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Systems Approach to Arms Control Verification

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Abstract:

Using the decades of experience of developing concepts and technologies for verifying bilateral and multilateral arms control agreements, a broad conceptual systems approach is being developed that takes into account varying levels of information and risk. The IAEA has already demonstrated the applicability of a systems approach by implementing safeguards at the State level, with acquisition path analysis as the key element. In order to test whether such an approach could also be implemented for arms control verification, an exercise was conducted in November 2014 at the JRC ITU Ispra. Based on the scenario of a hypothetical treaty between two model nuclear weapons states aimed at capping their nuclear arsenals at existing levels, the goal of this exercise was to explore how to use acquisition path analysis in an arms control context. Our contribution will present the scenario, objectives and results of this exercise, and attempt to define future workshops aimed at further developing verification measures that will deter or detect treaty violations.

Keywords: arms control verification; systems approach

1. Introduction

The reduction or elimination of nuclear arms is not likely to occur absent a lower perceived need for nuclear weapons and high confidence that commitments are being honoured. Over more than 50 years of IAEA verification has taught us that achieving confidence requires a coherent and comprehensive picture of the State's compliance with its obligations.

The traditional IAEA verification approach was based solely on the type and quantity of nuclear materials present in a state, without regard to other factors that correlate with proliferation risk. The State-Level Concept (SLC) was recently proposed as a way to increase the efficiency and effectiveness of safeguards. The SLC consists of the development of state-level safeguards approaches (SLAs) to identify areas of higher proliferation risk and the collection and evaluation of multi-source information, including safeguards information, to optimize future safeguards activities. By piecing together a broad range of information encompassing declared, undeclared, international technical monitoring data, information from national technical means, open source, state-level, and international trade controls, it may be possible to provide state-level confidence that commitments are being upheld. It takes into account broader State-specific factors, potentially allowing greater focus on areas of higher risk of non-compliance. This approach could be extended to all types of treaty verification, including nuclear arms control and disarmament. So, in addition to verifying compliance for a particular treaty or agreement, such as the Nuclear Non-proliferation Treaty, it could be used to identify areas where effective verification could provide the greatest confidence that a State is complying with its commitments, and therefore help inform the most fruitful avenues for future arms reductions or disarmament efforts.

2. State-level analytical approach in development of future arms reductions initiatives

The IAEA SLC methodology consists of three processes which help to develop SLAs (for more details see Cooley 2011):

1. Identification of plausible acquisition paths.
2. Specification and prioritization of State-specific technical objectives (TO).
3. Identification of safeguards measures to address the technical objectives.

Listner et al. (2012, 2013, 214) demonstrated how acquisition path analysis can be carried out using a formal methodology which is yet compatible with the principles defined by Cooley (2011). The acquisition path analysis method uses a three-step approach: First, the potential acquisition network is modelled based on the IAEA's physical model and experts' evaluations. Second, using this model all plausible acquisition paths are extracted automatically. Third, the State's and the inspectorate's options are assessed strategically. Moreover, Listner et al. (2015) proposed and evaluated also two possibilities for determining technical objectives.

Applied to verifying arms control reductions, the development of a SLA could include the following three steps:

1. Modelling of a cheating network and identifying cheating pathways. This is a purely technical assessment of attractiveness including technical difficulty, timing and costs;
2. Determination of technical objectives, including identifying limits for detection probabilities for each area of a potential cheating network. It is assumed that requirements for high confidence verification result in the need for high detection probabilities for areas of highest risk; and
3. Identification of the technical and administrative measures that would provide the required detection probabilities. This would be expanded beyond classical inspections and could include all types of measures related to the field of interest (e.g. information barrier approaches could be useful).

When an existing treaty or agreement is in effect, the legal commitments set out the context under which non-compliant behaviour needs to be detected by the monitoring regime. Ultimately, pathways identified in this context should be developed to better understand how to verify compliance with a specific set of treaty objectives and commitments. However, the methodology could be applied to a full range of assumed conditions, and therefore allow for a more general analysis. Following this approach, cheating pathways (CP) could be mapped out to produce a state-specific inter-connecting network of nodes and processes/flows for nuclear materials and weapons – beginning with more generic models to protect sensitive information. The "relative attractiveness" or usefulness in a particular nuclear weapons program CP could then be considered. It is recognized that expert judgment will be required where no data is available.

