CONFIRMING THE ABSENCE
OF NUCLEAR WEAPONS

NEUTRON AND GAMMA MEASUREMENTS DURING A VERIFICATION EXPERIMENT IN SWITZERLAND

Eric Lepowsky [1]
Manuel Kreutle [1]
Christoph Wirz [2]
Alex Glaser [1]

[1]Princeton University
[2]Spiez Laboratory

INMM & ESARDA Joint Annual Meeting
Vienna, May 2023

Revision 2b

BACKGROUND

THE MENZINGEN VERIFICATION EXPERIMENT

UNIDIR & SWISS ARMED FORCES, SWITZERLAND

EARLIER THIS 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

See Pavel Podvig, "Verifying the Absence of Nuclear Weapons: Results of a Field Exercise," INMM & ESARDA Joint Annual Meeting, Vienna, 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 output during measurements; no spectra, no data storage

Source: Pavel Podvig

Example of a container located onsite

Photo: Pavel Podvig

BUNKER AREA

PREPARED FOR RADIATION MEASUREMENTS

Source: Pavel Podvig

MEASUREMENT EQUIPMENT

NEUTRON DETECTOR

BERTHOLD LB 6414

MAIN TECHNICAL SPECS

- Helium-3 proportional counter tube in polyethylene moderator
- Integrated preamplifier, discriminator, and high-voltage supply
- Provided by Spiez Laboratory

www.berthold.com/en/radiation-protection/products/dose-and-dose-rate/neutron-survey-monitor-lb-6414/

GAMMA DETECTOR

ABSENCE CONFIRMATION DEVICE (ACX) 2.0

MAIN TECHNICAL SPECS

- Mirion/Canberra 2” x 2” NaI detector in lead collimator/shield
- Mirion/Canberra Osprey Digital MCA Tube Base
- Power-over-ethernet connection
- Raspberry Pi running dedicated Python code
- Numeric keypad and display for all I/O

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

IMPRESSIONS

Confirming dimensions of structures onsite

Photo: Pavel Podvig

Member of the host team aligns the sodium-iodide detector

Photo: Pavel Podvig

Setup for gamma measurements to confirm absence of uranium (with Cs-137 reference source in place)

Photo: Pavel Podvig

ACX 2.0 device (with keypad and worksheet) during a measurement

Photo: Pavel Podvig

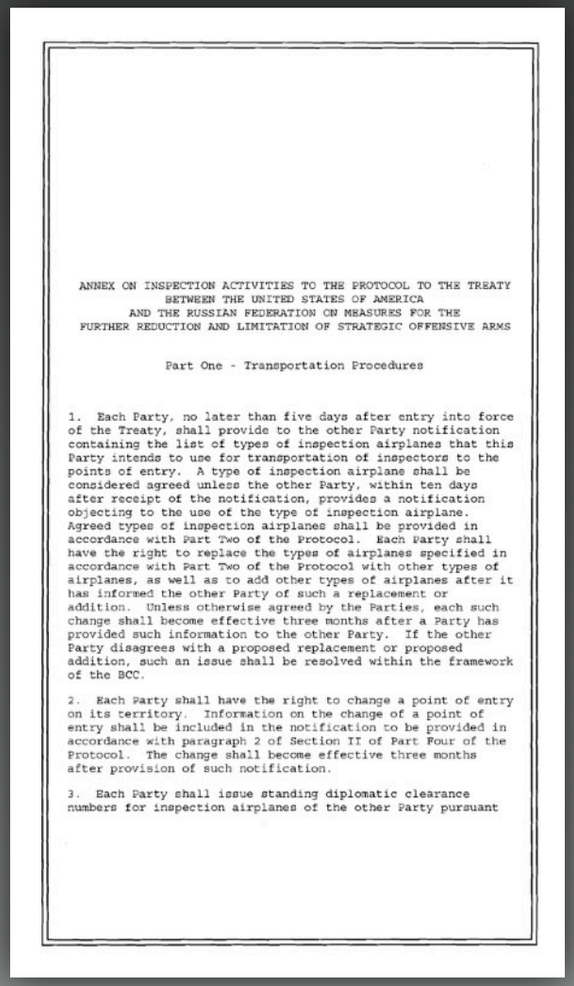
Reviewing measurement results

Photo: Pavel Podvig

INSPECTION RESULTS

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

NEUTRON MEASUREMENTS

Inspection Worksheet for Neutron Measurements (with LB 6414)

