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Y. Feldman, J. Reed, J. Siegel

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Assessing States' Industrial Capabilities in Support of Safeguards State Evaluation and Implementation Activities

Yana Feldman,[1] Jonas Siegel,[2] Justin Reed[2]
[1] Lawrence Livermore National Laboratory, Livermore, CA, USA | [2] Argonne National Laboratory, Lemont, IL, USA

ABSTRACT
Assessing States' industrial infrastructure, resources, and capabilities is important for supporting IAEA safeguards activities, such as acquisition path analysis, estimation of lead times to construct new nuclear fuel cycle (NFC) facilities clandestinely, and for building a foundation for understanding the overall picture of a State's nuclear fuel cycle and nuclear-related programs. The IAEA has been assessing States' industrial capabilities since the early 2000s, shortly after it began conducting structured state evaluation as part of the earliest implementation of the State Level Concept. Over the years, the IAEA's methodology for assessing States' industrial capabilities evolved alongside the State evaluation process. As the IAEA gained access to better information sources and analytical tools, and prioritized training on analytical methodologies, its approach to assessing States' industrial capabilities became more rigorous, more systematic, and objectives-oriented. Reflecting on the IAEA's approach to conducting industrial capabilities assessments, this paper reconsiders what the terms "industrial" and "capability" mean in different contexts. How these terms are defined dictate what activities are included and what technical proficiencies are taken into account when doing an industrial capabilities assessment. The paper argues that different safeguards evaluation objectives require focusing on different levels of State technical proficiency, and it demonstrates how both narrow and broad definitions of these terms could assist in conducting more efficient and effective analysis of States' industrial capabilities.

1. Introduction

Assessing States' industrial infrastructure and resources and other technical capabilities directly supports several IAEA safeguards activities, e.g., acquisition path analysis and estimation of lead times to build new nuclear fuel cycle (NFC) facilities clandestinely, which in turn helps prioritize technical objectives and determine the frequency and intensity of safeguards activities, and for the understanding of the overall picture of a State's nuclear fuel cycle and nuclear-related programs.

Over the years, the IAEA's methodology for performing assessments of States' industrial capabilities has evolved alongside the safeguards State evaluation processes. As the IAEA gained access to better information sources and analytical tools, and prioritized training on analytical methodologies, the IAEA's approach to assessing States' industrial capabilities has become more rigorous, with well-defined processes, procedures, and objectives.

This paper reviews the IAEA Department of Safeguards Division of Information Management's (SGIM) current approach to assessing States' industrial capabilities and identifies challenges and opportunities associated with such assessments. It then examines and reframes what constitutes industrial capabilities assessment and develops an approach to integrating these types of assessments into safeguards implementation and evaluation processes. In particular, it suggests tailoring the depth, breadth, and frequency of industrial capabilities assessments to specific safeguards activities so as to increase the effectiveness and efficiency of the safeguards process. A more structured and transparent IAEA industrial capabilities assessment process will ultimately benefit IAEA analysts and officials, and increase confidence in IAEA safeguards among member States.

2. Industrial Capabilities Assessments for Safeguards Evaluation and Implementation

Evaluation of Declared Information

Safeguards analysts conduct industrial capabilities assessments as part of their review of information that a State declares to the IAEA, for example, information required by INFCIRC/540 Additional Protocol (AP) Article 2.a declarations. Article 2.a.(iv) requires a State to describe the scale of operations for each location within its national boundaries that is engaged in the manufacture, construction, or assembly of certain nuclear fuel cycle equipment and materials, such as gas centrifuge rotor tubes, zirconium tubes, irradiated fuel element chopping machines, etc.[1] Under Article 2.a.(ix), the State is also required to declare exports of certain nuclear fuel cycle and non-nuclear material, specified in AP Annex II. Article 2.a.(x) requires States to declare their plans for the next ten years relevant to the development of the nuclear fuel cycle. Plans to develop or expand the capability to manufacture items subject to declaration under 2.a.(iv) and 2.a.(ix) would fall under this article. It is also useful to assess consistency between Article 2.a.(i) and 2.a.(x) for evaluating the State's current capability. If a State declares that they plan to construct a fuel fabrication facility under Article 2.a.x and also declares research in zirconium purification then that can be taken as a piece of evidence that they may not currently have the capability to purify zirconium.

