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Reorganizing the Physical Model to Enhance Its Value to the IAEA Department of Safeguards

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ABSTRACT

The Physical Model is the IAEA Department of Safeguards' encyclopedic reference for the nuclear fuel cycle. The Physical Model is the only Agency-authored reference specifically designed to be used during safeguards implementation. Also, the Physical Model is updated largely by relying upon consultants from various Member States under a Support Program request. This gives it a unique role in ensuring the consistency, objectivity, and effectiveness of the Department's work. While the Agency works to update and maintain the Physical Model in consultation with Member State experts, it is important to examine how the Physical Model can be utilized for maximum benefit in safeguards implementation. This paper describes the various IAEA tasks that the Physical Model supports, with a focus on the work of State Evaluation Groups, and it identifies how the Physical Model can contribute to the consistent, objective, and effective completion of those tasks. This paper also examines how indicators of nuclear activity are weighted in the Physical Model and offers options for enhancing their relevance to different types of analysis. Finally, it examines how re-organizing the Physical Model's content to better describe operational phases of each nuclear fuel cycle process could better support the Department's work related to pre- and post-operational phases of a process. Such a reorganization could support critical tasks like acquisition path analysis and the development of technical objectives for undeclared acquisition path steps. This paper documents how such a restructuring would enhance the Physical Model's value by encouraging Member State experts to focus on different phases of operation during periodic technical updates, and by considering the sources of safeguards information available at each phase.

1 INTRODUCTION

This paper synthesizes the authors' ideas over several years about how to improve the Physical Model, a technical tool developed by an IAEA Department of Safeguards together with Member States to describe and characterize the various components of the nuclear fuel cycle. The present work has largely occurred outside of the IAEA's formal process for examining and revising the Physical Model, and it is the hope of the authors that this outsider perspective provides renewed recognition of the value of the Physical Model as it is and renewed vigor towards its continued enhancement.

This paper considers three primary topics:

- The value and applicability of the Physical Model to the evolving tasks of the Department of Safeguards.

- An evolved approach for weighting of indicators of nuclear fuel cycle activity referenced in the Physical Model.
- A proposed reorganization of information in the Physical Model by a nuclear fuel cycle step's phase of operation.

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2 BACKGROUND

In a previous study,[1] the authors identified trends in safeguards implementation that should be considered during any review and update cycle for the Physical Model that go beyond technical advances in the nuclear fuel cycle. In particular, the study noted factors like the role of HQ analysis in the state evaluation process, the availability of open-source information, expanded implementation of the Additional Protocol, the State-level concept, and emphasis on acquisition path analysis as major developments since the initial drafting of the Physical Model in the late 1990s and limited revision efforts in the late 2000s.

The IAEA's stated purpose of the Physical Model is to support safeguards by helping the State Evaluation Groups (SEG) with *organizing* information regarding the state's nuclear fuel cycle, as well as in *recognizing* that certain information may constitute indicators of a certain fuel cycle step.[2] In the previous work, the authors recommended reviewing the Physical Model with a focus on these two goals, while remaining mindful of the developments in safeguards implementation. They then considered specific enhancements to the structure and content of the Physical Model.

3 THE VALUE OF THE PHYSICAL MODEL AND ITS APPLICABILITY TO THE TASKS OF THE DEPARTMENT OF SAFEGUARDS

The Physical Model is the Department of Safeguards' encyclopedic reference for the nuclear fuel cycle. Like any encyclopedia, it provides a thorough overview of its topic, however, it is not a substitute for deep technical expertise or documentation about individual topics. The Physical Model was produced in consultation with a small group of Member State fuel cycle experts and includes images and technical data not readily available in open sources.[3] And while the Physical Model is not the only fuel cycle

[1] Reed, J., Feldman, Y., "Updating the Physical Model for Open Source Analysts," INMM 58th Annual Meeting (2017)
[2] Liu, Z. and Morsy, S., "Development of the Physical Model," Symposium on international safeguards: Verification and nuclear material security; Vienna (Austria), October 29 – November 2, 2001, IAEA-SM-367/13/07.
[3] The Physical Model was initially drafted in the late 1990s as an element of the 93+2 strengthened safeguards initiative. Select volumes were updated in the mid-2000s. For more discussion on the history of the Physical Model and the need to adapt it for various stakeholders, see (Reed & Feldman, 2017)

reference available to the Department of Safeguards, it is the only Agency-authored reference specifically designed to be used during safeguards implementation.