Revision 0.6
Menzingen Experiment
March 2023

Date		March 8, 2023	
Local time		13:32	
Location		202	
Inspected item ID		Category B	
Measurement time proposed by host (60–150 seconds)	01	150	seconds
Measurement time chosen by inspector	02	150	seconds
Line 02 must be ≥ Line 01 but ≤ 150 seconds			
Average background count rate	03a	0.085	cps
Total background counts (B = Line 03a x Line 02)	03b	13	counts
Rounded up to next integer			
Reference number (R) with R = B + 4 x √B	04	28	counts
Rounded up to next integer			
Distance from detector to center of item	05	60	cm
Line 05 must be ≤ 70 cm			
Average count rate during inspection	06a	29.9	cps
Total counts acquired during inspection (Line 06a x Line 02)	06b	4485	counts
Rounded down to previous integer			
Check box if Line 06b ≤ Line 04			Non-nuclear object confirmed
Check box if Line 06b > Line 04	X		Anomaly detected

Notes

Californium-252 source
(90,000-95,000 n/s)

Inspection Worksheet for Neutron Measurements (with LB 6414)

Revision 0.6
Menzingen Experiment
March 2023

Date		March 8, 2023	
Local time		14:02	
Location		201	
Inspected item ID		Category B	
Measurement time proposed by host (60–150 seconds)	01	150	seconds
Measurement time chosen by inspector	02	150	seconds
Line 02 must be ≥ Line 01 but ≤ 150 seconds			
Average background count rate	03a	0.085	cps
Total background counts (B = Line 03a x Line 02)	03b	13	counts
Rounded up to next integer			
Reference number (R) with R = B + 4 x √B	04	28	counts
Rounded up to next integer			
Distance from detector to center of item	05	60	cm
Line 05 must be ≤ 70 cm			
Average count rate during inspection	06a	0.300	cps
Total counts acquired during inspection (Line 06a x Line 02)	06b	45	counts
Rounded down to previous integer			
Check box if Line 06b ≤ Line 04			Non-nuclear object confirmed
Check box if Line 06b > Line 04	X		Anomaly detected

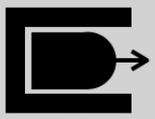
Notes

Container empty

INSPECTION PROTOCOL

FOR GAMMA 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

GAMMA MEASUREMENTS

Inspection Worksheet for Gamma Measurements (with ACX 2)

Revision 0.6
Menzingen Experiment
March 2023

Date		March 8, 2023	
Local time		14:30	
Location		204	
Inspected item ID		Category C	
Measurement time proposed by host	01	450	seconds
Measurement time chosen by inspector (and used)	02	450	seconds
Line 02 must be ≥ Line 01			
Background, Region of Interest for plutonium	03a	1971	counts
Background, Region of Interest for uranium	03b	318	counts
Distance from detector to center of item	04	48	cm
Line 04 must be ≤ 70 cm			
Reference source (without container)	05a	316370	counts
Reference source (with container)	05b	288337	counts
Container only (ROI for reference source)	06a	0	counts
Container only (ROI for plutonium)	06b	130	counts
Container only (ROI for uranium)	06c	0	counts
Critical limit (ROI for plutonium)	07a	146	counts
Critical limit (ROI for uranium)	07b	58	counts
Estimated thickness of shielding, lead-equivalent	08	1	mm
Max			
Max			

INSP

X

Anomaly detected

Container empty

Inspection Worksheet for Gamma Measurements (with ACX 2)

