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TESTING AND ASSESSMENT OF INPUTS FOR PROLIFERATION RISK ASSESSMENT TOOLS

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Robust and reliable quantitative proliferation risk assessment tools are critical to a strengthened nonproliferation regime and to the future deployment of nuclear fuel cycle technologies. Efforts to quantify proliferation resistance have thus far met with limited success due to the inherent subjectivity of the problem and interdependencies between attributes that lead to proliferation resistance. We suggest that these limitations flow substantially from weaknesses in the foundations of existing methodologies – the initial data inputs. In most existing methodologies, little consideration has been given to the utilization of varying types of inputs – particularly the mixing of subjective and objective data – or to identifying, understanding, and untangling relationships and dependencies between inputs. To address these concerns, a model set of inputs is suggested that could potentially be employed in multiple approaches. We present an input classification scheme and the initial results of testing for relationships between these inputs. We will discuss how classifying and testing the relationship between these inputs can help strengthen tools to assess the proliferation risk of nuclear fuel cycle processes, systems, and facilities.

I. INTRODUCTION

Although not a new concept, methodologies for evaluating the proliferation risk or resistance of nuclear fuel cycle technologies have increased in number and prominence in the last several years. Although many different measurements approaches have been considered and considerable work has gone into development and refinement, most agree that even the most prominent still require additional work. Even in their unfinished states, these tools have been employed in the service of a range of goals.

An evaluation of the most prominent tools suggests that, as a general matter, technical assessment tools are most effective when used to consider technical questions and must be used judiciously when high-level, policy questions are at stake. Furthermore, what is learned during the process of methodology application is more relevant than any final number purporting to represent a conclusion. The greatest contribution these tools can make is providing a structured method for evaluation, a "checklist" of key technical features which must be considered.

To perform this checklist function credibly and reliably, assessment tools should be structured in such a way that they are auditable, transparent, and flexible to account for a range of potential users and circumstances. Methodologies differ significantly in the degree to which they meet these criteria largely based on what information is considered, how that information is obtained, and how it is used.

This observation led us to focus our efforts not on the development of new methodologies or the modification of existing methodologies, but rather on the foundations of proliferation risk and resistance methodologies – the basic data inputs.

We have developed a set of inputs and attributes that can utilize multiple methodological approaches. In this paper, we present the inputs and attributes that relate specifically to the diversion of nuclear material from a civilian nuclear facility under international safeguards by the state which controls the facility. We demonstrate the approach we have developed to testing this list of inputs and attributes across four criteria: can numbers be associated with each input, does the set covers all important elements, how would the required information be obtained, and how do relationships between the inputs affect results.

Our goal is to produce a limited set of basic inputs which rely as little as possible on subjective judgment and which exclude internal interdependencies to the greatest degree possible. Where subjectivity is necessary and where dependencies are impossible to eliminate, we attempt to define the effect of each on aggregation schemes.

If successful, we believe this strengthened foundation can help to ensure that proliferation risk or resistance assessment tools are reliable guides for policy-makers and technology developers in efforts to make the civilian nuclear fuel cycle the least attractive path to the development of nuclear weapons.

II. DEFINITIONS AND ASSUMPTIONS

The demand from policy-makers for assessment tools, the diversity of approaches, and their increasing complexity, can, at times, cause confusion – especially for the uninitiated. One of our primary motivations in the work described below will be to contribute to the increased accessibility of these tools. Clearly and carefully defining terms and stating assumptions is a critical first step toward that goal.

In the most general sense, these tools are intended to help a variety of stakeholders evaluate how the features and characteristics of any nuclear process, facility, system, or activity intended for civilian use process could impede or aid the pursuit of non-civilian capabilities.[1]

One way in which methodologies differ is what their final result is oriented to show. Some are oriented toward assessments of how and to what degree these features impede proliferation, while others focus on how features – or the lack thereof – might make proliferation more likely. One way to characterize these two orientations is to describe the former as assessing "proliferation resistance" and the latter as describing "proliferation risk." The term "risk", however, tends to connote a sense of measurement precision that is beyond the capability of current methodologies.

In our work to strengthen the foundations of assessment tools meeting the definition above and to improve their *utility*, we have generally focused on evaluating proliferation risk, however we make no claim that our work leads to increased *precision*. We also believe that our work, with minor modifications, is equally applicable to approaches which seek to measure proliferation resistance. Where the distinction is irrelevant, we have used the more general term, "assessment tools".

