Nuclear arms control and verification overview

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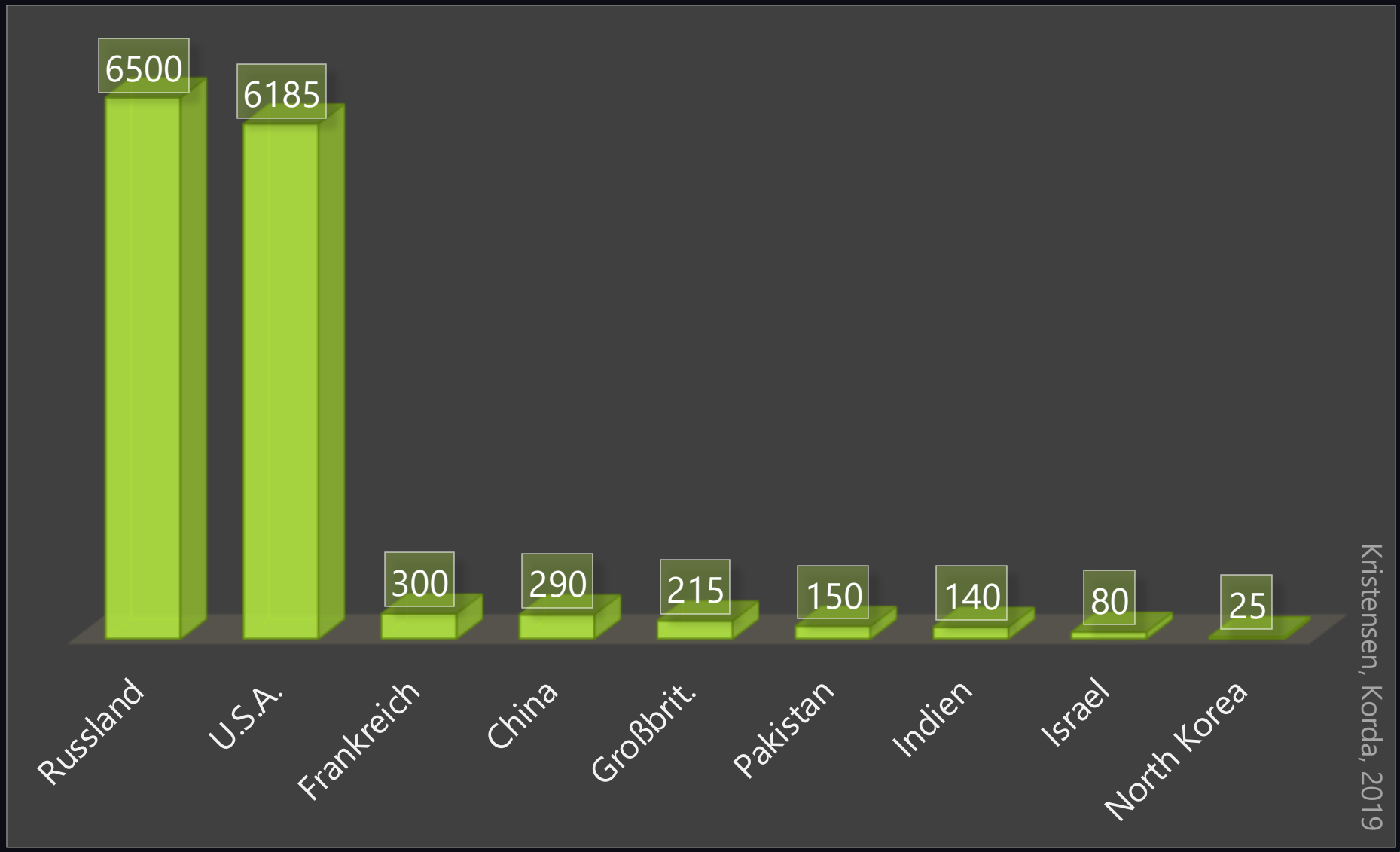
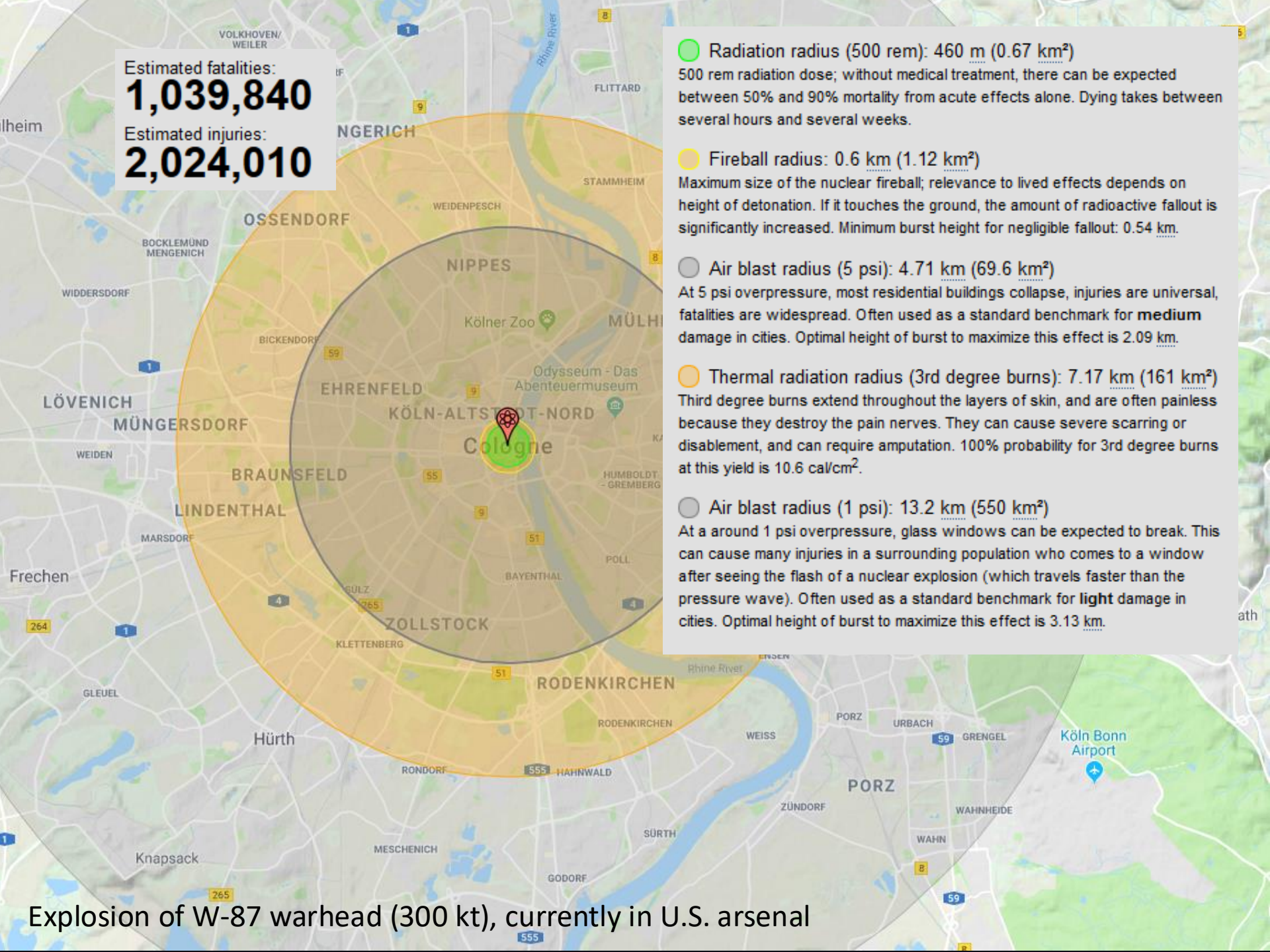
TECHNISCHE
UNIVERSITÄT
DARMSTADT

