

# CROSSING REALITIES

CONNECTING THE VIRTUAL AND  
THE PHYSICAL WORLD  
FOR REMOTE INSPECTIONS

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# THE TEAM



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# BACKGROUND I

Real & Virtual Verification Exercises

# (REAL) INSPECTION EXERCISES



Source: NuDiVe and FZ Jülich (top), [ukni.info](http://ukni.info) (bottom, left), [quad-nvp.info](http://quad-nvp.info) (bottom, right)



# VIRTUAL REALITY

## AS A TOOL FOR THE JOINT DEVELOPMENT OF NEW VERIFICATION APPROACHES



### THE ORIGINAL IDEA

Create open and flexible virtual environments to explore new verification concepts and approaches — which could then also lay the basis for live exercises and new policy initiatives



### (PREVIOUS) PRIMARY FOCUS OF PROJECT

Examine fundamental questions related to interactivity, user experience, and presence in virtual environments; but also explore “cheating scenarios” relevant for assessing the effectiveness of different verification approaches

*See our INMM papers in 2016, 2017, and 2021*

Source: Authors





Demonstration of earlier project at the UN, Geneva  
*on the margins of a meeting of the Group of Governmental Experts on  
nuclear disarmament verification, Palais des Nations, May 2018*

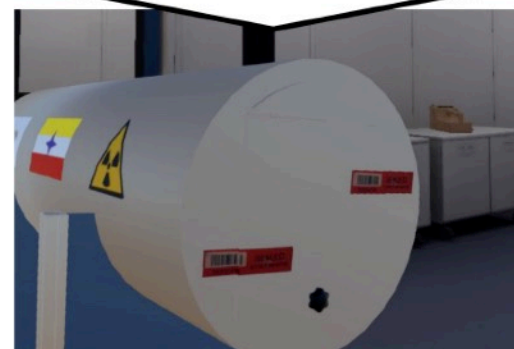
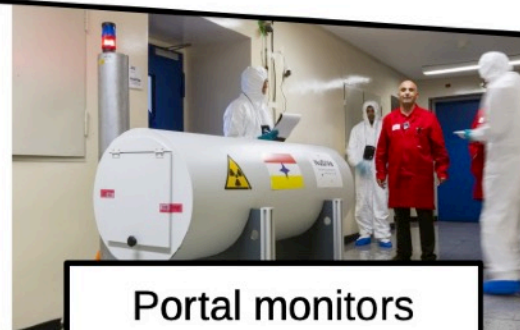




# NuDiVeR

Nuclear Disarmament  
Verification

Implements all major inspection technologies:



[www.haw-hamburg.de/fileadmin/Bilder-zentral/News-Presse-Veranstaltungen/2021/PDF/NuDiVeVR\\_RevCon\\_2022\\_poster.pdf](http://www.haw-hamburg.de/fileadmin/Bilder-zentral/News-Presse-Veranstaltungen/2021/PDF/NuDiVeVR_RevCon_2022_poster.pdf)

S. Sonder, J. Scheunemann, S. Hebel, and G. Kirchner, Nuclear Disarmament Verification in Virtual Reality, *INMM & ESARDA Joint Virtual Annual Meeting*, 2021

# BACKGROUND II

Secure Virtual (Remote) Inspections



# ONSITE VS REMOTE INSPECTIONS



## PROS & CONS OF ONSITE INSPECTIONS

Onsite inspections remain the “gold standard” for IAEA safeguards and nuclear arms-control verification

Inspections tend to be costly and are often considered intrusive, especially in the arms-control context