We have adopted a narrow definition of the term "proliferation" in the context of these assessment tools to include only those activities undertaken by a state to pursue a nuclear weapons capability using civilian nuclear technology under their control. Although a successful effort by any actor, non-state or otherwise, to *steal* nuclear material or technology would result in proliferation; it is a sufficiently distinct type of threat deserving separate consideration. Evaluating the performance of features to address theft-type threats may require a different approach, as technology features and characteristics which aid or impede host state-type threats may have not always have a consistent relationship to theft-type threats.

We further believe that assessment tools are most valuable when used to evaluate how a technology or activity *under International Atomic Energy Agency (IAEA) safeguards* may contribute to a state acquiring a nuclear weapon. The choice not to place a facility or activity under IAEA safeguards likely suggests a certain level of secrecy. That secrecy will most likely correlate with difficulties associated with obtaining the accurate, highly-specific information necessary well-informed, detailed assessments. It may still be possible to make a high-level assessment of a facility or activity not under safeguards but this is not the task to which assessment tools are *best suited.* We will return to the question of evaluate the effectiveness of safeguards systems below.

The technical objective of IAEA safeguards is limited to the, "timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities."[2] Verification of this objective is conducted through verification of material accountancy and control systems – the sum of which constitute an approach that is negotiated between the IAEA and the host-state and is facility (or activity) specific. The specifics of the approach and the data acquired are treated as confidential and are generally not available to outside parties. Although critically important to reducing the risk that nuclear fuel cycle facilities will contribute to any state's effort to develop nuclear weapons, safeguards do not offer a guarantee against proliferation and thus do not negate the value of assessment tools.

All assessment tools evaluate technology features or characteristics in some fashion and then attempt to aggregate those evaluations. The features and characteristics being assessed are referred to using a variety of terms including "indicators", "measures", and "attributes", and "metrics". In our work, we have adopted the following nomenclature:

- *Inputs* are discrete elements of a system, the most basic of which can be directly measured. To account for the possibility that some circumstance may not grant access to this level of data, in many cases, a hierarchy of inputs may be employed.

- *Attributes* are derived from the combination of one or more inputs
- *Methodology* refers to the process by which attributes are combined to draw analytic conclusions about a system, process, or facility.

III. ROLES AND LIMITATIONS OF ASSESSMENT TOOLS

With the increased interest in proliferation risk and resistance methodologies has come a desire to put the results of these assessments to a variety of ends which can be grouped into four general categories, the first two of which are primarily policy-focused and the last two of which are primarily technically-focused.

1. International Policy Considerations: Evaluations of the effect the acquisition of a particular nuclear technology has on a given state's ability to develop a weapons capability, and in some cases, the likelihood that it will. (Should certain reactor technologies be restricted from certain states of concern?)
2. Domestic Policy Considerations: Internal choices about the adoption of any given nuclear technology. (Is one reprocessing technology preferable to another?)
3. Technical Design and Evaluation Tasks: Design and assessment of fuel cycle and safeguards technologies; cost/benefit evaluations. (How should we design new technologies?)
4. Technical Analysis Capabilities: Improved ability to understand how system features impact nonproliferation goals.

Assessment tools become more effective as you move down this list. As a general matter, tools for conducting technical evaluations are best suited to make technical decisions. The more prominent political and policy considerations become, the more careful analysts must be when making claims about technical considerations. Particularly, for international policy decisions, the results of evaluating a particular technical system are – and likely should be – nearly inconsequential to policy decisions in comparison to the weight of political factors.

That said, the degree to which technical features mitigate or contribute to proliferation risk may be *one* of the factors considered in making nonproliferation-related policy decisions. While technical features will never be sufficient to stop a determined proliferator, they can make the civilian nuclear fuel cycle the least attractive path for a state and help to build confidence among neighboring states that civilian facilities are not a cover for military programs. Trusted assessment tools can support these policy objectives.

Technical evaluations of proliferation risk or resistance are also only *one* factor in overall technical evaluations of nuclear systems. Factors such as security, safety, and operational performance are, of course, also of critical importance as is an understanding how the achievement of each of these technical goals affects the other.

A careful understanding of the roles and limitations of assessment tools is important for two reasons. First, if applied to evaluations for which they are ill-suited, these tools will inevitably perform badly and cause policy-makers to lose confidence in even their ability to help us make the narrow evaluations for which they are well-suited. Second, well-defined goals can guide work to strengthen these tools.

