WARHEAD MONITORING & VERIFICATION

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Painting by Helen Audrey Schrayer, Acrylic on Canvas, 2017
VERIFICATION CHALLENGES
FOR NUCLEAR ARMS CONTROL AND DISARMAMENT

- Verifying numerical limits on declared nuclear warheads
- Confirming the authenticity of nuclear warheads
- Monitoring nuclear warheads in storage
- New START
- Fissile material production
- Assembly and maintenance
- Deployment and storage
- Dismantlement
- Disposition
- Hinterland
**REQUIREMENTS**
FOR RELEVANT MONITORING AND VERIFICATION TECHNOLOGIES

**ROBUSTNESS**
How difficult is it to defeat or circumvent the technology?

**NON-INTRUSIVENESS**
How intrusive are deployment and use of the technology?
for example, does it interfere with operations; is sensitive information put at risk?

**SIMPLICITY**
How easy is it to deploy and use the technology?
for example, passive systems are generally (much) preferable to active ones

Source: IAEA (top) and defenseimagery.mil (middle)
DEALING WITH SECRETS
CONTINUE IMPROVING TECHNOLOGIES AND APPROACHES

Work on information barriers with a particular focus on certification and authentication; in particular, identify joint hardware and software development platforms.

REINVENT THE PROBLEM: NEVER ACQUIRE SENSITIVE INFORMATION TO BEGIN WITH

Explore new verification technologies and approaches; for example, develop alternatives to onsite inspections at certain sensitive facilities.

REVEAL THE SECRET

Requirement to protect sensitive information is typically the main reason for complexity of verification approaches; for example, mass of fissile material in a nuclear weapon.

Source: Author (top and bottom), U.S. DOE (middle)
CONFIRMING NUMERICAL LIMITS

& WARHEAD MONITORING
WARHEAD MONITORING OPTIONS

PRIVACY-PRESERVING (“HASHED”) DECLARATIONS
States provide declarations only in hashed form; entries can be revealed as needed to confirm correctness of such declarations during short-notice inspections

For more, see: JASON, 1990; NAS, 2005; S. Philippe, A. Glaser, and E. Felten, Science & Global Security, 2019

BUDDY TAG
Instead of monitoring declared items directly, “buddy tags” are introduced as tokens to represent these items; initially, no access to any sensitive sites or items required

For more, see: M. Kütt and A. Glaser, IEEE Sensors, June 2020

REMOTE MONITORING OF DECLARED ITEMS
Batches of warheads are containerized, sealed, and prepared for long-term storage
Storage location of containerized warheads can remain unknown/secret

For more, see: A. Glaser and Z. Mian, Science, 361 (6406), September 7, 2018

Source: Sandia National Laboratories (top), author (middle and bottom)
Hashed Declarations

Verification Technology: Unclassified Version, JASON, 1990
Monitoring Nuclear Weapons and Nuclear-Explosive Materials, CISAC, National Academy of Sciences, 2005
“PRIVACY-PRESERVING DECLARATIONS”

Declaration in hashed form (with one entry per item)

ITEM 01: 67d97802b84a6db872aacc400a0f5eaebeb3cc5201250311891b0d1e89711605
ITEM 02: b3c22af35f9e55c5c5fc66b604e42bef1914e4e305b5e64f058926e068d7e62
ITEM 03: 92b77554264c800e81fb4b8a83f397f75146c8881e0937d4e5821c895a3
ITEM 04: 4161814e0f393b560958325ca0a3d39d210687f79b2c28c2e5e70a266b
ITEM 05: f5c53f5c375c2266e20554d5d7488f1c67e8a04f4d580aca7707c74755d7b12b
ITEM 06: fb28390a1b33d5d80b445348a88c8716d6c9f6a041825685b5f0c0df82b37c8
ITEM 07: 368fbfe3543c11dce2511b38e59d4dadf7ebe0ed7d132bdf83f13c0b37073c5
ITEM 08: a1e89078c7973cf88423965cc966645b62e2e21597e81b9c2a2e0a41778f4d
ITEM 09: f7618c3feadf245c3dbfb685fd99330a8870c96a3131d5f9d98877f813
ITEM 10: 2bd3756821de150072a6c3ec0e25a16c46deo5258605e0e2ef076e79f8520
ITEM 11: 9280cc30c39e662f6f082f2a57a48e865308e59b49c11d0d8f2606a8c
ITEM 12: 47467d431353ce15dfe06dc6395e90a68806df3222467fbb5e01105b90bb31
ITEM 13: 023c75f0c8d5a9c9c5a0a9bf79f2d3da555c980408d4f1c47c7977a0b6d42
ITEM 14: 4108879b321612633a5315b6203b36d6e12bc031e446896
ITEM 15: 348bcd404f3b340f2d75f0fa3ac00292702727c2c3e56b0a617d8153765n2
ITEM 16: bca49804e0b0052d8f533d91d680e26818752111538ead401277b6cfae2e3

