HOW TO KEEP A SECRET WHILE DISMANTLING AN ATOMIC BOMB

INFORMATION SECURITY IN NUCLEAR ARMS CONTROL AND VERIFICATION

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Center for Information Technology Policy
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Revision 3

BACKGROUND

(START DETECTOR CALIBRATION)

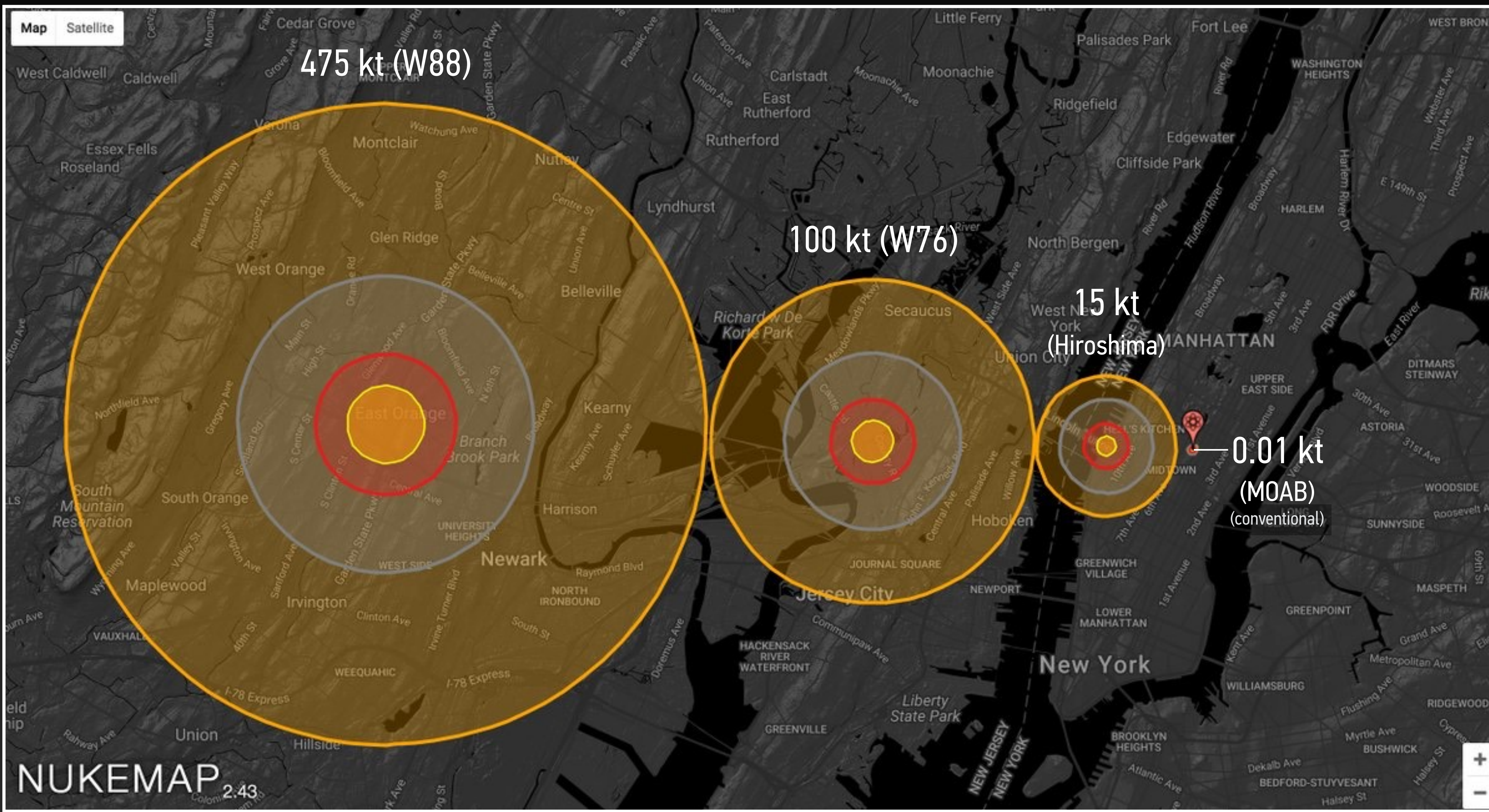
THERE ARE STILL ABOUT 15,000 NUCLEAR WEAPONS WORLDWIDE

Country	Nuclear Warheads
United States	6,800 *(includes 2,800 warheads awaiting dismantlement)*
Russia	about 7,000 *(large fraction awaiting dismantlement)*
France	fewer than 300
United Kingdom	215
China	about 260
Israel	80
Pakistan	120-130
India	110-120
North Korea	fewer than 10

Nuclear Notebook, January 2017, fas.org/issues/nuclear-weapons/status-world-nuclear-forces

THE EFFECTS OF NUCLEAR WEAPONS REMAIN UNPARALLELED

(AREAS OF COMPLETE DESTRUCTION FOR SEVERAL WEAPON TYPES)



Source: Alex Wellerstein, https://twitter.com/wellerstein/status/852658880022806528

WHAT'S NEXT FOR NUCLEAR ARMS CONTROL?

2015 STATEMENT BY JAMES MATTIS

"The nuclear stockpile must be tended to and fundamental questions must be asked and answered:

- *We must clearly establish the role of our nuclear weapons: do they serve solely to deter nuclear war? If so we should say so, and the resulting clarity will help to determine the number we need.*
- *Is it time to reduce the Triad to a Diad, removing the land-based missiles? This would reduce the false alarm danger.*
- *Could we re-energize the arms control effort by only counting warheads vice launchers?*
- *Was the Russian test violating the INF treaty simply a blunder or a change in policy, and what is our appropriate response?"*

General James N. Mattis, USMC (Ret.)
Former Commander, United States Central Command

Senate Armed Services Committee
Global Challenges and U.S. National Security Strategy
January 27, 2015

WHAT IS TO BE VERIFIED?

THOUSANDS OF NUCLEAR WEAPONS

ARE CURRENTLY NON-DEPLOYED (i.e., IN RESERVE OR AWAITING DISMANTLEMENT)