Additionally, the Physical Model contains data sets not widely represented in other Agency documents. For example, the Physical Model contains information on dual-use equipment and materials, as well as the manufacturing processes used to create especially designed or prepared nuclear equipment. This allows the Physical Model to be a repository not only of safeguards-declarable information, but all categories of safeguards-relevant information about nuclear fuel cycle processes.

The credibility of IAEA safeguards activities is of utmost importance to stakeholders in, and advocates for, an effective international nonproliferation regime. Credibility is built upon IAEA activities being performed in a consistent, objective, accountable, and effective manner without bias. All the Department of Safeguards' documents – whether policies, procedures, or safeguards technical reports – must have as their central purpose – whether explicitly stated or implied – the maintenance and enhancement of the Department's credibility. Using the Physical Model (and similar objective, Agency-produced documents) as a fundamental resource to support safeguards activities helps the Department maintain its credibility.

The Physical Model was originally developed during Programme 93+2 to provide "a technical tool to aid enhanced information analysis."[4] According to the IAEA, the Physical Model provides a "fundamental technical basis" for information analysis intended to be used for "evaluating States' nuclear activities," as well as assisting inspectors in preparing for in-field activity.[5] Some of the uses of the Physical Model include:

1. Reference for Consistency Checks. For consistency analysis, the Physical Model is an effective benchmark reference for the processes and activities that one should expect to see for a particular nuclear fuel cycle operation. When indicators are reported through declarations, observed by inspectors, or identified in other available information, the Physical Model can help assess whether the scale of observed or declared indicators is consistent with declarations about fuel cycle activities or intentions. Additionally, the Physical Model can help assess whether those indicators may be suggestive of a previously unknown activity, of other nuclear fuel cycle steps, or of related but not declarable activity.

2. Reference in Acquisition Path Analysis (APA). The Physical Model is a critical reference for APA because it describes all possible nuclear fuel cycle steps, as well as the pathways through those steps. As SEGs perform APA, they can use the Physical Model to map the indicators available to them to the schematic of the fuel cycle. Without the Physical Model as a guiding reference, SEGs might generate their own framework for describing the fuel cycle, which would reduce consistency across SEGs. While the Physical Model serves purposes beyond APA, given that it already provides an effective map of the nuclear fuel cycle, it would be efficient to include any APA-specific references developed by the Department within the Physical Model so that the Department only needs to maintain one fuel cycle reference.

3. Reference for Detection of Undeclared Activities. The Physical Model is a vital reference for the detection of undeclared activities because it includes safeguards-relevant information beyond what is subject to reporting under safeguards agreements that may offer useful context for understanding the

[4] (Liu & Morsy, 2007)
[5] (Liu & Morsy, 2007)

state and direction of a nuclear fuel cycle program. The Physical Model includes information on dual-use equipment, R&D activity, and other indicators relevant to developing undeclared capabilities. As part of the continuing effort to adapt the Physical Model for detection of undeclared and misuse, the IAEA should continue to identify and consider safeguards relevant indicators that are outside of what must be declared by the State, but which are suggestive of undeclared nuclear fuel cycle R&D or activity. Including generic development steps and timelines and improving the organization of the Physical Model's description of pre-operational activities like R&D or construction can enhance the document's utility as a reference.

4. Provision of Parameters and Key Words for Open-Source Research. The Physical Model's cataloguing of indicators provides a useful reference for not only individual words, but the relationships between words and phrases, to assist with developing search strings for manual information collection or training natural language processing (NLP) algorithms. A modest refinement of the Physical Model would be to expand the indicators list, or add an appendix, specifically focused on cataloguing proven high-value phrases or word relationships, and for identifying those terms that likely would be used in a text document describing a process. This will require testing and evaluation using both automated search tools and human analysts. While there are important advances in automated search and retrieval, there will likely always be a human component to searching for and assessing potentially safeguards-relevant information. Documenting proven relationships among words, phrases, and indicators will transform the Physical Model into a repository of this important corporate knowledge. An additional area where the Physical Model could be enhanced would be to capture a translation of the indicator lists, as well as proven words and phrases, into various non-English languages.[6]

5. Reference in Analysis of Nuclear-Related Trade. The Physical Model is an important resource for trade analysis because it captures all safeguards-relevant indicators, including and especially dual-use equipment and materials that are traded in the commercial market and can serve as the manufacturing base for an undeclared capability. Those wishing to analyze markets and manufacturers of nuclear components and dual-use goods can use the Physical Model as a training resource to familiarize themselves with the look and specifications of that equipment, as well as a first-line reference[7] for analyzing potential nuclear-related goods discovered in open-source research or during verification activities.