„We need to move back from the nuclear brink!“

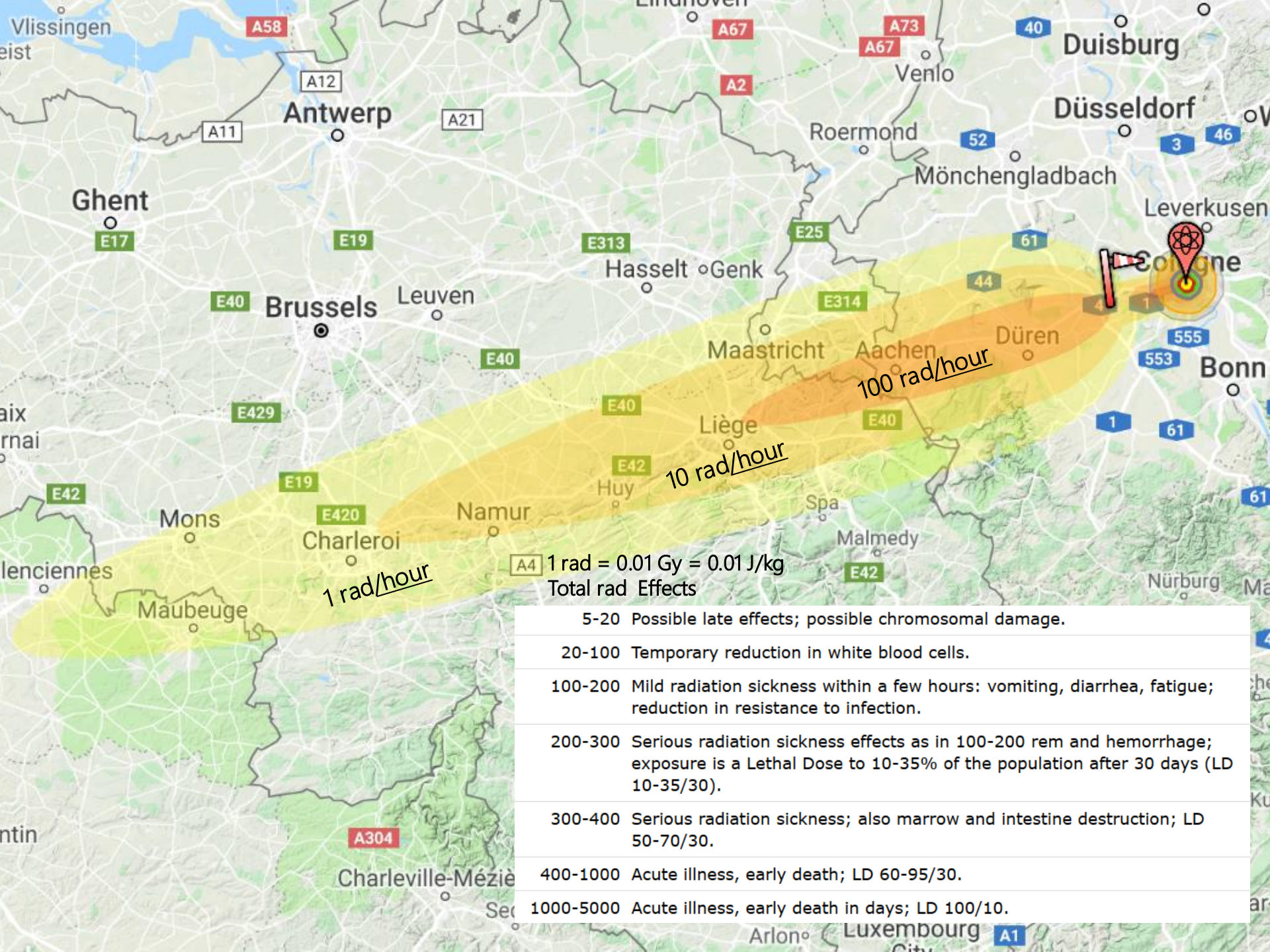
Nuclear threats and risks

Nuclear weapon states





Explosion of W-87 warhead (300 kt), currently in U.S. arsenal

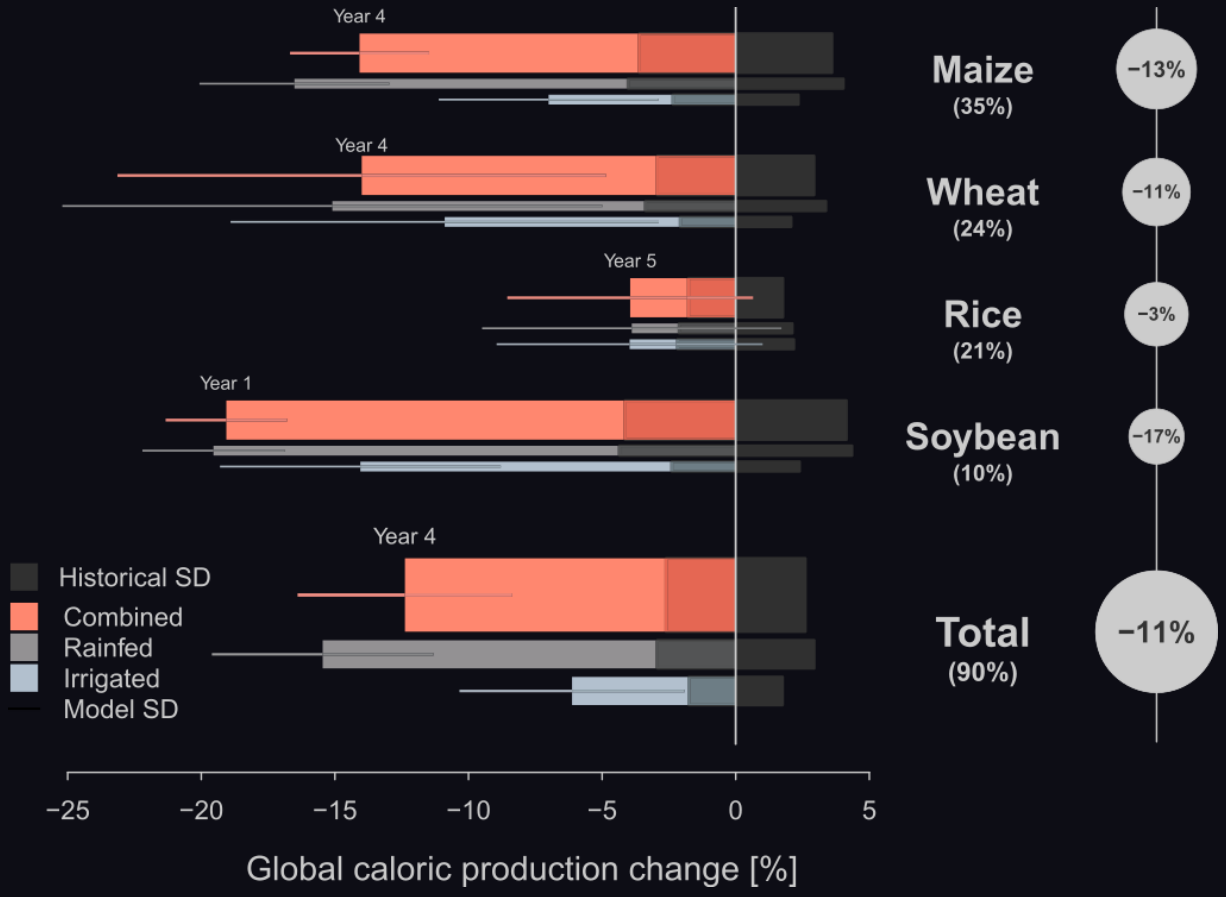


Total rad Effects

5-20	Possible late effects; possible chromosomal damage.
20-100	Temporary reduction in white blood cells.
100-200	Mild radiation sickness within a few hours: vomiting, diarrhea, fatigue; reduction in resistance to infection.
200-300	Serious radiation sickness effects as in 100-200 rem and hemorrhage; exposure is a Lethal Dose to 10-35% of the population after 30 days (LD 10-35/30).
300-400	Serious radiation sickness; also marrow and intestine destruction; LD 50-70/30.
400-1000	Acute illness, early death; LD 60-95/30.
1000-5000	Acute illness, early death in days; LD 100/10.

