NUCLEAR INSPECTIONS IN THE MATRIX
WORKING WITH RADIATION DETECTORS IN VIRTUAL REALITY

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Revision 2

BACKGROUND

COOPERATIVE VERIFICATION APPROACHES

Cooperative approaches to nuclear security and verification widely recognized as key to building confidence and addressing technical obstacles; however, these programs have all ended, and cooperation on nuclear-weapon issues continues only on a very small scale

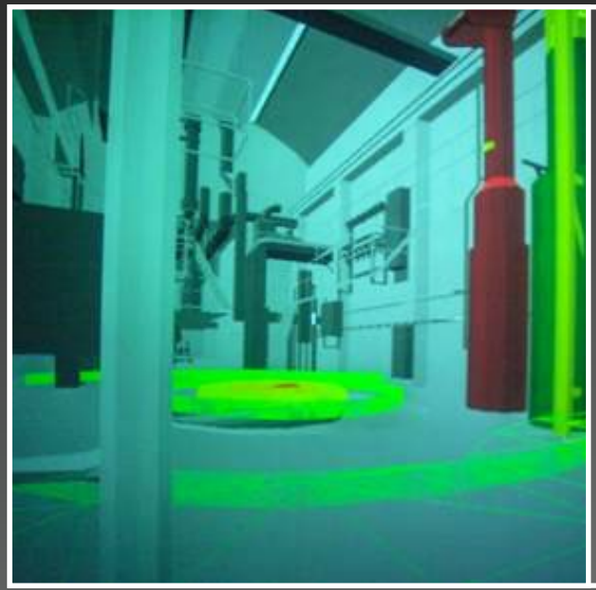
VIRTUAL REALITY

VR may offer a new pathway to support experts and governments in developing a shared, hands-on understanding of the challenges involved in nuclear security and verification

Source: Duncan MacArthur/LANL (top)

ACQUIRING GAMMA SPECTRA IN VIRTUAL REALITY

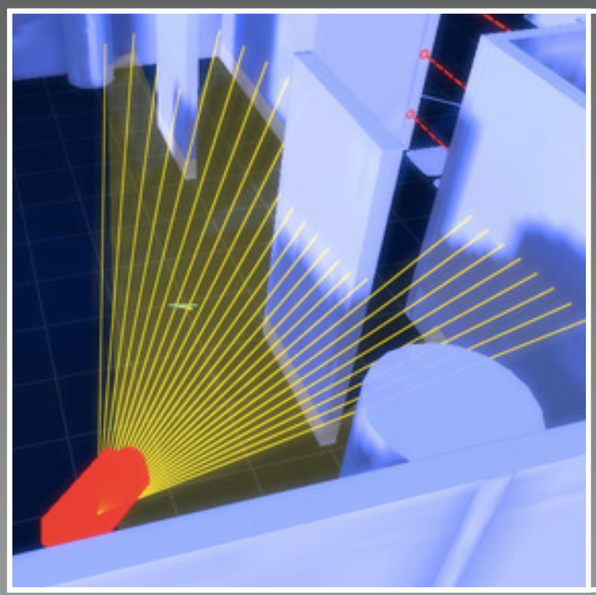
VIRTUAL RADIATION



WHY?

Radiation signatures of materials are relevant for many aspects of nuclear verification, and it is important to include them in the models

