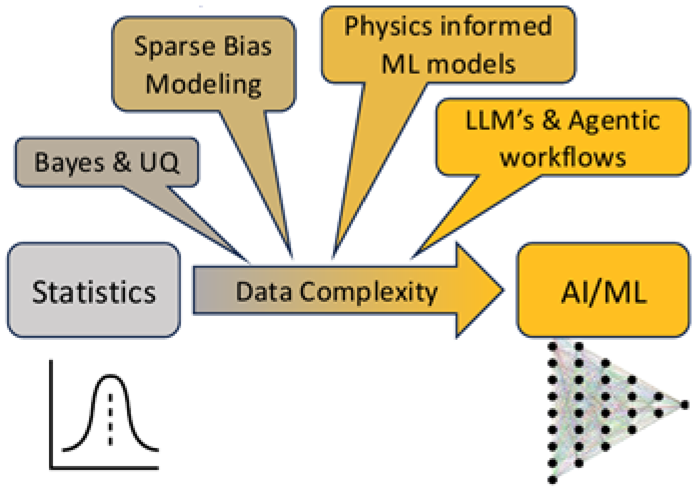

Figure 2: AI/ML techniques range from classical statistics (minimal data complexity, maximum expressability) to deep-learning.

The session emphasized that AI is not a replacement for physics-based modeling, but a force multiplier that has the potential to accelerate learning, inference, optimization, uncertainty quantification and propagation and could thus have a transformative impact on nearly all facets of nuclear data including the systematic production of usable uncertainties and covariances. Major goals identified by the community included accelerating evaluation workflows through the generalization of surrogate models and agentic frameworks, enabling automated and reproducible data pipelines through the curation of experimental datasets (e.g with bias detection) and development of AI-ready databases, advancing UQ frameworks and inverse Bayesian calibration, or optimizing operations at experimental facilities.

6.2 Grand Challenge

The grand challenge over the next five years is the ability of the nuclear data community to integrate trustworthy, uncertainty-quantified, physics-informed AI methods across the entire nuclear data pipeline ecosystem. The session identified three major areas of concern to meet this challenge:

1) **Extrapolation, precision, and bias of AI/ML models** – In reaction modeling, special attention must be paid to the predictive capability and precision of AI/ML methods. While such methods excel at interpolating, they do struggle in extrapolation tasks and nuclear data applications are no exception. There has been no compelling demonstration so far of the ability of AI/ML tools to exceed the performance of physics-based models.

2) **Infrastructure limitations** – The reliability and overall performance of AI/ML models, especially LLMs, is currently limited by deficiencies in the nuclear data infrastructure. This includes incomplete, inconsistent or ambiguous nuclear databases affecting both experimental (e.g., EXFOR) and evaluated data (ENDF, TENDL, JEFF, JENDL, etc.). For several of the success stories reported in the session, teams spent up to several months simply cleaning up the datasets, which sometimes required reaching out to experimentalists for additional information. Data-sharing constraints caused by the nature of the data and potential national security or proprietary concerns, as well as size and formats, are also obstacles that will need to be overcome.

3) **Workforce challenges** – There was unanimity that the push toward AI/ML must not be carried out to the detriment of domain expertise. The loss of institutional knowledge was also pointed out in other sessions. There is a risk that AI/ML could accelerate this loss of institutional knowledge instead of stopping or mitigating it. Participants also emphasized that non- or even semi-educated application of AI/ML models

to data is dangerous and can often lead to nonsensical results. Universities are already seeing early signals of students' over-reliance of engines such as ChatGPT. [25, 26]

6.3 Unique Opportunities and New Capabilities

The presentations and discussion that took place during the session can be summarized by the following four broad recommendations:

1. Expand and generalize the development of surrogates of theoretical physics models for systematic uncertainty quantification and rapid validation and verification

2. Identify the parts of the nuclear data pipelines that are most amenable to AI automation and develop a corresponding set of agentic workflows

3. Invest into data curation efforts through the adoption of big data community best practices in labeling and categorization ('nuclear taxonomy') and the systematic development and application of ML techniques for outlier or bias detection, etc.

