


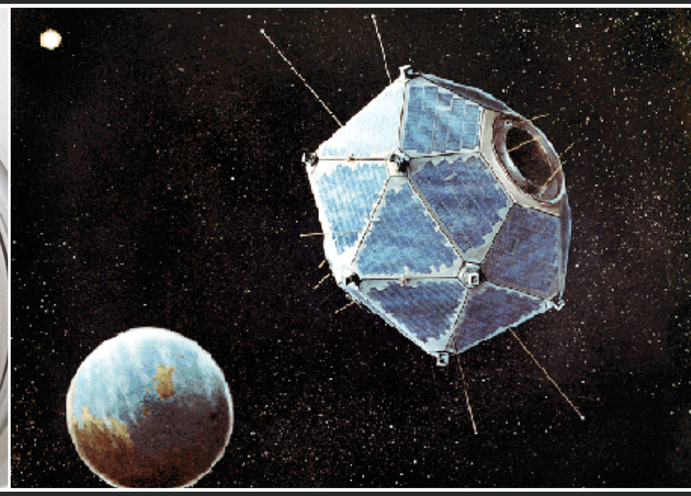

NUCLEAR ARMS CONTROL & VERIFICATION

HOW I LEARNED TO STOP WORRYING AND LOVE TO DISMANTLE THE BOMB

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Princeton School on Science and Global Security
October 11, 2024

Revision 0

Nuclear Disarmament Laboratory (J207)

BACKGROUND

THE CURRENT CRISIS IN NUCLEAR ARMS CONTROL

LANDMARK NUCLEAR ARMS CONTROL TREATIES

ANTI-BALLISTIC MISSILE TREATY
(1972–2002)

Source: U.S. Missile Defense Agency

The ABM Treaty barred the United States and Russia from deploying nationwide defenses against strategic ballistic missiles

The United States withdrew in 2002

INTERMEDIATE NUCLEAR FORCES
(1988–2019)

Source: www.defenseimagery.mil (now inactive)

The INF Treaty required the United States and Russia to eliminate all ground-launched ballistic and cruise missiles with ranges between 500 and 5,500 kilometers

START & New START
(1994–2009, 2011–2026)

Source: Alexander Zemlianichenko, Associated Press

START and New START requires the United States and Russia to reduce and limit their deployed strategic weapons

New START expires in 2026
(currently "suspended")

For details, see www.armscontrol.org/factsheets/USRussiaNuclearAgreements

LANDMARK NUCLEAR ARMS CONTROL TREATIES

LIMITED TEST BAN TREATY
(1963)


Source: NNSA

The LTBT (or PTBT) bans testing of nuclear weapons in the atmosphere, in outer space, and under water

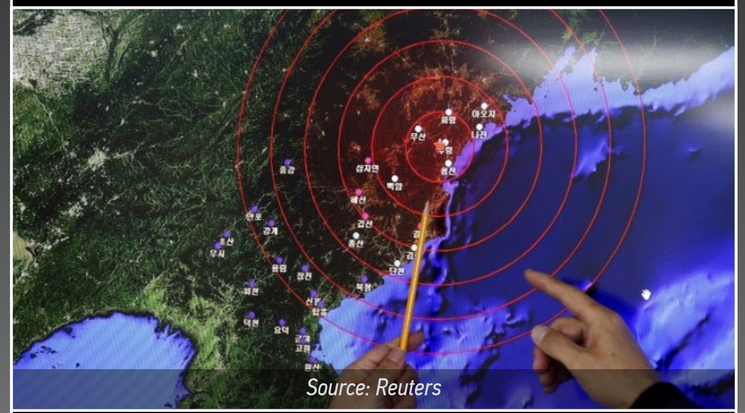
Original members are the United States, the United Kingdom, and the Soviet Union; France and China never joined

THRESHOLD TEST BAN TREATY
(1974/1990)


Source: NNSA

The Treaty on the Limitation of Underground Nuclear Weapon Tests (TTBT) between the United States and the Soviet Union prohibits tests with an explosive yield exceeding 150 kt(TNT)

COMPREHENSIVE TEST BAN TREATY
(1996, not in force)


Source: Reuters

The CTBT bans all nuclear explosions in all environments

As of Oct. 2024, signed by 187 states, ratified by 178 states; enters into force when 44 “nuclear capable” states have ratified the treaty

Nuclear capable (“Annex II”) states that haven’t ratified the CTBT are China, Egypt, India, Iran, Israel, North Korea, Pakistan, and the United States; www.ctbto.org/map/#status

NUCLEAR NON-PROLIFERATION TREATY

(1968/1970; INDEFINITE EXTENSION IN 1995)

THE NPT HAS "RECENTLY" TURNED FIFTY

Promises nuclear disarmament and access to civilian nuclear power in exchange for all other parties to forgo nuclear weapons; nearly universal today

2010–2019 was the first/only decade since the end of WW II without a new weapon state