IV. DESIRABLE CHARACTERISTICS OF TECHNCIAL ASSESSMENT TOOLS

The focus on tools which can credibly and reliably help users evaluate how technical features affect proliferation potential and the role they play in other systems considerations suggests that well-developed methodologies should be[3]:

1. *Auditable*: Assessment tools should readily allow others to review the results of their application and lend themselves to criticism and contestation.
2. *Transparent*: Users and reviewers should be able to easily determine *what* data was used, *how* it was obtained, and how each element or input affects the results. The use of expert judgment to obtain data should be explicit and its effect on the overall results determinable. Similarly, the existence of relationships between data inputs which may unintentionally weight or discount particular elements, should be identifiable and their effects understood.
3. *Flexible*: Assessment tools need to be flexible in three primary ways. First, they should allow for sensitivity analysis to evaluate the importance of the presence or absence of individual inputs. Second, they should be applicable to any process, facility, or activity in the nuclear fuel cycle and they should allow for the assessment of sets of technologies and activities. Evaluations of specific technologies in the absence of the fuel cycle context in which they exist offer only limited information. Finally, assessment tools should be applicable to multiple users. They should allow users to make evaluations of particular areas of interest and to apply tools even without access to full information. This flexibility, however, must be complemented with the ability to evaluate what is being missed when limited interest or information result in the performance of partial assessments.

A close examination of these desirable methodology characteristics reinforces the value of focusing on the foundations of assessment tools – the basic inputs and attributes. Understanding *which* features matter, *how* they matter individually, and how they affect other features is a prerequisite to designing better systems. To do this, assessment tools must help us ensure we are considering all the important elements.

V. APPROACH TO INPUT DEVELOPMENT AND EVALUATION

In support the goal of strengthened assessment tool foundations, we developed a draft set of model inputs and attributes applicable to multiple methodological and aggregation approaches which can facilitate the achievement of the goals discussed above. This set of inputs and attributes was developed by attempting to subdivide the proliferation pathway beginning in a safeguarded civilian facility into ever-smaller pieces until we reached as basic a level of input as possible.

In our first subdivision, we followed the Simplified Approach for Proliferation Resistance Assessment of nuclear systems (SAPRA) methodology[4] and divided the proliferation pathway into stages: diversion, facility misuse, transportation, transformation, and weapons fabrication (Fig. 1). The "facility misuse" stage is an optional stage which, depending on the context being assessed and the methodological approach used, may be omitted.

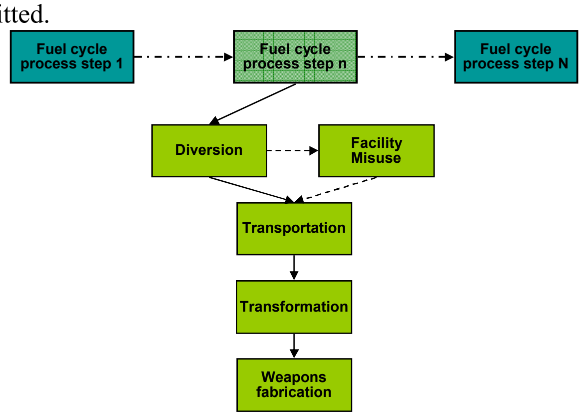

Fig. 1. Stages of proliferation.

The definitions of each stage are as follows:

- Diversion: Covertly removing from a safeguards controlled area, at least one significant quantity of IAEA declared nuclear material from the declared inventory of any given fuel cycle process step (to include those in reactors) during an activity taking place under international safeguards.
- Facility Misuse: The use of a civilian, safeguarded facility to produce at least one significant quantity of undeclared nuclear material. Facility misuse includes insertion of undeclared nuclear material into a safeguarded facility and undeclared removal of material (not necessarily identical to that material illicitly introduced) from the safeguarded facility.
- Transportation: The process of transporting diverted material (typically from a safeguarded facility to another facility)
- Transformation: Conversion of the diverted material to a weapons-usable metallic form in an unsafeguarded facility.
- Weapons Fabrication: The process of designing and building a weapon with the transformed material

Within each stage, we developed a set of attributes and within each attribute, a set of inputs using expert consensus.[5]

The attributes and inputs associated with the diversion stage are as follows:

Material handling difficulty during diversion: The difficulty of handling material during diversion is a function of the material form and properties of nuclear material. This includes the difficulties associated with the weight, volume, physical phase (as it relates to the container required), and hazard level of the material. It is likely that handling difficulties will be very minor. However, the attribute may have significant importance in the case of theft.

