PASSIVE RADIATION DETECTION TECHNIQUES FOR ABSENCE MEASUREMENTS

Alexander Glaser
Program on Science and Global Security, Princeton University

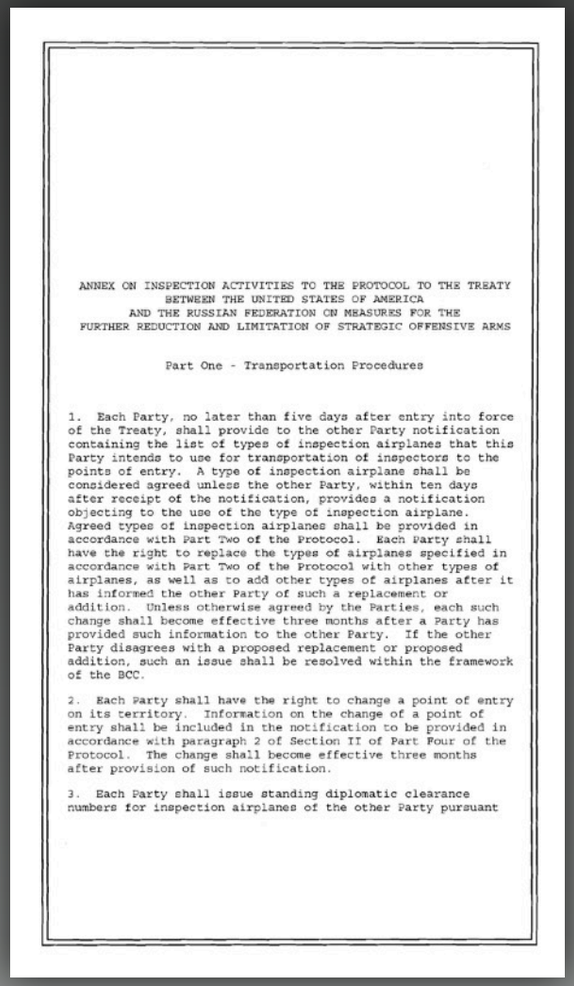
United Nations Institute for Disarmament Research, Geneva, April 14, 2022

REV 001

NEUTRONS

NEW START

ALLOWS FOR MEASUREMENTS ON ITEMS DECLARED AS NON-NUCLEAR OBJECTS



ANNEX ON INSPECTION ACTIVITIES TO THE PROTOCOL TO THE TREATY BETWEEN THE UNITED STATES OF AMERICA AND THE RUSSIAN FEDERATION ON MEASURES FOR THE FURTHER REDUCTION AND LIMITATION OF STRATEGIC OFFENSIVE ARMS

Part One - Transportation Procedures

1. Each Party, no later than five days after entry into force of the Treaty, shall provide to the other Party notification containing the list of types of inspection airplanes that this Party intends to use for transportation of inspectors to the points of entry. A type of inspection airplane shall be considered agreed unless the other Party, within ten days after receipt of the notification, provides a notification objecting to the use of the type of inspection airplane. Agreed types of inspection airplanes shall be provided in accordance with Part Two of the Protocol. Each Party shall have the right to replace the types of airplanes specified in accordance with Part Two of the Protocol with other types of airplanes, as well as to add other types of airplanes after it has informed the other Party of such a replacement or addition. Unless otherwise agreed by the Parties, each such change shall become effective three months after a Party has provided such information to the other Party. If the other Party disagrees with a proposed replacement or proposed addition, such an issue shall be resolved within the framework of the BCC.

2. Each Party shall have the right to change a point of entry on its territory. Information on the change of a point of entry shall be included in the notification to be provided in accordance with paragraph 2 of Section II of Part Four of the Protocol. The change shall become effective three months after provision of such notification.

3. Each Party shall issue standing diplomatic clearance numbers for inspection airplanes of the other Party pursuant

...

"If the average measurement of the neutron radiation level at the selected point is less than or equal to the comparison number calculated in accordance with subparagraph 14(e)(iv) of this Section, the inspected object is, in fact, a non-nuclear object. This fact shall be recorded in the inspection activity report."