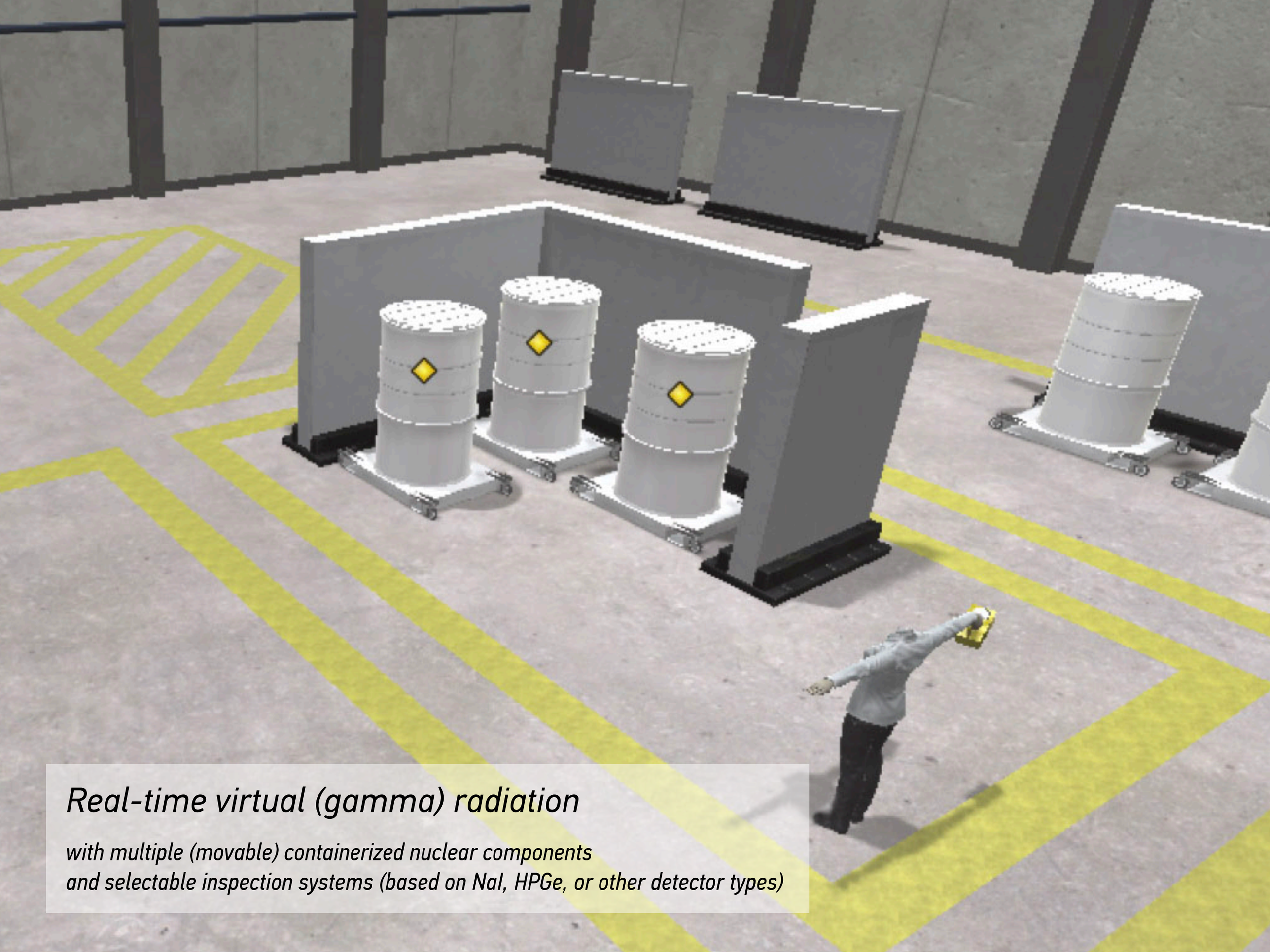
Goal: Quasi real-time treatment of nuclear (gamma) radiation



HOW?

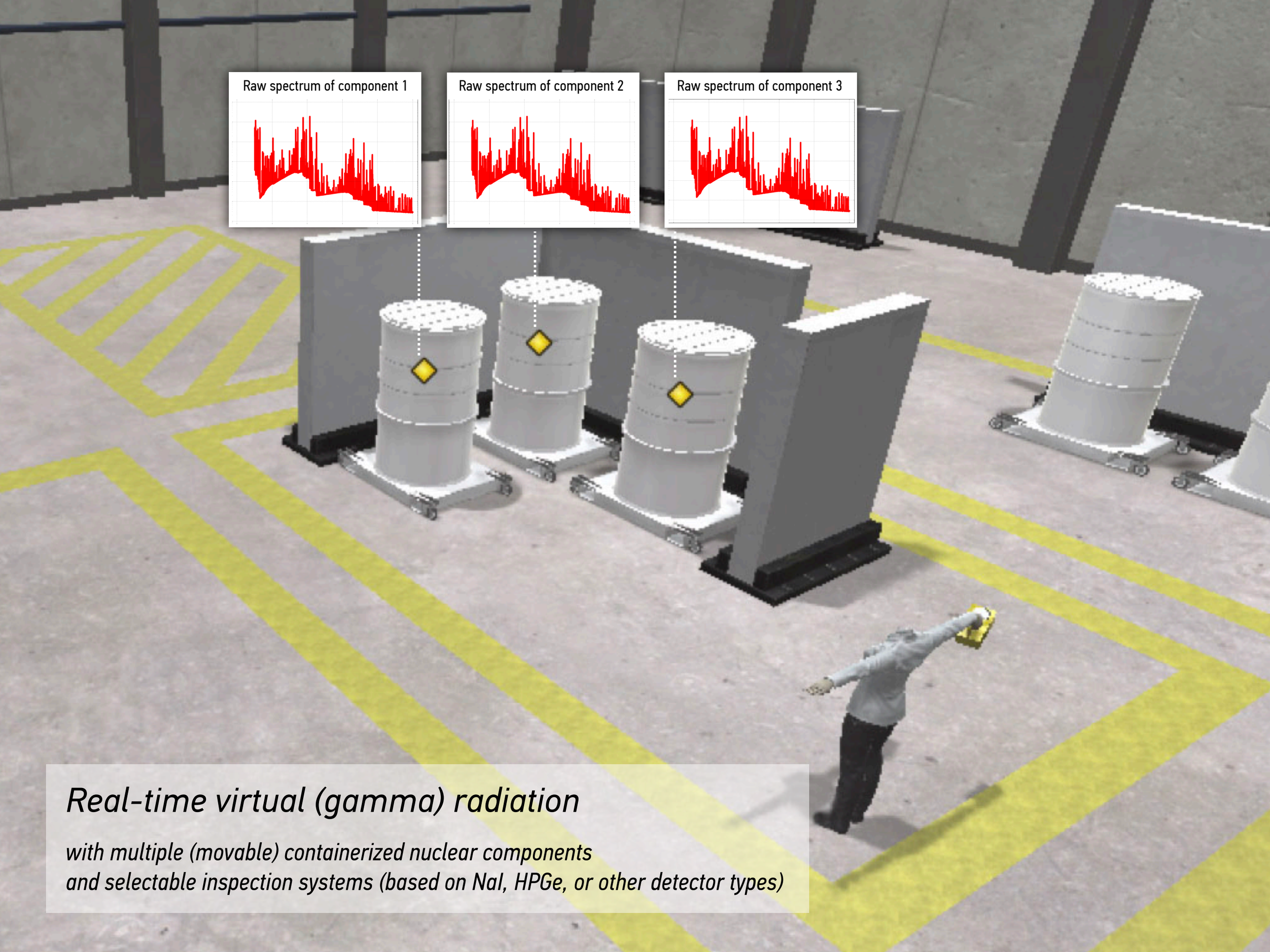
Our first implementation uses a simple point-kernel method for gamma radiation, i.e., direct radiation from the source is treated as a collection of rays originating from one or more radiation sources reaching a point of interest (detector)