Nuclear winter:
The myth of limited nuclear war

India vs. Pakistan



27,000,000 direct deaths

255,000,000 deaths from nuclear winter within 2 years

J. Jägermeyr et al., *PNAS* 117.13, 2020
L. Xia, Nat. Food 3, 2022

Nuclear threats and risks

"The United States would only consider the employment of nuclear weapons in extreme circumstances to defend the vital interests of the United States, its allies, and partners." (2018 U.S. Nuclear posture review)

"The Russian Federation shall reserve the right to use nuclear weapons in response to the use of nuclear and other types of weapons of mass destruction against it and/or its allies, as well as in the event of aggression against the Russian Federation with the use of conventional weapons when the very existence of the state is in jeopardy." (The military doctrine of the Russian Federation, 2015)

"China is firmly committed to a nuclear strategy based on self-defence and has upheld its commitment that it would not be the first to use nuclear weapons at any time and under any circumstances and that it would unconditionally refrain from using or threatening to use nuclear weapons against non-nuclear-weapon states or nuclear-weapon-free zones." (Position Paper of the People's Republic of China At the 66th Session of the United Nations General Assembly, 2011)

Close calls

1995

© Blix Dahle, NASA

- Russian missile warning system identified a rocket as a nuclear ballistic missile, on a path from Norway to hit northern Russia.
- Yeltsin was presented the briefcase to authorize a nuclear attack
- Minutes later, it appeared rocket would land beyond Russian territory
- Research rocket to study polar lights

The roles of scientists

"We appeal as human beings to human beings: Remember your humanity, and forget the rest." *

* Russell-Einstein Manifesto, 1955
i.a. Max Born, Albert Einstein, Linus Pauling, Joseph Rotblat, Bertrand Russell, 1955

PHYSIKALISCHE BLÄTTER
13. JAHRGANG 1957/HEFT 5

Die Göttinger Erklärung

Wir fühlen keine Kompetenz, konkrete Vorschläge für die Politik der Großmächte zu machen. Für ein kleines Land wie die Bundesrepublik glauben wir, daß es sich heute noch am besten schützt und den Weltfrieden noch am ehesten fördert, wenn es ausdrücklich und freiwillig auf den Besitz von Atomwaffen jeder Art verzichtet. Jedenfalls wäre keiner der Unterzeichneten bereit, sich an der Herstellung, der Erprobung oder dem Einsatz von Atomwaffen in irgendeiner Weise zu beteiligen.

u.a. O. Hahn, W. Heisenberg, M. von Laue, H. Maier-Leibnitz, C.-F. von Weizsäcker

Pugwash Conferences on Science and World Affairs

- Joseph Rotblat: only Manhattan Project scientist to resign on moral grounds
- Pugwash aims to develop and support the use of scientific, evidence-based policymaking, focusing on areas where nuclear and WMD risks are present
- long-standing tradition of 'dialogue across divides' (Nobel Peace Prize 1995): pioneers of "track 2" dialogue

1957, Pugwash, Canada

2015, Nagasaki, Japan

Science Diplomacy

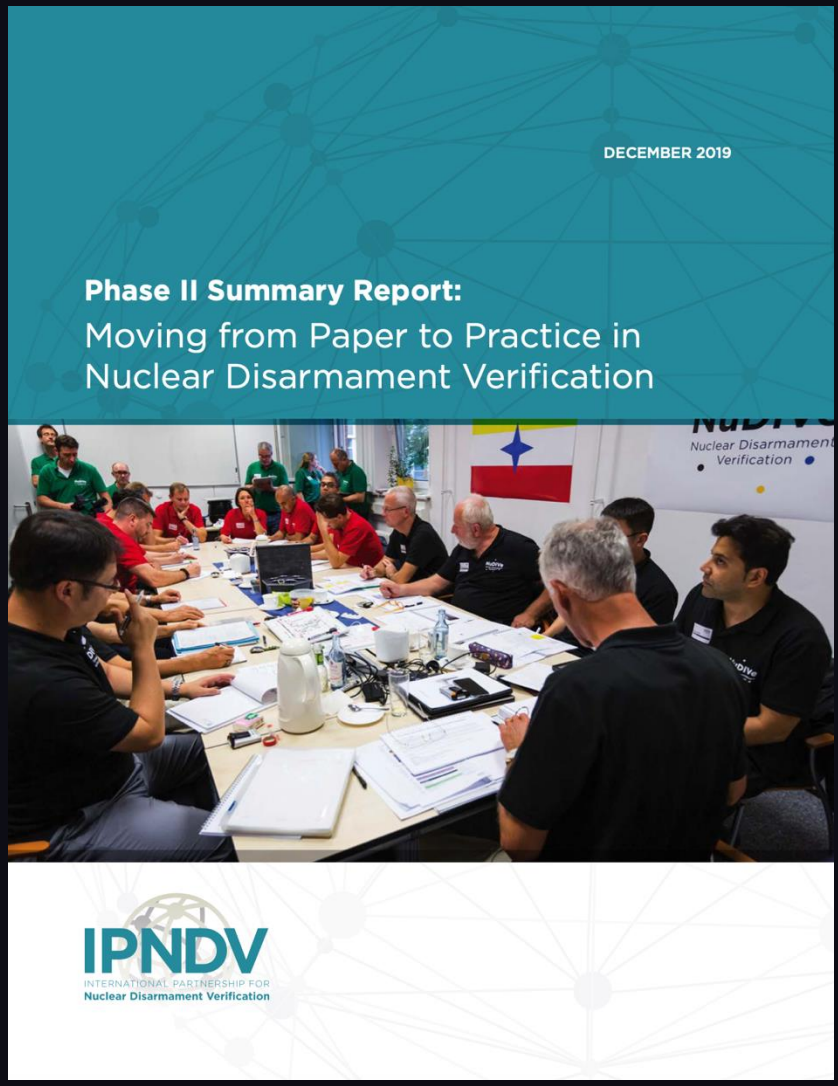
- Diplomacy for Science
  - facilitate international scientific cooperation
- Science for Diplomacy / Science for Peace
  - scientific collaboration to improve international relations (e.g. SESAME synchrotron, Jordan)
- Science in Diplomacy:
  - provide advice to inform and support foreign policy objectives

