SAND2021-16107PE

Minimally Intrusive Verification of Deep Nuclear Warhead Reductions: A Fresh Look at the Buddy Tag Concept

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- Each presentation must summarize the following:
- ~~**Why conduct the project:** Explain the objectives for the project with expected and achieved outcome? Explain how this project affects the objectives of Arms Control, Verification and Compliance Bureau. Please refer back to the Needs document.~~
- ~~**Who conducted the work:** Identify who participated in the project, explain each role, and any cost sharing arrangements.~~
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- **Describe the conclusions:** Was the project worth funding? If possible, could the money allocated to this project have been better spent?
- **Acknowledgements:** Identify those agencies and individuals who contributed to the overall effort.
- The Quad Chart submitted with the project white paper. (I can dig up copies if you don’t have any handy.)
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- This information should be presented in a presentation following the attached PowerPoint format (attachment ”2015 Program Review Presentation Format.pptx”).
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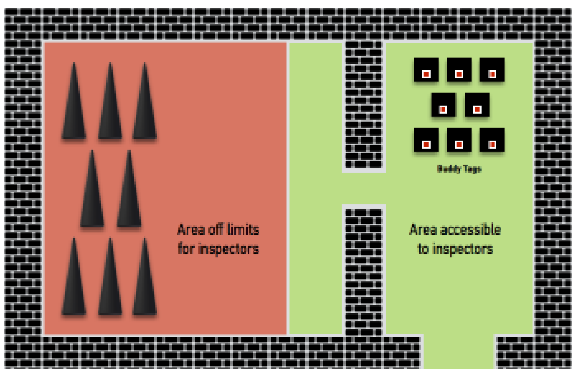
Buddy Tag Project Overview

Source: www.automoblog.net



Steve Fetter and Thomas Garwin, "Using Tags to Monitor Numerical Limits in Arms Control Agreements" in Barry M. Blechman, ed., Technology and the Limitation of International Conflict, Washington, DC, 1989, pp. 33–54

<u>Project Motivation</u>

- Future arms control initiatives may limit the total number of nuclear weapons in some arsenals.
- Tagging has long been recognized as an approach to monitor numerical limits
- However, attaching UIDs could be problematic
- Revisit "buddy tag" concept (next slide) developed in the 1990s

<u>Treaty Focus Area and R&D Need Objective</u>

- Addresses Section G in Needs Document: "… a control and/or transparency regime that is substantive, verifiable ..." relating to the warhead lifecycle, including "strategies and/or technologies to protect sensitive information while verifying compliance …."
- Minimally intrusive verification approaches could be important in addressing weapon states that have not been part of formal nuclear arms control agreements

Objectives:

- Understand the benefits and challenges of applying the Buddy Tag to smaller treaty limited items (TLIs), e.g., warheads
- Explore how advances in technology could be used for this concept

Cost $150K. Princeton University ($35K), Sandia National Laboratories ($95K), materials ($15K)**,** and travel ($5K)**.**

Principal Investigators: Alexander Glaser (Princeton) and Sharon DeLand (SNL)

Original Sandia Buddy Tag Concept

BASIC TAGGING CONCEPT

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- Issue one tag per treaty-limited item
  - Generally requires some way to authenticate the tag
  - Enables verification of limits by inspection of population subset
- Conduct short-notice inspections of declared infrastructure
  - Site stand-down to ensure no changes while inspectors transit
  - Finite probability of detecting the presence of excess, non-tagged items in the declared infrastructure

REQUISITE MONITORING CONTEXT

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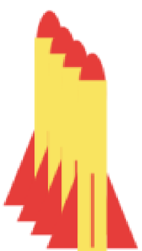
- Tagging operates in a larger treaty-monitoring framework
- Portal-perimeter monitoring or other reconnaissance needed to ensure host is not changing number of items at site
- Common to most tagging-based schemes

BUDDY TAG INNOVATIONS



- Buddy Tags are not affixed to TLIs; they must be kept "in proximity"
- Motion detection and analysis needed to ensure Buddy Tags are not brought on-site to hide presence of excess TLIs
- Buddy Tags did not have to be stored with TLIs – could be paired for the inspection
- Buddy Tags did not have to be associated with the same, specific TLI for the duration of the treaty – could protect operational patterns

1990s version was expected to be briefcase sized

Project Approach and Milestones

The overall approach was to apply a simplified, tailored systems engineering framework. Note however, that the aim was an experimentation and evaluation platform meant to convey the concept and facilitate discussion.

Objective 1: Understand the benefits and challenges if the Buddy Tag concept is applied to warheads?

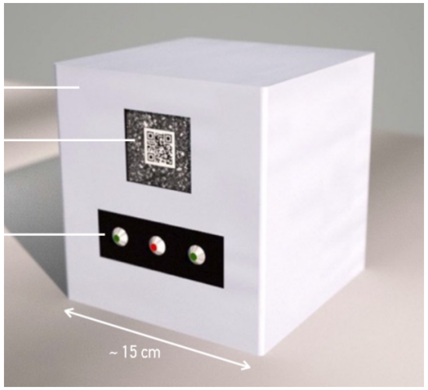
- Task 1: Define concept of operations and high-level requirements:
  - Initially completed Dec 2015
- Task 3: Demonstration and technical review
  - Presentation at INMM July 2016
  - Internal SNL review February 2017