THE NPT IS IN CRISIS (ALSO)

Insufficient progress in the areas of nuclear arms control and disarmament

Commitments of the 2000 Final Document ("13 Steps") and the 2010 Final Document ("Action Plan") unfulfilled; 2020 Review Conference (held in August 2022) was a failure

Source: International Atomic Energy Agency

USA
5,050

U.S. Nuclear Weapon

Russia
5,580

United Kingdom
215

France
300

Israel
80

Pakistan
170

India
170

China
500

North Korea
50

North Korean Nuclear Weapon

There ~~remain~~ are about 12,500 nuclear weapons in the world today

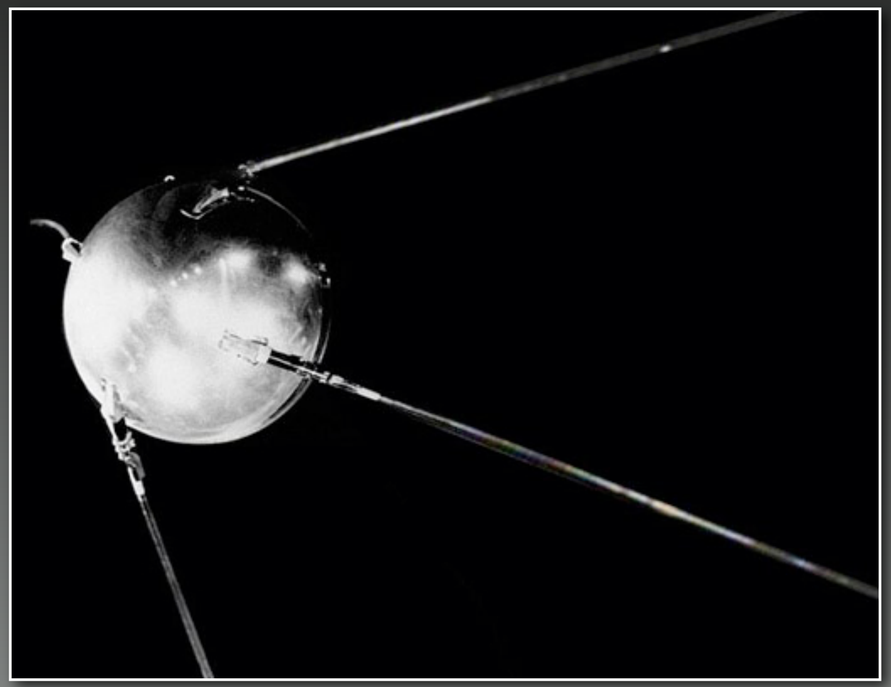
Hans Kristensen, Matt Korda, and Robert Norris, Nuclear Notebook, Federation of American Scientists and thebulletin.org/nuclear-risk/nuclear-weapons/nuclear-notebook/

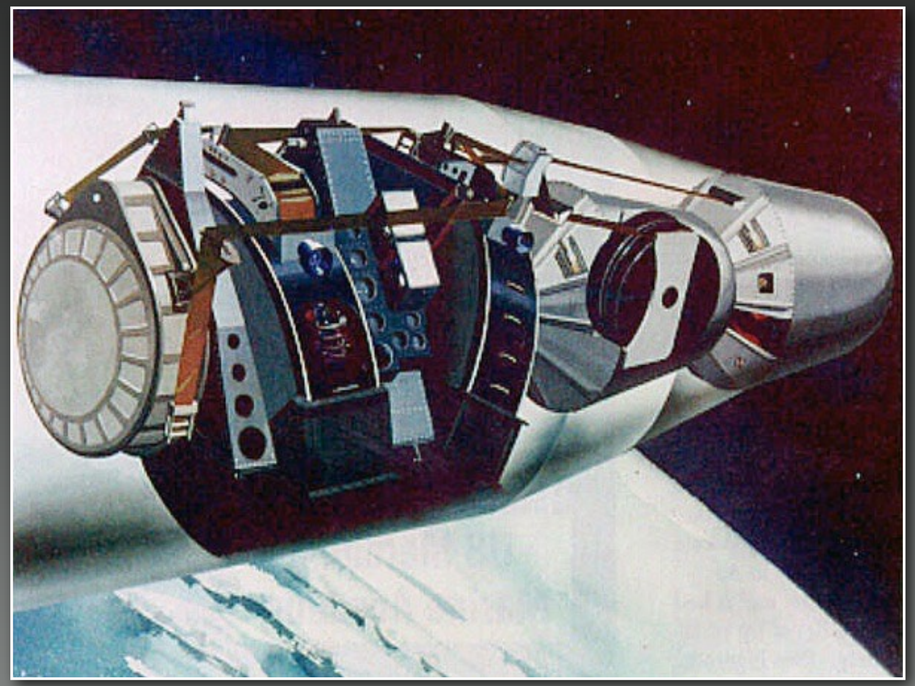
Verification

(why & how)