Declaration with entries for Site C revealed

ITEM 01: 67d97802b84a6db872aacc400a0f5eaebeb3cc5201250311891b0d1e89711605
ITEM 02: b3c22af35f9e55c5c5fc66b604e42bef1914e4e305b5e64f058926e068d7e62
ITEM 03: 92b77554264c800e81fb4b8a83f397f75146c8881e0937d4e5821c895a3
ITEM 04: 4161814e0f393b560958325ca0a3d39d210687f79b2c28c2e5e70a266b
ITEM 05: f5c53f5c375c2266e20554d5d7488f1c67e8a04f4d580aca7707c74755d7b12b
ITEM 06: fb28390a1b33d5d80b445348a88c8716d6c9f6a041825685b5f0c0df82b37c8
ITEM 07: 368fbfe3543c11dce2511b38e59d4dadf7ebe0ed7d132bdf83f13c0b37073c5
ITEM 08: a1e89078c7973cf88423965cc966645b62e2e21597e81b9c2a2e0a41778f4d
ITEM 09: f7618c3feadf245c3dbfb685fd99330a8870c96a3131d5f9d98877f813
ITEM 10: 2bd3756821de150072a6c3ec0e25a16c46deo5258605e0e2ef076e79f8520
ITEM 11: 9280cc30c39e662f6f082f2a57a48e865308e59b49c11d0d8f2606a8c
ITEM 12: 47467d431353ce15dfe06dc6395e90a68806df3222467fbb5e01105b90bb31
ITEM 13: 023c75f0c8d5a9c9c5a0a9bf79f2d3da555c980408d4f1c47c7977a0b6d42
ITEM 14: 4108879b321612633a5315b6203b36d6e12bc031e446896
ITEM 15: 348bcd404f3b340f2d75f0fa3ac00292702727c2c3e56b0a617d8153765n2
ITEM 16: bca49804e0b0052d8f533d91d680e26818752111538ead401277b6cfae2e3

Declaration in hashed form (with one entry per item)
Buddy Tag

Verification Technology: Unclassified Version, JASON, 1990
Sandia National Laboratories, 1991
Princeton University and Sandia National Laboratories, 2015–2020
TAGGING OPTIONS

1. Serial number on TAI
   123456

2. Unique ID on TAI

3. Buddy Tag
   Buddy Tag
THE ORIGINAL BUDDY TAG CONCEPT
(FOR MOBILE MISSILES)

Sabina E. Jordan, Buddy Tag’s Motion Sensing and Analysis Subsystem, Sandia National Laboratory, Albuquerque, New Mexico, 1991
2020 BUDDY TAG PROTOTYPE

ROBUSTNESS & SENSITIVITY
OF THE 2020 BUDDY TAG PROTOTYPE

Effect of attempted displacement (synthetic data, 20 µG acceleration)

Real (filtered) signal while train is passing by

A. Glaser and M. Kütt, IEEE Sensors Journal, June 2020
WARHEAD CONFIRMATION
MEASUREMENTS
Absence Measurements
A nuclear weapon is any device that has been declared by the host party to be a nuclear weapon.

An object is accepted as a non-treaty-accountable item if (a) it does not exceed an agreed radiation level (neutron/gamma or combined) or if (b) the inspector can confirm its nature as a non-treaty-accountable item, for example, through direct visual access.