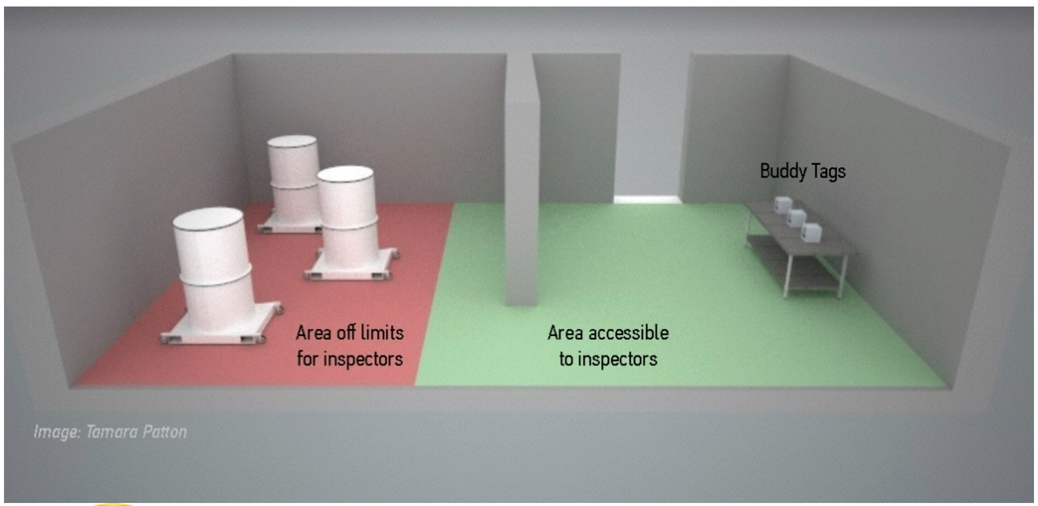
- Objective 2: Explore how advances in technology could be used for this concept
- Task 1: Define concept of operations and high-level requirements (per above)
- Task 2: Prototype manufacturing and testing
  - Motion system technology evaluation and selection (xxx 2015)
  - Motion detection algorithm devleopment (initial July 2016; update Jan 2017)
  - Enclosure design
- Task 3: Demonstration and technical review (per above)

Benefits and Challenges of Applying Buddy Tag to Smaller TLIs

The following slides review the Concept of Operations and Design Goals for a Buddy Tag Evaluation Platform

Current Buddy Tag (BT) Concept of Operations





Start up or Initialization.

- Each country gives the other a set of BTs = Treaty Limit Each country distributes received Buddy Tags to its sites There is at least one Buddy Tag at each site for each TLI

Enterprise operations between inspections.

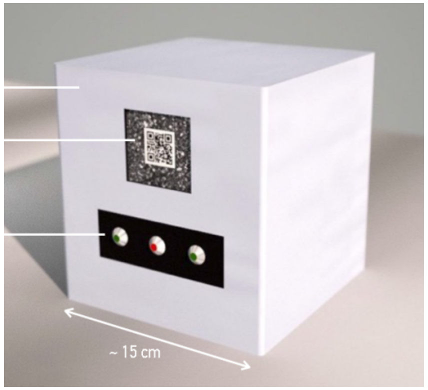
- A BT will be stored "near" each TLI – on same site
- If a TLI is moved between sites, a BT must go with it.

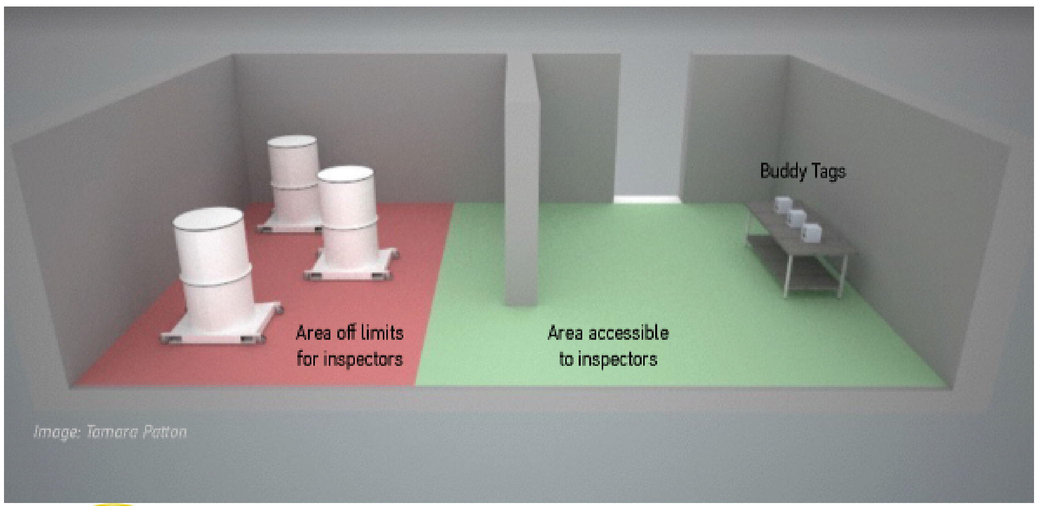
Conduct of short-notice inspections – next slide

Destruction of BTs associated stockpile reductions.

- In the event of stockpile reduction (verified separately) BTs must be jointly destroyed or returned to inspecting party

Current Buddy Tag (BT) Concept of Operations

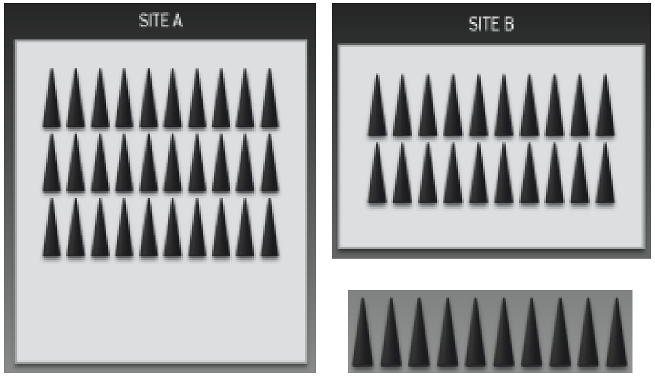




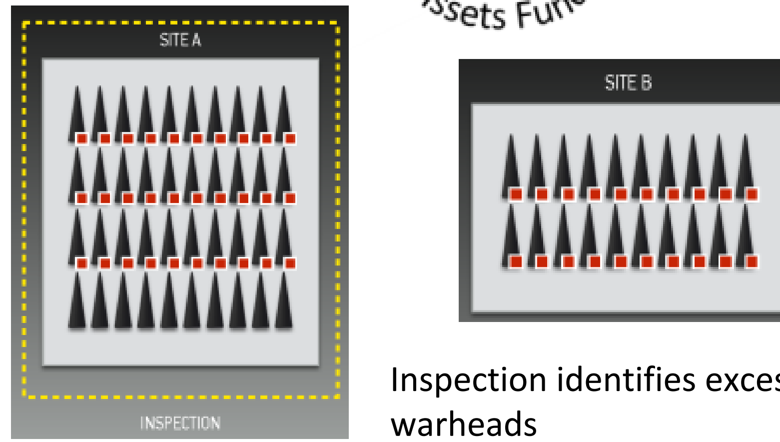
Conduct of short-notice inspections.