Source: Virtual Education and Research Laboratory (UIUC, top) and quickfingers.net (bottom)



Real-time virtual (gamma) radiation

with multiple (movable) containerized nuclear components
and selectable inspection systems (based on NaI, HPGe, or other detector types)



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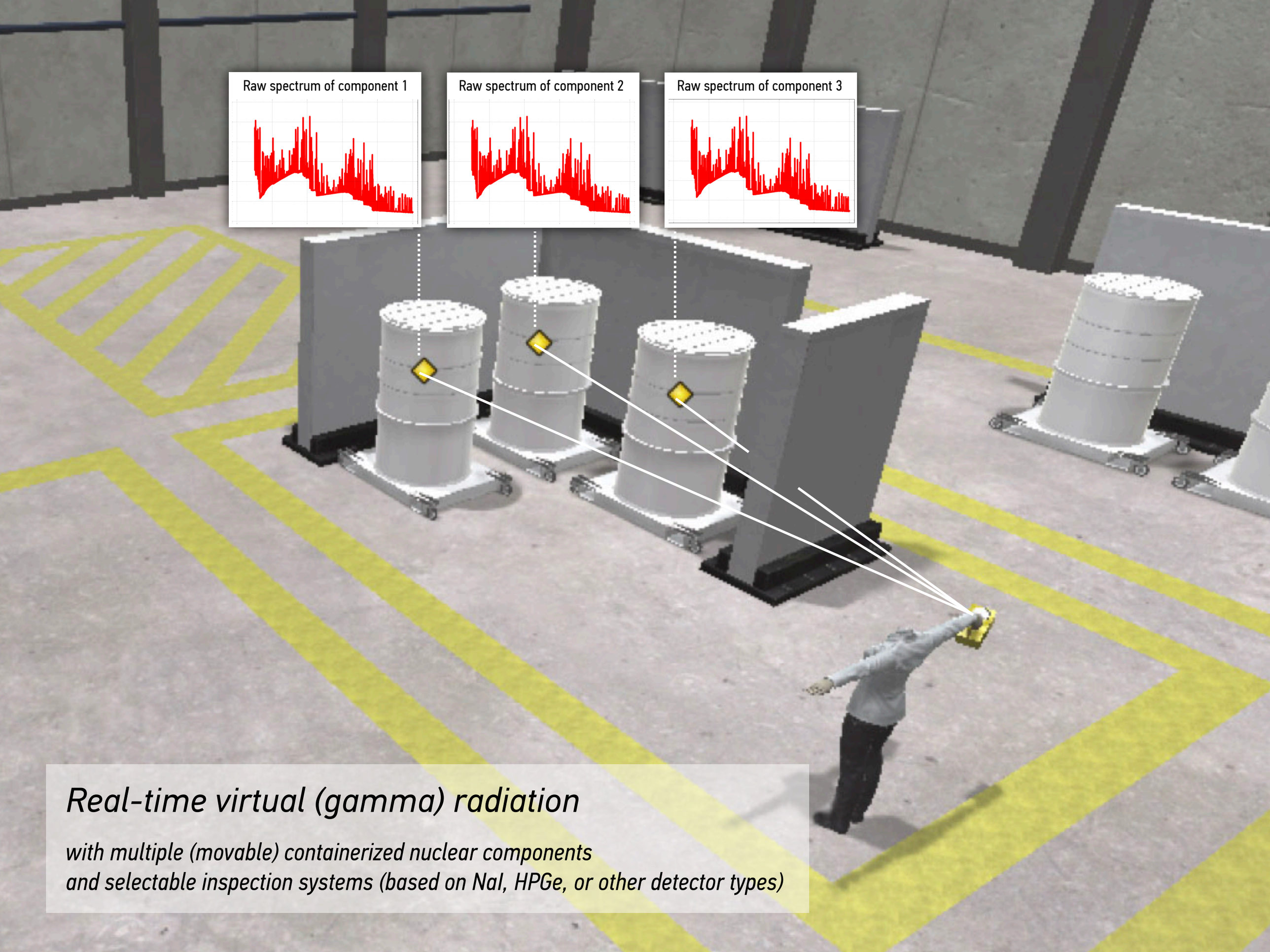