“THE GAME CHANGER”

FROM SPUTNIK 1 (OCTOBER 1957) TO THE FIRST RECONNAISSANCE SATELLITES (CORONA SERIES,1959–1972)





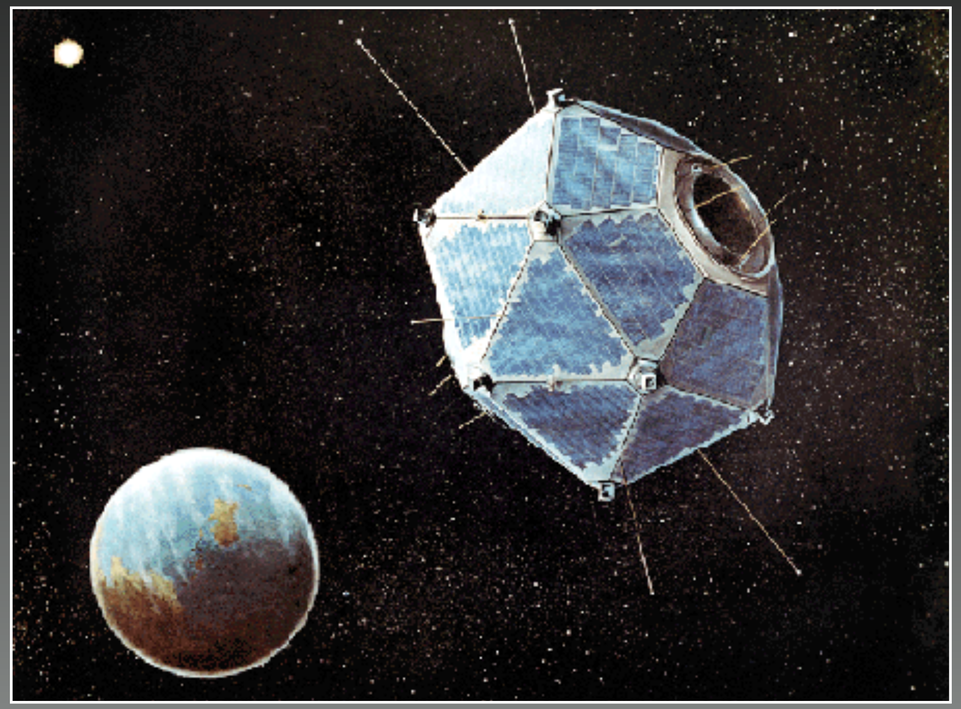
Sputnik: 83.6 kg (in orbit), 58 cm diameter, operational for 3 weeks, decay of orbit after 3 months, about 1400 orbits of earth

Corona series: 144 launches, more than 800,000 photographs returned

www.nro.gov/History-and-Studies/Center-for-the-Study-of-National-Reconnaissance/The-CORONA-Program/

USING SATELLITES FOR VERIFICATION PURPOSES

VELA (1963–1984) AND NAVSTAR/GPS (SINCE 1978)



Part of the system of “national technical means” to monitor compliance with the 1963 Limited Test Ban Treaty

(Satellites used non-imaging photodiodes to monitor light levels)

Navstar-2F Satellite (“GPS Block IIF”), U.S. Air Force

Insert shows the Space and Atmospheric Burst Reporting System (SABRS-2)

www.energy.gov/nnsa/articles/nnsa-delivers-enduring-space-based-nuclear-detonation-detection (March 2018)

It is one of the great ironies of the Cold War that techniques developed for threat assessment and war planning made it possible for the two bitter rivals to agree on limits to some of their more destructive and destabilizing weapons without the aid of on-site inspections.

Allan S. Krass, The United States and Arms Control, 1997

VERIFYING THE INF TREATY

(1988–2001, 2019)

ONSITE INSPECTIONS

U.S. inspectors at Votkinsk, 1988/89 (Source: Harahan, 1993)

Five types of (intrusive) onsite inspections until 2001, i.e., ten years after completion of the elimination phase of the treaty

Inspection types included: Baseline, Perimeter and Portal Continuous Monitoring (PPCM), Elimination, Closeout, and Short-Notice

Altogether about 850 onsite inspections under INF

VERIFIED ELIMINATION

Source: www.defenseimagery.mil (now inactive)

Verified elimination of almost 2,700 missiles

This included 846 U.S. systems (BGM-109G GLCM, Pershing 1a, and Pershing II) and 1,846 Soviet systems (SS-4, SS-5, SS-12, SS-20, SS-23, and SSC-X-4)

PERIMETER CONTROL

Source: Author

Perimeter and Portal Continuous Monitoring at Votkinsk, Russia, and at Magna, Utah

An industrial x-ray machine (CargoScan) was used at Votkinsk to confirm that only permitted single-warhead ICBMs (SS-25) were being produced

J. P. Harahan, *On-Site Inspections Under the INF Treaty*, U.S. Department of Defense, Washington, DC, 1993

START & NEW START

(1994–2009, 2011–2026)