...

Annex on Inspection Activities to the Protocol to the Treaty Between the United States of America and the Russian Federation on Measures for the Further Reduction and Limitation of Strategic Offensive Arms, 2009-2017.state.gov/documents/organization/141294.pdf

NEW START

INSPECTION PROTOCOL (SIMPLIFIED)

Background measurement (B)

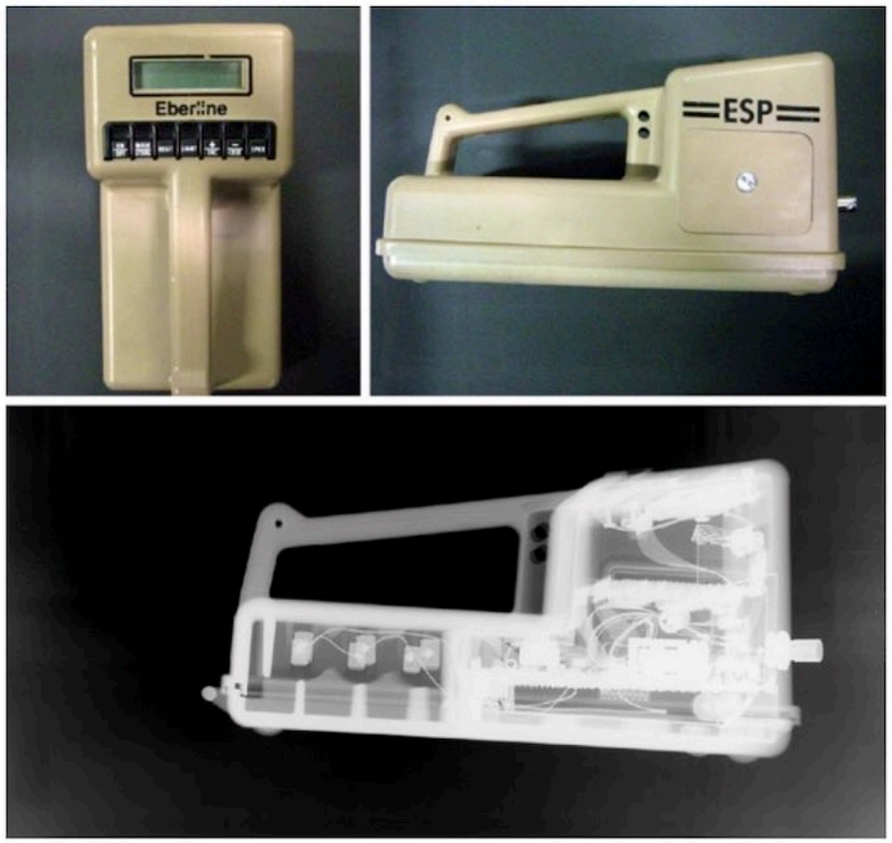
- Counting time between 5–150 seconds
- No more than 450 counts for selected measurement time

Inspection (M)

- Inspectors select a point on the inspected object for the measurements
- Radiation measurements are made 7–200 cm from the surface of the inspected object

If $M \leq B + (4 \times \sqrt{B})$, the inspected object is considered a non-nuclear object

Annex on Inspection Activities to the Protocol to the Treaty Between the United States of America and the Russian Federation on Measures for the Further Reduction and Limitation of Strategic Offensive Arms, 2009-2017.state.gov/documents/organization/141294.pdf



Modified U.S. Eberline ESP-2 Detector

Defense Threat Reduction Agency, 2011

Source: Randy Montoya, share-ng.sandia.gov/news/resources/news_releases/treaty_equipment, February 2018

ESTIMATED NEUTRON EMISSIONS

FROM VARIOUS PLUTONIUM MASSES, COMPOSITIONS, AND CONFIGURATIONS

	Low	Intermediate	High
Amount of plutonium	0.5 kg	3 kg	8 kg
Pu-240 content	2% (10 grams)	6% (180 grams)	20% (1600 grams)
Neutron multiplication	2 (k = 0.5)	5 (k = 0.8)	5 (k = 0.8)
Neutron emissions (gross)	20,000 n/s	1,000,000 n/s	8,000,000 n/s
Shielding	90%	90%	50%
Neutron emissions (net)	**2,000 n/s**	**100,000 n/s**	**4,000,000 n/s**