Inputs:

- Mass/SQ of nuclear material (mass)
- Volume/SQ of nuclear material (volume)
- Number of items/SQ (count)
- Material Form – solid, powder, liquid, gas
- Radiation level in terms of dose (Sv/hr)
- Chemical reactivity
- Process temperature
- Heat load of material (Thermal watts)

Difficulty of evading detection by the accounting system: Detection through the accounting system is provided through the international inspection activities. These activities are used to confirm the adequacy and veracity of the State System of Material Accounting and Control (SSAC). Each state under IAEA safeguards must implement a SSAC. This system, based upon discrete "material balance areas", makes provision for keeping track of incoming, outgoing, produced and destroyed nuclear materials. Declarations of periodic inventories, based upon material measurements that confirm that any record imbalance (material unaccounted for or MUF) meet the required safeguards criteria and are within measurement uncertainties are provided to the international inspectors. Inspectors must verify the validity of these declarations.

Inputs:

- Uncertainty in accountancy measurements (mass)

- Expect vs. Actual MUF (mass)
- Frequency of accounting record comparisons and verifications (number/unit time)
- Amount of material available

Difficulty of evading detection by the material control system: This attribute measures the effectiveness and efficiency (timeliness) of the available systems and procedures for evaluating the integrity of safeguards relevant data and accountancy systems (continuity of knowledge) and the physical containment of a facility to detect the undeclared insertion or undeclared movement of material. The measures include physical sampling, containment and surveillance systems (C/S), and physical inventory verifications.
Inputs:
- Probability of detection based on vulnerability analysis of material control system in place

Difficulty of conducting undeclared facility modifications for the purposes of diverting nuclear material: This attribute evaluates the difficulty of conducting undeclared modifications of a civilian nuclear facility for the purpose of covertly removing nuclear material from the normal process stream.
Inputs:
- Is there enough physical space and access to actually make the modifications
- Number of people needed to perform modifications
- Requirement for use of remote handling tools
- Requirement for specialized tools
- Requirement to stop process to make modifications
- Risk of modification (safety)
- Risk of penetrating containment

Difficulty of evading detection of the facility modifications for the purposes of diverting nuclear material: This attribute evaluates the difficulty of conducting undeclared modifications of a civilian nuclear facility for the purpose of covertly removing nuclear material from the normal process stream.
Inputs:
- Probability of detection based on vulnerability analysis of design verification system to include factors such as percentage of facility or process step under effective IAEA surveillance and frequency of inspection (number/year)

We then began several phases of testing of this list. An initial evaluation of the completeness of the list was conducted by applying the list to high-level scenarios covering a variety of facilities and approaches to host-state diversion-based proliferation. We then adopted a more rigorous approach to testing the attribute and input list against the audit-ability, transparency, and flexibility performance standards with the goal of using results to refine and revise the attribute and input list. Our test process involves the evaluation of multiple detailed scenarios or "case studies" across all relevant stages of proliferation and the incorporation the inputs and attributes into multiple methodological approaches. The following section offers an example of this testing process.

VI. DEMONSTRATION OF TEST AND EVALUATION APPROACH

As with earlier attribute and input list evaluations, these tests were conducted using detailed scenarios or "case studies". To adequately test basic level inputs, these case studies must follow a standardized approach and include substantial detail. For the purpose of this example, we will evaluate only the diversion stage (inputs and attributes listed above) of a single case study. Where aggregation of the inputs and attributes was necessary to perform a test, we have used a simple additive approach.[6]

The conclusions that are reachable using this example are necessarily limited. In the next section, we discuss some of the issues associated with extending this testing beyond the current example.

In this example case study, the host state diverts 500 kg of low-enriched uranium (LEU) in the form of UF_6 from legal shipments of material over a protracted period. These shipments arrive at the facility from a multi-national fuel supplier and are processed by the host state to produce LEU fuel for its power reactors. The host state will then enrich the material diverted to high-enriched uranium and convert it to metal in a covert facility and fabricate a nuclear weapon.