W87/Mk-21 Reentry Vehicles in storage, Warren Air Force Base, Cheyenne, Wyoming

Photo courtesy of Paul Shambroom, www.paulshambroom.com

MAPPING NUCLEAR VERIFICATION

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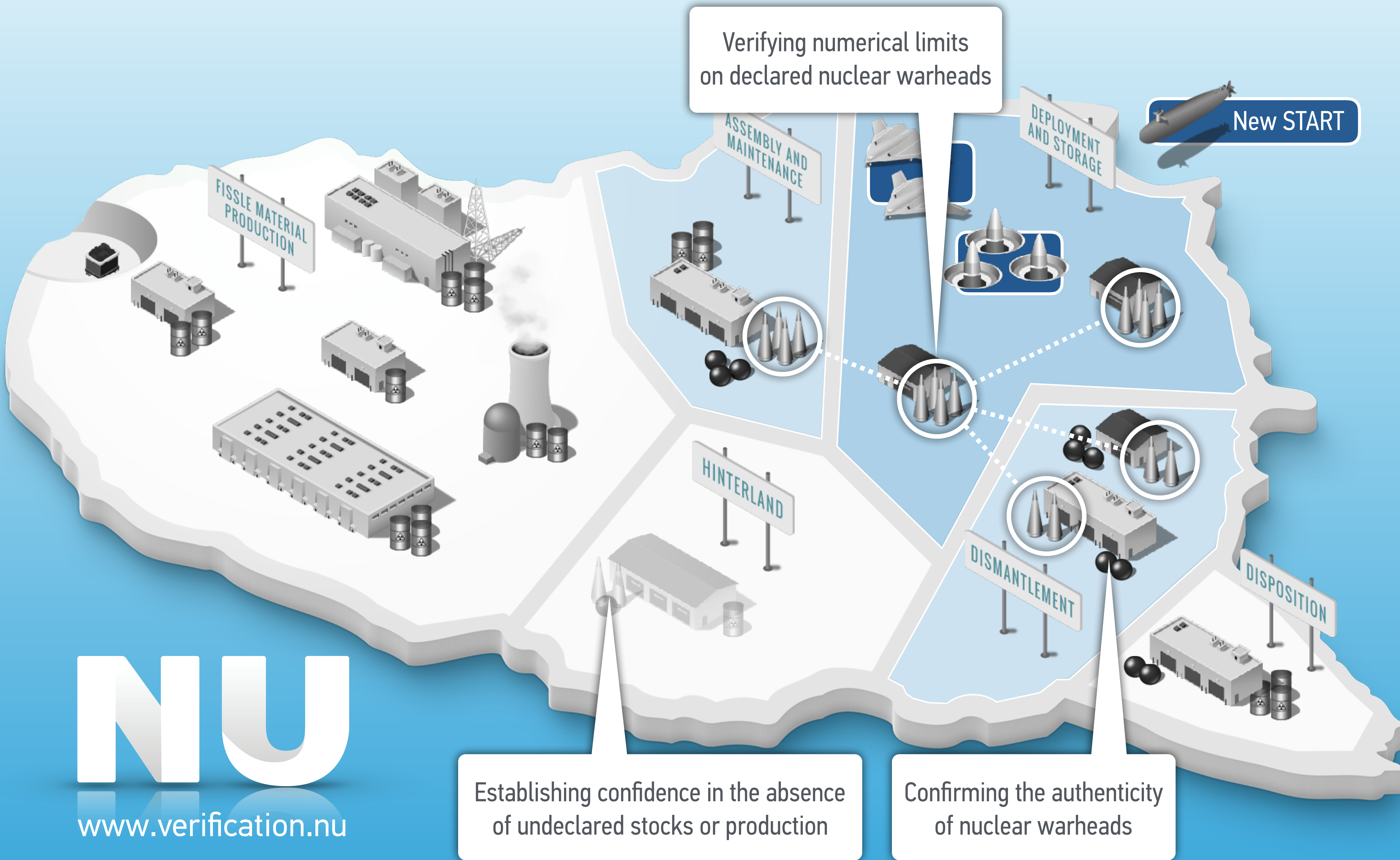
VERIFICATION CHALLENGES OF DEEP REDUCTIONS



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WHY ARE WARHEAD INSPECTIONS SO HARD?

(AS SEEN FROM INSPECTOR'S PERSPECTIVE)

VERY LITTLE (IF ANY) INFORMATION ABOUT THE INSPECTED ITEM CAN BE REVEALED

Some information may be shared in advance, but no additional information during inspection

ADVERSARY/COMPETITOR HAS (DE FACTO) INFINITE RESOURCES

ADVERSARY/COMPETITOR MAY BE EXTREMELY MOTIVATED (TO DECEIVE INSPECTOR)

Stakes are very high (especially when the number of weapons drops below ~1,000)

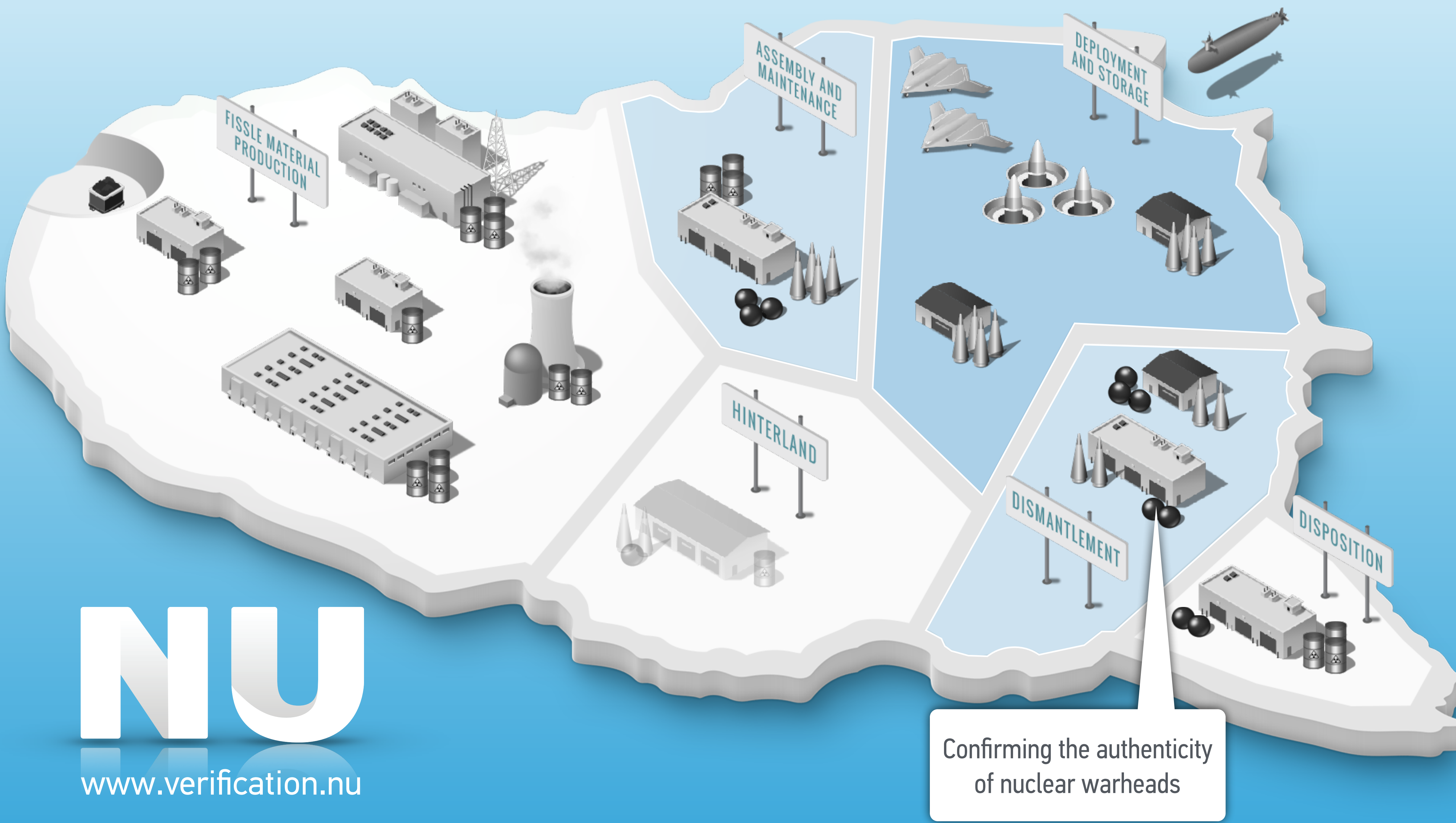
HOST HAS LAST OWNERSHIP OF INSPECTION SYSTEM <u>BEFORE</u> THE MEASUREMENT

(and inspector never again has access to system <u>after</u> the measurement is complete)

CONFIRMING THE AUTHENTICITY OF WARHEADS

(THE ORTHODOX APPROACH)