As part of an assessment of information a State declares under its respective safeguards agreements and protocols and information derived from field verification activities, an analyst would perform a detailed open-source investigation into the State's capabilities (and plans) to produce indigenously nuclear fuel cycle-related equipment or necessary non-nuclear materials, beyond what may be subject to declaration under an AP, in order to ensure a complete picture of the State's capabilities, and to inform analysis of acquisition paths and the development of the State level approach (see next section).

Acquisition Path Analysis

In addition to evaluating States' declarations, safeguards analysts assess States' industrial capabilities in support of the State evaluation process. This enables the analysts to develop a broad understanding of the State's nuclear program, physical infrastructure, human resource base, and how the relevant activities and resources within the State are organized in support of its nuclear fuel cycle program (private versus government-owned, the degree of multinational control and links to international partners, etc.). This knowledge feeds into acquisition path analysis (APA), an important component in the development of State-level safeguards approaches (SLAs) and the state evaluation process.

As part of APA, analysts collect, analyze, and consolidate information about the State's past, present, and planned nuclear fuel cycle and related capabilities and infrastructure. The inputs to APA include declared nuclear material, facilities, and NFC and related processes (including uranium mines and concentration plants); information on NFC research and development (R&D), including research not involving nuclear material; exports and imports of specified equipment and non-nuclear material, other NFC-related R&D and industrial capabilities.[2] Analysts derive this information from what the State has declared under its safeguards agreements and related protocols and other voluntary reporting undertakings; from the findings of the IAEA's own safeguards activities within the State; and from other sources, including open sources and third parties.

The APA process includes information that is generally broader than what is required for State evaluation. As the 2015 PNNL-LLNL study of acquisition path analysis noted, “While State evaluation focuses on identifying and evaluating a State’s experience, activities and plans relevant to the nuclear fuel cycle, an APA must consider these items as well as *potential* capabilities and *possible* actions that could fill gaps in the State’s existing capabilities”[3] (emphasis in the original).

As part of a September 2019 initiative called the SLA Improvement Project (SLAIP),[a] the Department of Safeguards updated the procedures for APA.[4] The updated guidance elaborates on how State Evaluation Groups (SEGs) are to use information about the nuclear fuel cycle and related technical capabilities of the State in the analysis of acquisition paths. According to the guidance, the State’s industrial capabilities, along with the overall size and scope of the State’s nuclear program and its R&D capabilities, contribute to a rating of the State’s overall technical capability associated with a specific stage of the NFC.[b] The SEGs use the capabilities-based rating to determine the lengths of acquisition path steps, guided by departmental “standards” for estimating the lead time required to develop undeclared NFC facilities, and associated processing times involved in NFC processes. Having an accurate picture of a State’s technical capabilities, including industrial capabilities, enables the SEG to make a well-informed judgment about how long it might take a State to complete a potential undeclared fuel cycle step. This in turn contributes to the development of the Department’s State-Level Approach for that country.

3. IAEA’s Methodology for Industrial Capabilities Assessments

The IAEA has been conducting assessments of States’ industrial and other technical capabilities since the early 2000s when it began conducting structured state evaluation as part of the earliest implementation of the State Level Concept. The purpose of these assessments is to evaluate the correctness and consistency of a State’s declared nuclear program and nuclear imports and exports by reviewing information derived from open and other safeguards-relevant sources.[c]

The scope of the IAEA’s approach includes a State’s nuclear manufacturing capabilities, i.e., infrastructure to manufacture nuclear material, equipment and technology listed in AP Annex I, and dual-use manufacturing capability (listed in the annex of INFCIRC/254 Part 2). The IAEA methodology incorporates both narrowly formulated, targeted tasks, e.g., understanding a State’s capability to manufacture components of a hot cell, and tasks with a broader focus, such as establishing how the country’s general industrial base supports its nuclear program.

