PERFORMANCE TARGETS FOR DETECTION AND INVESTIGATION OF UNDECLARED NUCLEAR ACTIVITIES IN THE STATE AS A WHOLE

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ABSTRACT

Detecting undeclared nuclear activities anywhere in the State as a whole is an open-ended challenge, and the IAEA cannot realistically control or even know how readily its available detection measures can detect clandestine activities at unspecified locations. As a result, performance targets for undeclared-activities detection may as a practical matter need to be framed in terms of what should be done to look for and pursue evidence of undeclared activities rather than in terms of quantitative detection outcomes. This paper builds on previous work by us and others to suggest how such targets could be established. The suggested approach is intended to be broadly compatible with the IAEA's existing methodology for analyzing potential acquisition paths and for developing State-level safeguards approaches (SLAs).[1] Safeguards technical objectives associated with undeclared-activities detection can be thought of as having two components: (i) *monitoring for possible indications* of undeclared activities and (ii) *following up* to assess, investigate and resolve detected indications. We describe a method for prioritizing these objectives and for specifying, where possible, the frequency and intensity of safeguards activities implemented to accomplish them. We include discussion of a fictional case study to illustrate how such an approach might work in practice.

INTRODUCTION

Performance targets are essential both for planning safeguards implementation activities and for evaluating safeguards effectiveness. For safeguards activities directed at detecting diversion of declared nuclear material, the IAEA can establish outcome-based metrics in terms of detection probability and detection time for diversion of a significant quantity of material, and can select specific safeguards activities, including their frequency and intensity, that can meet those targets. By contrast, for assuring the absence of undeclared nuclear materials and activities detection, the relationship between the frequency and intensity of safeguards activities and actual detection outcomes is at best only qualitative. This which complicates the task of establishing concrete performance requirements for applicable measures such as open-source information analysis, complementary access (CA), and environmental sampling (ES), and satellite imagery analysis. As suggested in previous studies,[2] it may be useful to frame undeclared-activities-detection requirements not in terms of quantitative detection outcomes but rather in terms of the due diligence required in <u>monitoring for available indications</u> of possible undeclared activities and requirements for <u>follow up and resolution of such indications</u> as they are discovered through IAEA-directed activities or otherwise come to the IAEA's attention.

PERFORMANCE TARGETS FOR MONITORING-TYPE TECHNICAL OBJECTIVES

We discuss performance targets for the monitoring component of undeclared-activities-detection technical objectives by first considering how those objectives could be *prioritized*, then identifying relevant *metrics* of performance, and finally describing what factors could be used to set *target values* with respect to those metrics.

<u>Prioritizing Monitoring-Type Technical Objectives</u>

The priority of technical objectives (TOs) for discovering available indications of undeclared activities in any given nuclear fuel cycle (NFC) step could be established based primarily on two factors:

- The IAEA's assessment of the State's *<u>level of technical capability</u>* to complete the development, construction, and operation of an undeclared facility of that type with proliferation-relevant throughput, i.e., on the order of one significant quantity SQ of product per year. The assessment would take account of relevant information on the State's known accomplishments in that NFC process (and uncertainties therein), the size and complexity of the State's overall nuclear program, and any relevant R&D and industrial strengths that the State could draw on to close remaining technical gaps. The IAEA has described a similar approach (Ref. 1). We will assume the State's capability in each NFC process is scored on a 5-level scale, with "5" representing a highly advanced capability and "1" denoting very little or no capability.

- The *proliferation sensitivity of the NFC step*; that is, how close the completion of that step would bring the State to clandestine acquisition of unirradiated direct-use nuclear material. For example, proliferation sensitivity could be assigned one three levels: "high" for enrichment or reprocessing, "medium" for reactors, and "low" for uranium ore concentrate (UOC) production, uranium conversion, or fuel fabrication.

Combining those two factors, one could prioritize monitoring-type technical objectives as suggested in Table 1 below.