- Once a short notice inspection is called, the designated site goes into a stand down
- Inspected Party may not move any TLIs or Buddy Tags on/off site until the inspection is complete. (effective monitoring required)
- Buddy Tags are paired with TLIs
- Inspection objective is confidence that there is an authentic BT for each TLI present *and* that the BT that hasn't been brought on site
  - BT should indicate if it has been moved
- Inspection covers a subset of areas declared to contain TLIs
- Inspection covers other areas large enough to contain a TLI
- Inspectors authenticate BTs
- Inspectors accept declared TLIs without further authentication
- Inspectors can verify declared non-TLI

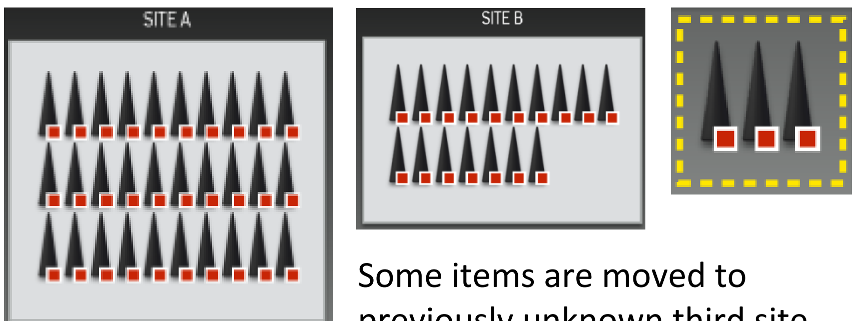
Scenarios to Consider



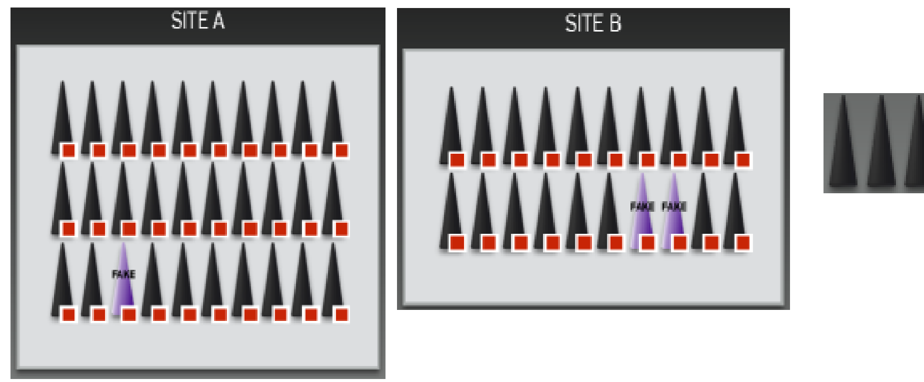
Consider an enterprise with two declared sites and 50 declared WH



Inspection identifies excess warheads



Some items are moved to previously unknown third site … Without buddy tags, the presence of these items may be considered suspect



The host could swap genuine warheads for mockups

This scenario is not addressed by the Buddy Tag concept

Could be opportunities to address elsewhere

Buddy Tag Requirements

Req. No.	High-Level Requirement	Operationalized Evaluation Platform Requirement
1	Inspectors must be able to determine a Buddy Tag is authentic	The Buddy Tag shall indicate to the inspector that it is authentic.
2	Inspectors must be able to determine if a Buddy Tag has been tampered with	If the Buddy Tag has been tampered at any point following initialization, it shall indicate to the inspector that it has been tampered. Otherwise, it shall indicate to the inspector that it has not been tampered. It is assumed that each Buddy Tag is used only once following initialization.
3	Inspectors must be able to tell if the Buddy Tag has been brought on site during the stand-down period	If the Buddy Tag has moved (translated) more than one meter from its original location during the short notice inspection period, it shall indicate this motion to the inspector.
4	The Buddy Tag should not false alarm against environmental noise	If the Buddy Tag has moved (translated) less than .75 meter from its original location during the short notice inspection period, it shall indicate to the inspector that it has not moved.

As the hardware was being implemented and tested, the project moved away from translation-focused requirements. Technical reviewers cautioned that acceleration-focused requirements would be more robust and that spoofing modes had to be considered more explicitly.

