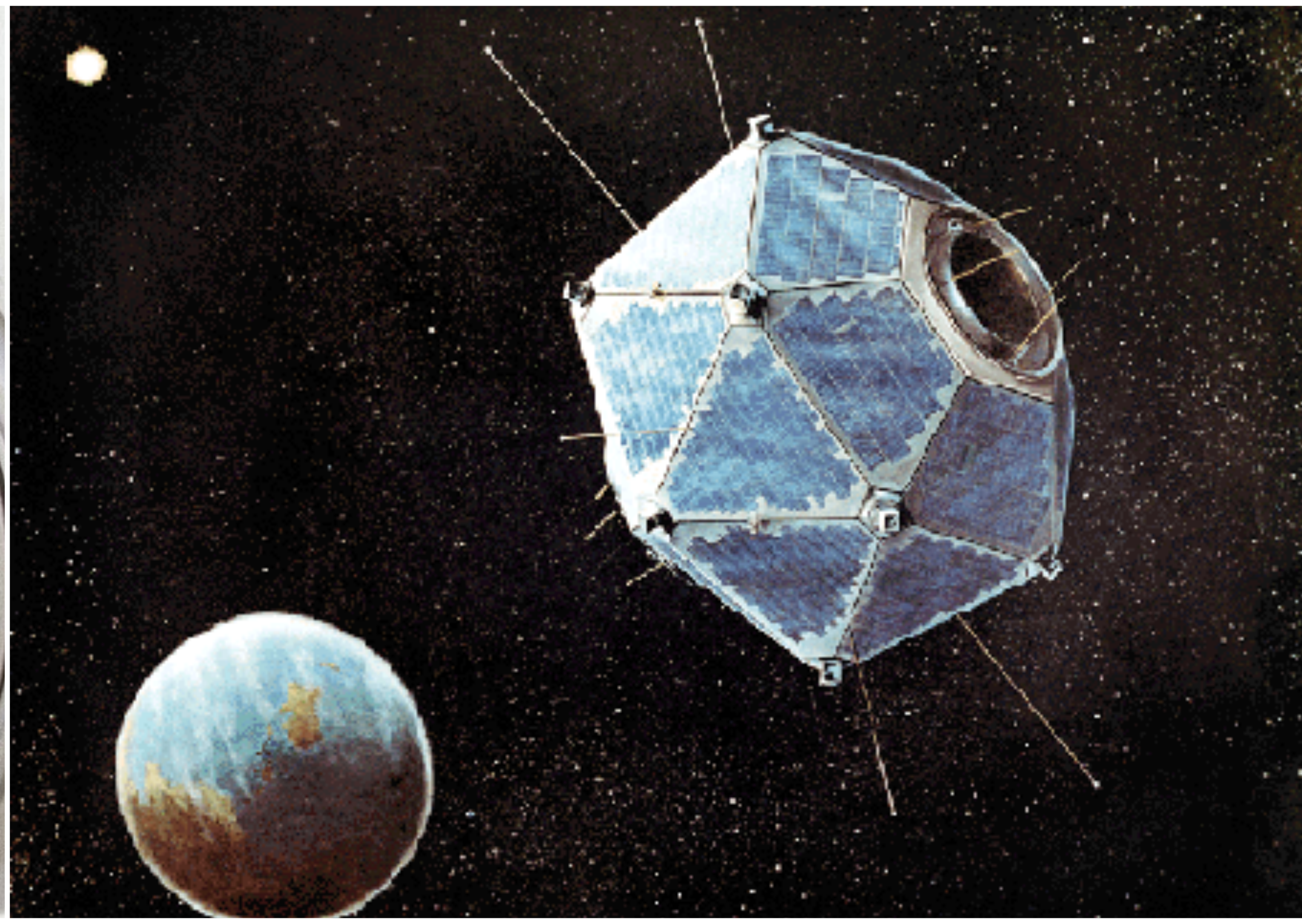


NUCLEAR ARMS CONTROL & VERIFICATION

PAST, PRESENT, AND FUTURE

Alex Glaser
Program on Science and Global Security
Princeton University

Princeton School on Science and Global Security
October 17, 2022

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

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 will expire in 2026

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

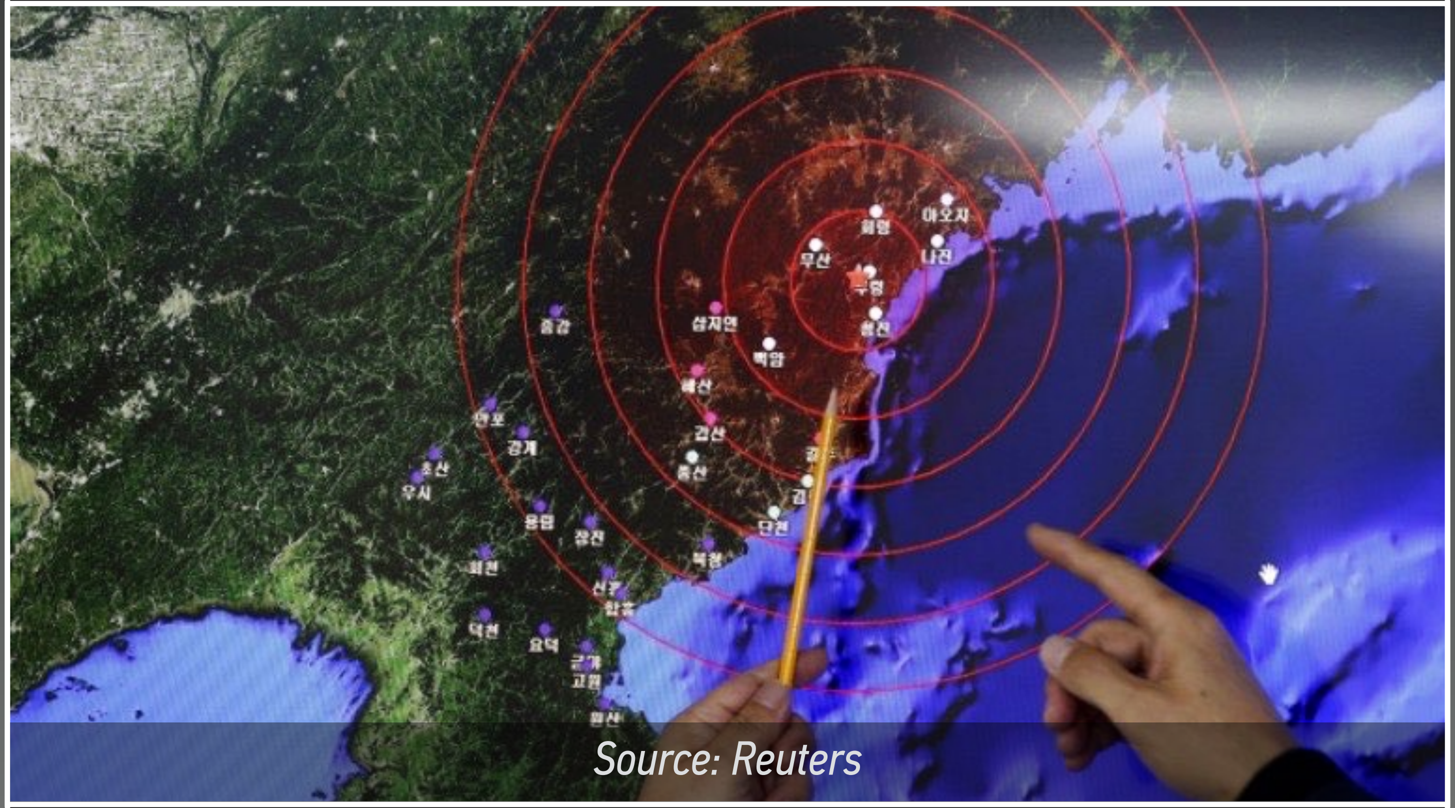
(1974/1990)

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. 2022, signed by 186 states, ratified by 176 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