Revision 0.6
Menzingen Experiment
March 2023

Date		March 8, 2023	
Local time		16:30	
Location		205	
Inspected item ID		Category C	
Measurement time proposed by host	01	300	seconds
Measurement time chosen by inspector (and used)	02	300	seconds
Line 02 must be ≥ Line 01			
Background, Region of Interest for plutonium	03a	1767	counts
Background, Region of Interest for uranium	03b	255	counts
Distance from detector to center of item	04	40	cm
Line 04 must be ≤ 70 cm			
Reference source (without container)	05a	226735	counts
Reference source (with container)	05b	177113	counts
Container only (ROI for reference source)	06a	2275	counts
Container only (ROI for plutonium)	06b	10603	counts
Container only (ROI for uranium)	06c	1744	counts
Critical limit (ROI for plutonium)	07a	138	counts
Critical limit (ROI for uranium)	07b	52	counts
Estimated thickness of shielding, lead-equivalent	08	1	mm
Max			
Max			

INSP

X

Anomaly detected

DU projectiles
(800 grams of U-238)

GAMMA MEASUREMENTS

Inspection Worksheet for Gamma Measurements (with ACX 2)

Revision 0.6
Menzingen Experiment
March 2023

Date		March 8, 2023	
Local time		14:30	
Location		204	
Inspected item ID		Category C	
Measurement time proposed by host	01	450	seconds
Measurement time chosen by inspector (and used)	02	450	seconds
Line 02 must be ≥ Line 01			
Background, Region of Interest for plutonium	03a	1971	counts
Background, Region of Interest for uranium	03b	318	counts
Distance from detector to center of item	04	48	cm
Line 04 must be ≤ 70 cm			
Reference source (without container)	05a	316370	counts
Reference source (with container)	05b	288337	counts
Container only (ROI for reference source)	06a	[illegible]	counts
Container only (ROI for plutonium)	06b	130	counts
Container only (ROI for uranium)	06c	[illegible]	counts
Critical limit (ROI for plutonium)	07a	146	counts
Critical limit (ROI for uranium)	07b	58	counts
Estimated thickness of shielding, lead-equivalent	08	1	mm
Max			
Max			

INSP

X

Anomaly detected

Container empty

Inspection Worksheet for Gamma Measurements (with ACX 2)

Revision 0.6
Menzingen Experiment
March 2023

Date		March 8, 2023	
Local time		16:30	
Location		205	
Inspected item ID		Category C	
Measurement time proposed by host	01	300	seconds
Measurement time chosen by inspector (and used)	02	300	seconds
Line 02 must be ≥ Line 01			
Background, Region of Interest for plutonium	03a	1767	counts
Background, Region of Interest for uranium	03b	255	counts
Distance from detector to center of item	04	40	cm
Line 04 must be ≤ 70 cm			
Reference source (without container)	05a	226735	counts
Reference source (with container)	05b	177113	counts
Container only (ROI for reference source)	06a	2275	counts
Container only (ROI for plutonium)	06b	10603	counts
Container only (ROI for uranium)	06c	1744	counts
Critical limit (ROI for plutonium)	07a	138	counts
Critical limit (ROI for uranium)	07b	52	counts
Estimated thickness of shielding, lead-equivalent	08	1	mm
Max			
Max			

INSP

X

Anomaly detected

DU projectiles
(800 grams of U-238)

PPPL MEASUREMENTS

(Post Menzingen)

LABORATORY SETUP

(PRINCETON PLASMA PHYSICS LABORATORY)