Table 1. Priority of TOs for monitoring for indications of undeclared activities in a given NFC process as a function of the State's technical capability and the proliferation sensitivity of the NFC process.

State's NFC-step specific technical capability	Monitoring priority		
	For low sensitivity NFC steps	For medium sensitivity NFC steps	For high sensitivity NFC steps
5	Medium	High	Very High
4	Low	Medium	High
3	Low	Medium	Medium
2	Very Low	Low	Medium
1	Very Low	Very Low	Low

IAEA presentations and papers (Ref. 1, for example) have described a somewhat more complex prioritization methodology that uses the State's assessed technical capability to estimate path-step lead times and total acquisition path times and uses those result, together with certain other factors such the availability of effective detection means, to set TO priorities. We believe the simplified scheme shown in Table 1 would likely yield generally similar prioritization results, at least for technical objectives related to discovering indications of undeclared facilities. In any case, the method discussed below for establishing performance targets could be adapted to whatever prioritization scheme were used.

Performance Targets for Measures Used to Detect Indications of undeclared activities

For safeguards measures applied at declared facilities and LOFs, the IAEA usually can express its verification goals for detecting the diversion or undeclared production of a significant quantity of nuclear material in terms of the required detection probability (which informs the *intensity* of safeguards activities) and required timeliness (which guides the *frequency* of safeguards activities). While it does not appear to be realistic to set such detection-outcome-based goals for discovering undeclared activities anywhere in the State as a whole, we believe it would be useful to express performance requirements in terms of broadly analogous metrics that still express how deeply and how frequently the IAEA looks for available indications. We call these metrics "depth of look" and "frequency of look." In general terms, higher priority TOs should be allocated more intense and more frequent monitoring effort than lower priority TOs.

Performance Targets for Analysis of Open-Source and Trade Information. Collection and analysis of open source and trade information is particularly amenable to distinguishing among depth-of-look levels, ranging from broad, largely passive monitoring of readily available information sources to more intensive collection and analysis efforts focused on a specific issue. By way of illustration, we suggest a notional four-level categorization of information collection and analysis activities, recognizing that the appropriate number of levels—and the activities associated with each—would need to be determined by experts within the IAEA staff having direct experience and knowledge of their processes and workflows:

- Level 1 - Maintain awareness of relevant information about the State that is pushed to analysts through the IAEA's routine global daily information collection and review processes or is otherwise passively available via pre-set alerts.
- Level 2 - Maintain awareness of information readily available for analyst retrieval on demand. Monitor a predetermined list of general news/industry open sources; passively monitor trade and technology sources for information on nuclear fuel cycle and related capabilities.
- Level 3 - Collect information from a more comprehensive set of sources including S&T databases; conduct structured review and perform broad analysis of all information collected in Level 1 – 3 activities
- Level 4 - Conduct targeted, deep-dive analyses, drawing as need on less readily available information sources.

Table 2 below illustrates how specific depth-of-look and frequency targets for open-source collection and analysis could be specified as a function of the monitoring priorities.

Table 2. Notional requirements for open-source collection and analysis activities to fulfill the monitoring component of undeclared activities detection objectives, as a function of monitoring priority.

Priority for monitoring	Frequency of required activities (using depth of look levels 1 – 4)			
	Level 1	Level 2	Level 3	Level 4
Very high	Continuous	At least monthly	Every 6 months	Annually
High	Continuous	At least quarterly	Annually	Every two years
Medium	Continuous	At least annually	Every two years	Within one-half the assessed lead time
Low	Continuous	At least annually	Within one-half the assessed lead time	Not required
Very low	Continuous	At least annually	Within one-half the assessed lead time	Not required

We also note that the State's assessed level of capability in a given nuclear fuel cycle process would influence the focus of the analysis: For an NFC process in which the State had little or no known capability, collection and analysis might focus on looking for early R&D and other capability-development activities. For a process in which the State already had a known capability or near-capability, there would be more emphasis on looking for any available indications of actual construction, commissioning, or operation of a clandestine facility.