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

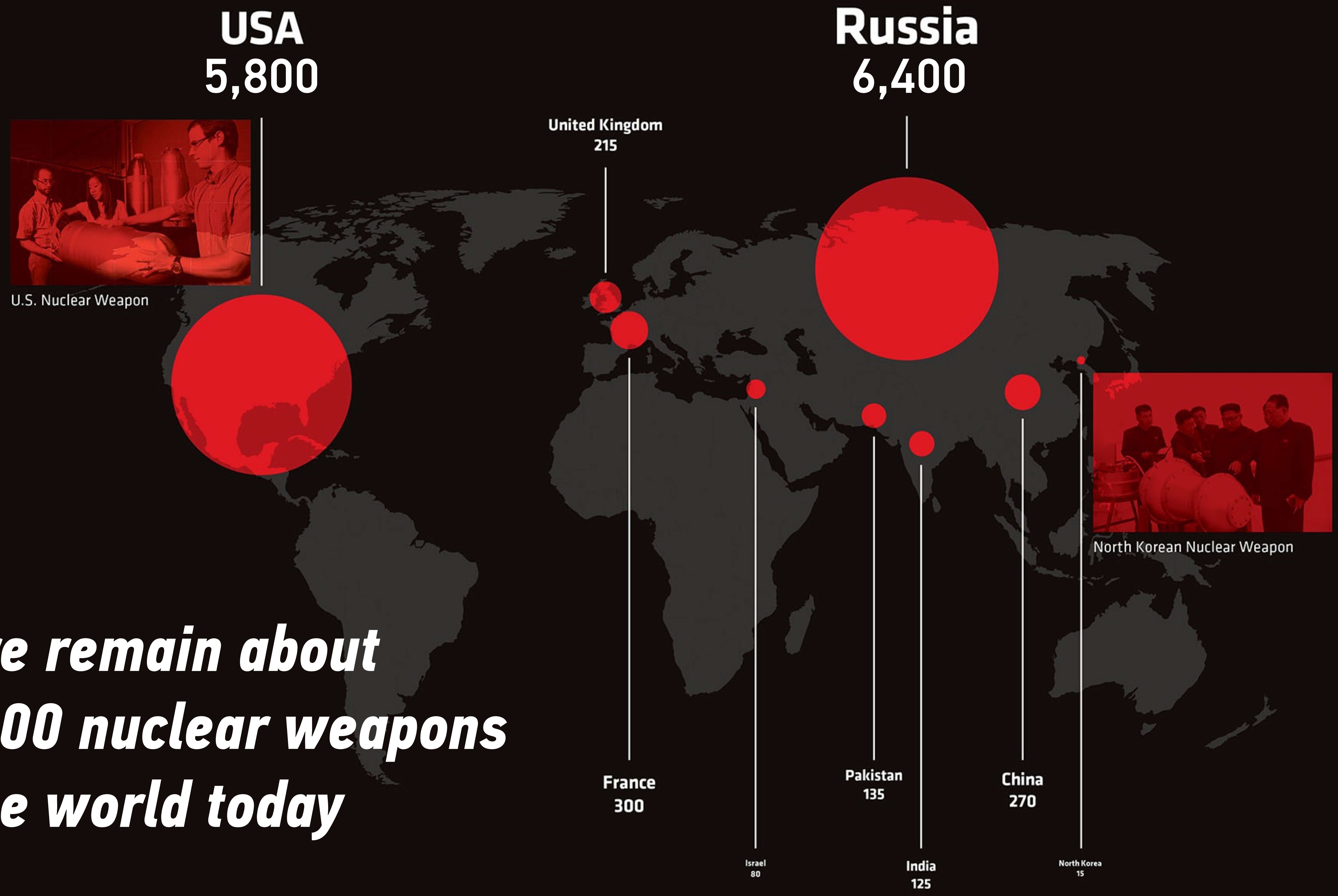
THE NPT IS IN CRISIS (ALSO)

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


ALFRED NOBEL
ICAN



There remain about 13,000 nuclear weapons in the world today

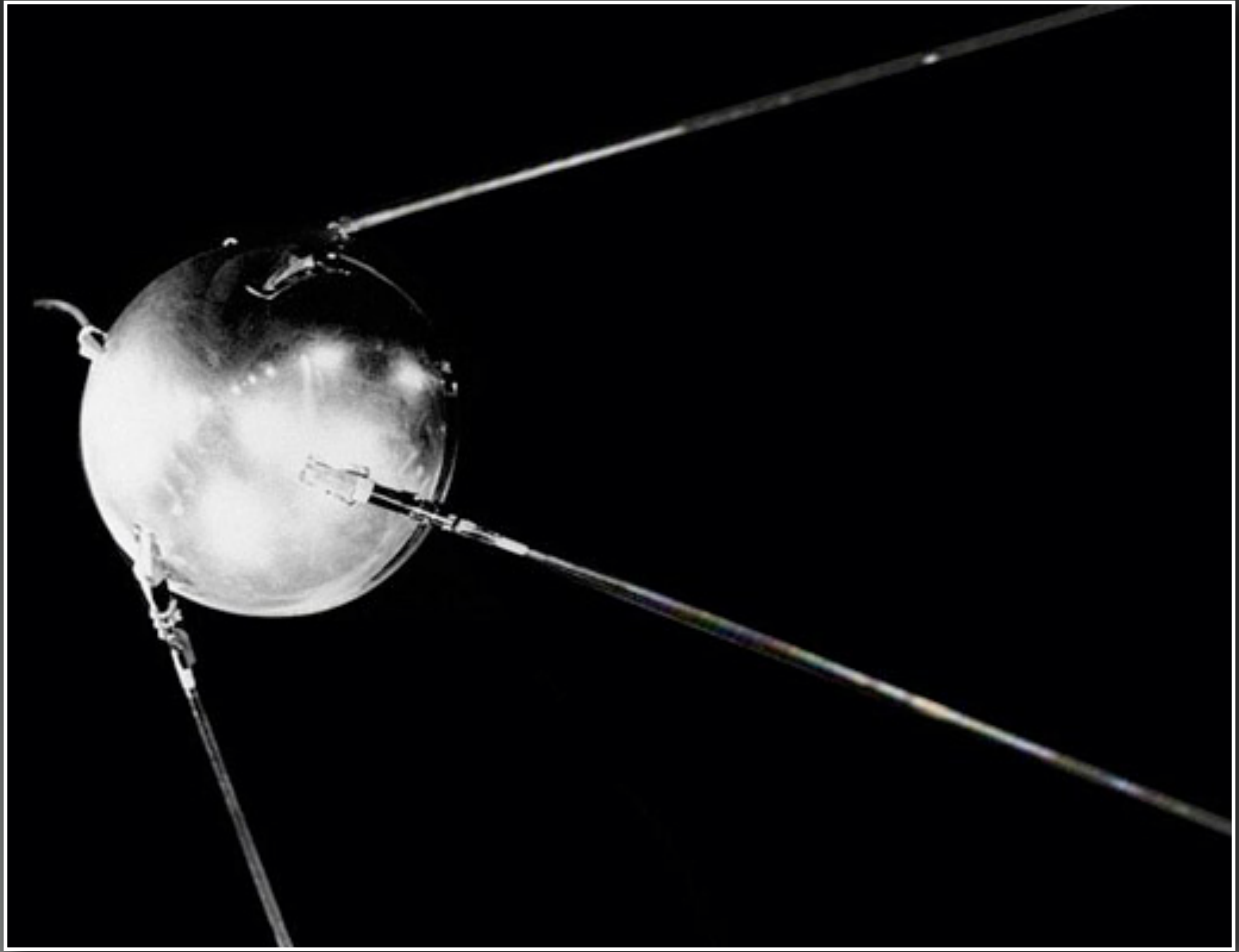
Hans Kristensen, Matt Korda, and Robert Norris, Nuclear Notebook, Federation of American Scientists and thebulletin.org/nuclear-risk/nuclear-weapons/nuclear-notebook/