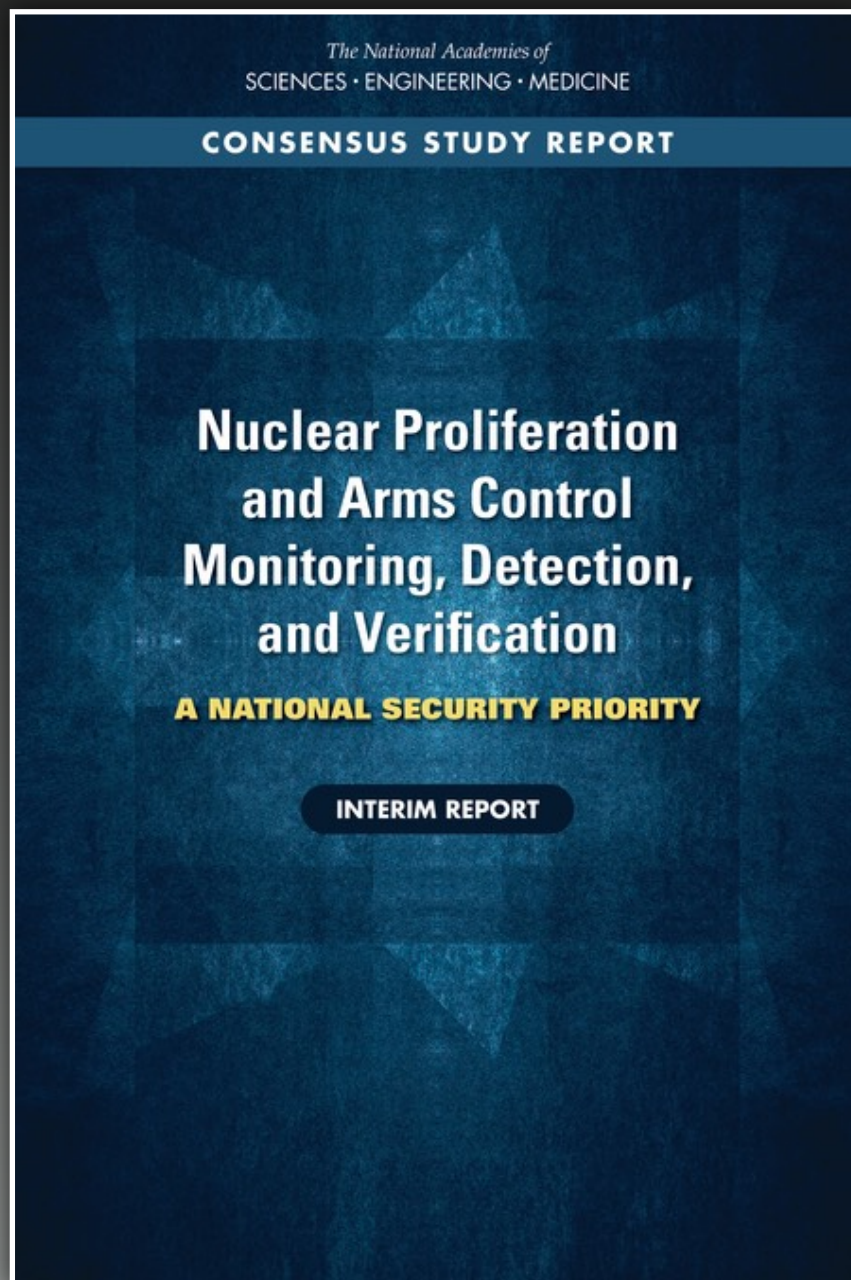
## CAN WE (PHYSICALLY) “SEPARATE” HOST & INSPECTOR?

Many concerns could be addressed and resolved if inspectors were not “physically” present onsite

Many ways to imagine various remote inspections techniques, which could be as simple as standard video transmissions

Source: [ukni.info](http://ukni.info) (top) and [microsoft.com](http://microsoft.com) (bottom)

# CAPABILITY NEEDS FOR ARMS CONTROL



## 3.4 MDV FOR ARMS CONTROL

### 3.4.1 Capability Needs

...

*Treaties that include weapons in storage or weapons designed for shorter-range delivery systems are anticipated to require new MDV techniques. As a minimum, such treaties would likely require access to storage areas either directly or remotely, and confirmation of warhead count (either a baseline confirmation or through routine/challenge inspections).*

*Jill Hruby, Corey Hinderstein, et al., Committee on the Review of Capabilities for Detection, Verification, and Monitoring of Nuclear Weapons and Fissile Material, National Academy of Sciences, Washington, DC, 2021, [doi.org/10.17226/26088](https://doi.org/10.17226/26088)*





*Mk21 reentry vehicles and containerized W87 warheads at F. E. Warren Air Force Base, Cheyenne, Wyoming, October 1992*

Source: Paul Shambroom, [paulshambroom.com](http://paulshambroom.com)





*Demonstration of the B61 nuclear weapon disarming procedures using an inert training version, Volkel Air Base, June 2008*

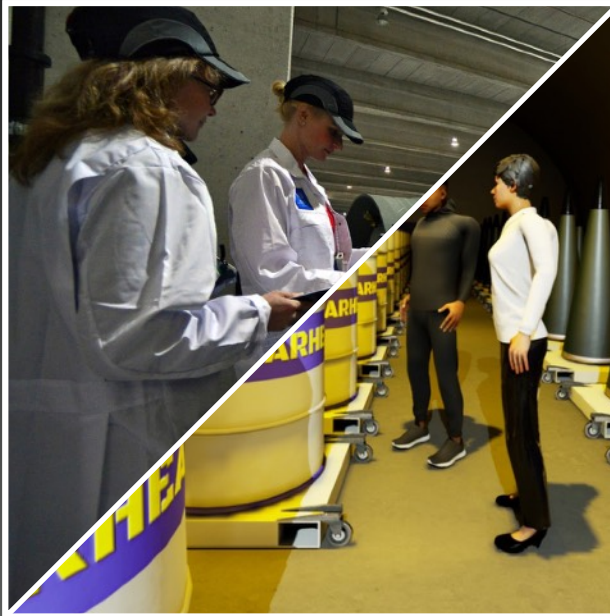
*Source: U.S. Air Force*



IDEA

Remote Inspections Leveraging Virtual Reality

# REMOTE INSPECTIONS VIA VIRTUAL REALITY



## BASIC CONCEPT

Remote inspector participates via “digital twin” of the inspected facility

The virtual facility could be a faithful reproduction of the physical facility or it could be purposefully simplified such that only relevant areas are represented