Science in (Nuclear) Diplomacy: Group of Scientific Experts

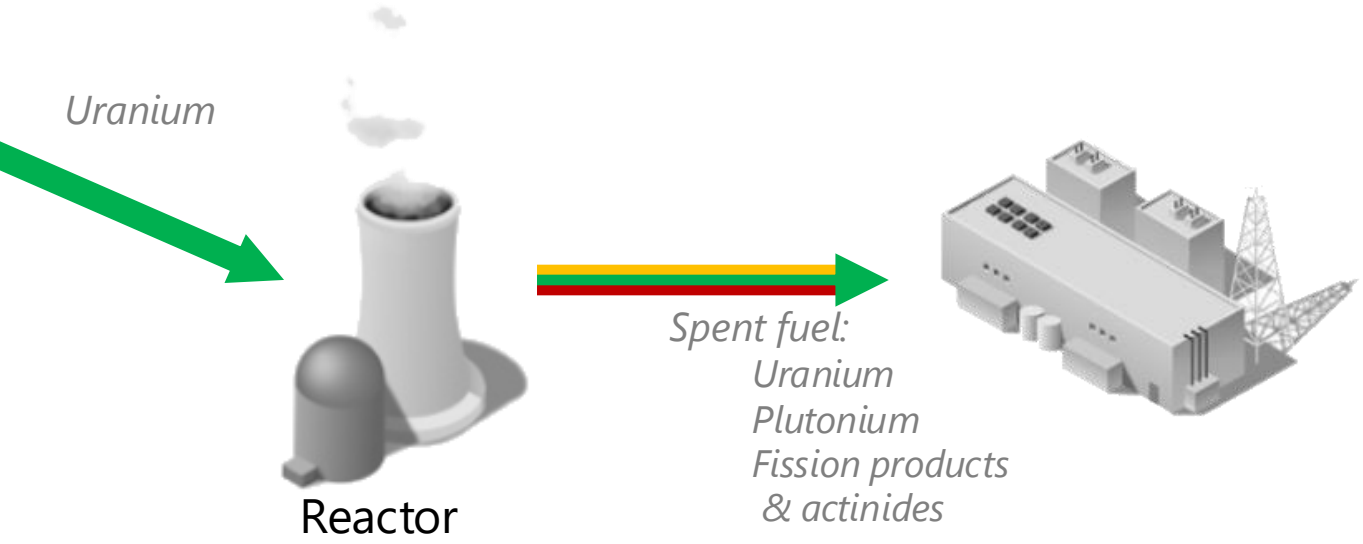
CTBTO Sepctrum 12, 2009

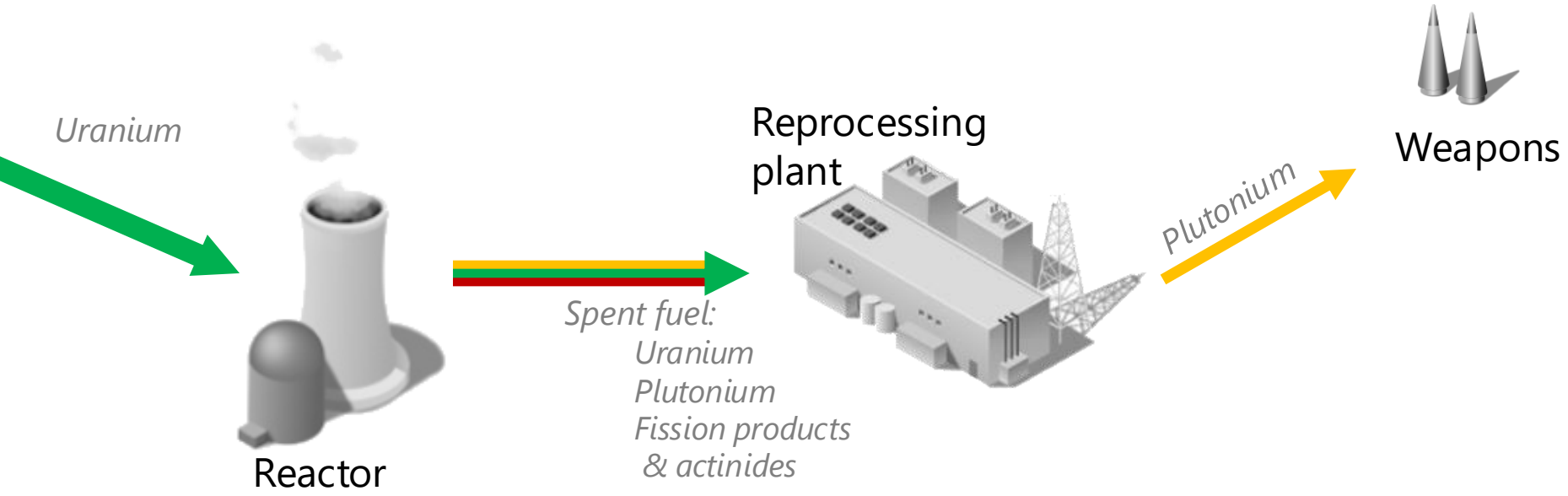
Geneva, 1978

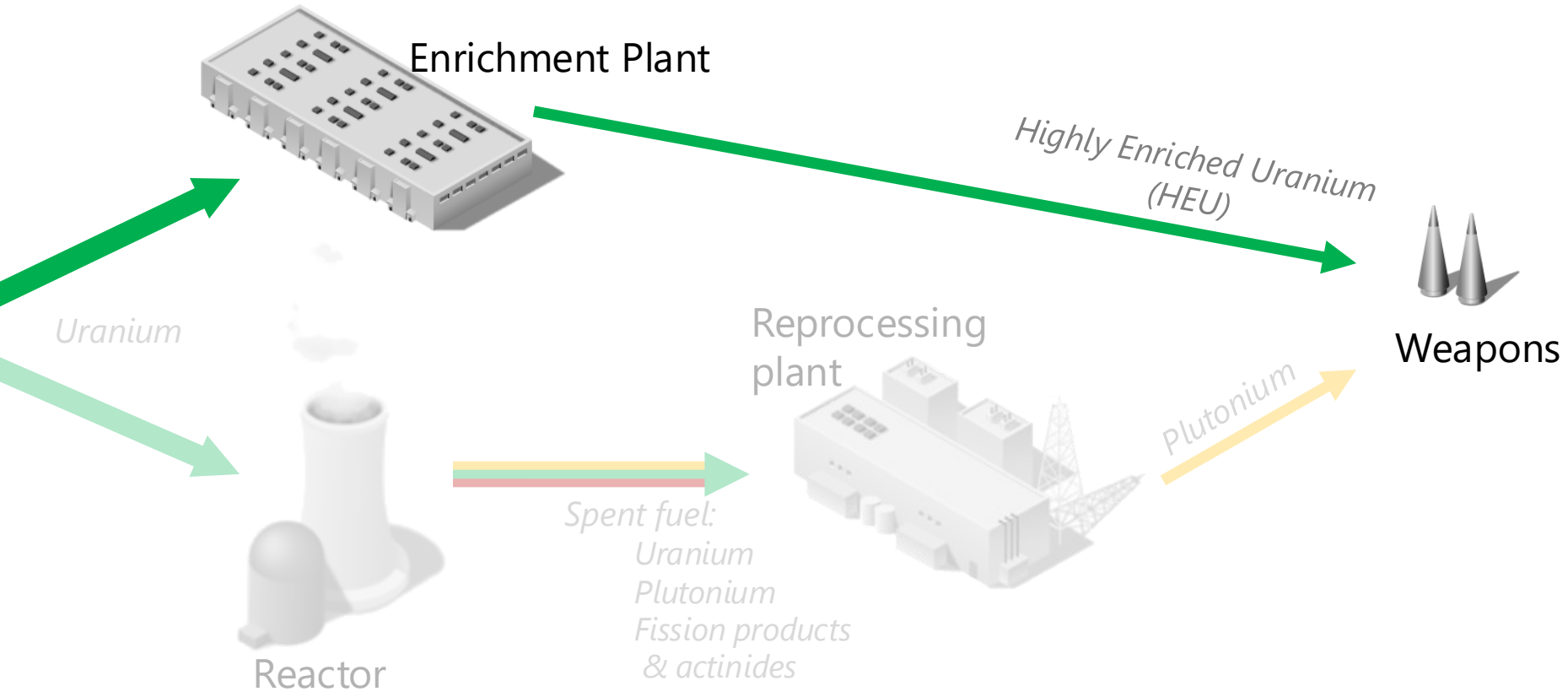
Science in (Nuclear) Diplomacy



Nonproliferation


Uranium
Reactor
Spent fuel:
Uranium
Plutonium
Fission products
& actinides


Uranium
Reactor
Spent fuel:
Uranium
Plutonium
Fission products
& actinides
Reprocessing
plant
Plutonium
Weapons


Enrichment Plant
Highly Enriched Uranium
(HEU)
Uranium
Reprocessing
plant
Weapons
Plutonium
Spent fuel:
Uranium
Plutonium
Fission products
& actinides
Reactor

The Non-Proliferation Treaty 1968

Separation of members into non-nuclear weapon states (NNWS) and nuclear weapon states (NWS), based on whether they had tested weapons before 1967

Articles I/II

- NNWS: not manufacture or acquire nuclear weapons, not to seek assistance
- NWS/NNWS: Not transfer nuclear weapons to NNWS