SCOPE

START-I required a 40% reduction in deployed strategic nuclear weapon systems (ICBMs, SLBMs, and heavy bombers)

New START limits total number of deployed strategic warheads to 1,550 on each side

(Russia "suspended" New START in 2023)

VERIFICATION APPROACH

Source: www.vandenberg.af.mil/News/Photos/igphoto/2000614747

START-I used "counting rules" to facilitate verification (e.g. a fixed number of warheads were attributed to a particular missile type)

As INF, strong emphasis on data exchange and onsite inspections (more than 1,100 START inspections until 2009)

New START vs START

Source: Randy Montoya

"Simplified and less costly"

More realistic counting ("actual" number of warheads)

Limited number of onsite inspections

Two vs twelve types of inspections (Type 1 and 2)

UIDs now on all delivery systems

No open display of mobile ICBMs

Edward Ifft, "Verification Lessons Learned from the INF, START I, and New START Treaties," *55th Annual INMM Meeting,* July 2014

“DISPLAY IN THE OPEN”

June 22, 2005 @ LAT +55.381 LON +82.920

(Credit: Google Earth)

Article XII

Each Party shall, if the other Party makes a request ..., carry out the following cooperative measures: (a) a display in the open of the road-mobile launchers of ICBMs located within restricted areas specified by the requesting Party. ... For each specified restricted area, the roofs of fixed structures for road-mobile launchers of ICBMs shall be open for the duration of a display. The road-mobile launchers of ICBMs located within the restricted area shall be displayed either located next to or moved halfway out of such fixed structures ...

Treaty Text (START I)

WHAT NEXT?

NUCLEAR (DISARMAMENT) VERIFICATION

OVERLY COMPLICATED … OR RELATIVELY SIMPLE?

Future nuclear disarmament treaties … likely will contain more intrusive verification mechanisms, and operate in more challenging environments than any others in history.

Statement by the International Partnership for Disarmament Verification (IPNDV), December 2017

2017-2021.state.gov/the-international-partnership-for-nuclear-disarmament-verification-phase-i/index.html

How can the two presidents make the best of their one shot at setting the nuclear table? I have some advice for them: Keep it simple.

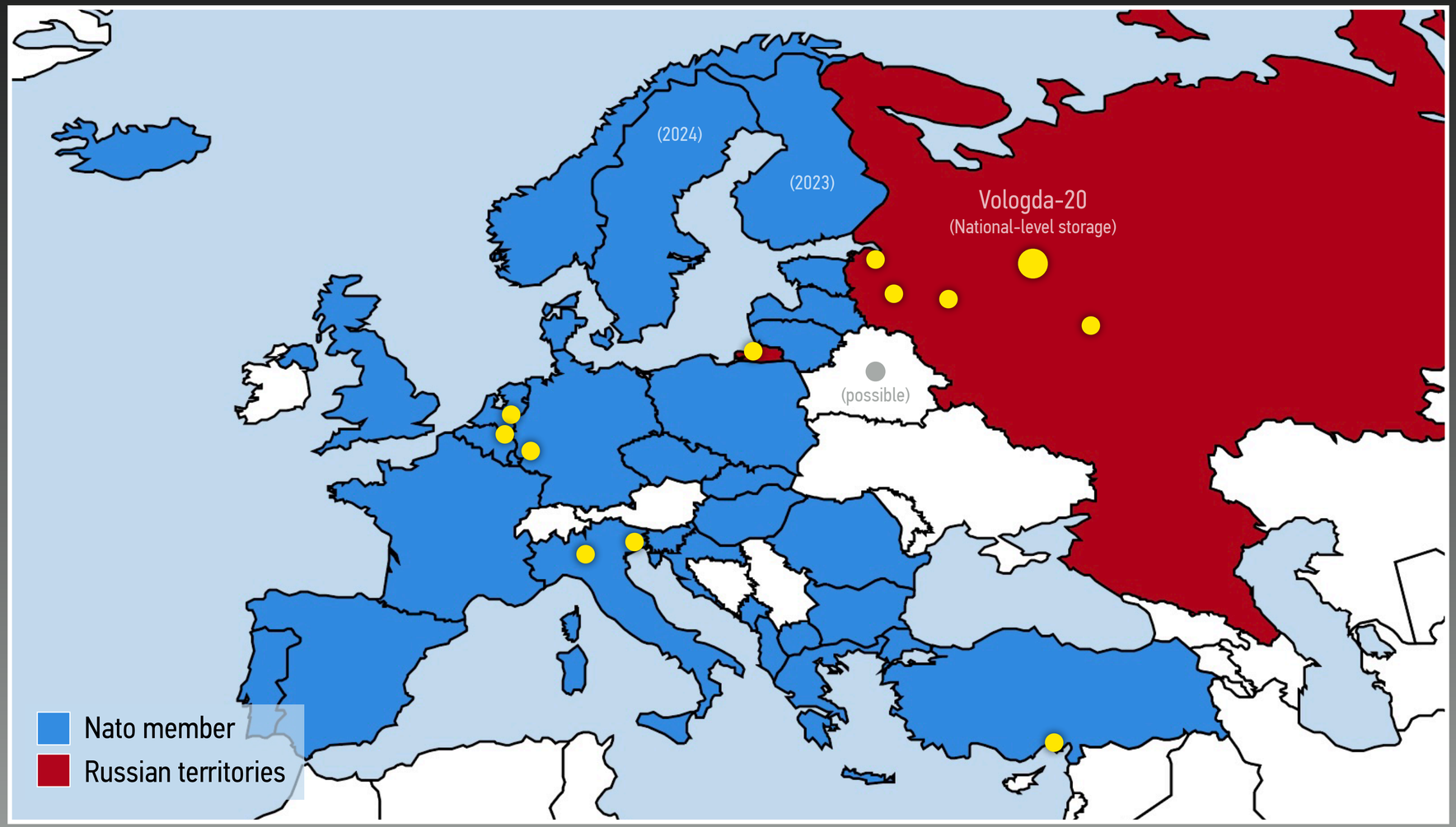
Rose Gottemoeller, June 2021, Lead U.S. negotiator of New START (2009)