VERIFICATION CHALLENGES OF DEEP REDUCTIONS



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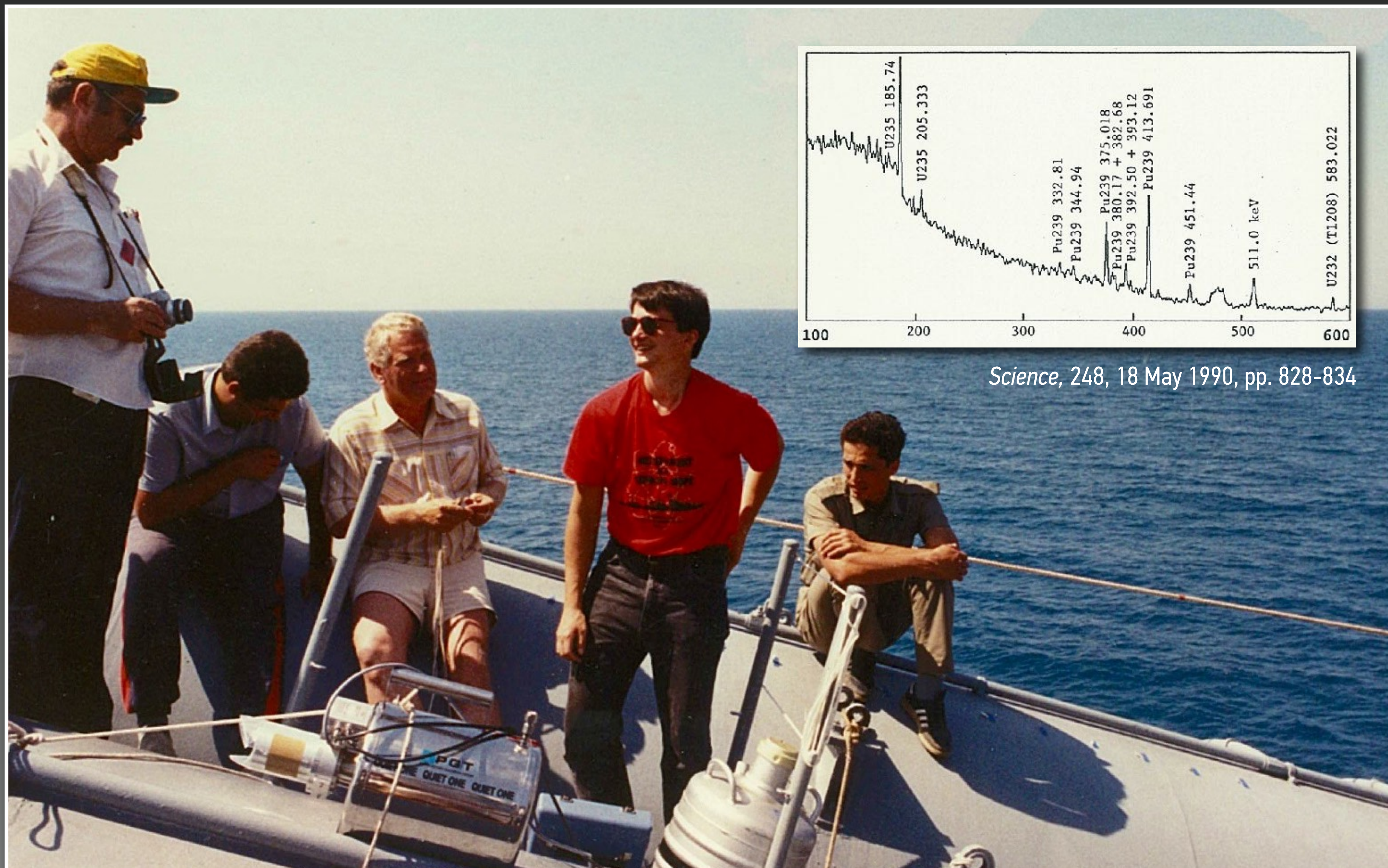
NUCLEAR WEAPONS HAVE UNIQUE SIGNATURES

BUT THEY ARE SENSITIVE AND CANNOT BE REVEALED TO INSPECTORS

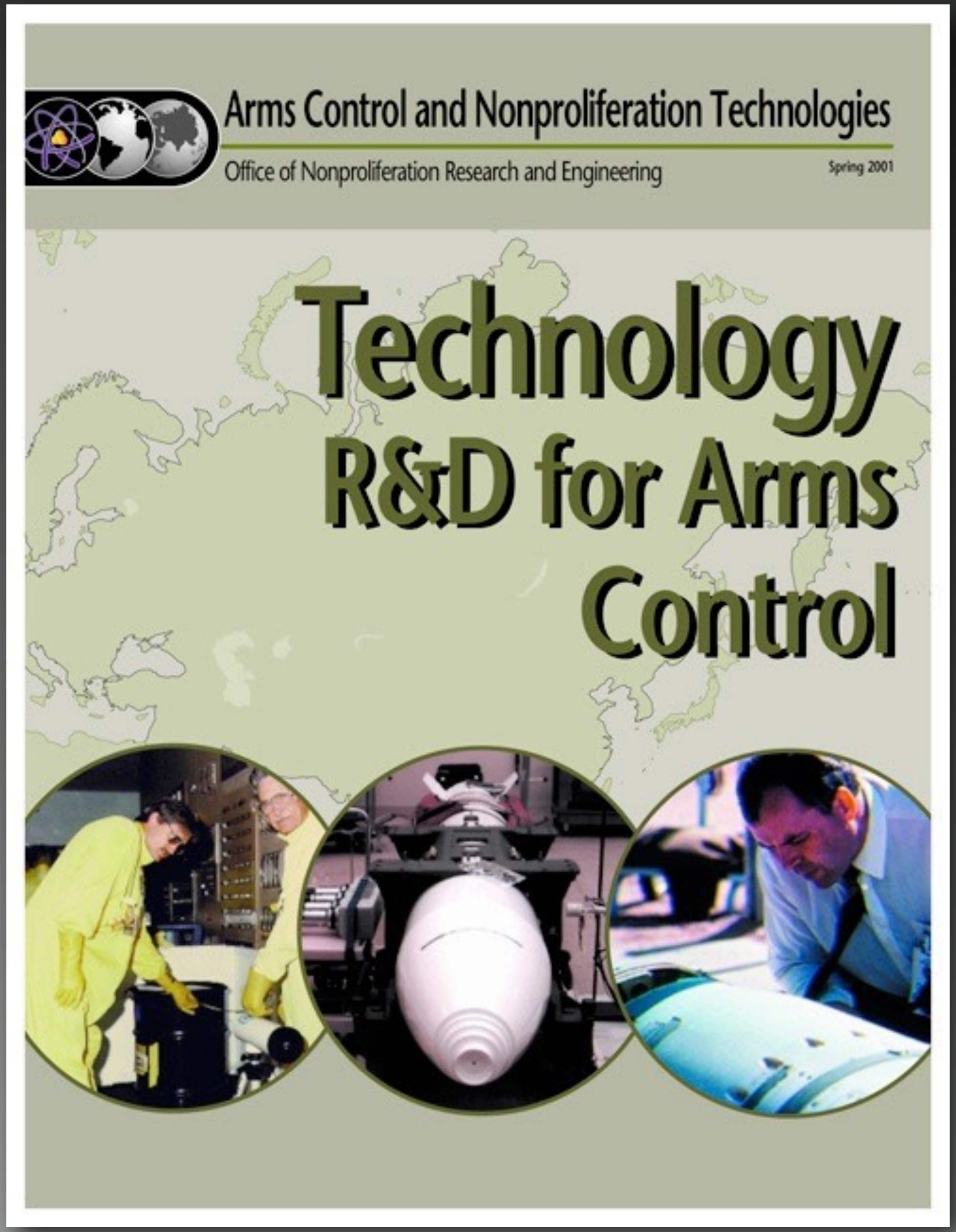


Science, 248, 18 May 1990, pp. 828-834

U.S. Scientists on a Soviet Cruiser in the Black Sea, 1989

NUCLEAR WARHEAD VERIFICATION

KEY CONCEPTS OF (PROPOSED) SYSTEMS



edited by D. Spears, 2001

ATTRIBUTE APPROACH

Confirming selected characteristics
of an object in classified form
(for example, the presence/mass of plutonium)