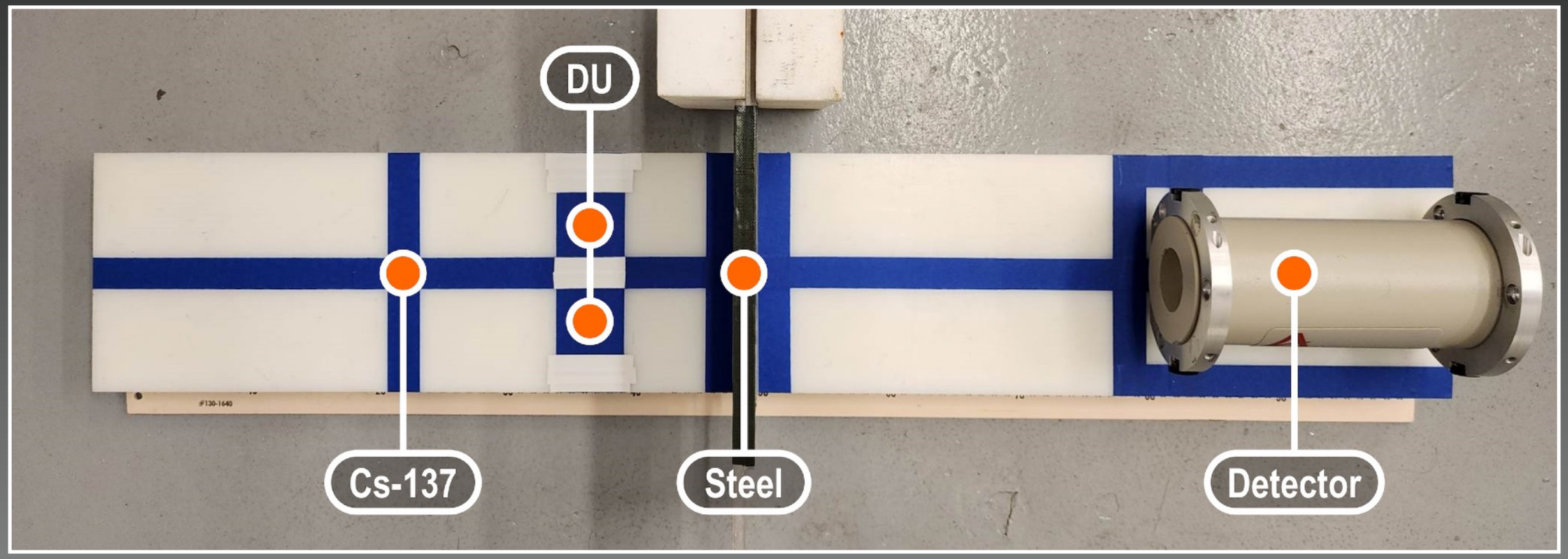