Photo credit: NATO

Example #1

CONFIRMING ABSENCE

NUCLEAR WEAPONS IN EUROPE



Adapted from Pavel Podvig and Javier Serrat

MENZINGEN VERIFICATION EXPERIMENT

UNIDIR & SWISS ARMED FORCES, SWITZERLAND

LAST YEAR IN SWITZERLAND

In March 2023, UNIDIR organized a verification experiment that included a mockup onsite inspection at a former military facility in Menzingen, Switzerland

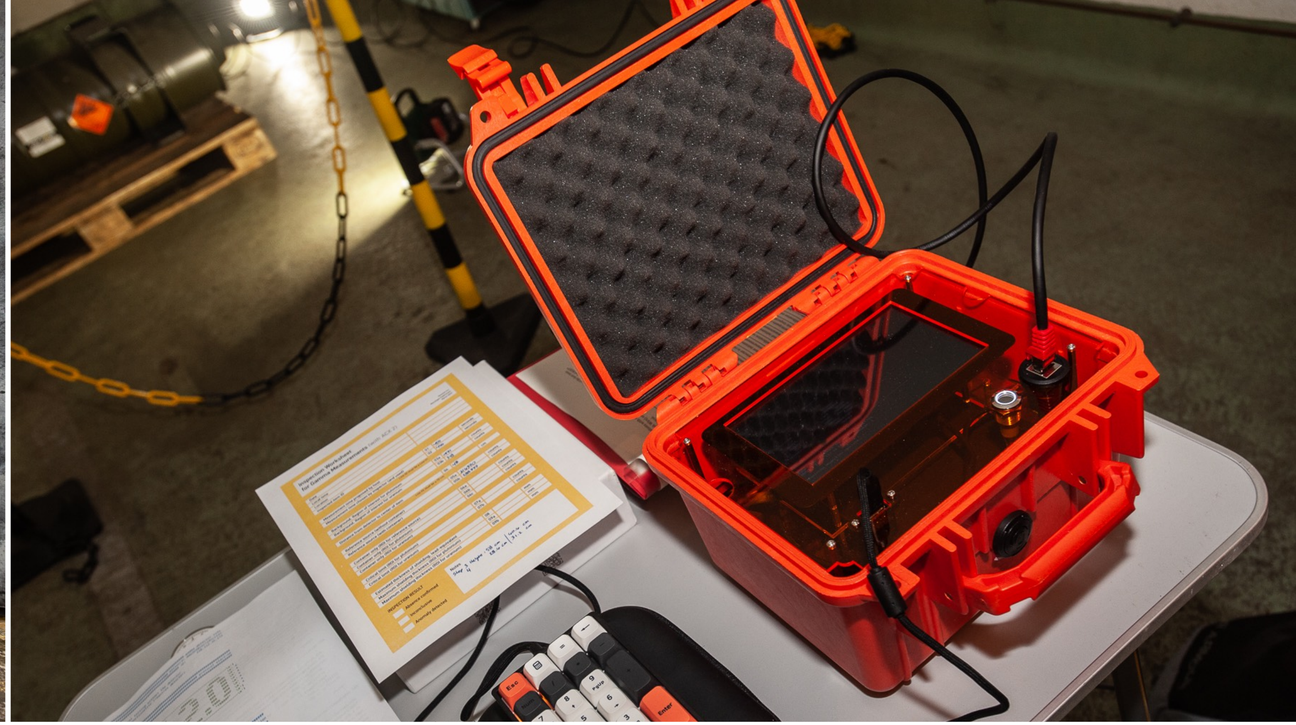
P. Podvig (ed.), Menzingen Verification Experiment: Verifying the Absence of Nuclear Weapons in the Field
United Nations Institute for Disarmament Verification (UNIDIR), Geneva, Switzerland, July 2023