We test the attribute and input set across four characteristics which flow from our determination of proper assessment tool roles and desirable characteristics identified above:

1. Quantifiability – the ability to associate a number on each input
2. Completeness – an assessment of whether the input and attribute set accounts for all proliferation-relevant factors
3. Subjectivity – where is subjective judgment required to obtain a number for each input
4. Independence – the existence of relationships and dependencies between inputs and attributes

VI.A. Quantification

We evaluated the ability to associate a number with each diversion input and found three types of results:

1. *Input numbers could be calculated or obtained through direct measurement (assuming sufficient access).*

- Mass/SQ of nuclear material: 500 kg (per SQ of finished product)
- Volume/SQ of nuclear material: 0.10 (in solid form)
- Number of items/SQ: 34 (Assume that each diversion is 1% of 1500 kg shipment)
- Radiation level in terms of dose: 88 (number of canisters material is diverted from)
- Chemical reactivity: Not applicable
- Process temperature: 100°C (temperature of material in gaseous form)
- Heat load of material: 0 Watt/cc
- Amount of material available: 600,000 kg of UF_6
- Number of people needed to perform modifications: 1

In some cases, the calculations relied on data from external sources. Given that, in some cases, there are multiple data sources (e.g., material characteristics), quantifying inputs requires the consistent use of the same sources.

2. *Input numbers had to be assumed due to lack of data*

- Uncertainty in accountancy measurements: The scenario description gives an average measurement uncertainty of 0.14%. This is applied to the weight of the material and container (635 kg). Thus for a container containing 1500 kg LEU, the measurement uncertainty is about 3 kg.
- Expect vs. Actual MUF: This input requires plant operational data and thus will never be available for hypothetical cases. The case assumption is that expected MUF is 3% of the throughput. As such, the amount diverted is 1/3 of that value. If system losses and holdup are minimized, the actual MUF may be less than the expected.
- Frequency of accounting record comparisons and verifications: Once per year
- Probability of detection based on vulnerability analysis of material control system in place: Full incoming containers will have a mechanical seal to assure that it has not been tampered with during shipment. No additional material control would be expected until it arrives at the conversion facility, so probability of detection is zero.
- Probability of detection based on vulnerability analysis of design verification system: Inspections will occur nominally once a year. It is expected that the modifications will take place soon after an inspection. They should be modest enough (relatively minor plumbing) that they can be reversed before another inspection. So, again, the PD is zero.

3. *Input numbers were associated with qualitative processes (e.g., yes = 1)*

- Material Form – solid, powder, liquid, gas: Gas
- Is there enough physical space and access to actually make the modifications: Yes
- Requirement for use of remote handling tools: No
- Requirement for specialized tools: No
- Requirement to stop process to make modifications: No
- Risk of modification (safety): Minimal
- Risk of penetrating containment: Not applicable

Given the details of the case study under consideration and the resulting inputs, without employing any formal assessment, it is clear that the inputs that most directly impact the proliferation risk are the details of the safeguards system. The quantity being diverted is small compared to the total throughput so that the expected MUF, probably dominated by material holdup, may mask the diverted material. It was assumed that there were no material control measures in place capable of detecting this diversion scenario.

VI.B. Completeness

For this limited case study, the input parameters seemed to be sufficient to form a basis for analysis. Some, of course, are not applicable to this scenario, but that is to be expected because our inputs are meant to have a wide enough scope to cover all potential scenarios. The parameters most likely to dominate the analysis are the mass diverted and the characteristics of the safeguards system. Radiation and heat loads are small and do not contribute to the difficulty of the task or the ease of detection for this scenario.

Confidence in completeness can only come through detailed examination of multiple case studies and application of the input list to determine whether it is sufficient to cover all characteristics. The developer can maximize the utility of a single case study by imagining excursions or variations from that case and repeating the query. In addition, we encourage review of this list by the expert community and solicit additional case studies and comments which can be posted to website we have developed to encourage a broad and ongoing dialogue.[7]

VI.C. Subjectivity

We classified each input based on whether it could be evaluated objectively or subjectively and whether measurement could be done quantitatively or qualitatively. Examples of each are as follows:

- Objectively quantitative: Mass
- Objectively qualitative: Material form
- Subjectively quantitative: Percentage of facility under effective surveillance

- Subjectively qualitative: Need for nuclear engineering expertise

In the diversion stage, we identified no inputs as being obtainable via subjective judgment and only expressible through qualitative terms. More than 40 percent were objectively quantifiable (Fig. 2). Additional evaluation and case studies will be required to determine the effect of the quantitative/subjective and qualitative/objective inputs on the results.