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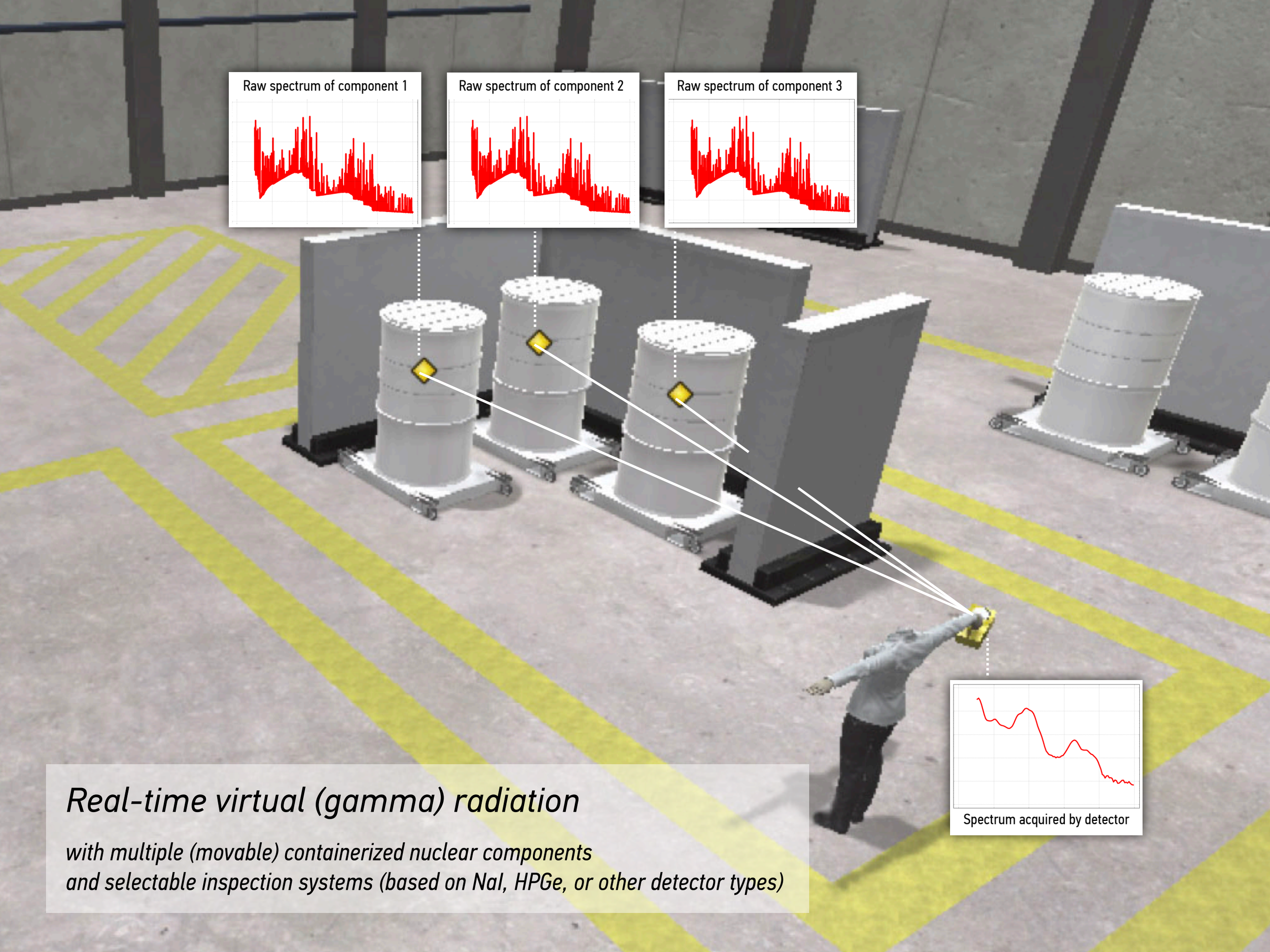

