LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-CONF-673702

Developing a Systems Approach to Arms Control Verification - Results from the ESARDA Verification Technologies & Methodologies (VTM) Working Group Workshop

C. D. Chen, M. Dreicer, K. Allen, I. Niemeyer, C. Listner, G. Stein

June 22, 2015

Institute of Nuclear Materials Management Annual Meeting
Indian Wells, CA, United States
July 12, 2015 through July 16, 2015

Disclaimer

This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Lawrence Livermore National Security, LLC, nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or Lawrence Livermore National Security, LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or Lawrence Livermore National Security, LLC, and shall not be used for advertising or product endorsement purposes.

Developing a Systems Approach to Arms Control Verification – Results from the ESARDA Verification Technologies & Methodologies (VTM) Working Group Workshop

Cliff Chen[1], Mona Dreicer[1], Keir Allen[2], Irmgard Niemeyer[3], Clemens Listner[3], Gotthard Stein[4]

[1] Lawrence Livermore National Laboratory, Livermore, USA
[2] Atomic Weapons Establishment, Aldermaston, UK
[3] Forschungszentrum Jülich GmbH, Jülich, Germany
[4] Consultant, Bonn, Germany

Introduction

The reduction or elimination of nuclear arms is not likely to occur absent a lower perceived need for a nuclear weapons arsenal and confidence that other states are upholding their commitments. Lessons from verification of peaceful uses of nuclear fuel cycle activities by the International Atomic Energy Agency (IAEA) over more than 50 years has taught us that achieving confidence requires a coherent and comprehensive picture of the State's compliance with its obligations.

The IAEA's State-level concept (SLC) has recently been advanced as a way to increase the effectiveness and efficiency of safeguards[1]. The SLC sought to address the shortcomings in the traditional approach that focused on verifying the non-diversion of declared nuclear materials at individual nuclear facilities. Instead, by designing a safeguards regime that treats the state as a whole rather than as a collection of unrelated facilities, and by piecing together a broad range of information encompassing declarations, technical monitoring data, and other safeguards-relevant information such as open source, nuclear-related trade, and information from member states' national technical means, it may be possible to provide state-level confidence that commitments are being upheld.

Verification of nuclear arms control agreements has historically focused on monitoring a state's compliance with specific associated declarations. As the quantity of nuclear weapons is reduced, the need for higher confidence drives increasingly intrusive and costly verification measures. At the same time verification must be balanced with a state's need to control access to sensitive information and uphold its Nuclear Non-Proliferation Treaty (NPT) Article 1 or 2 commitments. Developing a systems approach that evaluates the state as a whole could help identify areas where effective verification could provide the greatest confidence that a state is complying with its commitments. This would help inform the most fruitful avenues for future arms reductions or disarmament efforts, assist in the analysis of tradeoffs, and aid the prioritization of evaluation of new approaches and technologies for verification.

Work performed under the auspices of U.S. Department of Energy by LLNL under Contract DE-AC52- 07NA27344. LLNL-CONF-673702

A series of workshops to explore the systems approach have been held, beginning in 2011[2]. The most recent workshop was held in conjunction with the 2014 Fall Meeting of the ESARDA Verification Methods and Technologies (VTM) Working Group in Ispra, Italy. It focused on studying possible parallels with the SLC. This paper describes the discussions and exercise conducted during the workshop and summarizes the key issues identified.

State-Level Approach and Acquisition Path Analysis (APA)

A central component of the SLC is the development of a customized State-level safeguards approach (SLA), which describes the process for planning safeguards activities within a state. The SLA is comprised of three elements[3]:

1. Analyzing plausible acquisition paths
2. Establishing and prioritizing technical objectives
3. Identifying applicable safeguards measures to address the technical objectives.

An acquisition path is the sequence of technical activities a state can use to obtain weapons-usable nuclear material. The APA is based on the IAEA's physical model, developed during the Programme 93+2[4], which identifies and characterizes all possible components of each stage of the nuclear fuel cycle. Each path represents the material forms traversed and set of processes exploited to obtain the weapons-usable nuclear material. These process steps may involve diversion from declared facilities, misuse of declared facilities, undeclared import of nuclear materials, or the operation of undeclared facilities. Information about a state's nuclear activities is used to constrain the set of possible paths.