4. Prioritize joint teams of nuclear scientists and machine learning researchers to maximize impact.

5. Leverage the DOE Genesis Mission Data Pillar, tying AI/ML driven work into an integrated, shared resource.

Computational surrogate models of reaction theory codes based on AI/ML techniques can at times enable million-fold computational speedups. Such speedups are essential to enable large-scale sampling of model parameters spaces or the computation of theoretical covariances. Existing tools such as the Evaluated Means and Uncertainties (EMU) framework at LLNL rely on such covariances to generate samples of full, and fully processed, nuclear data libraries to explore the space of variations around evaluated values contained in, e.g., the ENDF/B library. Current computing facilities provide enough cycles to enable the development of accurate and precise surrogate models, which are likely to play an important role in the next few years. Nuclear theory offers an especially compelling success story in surrogate modeling. High-fidelity emulators using eigenvector continuation, for example, have demonstrated exceptional performance in delivering nearly exact solutions with very few training samples. Initially, these emulators were tested to explore the parametric dependency of model Hamiltonians, but these techniques may be applicable in other domains. Truly novel AI/ML concepts such as parametric matrix models may also have the potential to be deployed in the nuclear data pipeline.

There was a general consensus that agentic workflows offered a tremendous potential to accelerate and optimize many of the menial or tedious tasks involved in producing or testing an evaluation, be it in extracting actual data from the scientific literature, setting up semi-autonomous workflows, providing simple user interface to end users, etc. Participants equated the emergence of AI agents to the advent of personal computers as a major productivity multiplier. However, significant effort must be expended toward rethinking how the nuclear data pipeline operates and where agentic workflows would be most beneficial. AI-driven experiment optimization has also greatly improved operation efficiency at accelerator facilities by accelerating radioactive beam tuning with Bayesian methods. This enables scientists to focus on development or science rather than on tedious tasks. Such efforts could also benefit from agentification.

Data curation is an especially critical part of this pipeline. Speakers and participants of the session emphasized that AI/ML models should not be deployed 'blindly' on nuclear datasets. Building experimental covariances often involves combining several different datasets of differing quality, with uncertainties that may be incomplete, missing or poorly documented. Sparse Bayesian modeling was shown to be a powerful tool to identify experimental bias in datasets while maintaining interpretability. Taking a longer view, Large Language Models (LLMs) or foundational models represent an opportunity that should clearly be explored. However, it is not clear that the current state of nuclear data would enable the successful deployment of such systems. Some participants emphasized the relatively small size of nuclear data compared, e.g., to languages which can rely on billions and billions of words and sentences. Others remarked that notions that have been shown to be important in scaling AI/ML in other fields are largely missing in nuclear data, especially taxonomy and ontology. In practice, some concepts are not rigorously defined (ex.: what is a short-lived fission product?) and there has never been an attempt at organizing nuclear data into formal categories and sub-categories with relationships between them.

In scientific computing, the past two decades have demonstrated the success of forming joint teams of domain scientists partnered with, e.g., computer scientists or applied mathematicians as evidenced, e.g. by the success of the Scientific Discovery Through Advanced Computing (SciDAC) program of the DOE. Session participants were unanimous in advocating for a similar form of collaboration in the deployment of AI/ML in nuclear data. This would simultaneously ensure that there is no loss of institutional knowledge (one of the identified challenges) and that the right AI/ML methods are applied properly (another one of the identified challenges).