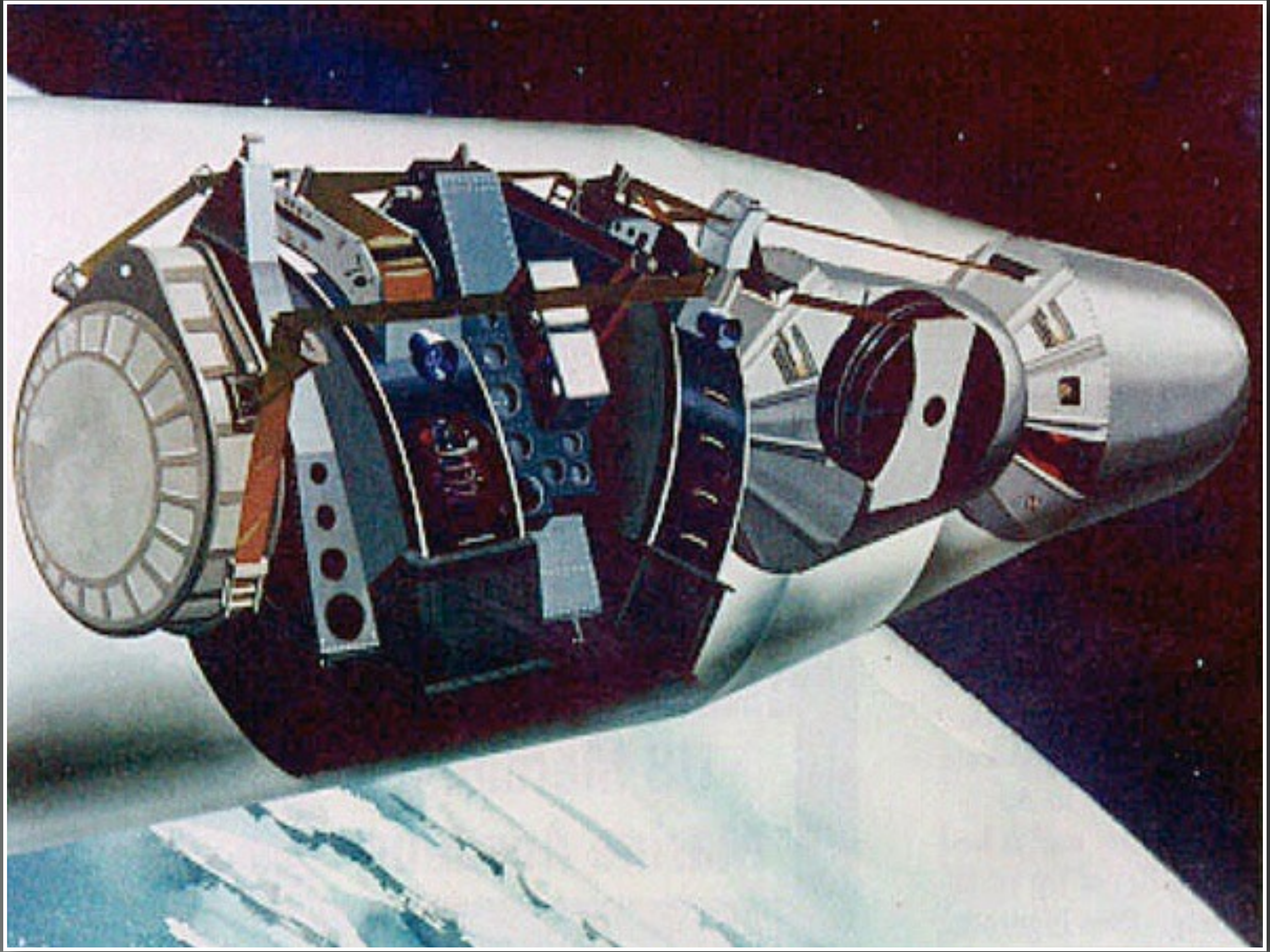
THE PAST

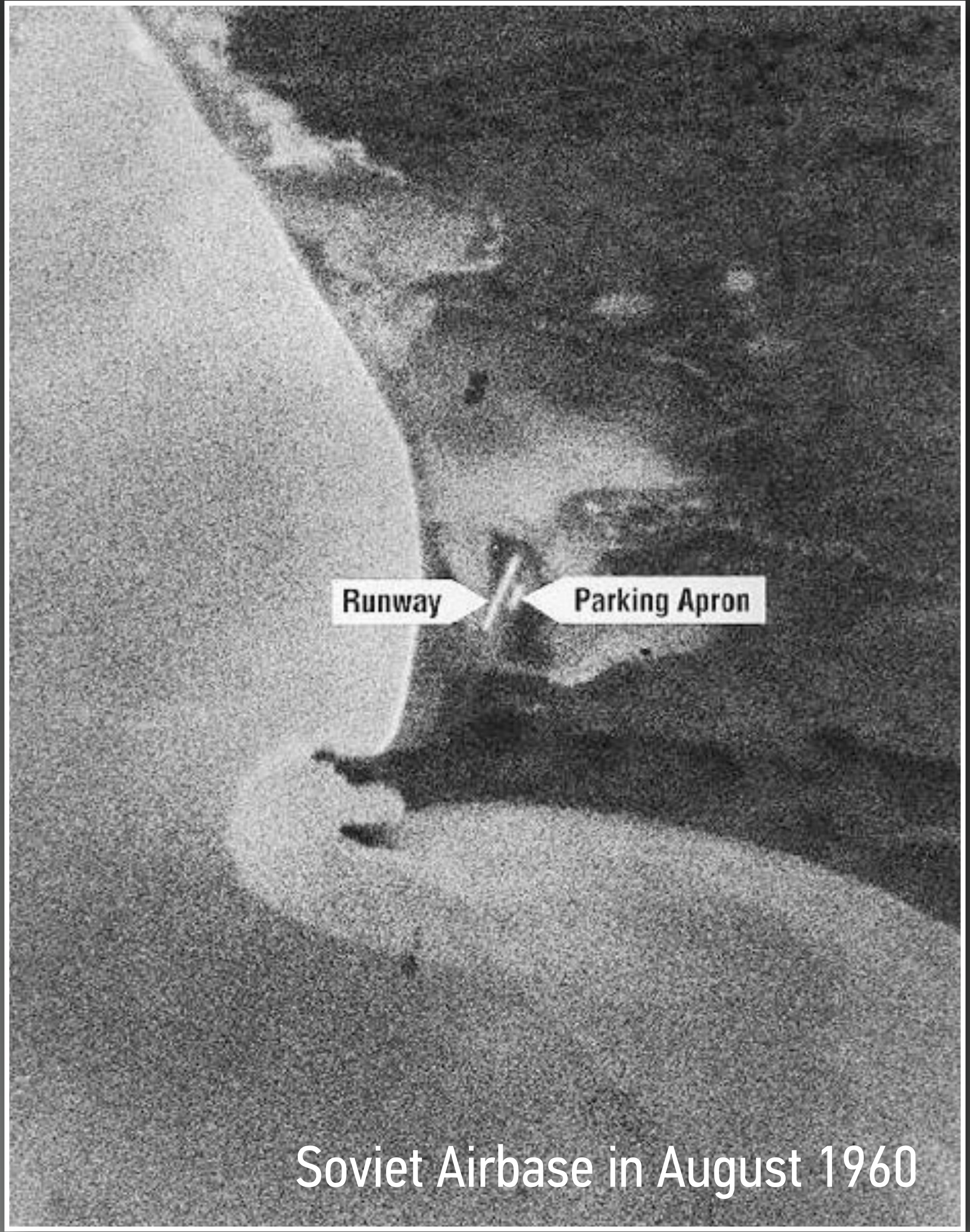
THE ERA OF “NATIONAL TECHNICAL MEANS”

“THE GAME CHANGER”

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







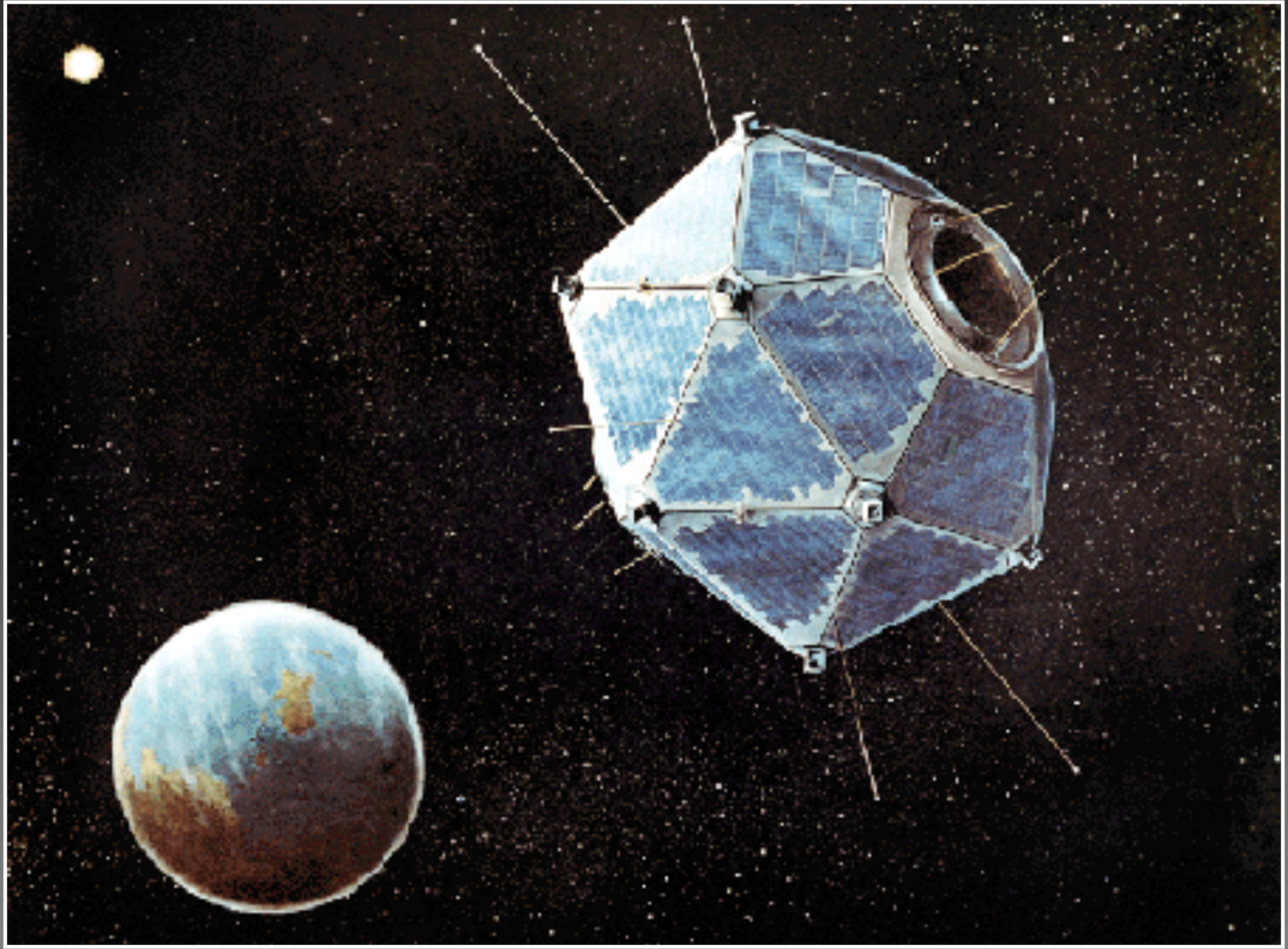
Soviet Airbase in August 1960

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)

STRATEGIC ARMS LIMITATION TALKS (SALT)

FIRST ROUND (1969–1972): THE INTERIM AGREEMENT ("SALT I") AND THE ABM TREATY

BACKGROUND

Upon signing the NPT in July 1968, President Johnson announced that the United States and the Soviet Union would begin discussions on "the limitation and the reduction of both strategic offensive and defensive systems."