A plausible nuclear warhead (containing plutonium) may emit on the order 100,000 neutrons per second
(A 1993 Jason report also noted that about 100,000 n/s "make it out" from "a typical primary")

Using the New-START criterion, detection of such an object would be extremely quick

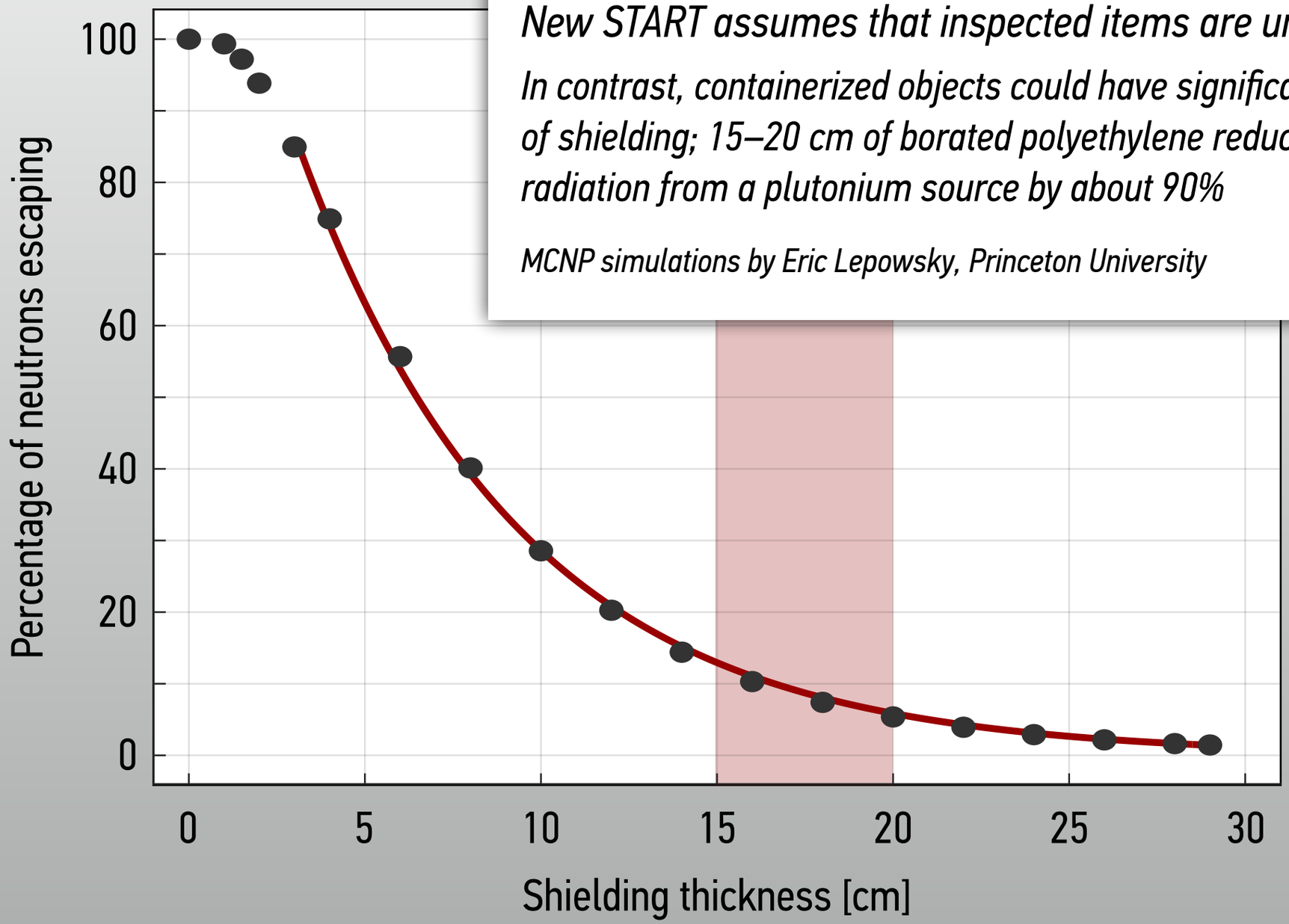
SHIELDING NEUTRONS

(WITH BORATED POLYETHYLENE)