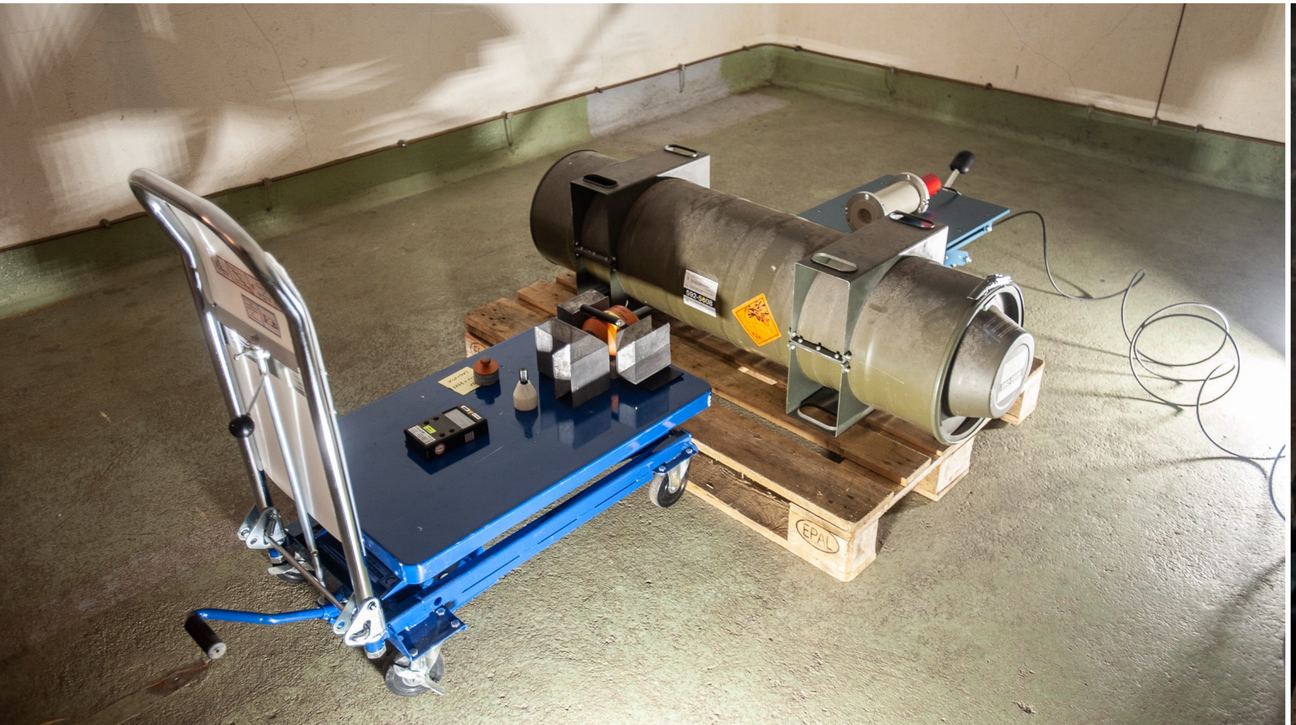
ABSENCE MEASUREMENTS

The main objective of the experiment was to examine procedures that could help to confirm the absence of nuclear weapons at a declared military site

Partly based on (neutron and gamma) radiation measurements; minimum information; no spectra; no data storage