Listner et. al.[5,6,7] demonstrated a formal methodology and computational tool for the APA based on a directed graph methodology. The method identifies a comprehensive set of paths based on the IAEA physical model. For a given state instantiation, the types of facilities and activities within a state are parameters that down-select the set of paths for the state. Expert opinion on the attractiveness of each path segment (based on a defined set of attractiveness measures) for the given state is used as a model input. When run, all acquisition paths are automatically extracted and used to prioritize technical safeguards objectives for each state.

Systems Approach for Arms Control

Developing a framework for the systems approach for arms control involves the following components:

1. Understanding the selection of objectives for the systems approach
2. Extending the IAEA materials-only physical model to encompass the range of facilities and activities in an active nuclear weapons enterprise
3. Developing a methodology for evaluating and prioritizing pathways
4. Understanding the establishment of detection goals

5. Identifying the types of verification measures and technologies relevant to arms control, including assessing performance characteristics and tradeoffs
6. Identifying the political, legal, and security considerations that influence the usefulness of the approach

A workshop held in conjunction with the 2014 Fall Meeting of the ESARDA VTM Working Group began to explore this systems approach by studying the possible parallels with the IAEA's SLC. The workshop focused on identifying acquisition pathways and understanding how to evaluate their attractiveness. In addition, the VTM working group also discussed analogies to IAEA detection goals.

An exercise scenario was presented at the workshop that bridged the gap between safeguarding nuclear materials and New START style verification of nuclear weapon delivery systems. The scenario presented a bilateral treaty between two hypothetical nuclear weapons states (NWS) that established specific limits to deployed warheads and delivery systems. Members of the VTM WG were presented with a set of potential pathways one of the states could take to cheat on its treaty commitments and were asked to assess how an APA could be used to identify verification priorities and detection goals. The workshop discussion resulted in a number of lessons that will require further consideration as a systems approach is refined.

State Security Objectives

The NPT obligation undertaken by Non-Nuclear Weapons States (NNWS) to not acquire nuclear weapons defines the commitment against which the IAEA evaluates state-level confidence. In safeguards, the acquisition of weapons-usable nuclear material serves as the endpoint of the APA. No such overarching agreement exists in the arms control context. While the IAEA intends to apply the SLC to Nuclear Weapons Possessing States (NWPS) to the extent relevant to their Voluntary Offer Agreement (VOA) or INFCIRC/66 agreements, these facility or item-specific agreements do not define a basis for state-level confidence. Alternatively, while Article 6 obligations commit NWS to pursue disarmament, such a narrow definition limits the practical utility of the systems approach.

Although the goal is to define a framework that can be used without a specific agreement drafted, it became clear that application of a pathway analysis needs objectives to be specifically identified. These objectives are either specified by treaty commitments, or if being applied in a broader context, identified by strategic concerns. The broader context helps identify the types of agreements that would be useful in achieving a state's security objectives (SSOs). A path analysis to endpoints that contravene these objectives can then be used to identify the parts of the enterprise where arms control agreements could be most effective. Such an analysis could provide a cohesive approach that evaluates the state as a whole, and potentially leads to more flexibility in evaluating tradeoffs across treaty regimes. In the context of a specific treaty with specific commitments, these SSOs function as

part of the strategic assessment stage to help rank pathways for verification.

One key lesson of the workshop was that these SSOs must be defined and prioritized by the political and military leadership and supplied to the technical verification community. These SSOs can then be used as the endpoint of the technical analysis.

Acquisition Pathways

To achieve state-level confidence, the acquisition pathway analysis methodology will need to take into account materials, weapons, and the links between the two. The SLC has been designed for verifying peaceful uses of nuclear materials in NPT Non-Nuclear Weapons States (NNWS) as well as for NPT NWS or non-NPT states to the extent consistent with their respective Voluntary Offer Agreements (VOAs) or INFCIRC/66-type item-specific agreements. Significant work would be required to expand the model to nuclear weapons due to national security and NPT Article 1 and 2 constraints on access to detailed information. To date, considerations regarding verification of nuclear materials and nuclear weapons disarmament verification have usually been addressed separately, but the importance of these linkages has been recently presented[8].

During the exercise, an abstract acquisition pathway was provided to represent the weapons enterprise. Figure 1 illustrates a simple pathway (highlighted in red) that could be taken by the state. The possibility of developing a more concrete framework within national security and NPT constraints requires further research.