Performance Targets for Complementary Access in a Monitoring Role. In a State with an additional protocol (AP) to its comprehensive safeguards agreement (CSA) in force, complementary access (CA) is a key measure available to address TOs related to the detection of undeclared activities and is used to both monitor for and follow-up on indications of such activities. In a monitoring role, the IAEA can use CA to assess the capabilities at a location or to verify compliance. For example, the IAEA may use CA to determine whether a location has capabilities or infrastructure that would warrant periodic attention to verify compliance or that would change the IAEA's assessment of the State's level of technical capability and possibly require updates to the SLA.

The justification required for conducting complementary access depends, in part, on the location type. Article 4 of the AP defines the purposes for which the IAEA can conduct a CA, and Article 5 differentiates among various location types. Using CA in a monitoring role is generally more straightforward at Article 5.a locations (i.e., buildings on sites of facilities and LOFs, locations with nuclear material not subject to full safeguards procedures, and decommissioned facilities) than at 5.b locations (e.g., locations of certain manufacturing activities or fuel cycle R&D without nuclear material) and 5.c locations (other locations anywhere in the State). This is because to conduct CA at 5.b and 5.c locations, the IAEA must be able to articulate a specific question or inconsistency that needs resolution. That said, the threshold for what constitutes a question or inconsistency is chiefly at the discretion of the IAEA, so that CA with a monitoring-type purpose can sometimes be conducted even at 5.b and 5.c locations, especially if the access is framed as relating to a question about the completeness of the State's declaration rather than a specific inconsistency in that declaration.

For CAs used in a due-diligence monitoring role, we suspect that establishing Department-wide standards requiring a certain minimum number of CAs as a function of a given TO's priority could prove too rigid and simplistic. The safeguards coverage value of any particular CA would depend in part on whether a meaningful location(s) could be identified and whether CA was likely to be an effective tool in furthering the monitoring objective. Therefore, it may be sufficient for the IAEA to develop and document internal criteria by which to judge the expected safeguards value of a CA at a given location for a given purpose.

Environmental Sampling. Except in connection with inspection or design information verification activities at declared nuclear facilities and LOFs, the collection of environmental samples normally would occur in conjunction with CA. Like CA, environmental sampling (ES) can serve both as a monitoring tool to detect initial indication of undeclared activities and as a follow-up tool to investigate or confirm indications derived from other information sources. Even in a State with a CSA but no AP implemented, environmental samples collected at declared facilities and LOFs may conceivably contain signatures originating from activities elsewhere in the State and inadvertently carried to the inspected location in trace amounts on individuals' clothing or on containers or vehicles. In that light, both for AP and non-AP states, periodic comprehensive review and analysis of past and current environmental sample analytical results for the State is an important activity that should be conducted as part of State evaluation.

Satellite Imagery Analysis. Satellite imagery analysis also can serve in a monitoring role and to support follow-up activities. In a monitoring role, satellite imagery is especially useful as a tool to monitor locations otherwise inaccessible to the Agency and to monitor other high-priority sites for indications of new construction, modifications, or other new activities inconsistent with State declarations. Satellite imagery is also an important tool for vetting and assessing indications derived from other sources, such as news media or third parties.

PERFORMANCE TARGETS FOR FOLLOW-UP OF DETECTED INDICATIONS

Initial Assessment of Discovered Indications

When the IAEA discovers a possible indicator of undeclared activities or encounters information that could impact its assessment of the State's capability with respect to a given NFC process, an initial assessment of that information should be performed, to include evaluating the credibility and reliability of the information encountered as well as searching and cross-checking against other relevant information sources. This initial assessment would aim to determine whether there indeed appears to be an unresolved inconsistency and, if so, establish its priority for follow-up and resolution. In a case where credible new information suggests the State is significantly further advanced in the NFC process than previously known, the initial assessment also could recommend reviewing the current State-level safeguards approach to ensure that coverage of affected acquisition paths remains adequate.

Priority for follow-up.