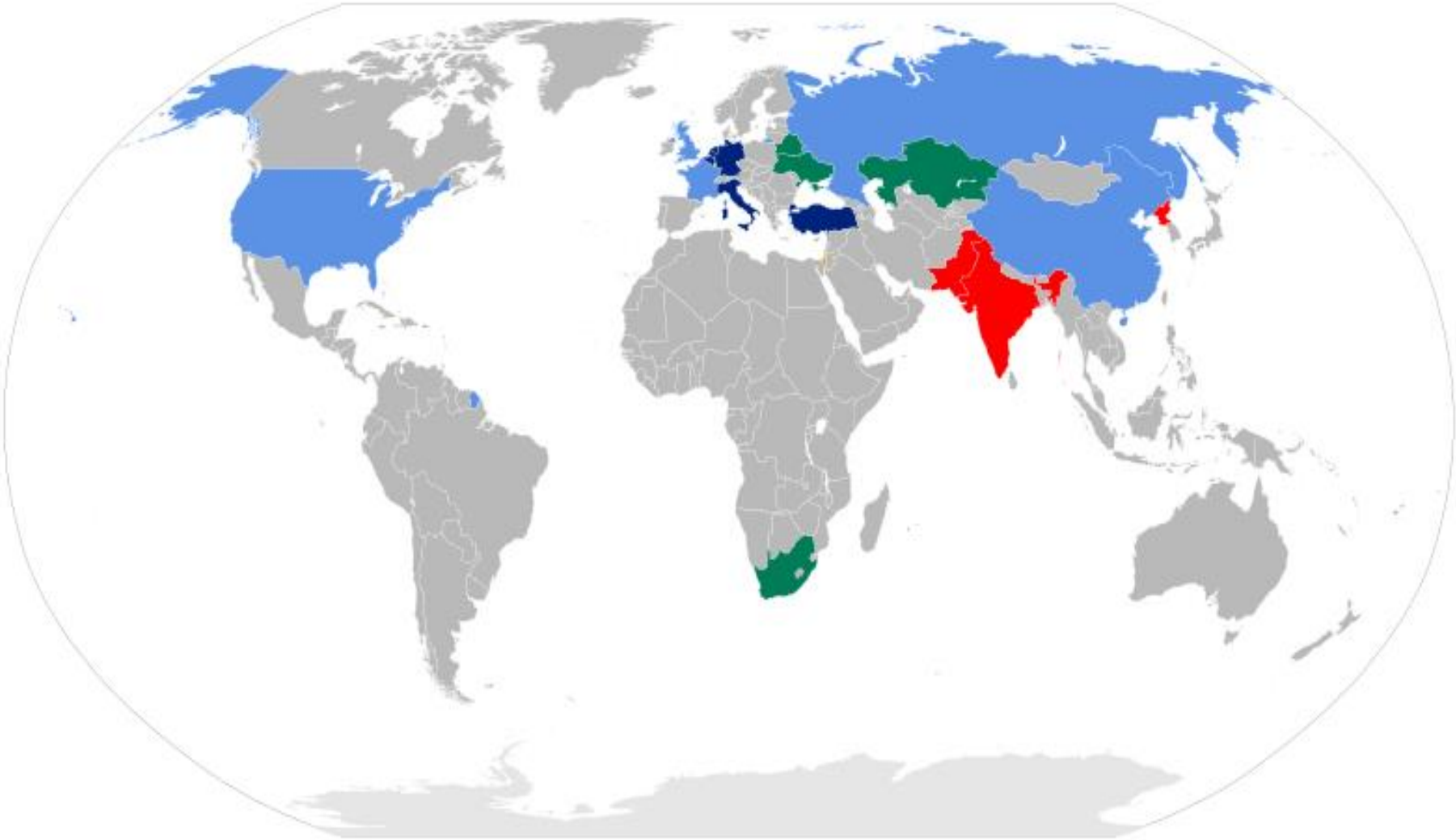
Article IV

- NWS/NNWS: inalienable right to develop research, production and use of nuclear energy for peaceful purposes
- NNWS should be supported in building nuclear energy programs

Article VI

- “Each of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures relating to […] nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control.”

The Non-Proliferation Treaty



Safeguards

Article III

- "Each **non-nuclear-weapon State Party** to the Treaty undertakes to accept safeguards, as set forth in an agreement to be negotiated and concluded with the International Atomic Energy Agency […], for the exclusive purpose of verification of the fulfilment of its obligations assumed under this Treaty with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices. […] The safeguards required by this Article shall be applied on **all** source or special fissionable material in all peaceful nuclear activities […]."

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Safeguards

Verifying declared nuclear materials

Nuclear material accountancy

- On-site inspections in nuclear facilities

Safeguards

Iraq:

- Undeclared research into uranium enrichment technology
- Undeclared import of uranium stocks
- Significant research in nuclear weapons design before 1991

→ UNSCOM (UN Special Commission) 1991-1997

→ Later: UNMOVIC (until war)

Safeguards

Verifying undeclared nuclear materials and activities:
The Additional Protocol

- Challenge inspections
- Open Source Analysis (e.g. satellite imagery, trade data)

Banning nuclear weapon tests

Comprehensive Test Ban Treaty

- Prohibits all nuclear weapons explosions
- Signed in 1996, but not yet in force
- Required ratifications: China, Egypt, India, Iran, Israel, North Korea, Pakistan, Russia, United States

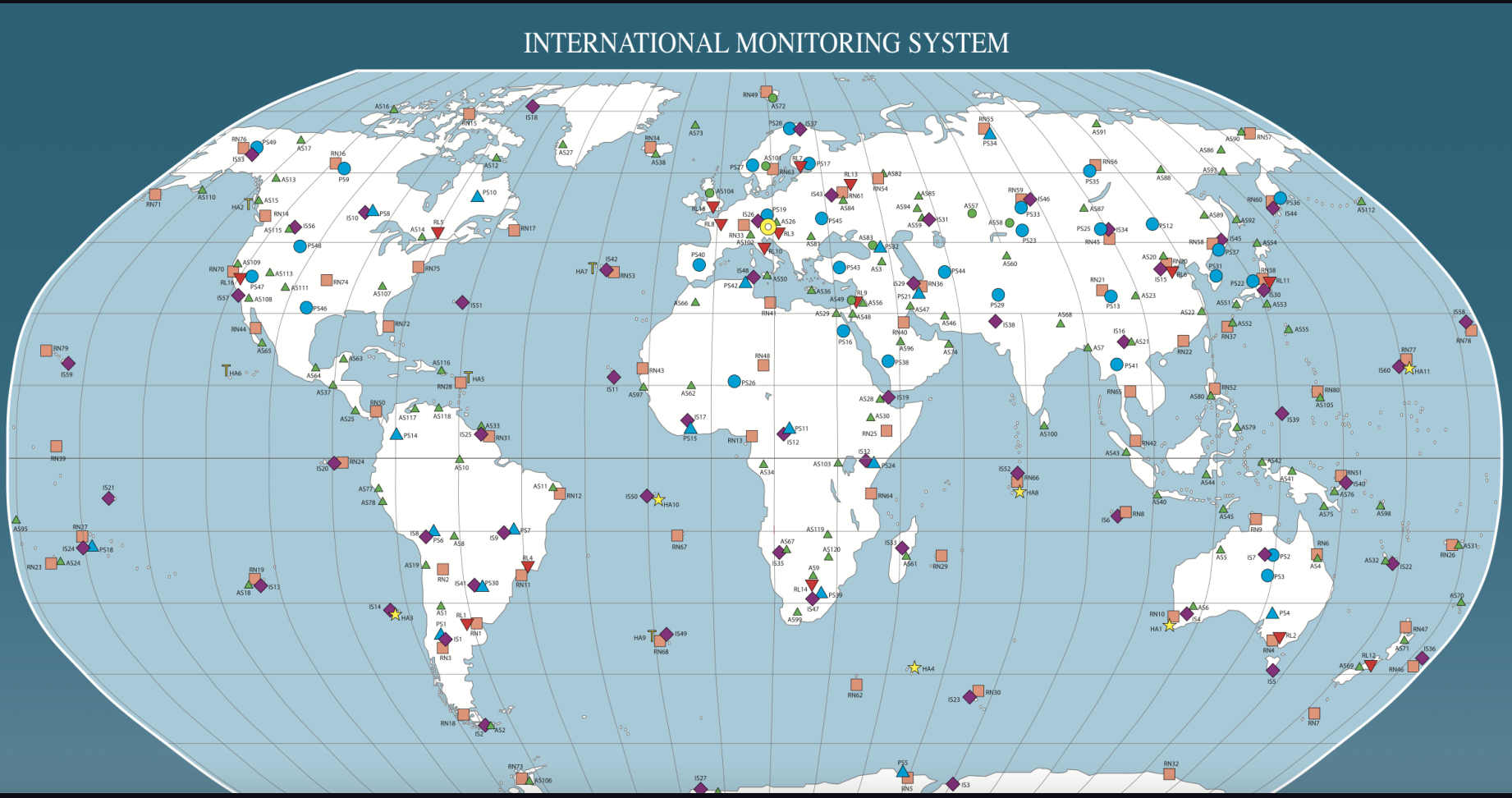
CTBTO

- Comprehensive Test Ban Treaty Organisation in place
- includes the Provisional Technical Secretariat, tasked with the establishmnt of a comprehensive verification regime:
- International Monitoring System, International Data Center & On-Site Inspections