Broadly focused assessments that build a profile of a State’s entire nuclear industry are time-consuming and resource intensive, but they are also necessary as SEGs undertake certain types of analysis, e.g., evaluations that follow the signing of a new safeguards instrument, such as the AP; initial, baseline evaluations of a State’s acquisition paths; or the process of drawing an initial broader conclusion.

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[a] The objective of the SLA Improvement Project is to refine the methodologies for the development of SLAs to ensure consistency in developing SLAs across States with comprehensive safeguards agreements (CSAs).
[b] The rating bins States into five general categories based on the SEG’s assessment of the State’s level of experience with a particular NFC technology: a holder, proficient, user, having emerging capabilities in, or none.
[c] It should be noted that while the open-source information is central to these assessments, it is the integration of that information with data collected in the course of verification activities that is essential for SEG assessments. During field activities, such as design information verifications and complementary accesses, inspectors have the opportunity to observe the make, manufacturer, technical specifications, capacity, quality, etc. of the AP Annex I or Annex II equipment, which is critical to making analytical judgments about the relevance of that equipment to States’ capabilities.

Industrial capabilities assessment is carried out in the context of related analytical inquiries, such as those related to procurement inquiries, imports and exports of materials and technologies, and broader scientific and technical (S&T) capabilities, including research and development. Analysts consult a standard list of information sources, as well as technical references to evaluate the relevance and suitability of indicators. The analysts use the IAEA Physical Model as the standard taxonomy for search and analysis.[5]

The SGIM analyst consults the following generic information sources in performing industrial capability assessments:

- Existing State files, including AP declarations and nuclear material reports, if relevant, as well as results of field activities, e.g., design information verification and complementary access.
- Trade-focused sources, such as business-to-business and business-to-consumer sites, e.g., Alibaba.com, and local sites.
- Industrial commercial sources, e.g., Domain-specific business directory guides, e.g., *World Energy Nuclear Directory*, *Nuclear News Buyers Guide.*
- Scientific and Technical R&D sources, e.g., patent databases, global and country-specific databases of scientific publications, such as INIS or Science Direct, websites of academic institutions focusing on nuclear and related sciences.
- Other relevant sources, e.g., IAEA/OECD Uranium Red Book, U.S. Geological Survey

Within SGIM, a group of trade and technology analysts consults a separate set of technology-focused sources in preparation of a report on a country's indigenous capabilities to manufacture select nuclear-related materials and equipment. These include analysis of UN Comtrade database of trade statistics; commercial business directories and databases and corporate registries, e.g., Kompass, Panjiva; proliferation-sensitive item manufacturing profiles by academic institutions;[6] Procurement Outreach Programme records,[7] if relevant. The main thrust of this approach is to identify domestic manufacturers of a set of key technology inputs from various stages of the nuclear fuel cycle. The capabilities are those of relevance to the safeguards process, e.g., included in the AP Annex II, not overly ubiquitous in non-nuclear industries to lose their diagnosticity value for safeguards purposes, or broadly indicative of capabilities that could be leveraged for developing the nuclear fuel cycle.[8] An important element of the approach is to differentiate between *actual production* of a good or technology and manufacturing *capability*.