In May 1972, signature of two basic SALT I documents: an Interim Agreement (SALT I) and the ABM

SCOPE

Under the Interim Agreement (SALT I), the parties undertake to "freeze" the number of ICBM and SLBM launchers at their current levels at the time (and for a period of five years)

Under the ABM, the parties undertake "not to deploy ABM systems for a defense of the territory of its country"

Source: Richard Nixon Foundation & Library (top) and U.S. Air Force (bottom)

VERIFYING "SALT I" AND THE ABM TREATY

Article V (SALT I) and Article XII (ABM)

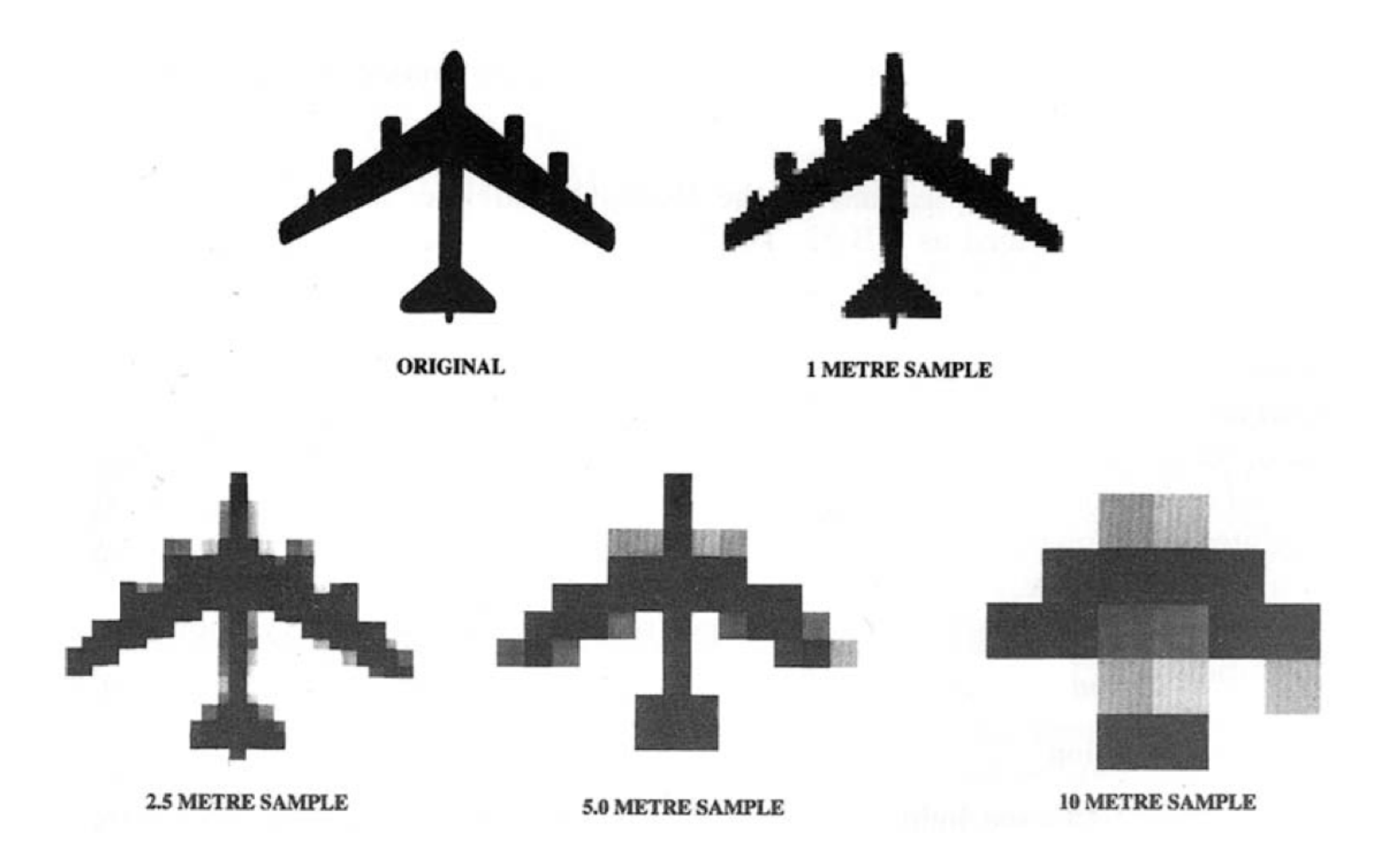
1. For the purpose of providing assurance of compliance with the provisions of this [Interim Agreement], each Party shall use national technical means of verification at its disposal in a manner consistent with generally recognized principles of international law.
2. Each Party undertakes not to interfere with the national technical means of verification of the other Party operating in accordance with paragraph 1 of this Article.
3. Each Party undertakes not to use deliberate concealment measures which impede verification by national technical means of compliance with the provisions of this [Interim Agreement]. This obligation shall not require changes in current construction, assembly, conversion, or overhaul practices.

media.nti.org/documents/salt_1.pdf and media.nti.org/documents/abm_treaty.pdf

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

RESOLUTION OF SATELLITE IMAGERY



Resolution scales with diameter of the lens and inversely with altitude

(e.g. 8 cm resolution for a 2.4 m lens and an altitude of 300 km)

Source: B. Jasani and G. Stein, *Commercial Satellite Imagery. A Tactic in Nuclear Weapon Deterrence,* Springer, 2002 (left) and Google Earth (Right)

Donald J. Trump @realDonaldTrump · Aug 30, 2019

The United States of America was not involved in the catastrophic accident during final launch preparations for the Safir SLV Launch at Semnan Launch Site One in Iran. I wish Iran best wishes and good luck in determining what happened at Site One.

twitter.com/realDonaldTrump/status/1167493371973255170 (account currently suspended) more recent past &

THE PRESENT

THE ERA OF ONSITE INSPECTIONS

INTERMEDIATE NUCLEAR FORCES (INF) TREATY

(1988–2019)

SCOPE

Source: White House Photographic Office

Eliminated all ground-launched ballistic and cruise missile (and their launchers) with ranges between 500 km and 5,500 km

Treaty banned missiles tipped with both nuclear and conventional warheads, but did not cover air-launched and sea-launched missiles

ALLEGATIONS

Source: Pavel Golovkin/AP

Since 2014, the United States had been accusing Russia of violating the treaty by testing a ground-launched cruise missile to intermediate range

The missile was later identified as the 9M729

Russia too accused the United States of violating the treaty by deploying Mark 41 Vertical Launching Systems (Mk 41 VLS) in Eastern Europe

COLLAPSE

Source: fr.usembassy.gov

The United States withdraws from the INF Treaty in August 2019 after formally announcing its decision to do so in February 2019

President Trump first mentioned intention to withdraw in October 2018; according to Article XV of the treaty, withdrawal takes effect six months after giving formal notice of the party's decision to withdraw

VERIFYING THE INF TREATY

ONSITE INSPECTIONS


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

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

Nuclear Instruments and Methods in Physics Research A299 (1990) 559–561
North-Holland

A fast-neutron detector used in verification of the INF Treaty

Ronald I. Ewing and Keith W. Marlow
Sandia National Laboratories, Albuquerque, NM 87185, USA

We describe the design and calibration of the neutron-detection equipment used in support of the INF Treaty, and some measurements made on Soviet missiles. The fast-neutron detector, consisting of twelve ^3He gas proportional tubes in a cadmium-covered polyethylene moderator, produces about 67 counts/s in a flux of neutrons from ^{252}Cf equal to 1 neutron/cm^2 s. This detector is used to determine the spatial pattern of neutrons emitted from the nuclear warheads on the missiles.

1. Introduction

The INF Treaty [1] provides for the use of radiation detection devices to assure that a Soviet SS-20 missile (a treaty-limited item) is not contained in the canister of a SS-25 missile (not treaty-limited) located at a former SS-20 base. The Treaty created the Special Verification Commission (SVC) to work out details of the Treaty, including the use of radiation detection devices. The SVC reached agreement on the use of a detector of fast neutrons and a pattern of measurements to be made outside the canister containing the missile. Neutrons are produced by spontaneous fission in the plutonium of the nuclear warheads, located in the re-entry vehicles on the missiles. The SS-25 carries one warhead and the SS-20 has three. Cooperative measurements (the Benchmark) were performed in the Soviet Union using the neutron detector described here to determine the spatial pattern of neutrons from each of the two missile types.