Source: Pavel Podvig

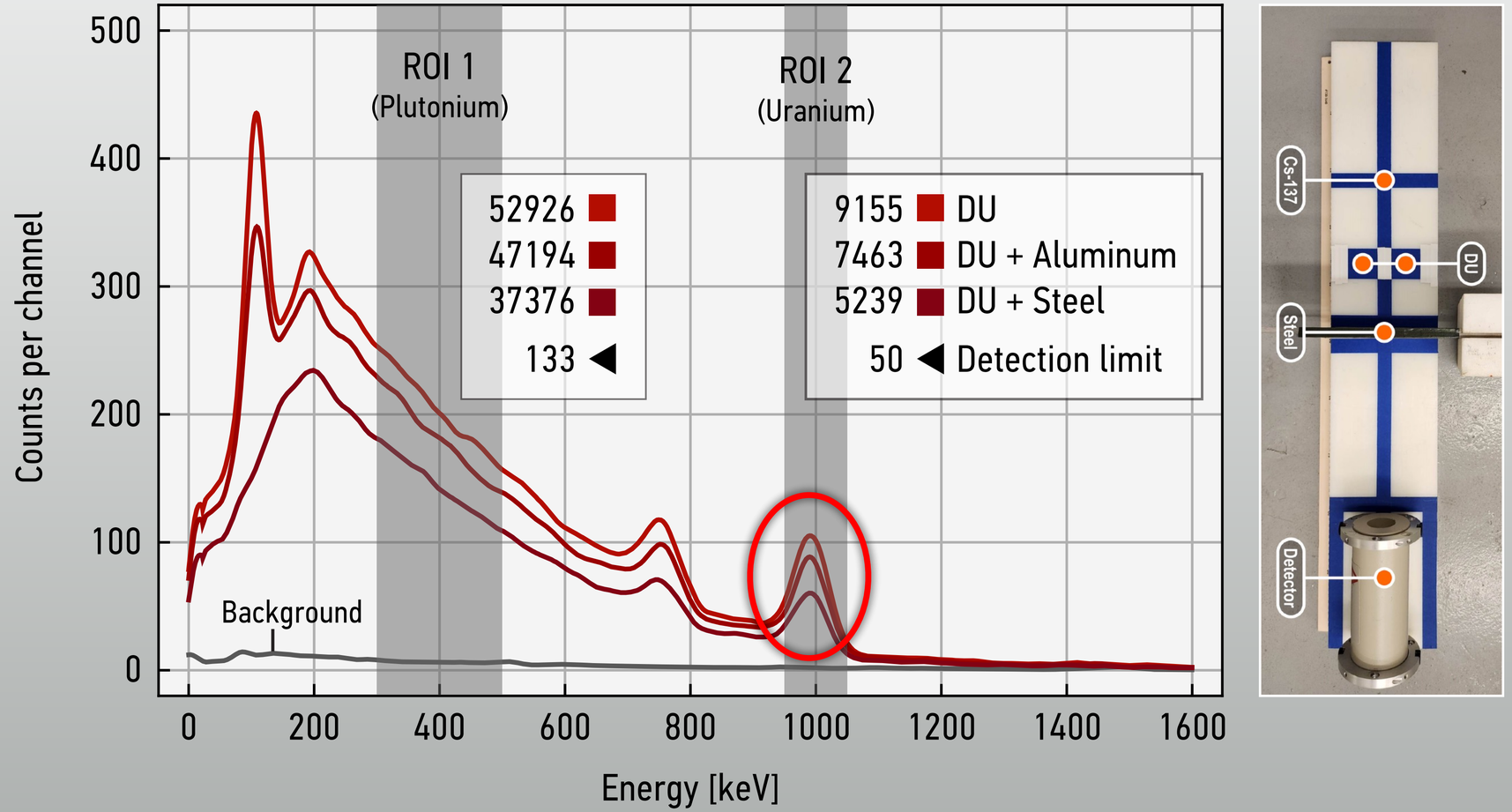




All photos: Pavel Podvig

LABORATORY ANALOG FOR GAMMA MEASUREMENTS

EXPERIMENTAL SETUP AT PPPL SIMULATING MENZINGEN SITUATION



E. Lepowsky, M. Kreutle, C. Wirz, and A. Glaser, Ceci N'est Pas Une Bombe, *Science & Global Security,* September 2023

Example #2

REMOTE (ONSITE) INSPECTIONS

REMOTE & VIRTUAL INSPECTIONS

PROS & CONS OF ONSITE INSPECTIONS FOR ARMS CONTROL

Onsite inspections remain the “gold standard” for nuclear arms-control verification (and IAEA safeguards) — but inspections tend to be costly and are often considered intrusive

CAN WE (PHYSICALLY) “SEPARATE” HOST & INSPECTOR?

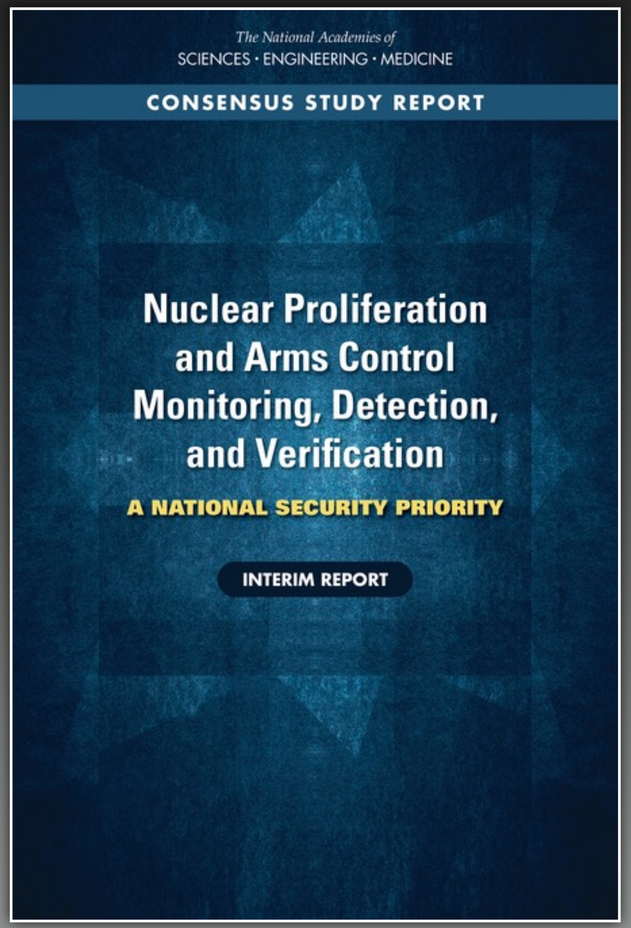
Many concerns could be addressed and resolved if inspectors were not “physically” present onsite