4. Reflections on IAEA's Approach

Over the years, the IAEA's approach to conducting industrial capabilities assessment has evolved in source coverage, scope, and analytical rigor, to make industrial capabilities assessments a meaningful and constructive contribution to the state evaluation process. In reflecting on the current process, we offer a few observations:

- It is not obvious whether the methodologies are meant to guide a one-time baseline review of States' capabilities, and, if so, how the process would change for periodic updates, and to what extent it is possible, and desirable, to monitor States' industrial capabilities in a continuous way. Recognizing that preparing these assessments is time-consuming, and that updating them regularly or performing continuous monitoring may not be as straightforward for industrial capabilities as it is for other areas of interest, e.g., scientific research activity, the IAEA's work processes could be further refined to suggest how frequently industrial capability assessments should be revisited, how comprehensive the updates should be, and what criteria would motivate updates to baseline reports.

- There is room to better integrate all open-source resources available to SEG analysts for a more effective assessment. Focusing on a pre-determined set of items focuses the analyst's collection effort to a manageable scope. While these assessments are targeted, highly relevant, and less time-consuming, they are also limited in scope – by definition – and would be strengthened by better integration with the general open-source analysis processes that look at information sources of a broader scope to get a fuller picture of the State's activities, e.g., academic research that may eventually support relevant industrial capabilities; assistance, collaboration, or interaction with companies, facilities, scientists, or *other entities of another State*, etc. Knowledge of that context undoubtedly would enhance overall analysis of industrial capabilities. For example, better understanding of how foreign assistance, in particular clandestine procurement from abroad, could disrupt industrial capabilities assessment, would lead to higher confidence in assessments of States' gaps in capabilities and overall acquisition paths, and better position the SEG to respond to abrupt changes in APA in timely manner.
- The IAEA takes advantage of a multitude of sources that are diverse, credible, and relevant in assessing States' industrial capabilities. For targeted, narrowly focused inquiries, the IAEA's sources clearly are carefully selected to balance comprehensiveness and efficiency. When analysts cannot review an information source without manually sifting through a significant amount of content that is likely irrelevant, it is hard to justify adding it to the source list. There is a real need for software and algorithms that would facilitate a more systematic collection, processing, and review of data, going beyond existing techniques, such as visualization and network analysis. The new tools likely would take advantage of advanced machine learning algorithms, such as deep neural networks. The IAEA is already investing in developing such systems, as evident for example in their efforts to enhance the Department of Safeguards' capabilities to exploit more systematically the growing volume of open-source visual data, such as videos and images, the so-called Safeguards Multimedia Information Analysis and Integration Project,[9] and the ICORE component of the Collaborative Analysis Platform that uses natural language processing to automate the collection and categorization of information.[10]

5. Customizing Technical Capabilities Assessments to Analytical Tasks

In an effort to consider how the IAEA industrial capabilities assessment methodology could be further refined, we propose an approach that suggests making use of categories of nuclear and dual-use production proficiencies that take into account the uniqueness of the safeguards analysis mission and relate them to other ways of categorizing research and commercial activities and capabilities. Within the technical capabilities assessment process, different safeguards evaluation objectives require focusing on different types of proficiency.

To that end, we reconsider what the terms "industrial" and "capability" mean in different analytical contexts. How "capability" and "industrial" are defined will dictate what activities and proficiencies are included within it and how specific analytical assessments are conducted. For example, do industrial capabilities only encompass large-scale operations that can produce high-quality goods and services—operations such as a commercial uranium enrichment plant? Or do they also include the ability to produce enriched uranium at any scale or quality, e.g., only gram scale versus kilogram?

A more nuanced understanding of what a State can and cannot produce domestically, the quality and quantity of production, and whether it constitutes a complete (or a part of an) acquisition path step will allow for IAEA analytical goals to be more directly linked to assessing a State's specific corresponding nuclear and dual-use production proficiencies. This process would also help to standardize the industrial capabilities assessment process for analysts and provide assurances that SEGs use the processes in objective and transparent ways.

Definitions

We consider "industrial capability" along several dimensions: what is being measured (general industrial base versus dual-use without NFC-specific characteristics versus specially designed or dual-use with NFC-specific parameters), at what level/scale of production (academic S&T, research/lab-scale, or commercial-scale), and the completeness of the capability (individual components versus a completed/assembled process).