Sensitive features are never modeled



## REQUIREMENTS

- Tracking and navigation in the virtual and physical facilities
- Real-time communication
- Meaningful interactions between the host and the inspector

*Source: IAEA and authors (top) and UKNI (bottom)*



## Mockup warhead

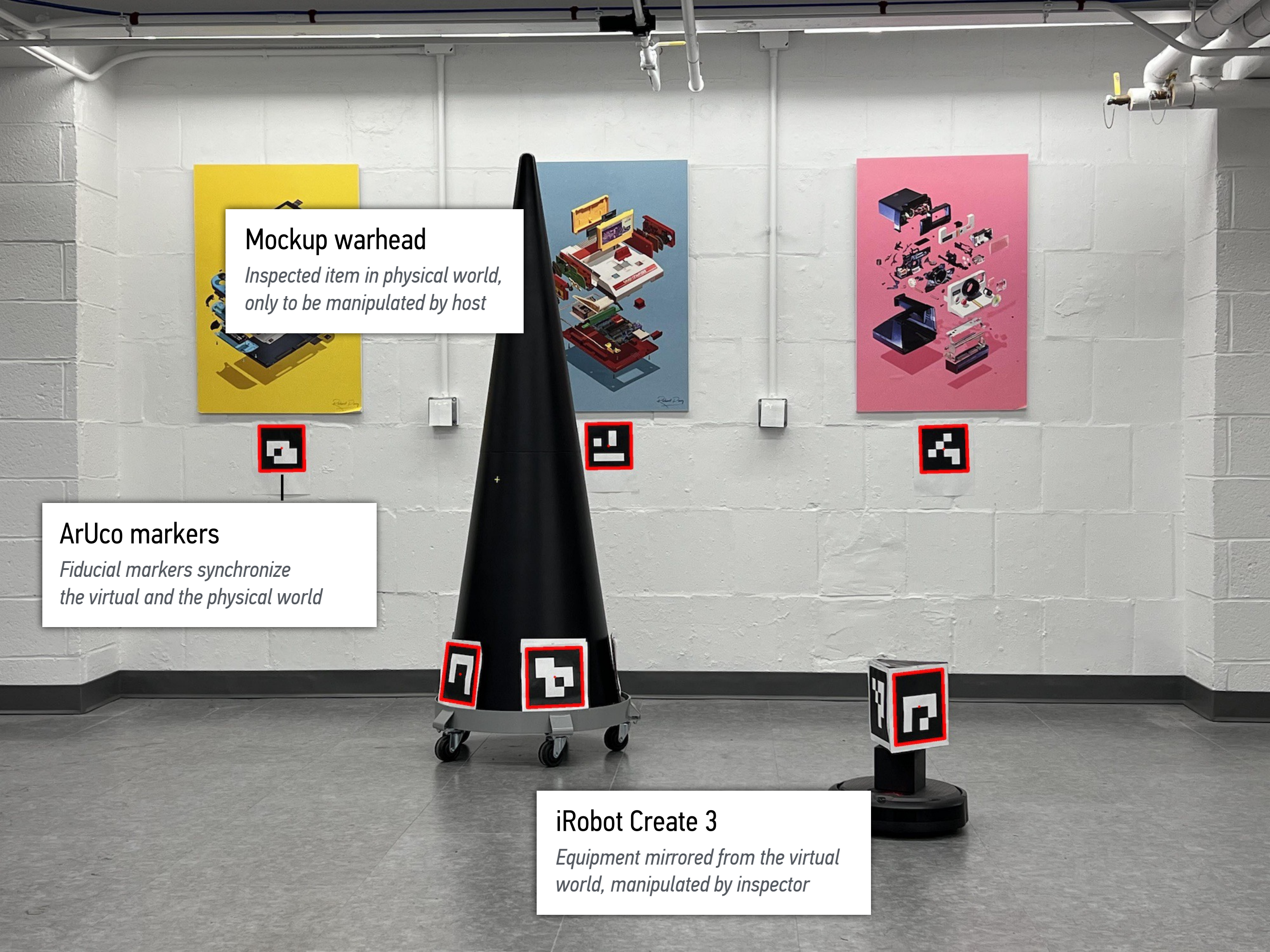
*Inspected item in physical world,  
only to be manipulated by host*