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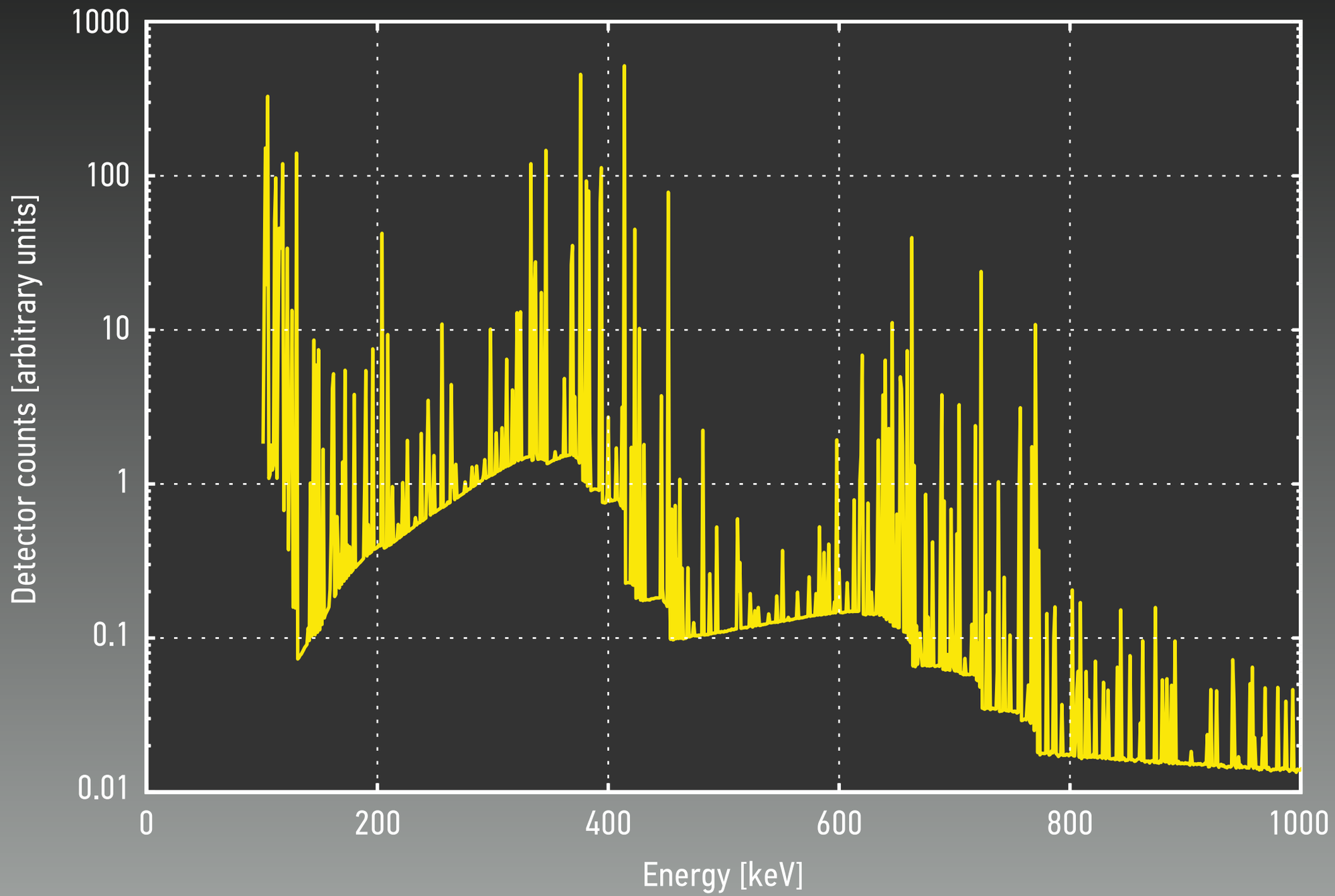
INFINITE-RESOLUTION GAMMA SOURCE TERM

BALL OF WEAPON-GRADE PLUTONIUM, PRE-COMPUTED (WITH MCNP)