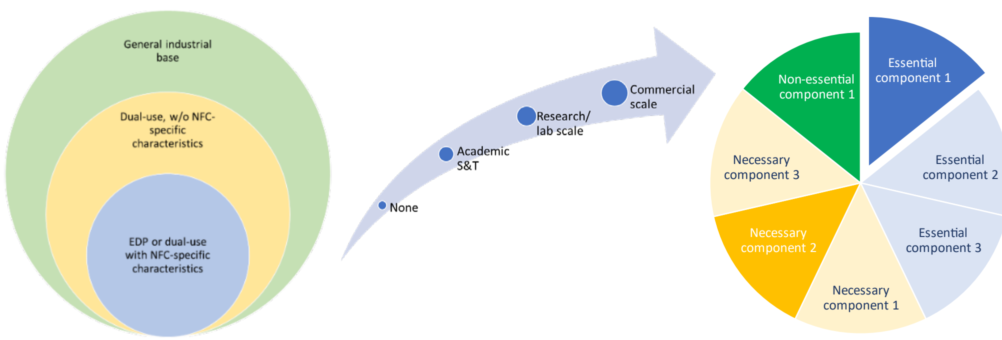

Figure 1: Dimensions of "industrial capability" (from L to R): what is being measured, scale of production, completeness of the capability

Industrial ***"Capability"***

"Capability" could be narrowly defined as requiring the demonstrated ability to produce an integrated, manufactured good or service that constitutes a step in a nuclear fuel cycle acquisition pathway. Under that definition, States that have or have access to manufacturers of one or multiple components of a gas centrifuge enrichment plant (GCEP), for example, aluminum tubes, vacuum pumps, and carbon fiber, do not *necessarily* have a demonstrated GCEP capability, only a demonstrated capability to manufacture these discrete GCEP components.[11] The capability to manufacture components is important, but in and of itself it is insufficient for an assessment that a State has a gas-centrifuge enrichment capability for the purposes of acquisition path analysis. Under the restrictive definition, a GCEP capability would include – in addition to the ability to manufacture individual components – the ability to integrate them into a completed, well-performing process/facility.

Alternatively, it is possible to define a capability in a less restrictive way to include capacity or activity to produce some equipment, materials, or know-how that *contribute* to a step in an acquisition pathway. Focusing on the pieces or components of what the first proposed definition suggests is a capability or an ability to make items that are in the same category but not meeting the precise parameters of what's required for use in a nuclear facility – vacuum pumps that meet the NSG criteria for isotope-separation equipment versus low vacuum pumps for, say, freeze dryers, is a more conservative approach. This definition would imbue more States with more "capabilities" for executing a particular acquisition pathway.

"Industrial" Capability

A narrow definition would consider as "industrial" only those capabilities that are deployed at a large scale and capable of resulting in high-quality services or goods that meet a market need. Under this definition, analysts would focus on those proficiencies that could most readily be directed in service of an acquisition path. This approach would allow analysts to differentiate based on quantity and quality of production proficiencies and would open up the possibility of separately examining proficiencies that are less than industrial in scale and quality, but could still contribute to an acquisition path.

In a more inclusive approach, even a research or lab-scale proficiency to produce a specific good or service could be relevant in the analysis of acquisition paths, in that it employs material technologies and expert skill to produce the good or service, even if its contribution to an acquisition path is less assured. This broader definition, however, has the potential to obfuscate the most relevant proficiencies to completing a path step, which could lead to either under or over estimation of capabilities.