## ArUco markers

*Fiducial markers synchronize  
the virtual and the physical world*

## iRobot Create 3

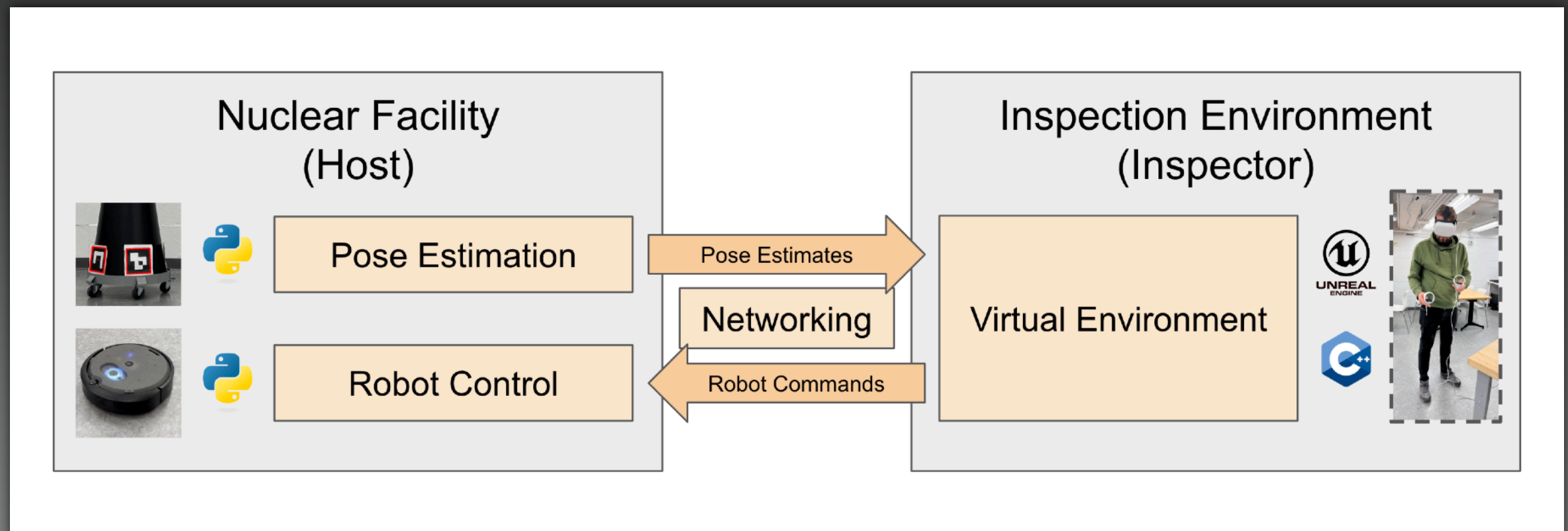
*Equipment mirrored from the virtual  
world, manipulated by inspector*