A refinement of the Physical Model could add more technical information about trade in equipment and materials. This could include pictures or diagrams of equipment in a shipping configuration, information on typical suppliers or brands (while this is dynamic in the real-world, some major suppliers should be persistent over time), distinguishing features, and other relevant data to help assess whether an item meets technical criteria to be nuclear-related.[8] Additionally, to enhance its support for industrial

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[6] This would also include situations where the non-English word or phrase for a particular indicator is not a straightforward translation of the English words. For example, the words used for nuclear "reactor" in some languages may be closer to the English words nuclear "pile", meaning that a literal translation of the word "reactor" would not be as useful as identifying the correct term used in the other language.
[7] It would not be possible (or appropriate) for the Physical Model to replace expert knowledge of specific equipment or materials, however it can be used as an effective filter by generalist-analysts before consulting with specialists.
[8] Note that a joint European Commission Joint Research Centre-IAEA project transformed the indicators in the Physical Model into a database format and integrated it with "The Big Table", a collection of references like the Additional Protocol Handbook and the NSG Guidelines to enable queries across these resources. This is different from the proposal here which would incorporate more equipment and materials information in the Physical Model itself. For more information on the JRC-IAEA project, see Versino, C., et al., "Integrating IAEA's Physical Model with

capability assessments performed by trade analysts, the Physical Model could include information on the technical difficulty or underlying capabilities required to produce nuclear and dual-use equipment and materials.

4 Weighting the Strength of Indicators

The Physical Model includes lists of the various indicators of a given nuclear fuel cycle process. The indicators are categorized as equipment, materials, or techniques associated with a given process; examples of indicators included in the Physical Model are items and materials listed in the Nuclear Suppliers Group Guidelines.[9] Each indicator in the Physical Model has a strength rating of strong, medium, or weak depending on the specificity, or the discriminatory value, of that indicator to the given fuel cycle step, i.e., how particular a given indicator is to one step of the fuel cycle.[10] Agency staff and consultants give each indicator a rating based on their assessments. [11]

An expanded approach to indicators could include additional information. Rather than focusing only on "specificity" of the indicator, additional weighting schemes that would be valuable to include in the Physical Model could focus on:

1. **Intrinsic Importance.** This addresses how necessary a particular indicator is to the fuel cycle step in question. This could help capture when multiple technology approaches could achieve the same end of a fuel cycle step. For example, both maraging steel and carbon fiber, and their associated machine tools, could be used in the manufacture of gas centrifuge rotors, so neither material is intrinsically important to gas centrifuge enrichment. Stated differently, there are multiple technology development paths that could produce equipment especially designed for gas centrifuge enrichment.

2. **Relevance to Nuclear Applications.** Some materials or equipment might not be specific to any given process but are always of safeguards interest. For example, UF6 is used in gas centrifuge enrichment, but it is also used in other enrichment processes and fuel cycle steps. Therefore, while its specificity or discriminatory value may be low for a given fuel cycle step, it is always of high importance to safeguards. Stated differently, while discovery of UF6 does not directly identify a specific fuel cycle step or process, its discovery would always be of great interest to a safeguards inspector.

Safeguards investigations often begin with a collection of disparate and incomplete indications of nuclear activity, and staff need methods to choose which indicators to pursue further, and to prioritize both how and what to look for next. These additional dimensions can help analysts and SEGs objectively identify appropriate next steps, as well as integrate other information available to them.

JRC's The Big Table document search tool," JRC Scientific and Policy Report (2013), available at https://publications.jrc.ec.europa.eu/repository/bitstream/JRC77541/lc-na-26215-en-n%20%28online%29.pdf

[9] INFCIRC/254/Part 1 & Part 2

[10] (Liu & Morsy, 2007)

[11] (Liu & Morsy, 2007)

5 ORGANIZING BY PHASE OF OPERATION

Another way to enhance the value of the Physical Model is to examine its overarching content and organization. Currently, the Physical Model is divided into separate volumes for each fuel cycle step, and chapters within each volume deal with different types of process within that step. For example, one volume address uranium enrichment; chapters within the volume address enrichment of uranium metal, UF6, etc.; and subchapters address processes, such as gas centrifuge and gaseous diffusion. At the process level, the Physical Model's organization focuses on indicator components, such as materials and equipment.[12] While it mentions dual-use equipment and research, the current Physical Model primarily focuses on indicators in an operational phase and at industrial scale.