Additional design goals defined and in backups

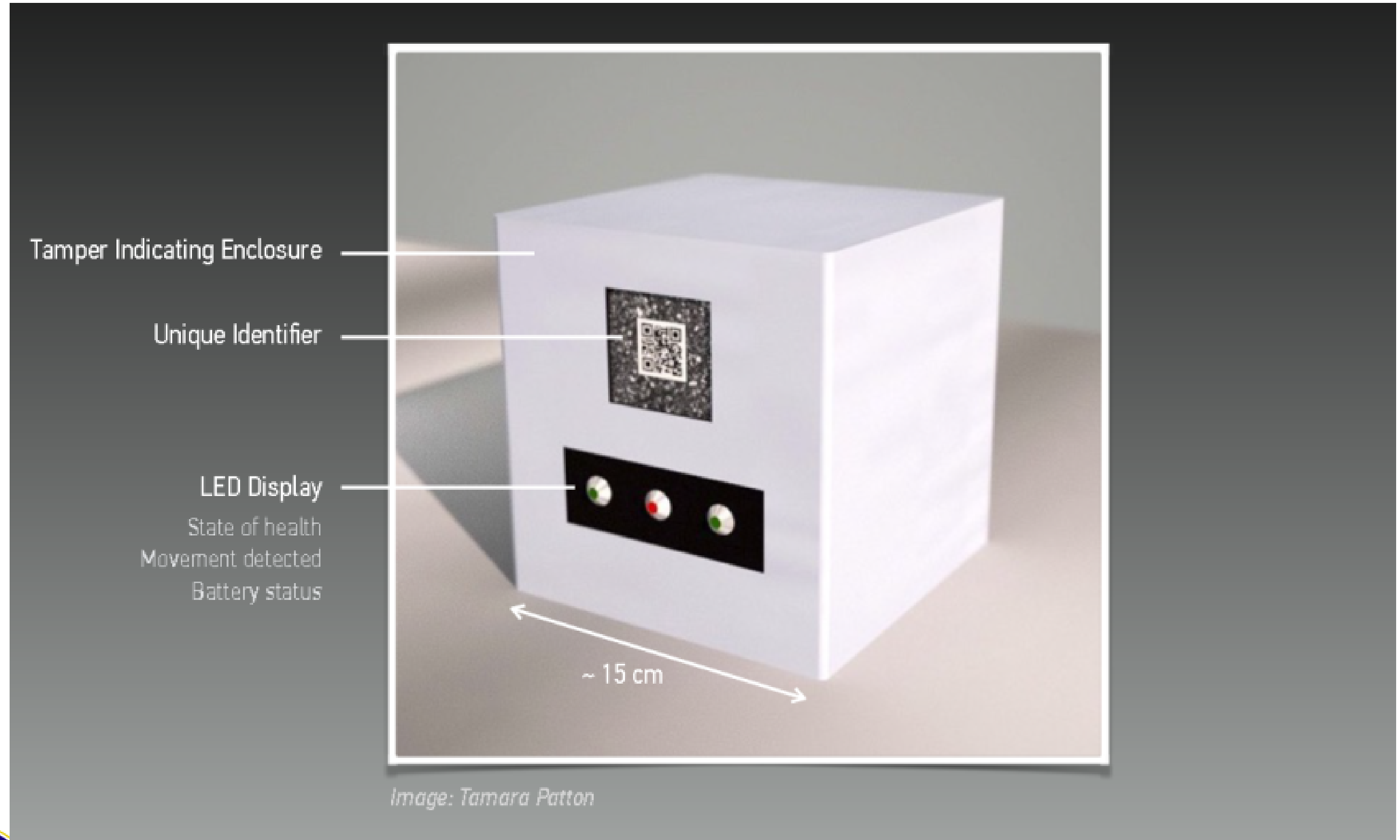
Observations and Lessons Learned

- The original Buddy Tag concept was developed with missiles in mind as the TLI. The concept included inspecting any facility on site large enough to contain a missile
  - On-site intrusiveness was limited because of the size of the missiles
  - Applying this smaller TLIs increases the intrusiveness
- The Buddy Tag concept operates within a larger monitoring regime.
  - The ability to monitor the site perimeter during the period between when the inspection is announced and when it is conducted is essential
  - This project did not consider how to accomplish monitoring the site
  - Smaller TLIs (compared to missiles) can make this more challenging
- A robust design would require more effort and iteration
  - There is an interaction among technology choices and spoofing options that impacts how requirements are framed, especially at lower levels

Exploration of Impacts of Technology Advances

The following slides describe the Buddy Tag evaluation platform implementation.

Elements of a Buddy Tag



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Inertial Measurement

VERIFICATION Assets Fund

ADXL362
Triple-axis accelerometer
Sensitivity : 1 mg/LSB
Price $15
Source: Sparkfun

ITG3200/ADXL345
Inertial measurement unit
Sensitivity : 4 mg/LSB
Price $45
Source: Sparkfun

STIM300
Inertial measurement unit
Sensitivity : 2 μg/LSB
Price $15
Source: Sparkfun

All systems are strap-down systems based on micro-machined electromechanical systems (MEMS) technology