New START assumes that inspected items are unshielded

In contrast, containerized objects could have significant amounts of shielding; 15–20 cm of borated polyethylene reduce neutron radiation from a plutonium source by about 90%

MCNP simulations by Eric Lepowsky, Princeton University



Helium-3 neutron detector
SNM-56 (Russia)

Portable radiation survey instrument
Eberline Smart Portable (ESP-2)

GAMMA RADIATION

PROTOTYPE OF AN ABSENCE MEASUREMENT SYSTEM

USING PASSIVE GAMMA-RAY DETECTION

Photos: Jihye Jeon and Eric Lepowsky

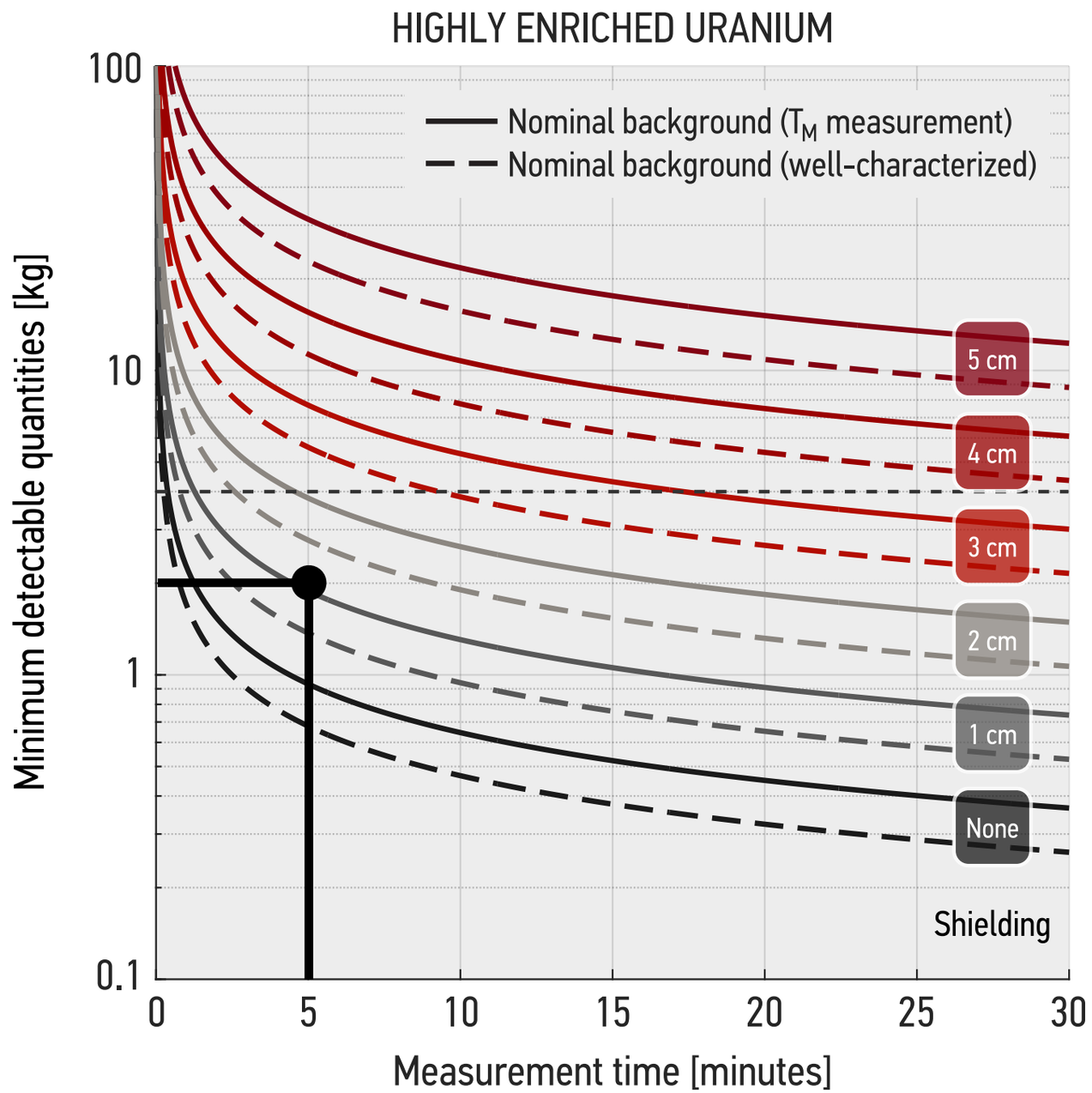
E. Lepowsky, J. Jeon, and A. Glaser, "The Absent-Minded Inspector: Confirming the Absence of Nuclear Warheads Via Passive Gamma-ray Measurements," this conference; see www.youtube.com/watch?v=JuNA6D4kGe4 for a demonstration