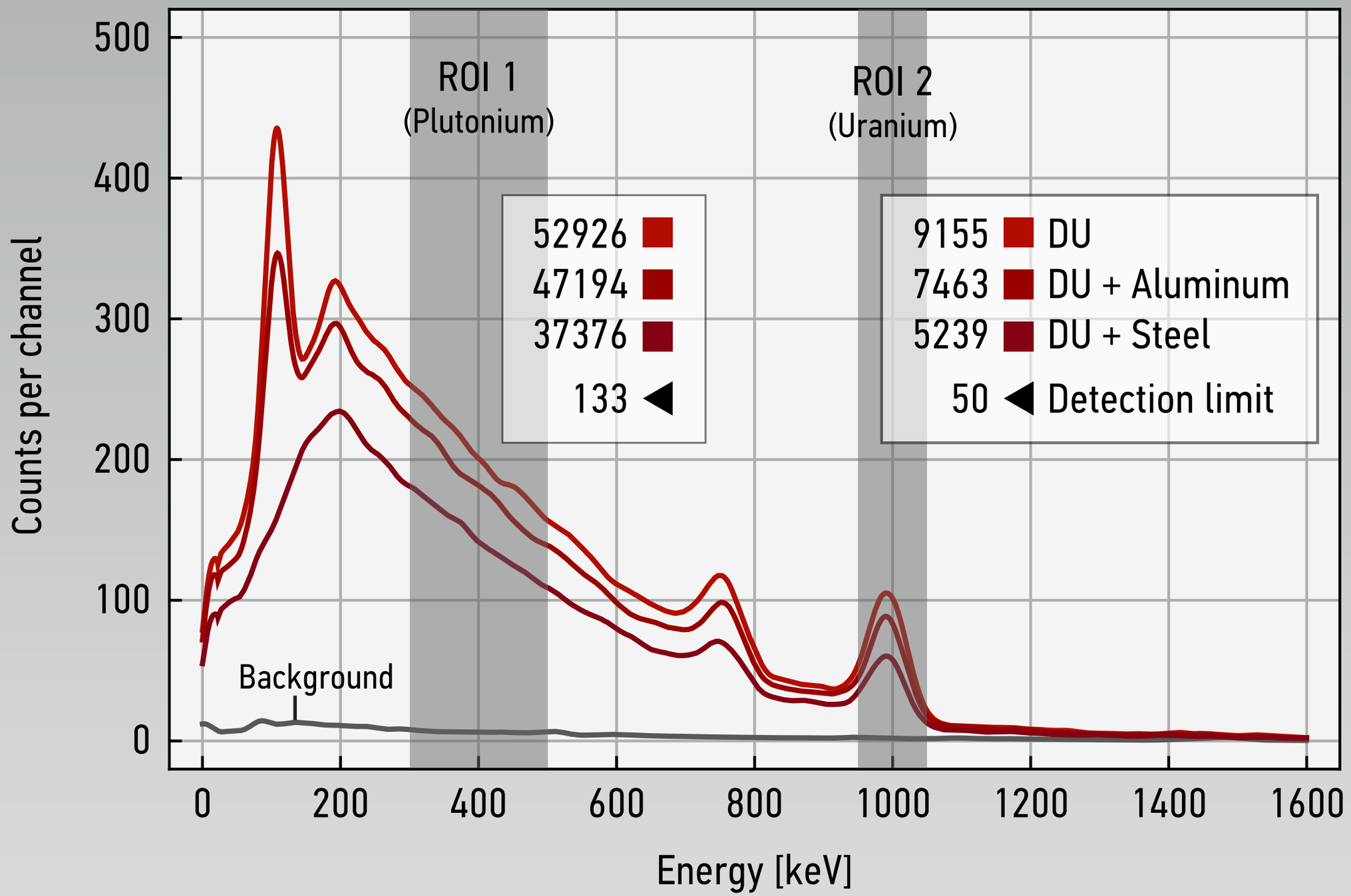