TEMPLATE APPROACH

Comparing the radiation signature
from the inspected item with a reference item
("golden warhead") of the same type

INFORMATION BARRIERS

Technologies and procedures that
prevent the release of sensitive nuclear information
(generally needed for both approaches)

THE ORTHODOX APPROACH

25 YEARS OF R&D … BUT SO FAR NO WINNING TECHNOLOGY OR DESIGN

Inspection System developed as part of the Trilateral Initiative during a demonstration at Sarov
Source: Tom Shea

2nd Prototype of the Information Barrier developed as part of the UK-Norway Initiative
Source: ukni.info

Trusted Radiation Identification System (TRIS) developed by Sandia National Laboratories
Source: U.S. Department of Energy

Fundamental challenge: How can information barriers simultaneously be authenticated and certified, i.e., trusted by inspector team and host team at the same time?

HARDWARE TROJANS

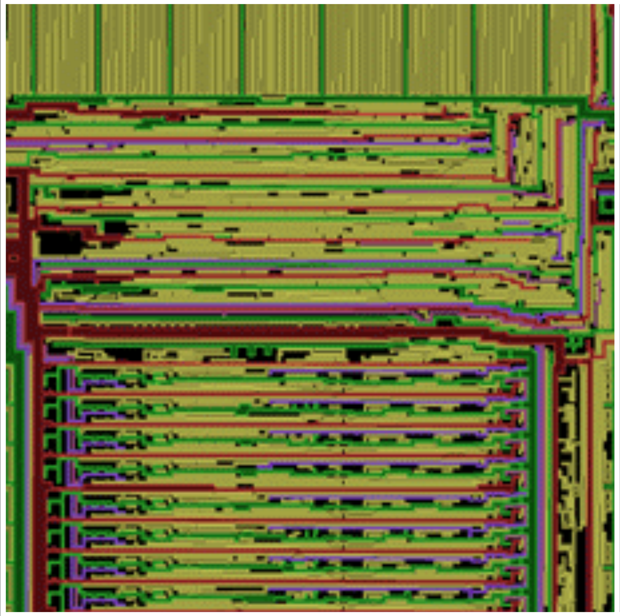
STEALTHY MODIFICATIONS TO AN INTEGRATED CIRCUIT THAT ADD OR REMOVE FUNCTIONALITIES

CAN YOU TRUST THIS CHIP?

Does the hardware meet the design specifications?

Does it perform as intended?

Insertion of trojan is possible at every stage of the product cycle
in particular, during design, manufacturing, assembly, and shipping (supply chain)



HARDWARE VERIFICATION CHALLENGES

Reproducibility is difficult; trojans can be triggered by aging mechanisms or environmental conditions; extremely hard for inspector to reproduce

Below transistor level: Terra Incognita; so far no solutions

G. T. Becker, F. Regazzoni, C. Paar, W. P. Burleson, “Stealthy dopant-level hardware Trojans,” *Journal of Cryptographic Engineering,* (4) 1, April 2014.

ONE (BIG) ISSUE REMAINS

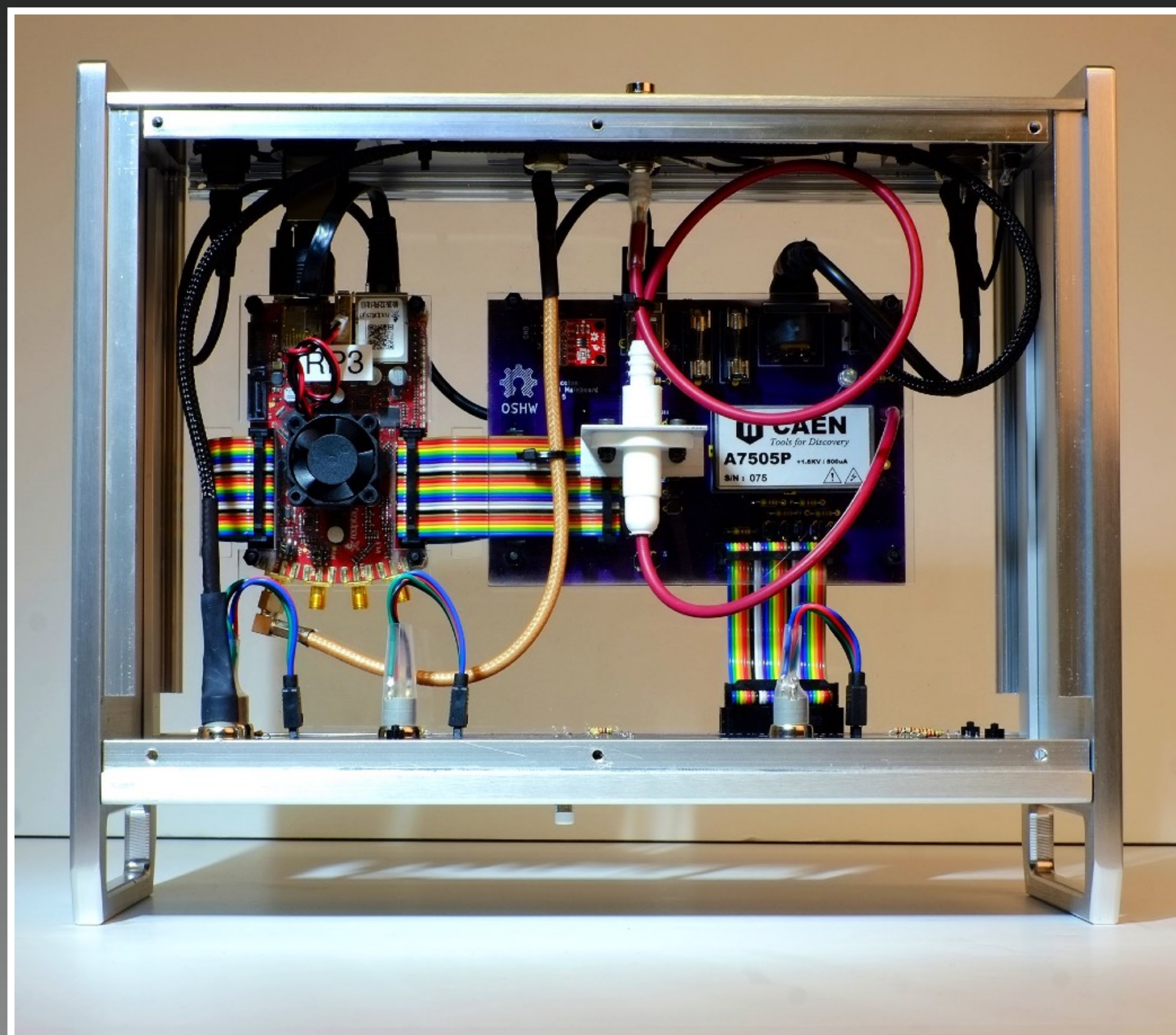
NO POST-MEASUREMENT INSPECTION OF EQUIPMENT