This section looks at how the Physical Model currently handles the different phases of a nuclear fuel cycle step, and it proposes ways to better organize existing content and to include additional relevant content. In this context, "Phase" refers to whether an activity or indicator is associated with a "pre-operational", "operational", or "post-operational" part of a nuclear fuel cycle step.[13] Re-organizing the Physical Model to create a continuum from pre-operational to post-operational phases could better assist SEGs with various tasks, including estimating lead times or deployability readiness for acquisition path steps, ranking the strength of indicators, and developing prioritized technical objectives and performance targets.

This proposed change could benefit the Physical Model in two related ways: It could 1) enhance the user experience, and 2) streamline the process of updating the Physical Model.

From the user perspective, some indicators are applicable to multiple phases of operation. By organizing each fuel cycle process around phase of operation, the Physical Model would more effectively catalogue the applicability of specific indicators and allow for the strength of an indicator to be adjusted depending on which phase of operation it is attached to. For example, a filament winding machine is a dual-use indicator of gas centrifuge enrichment, but because it makes components for the process, it would not be used on the operating floor of enrichment plant. This change would also create opportunities within the Physical Model to develop more robust narratives of the different phases. This would transform the Physical Model from a listing of indicators to a process that provides important contextual information about those indicators – which in turn would help staff assess the strength of observed indicators and their impact on the work of the SEGs. If revised in this way, the Physical Model could better support a wider variety of tasks, including acquisition path assessment, industrial capability assessment, evaluation of state declarations, and planning for in field verification.

Organizing the Physical Model by phase of operation would also help ensure that the right experts are considering the right factors when drafting updates. The Physical Model is updated largely by relying upon consultants from various Member States under a Support Programme request. Each phase of operation may have different sets of experts associated with it – for example, researchers involved in R&D of a fuel cycle process are likely to have a different understanding of process indicators than operators of a facility utilizing the process. Ideally, as part of consultations focused on updating the

[12] (Liu & Morsy, 2007)

[13] The "pre-operational" phases includes all the steps necessary to develop and operationalize a facility, while the "operational" phase refers to the normal operational activities including start-up and shut-down, and finally the "post-operational" phase refer to that activities that occur following final shut-down of a facility.

Physical Model, the IAEA would select the appropriate experts to support a particular update. By allowing appropriate experts to focus on a specific phase of operation for a fuel cycle process, they will also be more likely to provide a robust description of that process in a way that enhances the document for other users.

While the current Physical Model includes elements of pre- and post-operational phases, the organization around indicator type drives the description toward the industrial-scale operational phase. The operational phase is of obvious importance to safeguards implementation. However, for safeguards inquiries where the focus is on pre- or post-operational phases, the Physical Model does not organize the relevant information in a way that readily supports those analytical processes. This ultimately complicates the process of using the current Physical Model to identify technical objectives and performance targets.[14] Because the Agency is concerned with nuclear activities regardless of scale (e.g., laboratory, pilot, industrial), reorganizing the Physical Model by phase should also make it easier to discuss how indicators vary depending on the scale of the activity.

Finally, it is notable that different information may be available to the IAEA at different phases of a safeguards-related activity. For example, certain pre-operational information may only be available from AP declarations, yet the type of physical access available depends on the operational status[15] and presence or absence of nuclear material. Organizing the Physical Model by phase of operation would assist with safeguards planning by documenting the authorities the Agency has to gather information for a given phase and explicitly tying those authorities to the types of indicators that may be observed.

6 Conclusion and Recommendations

This paper presents options for updating the IAEA's Physical Model to consider both technical advances in the nuclear fuel cycle and the evolution in the various aspects of the implementation of international safeguards. As an encyclopedic reference, the Physical Model's strength is its breadth, not depth, of nuclear fuel cycle coverage, and its objectivity and credibility, because it is a Member State supported product that is officially produced by the IAEA Department of Safeguards.

In addition to periodic updates that consider nuclear fuel cycle advances, this study proposed three broad areas of consideration:

1. Updates to maintain alignment with Department of Safeguards tasks.
2. Expanded indicator strength weightings across multiple dimensions.
3. Reorganization of information by fuel cycle step.

Taken together, these proposals should help maintain the Physical Model as a key resource for the Department as it seeks to make effective use of all available safeguards-relevant information.

[14] For more on performance targets, see Lockwood, D., et al., "The Role of Performance Targets in Safeguards," IAEA-CN-267.

[15] For example, the inspection authority is lost once the IAEA and state agree that a facility has been decommissioned, however CA authority may remain at that location in states with APs.