CTBTO
PREPARATORY COMMISSION

International Monitoring System

seismic, hydroacoustic, infrasound and radionuclide monitoring

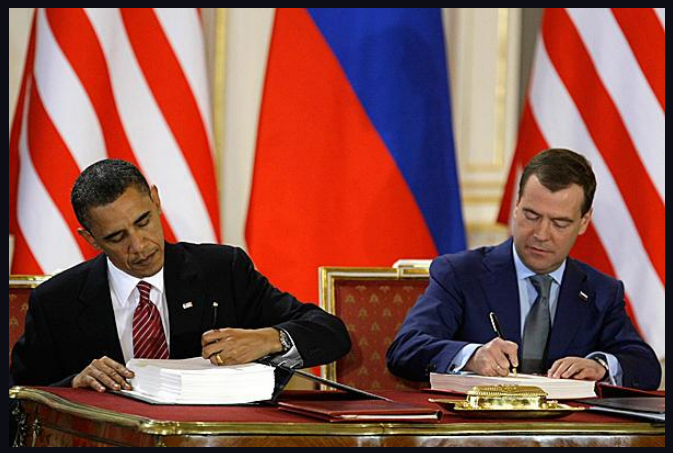


Arms control & disarmament

Strategic arms control

New START Treaty (2010)

- Bilateral US-Russian arms control
- Last agreement in a series initiated during the Cold War
- Limits deployed delivery systems to 700
- Limits deployed warheads to 1550, no limits on total warheads
- Verification regime
- Agreement on extension reached in last minute, 2021
- Treaty expires 2026, **currently suspended**. Limited prospects of negotiations for successor during war.



Nuclear disarmament verification

Delivery systems

Warheads

Fissile materials

92
U

94
Pu

Nuclear disarmament verification

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Warheads

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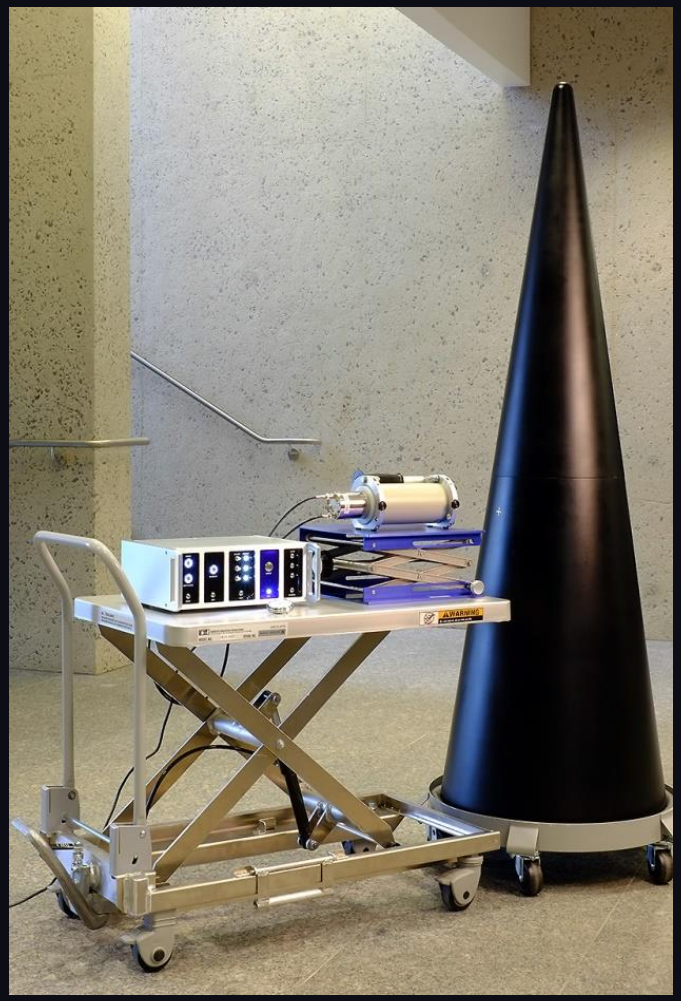
Warhead confirmation

Verify that an item is a nuclear warhead (without visual access)

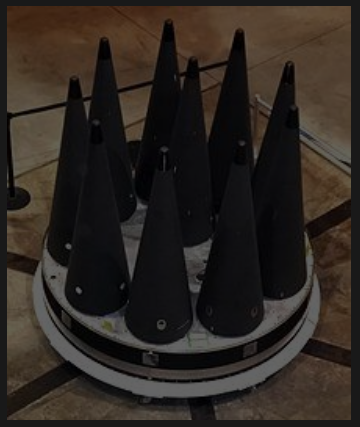


M. Göttsche, G. Kirchner, Measurement Techniques for Warhead Authentication with Attributes: Advantages and Limitations, *Science & Global Security* 22:83-100, 2014

