CONFIRMING THE ABSENCE OF NUCLEAR WEAPONS VIA PASSIVE GAMMA-RAY MEASUREMENTS

Eric Lepowsky, Jihye Jeon, and Alex Glaser
Princeton University

Consortium for Monitoring, Technology, Verification (MTV)
Annual Meeting 2021

Revision 0.5

INTRODUCTION & MOTIVATION

NEW START EXTENSION

Source: Alexander Zemlianichenko, Associated Press

New START between Russia and the United States recently extended until 2026

Limits number of deployed strategic nuclear weapons to 1,550 on each side

NEW START VERIFICATION

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

New START verification is based on data exchange, notifications, and a limited number of onsite inspections

The only specialized equipment used are neutron detectors to confirm the non-nuclear nature of an object

Modified U.S. Eberline ESP-2 Detector
Defense Threat Reduction Agency, 2011

Source: Sandia National Laboratories, Randy Montoya
share-ng.sandia.gov/news/resources/news_releases/treaty_equipment

MISSION RELEVANCE

TOWARD ALL-WARHEAD AGREEMENTS

Source: Sandia National Laboratories, Randy Montoya

Building on the experience with New START, confirming compliance with all-warhead agreements could similarly rely on absence measurements with minimum access to treaty accountable items

NON-CONVENTIONAL APPLICATIONS

Source: Korean Central News Agency (KCNA)

Simple inspection systems and approaches, minimizing intrusiveness, could play an important role in other nuclear arms control contexts