UNCOLLIDED PHOTON FLUX

UNCOLLIDED (GROUP) PHOTON FLUX

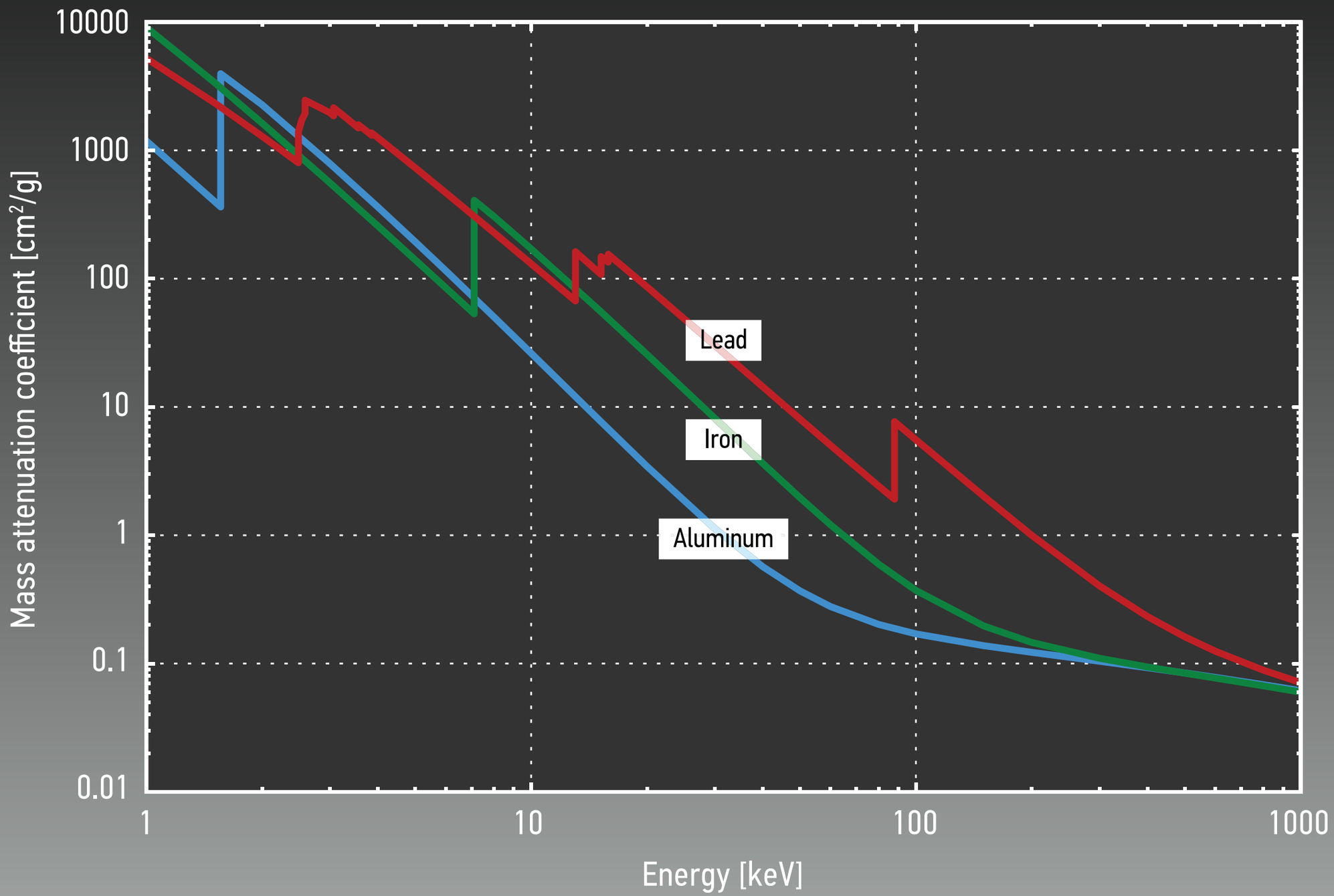
$$C(E_j) = C_j \approx \sum_i S_{i,j} \frac{1}{4\pi r_i^2} \exp\left(-\sum_k \mu_{k,j}\, d_{k,i}\right)$$

$S_{i,j}$ is the relative strength of source i at energy j
$\mu_{k,j}$ is the linear attenuation coefficient for material k at energy j
$d_{k,i}$ is the thickness of material k as seen by source i in the direction of the detector

TOTAL UNCOLLIDED PHOTON FLUX (FOR GEIGER-MÜLLER COUNTER)