Nuclear disarmament verification

Delivery systems

Warheads

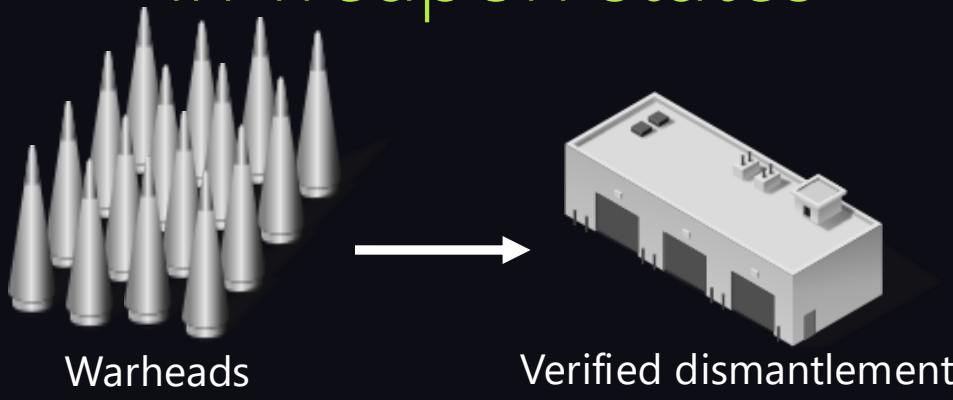


Fissile materials

92
U

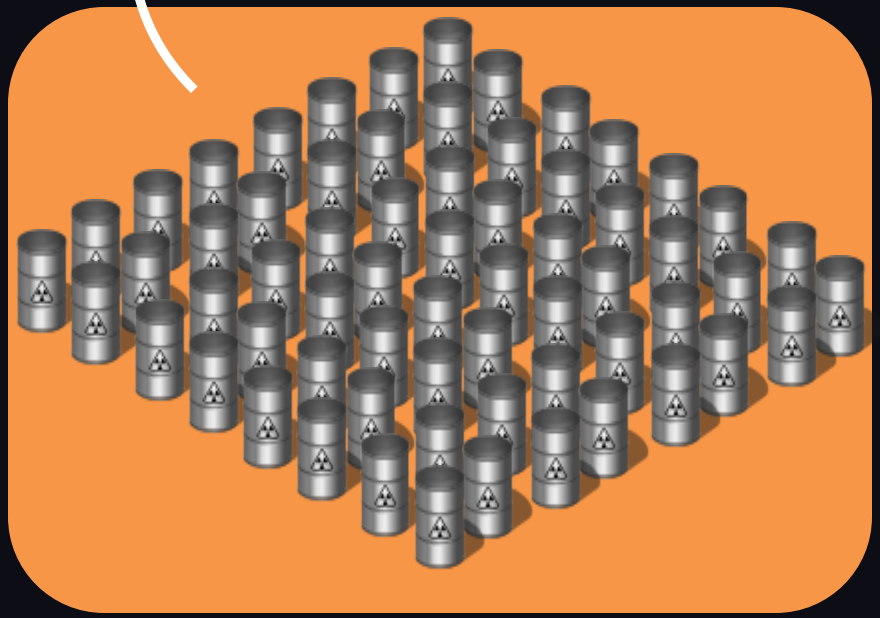
94
Pu

Verifying Fissile Material Inventories
in weapon states



Warheads

Verified dismantlement



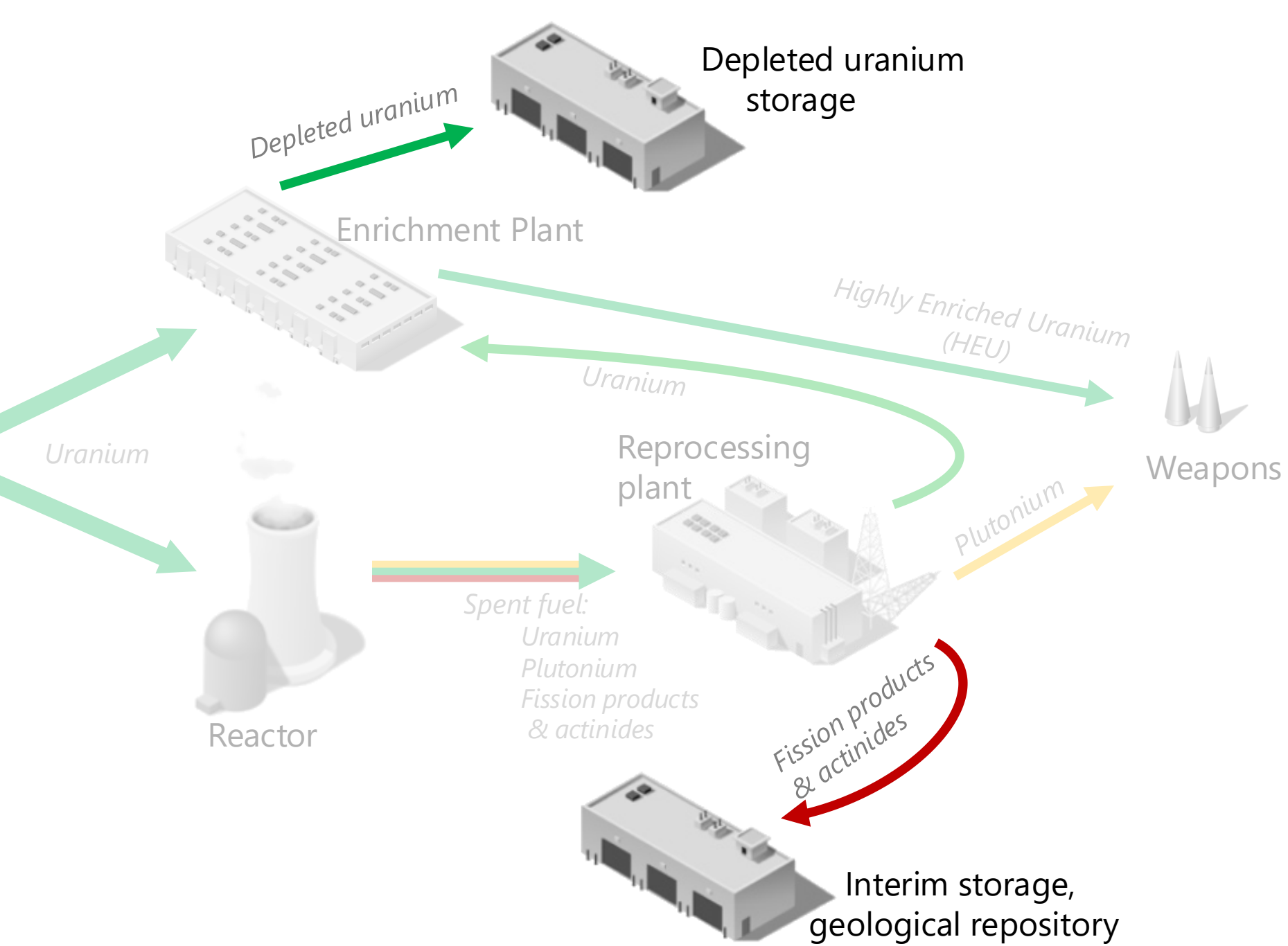
12,000 weapons today

> 100,000 weapon-equivalents of non-civil fissile materials

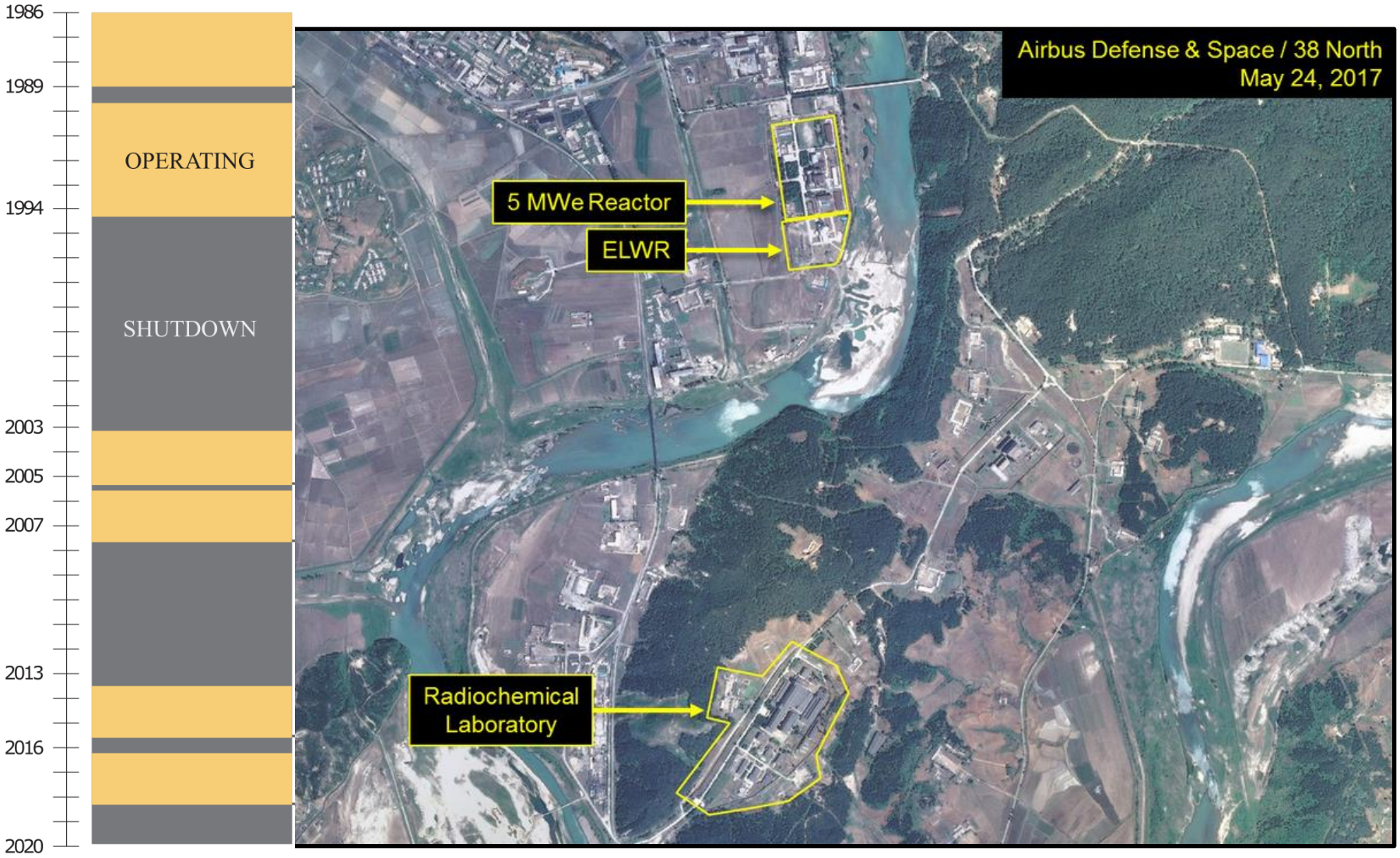
M. Göttsche, *Nonproliferation Review*, 2024