To achieve a state-level approach for arms control or disarmament, the methodology will need to take into account materials, weapons and the links between the two. Being that the IAEA SLC has been designed for implementation in Non-Nuclear Weapons States (NNWS) for verifying peaceful uses of nuclear materials, it may not be much of a stretch to expand to verification of nuclear *material* cycles to states possessing nuclear weapons. However, significant work will be needed to expand the model to *nuclear weapons*, because national security requirements and Nuclear Non-Proliferation Treaty (NPT) Articles 1 and 2 commitments will impede the ability to provide many details. To-date, considerations regarding verification of nuclear materials and nuclear weapons disarmament verification have usually been addressed separately but the importance of these linkages have been recently presented (NTI 2014).

3. Applying the material pathway analysis to nuclear weapons-possessing states

For the purposes of developing the methodology, we will consider the verification of nuclear materials in a state possessing nuclear weapons that is subject to international commitments. It is assumed that an international inspectorate exists. It is important to remember that non-compliant behaviour is defined as the violation of commitments so the legal situation or the assumptions must be taken into account. Two examples that we considered are:

- Nuclear Weapons State (NWS) within NPT and Voluntary Offer Agreement (VOA). A State having signed a VOA must not use the facilities under this agreement to produce material that will be used in a weapon.
- State outside NPT and INFCIRC/66 in-force. A State outside the NPT but with facility or item-specific commitments (INFCIRC/66 type agreements) must not use these facilities or items for military purposes.

Possible non-compliant behaviour (edge types), in addition to clandestine processing, misuse of existing facilities, undeclared import and diversion from existing facilities considered for NNWS would be included to account for the possible additional commitments beyond the NPT and IAEA safeguards. Depending on the commitments, clandestine processing (i.e. production in undeclared facilities) would not be part of the model because without a comprehensive agreement like in INFCIRC/153, states producing fissionable material in undeclared facilities would not be violating a commitment.

In states possessing nuclear weapons, two additional edge types could be considered: diversion from the military fuel cycle and military processing. These are illustrated in Figure 1.

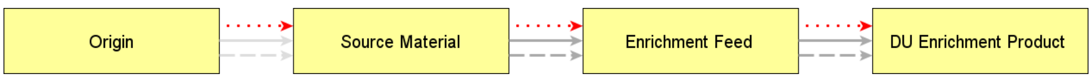

Figure 1: Example for a Cheating Path. Grey arrows represent misuse and diversion in the civil nuclear fuel cycle. Additional edge types consider the military fuel cycle: Diversion from the military fuel cycle is represented by the red arrow from "origin" to "source material" and military processing is represented by all the remaining red arrows).

So, depending on the type of commitment, these processes could be carried out by the state without violating international law (e.g. in a INFCIRC/66 case but not if a multilateral treaty was in-force). When an activity is allowed, it would be represented in the model but the detection probability would be set at 0% because an allowed activity will not need to be monitored.

The methodology could be applied to three example scenarios:

1. A state with a complete military fuel cycle without safeguards but with the civilian facilities under safeguards. This could be under INFCIRC/66 or a VOA. In this case, where a military fuel cycle is allowed, the military pathways will remain the most attractive pathway for producing materials for weapons and therefore it is assumed that there will be no need for misuse or diversion from the declared civil fuel cycle. The risk of sanctions, if non-compliant behaviour (such as pursuing a pathway that using civil installations under international surveillance) is detected would also deter misuse and possibly eliminate the need for an inspection effort at this pathway.

2. A case where some gaps in military fuel cycle exist, where those gaps would be represented by missing diversion edges or reduced processing attractiveness values in the acquisition path model. Effective verification, possibly including increased monitoring, could deter non-compliant behaviour so that if State finds these pathways attractive, appropriate monitoring measures in particular facilities would increase the risk to the State of detection, should they attempt to exploit the pathway. If the risk (and costs) of detection are high, the State should be deterred from non-compliant actions.

3. Military facilities & materials put under fissile material control regime. If military facilities and materials are put under a multilateral treaty, these installations may be under the same restrictions as civil facilities under the NPT. Therefore there could be increased attractiveness to use these facilities for the production materials for nuclear weapons. To deter the use of these paths in violation of the commitments, the model would recommend a significant increased monitoring/inspection effort. The ability to verify a baseline declaration and knowledge of past production will be a key factor.

4. Applying the nuclear weapons pathway analysis to weapons-possessing states

To-date, consideration of monitoring and verification of weapons or weapons components has been in the context of specific treaties or during negotiations of possible new regimes. In applying a state-level methodology to weapons, and developing the appropriate CPs, it will be important to consider the strategic objectives of a state. The CPs could be different if the objective is to expand the size of the national stockpile or to increase the degree of technical sophistication of their stockpile. Some potential cheating pathways include warheads or weapons that were not included in baseline declarations, diversion of materials or components from dismantlement, and undeclared production of warheads. Ways to link monitored nuclear material and facilities with warhead production & dismantlement will need to be considered to achieve confidence that new production is not occurring.