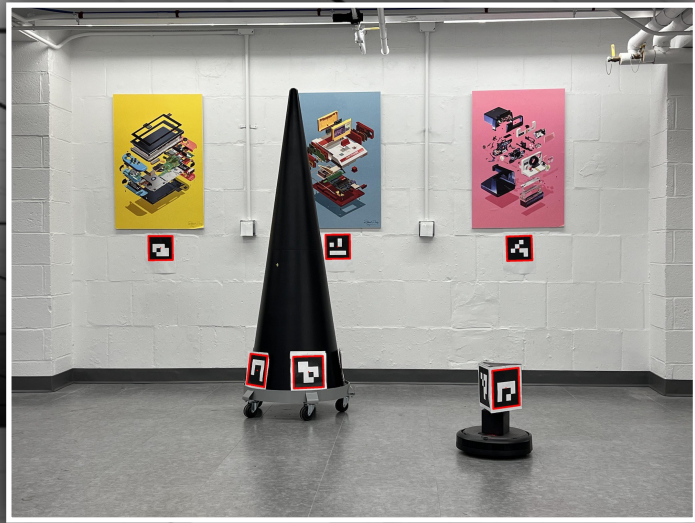
# TECHNICAL ARCHITECTURE

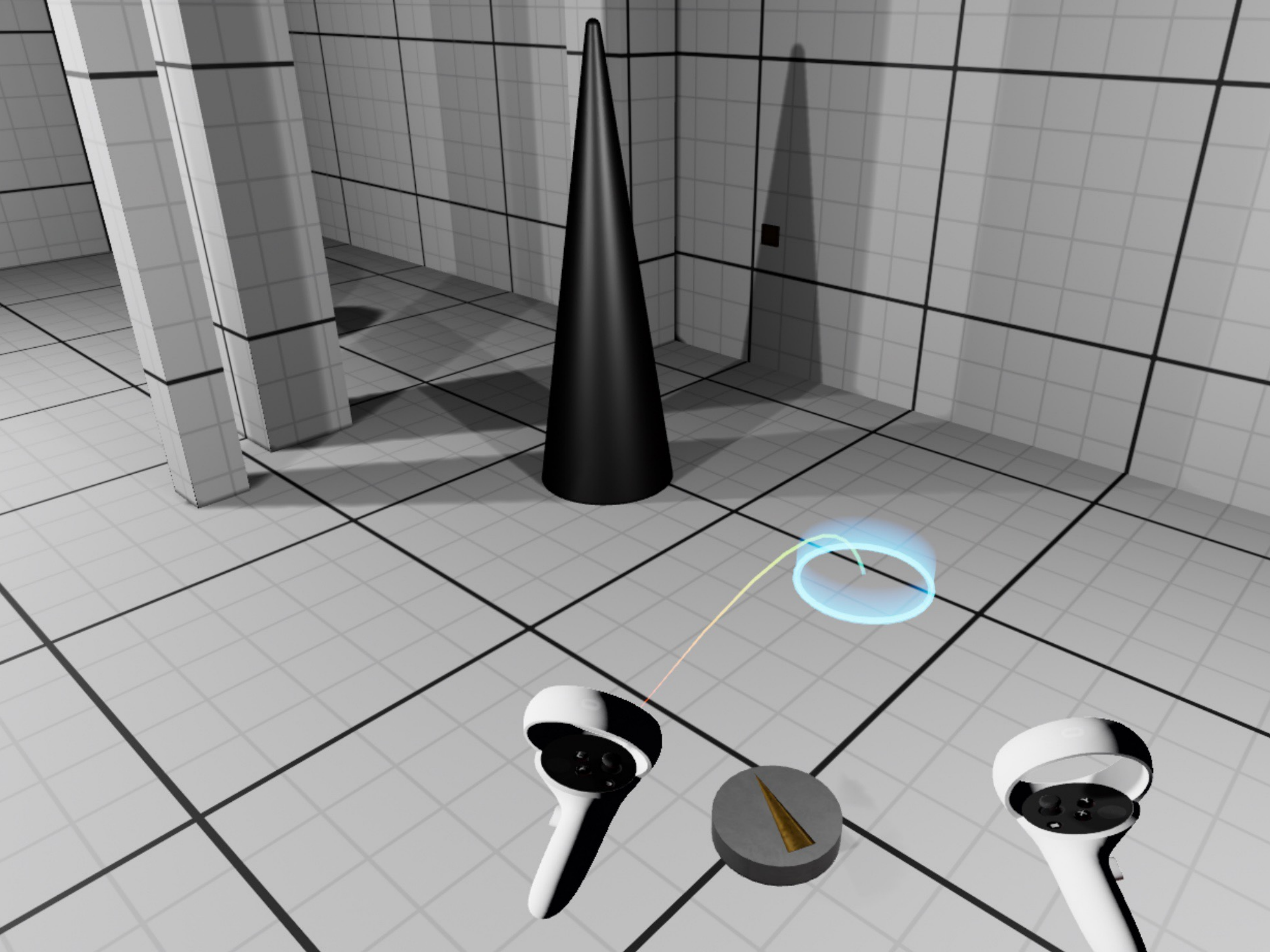
(POSE ESTIMATION, NETWORKING, ROBOT CONTROL)



Code available at [github.com/daphne-barretto/crossing-realities\\_remote-inspections](https://github.com/daphne-barretto/crossing-realities_remote-inspections)









# BENEFITS & CHALLENGES OF REMOTE INSPECTIONS



## BENEFITS (REVISITED)

- Reduced intrusiveness, time, and cost compared to onsite inspections  
*Potentially also of interest for some routine IAEA inspections*
- Reduced security risks of disclosing sensitive information  
*Sensitive details and objects are never modeled*



## CHALLENGES

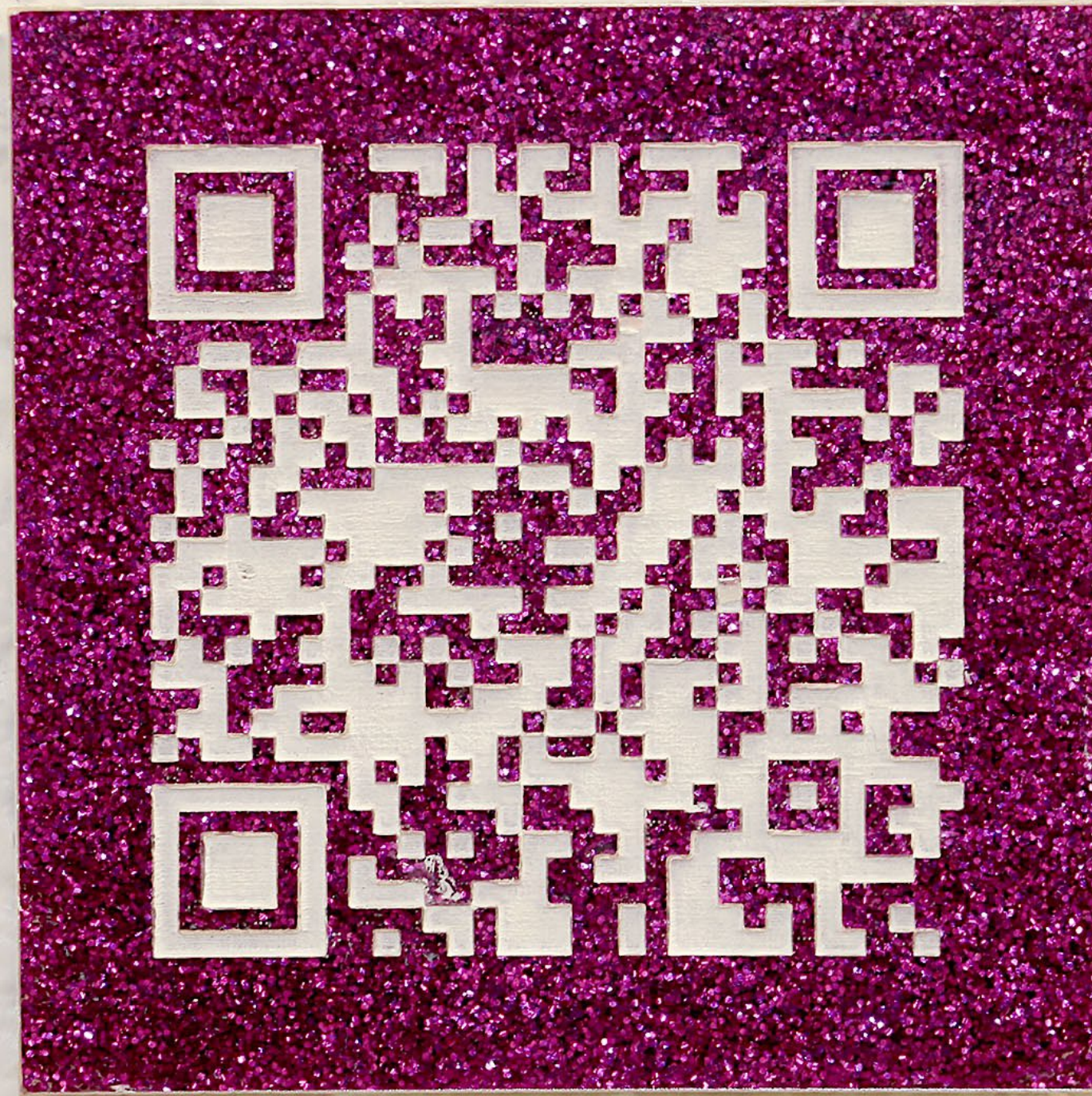
- Security and integrity of transmitted data
- Live and local verification  
*Roger G. Johnston and Jon S. Warner, "Unconventional Approaches to Chain of Custody and Verification," 51st INMM Meeting, Baltimore, MD, July 2010*