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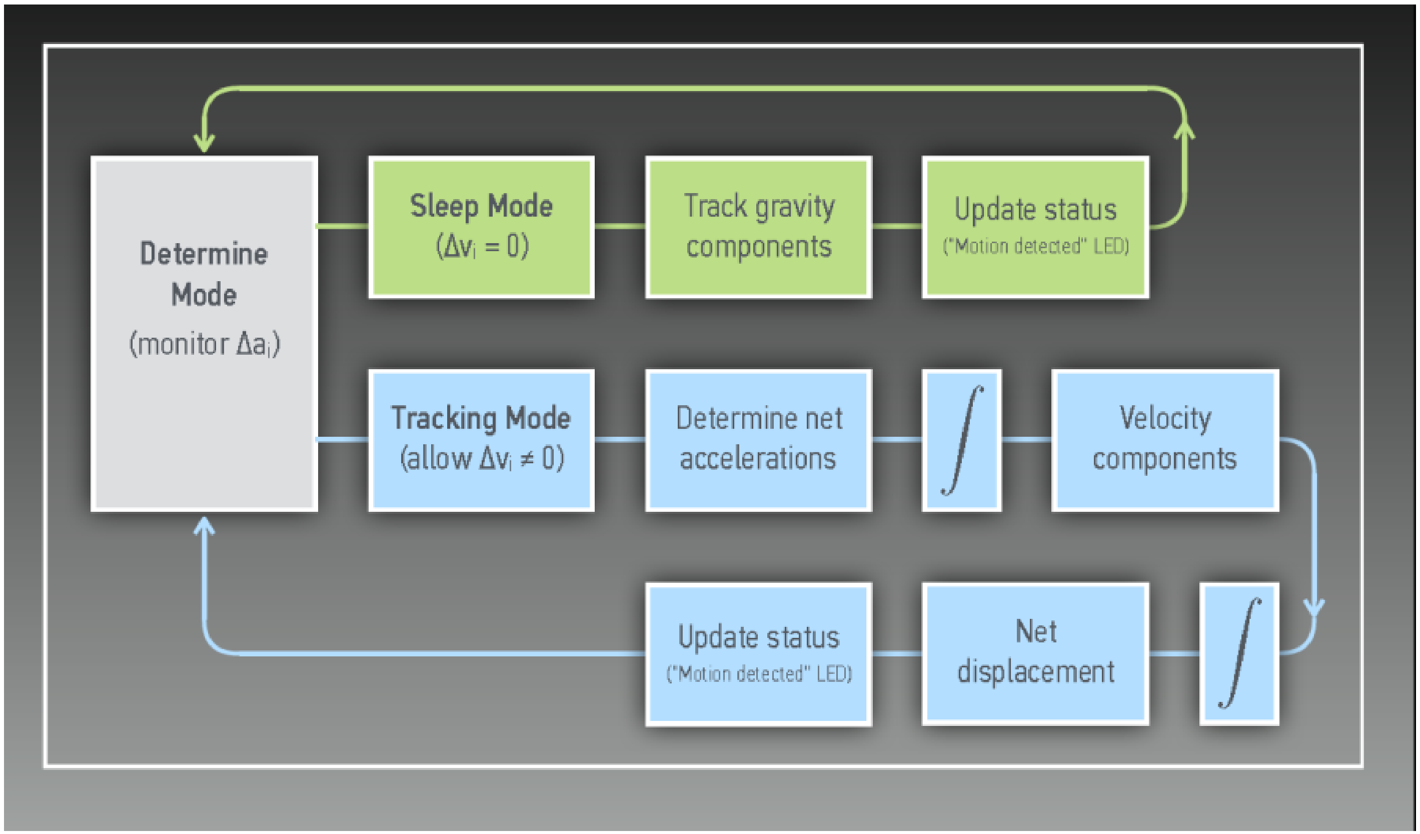
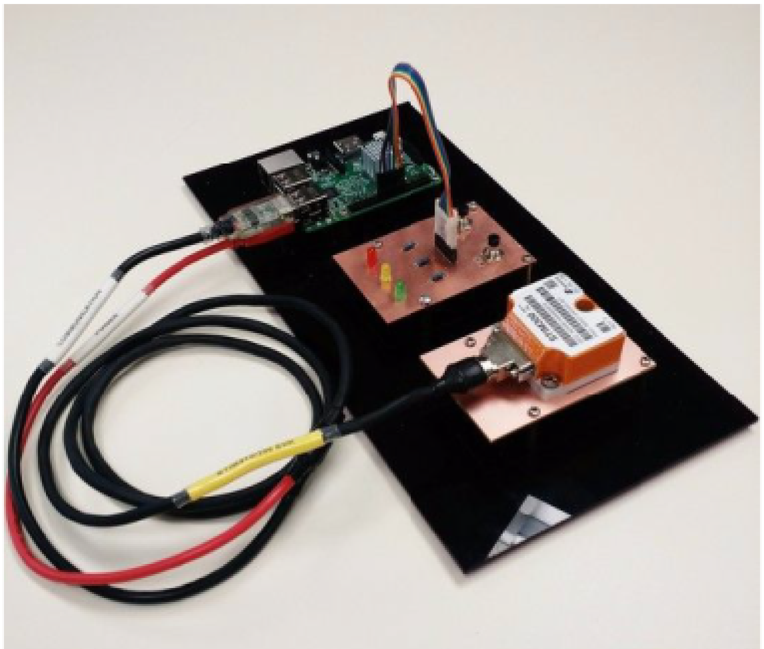
Mode of Operation



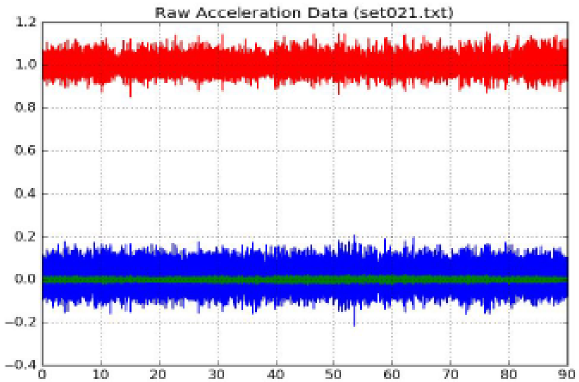
Prototyping Board

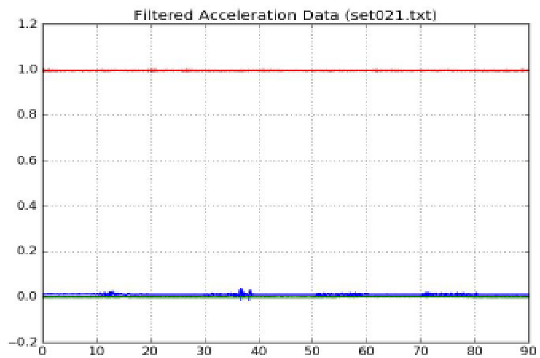


Acquires data and analyzes in near-real time (Python scripts)

Useful for fine-tuning algorithm (window size, threshold, accelerometer sampling rate

Algorithm Overview





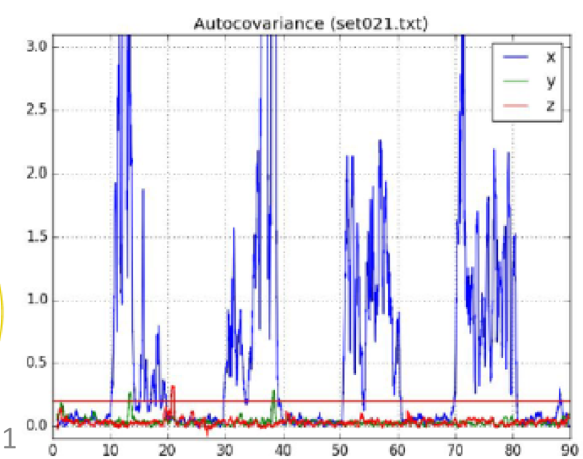
Autocovariance for accelerometer-based event detection (Smidla 2013a, 2013b)