6.4 Synergistic Work & Cross-Cutting Needs

By nature, AI/ML is itself a cross-cutting activity and the speakers and participants emphasized this by discussing applications covering different areas of the (extended) nuclear data pipeline such as fundamental theory, reaction modeling for nuclear engineering and astrophysics, reactor safety, radiation transport, nuclear security, and more. Synergistic work that would benefit all these efforts include, but are not limited to:

- **Uncertainty quantification** – This theme unifies nearly all AI efforts in nuclear data. Participants pointed the need to quantify the uncertainties of the AI/ML methods themselves, e.g. using techniques such as Delta-UQ. Quality assurance techniques such as stress testing, fabricated-error injection, and covariance benchmarking were mentioned as critical for trust-building and are generalizable.

- **Database modernization** – This is essential for ML-readiness, requiring structured features, curated metadata, and standardized formats. For reaction data, GNDS is a good first step in this direction since it incorporates explicit, documented and enforceable schemas (in the computer science sense). GNDS is very focused on reaction data and very little on structure data. In information science, categories describe the data, ontologies describe their relationships, and schemas implements all this in computer format: GNDS is a schema, but the underlying categories/ontologies were never discussed by the community.

  Generalizing GNDS to also include nuclear structure data and rooting the format into proper concepts of information science would facilitate interacting with AI models. Lessons learned during the development of GNDS, together with best practices from other communities leveraging LLMs for big data would benefit the whole community.

- **Physics constraints** – Interpretability and physics integration remain vital, especially since nuclear cross sections and nuclear data libraries must satisfy many different constraints. Symbolic ML may offer promising interpretable alternatives to black-box models and could find a place in the nuclear data ecosystem.

- **Workforce development** – This was perhaps recognized as the most critical (cross-cutting) need: nuclear scientists must understand AI, and AI developers must understand nuclear data. Institutional knowledge must be preserved while leveraging AI to enhance productivity.

6.5 Path Forward and Recommendations

While the nuclear data community has been using ML techniques such as Bayesian methods for decades, it has recently begun to adopt more 'modern' techniques belonging to the AI field proper, such as deep-learning techniques, LLMs or (so far simple) agentic systems. The grand challenge of ensuring that AI/ML can transition from such exploratory research to full operational capability will require significant and sustained investments in:

- developing emulators of physics models for systematic uncertainty quantification and propagation;
- implementing agentic automation of parts of the nuclear data pipeline;
- maintaining robust validation schemes and expanding them by adopting big data best practices;
- and investing smartly in the workforce by emphasizing joint teams of nuclear data scientists and machine learning researchers.

This will depend on successfully securing or leveraging the proper infrastructure and preserving expert knowledge and oversight, some of which could be provided as part of the Genesis Mission. It is the opinion of nearly everyone in the nuclear data community that AI must augment—not replace—physics models. If implemented with discipline and joint (AI/ML and nuclear data) domain expertise, AI/ML will deliver its full transformative potential to nuclear data.

7 Instrumentation and Facilities for Nuclear Data

7.1 Session Summary

This session provided a facility-focused survey of U.S. capabilities that enable nuclear data measurements, spanning rare-isotope beam production, accelerator-based neutron and photon sources, integral experiments, and high-flux neutron sources. The goal was to identify what can be measured now (and with what precision and throughput), what new instrumentation is coming online, and how these assets can be coordinated to reduce key nuclear data uncertainties for national security, advanced reactor development, isotope production, and nuclear astrophysics. Presenters emphasized that progress depends not only on higher beam intensities or new detectors, but also on experiment designs that capture multiple observables and support robust uncertainty quantification.

Several talks highlighted completed upgrades and operational realities. FRIB described a mature user facility with all experimental areas ready for user experiments and an expanding detector ecosystem, while Argonne's Tandem Linac Accelerator System (ATLAS) and its nuCARIBU program described near-term operations and increasing access to neutron-rich fission fragments. The Los Alamos Neutron Science Center (LANSCE) outlined upgrades and new concepts intended to extend precision and reach to shorter-lived nuclei through the development of a novel neutron target, while Oak Ridge National Laboratory showcased high-priority validation measurements for thermal neutron scattering and transmission at the Spallation Neutron Source (SNS). Complementary talks covered Lawrence Livermore National Laboratory platforms targeted at high-precision actinide data needs at NIF, PRISM and LiNuS, Sandia National Laboratories' integral benchmark and training assets with SCX and ACRR, Texas A&M University's Detector Array for Photons, Protons, and Exotic Residues (DAPPER) enabling indirect reaction method approaches to constrain neutron capture model parameters, Lawrence Berkeley National Laboratory's neutron/gamma measurements with the GENESIS array, Idaho National Laboratory's plan to restore a modern horizontal split-table critical facility (SPARC), and Florida State University's efforts to re-establish unique low-energy triton beams in the United States.