Source: IAEA (top) and Johnston and Warner, 2010 (bottom)

LIVE & LOCAL VERIFY

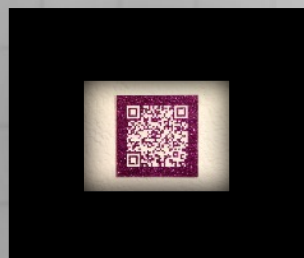
(Example)





*Assume that Unique Identifiers (UIDs, such as reflective particle tags) can be embedded in the inspected facility ...*





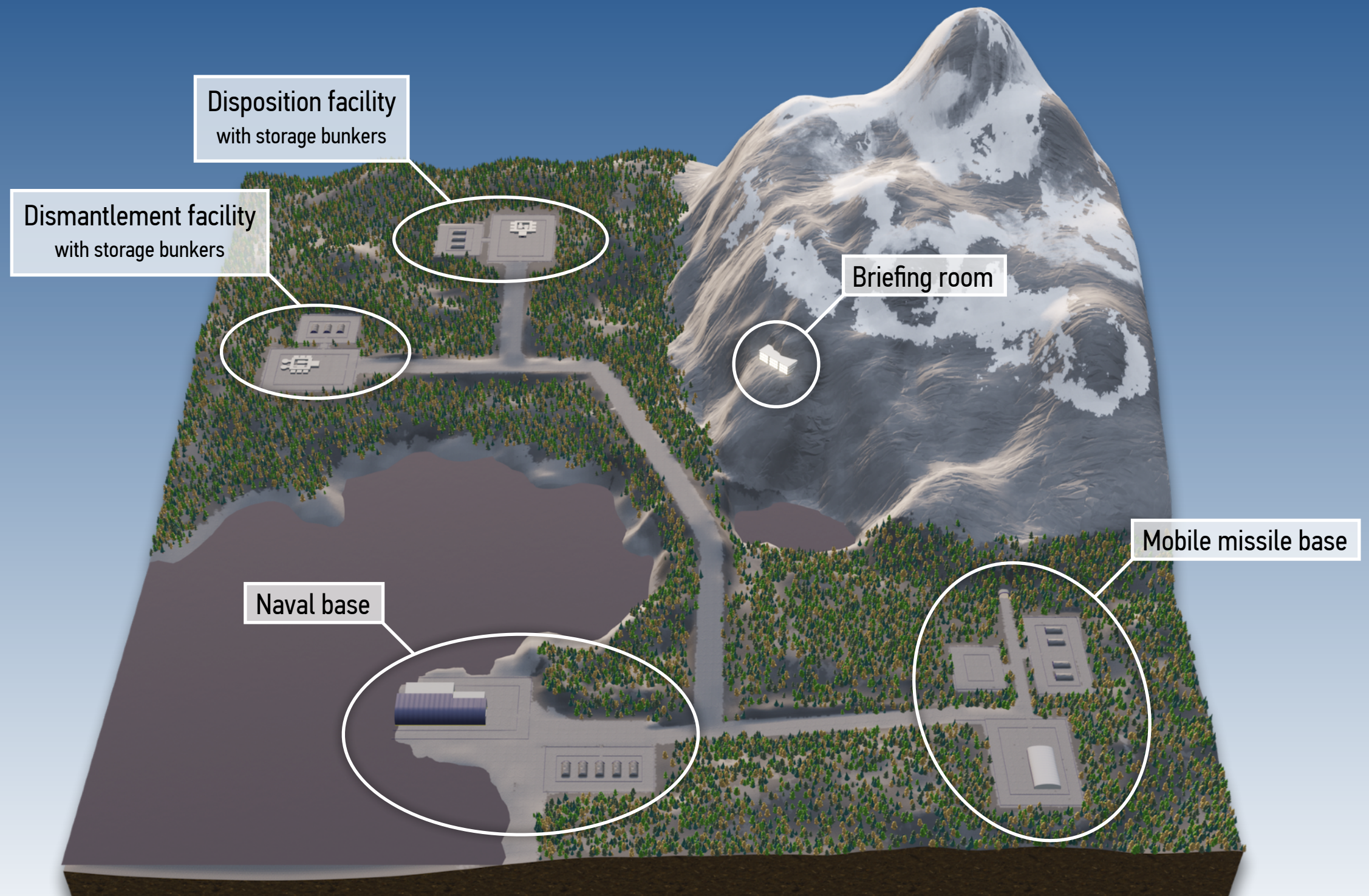
*“Peeking into the physical world” — We envision a procedure through which a unique feature of the inspected facility can be remotely confirmed so that the inspector is confident that activities are taking place at the correct site.*