Autocovariance is defined as:

This is applied as a moving window on all three axes separately

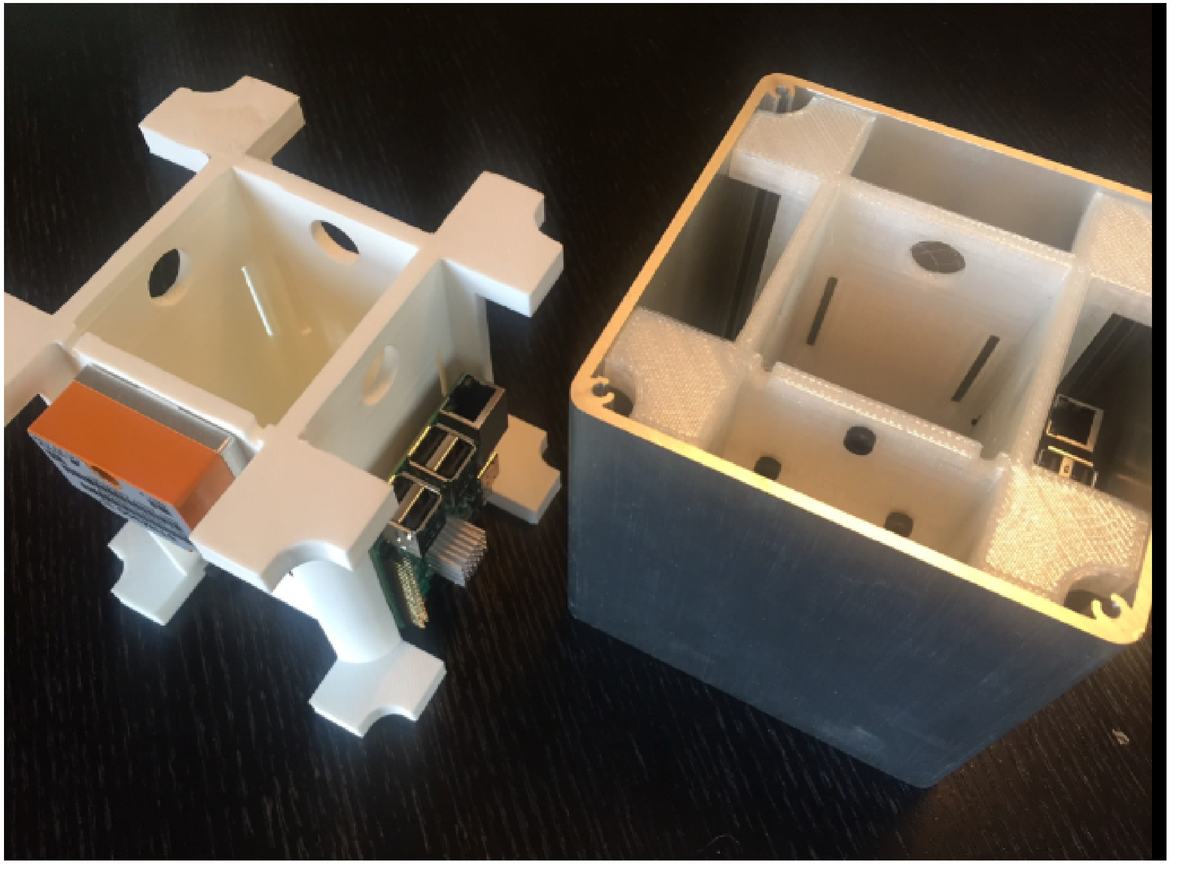
Testing with industrial noise background