NTI (2014) has worked to advance methods to verify material and warhead baseline declarations in states possessing nuclear weapons. The confidence in these declarations will be key to modelling an effective monitoring/verification regime that could detect clandestine activities.

One option to begin modelling the weapons complex would be to use IAEA Physical Models and indicators and modify them as appropriate. There will also be a need to consider weaponization indicators, to take into account possible reconstruction of existing warhead designs without use of development/testing facilities as well as acquisition of a weapon or development of more sophisticated weapons. A challenge to the successful modelling of the weapons complex arises from the fact that many of the processes, actions and infrastructure that might constitute an indicator of non-compliance in a proliferant state may exist or take place as a matter of course in a weapons state.

5. Workshops

A workshop held at the European Joint Research Center in Ispra, in conjunction with the 2014 Fall Meeting of the ESARDA Verification Methods and Technologies (VTM) Working Group (WG), began to explore this systems concept by studying the possible parallels with the IAEA's State Level Approach (SLA), currently used to develop effective safeguards for nuclear materials.

An exercise scenario was presented to the working group that bridged the gap between safeguarding of materials and NEW START style verification of nuclear weapon delivery systems. Under this scenario, a treaty was signed by two states that required each state to cap the total number of warheads in its nuclear arsenal and to cap the number warheads it deployed to no more than 500. Each state maintained a full nuclear weapons enterprise from material production and weapons design, through manufacture and deployment on multiple delivery systems. Members of the VTM WG were asked to consider the potential pathways one of the states could take to cheat on its treaty commitments, and discuss the possible application of acquisition pathway analysis and a state level approach for identifying verification requirements for the treaty. Figure 2, below, illustrates a simple example pathway (highlighted in red) that could be taken by the state.

The workshop resulted in a number of lessons that will require further consideration as the application of systematic level analysis to arms control verification is refined. They are introduced below:

6. Verification Objectives

Verification objectives need to be specifically identified for arms control treaties, in order for the systems approach to be applied correctly. The IAEA has a well defined "significant quantity" concept around which an APA can be organized; safeguards measures are designed to be capable of detecting the diversion of one significant quantity of material within four weeks of diversion.

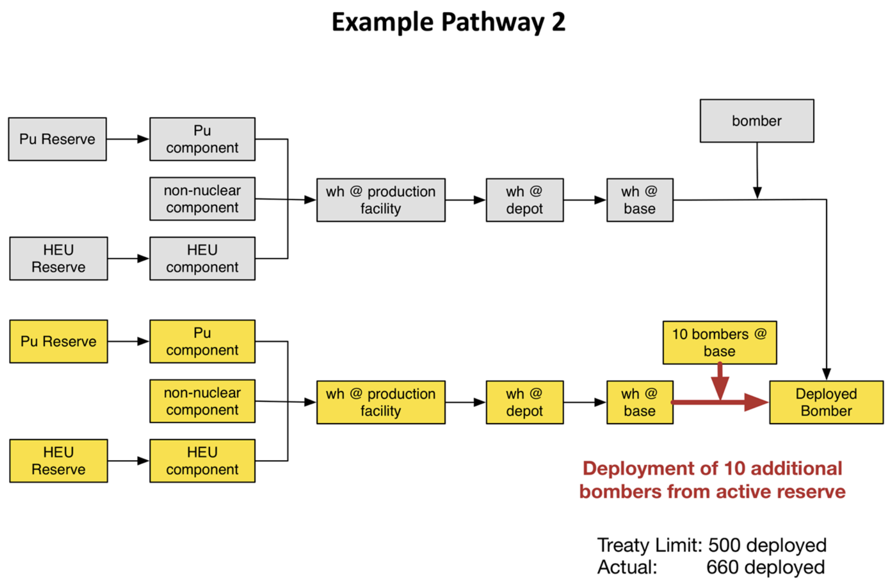

Figure 2: An example pathway used during the workshop, visualising the weapons enterprise as a linear flow from weapons useable material to deployed weapons. Declared facilities are coloured yellow, undeclared facilities are coloured grey. In this example, the pathway exploited is to deploy additional warheads from the total declared stockpile onto reserved aeroplanes, increasing the total number of deployed warheads from 500 to 660, significantly breeching treaty limits. Neither the declared reserve aeroplanes, nor the declared reserved warheads, would breech the treaty so long as they remain in reserve. More complex pathways exist which may involve combinations of declared and undeclared materials, components, weapons, facilities, process, stockpiles and delivery vehicles.