2. Detector design

The SVC agreement called for the measurement of the neutron pattern using a single channel of neutron detection. The neutron detector had to be easily portable, small enough to resolve the spatial pattern of the neutrons, and sufficiently sensitive to accomplish this measurement in a reasonable amount of time. Neutrons are emitted from the plutonium with a continuous energy distribution of average energy about 2 MeV (fission spectrum). This energy distribution will be considerably modified by neutron scattering in the materials of the warhead and the missile, particularly the hydrogen in the high explosive of the warhead. Calculations indicate that a sizeable fraction of the neutrons outside the re-entry vehicle will be "fast" (energy greater than the "cadmium cutoff", about 0.3 eV).

The principal elements of the neutron detector are shown in fig. 1. The twelve ^3He gas tubes are inserted into the polyethylene moderator, whose dimensions are $25.4 \times 29.5 \times 6.35$ cm. Fast neutrons are slowed to thermal energy in the moderator by elastic collisions, principally with hydrogen. These thermal neutrons can be detected by the ^3He (n, p) reaction in the gas proportional counter tubes, which are nominally 2.5 cm in diameter, 25 cm in active length, and filled with ^3He to a pressure of 10 atm. The tubes are inserted into holes drilled through the 29.5 cm length of the polyethylene block. A cadmium cover, 0.08 cm thick, surrounds the detector to capture externally produced thermal neutrons. This arrangement of moderator and tubes was designed, on the basis of earlier studies, to produce an

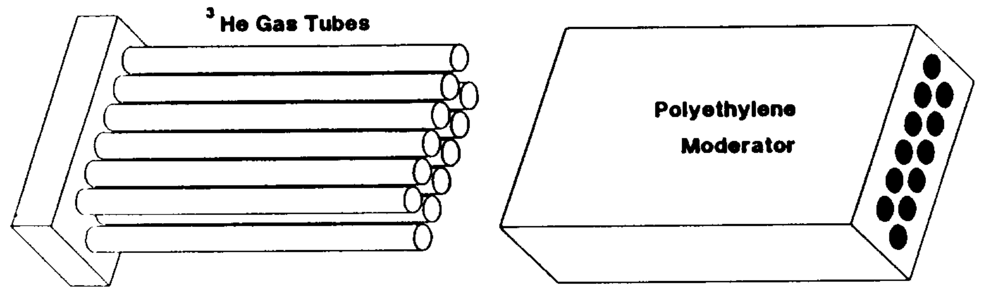


Fig. 1. Neutron detector.

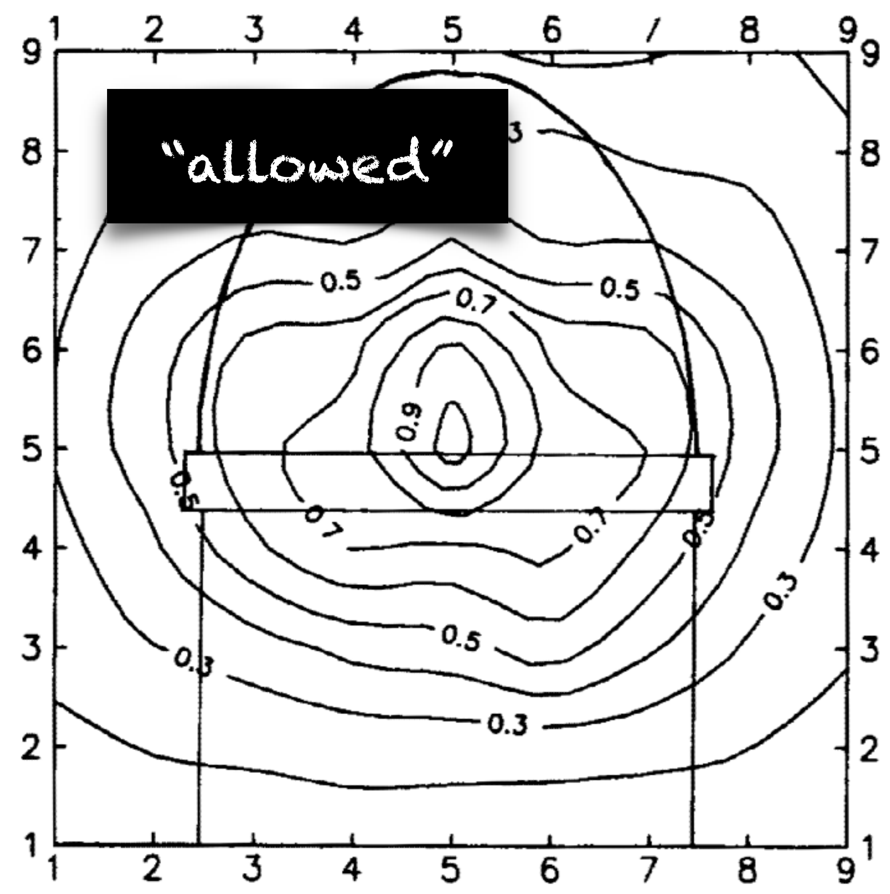


Fig. 2. Neutron flux contours, SS-25 missile simulation.

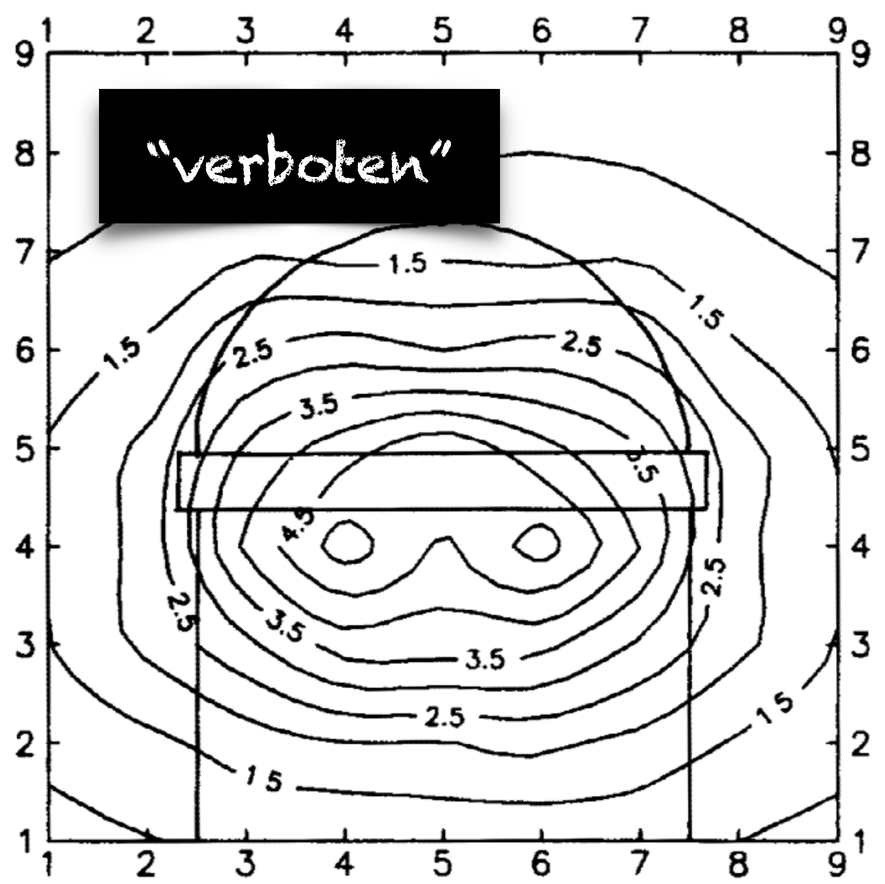
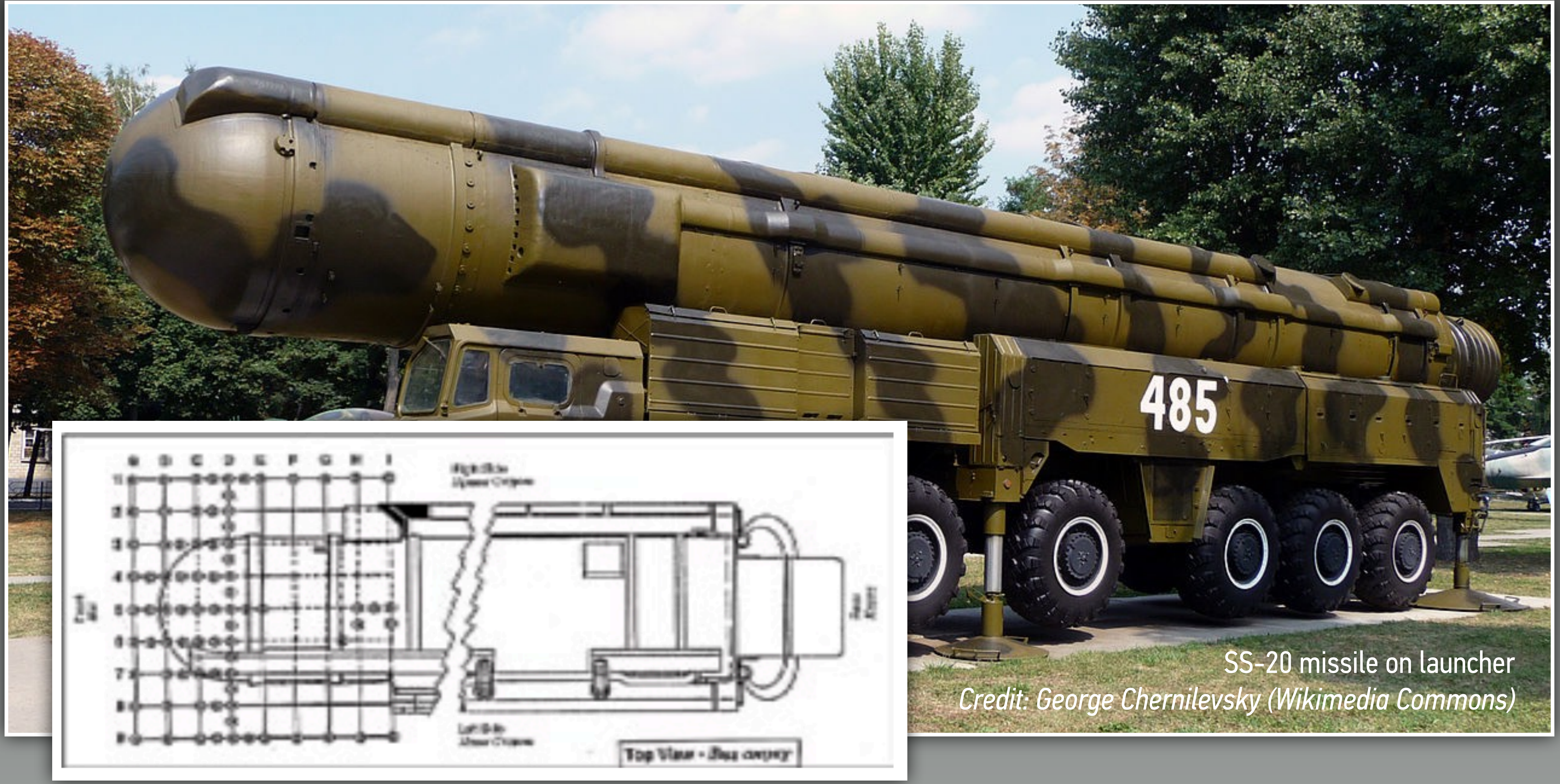