The priority for follow up of discovered indications should reflect both the strength of the indication and the safeguards significance of the indicated activity, as suggested in Table 3 below.

- By "strength of indication" we mean how strongly the information implies possible undeclared activity related to the NFC step in question. In evaluating strength of indication, we consider two factors: first the reliability of the information containing the indication, and second the degree to which the information, if correct, implies the existence of undeclared activity related to the NFC step in question.
- The safeguards significance would also be a function of two factors: first, the proliferation sensitivity of the NFC step, and second, if discernable from the available information, the scale and degree of progress of the indicated activity (e.g., early R&D, advanced development, or actual construction or operation of a proliferation-scale installation).

Table 3. Prioritizing detected indications of possible undeclared activities for follow-up and resolution

		Strength of indication		
		Low	Medium	High
Safeguards significance of the indicated activity	High	Medium	High	Very high
	Medium	Low	Medium	High
	Low	Very Low	Low	Medium

Performance Targets for Follow-Up

The intensity and time-sensitivity assigned to efforts to follow up and resolve indications of undeclared activities should be commensurate with their priority. In particular, guidelines could be established for how quickly inconsistencies of a given priority should be resolved to ensure safeguards effectiveness. An IAEA paper presented at the 60th INMM Annual Meeting[3] indicated that the Agency recently had expanded the scope of its previously existing internal procedures for handling inconsistencies encountered during safeguards implementation at declared facilities to now include safeguards issues arising in other areas, potentially including irregularities relevant to possible undeclared activities.

While it appears practical to set targets for how quickly and intensely actions should be taken to resolved indications of undeclared difficulties, it would be difficult to prescribe in advance which of the available safeguards measures to employ with what speed and depth absent the specific context of a given case. For example, in deciding whether and how to use complementary access in a follow-up role, the priority of the follow-up objective would be a key consideration but so, too, would be case-specific factors such as whether available information pointed to specific candidate locations and whether the suspected activity was one whose traces could reasonably be observed by (or ruled out through) CA or could at least produce further leads. In most cases, a follow-up type CA would be preceded by other Headquarters-based measures, including open-source and trade information collection and analysis and satellite imagery analysis, if only to support the planning of the CA activity.

CASE STUDY OF FICTIONAL STATE, JADERNIA

In this section, we provide a case study to illustrate how the priority of undeclared activities monitoring technical objectives and the corresponding performance targets for the associated safeguards measures would be set. We also illustrate how indications encountered in the course of monitoring would be evaluated to determine whether unresolved inconsistencies exist and to prioritize the need for follow-up measures and to determine whether adjustments may be needed to the SLA.

Overview of the State

This case study involves a fictional state, Jadernia, which has a moderate-size nuclear fuel cycle, including uranium resources, light-water reactor fuel fabrication (including deconversion of imported low-enriched UF_6), operation of research and power reactors, and limited R&D in reprocessing, but has no known enrichment activities. Jadernia has moderately advanced indigenous scientific, technical, and industrial capabilities, including the capability to manufacture some major nuclear components and equipment and the ability to maintain and operate its imported fuel cycle facilities. Jadernia has both a CSA and AP in force, and for more than a decade the IAEA has drawn and reaffirmed the broader conclusion for the State.

Assessing Jadernia's nuclear fuel cycle and related technical capabilities.

As part of its acquisition path analysis (APA) process, the State evaluation group (SEG) for Jadernia would assess Jadernia's level of technical capability to complete development, construction, and operation of an undeclared facility of a proliferation-relevant scale for each nuclear fuel step. For the purposes of this paper, we assume the SEG has assessed Jadernia's capability levels as shown in Table 4 below, using a five-level scale as described in recent IAEA presentations.