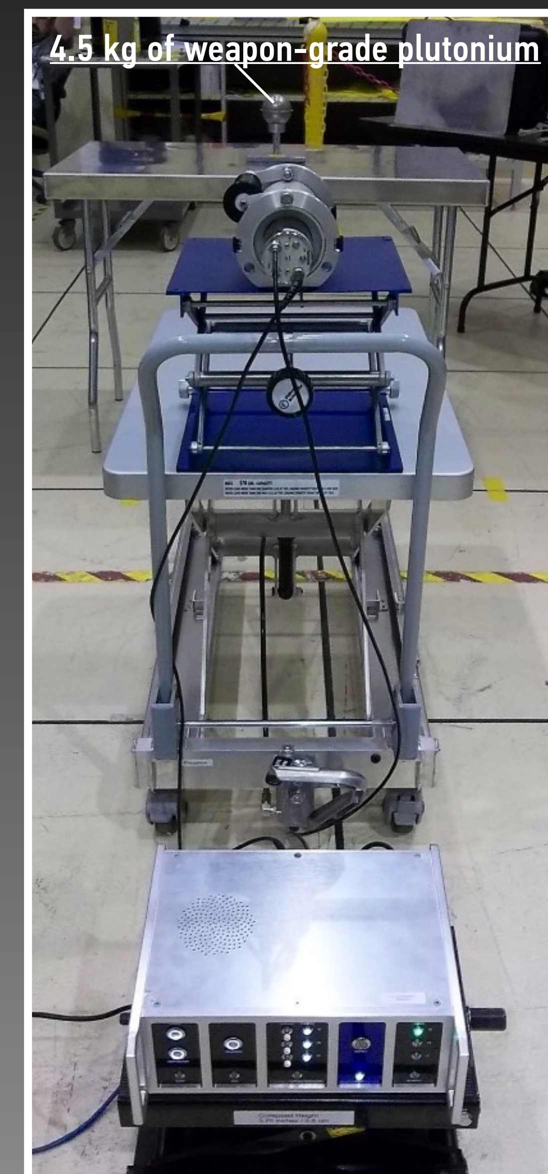
After all these years, no one has yet demonstrated either an attribute or template type system using a classified test object in such a way that specialists from the inspecting country can then [i.e., after the measurement] thoroughly examine and proof the measurement equipment."

James Fuller, October 2012

INFORMATION BARRIER EXPERIMENTAL

A PROTOTYPING PLATFORM FOR HARDWARE AND SOFTWARE CHALLENGES?





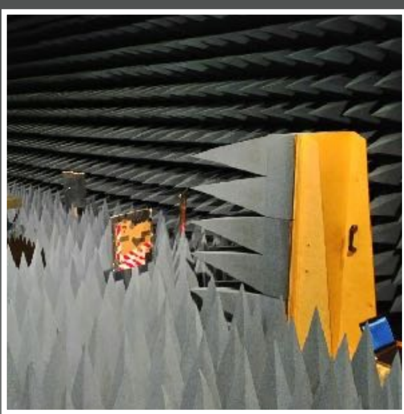
M. Kuett, M. Goettsche, and A. Glaser, "Information Barrier Experimental," *under review*

M. Goettsche, J. Schirm, and A. Glaser, "Low-resolution Gamma-ray Spectrometry for an Information Barrier Based on a Multi-criteria Template-matching Approach," *Nuclear Instruments and Methods A,* 840, 2016, pp. 139–144

WHAT TO DO WHEN THERE REMAIN ENDURING CONCERNS ABOUT INFORMATION SECURITY

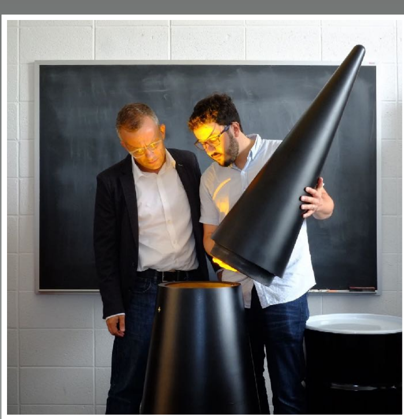
CONTINUE IMPROVING TECHNOLOGIES AND APPROACHES

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 radically different verification approaches; for example, consider zero-knowledge protocols and develop alternatives to onsite inspections at certain sensitive facilities



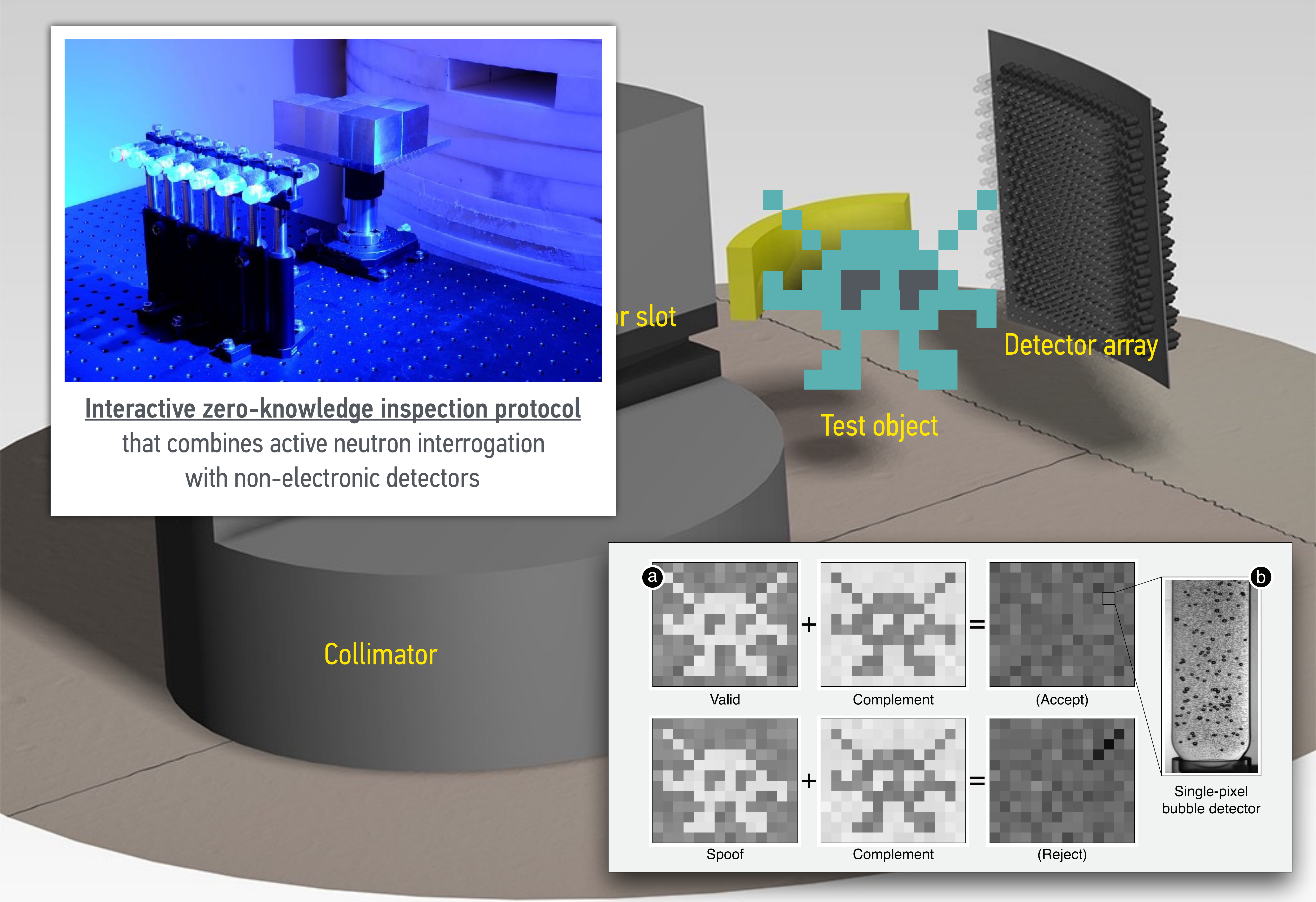
REVEAL THE SECRET

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), Christian Zenger (middle)