Need instruments that can detect plutonium <u>and</u> uranium

Using Gamma-ray Measurements

to confirm the absence of kilogram quantities of plutonium and uranium

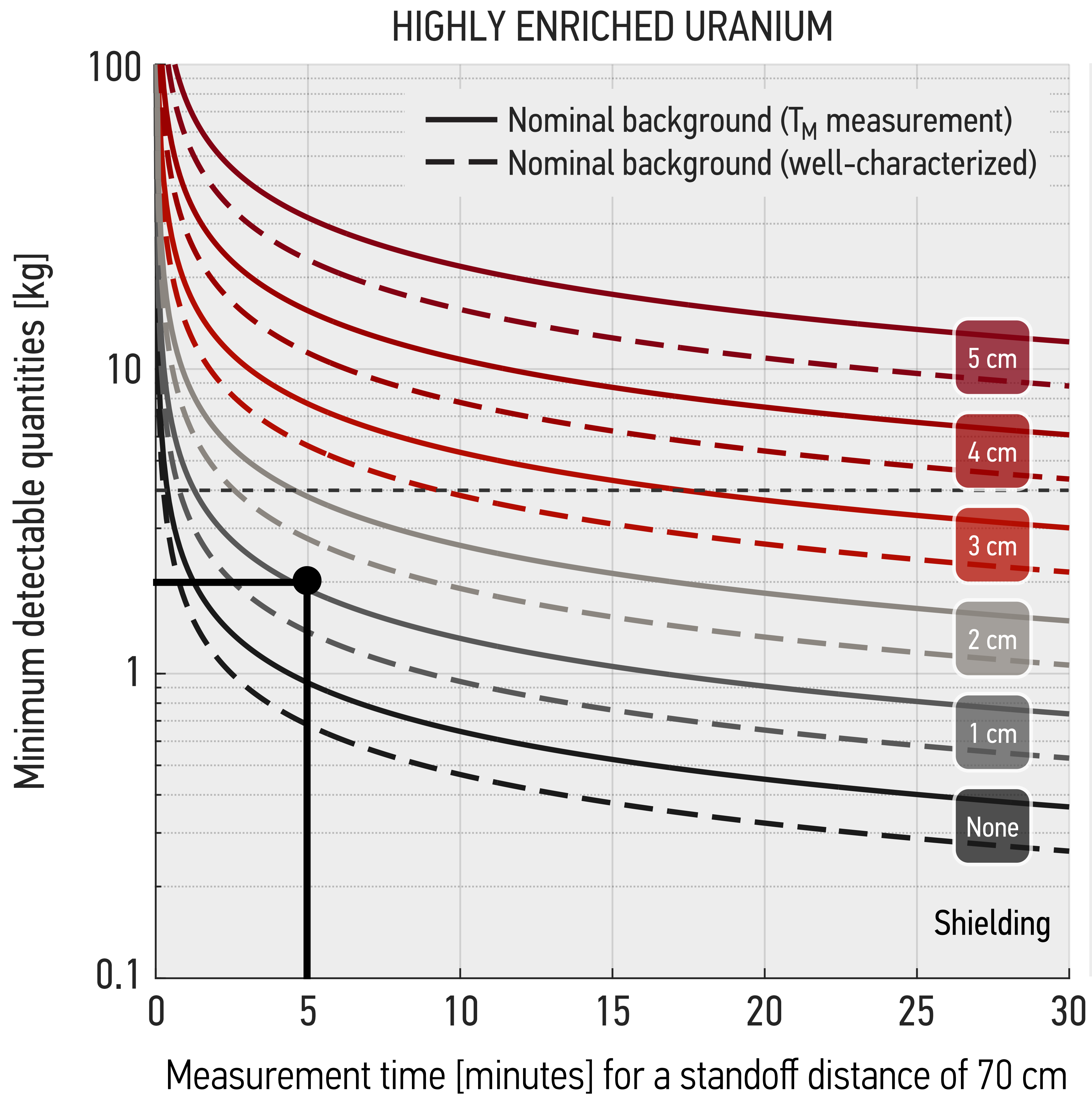
GAMMA-RAY EMISSIONS

FROM ASSUMED MINIMUM QUANTITIES OF SPECIAL NUCLEAR MATERIAL

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	$1.30 \times 10^8\ s^{-1}$	$2.36 \times 10^8\ s^{-1}$	$2.92 \times 10^4\ s^{-1}$
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	$3.23 \times 10^7\ s^{-1}$	$3.01 \times 10^6\ s^{-1}$	$7.43 \times 10^3\ s^{-1}$

MINIMUM DETECTABLE QUANTITIES

OF PLUTONIUM AND URANIUM VERSUS MEASUREMENT TIME & SHIELDING



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 4 kg of HEU*

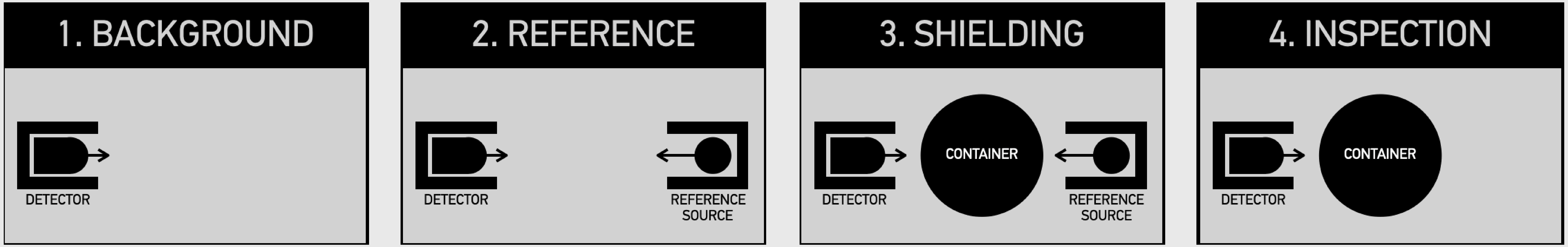
  For the chosen measurement time, the system can confirm with high confidence the presence of 2 kg of HEU

  In contrast, 3 cm of lead-equivalent shielding would have resulted in an inconclusive measurement (and requires a longer measurement time)