A. Glaser, “Ceci N’est Pas Une Bombe: Toward a Verifiable Definition of a Nuclear Weapon,” 58th Annual INMM Meeting, Indian Wells, CA, July 2017

See also: Verification of Nuclear Weapons Declarations, Report by Working Group 4
International Partnership for Nuclear Disarmament Verification (IPNDV), 2020, www.ipndv.org/reports-analysis
Measurements could be very straightforward, perhaps, only based on gamma measurements. Inspection could include two separate steps to determine (1) amount of shielding in container and (2) emissions from container/item. U-235 is difficult to detect, focus on U-238 (1.001 MeV) instead; plutonium has most prominent emissions in 300–500 keV region. If host is honest, no sensitive information at risk. Certain sensitive objects (e.g., “trainers” with depleted uranium) may have to be declared as treaty accountable.
ABSENCE MEASUREMENTS
 USING LOW-RESOLUTION GAMMA SPECTROMETRY

Values are for a 2” x 2” sodium-iodide detector and a solid ball of fissile material (maximum self-shielding)

Zero-knowledge Verification
ZERO-KNOWLEDGE VERIFICATION
WITH NON-ELECTRONIC, PRE-LOADABLE DETECTORS

14-MEV NEUTRON RADIOGRAPHY FOR OBJECT COMPARISON

Neutron transmission radiography using high-energy (14 MeV) neutrons is effective in detecting geometric and elemental differences.

In 2016, demonstration of a physical zero-knowledge proof for different configurations of two-inch metal cubes.

PRE-LOADABLE NON-ELECTRONIC DETECTORS (YALE)

Superheated droplet detectors (developed by Yale) allow preloading and offer a way to implement proposed zero-knowledge protocol.

Detectors are insensitive to gammas and avoid detector-side electronics (and their functionality can be confirmed by inspectors post measurement).

EXCALIBUR @ PPPL
(EXPERIMENT FOR CALIBRATION WITH URANIUM)

ZERO-KNOWLEDGE VERIFICATION

STATUS AND NEXT STEPS

SETUP FOR TRANSMISSION MODE & MODERATED MODE

The revised configuration maximizes fraction of neutrons with energies below 1 MeV to selectively drive fission events (e.g. in U-235 vs U-238) and detect these with side detectors to provide improved isotopic sensitivity

Note: Side detectors need additional shielding to reduce background (not shown in rendering)

RESULTS (MONTE CARLO SIMULATIONS)

The system can detect substitution of 500 g of uranium-235 limited by counting statistics in bubble detectors (here: 48 detectors, ~350 bubbles per detector)

Experimental campaign at PPPL currently planned for different configurations of (enriched and depleted) uranium cubes to confirm isotopic sensitivity
Vintage Verification
VINTAGE VERIFICATION
“TRUST THROUGH SIMPLICITY AND OBsolescence?”

IDEA
Use simple, quasi open-source hardware from 1970s; backdoors and hidden switches unlikely in hardware designed in the distant past, at a time, when use for sensitive measurements was never envisioned.

IMPLEMENTATION / PROTOTYPE
MOS 6502 (3,500 transistors, 1 MHz) and an Apple IIe, combined with a standard sodium-iodide detector and using a template-matching approach; achieves ~ 2000 cps and acquires statistically robust data in 1–2 minutes; ability to detect small differences in signatures.

M. Kütt and A. Glaser, PLOS ONE, October 2019, doi.org/10.1371/journal.pone.0224149
INFORMATION BARRIER EXPERIMENTAL II
(STANDARD SODIUM-IODIDE DETECTOR & 12-BIN TEMPLATE)

M. Kütt and A. Glaser, PLOS ONE, October 2019, doi.org/10.1371/journal.pone.0224149
A. Glaser, B. Barak, M. Kütt, and S. Philippe, Physical Public Templates for Nuclear Warhead Verification
VIRTUAL REALITY

AS A TOOL FOR THE JOINT DEVELOPMENT OF NEW VERIFICATION APPROACHES
Storage bunker with warhead storage containers; inspectors can select one or more containers for inspection with information barrier.
Closeup of information barrier during inspection using a sodium-iodide detector and a template-matching approach.