REINVENTING THE PROBLEM # EXAMPLE 1

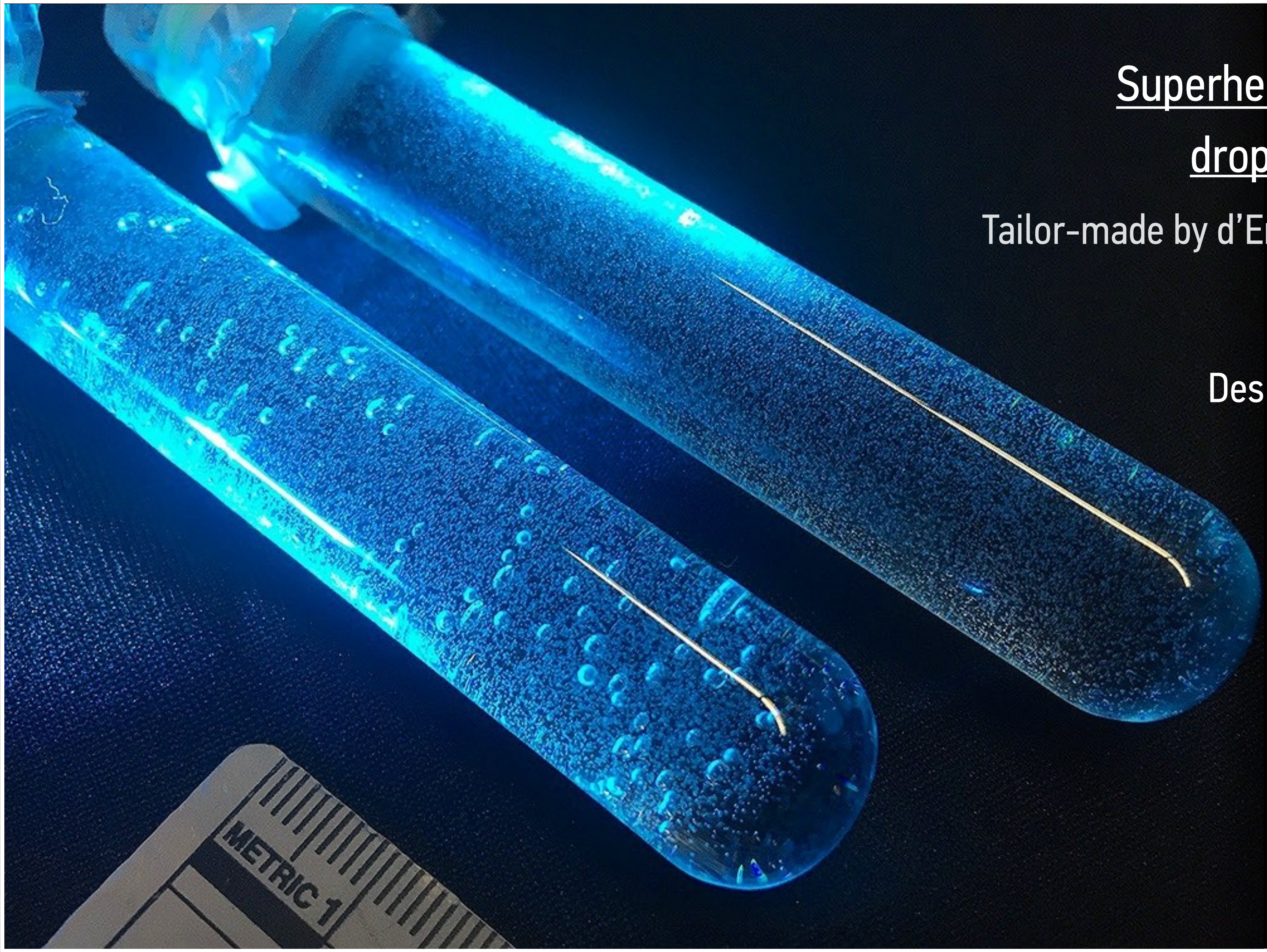
ZERO-KNOWLEDGE NUCLEAR WARHEAD CONFIRMATION



A. Glaser, B. Barak, R. J. Goldston, "A Zero-knowledge Protocol for Nuclear Warhead Verification," *Nature*, 510, 26 June 2014
S. Philippe, R. J. Goldston, A. Glaser, F. d'Errico, *Nature Communications*, 7, September 2016, www.nature.com/articles/ncomms12890

SUPERHEATED DROPLET DETECTORS OFFER A WAY TO IMPLEMENT THIS INSPECTION PROTOCOL

AND AVOID DETECTOR-SIDE ELECTRONICS



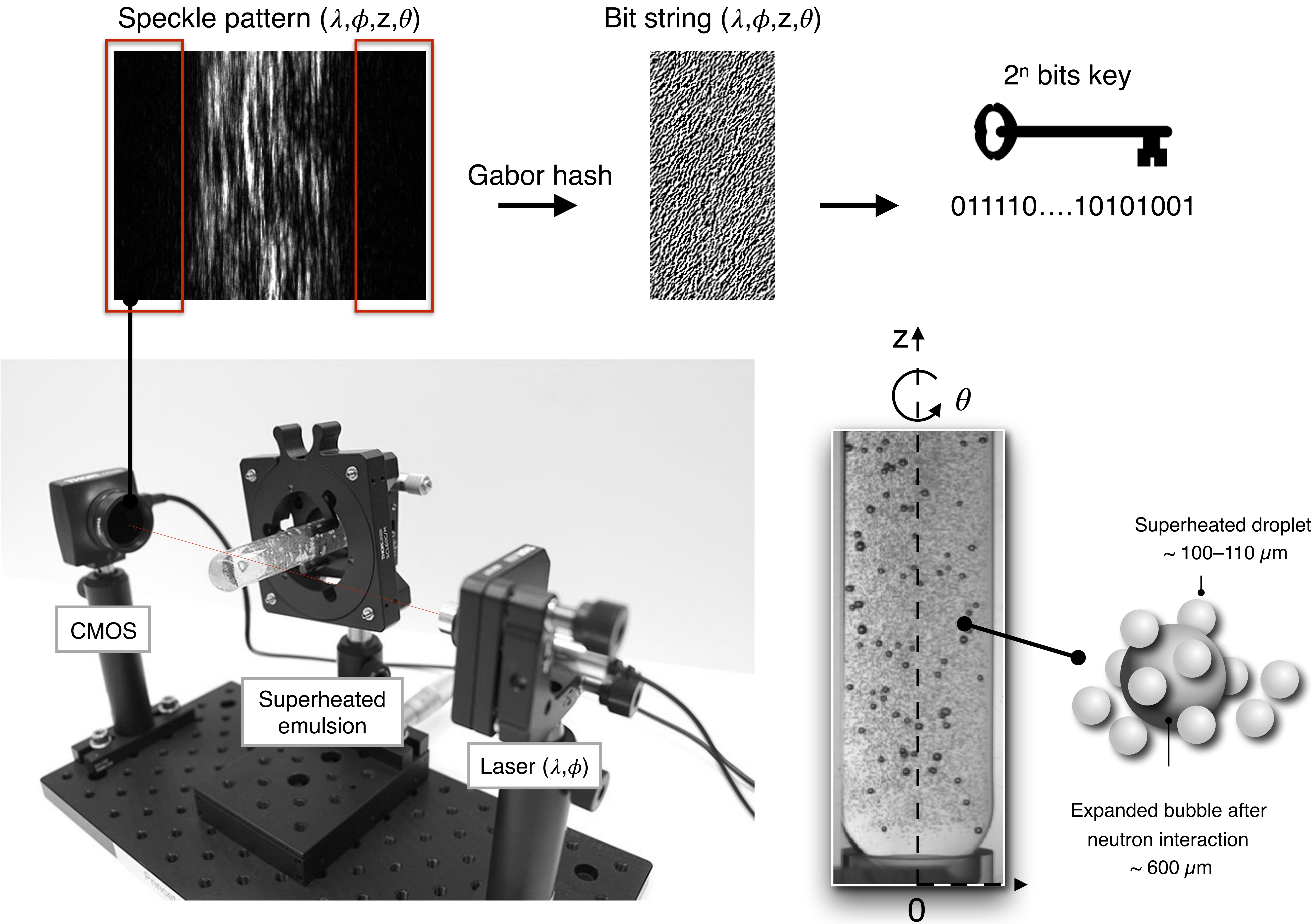
Superheated C-318 fluorocarbon (C_4F_8) droplets suspended in aqueous gel