Detection Goals

The IAEA has a well-defined timeliness goal of detecting the diversion of one significant quantity (SQ) of unirradiated direct use material within a timeliness goal of four weeks. Other material forms have different timeliness goals. In contrast, no agreed upon definition of a significant quantity analogue exists in the arms control context. The United States has in the past deemed a treaty effectively verifiable if it has confidence that it can detect militarily significant violations in time to respond and offset the threat posed by the violation[9]. The terms "militarily significant" and "in time to respond" imply that strategic and political considerations, rather than technical ones, drive the establishment of detection goals.

Perceptions of what constitutes a threat will also differ between states. In the exercise scenario, the discussions of timeliness and SQ for reserve warheads were influenced by the higher perceived threat of the large numbers of deployed weapons. Thus detection goals established under conditions of high numbers of deployed weapons may not be suitable when these numbers are considerably reduced. High uncertainty tolerances may over time, accumulate to an unacceptable uncertainty in the long term. It is therefore important to develop a mechanism for achieving consensus on these detection goals or allow the framework to adjust to differences.

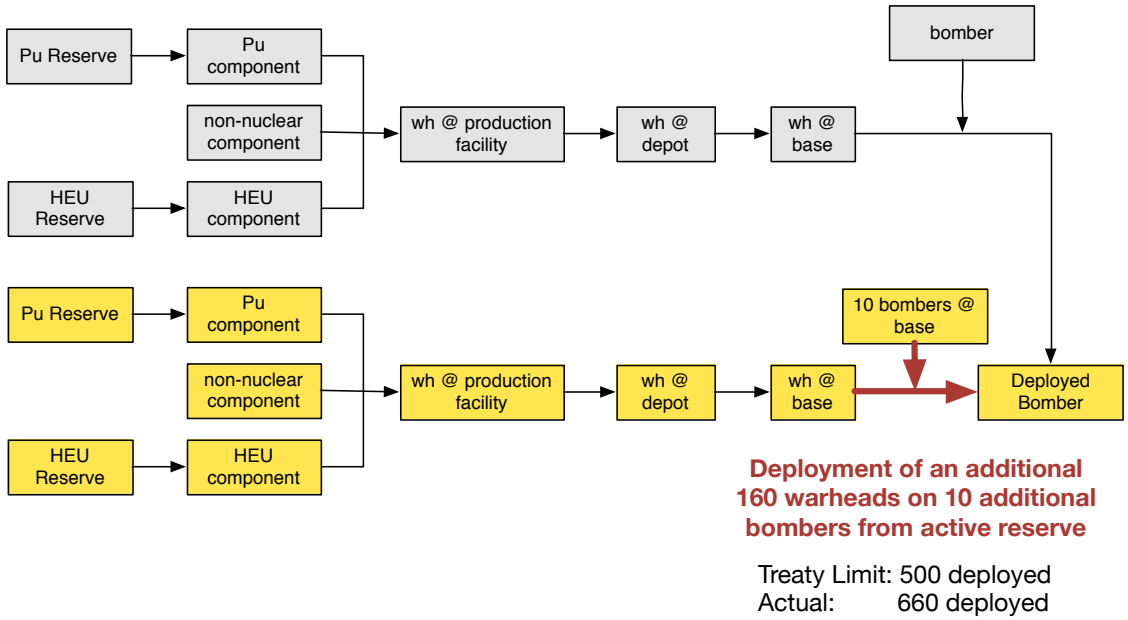

Figure 1. An example pathway visualizing the weapons enterprise as a linear flow from weapons usable material to deployed weapons. Declared and undeclared facilities are represented in yellow and grey, respectively. In this example, the pathway exploited is to upload additional declared reserve warheads onto declared bombers, thus violating the limits on the number of deployed warheads.