7.2 Grand Challenge

The dominant obstacle for the next five years is delivering high-priority nuclear data with defensible uncertainties (including covariances) quickly enough to meet pressing needs in stockpile science, nonproliferation and forensics, advanced reactors, and astrophysics. The presentations collectively underscored that the hardest problems are those where (1) targets are scarce, radioactive, or difficult to handle, and (2) the physics is complex enough that single-observable measurements do not adequately constrain models (e.g., fission and radiative capture on unstable nuclei). A closely related challenge is sustaining the experimental and evaluation workforce and infrastructure needed to translate facility measurements into evaluated nuclear data.

Good opportunities for students include tackling measurement strategies that combine multiple correlated observables (e.g., neutrons and gamma rays in coincidence, angular distributions, transmission plus capture constraints), and building analysis pipelines that connect raw data to evaluation-ready quantities. They can also make high-impact contributions by addressing throughput barriers including proposal-to-beamtime logistics, sample preparation pathways, detector characterization, and computationally efficient forward-modeling methods. This is because these often determine how fast the field can respond to evolving priorities. These challenges map directly onto national program drivers highlighted in the talks, including improved actinide reaction data for certification and code validation, integral benchmarks for reactor licensing and criticality safety, and foundational nuclear reaction and structure inputs that underpin predictive reaction modeling.

7.3 Unique Opportunities and New Capabilities

A major opportunity is the growing ability to study nuclei off stability with instrumentation that also produces data relevant to applications. FRIB reported a large campus-integrated operation (on the order of ~800 employees and >1800 users) supporting fast, stopped, and reaccelerated rare-isotope beams. Key instrumentation developments include the Gamma-Ray Energy Tracking Array (GRETA), which is being installed and commissioned, and the community-driven FRIB Decay Station initiator (FDSi), which integrates charged-particle, neutron, and photon detectors for comprehensive beta-decay studies. Early FDSi results illustrate application-relevant outputs such as half-lives, beta-delayed neutron emission, isomer spectroscopy, and branching ratios. FRIB also highlighted a distinct applied pathway via isotope harvesting from unused isotopes produced during operations; examples included solid-collector harvesting of medically relevant radionuclides (e.g., ^{197}Pt and ^{47}Ca as a parent for ^{47}Sc).

ANL presented complementary strengths with ATLAS and nuCARIBU: stable beams from protons to uranium at energies up to ~10–20 MeV per nucleon, and neutron-rich beams post-accelerated to ~15 MeV per nucleon. ATLAS emphasized high operational availability (thousands of hours per year) and strong compatibility with both in-house and community detector systems. Notably, nuCARIBU is transitioning from spontaneous fission sources toward neutron-induced fission of actinides (starting with ^{235}U), enabling higher yields and easier operation and maintenance. High-resolution separation and trapping (e.g., multi-reflection time-of-flight purification and Penning trap-based selection) supports isotopic and isomeric purification, enabling studies of isomeric yields and, prospectively, direct measurements of short-lived fission product yields for neutron-induced fission of ^{235}U and ^{239}Pu. ATLAS will also enable experimental approaches that directly inform nuclear data needs, including fission barrier related studies with the Helical

Orbit Spectrometer (HELIOS) and indirect constraints on neutron capture using surrogate and beta-Oslo methods.