From independent fissile material estimates
to cooperative verification:

Nuclear archaeology


Depleted uranium storage
Depleted uranium
Enrichment Plant
Highly Enriched Uranium (HEU)
Uranium
Uranium
Reprocessing plant
Weapons
Plutonium
Spent fuel:
Uranium
Plutonium
Fission products & actinides
Reactor
Fission products & actinides
Interim storage, geological repository

North Korean plutonium program



J. de Troullioud, M. Kütt

Inventory estimates: North Korea

20-40 kg plutonium

200-450 kg HEU

→ 20-25 nuclear weapons

Atomic Scientists, North Korean nuclear
interview with Siegfried

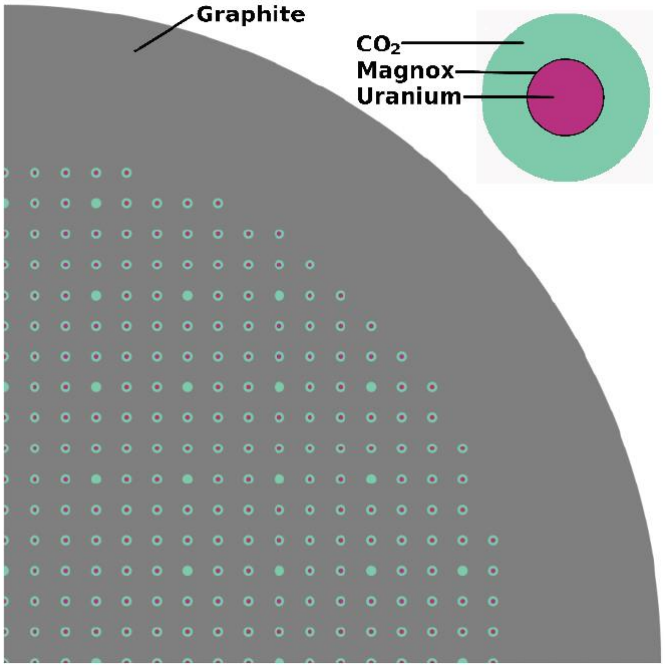
How to verify these inventories ?

U.S. Defense Intelligence Agency:

Up to 60 nuclear weapons

Washington Post, North Korea now making missile-ready nuclear weapons, U.S. analysts say, 8 August 2017

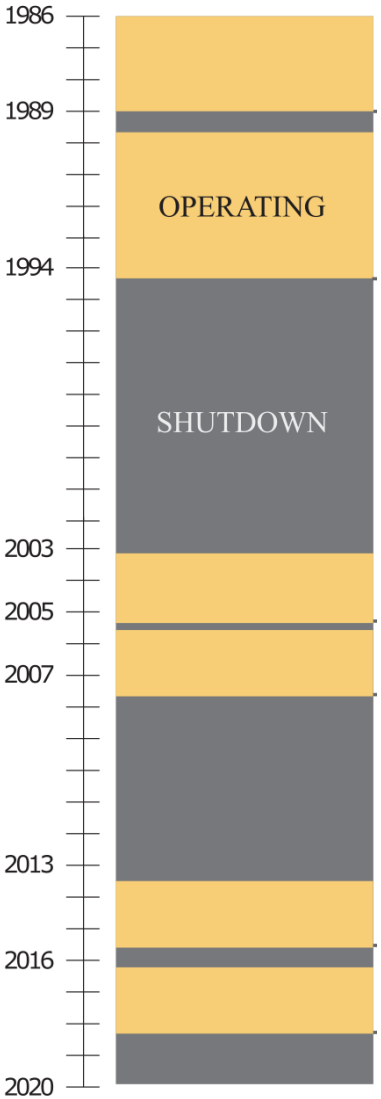
Archaeology with shut-down reactors



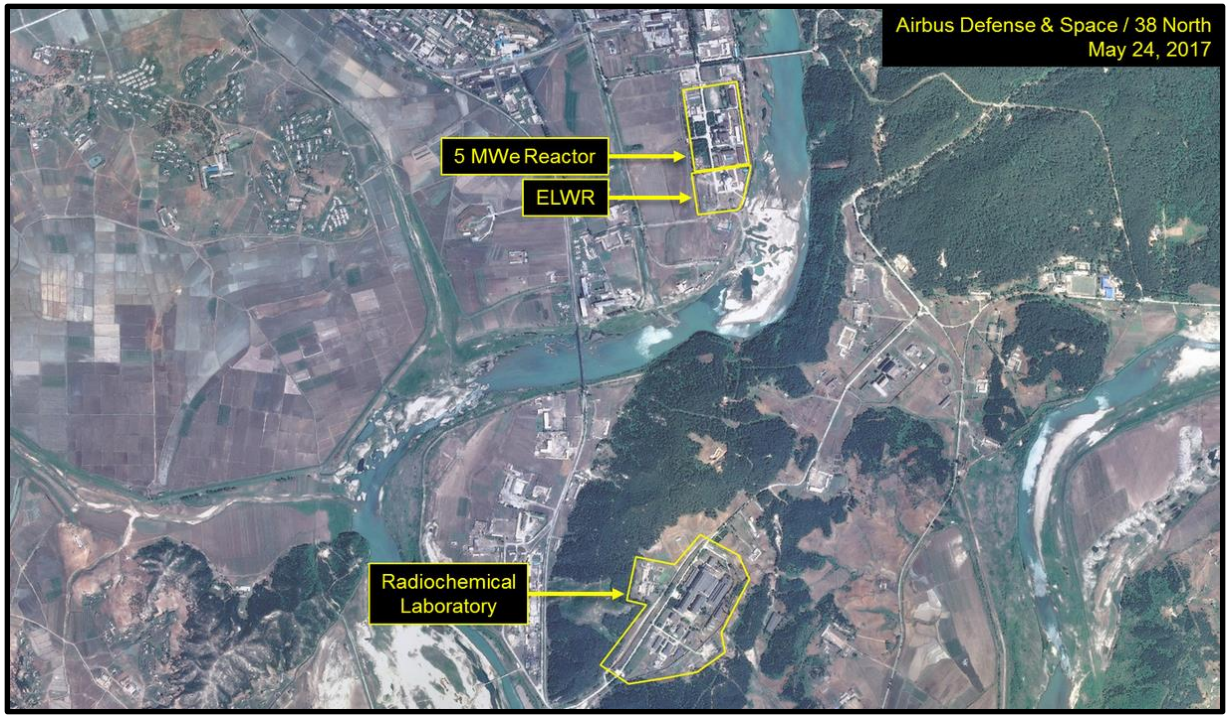
- Sampling permanent structures inside core
- Trace elements in graphite, (zircaloy,…)
- Mass spectrometric measurements
- Sensitivity analysis to identify isotopic ratios that tell about the history

B. Jung, M. Göttsche, Science & Glob. Sec. 30, 2022
L. Rademacher, M. Göttsche, INMM Annual Meeting, 2022

Archaeology with Reprocessing Waste



J. de Troullioud, M. Kütt



1992:

2.4 % Pu-240 in 84 g product vs. **2.25 %** Pu-240 in waste

Conclusion: Undeclared separation of plutonium, indication of undeclared waste storage

"No, you dismantle your nuclear arsenal first."