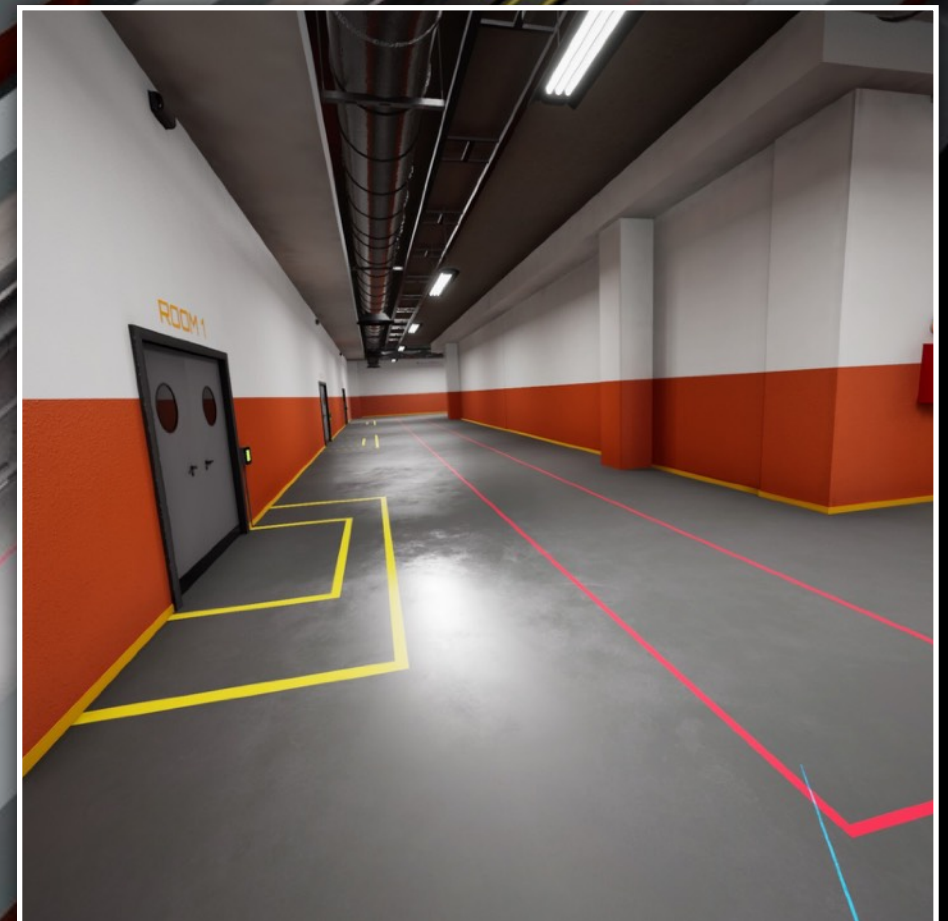
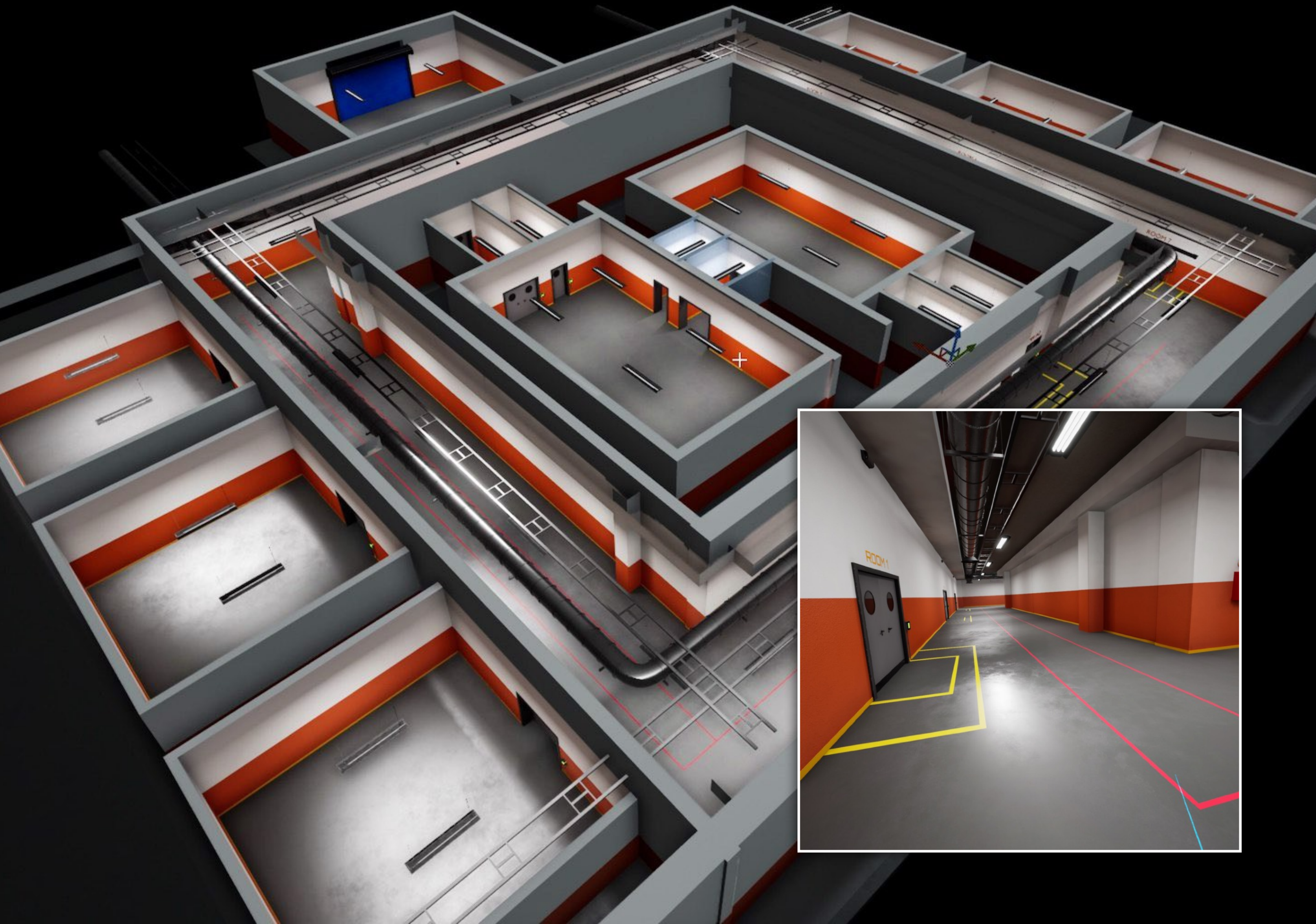
WAY FORWARD