Several presentations showcased unique high-flux environments that can enable measurements otherwise limited by sample mass, backgrounds, or short half-lives. LLNL described defense program-driven requirements for plutonium-239 (^{239}Pu) reactions, including ^{239}Pu(n,n') with ~5% uncertainties from 1–5 MeV (and interest in the outgoing neutron spectrum) and ^{239}Pu(n,2n) with very small target uncertainties (e.g., percent-level near 14–15 MeV and a few percent across 7–12 MeV). To address these, LLNL is developing the proposed Livermore Nuclear Science (LiNuS) Center to deliver high-flux, pulsed, tunable monoenergetic neutrons (complementary to broad-spectrum sources), and is leveraging the Center for Accelerator Mass Spectrometry (CAMS) for high-precision activation-based approaches where appropriate. LLNL also described the PRISM electron linac platform for bremsstrahlung photon experiments, motivated by renewed importance of photonuclear data for high-energy radiography (photon energies above ~7 MeV), and outlined a NIF platform for (n,2n) measurements on radioactive species using extremely high neutron fluxes in very short burn times and ratio-to-reference methods; a recent example was development and post-shot radiochemistry enabling detection of products from an ^{88}Y(n,2n) measurement.

At Sandia, the Annular Core Research Reactor (ACRR) provides a distinctive pulsed and steady-state test environment with a large dry central cavity and configurable neutron spectra using bucket moderators/filters, supporting materials irradiation, fuels testing, isotope production, and imaging. SNL also described its Sandia Critical Experiments (SCX) program, including low-enriched uranium critical benchmark series (e.g., the Seven Percent Critical Experiment and burnup-credit experiments documented in the International Criticality Safety Benchmark Evaluation Project handbook), plus hands-on criticality safety training that has served hundreds of students. A forward-looking capability is CREST (Combined Radiation Environments for Survivability Testing), a planned modern replacement facility intended to preserve and extend ACRR-like capabilities while integrating modern standards and coupled environments.

The presentation for LANSCE at LANL highlighted selected nuclear data capabilities among the wide breadth of experimental campaigns being carried out, including fission fragment yields, charged-particle emission, and neutron capture cross sections. In particular, the Correlated Gamma-Neutron Array for sCattering (CoGNAC) was described showing the ability to obtain simultaneous and correlated white-source measurements of elastic and inelastic scattering reactions, which is currently being upgraded to include incident and emitted neutron energy- and angular-dependent measurements of (n,2n) reactions as well. The Device for Indirect Capture Experiments on Radioactive nuclei (DICER) instrument was also shown, emphasizing the simultaneous capture and total cross section measurement techniques with a binocular sample system and the ability to handle small radioactive samples, frequently generated onsite at LANSCE through the Isotope Production Facility (IPF). In addition to the existing capabilities, the Los Alamos Modernization Project (LAMP) effort to upgrade the front end of the LANSCE accelerator was described along with the concurrent establishment of high-intensity proton beams in the underutilized Area A for development of the Neutron Target Facility (NTF) as part of the LANSCE Enhancements (LANE) project. NTF is being developed to address from a myriad of NNSA program drivers relating to nuclear reactions on short-lived nuclei. Successful early-stage demonstrations of the NTF experiment concept have been promising, generating the momentum to establish this unique and potentially revolutionary nuclear data capability.

Other unique capabilities include TUNL assets: the High Intensity Gamma-ray Source (HIγS) provides highly polarized, intense, pulsed photon beams across a broad energy range and supports nuclear resonance fluorescence and activation-based measurements (including cumulative fission product yields), while the TUNL Tandem facility supports extensive light-ion and neutron-beam research with strong student training value. LBNL described modular neutron and gamma-ray measurement infrastructure at the 88-Inch

Cyclotron, including the GENESIS array for (n,xnγ) measurements, a separate high-flux fast-neutron source targeting substantially higher flux with a new target, and a tagged 14-MeV DT neutron source (NEXUS) using associated-particle imaging techniques for neutron path identification and background suppression, potentially valuable for normalizing GENESIS measurements. INL presented the SPARC (System Physics Advanced Reactor Critical) facility plan to restore a flexible horizontal split-table capability for modern criticality safety and reactor physics needs, particularly for emerging fuels and configurations. Finally, FSU described a concentrated effort to re-establish pure, low-energy triton beams (roughly 3–17 MeV), a capability currently absent elsewhere in the U.S., with extensive engineered safety controls and a planned multi-thousand-hour campaign once reliable cathode loading is achieved.