Table 4. Jadernia's assessed technical capability to develop, build, and operate various nuclear fuel cycle facilities at proliferation scale (where 5 indicates a very high capability and 1 indicates very little or none

NFC process	Capability level	Comments/Rationale
Mining/milling	4	Carried out extensive uranium mining and ore concentration operations in the past, but mills have been decommissioned.
Conversion	3	Has commercial-scale experience handling UF_6 and deconversion of UF_6 to UO_2. Had limited small-scale experience in conversion to U metal. The State's overall capability in chemical engineering is high.
Enrichment	3	State has no known past or current R&D in enrichment, but its overall technical-industrial capability is moderately high.
Fuel fabrication	5	Operates a commercial-scale LWR fuel fabrication plant that was built with foreign help; by now has the acquired the technical-industrial capability to manufacture most equipment.
Reactors	4	Existing power reactors were imported, but the State now can manufacture most major reactor components.
Reprocessing	4	Conducted small-scale Purex reprocessing several decades ago; has conducted more recent R&D on non-aqueous methods; has significant hot-cell experience and potentially capable hot cells.

Setting Performance Targets for Discovering Indicators of Undeclared Activities in Jadernia

Prioritization of Monitoring Objectives. Based on the technical capability assessments in Table 4 and the relative proliferation sensitivity of the different NFC processes, the SEG would assign priorities to monitoring for indicators of undeclared activities in those respective processes, using guidance like that shown earlier in Table 1 or other suitable prioritization approaches such as that described by the IAEA in Ref. 1. For the purposes of this case study, we assume the SEG has assigned the priorities shown below in Table 5.

Table 5. Initial assignment of monitoring priority for discovery of undeclared activities in Jadernia.

Nuclear Fuel cycle step	Monitoring priority
Mining/Milling	Low
Conversion	Low
Enrichment	Medium
Fuel Fabrication	Medium
Reactor	Medium
Reprocessing	High

Next, based on those priorities, the SEG would select the frequency and intensity of applicable monitoring measures. For open-source and trade information analysis, for example, drawing on the notional guidance described earlier in Table 2, the SEG could set open-source performance targets for each of the various NFC processes. Table 6 below shows the targets the SEG might set with respect to undeclared reprocessing and enrichment activities.

Table 6. Frequency and depth-of-look performance targets for open-source collection and information analysis to support detection of indications of undeclared reprocessing and enrichment activities in Jadernia. The monitoring activities for each level are detailed in Table 2 above.

Depth of Look Levels	Reprocessing (high priority)	Enrichment (medium priority)
Level 1	Continuously	Continuously
Level 2	At least quarterly	At least annually
Level 3	Annually	Every 2 years
Level 4	Every 2 years	Every 4 years

Additionally, we assume the SEG would set targets for using other applicable measures like complementary access, environmental sampling, and satellite imagery in a monitoring role. These might include, for example:

- To monitor for undeclared production of source material, the SEG might call for reviewing satellite imagery of Jadernia's largest closed-down uranium mines every four years, as well as setting a 20% selection probability each year for Article 5.a(ii) CA to Jadernia's closed down in-situ leaching plant to confirm its current operational status.
- For detecting indications of undeclared reprocessing, the SEG might set, say, a 50% selection probability each year for conducting Article 5.a(i) CA (including visual access and the taking of environmental samples) at hot cell facilities at the Jadernia Nuclear Research Center as well as CA every three years to another installation at the same Center where non-nuclear surrogate materials are used in process-development research on non-aqueous reprocessing methods.

Scenario for assessment and follow-up of discovered indications

A new development: In this scenario, we suppose that in the course of a periodic focused analysis of Jadernia's technical capabilities relevant to uranium enrichment, IAEA analysts have discovered an abstract for an upcoming scientific conference paper that reports on computational studies being performed at a Jadernia State University to model the performance of gas centrifuges for isotope separation. They also have noted the mention, in the social media profile of a Jadernia Nuclear Research Center staff member, that he is researching isotope separation.