# GEOGRAPHY OF OUR VIRTUAL WORLD

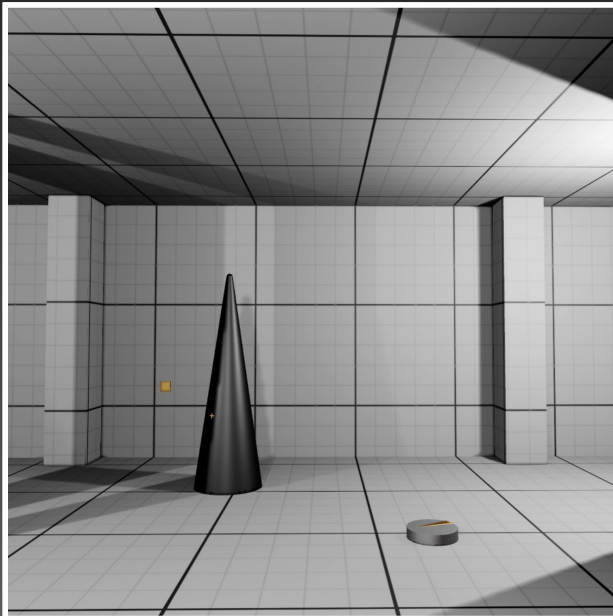








# CONCLUSION & OUTLOOK



## THE POTENTIAL ROLE OF REMOTE & VIRTUAL INSPECTIONS

While no substitute for onsite inspections, remote monitoring and virtual inspection techniques could play an increasingly important role in future arms-control verification and safeguards

Successful proof-of-concept remote inspection using virtual reality



## NEXT STEPS

Development of a “deployable” prototype system

- Users in distinct locations
- Improved camera system (motion-capture system or RGB-depth camera)

Conduct small verification exercise following a notional inspection protocol

*Source: Authors (top) and M. Schöppner (bottom)*