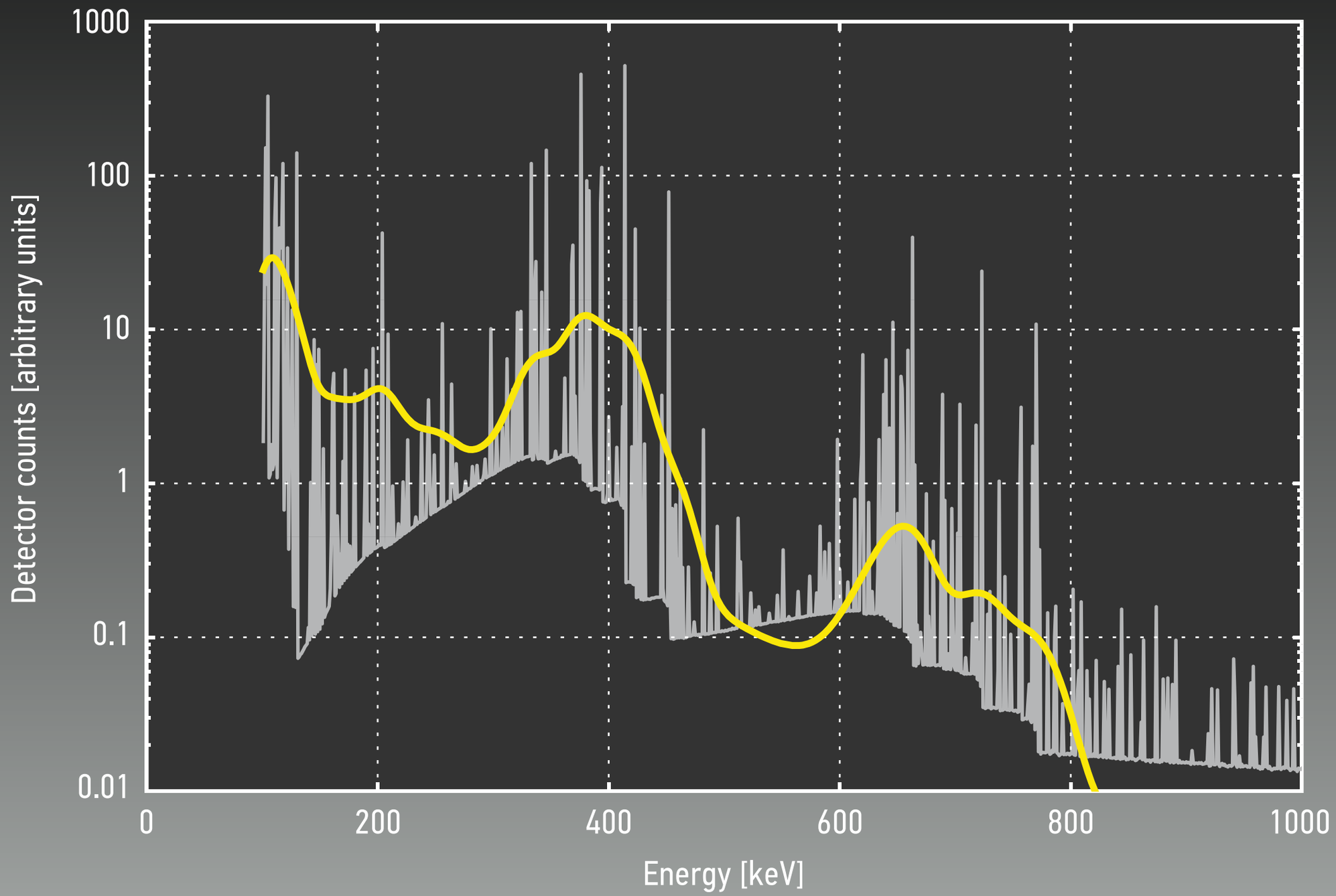
$$C \approx \sum_{i,j} S_{i,j} \frac{1}{4\pi r_i^2} \exp\left(-\sum_k \mu_{k,j}\, d_{k,i}\right)$$

MASS ATTENUATION COEFFICIENTS



SIMULATED SPECTRUM

BALL OF WEAPON-GRADE PLUTONIUM WITH SODIUM-IODIDE DETECTOR



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Closeup of detector and information barrier with simulated radiation spectrum and shielding material handled by user

VIRTUAL ENVIRONMENT

FULL-MOTION CAPABILITY

Freely navigate in a tracking space of any size and shape; enables truly immersive VR experience; currently using WorldViz/Oculus Rift and HTC Vive

UNITY AND OPEN SOURCE

Unity is a cross-platform game engine with broad VR support and a vibrant developers' community; most development toolkits are open source

INTERACTIVITY AND CO-PRESENCE

Critical for operating equipment, host-inspector interactions, and remote collaborations

EXERCISE FRAMEWORK

STUDENT INSPECTION EXERCISE, APRIL 2017

“NON-START AGREEMENT”

REVISION 0

VERIFICATION OF TREATY BETWEEN THE UNITED STATES OF NU AND THE FEDERATION OF KAPPA ON MEASURES FOR THE FURTHER REDUCTION AND LIMITATION OF NON-DEPLOYED STRATEGIC OFFENSIVE ARMS (NON-START)

JOINT BRIEF TO HOST AND INSPECTION TEAMS

January 16, 2028

At 0001 hours today, the Non-START agreement went into effect. At 1000 today, pursuant to Article XI of the Treaty, the government of Kappa gave notice for an on-site inspection at the Base Alpha storage facility in the United States of Nu (USN). The inspection will take place immediately after the 24-hour notice period has elapsed, at 1000 on January 17, 2028.