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



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

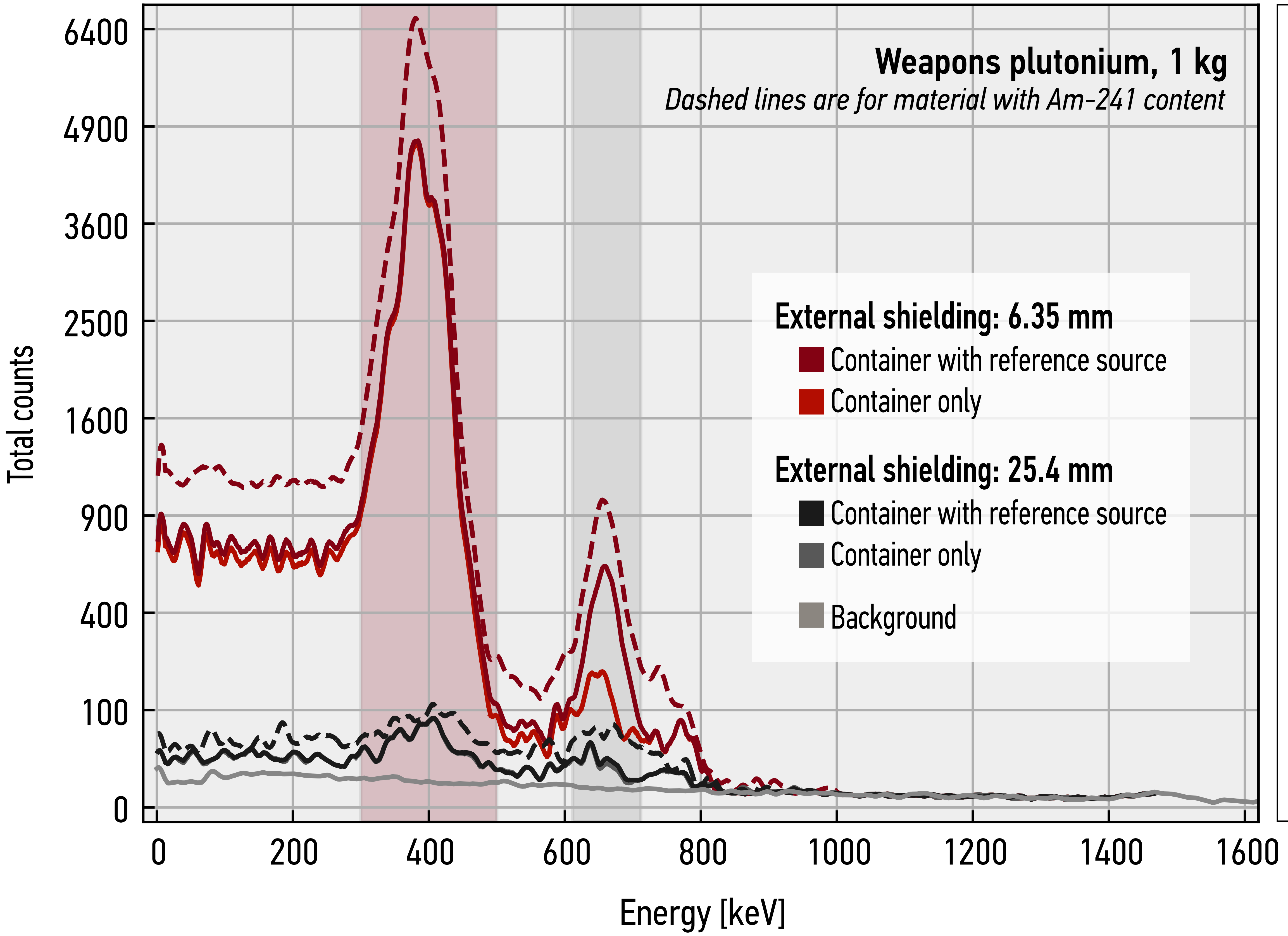
In Step 3, the same region of interest is used to estimate the amount of shielding (millimeters of lead-equivalent) introduced by the object

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”

SAMPLE RESULTS

MCNP SIMULATIONS FOR A SHELL OF PLUTONIUM



	Field Setup (Simulated)
Measurement Time	600 seconds
Standoff distance	70 cm
Isotope	**Pu-239**
Mass	0.93 kg
SNM shell thickness	1.7 mm
External lead shielding thickness	12.7 mm
Region of Interest	300–500 keV
1. Background	1,772 counts
2. Reference	330,738 counts
3. Shielding	6,385 counts
4. Inspection	134,515 counts
Inspection outcome	**Anomaly detected**
Time to detection	0.03 seconds
Estimated shielding (lead-equivalent)	17.4 mm
Shielding limit (lead-equivalent)	43.0 mm

E. Lepowsky, J. Jeon, and A. Glaser, 2021, op. cit.

Making Absence Measurements

for teaching & inspection exercises

MTV COURSE DEVELOPMENT & OFFERINGS

PRINCETON UNIVERSITY, SPRING 2020

PRINCETON UNIVERSITY

Office of the Registrar

Unmaking the Bomb:The Science &Technology of Nuclear Nonproliferation, Disarmament, and Verification

2019-2020 Spring

MAE 354

GRADING BASIS:

P/D/F Only

INSTRUCTORS:

- Alexander Glaser

LINKS:

- Books
- Evaluations

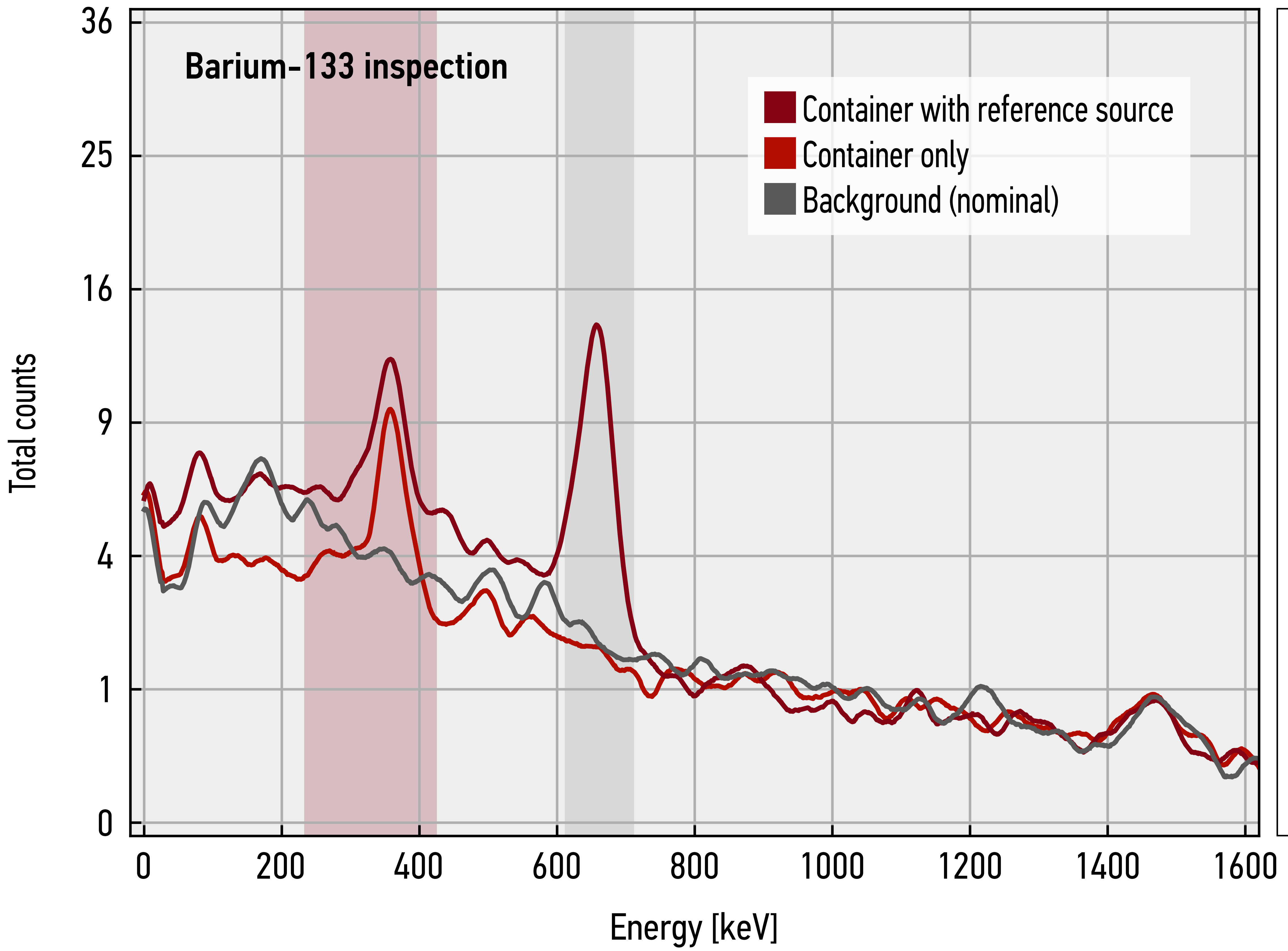
Description

Nuclear weapons have re-emerged as one of the main global security challenges of our time. Reducing the dangers posed by these weapons will require new verification technologies, and this course covers the relevant science and technology to understand and support such efforts. In the first half of the semester, we will examine the fundamental principles of nuclear fission, nuclear radiation, and radiation detection. As part of hands-on final projects in the second half of the semester, teams of students will prototype and benchmark inspection systems and test them during a joint verification exercise.

registrar.princeton.edu/course-offerings/course-details?term=1204&courseid=013115

EXPERIMENTAL DEMONSTRATION

USING STANDARD CHECK SOURCES FOR TEACHING AND INSPECTION EXERCISES



	Lab Setup (Experimental)
Measurement Time	300 seconds
Standoff distance	20 cm
Isotope	**Ba-133**
Activity	1.4 μCi
Lead shielding thickness	12.7 mm
Region of Interest	233–426 keV
1. Background	1,042 counts
2. Reference	4,227 counts
3. Shielding	841 counts
4. Inspection	299 counts
Inspection outcome	**Anomaly detected**
Time to detection	162 seconds
Shielding limit	13.6 mm

E. Lepowsky, J. Jeon, and A. Glaser, 2021, op. cit.

EXPECTED IMPACT & NEXT STEPS

BUILDING A FIELDABLE SYSTEM

Credit: Egan Jimenez, Princeton University

Construction of a portable version of the system should be (relatively) straightforward

In a verification regime based on absence measurements, no weapons should ever be part of an inspection, and safety & security concerns would therefore be dramatically reduced

SUPPORTING FUTURE INSPECTION EXERCISES

Credit: Swedish Defence Research Agency

Field-testing of such a system could help develop the concept further and enable red-teaming of the proposed verification protocol

ACKNOWLEDGEMENTS

This work was partly funded by the Consortium for Monitoring, Technology, and Verification (MTV) under Department of Energy National Nuclear Security Administration Award DE-NA0003920

The Consortium for Monitoring, Technology, and Verification (MTV)
would like to thank the NNSA and DOE for the continued support of these research activities

Consortium for Monitoring Technology and Verification