Fig. 3. Neutron flux contours, SS-20 missile simulation.



R. I. Ewing and K. W. Marlow, "A Fast-neutron Detector Used in Verification of the INF Treaty," *Nuclear Instruments and Methods in Physics Research,* A299, 1990
Radiation Detection Equipment: An Arms Control Verification Tool, Product No. 211P, Defense Threat Reduction Agency, October 2011

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

Both sides met this target early

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

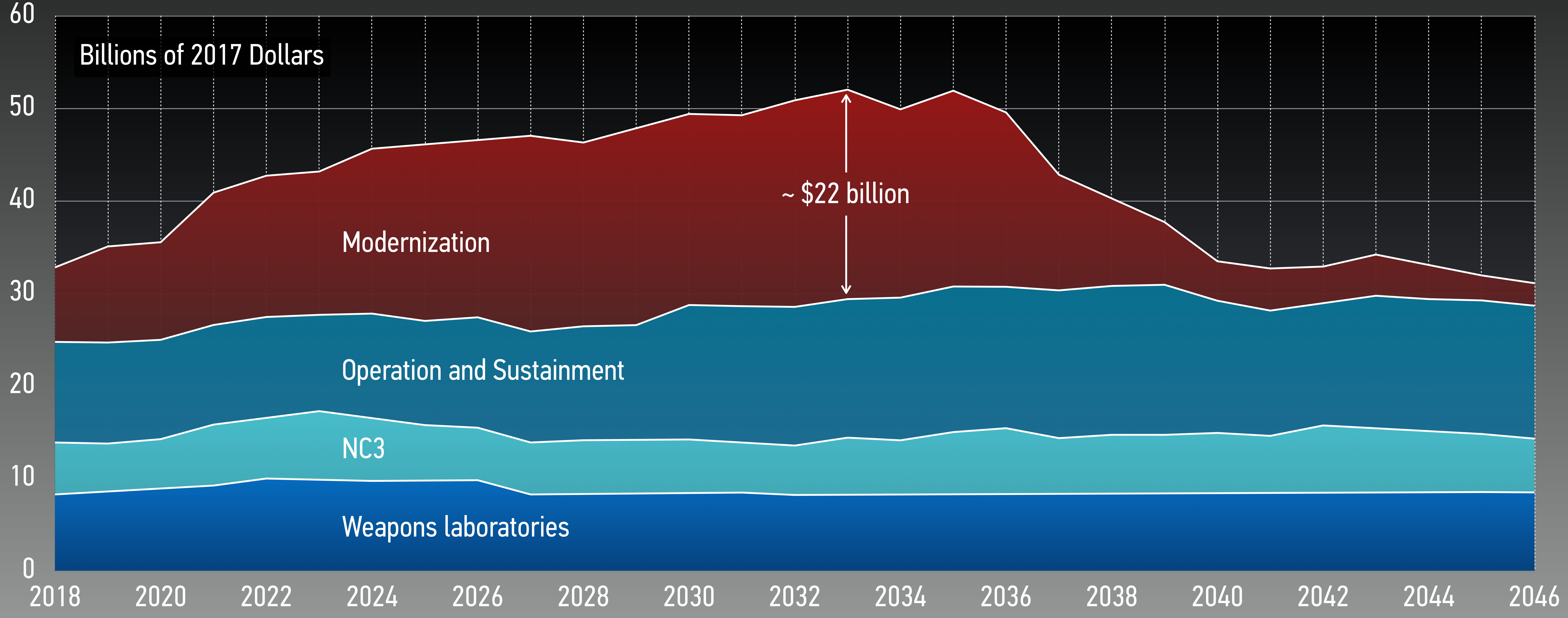
Edward Ifft, "Verification Lessons Learned from the INF, START I, and New START Treaties," *55th Annual INMM Meeting,* July 2014

SO WHAT?

WHAT IS NEW HERE AND WHY DOES IT MATTER?

(skip)

COSTS OF U.S. NUCLEAR FORCES, 2018–2046



Source: *Approaches for Managing the Costs of U.S. Nuclear Forces, 2017 to 2046*, Congressional Budget Office, October 2017, www.cbo.gov/publication/53211

TECHNOLOGIES ON THE HORIZON

NEW TYPES OF DELIVERY SYSTEMS

In addition to replacing and modernizing existing weapon systems, new types of weapons and delivery systems are being introduced by several nuclear weapon states; these include, in particular, hypersonic weapons and various "exotic" Russian systems

NEXT-GENERATION ("EMERGING") TECHNOLOGIES

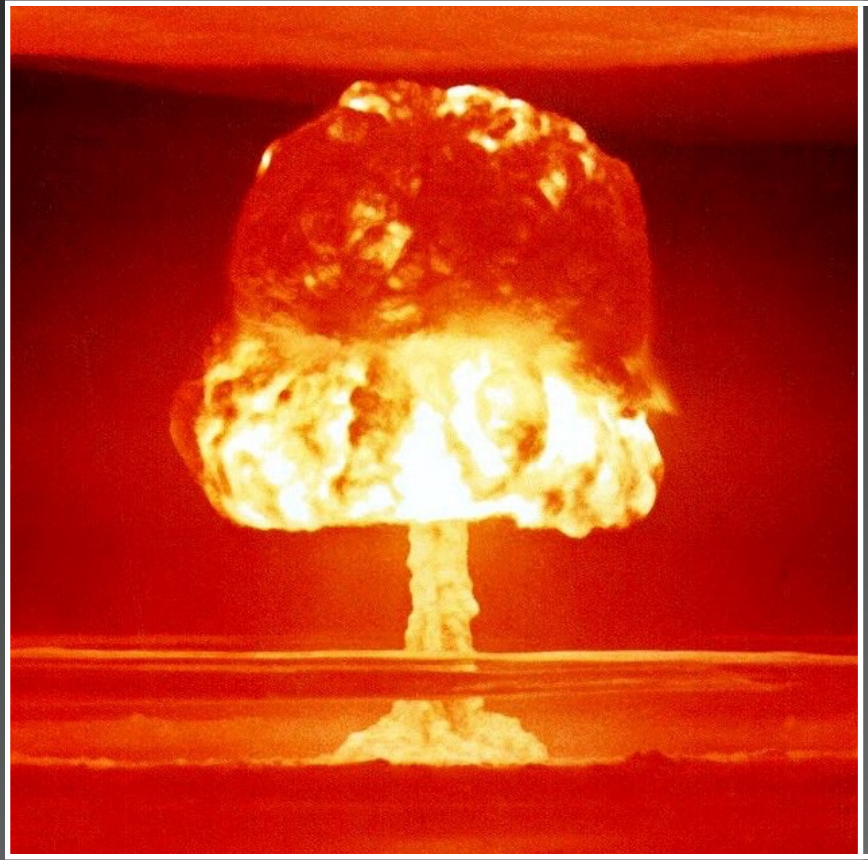
Pinpoint accuracy without relying on global navigation satellite systems (GNSS)