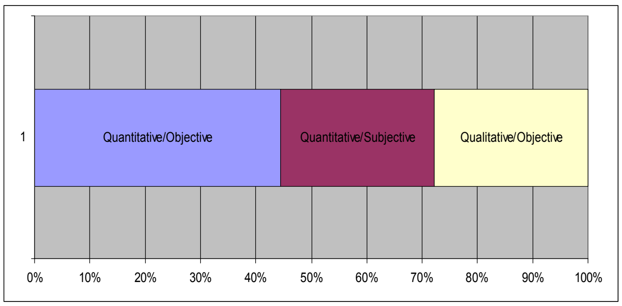

Fig. 2. Characterization of diversion inputs

VI.D. Independence

To evaluate relationships between inputs, we conducted two types of tests. In the first, we created maps showing how basic inputs combined to form higher level inputs and how those, in turn combined to form attributes. Based on this, we identified two ways in which inputs were interrelated, repeated use and physical or conceptual dependency.

VII. CONSIDERATIONS ASSOCIATED WITH FURTHER EVALUATION AND TESTING

While, the preceding example of our approach to testing our attributes and inputs did provide a number of insights, the limited scope of the example does have limitations. Further testing across all stages of proliferation, evaluating alternative case studies, and likely employing more complex aggregation methods is necessary before conclusions can be reliably reached. A number of additional issues are likely to arise in the course of full-scope testing, while others may fade. In fact, even this interplay will offer insights into the attribute and input list.

The primary effect the extension of testing across all stages of proliferation is likely to reveal relates to relationships between inputs and attributes. Some of the inputs may point in opposing directions in different stages. Fore example, isotopic composition may make diversion more difficult but transformation easier.

The inclusion of additional case studies is likely to raise new issues through the introduction of diverse facilities and activities. Testing may reveal problems across all four testing areas, but particularly in quantification and completeness.

VII. CONCLUSION

This research begins from the premise that well-developed proliferation risk and resistance assessment tools have the potential to contribute significantly to fuel cycle and safeguards technology development activities. The use of tools which are credible and reliable can help to guide the efficient allocation of resources toward ends which actually reduce proliferation risk and build confidence in the nonproliferation regime. Analysis early in the design cycle can also avoid mistakes that are costly to remedy after construction.

Our evaluation of the most effective uses of these assessment tools and their desired characteristics point strongly toward devoting significant attention to the foundations of these tools – the individual data inputs upon which all assessments are built. Methodological approaches to using and aggregating these data inputs are important, but to be most valuable, must be auditable, transparent, and flexible.

These goals are best achieved through the development of a common set of inputs and attributes that, even in the absence of a methodological framework, can contribute to nonproliferation efforts by providing technical experts and policy-makers alike a "checklist" of critical technology factors that must be evaluated to understand how any specific technology or activity may impact proliferation.

In this paper, we demonstrated our approach to testing one stage of our attribute and input list for the ability to associate numbers with inputs, the completeness of the set, the method of obtaining information, and the relationships between data inputs. While additional testing will be required to reach conclusions which can used to revise the list, this example testing process suggests that this draft set of inputs and attributes substantially – though not completely – fulfils the performance targets developed.

Addition testing currently underway will result in a fully tested draft set of attributes and inputs about which conclusions can be drawn. While further refinement may be necessary, this work will further the goal of developing credible and reliable assessment tools which can contribute to the ability to develop nuclear technologies that efficiently and effectively make the civilian nuclear fuel cycle the least attractive path to nuclear weapons development.

REFERENCES

1. The most common definition of "proliferation resistance" is "the characteristic of a nuclear system that impedes diversion or undeclared production of

nuclear material, or misuse of technology, by States in order to acquire weapons or other explosive devices."

2. IAEA Safeguards Glossary, 2001.
3. C.M. MENDEZ et. al., "Strengthening the Foundation of Proliferation Risk Assessment Methodologies," Proceedings 47th INMM Annual Meeting, Nashville, Tennessee, July 2006.
4. D. GRENECHE et. al., "Simplified Approach for Proliferation Resistance Assessment of Nuclear Systems – Final Report, French Working Group on Proliferation Resistance and Physical Protection," 2007.
5. A full list of the attributes and inputs, as well as the results of more detailed testing will be available in a forthcoming Sandia National Laboratories report.
6. Further details and assumptions for the case study will be included in the forthcoming report Sandia National Laboratories Report.
7. Details on how to access the website will be included in the forthcoming Sandia National Laboratories report.