Tailor-made by d'Errico Research Group, Yale University

Sensitive to neutrons with $E_n > E_{min}$

Designed to be insensitive to γ-radiation

Active volume .... : 6.0 cm^3
Droplet density .... : 3500 cm^{-3}
Droplet diameter ...... : ~100 μm
Absolute Efficiency ... : 4×10^{-4}



R. Pappu, et al., “Physical one-way functions,” *Science,* 297 (5589), 2002

S. Philippe, R. Barnett, A. Glaser, “Superheated Emulsions as Neutron-Sensitive Physically Unclonable Functions”, *INMM Annual Meeting, July* 2017

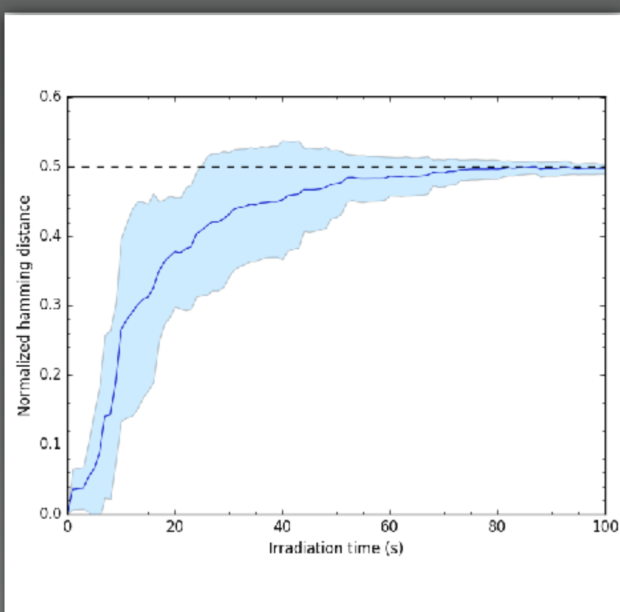
NEUTRON-SENSITIVE PUFS AS TRUSTED DETECTORS

OPEN PATH FOR DATA COMMITMENT AND CRPs PROTOCOLS

DATA COMMITMENT

Would allow host to review data before the inspector sees it while giving the inspector confidence the data was not tampered with

First experimental results are promising: detectors are unique objects, physically unclonable, and challenge response pairs are sensitive to neutron interaction



CRPs PROTOCOLS

Sensor-PUFs can be used in Challenge Response Pairs Protocols to perform trusted measurements without inspectors being present

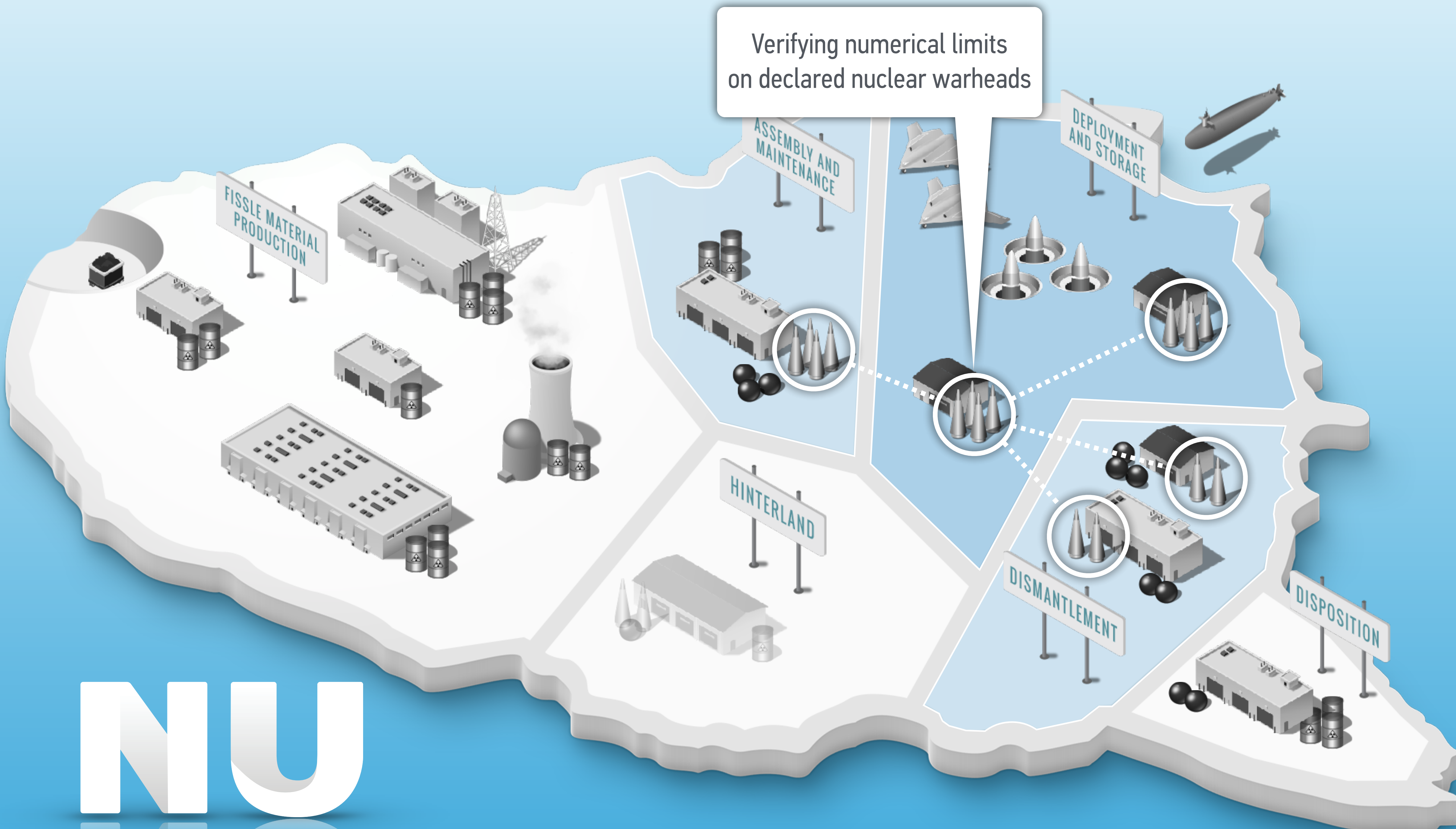
Security depends on the simulation hardness of the laser/detector interaction and not on classical tamper proof hardware and secret cryptographic keys