Space-based weapons systems may have a "come back"

Autonomous weapons systems … conventional for now, but potentially dual capable

Source: U.S. Department of Defense (top) and NASA/JPL-Caltech (bottom)

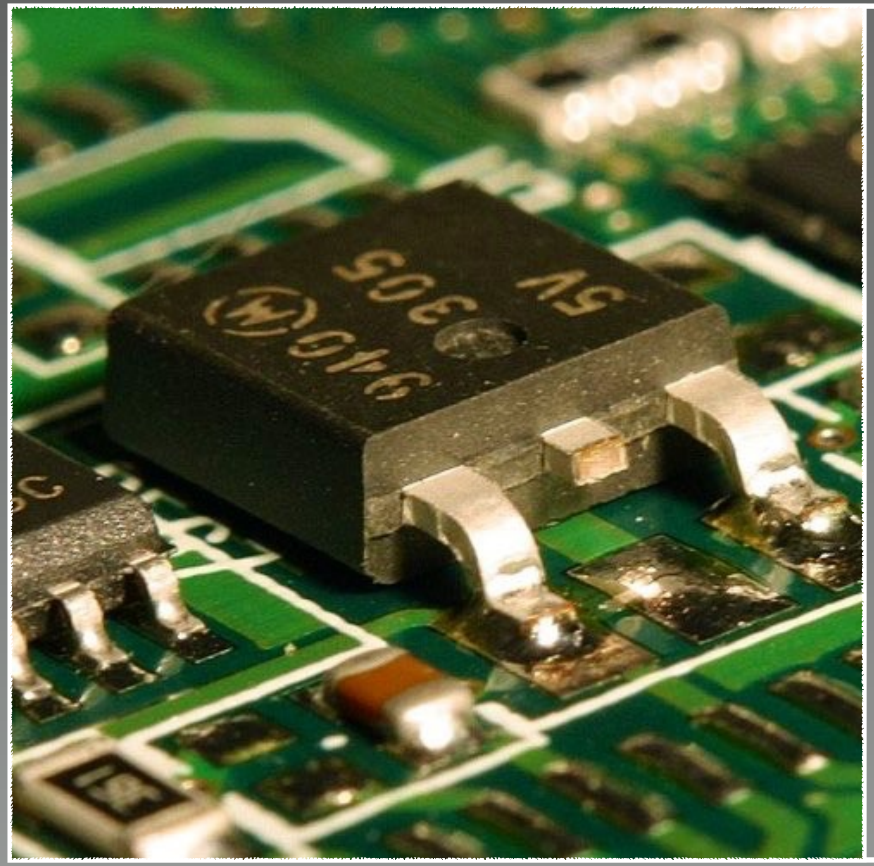
NEW ~~TECHNOLOGIES~~ risks & vulnerabilities



NUCLEAR WEAPONS MAY BE PERCEIVED AS “MORE USABLE”

Nuclear weapons with lower yield (5–7 kt) delivered with “pinpoint” accuracy
Belief that missile defenses may be effective against an adversary’s retaliatory strike

2018 Nuclear Posture Review expanded conditions for possible nuclear weapons use



CYBER VULNERABILITIES

Nuclear weapons and related systems predate digital electronics and are “tightly coupled”
Several types of systems may be exposed to attack (via network, supply chain, etc.)

Modern cyber threats further increases the risk of miscommunication and miscalculation

Source: Castle Bravo (top) and wikimedia.org/pdphoto.org (bottom)

Despite the remarkable achievements and steady growth of monitoring, data processing and analytical capabilities there are trends in weapon system development which if allowed to continue will outrun the ability of technology to monitor them.

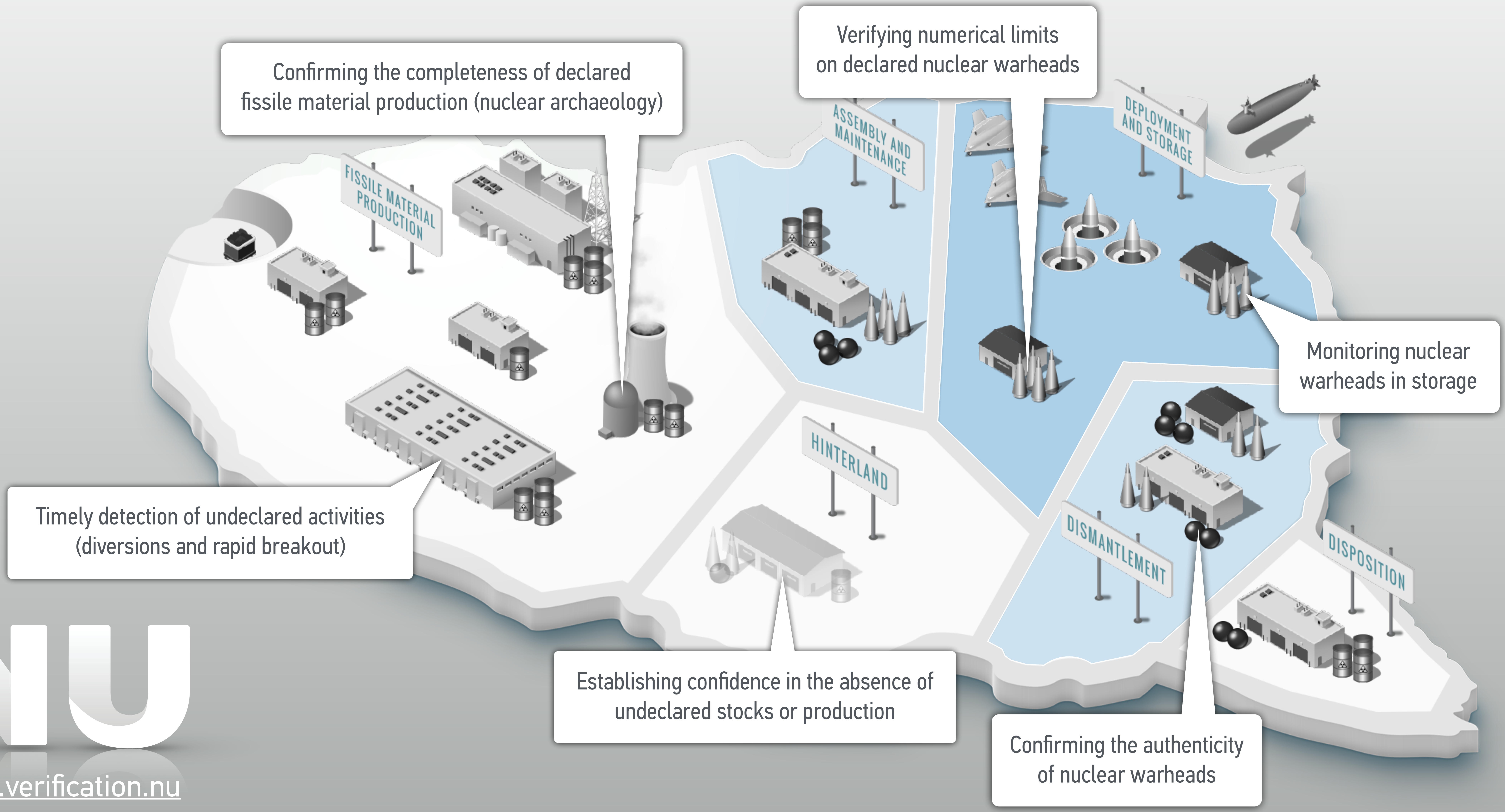
Allan S. Krass, 1985, Proposition #11

THE FUTURE

"MORE AWARENESS & CONFIDENCE WITH LESS ACCESS"