Raw data -> Lowpass filter (10 Hz) -> Autocovariance

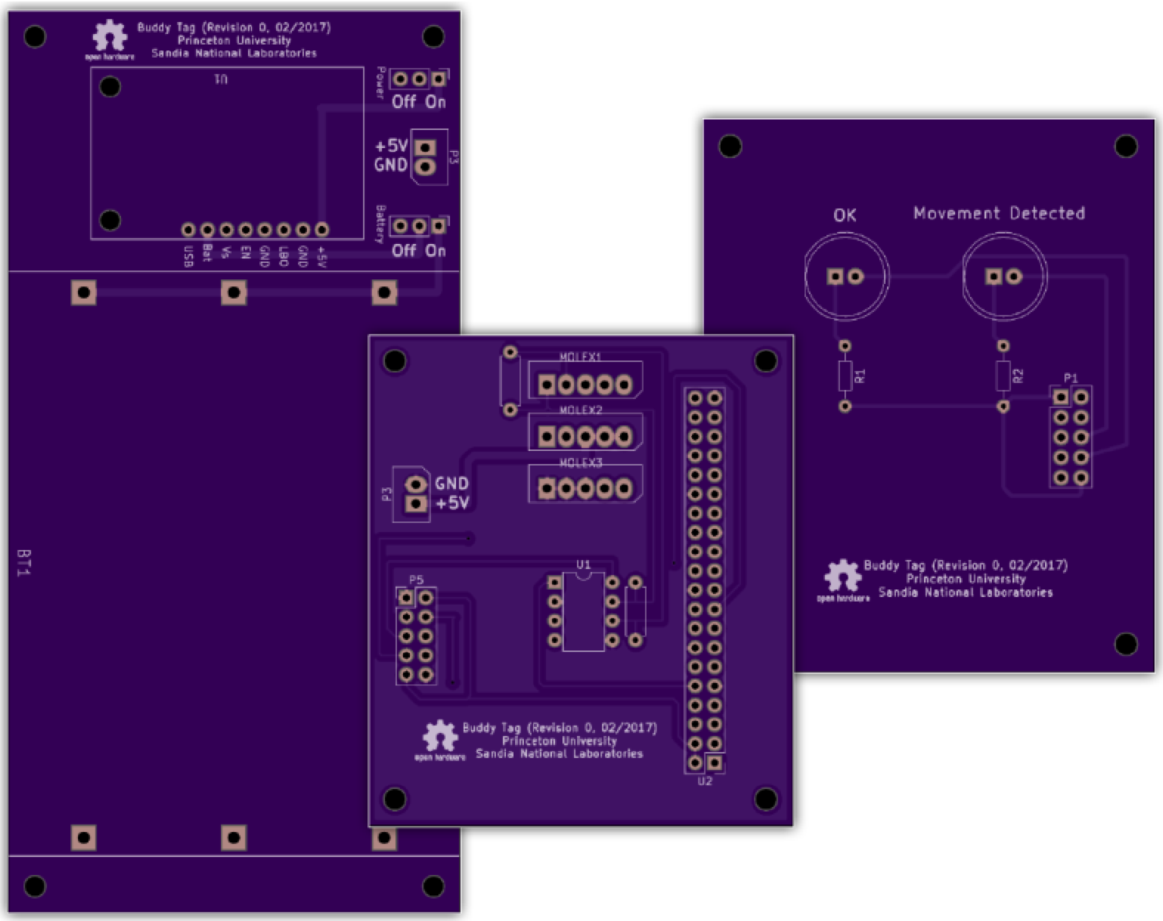


These are initial tests -- more testing with lower frequency noise is needed as well as tests that assess lowest detectable acceleration.

Tag Interior



Board Layout



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Summary and Next Steps

Verifying Numerical Limits: Buddy Tag provides a method to non-intrusively verify numerical limits on sensitive items with opportunities for gradual enhancements

Next Steps: Reviewing the Concept
Joint construction of a number of full-up prototypes for review by independent experts

Buddy Tag as a platform for technology demonstration: relevant technologies include unique identifiers, tamper-indicating enclosures, secure electronicss, secure software, and advanced algorithms.

Topics for Buddy Tag Review and Presentation

Buddy tag review

- ~~Title~~
- Purpose of Project
- ~~Purpose of Review~~
- ~~Set funding level and expectations~~
- ~~Original Buddy Tag Concept~~
- Application to Warheads (consider scenarios from INMM)
- Concept of Operations
- New Hardware
- ~~New Algorithm and Performance~~
- Enclosures
- Next Steps

- Requirements
- Concept of Operations

VFUND presentation

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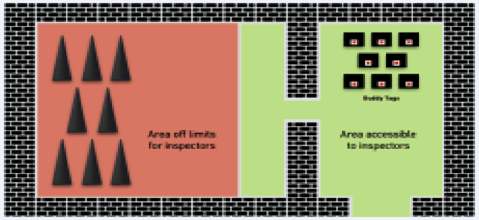
Backups

BAA Number: BAA-2015-DOS-AVC-VTRDN
Document ID: Princeton University and Sandia National Laboratories (PU-SNL-1)
Proposal Title: Minimally Intrusive Verification of Deep Nuclear Warhead Reductions: A Fresh Look at the Buddy Tag Concept

Alexander Glaser (Princeton University), Sharon DeLand (SNL), and Jay Brotz (SNL), June 12, 2015



Buddy Tags for Minimally Intrusive Onsite Inspections at a Hypothetical Storage Site. Inspectors have access to agreed areas where buddy tags are stored and confirm the authenticity of the tags based unique identifiers affixed to them. Inspectors can then visually confirm that an identical number of treaty-accountable items are also present at the site; they cannot, however, directly access or inspect them.

Treaty Focus Area and R&D Need Objective

The buddy tag concept relates directly to AVC's objectives emphasized in Section G of the request for proposal, which highlights work on "the warhead life cycle, that would lend themselves to a control and/or transparency regime that is substantive, verifiable ..." and "strategies and/or technologies to protect sensitive information while verifying compliance with a nuclear warhead control or dismantlement regime."

Minimally intrusive verification approaches could be particularly important in facilitating discussions with weapon states that have so far not been part of formal nuclear arms control agreements, especially China.

Technical Approach

Next-generation nuclear disarmament treaties may place limits on the total number of nuclear weapons in some arsenals. Attaching UIDs directly to nuclear warheads could be problematic due to a range of concerns by the host. To resolve this dilemma, we revisit the so-called "buddy tag" concept. Buddy tags are tokens that are used to prove that one owns an object without having to present it. In an arms-control context, each treaty partner would receive a number of buddy tags, nominally one for each treaty accountable item. Sensors on the buddy tag would show that it had not been moved to the site after the inspection was declared.

Tasks and phases: This one-year project has three phases: (1) joint definition of requirements and development of the enhanced buddy-tag concept; (2) prototype manufacturing and testing; and (3) demonstration and technical review.

Schedule and deliverables: Kickoff meeting (October 2015); requirements complete (December 2015); buddy-tag prototypes complete (June 2016); demonstration and technical review (August 2016); and final report (September 2016).

Cost: The total cost for this proposal will be $150K. This includes partial support for a postdoctoral researcher at Princeton University ($35K), Sandia National Laboratories ($95K), materials ($15K), and travel ($5K).

Principal Investigators: Alexander Glaser (PU) and Sharon DeLand (SNL)

Operational and Performance Capability (Summary)

Since buddy tags cannot be quickly transferred between sites to match the number of warheads at the selected site, the concept can provide confidence in treaty compliance even when only one site is inspected at a time. The concept was originally developed by SNL in the early 1990s. Enhanced and miniaturized prototypes using modern software and hardware concepts will help demonstrate the viability and value of the concept for verifying future arms control agreements.

Synergistic activities: The proposal partners are part of DOE's Consortium for Verification Technology (CVT). As part of the CVT, Princeton is building a 3D virtual environment, in which the enhanced buddy-tag concept could be demonstrated.