7.4 Path Forward and Recommendations

- Across the talks, the strongest cross-cutting theme was the need to design experiments and facility programs around datasets that constrain models and evaluations, not just individual observables.
    - DAPPER exemplifies this philosophy by using inverse-kinematics indirect reactions to extract nuclear level densities (NLDs) and photon strength functions (PSFs). These are key inputs for neutron-capture modeling—while enabling internal consistency checks via multiple analysis approaches (e.g., Oslo-type methods and computationally intensive forward-modeling of gamma-ray cascades).
    - Extending these measurements along isotopic chains, and combining them with complementary data streams (e.g., direct neutron capture where feasible, beta-decay constraints, or triton-induced indirect reactions), was presented as a practical way to reduce systematic uncertainties and improve predictive power for unstable nuclei that cannot be measured directly.
- A second cross-cutting need is validation and benchmarking of data used in applications.
    - ORNL emphasized that thermal scattering law data (how materials scatter thermal neutrons, including temperature dependence) is a high-priority validation area because it strongly affects neutron transport, moderation, and criticality predictions; high-flux differential and transmission measurements (including time-dependent background characterization and non-destructive assay demonstrations) provide a pathway to reduce uncertainties that propagate broadly across reactor analysis, safeguards, and forensics.
    - Sandia's SCX and the planned INL SPARC facility address the complementary integral side: modern transport codes can be highly accurate only if anchored to well-characterized critical benchmarks spanning fuels, moderators, reflectors, and modern compositions relevant to HALEU systems and advanced reactor concepts.
- Finally, multiple presentations highlighted a workforce-and-continuity synergy: large user facilities (FRIB, ATLAS, LANSCE, SNS) and specialized university-scale laboratories (TUNL, FSU, Ohio University, Rensselaer Polytechnic Institute, the University of California, Berkeley, Texas A&M, the University of Kentucky, and the University of Notre Dame) play different but mutually reinforcing roles.
    - University facilities often provide faster iteration, training, more flexible availability, and niche capabilities (e.g., triton beams, specialized neutron production), while flagship DOE facilities provide access to rare isotopes, extreme flux, and large-scale detector systems.

- Coordinating these roles, while prioritizing multi-observable measurements and ensuring that data products are evaluation-ready, was framed as the most effective path to meet national nuclear data grand challenges within realistic time and budget constraints.

8 Conclusions

The robust discussion identifying cross-cutting needs and synergistic capabilities highlighted the continuing benefit of WANDA to both the larger nuclear data community as well as cognizant federal program managers.

The main needs identified through this workshop are summarized below, many of which are common themes and would benefit multiple WANDA topic areas.

1. **Workforce Development**:
    - Continuous learning and training programs to keep up with new technologies and methodologies.
    - Importance of maintaining a robust pipeline of talent, including early-career scientists and interdisciplinary teams.
    - Collaboration between nuclear scientists and machine learning researchers to maximize impact.
2. **Infrastructure and Experimental Design**:
    - Robust experimental facilities and detector systems to provide high-quality data.
    - Coordination between experimental design and computational modeling to ensure data relevance and quality.
3. **Validation and Benchmarking**:
    - Systematic validation and benchmarking of data and models to ensure reliability and traceability.
    - Development of common standards and tools to facilitate data sharing and usage across the community.
4. **Uncertainty Quantification**:
    - Importance of quantifying uncertainties in both data and models to improve predictions and decision-making.
    - Development of tools and workflows for systematic uncertainty quantification and propagation.
5. **Transparent Data and Data Availability**:
    - Ensuring data is accessible and transparent to support collaboration and reuse.
    - Standardizing data formats and metadata to improve interoperability and ML-readiness.
6. **AI/ML to Enhance the Data Pipeline**:
    - Utilizing AI/ML to streamline and accelerate the nuclear data pipeline while preserving data quality.
    - Leveraging AI/ML to improve data quality, model predictions, and decision making.