GRAND VERIFICATION CHALLENGES

FOR NUCLEAR ARMS CONTROL AND DEEP(ER) CUTS IN THE ARSENALS



NU

www.verification.nu

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

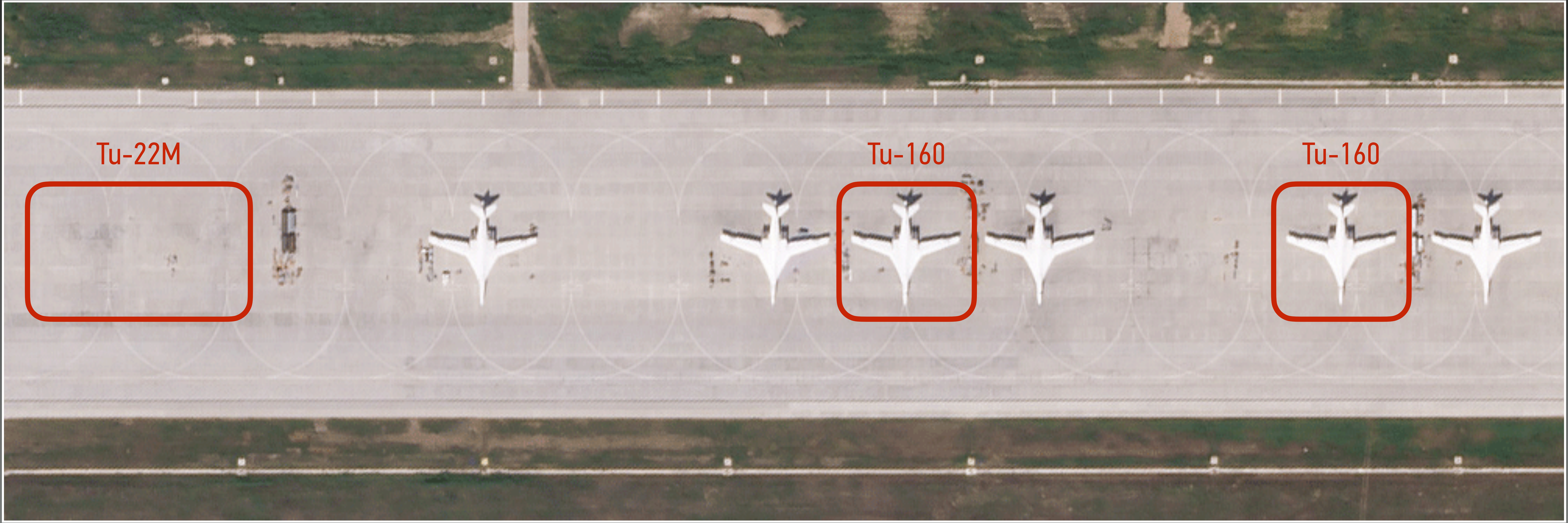
How can the two presidents make the best of their one shot at setting the nuclear table? I have some advice for them: Keep it simple.

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

Photo credit: NATO

"SATELLITE IMAGERY 2.0"

QUASI-REALTIME SATELLITE IMAGERY MAY ENABLE "PATTERN OF LIFE" ANALYSIS



Six images captured between August 18, 2018 and August 21, 2018 show the movement of the Tupolev Tu-22M (Backfire) and Tupolev Tu-160 (Blackjack) bombers on the flight line of Engels Air Base, Russia

Sub-daily rapid revisit capability (for SkySat, up to 12 times per day; global average of 7 times per day) may allow "pattern of life" analysis

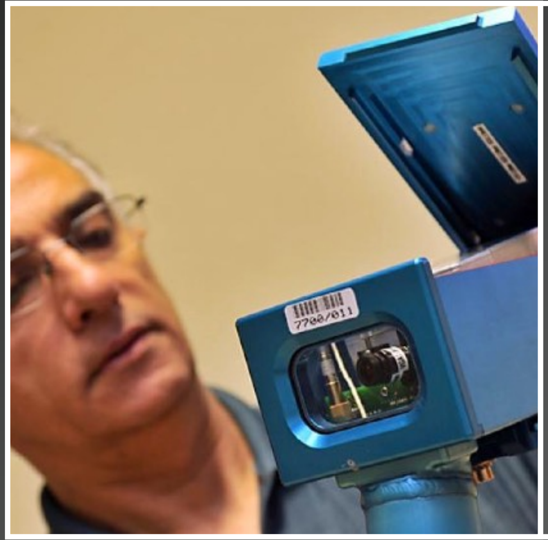
www.planet.com/pulse/what-is-rapid-revisit-and-why-does-it-matter and www.planet.com/pulse/12x-rapid-revisit-announcement

HIGH-DEFINITION VIDEO FROM SPACE

Posted in February 2014, www.youtube.com/watch?v=BsW6IGc4tt0; Skybox Imaging later became Terra Bella, now Planet (Google)

"THINKING OUTSIDE THE BOX"

DEVELOPING ALTERNATIVES TO ONSITE INSPECTIONS FOR (SENSITIVE) FACILITIES



UNATTENDED (REAL-TIME) MONITORING OF NUCLEAR FACILITIES

Opportunities for real-time monitoring of nuclear fuel-cycle facilities
(relevant, in particular, for strengthened IAEA safeguards in uranium enrichment plants)

STANDOFF DETECTION AND (PERHAPS) PERIMETER CONTROL

For facilities where access is initially considered too intrusive, nearby or regional sensors could provide reassurance of compliance; alternatively, concept of "deferred verification" excludes facilities from inspection*

NEVER ACQUIRE SENSITIVE INFORMATION WHEN ONSITE INSPECTIONS ARE NECESSARY

Simplicity and non-intrusiveness as guiding principles (for example, passive systems are preferable to active ones)
Accept "items declared as weapons" and use "absence measurements" (as introduced in START/New START)

*Pavel Podvig and Jospeh Rodgers, Deferred Verification, *Nonproliferation Review*, 26 (3–4), 2019

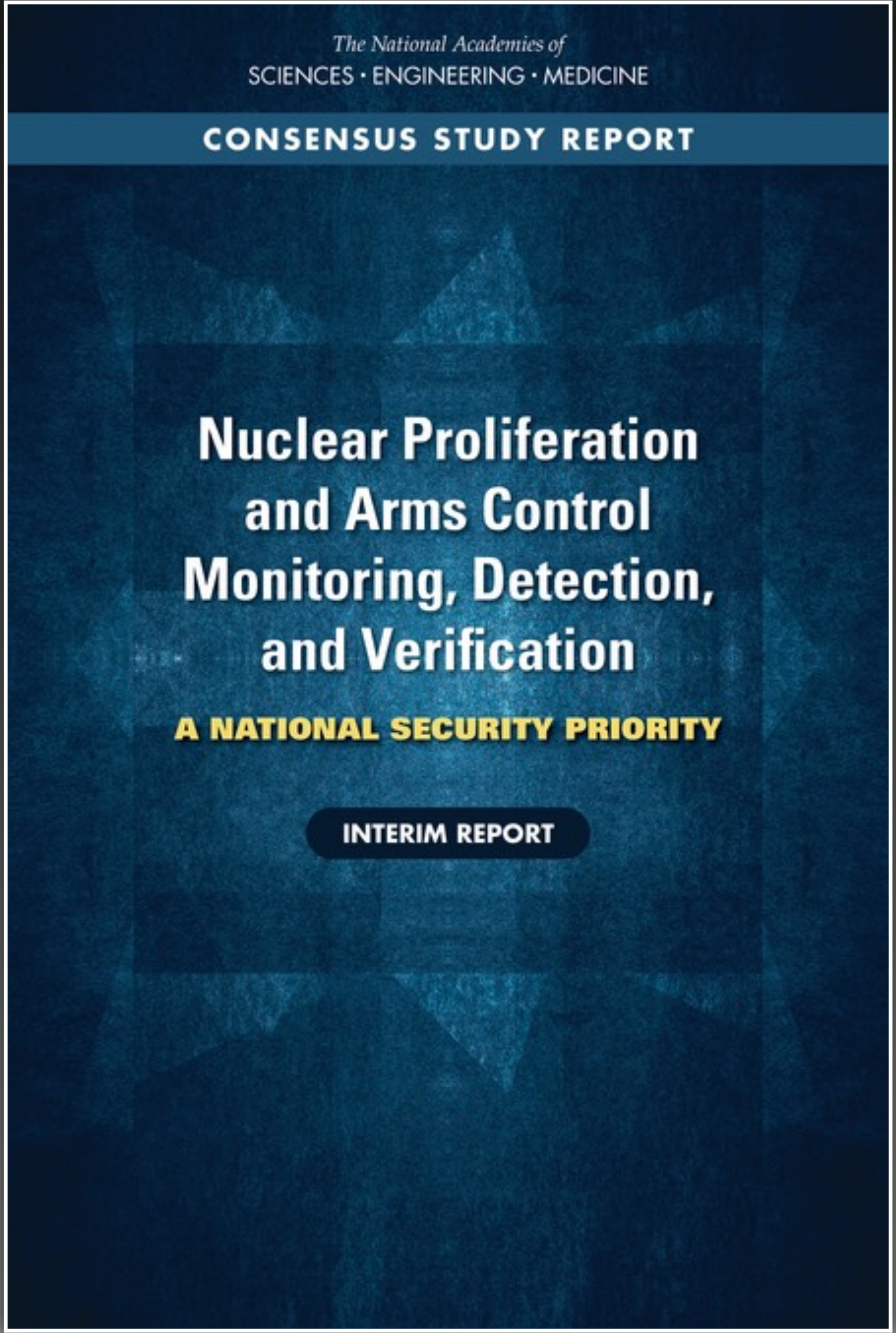
Can we (physical) “separate” host & inspector?

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

Can we remotely follow certain (allowed) activities that the host performs ?

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

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

A PATH FORWARD

FOR NUCLEAR DISARMAMENT VERIFICATION

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

RE-IMAGINING NUCLEAR DISARMAMENT VERIFICATION

Explore verification approaches that minimize the need of access to sites and treaty accountable items or avoid measurements on those; consider approaches that offer "on-ramps," i.e., that start off simple and can accommodate "upgrades" later on

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