Calibrating "industrial capability" to serve the safeguards assessment process

Safeguards evaluation activities vary in the level of specificity and scope of technical capabilities assessments they require. Furthermore, safeguards processes overlap, for example, evaluating state declarations will also support preparing acquisition path analysis. Thus one could consider the restrictive and inclusive definitions discussed above as two extremes of a continuum, where the focus of industrial capability assessment and the data sources used vary depending on the task at hand and possibly the State in question.[d]

To fully demonstrate how these definitions could assist in conducting industrial capabilities analysis, we propose the following categories of nuclear and dual-use production proficiency that take into account the uniqueness of the safeguards analysis mission and relate them to other ways of categorizing research and commercial activities and capabilities.

Table 1. Categories of nuclear fuel cycle-related technical proficiency[e]	Often referred to as this type of activity
1. Access to relevant information and know-how. There are entities in the State that have knowledge about production processes and requirements but have not worked to develop and implement production of components for a specific capability.	Scientific
2. Scientific R&D. An entity within a State conducts applied-level research and development that enables the State to develop a capability to perform nuclear fuel cycle processes, build a NFC facility, or to manufacture necessary goods or services.	Scientific

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[d] We suspect the nature of the safeguards agreement, CSA only versus CSA plus AP, would not be a deciding factor in selecting an appropriate industrial capability assessment methodology. While the task of assessing a State's AP declaration is moot for CSA-only States, the SEG for a CSA-only State still must perform an evaluation of the State's industrial capabilities in order to build a picture of the NFC-relevant activities and perform acquisition path analysis.

[e] The categories are not meant to be a progression of scale of capabilities. The numbers are included for ease of reference to different types of categories of capabilities.

3. Dual-use component manufacturing. An entity within a State actively produces (or has produced in the past) dual-use components that are relevant to a specific nuclear capability but have never (or not recently) been applied to that end. This includes the ability to produce items listed in Part 2 of INFCIRC 254.	Industrial
4. R&D-scale capability. An entity within a State produces the good for research/lab-scale purposes, in a quantity and quality that is insufficient to meet commercial market needs. This capability includes component demonstration but not full integration. It also includes the ability to reliably produce items listed in Part 1 of INFCIRC 254.	Technical/industrial
5. Pilot-scale capability. An entity within a State actively produces the identified good or service (referring here to the overall capability of an NFC step) at a level below commercial scale but capable of generating 1 SQ/year.	Industrial
6. Commercial-scale capability. An entity within a State actively produces the identified good or service (referring here to the overall capability of an NFC step) for domestic use or export in a quantity and quality that meets domestic requirements or market needs.	Industrial

Matching categories of proficiency to assessment objectives

Industrial capabilities assessment is one of many tools that safeguards analysts have at their disposal to support state-level assessments. Within the industrial capabilities assessment process, different safeguards evaluation objectives require focusing on different categories of proficiency. For example,

- To evaluate state declarations, which an SEG would need to do throughout the year as declarations come in, examining categories 2, 4, 5, and 6 activities (as described in Table 1 above) would most appropriate;
- To determine plausible acquisition paths and to estimate lead times, helping to prioritize technical objectives, and ultimately determining the frequency and intensity of safeguards measures, examining information on all categories would be necessary.

If the analyst's task is to evaluate a State's declaration, then examining proficiency categories 2, 4, 5, and 6 would seem to be the most important, because they consist of capabilities that may be subject to declaration and, with respect to categories 4, 5, and 6 would constitute operational capabilities that are, or could be, deployed in a relatively short time and should already be reported by the State to the IAEA.

If the immediate objective of industrial capabilities analysis is to identify potential undeclared fuel-cycle activities, then examining proficiency categories 2, 3, and 4 takes on greater significance. If a State is able to operate an undeclared fuel cycle facility without detection, identifying entities within the State that produce relevant components that could be used to achieve that capability would help bring to light that undeclared facility or activity. In this context, industrial capabilities analysis would need to be paired with trade analysis to get a full picture of what acquisition path steps a State could have clandestinely achieved by procuring the missing goods from abroad.