The host performs the prescribed activities onsite, while the inspector follows, influences, or directs the activities remotely

Source: ukni.info (top) and microsoft.com (bottom)

Mk21 reentry vehicles and containerized W87 warheads at F. E. Warren Air Force Base, Cheyenne, Wyoming, October 1992
Source: Paul Shambroom, paulshambroom.com

FINDINGS FROM 2021 NATIONAL ACADEMIES STUDY



3.4 MDV FOR ARMS CONTROL

3.4.1 Capability Needs

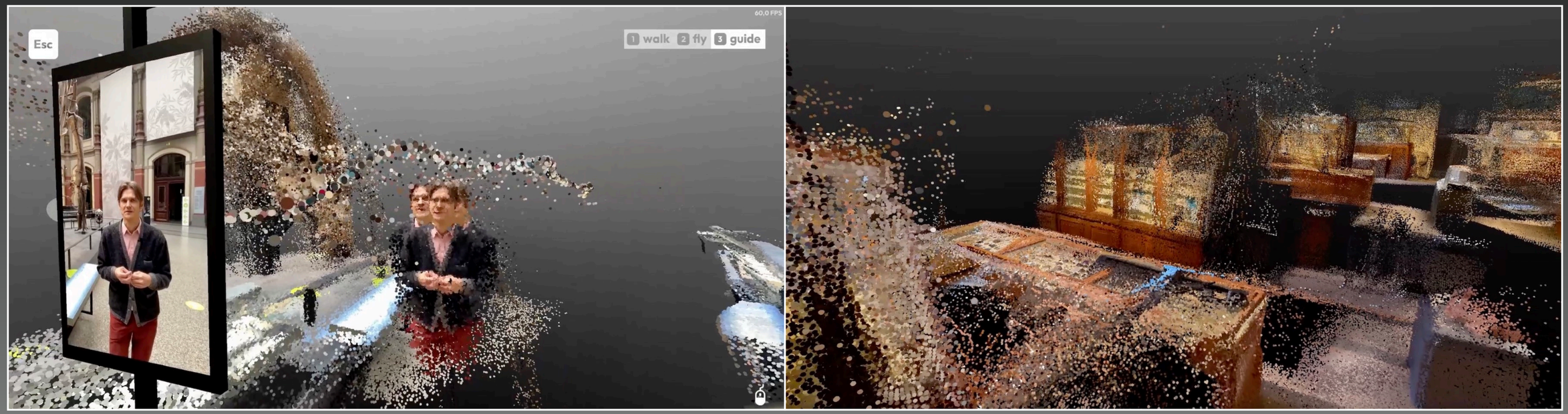
...

Treaties that include weapons in storage or weapons designed for shorter-range delivery systems are anticipated to require new MDV techniques. As a minimum, ***such treaties would likely require access to storage areas either directly or remotely****, and confirmation of warhead count (either a baseline confirmation or through routine/ challenge inspections).*

Jill Hruby, Corey Hinderstein, et al., Committee on the Review of Capabilities for Detection, Verification, and Monitoring of Nuclear Weapons and Fissile Material, National Academy of Sciences, Washington, DC, 2021, doi.org/10.17226/26088

BUT … HOW TO IMPLEMENT THEM?

(ONE IDEA)



Point Cloud Walk, a software prototype developed by ART+COM (artcom.de) in 2021/2022 for a museum in Berlin

Point Cloud Walk uses a real-time LIDAR scan performed by the host to generate the virtual environment, which the digital visitor can then explore

The prototype also enables interactions between the physical and the virtual worlds and participants

Credit: Jussi Ängeslevä (angesleva.iki.fi) and Jürgen Geuter (ART+COM)

SPOT “inspecting” QR codes on Princeton’s VR Deck
mae.princeton.edu/about-mae/spotlight/robot-cant-remember-it-could-be-future-nuclear-arms-control

BENEFITS & CHALLENGES
OF REMOTE INSPECTIONS

BENEFITS (REVISITED)

- Reduced intrusiveness, time, and cost compared to onsite inspections
  Potentially also of interest for some routine IAEA inspections
- Reduced security risks of disclosing sensitive information
  Sensitive details and objects are never modeled

CHALLENGES

- Security and integrity of transmitted data
- Live and local verification

Roger G. Johnston and Jon S. Warner, "Unconventional Approaches to Chain of Custody an Verification"
51st INMM Meeting, Baltimore, MD, July 2010

Source: IAEA (top) and Johnston and Warner, 2010 (bottom)

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