- Development of physics-aware AI models and data curation practices to enhance productivity.

These themes highlight the importance of a coordinated effort to address the complex challenges in nuclear data, emphasizing the need for continuous improvement in data infrastructure, experimental design, and computational capabilities. All of these themes are interconnected but are also individually important. Workforce development interfaces with and is needed at all stages of the nuclear data pipeline, and this was highlighted across nearly all the sessions. Infrastructure and experimental design are essential components for the generation of high-quality nuclear data, both for integral and differential measurements which of course couple closely with validation and benchmarking against outputs of predictive computational models. Along all steps of this process, uncertainty quantification is of extreme importance to reduce overall uncertainties and generate confidence in both experimental and computational results. The session on generating an inventory sub-library highlighted the importance and need for data transparency as well as data availability, ensuring that all steps of the pipeline needing this data to improve their own step in the nuclear data pipeline have access to it. Cutting across all subject matter areas and a large discussion at WANDA this year was, again, the best way to leverage AI/ML to accelerate and streamline the nuclear data pipeline while not compromising on data quality.

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10 Acronyms and Abbreviations

Acronym	Definition
ACRR	Annular Core Research Reactor
AI/ML	Artificial Intelligence/Machine Learning
ANL	Argonne National Laboratory
ATLAS	Argonne Tandem Linear Accelerator System
CAMS	Center for Accelerator Mass Spectrometry
CE	Continuous-Energy
CoGNAC	Correlated Gamma-Neutron Array for sCattering
CREST	Combined Radiation Environments for Survivability Testing
DAPPER	Detector Array for Photons, Protons, and Exotic Residues
DICER	Device for Indirect Capture Experiments on Radioactive nuclei
ENDF	Evaluated Nuclear Data File
FDSi	FRIB Decay Station initiator
FPY	Fission Product Yield
FRIB	Facility for Rare Isotope Beams
FSU	Florida State University
GRETA	Gamma-Ray Energy Tracking Array
HALEU	High-Assay Low-Enriched Uranum
HELIOS	Helical Orbit Spectrometer
HIγS	High Intensity Gamma-ray Source
HPGe	High-purity germanium
INL	Idaho National Laboratory
IPF	Isotope Production Facility
LAMP	Los Alamos Modernization Project
LANE	LANSCE Enhancements project
LANL	Los Alamos National Laboratory
LANSCE	Los Alamos Neutron Science Center
LBNL	Lawrence Berkeley National Laboratory
LLM	Large Language Model
LiNuS	Livermore Nuclear Science
LLNL	Lawrence Livermore National Laboratory
MC&A	Nuclear Material Control and Accountability
ND	Nuclear Data
NDA	Nondestructive Assay
NDIAWG	Nuclear Data InterAgency Working Group
NDWG	Nuclear Data Working Group
NIF	National Ignition Facility
NOFO	Notice of Funding Opportunity
NLD	Nuclear Level Density
NTF	Neutron Target Facility

Acronym	Definition
ORNL	Oak Ridge National Laboratory
PSF	Photon Strength Function
SciDAC	Scientific Discovery Through Advanced Computing
SCX	Sandia Critical Experiments
SNL	Sandia National Laboratories
SPARC	System Physics Advanced Reactor Critical
TKE	Total Kinetic Energy
TRL	Technical Readiness Level
TUNL	Triangle Universities Nuclear Laboratory
UQ	Uncertainty quantification
V&V	Verification and validation
WANDA	Workshop for Applied Nuclear Data Activities