If the objective is to determine the most likely acquisition pathway for a specific State or to re-evaluate potential acquisition pathways, an activity an SEG is likely to undertake every few years, then an analyst would need to evaluate the State's ability to achieve any category of proficiency. For instance, if a State has a specific declared proficiency capability 5 or 6, an analyst might want to evaluate whether a related step in a specific acquisition pathway is under development and has yet to be declared. This would entail examining a broad range of proficiencies. Considering the role that APA plays in assessing overall safeguards implementation, it makes sense to evaluate potential acquisition pathways on an iterative basis and not merely assume that the technically plausible paths remain as previously identified.

6. Conclusions

Assessing States' industrial infrastructure, resources, and capabilities is important for supporting IAEA safeguards activities, such as acquisition path analysis, estimation of lead times to construct new nuclear fuel cycle (NFC) facilities clandestinely, and for building a foundation for understanding the overall picture of a State's nuclear fuel cycle and nuclear-related programs. The paper reviewed the IAEA Department of Safeguards' approach to assessing States' industrial capabilities. We considered what the analysis of industrial capabilities entails, and noted challenges and caveats associated with such assessments. We proposed an approach that suggested making use of categories of nuclear and dual-use production proficiencies that take into account the uniqueness of the safeguards analysis mission and relate them to other ways of categorizing research and commercial activities and capabilities. Different safeguards evaluation objectives require focusing on different types of technical proficiency. Our proposals aimed to suggest ways to enhance the IAEA's ability to conduct industrial capabilities assessment that support various safeguards analytical processes, such as acquisition path analysis, by customizing types of proficiency assessments to safeguards analytical tasks. Adopting a more standardized approach to conducting industrial capabilities assessments would allow for more consistency and transparency across State evaluation groups.

References

[1] INFCIRC/540, Article 2.a.(iv).

[2] A. Nakao et al., "Acquisition Path Analysis as a Collaborative Activity," Symposium on International Safeguards, 20-24 October 2014, Vienna, Austria.

[3] G. Dupuy et al., "Roles for Open Source Analysts in Acquisition Path Analysis for IAEA Safeguards," Report for NA-241, PNNL-24915, November 2015.

[4] M. Aparo and T. Renis, "Enhancing Consistency in the Development of State-level Safeguards Approaches," presented at INMM 2020 Annual Meeting, July 12-16, 2020.

[5] E. Marinova et al., "Analysis of nuclear relevant information on international procurement and industrial activities for safeguards purposes," Symposium on International Safeguards, 20-24 October 2014, Vienna, Austria.

[6] I. Stewart, "The Manufacturing Base for Proliferation-Sensitive Items, Symposium on International Safeguards, 5-8 November 2018, Vienna, Austria.

[7] P. Schot et al., "Collecting Safeguards Relevant Trade Information: The IAEA Procurement Outreach Programme," IAEA Symposium on International Safeguards, Vienna, Austria, November 1-5, 2010, IAEA-CN--184/044; M. Ardhammar, "Analysis of nuclear-related trade and procurement information in support of IAEA safeguards," 41st ESARDA Annual Meeting, Stresa, Italy, May 14-16, 2019.

[8] E. Marinova, Nuclear-related industrial capabilities update, ESARDA Verification Technologies and Methodologies Working Group meeting, March 19, 2021.

[9] M. Fowler, "Optimizing the Use of Multimedia Information in IAEA Safeguards," presented at the IAEA Symposium on International Safeguards, November 5-8, 2018, Vienna International Centre, Vienna, Austria.

[10] Development and Implementation Support Programme for Nuclear Verification 2018-2019, IAEA, STR-386; Development and Implementation Support Programme for Nuclear Verification 2020-2021, IAEA, STR-393.

[11] L. Kim et al., "Guidance for Estimating Gas Centrifuge Enrichment Plant Lead Times," LLNL Technical Report, LLNL-TR-795178, October 2019; L. Kim, "Assessing the Deployability of Acquisition Path Steps," LLNL Technical Report, LLNL-TR-818094, December 2020.

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