GAMMA-RAY EMISSIONS

Property	**Pu-239**	**U-235**	**U-238**
Mass	0.93 kg	3.72 kg	0.28 kg
Region of interest	300–500 keV	130–230 keV	950–1050 keV
Dominant gamma line	(multiple)	185.7 keV	1001.0 keV
Emission rate of point source	$1.30 \times 10^8\ \mathrm{s}^{-1}$	$2.36 \times 10^8\ \mathrm{s}^{-1}$	$2.92 \times 10^4\ \mathrm{s}^{-1}$
Shell outer diameter	10 cm	10 cm	10 cm
Thickness of shell	0.17 cm	0.78 cm	0.78 cm
Escape probability	24.8%	1.3%	25.5%
Effective emission rate of shell	$3.23 \times 10^7\ \mathrm{s}^{-1}$	$3.01 \times 10^6\ \mathrm{s}^{-1}$	$7.43 \times 10^3\ \mathrm{s}^{-1}$

E. Lepowsky, J. Jeon, and A. Glaser, "Confirming the Absence of Nuclear Warheads via Passive Gamma-Ray Measurements" Nuclear Instruments and Methods in Physics Research A, 990, 2021, doi.org/10.1016/j.nima.2020.164983

MINIMUM DETECTABLE QUANTITIES



Scenario

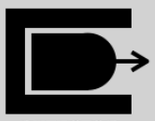
- *The inspector selects a container for inspection that the host considers sensitive though the content is not treaty accountable*
- *The configuration introduces 1 cm of lead-equivalent shielding*
- *The host proposes a measurement time of 5 minutes*
- *The system is able to confirm the absence of 2 kg of HEU (i.e., below the 4-kg threshold)*

E. Lepowsky, J. Jeon, and A. Glaser, "Confirming the Absence of Nuclear Warheads via Passive Gamma-Ray Measurements" Nuclear Instruments and Methods in Physics Research A, 990, 2021, doi.org/10.1016/j.nima.2020.164983

TECHNICAL APPROACH

STEPS OF THE PROPOSED VERIFICATION PROTOCOL FOR ABSENCE MEASUREMENTS

1. BACKGROUND



2. REFERENCE

3. SHIELDING

4. INSPECTION

In Step 2, system confirms presence and strength of reference source (Cs-137) in region of interest (661.7 keV ± 50 keV)

In Step 3, the same region of interest is used to estimate the amount of shielding (mm of Pb-equivalent) introduced by the object

In Step 4, system looks for plutonium and uranium in separate regions of interest
(300–500 keV for Pu-239 and Am-241; 950–1050 keV for U-238)

Based on these data, system reports: "absence confirmed", "inconclusive result", or "anomaly detected"

E. Lepowsky, J. Jeon, and A. Glaser, "Confirming the Absence of Nuclear Warheads via Passive Gamma-Ray Measurements" Nuclear Instruments and Methods in Physics Research A, 990, 2021, doi.org/10.1016/j.nima.2020.164983