Attractiveness Measures

The working group considered how to define attractiveness measures relevant to evaluating and prioritizing cheating pathways. Potential attractiveness measures were compared to the proliferation resistance measures defined in the *Evaluation Methodology for Proliferation Resistance & Physical Protection of Generation IV Nuclear Energy Systems*[10] report. They were divided into intrinsic factors and extrinsic factors, which represent the inherent attractiveness of the pathway and pathway attractiveness under the application of verification measures, respectively. For safeguards, intrinsic factors include Proliferation Technical Difficulty, Proliferation Cost, Proliferation Time, and Fissile Material Type. Extrinsic measures include the Detection Probability and Detection Resource Efficiency. For evaluation in a nonproliferation context, these measures were broadly considered to be suitable but are as follows:

- *Proliferation Technical Difficulty* – Since weapons states already maintain a full weapons enterprise, the knowledge and capability to build additional weapons or modify stockpiles, this measure is considered a minor influence on the attractiveness of a pathway. Pathways that involve new weapons designs, particularly if testing is constrained, may present significant levels of technical difficulty.
- *Proliferation Cost* – The capital and operational costs of pathways and their influence on attractiveness will vary significantly across states. These costs

are often associated with the existing enterprise and accounted for in national budgets. Only pathways requiring significant capital investments may be deemed less attractive to a state wishing to cheat.

- *Proliferation Time* – The minimum amount of time it takes to achieve a strategically significant quantity of weapons. The significance of time is closely tied to the strategic goals of the state. A state may have multiple strategic objectives and path segments time factors may need to be normalized for each of those objectives.
- *Fissile Material Type* – Only relevant when considering material acquisition by the weapons state.
- *Detection Probability* – With no standard set of verification measures cumulative detection probabilities cannot be quantified in advance. However, the APA can be used to structure the pathway probabilities and help identify procedural and technological requirements.
- *Detection Resource Efficiency* – In the arms control context, the "costs" of a monitoring regime are multidimensional. In addition to fiscal costs, the risk of information exposure and the impact on facility operations are also considerations. While these have analogues in safeguards, these other factors may be of primarily importance in considering "efficiency".

Summary and Future Development

Developing the systems approach and framework to assist the dialogue between non-nuclear and nuclear weapons states in advancing future arms control efforts will require a sustained effort in advancing conceptual underpinnings as well as the technical framework. Work needs to be done to create common objectives, mutually understood terminology, and approaches. Such a framework would facilitate dialogue between stakeholders and allow for effective analysis and communication when considering options and tradeoffs to increase confidence. The primary benefit of the systems approach may be to better engage states without the experience or capacity for analyzing verification regimes and promote understanding about the security and technical challenges associated with arms control verification.

Future workshops are being planned to advance the use of acquisition path analysis and understand the factors that influence the achievement of confidence that a state's security objectives can be met by a particular regime. International partnerships, including both NNWS and NWPS not traditionally involved in arms control agreements, would be useful in providing a broader range of perspectives and expertise while simultaneously building international capacity for arms control verification analytics. These new frameworks and partnerships could help identify creative solutions to future arms control problems and inform the direction of future negotiations.

[1] IAEA. 2013. Conceptualization and Development of Safeguards Implementation at the State Level, *GOV/2013/38*

[2] Dreicer, M., Stein, G. 2013. Applicability of Nonproliferation Tools and Concepts to Future Arms Control, European Safeguards Research and Development Association (ESARDA) Bulletin No 49, June 2013.

[3] Cooley, J. N. 2011. Progress in Evolving the State-Level Concept, *Seventh INMM/ESARDA Joint Workshop Future Directions for Nuclear Safeguards and Verification.*

[4] Liu, Z. and Morsy, S. 2001. Development of the physical model, *IAEA-SM-367/13/07*

[5] Listner, C., Canty, M.J., Rezniczek, A. Stein, G. Niemeyer, I. 2012. A Concept for Handling Acquisition Path Analysis in the Framework of the IAEA's State-level Approach, *Proceedings of the INMM Annual Meeting 2012*.

[6] Listner, C., Canty, M.J., Rezniczek, A. Stein, G. Niemeyer, I. 2013. Approaching acquisition path analysis formally – a comparison between AP and non-AP States, *Proceedings of the 35th ESARDA Annual Meeting 2013*.

[7] Listner, C., Canty, M.J., Rezniczek, A. Stein, G. Niemeyer, I. 2014. Evolution of Safeguards – What can formal Acquisition Path Analysis contribute, *Proceedings of the INMM Annual Meeting 2014*.

[8] Nuclear Threat Initiative. 2014. Verifying Baseline Declarations of Nuclear Warheads and Materials. *Innovating Verification: New Tools & New Actors to Reduce Nuclear Risks.*

[9] Woolf, A. 2011. Monitoring and Verification in Arms Control, *Congressional Research Service R41201*.

[10] Generation IV International Forum PR&PP Expert Group, *Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems, Rev 6* (2011)