Initial Assessment: As part of the initial assessment of the above indications, analysts have conducted a priority search of S&T databases for other publications by the above authors and their respective co-authors. The search has yielded a few additional articles relevant to isotope separation, focused chiefly on computational studies of the performance and design of gas centrifuges, suggesting at least a theoretical R&D capability. There was no mention of specific isotopes in use of envisioned for future applications, but some of the authors have been involved in nuclear fuel cycle research or have worked in the Nuclear Engineering Department at the state university. A cross-check with Jadernia's past and current AP declarations has found that the State has not to date declared any enrichment R&D activities, any fabrication or assembly of centrifuge rotors, nor any plans in the next 10 years for developing uranium enrichment.

Strength of indication. Some of the information sources, including the scientific papers, were judged to be highly credible. Furthermore, research on gas centrifuge isotope separation technology, especially when occurring at a nuclear research institute and a nuclear engineering department, is strongly suggestive of interest in uranium enrichment applications. Therefore, the SEG views this as a moderately strong indication of activities previously unknown to the IAEA and which may have required declaration under Jadernia's AP.

Safeguards significance. The work described in the discovered publications suggests that undeclared uranium enrichment activity, if it indeed is occurring, is probably still at an R&D stage rather than in advanced development or deployment. Nevertheless, given the high proliferation sensitivity of this NFC process, the SEG deems the indicated activity to be of medium to high safeguards significance.

Performance target for follow-up. In view of the strength of indication and its safeguards significance, the SEG judges the matter to be a moderately high priority for further follow-up action, and it sets a goal of clarifying or resolving the issue within the next 6 months.

Follow-up actions: In this scenario, the SEG might decide to initiate the following activities:

- The IAEA Country Officer for Jadernia proceeds to draft for management approval a letter to the Jadernia State Authority citing the relevant publications and requesting that the State provide clarification regarding whether those entities are conducting uranium enrichment related R&D that requires declaration under Articles 2.a(i), 2.a(x), or 2.b(i) of Jadernia's AP and/or its CSA.
- Meanwhile, a small team consisting of an inspector familiar with the Jadernia Nuclear Research Center, an IAEA information analyst, and an IAEA satellite imagery analyst undertakes a quick study to identify and recommend candidate locations on the research center site and at the university for complementary access that might help determine the exact nature of the research, especially if Jadernia's response to the above letter should be slow in coming or provide insufficient clarification.
- The SEG also schedules a focused deep-dive analysis of Jadernia's enrichment related capabilities.
- Finally, pending further clarification and possible formal revision of the APA and SLA documents, the SEG recommends immediate provisional adjustments to the verification goals for detecting diversion of UF_6 from declared stocks and flows at Jadernia's fuel fabrication facility and for detecting further indications of undeclared enrichment activities. These adjustments include deeper and more frequent monitoring of open source and procurement information, more frequent Article 2.a(i) complementary access at the research center, and the taking of environmental samples in connection with all PIV, IIV, DIV, or CA activities at the nuclear research center.

CONCLUSIONS

In specifying verification requirements for measures to monitor for indications of undeclared nuclear activities in a given nuclear fuel cycle process, we encourage the use of performance targets that express the required depth and frequency of applicable measures. Target values should be consistent with a priority that reflects acquisition path considerations, such as the proliferation sensitivity of the nuclear fuel cycle step and the State's technical capabilities.

We recognize that follow-up of detected indications of possible undeclared activities is an iterative process, and that decisions regarding which applicable safeguards measures will be most effective in pursuing inconsistencies cannot be made outside a case-specific context. Nevertheless, it is desirable that there be documented guidance for prioritizing detected inconsistencies and for setting goals regarding how quickly and with what intensity actions should be taken.

Despite the only qualitative nature of the assurances that can be achieved with respect to undeclared activities in the State as a whole, it will be desirable for the IAEA's safeguards effectiveness evaluation process include explicit examination of whether undeclared-activities-related technical objectives have been met at a level consistent with their priority.

Finally, we note that some of the activities the IAEA carries out to monitor for indications of undeclared activities also help it maintain awareness of advances (whether hidden or overt) in the State's technical capabilities. This ensures that assumptions about those capabilities can be revised—and verification goals for technical objectives on affected acquisition paths adjusted—as necessary.

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