As a reminder, recall that the Non-START agreement limits the USN and Kappa to one hundred (100) non-deployed warheads each, held within the territory of each State Party, under its jurisdiction, or under its control anywhere. To facilitate verification of this agreement, each State Party has been issued 100 non-counterfeitable buddy tags. Non-deployed warheads that are not in transport must be accompanied by a buddy tag, which must be stored and displayed in a designated area of each facility where non-deployed warheads are located. For non-deployed warheads in transport, a buddy tag must be carried in the same vehicle as the warhead. The existence of any non-deployed warheads (i.e. those not mated to missiles, or those not a heavy bomber bases) unaccompanied by buddy tags, under any circumstances, constitutes a Treaty violation.

The Non-START agreement allows each State Party to conduct ten (10) on-site inspections with 24-hour notice each calendar year. Details of the inspection procedure are given below.

INSPECTION PROCEDURE

1. Notice for an on-site inspection at a storage facility must be given at least 24 hours prior to arrival of inspectors at the facility.

2. Upon receiving notice, the host country must activate all buddy tags at the facility. While activated, motion detectors in the buddy tag will look for illicit movements of the tag. For the first 24 hours after activation, buddy tags will display a yellow light.

3. Once 24 hours have elapsed, the inspection team will arrive at the facility. The inspectors will *first* visit the buddy tag display area to count and record the condition of the buddy tags.

   Buddy tags have not been tampered with or moved will display a green light. Buddy tags that have been tampered with or moved since being activated will display a red light. Buddy tags that have been turned on too late will display a yellow light.

   The inspection team reserves the right to demand information from the host to explain the position, condition or status of any buddy tag.

4. During each inspection, the inspection team has the right to visit one (1) storage bunker after visiting the buddy tag display area.

   The Base Alpha storage facility houses three bunkers: Bunker A, Bunker B, and Bunker C.

5. During the bunker inspection, the inspection team will be escorted by the host. The inspection team may choose one (1) item for a warhead confirmation measurement by means of the Information Barrier (IB) system.

6. The IB system will be operated by the host, under the direction of the inspection team.

7. The IB will measure the gamma spectrum of the selected item. The IB will display a green light if the measured warhead is of a type covered in the Non-START agreement. The IB will display a red light if the item is not a warhead of the type covered in the treaty (it could be another type of warhead, or something else).

Restrictions on activities of the inspection team

- In the buddy tag display area, inspectors must stay at least 1 meter away from the buddy tag shelves.
- In storage bunkers, inspectors may not touch or interact in any way with any items.
- During the authentication process, inspectors may not interact with the information barrier, and must stay at least 1 meter away from it. Inspectors may not stand between the information barrier and the item being inspected.

Restrictions on activities of the inspection team

- In the buddy tag display area, host personnel must stay at least 1 meter away from the buddy tag shelves.
- During the authentication process, host personnel may not stand between the information barrier and the item being inspected.

“NON-START AGREEMENT”

REVISION 0

VERIFICATION OF TREATY BETWEEN THE UNITED STATES OF NU AND THE FEDERATION OF KAPPA ON MEASURES FOR THE FURTHER REDUCTION AND LIMITATION OF NON-DEPLOYED STRATEGIC OFFENSIVE ARMS (NON-START)

[illegible] AND INSPECTION TEAMS

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REVISION 0

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STUDENT INSPECTIONS IN VIRTUAL REALITY

DEMO

(video)

www.youtube.com/watch?v=rqckeacqR1k

Display area with a tabletop model of the site;
In the background, shelves
with buddy tags, one of them disturbed

Storage bunker with warhead storage containers;
Inspectors can select one or more
containers for inspection with information barrier

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Closeup of information barrier during inspection using a sodium-iodide detector and a template-matching approach

STUDENT INSPECTOR

OUTLOOK / NEXT STEPS

WHAT CAN BE LEARNED FROM VIRTUAL EXERCISES?

1. ARCHITECTURE

Existing versus dedicated facilities?

Should the structure prioritize disassembly efficiency or verification?

How "integrated" can inspectors be in the facility?

2. VERIFICATION TECHNOLOGY

Differences in protocols for different technologies (e.g. templates vs attributes)

Continuity of knowledge: how to track weapons and components?

3. MANAGED ACCESS

How can hosts grant inspector confidence without revealing classified information?

How can inspectors gain confidence without gathering any proliferation-sensitive information?

4. SYSTEM INTEGRATION

How do aspects of the larger nuclear weapon life cycle and fuel cycle influence verification at the warhead level?

OUTLOOK / NEXT STEPS

EXPANDING THE FRAMEWORK

Further development of radiation module and improving functionality and variety of detectors

Improving ability to interact with VR environment and with other players and building a greater variety of facility types

FACILITATING COLLABORATIONS / ENGAGING NEW AUDIENCES

Collaborative VR exercises can help facilitate new partnerships and lay the basis for live exercises and new policy initiatives

VR also appears effective in engaging students on arms-control issues

ACKNOWLEDGEMENTS

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