In contrast, verification objectives are not yet defined for future warhead treaties and may well be treaty dependent. For example, under the exercise scenario, the definition of a significant quantity of weapons as agreed by the states might be tolerant of small discrepancies since each state is allowed to deploy 500 weapons and small fluctuations around this limit may not pose threat to either state. Small fluctuations may not threaten strategic security or stability and so may not be strategically significant. Nevertheless, the discovery of even one extra deployed weapon might be indicative of larger scale cheating that could threaten the security of one or the other state. Overall perceptions of what constitutes a threat may well differ between treaty parties. It may be useful to separately consider a significant quantity for detection purposes and a strategically significant quantity for stability considerations and the purpose of identifying detections timeliness requirements. Lastly, it might be that a suitable definition of a significant quantity during treaties where large numbers of warheads remain deployed is not suitable when deployed numbers are considerably reduced. It is therefore important to develop a mechanism for achieving consensus on these verification objectives.

It is also important to define a significant quantity of the controlled item in such a way that declarations made about it in relation to the treaty can be verified effectively. Because of the secrecy surrounding weapons systems, verifying that an item declared to be a weapon is a weapon (and that it is in the declared status of deployment) could be challenging. Therefore definitions of category of weapon by deployment status (e.g. deployed or non-deployed, in reserve, inactive, disassembled, or weapon component) should be framed in a verifiable way, which also allows items that are declared as none of those categories to be verified as ‘none of the above’. Significant detail concerning the activities of the nuclear enterprise and locations of declared weapons may need to be shared, and updates exchanged regularly, to facilitate verification of deployment status.

To be effective, any verification system must be capable of detecting the diversion (or clandestine production and deployment) of the significant quantity (of weapons) in a timescale that ensures that the strategic security of treaty signatories or the security of the wider international community is not undermined by the actions of a state that cheats.

An extension of the Acquisition Path Analysis approach to monitoring weapons as well as materials could include additional terms. See Table 1 for a suggested extension.

Graph Theory	Route Planning	Acquisition Path Analysis	Weapons Verification
Node	Location	Material form	Weapon status/form
Edge	Street	Process / path segment	Deployment process/path segment
Path	Route	Acquisition Path	Deployment Path
Edge Weight	Distance	Attractiveness	Attractiveness

Table 1: An example extension of the acquisition path model to include nuclear weapon verification by deployment status

7. Measures of Attractiveness

The working group discussed suitable measures of attractiveness for identifying the cheating pathways most likely to be exploited under this scenario. Comparison was made with the proliferation resistance metrics defined in the Evaluation Methodology for Proliferation Resistance &Physical Protection of Generation IV Nuclear Energy Systems (2011). Broadly, the metrics were considered to be suitable. The metrics are titled below as per the Gen IV definitions for simplicity and are accompanied by a summary of the discussion of each:

- *Proliferation Technical Difficulty* – Since weapons states already maintain the full weapons enterprise, the ability to deploy existing weapons, build additional weapons or modify stockpiles is not considered to be beyond the state's capability. Furthermore, such actions could be masked to a large extent by allowed processes. Nevertheless, some pathways may require mobilisation and coordination of greater resources than other pathways (e.g. deployment of reserve warheads onto reserve bombers may be accomplished more simply than building a clandestine stockpile of new weapons and secretly loading them onto a submarine). *Proliferation Difficulty* and *Detection Probability* were discussed in terms of the stealth required to successfully exploit a CP.
- *Proliferation Cost* – The cost of certain pathways relative to others is evident (see example in previous bullet point). Nevertheless, capital and operational costs of pathways may already be accounted for in national budgets. Only pathways requiring significant capital investment may be deemed less attractive to a state wishing to cheat. Overall, cost may not be a primary factor in the decision to exploit a CP.
- *Proliferation Time* – The minimum time required to deploy a strategically significant quantity of additional weapons. The significance of the proliferation time is closely tied to the strategic goals of the state. For example, a short proliferation time allowing the deployment of large numbers of weapons very quickly might be considered strategically advantageous in some situations by a cheating state. Equally, a long proliferation time associated with a very stealthy build up of a clandestine stockpile might be considered attractive in other circumstances. Since both routes could be attractive, each should be appropriately weighted in a state level model.
- *Fissile Material Type* – Not discussed in great detail since stockpiles of material were declared under the treaty.
- *Detection Probability* – With no standard set of verification measures assumed to have been agreed or allowed under this treaty, cumulative detection probabilities cannot be determined in advance. This reflects well the situation for future nuclear warhead arms control verification where no specific verification technologies or methods have been agreed. However, Acquisition Path Analysis can be used to identify where specific verification measures might be of most benefit. Design requirements for technologies can then be stipulated based upon the identified verification requirement. This systems level analysis can therefore help identify technology requirements for future treaties. Weapons or weapons components require