Photo: Eric Lepowsky

MEASUREMENT RESULTS

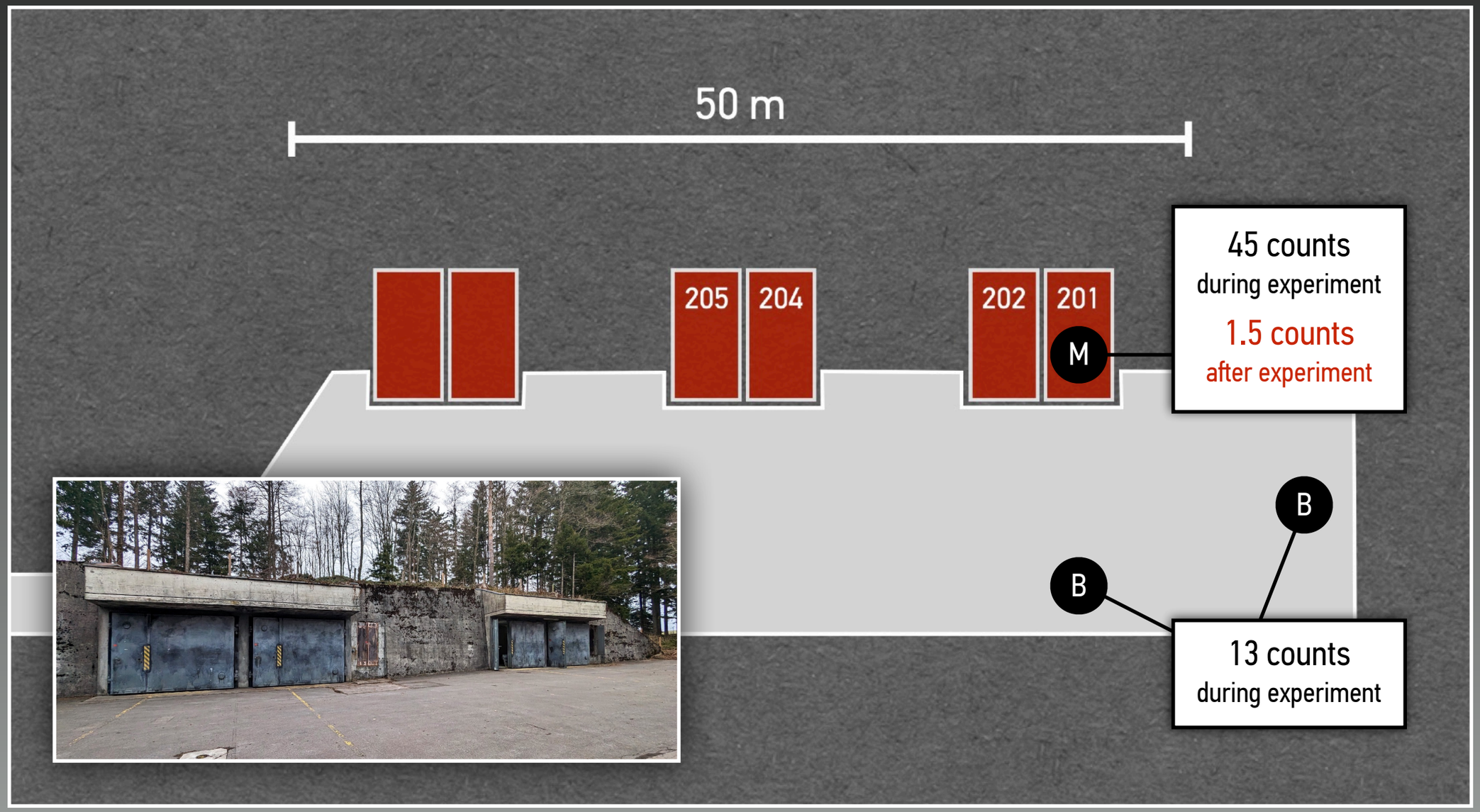


LESSONS LEARNED

n

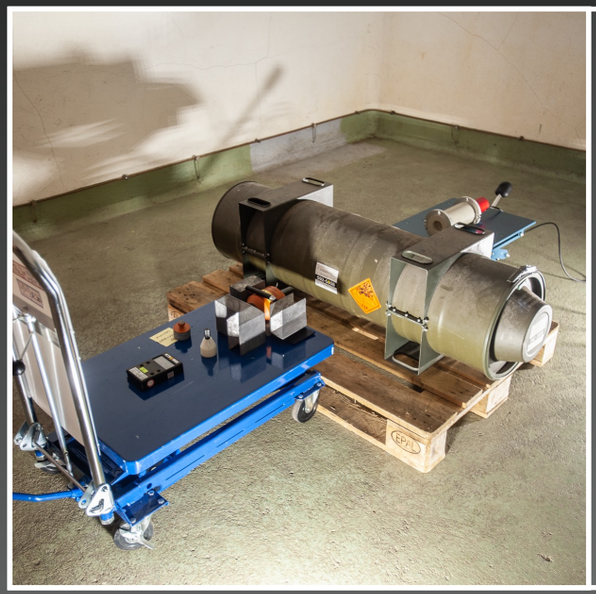
BACKGROUND MEASUREMENTS

(ACQUIRED DURING & AFTER EXPERIMENT)



Total counts are for a measurement time of 150 seconds

LESSONS LEARNED & CONCLUSIONS



ON THE DIFFICULTY OF "IN-SITU" MEASUREMENTS

For verification approaches that envision the inspection of items in storage it is critically important that such items can be moved to a dedicated staging area, where the background is well-characterized

This is relevant for both absence and confirmation measurements

ON NEUTRON vs GAMMA MEASUREMENTS

As demonstrated under New START, neutron measurements are relatively straightforward and adequate to confirm absence of plutonium

Gamma measurements are generally more complex and less "specific" but a necessary complement if the absence of uranium is to be confirmed

Source: Pavel Podvig

ACKNOWLEDGEMENTS

The experimental analog presented in this work would not have been possible without the support of numerous researchers, staff, and the Health Physics team from **Princeton Plasma Physics Laboratory (PPPL).**

This work was partly supported by the **Consortium for Monitoring, Technology, and Verification (MTV)** under Department of Energy National Nuclear Security Administration award number DE-NA0003920. We acknowledge the **Spiez Laboratory, UNIDIR, and the Swiss Armed Forces** for their coordination in making these measurements possible, with special thanks to **David Chichester, Steve Fetter, Moritz Kütt, and Pavel Podvig**, along with all other participants in the Menzingen Verification Experiment.