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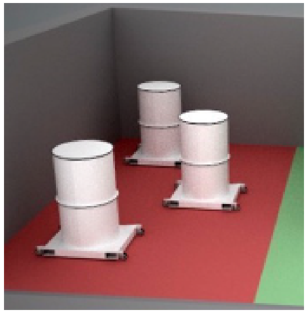
Verification Challenges for Nuclear Arms Control

VERIFICATION Assets Fund



1. Verifying Numerical Limits of Declared Warheads
   Requires techniques to account for (and identify) nuclear warheads in storage
   For example, using (hashed) declarations and/or unique identifiers (UIDs)

2. Confirm Authenticity of Nuclear Weapons
   Requires dedicated inspection systems
   For example, based on radiation-detection techniques (passive/active, neturon/gamma)

3. Establish Confidence in Absence of Undeclared Items or Materials
   How to make sure that no covert warheads/materials exist outside the verification regime?
   No silver bullet; not much different from NPT verification challenges

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Image Sources:
Tamara Patton, Princeton (top)
Joint U.S.-U.K. Report, U.S. Department of Energy, May 2015 (middle) and
Google Earth (bottom)

Purpose of Today's Review

Review and provide feedback (strengths, weaknesses, questions, next steps) on

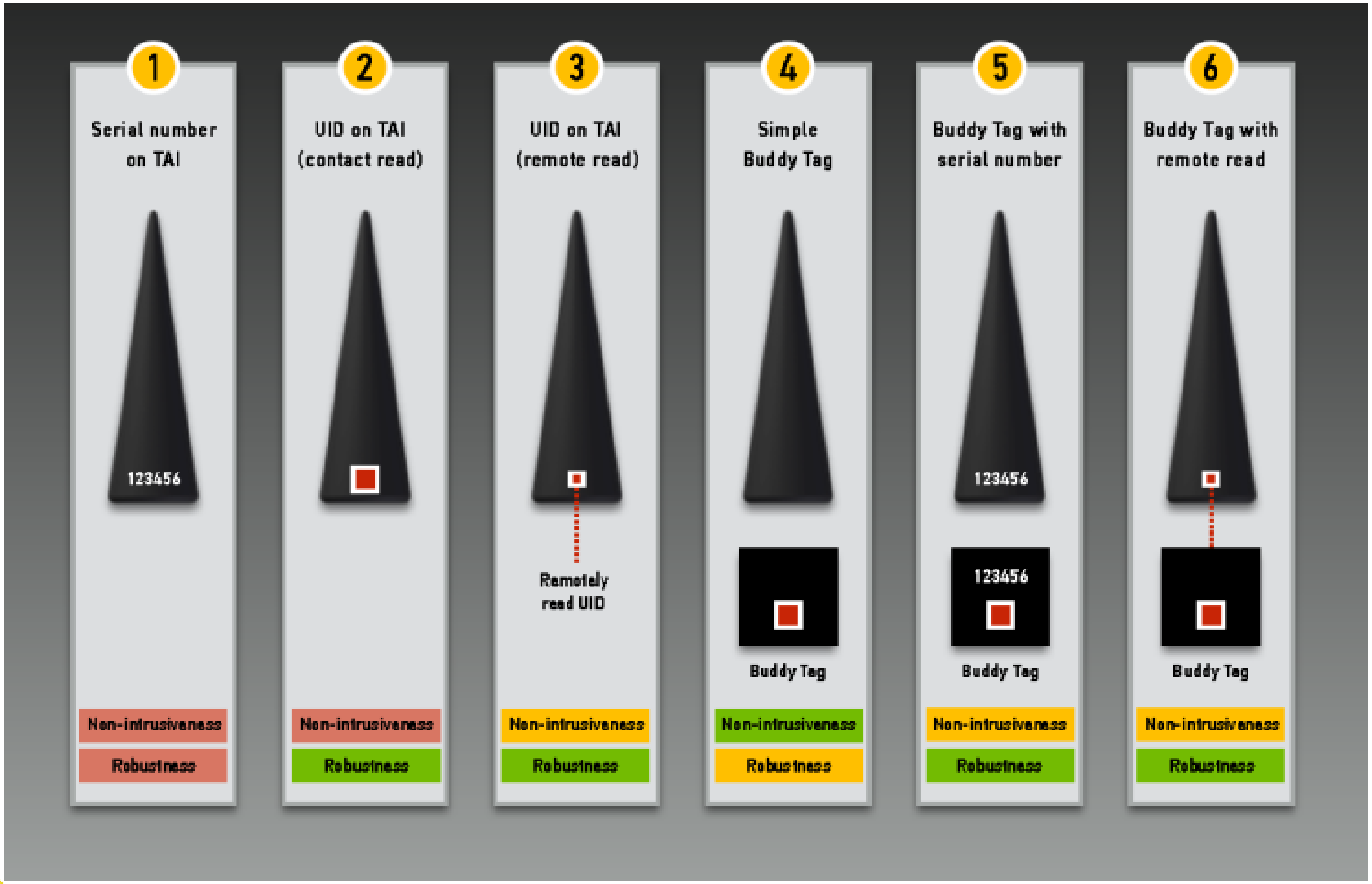
- Buddy Tag concept applied to verifying limits on nuclear warheads
- Buddy Tag prototype hardware, including enclosure
- Analysis algorithms

Context: This fresh look at the Buddy Tag concept was funded as a State Department VFUND project with total funding $150K between SNL and Princeton

- Stan Fraley has been a strong advocate of this concept as a "tool in the toolbox"
- Buddy Tag is a very different approach than other concepts we have been exploring
- Valuable to open the conversation …
- Hardware and software has changed a lot in 20 years. What could we do today?
- Collaboration with Princeton conducted at UUR level

Comments to be incorporated into VFUND Program Review March 8-9
Comments inform an external review to be held in June

Example Warhead Counting Options



This notional assessment assumes that some form of perimeter monitoring is available and effective

Buddy Tag Design Goals

Goal No.	Goal (in order of priority)	Evaluation Method
1	Minimize time to verify the authenticity, tamper state, and motion state of the Buddy Tag	Measure time to perform each verification
2	Design for a ten year lifetime	Analyze design for power consumption over ten years
3	Minimize opportunities for tampering	Analyze design and prototype for opportunities for tampering
4	Maximize reliability	Analyze design and prototype for reliability concerns
5	Maximize robustness to handling	Analyze design and prototype for robustness to handling
6	Maximize robustness to environment	Analyze design and prototype for robustness to a variety of environments