sufficiently robust monitoring to ensure that their location remains known to the inspectorate to a high level of confidence, thus ensuring that they are not deployed in breach of treaty commitments. High confidence might also be required in ensuring that only declared items can interact with declared delivery systems. Detection probabilities for undeclared items at declared deployment sites must therefore be sufficiently high. Linked to this, the detection times in such instances should also be very rapid.

- *Detection Resource Efficiency* – The efficiency in the use of staffing, equipment, and funding to apply verification measures across different parts of the weapons enterprise. There may be points in the nuclear weapons enterprise where the ability to verify declarations with high confidence would be particularly beneficial. In the case of the exercise scenario, the monitoring to ensure delivery systems only carried the declared number of warheads was identified to be important. Nonetheless, the verification focal point could shift depending upon the aims and objectives of the treaty.

8. System Level Analysis Benefits

A systematic or state level analysis is likely already performed by states (such as US and Russia) that have extensive experience in arms control agreements. In the context of bilateral arms control agreements, Weapons States have a basic understanding of a nuclear weapons complex, in particular the competing needs for effective verification, protection of national security information, and upholding NPT Article VI commitments. In this case, the system level analysis can help identify specific verification requirements based upon a state's own strategic concerns. It can help identify useful ways of framing and defining verifiable objects and timescales and identify the types of technologies needed to provide monitoring capabilities in specific locations. While a formal approach may add value to a Weapons State's analysis, its primary benefit may be the common framework it can provide to states without the capacity for or experience with analysing arms control verification regimes. In this case, the state level approach can promote understanding about the strategic and technical challenges associated with arms control verification.

9. Further considerations

The development of a state-level approach to modelling material CPs is more advanced than for weapons, but work can be done to further expand the models and make the linkages between material and weapons cycles. As mentioned earlier, a challenge to the successful modelling of the weapons complex arises from the fact that many of the processes, actions and infrastructure that might constitute an indicator of non-compliance in a proliferant state many exist or take place as a matter of course in a weapons state. True indicators of non-compliance with agreements may therefore be much more subtle in nuclear weapons states, requiring detailed information of the level of expected activity in the state with regards to the weapons enterprise. Verification methods need to be fine tuned such that allowed activities do not mask cheating. Furthermore, non-compliant actions with potentially significant consequences could take place of very short time scales, and so detection times must be commensurately short. Therefore the level of intrusiveness required to effectively monitor allowed activities may be considerably greater than for current or historical agreements. All of these factors can be incorporated into suitable systems level models to improve the links between materials and weapons.

The challenges associated with the protection of national security and non-proliferation information must be taken into account as a realistic physical model is developed that incorporates further intrusiveness. Existing ideas for managing access for routine and challenge inspections or new ideas will need to be considered. Verification that declared items are situated in their declared location may prove to be a relatively traditional matter of accounting, assuming suitable managed access procedures can be developed. In contrast, verifying the absence of undeclared items, either in declared facilities or undeclared facilities, could be perceived to be an onerous task. Nevertheless, as suggested by the results of the workshop, early priorities in this area could focus of ensuring undeclared items cannot successfully be mated with delivery systems and there are parallels following this approach to verifying the absence of warheads on delivery systems as accomplished under NEW START at present.

Systems level analysis, including acquisition path analysis can therefore provide clear verification objectives for site visits based upon information already provided by the inspected state. Clear verification objectives may enable managed access procedures to be defined that met those objectives whilst protecting sensitive information.

Any advancement in arms reductions and disarmament is likely to proceed in a step-by-step way. Bilateral agreements are likely to provide the steps that will pave the way for more multilateral implementation. For example, future US/Russia disarmament treaties limiting warhead numbers may build the infrastructure for facility monitoring and inspection activities, and transparency and confidence-building measures amongst the de-facto nuclear weapons states may provide capital for more intrusive monitoring activities. Such a state-level methodology could help inform the direction of future negotiations, present day technology R&D, and assessment of possible effective verification regimes.

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