Source: Authors (Top: Experimental Set-up; Bottom: Destruction of CRPs upon neutron irradiation)

REINVENTING THE PROBLEM # EXAMPLE 2

CONFIRMING NUMERICAL LIMITS ON NUCLEAR WARHEADS

VERIFICATION CHALLENGES OF DEEP REDUCTIONS



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TAGGING

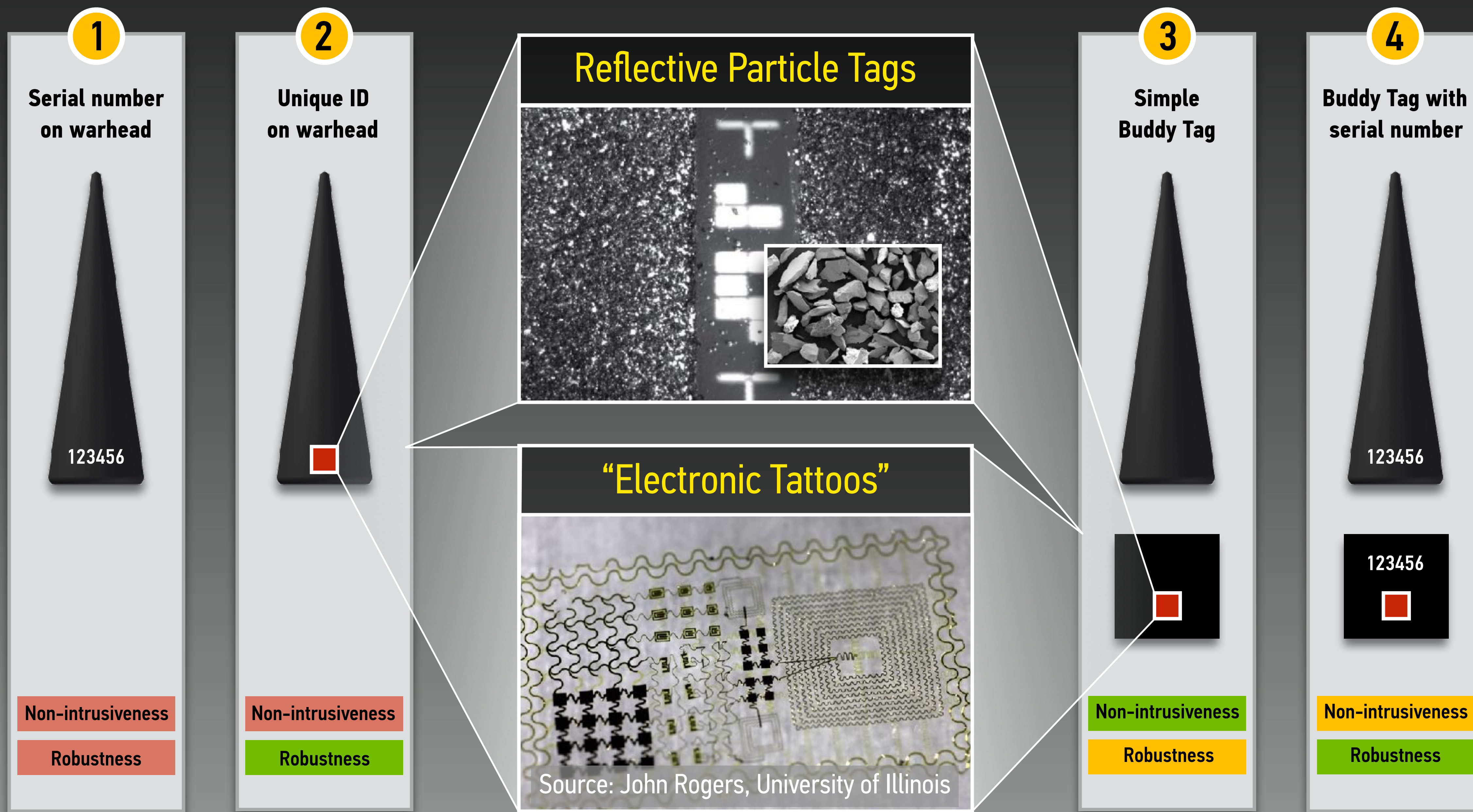
TRANSFORMING A "NUMERICAL LIMIT" INTO A "BAN ON UNTAGGED ITEMS"

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

VERIFYING NUMERICAL LIMITS OF DECLARED NUCLEAR WARHEADS

WARHEAD TAGGING OPTIONS



Reflective particle tag concept: A. Gonzales, *Reflective Particle Tag for Arms Control and Safeguards Authentication,* Sandia National Laboratories, 2004
Original buddy tag concept: S. E. Jordan, *Buddy Tag's Motion Sensing and Analysis Subsystem,* Sandia National Laboratories, 1991

HASHED DECLARATIONS

```
ITEM 01: 67d97802b84a6db872aacc400a0f5eaeebcec52012503111891b0d1e89711605
ITEM 02: b3c22af3a5f9ecc51c5cf6b4604e2bef191e4ceb305c6ef4a9589206e0bd7e62
ITEM 03: 0b277554264c8d00e81fb4b0af3f39f753146c8881ce093d7d45e8212cce95ac
ITEM 04: 4161814ef03933b605958325ca0aa3a3d9d2106f8f79b2c28cec5e75ea70266b
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```

Declaration in hashed form (with one entry per item)

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ITEM 01: 67d97802b84a6db872aacc400a0f5eaeebcec52012503111891b0d1e89711605
ITEM 02: b3c22af3a5f9ecc51c5cf6b4604e2bef191e4ceb305c6ef4a9589206e0bd7e62
ITEM 03: 8edd164eb3fd9116 SITE C :: W99 :: TIME 12345678 a562c8ffeefbc2fb
ITEM 04: 4161814ef03933b605958325ca0aa3a3d9d2106f8f79b2c28cec5e75ea70266b
ITEM 05: f5c53f5c375c22f6e20554d5d7488f1cc678caa4fdc50aca77057c4755d7b12b
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Declaration with entries for Site C revealed

Adapted from:
Monitoring Nuclear Weapons and Nuclear-Explosive Materials
National Academy of Sciences, Washington, DC, 2005

WAY FORWARD & NEXT STEPS

PREPARING FOR DEEPER REDUCTIONS AND MULTILATERAL NUCLEAR ARMS CONTROL

TAKING INFORMATION SECURITY SERIOUSLY

Jointly develop and demonstrate methods to confirm numerical limits on nuclear warheads and confirm their authenticity

Focus initially on non-intrusive approaches that are acceptable to all participants (but can accommodate “upgrades”)

THINKING OUTSIDE THE BOX

- Proof of knowledge and Trusted sensors
- Next-generation data exchange (hashed declarations, blockchains)
- IBX Hackathon

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