Virtual Reality in Support of Nuclear Disarmament

Interactivity, Curveballs, and Gameplay

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Abstract. We have developed the prototype of an extensive multiplayer virtual environment ("NuVR") using *Unreal Engine* that seeks to enable international collaborations in the area of nuclear arms control and disarmament. The virtual world includes several key facilities and areas relevant for nuclear verification, including a naval base with a docked submarine, a mobile missile base, a warhead dismantlement facility, a disposition facility, and a number of storage bunkers available at various sites of the environment. The primary goal of the project has been to make possible effective interactions between remote participants of a virtual inspection exercise in this environment. Users can use several types of instruments and perform activities relevant to the inspection scenario with an emphasis on warhead inspections. We have been particularly interested in incorporating gameplay elements, including non-compliance scenarios and unexpected events ("curveballs") to create an illusion of spontaneity for the participants, which enables us to examine the effects of these events on the overall robustness of the approaches considered.

Background

At the end of the Cold War, cooperative approaches to nuclear security and verification were widely recognized as key to building confidence and addressing technical obstacles vis-à-vis future arms-control and disarmament measures. These programs have all ended, however, and cooperation on nuclear arms-control issues continues only on a very small scale and does not involve many relevant parties. New approaches are urgently needed to revitalize nuclear security and arms-control initiatives at the government level. Here, we explore the potential of virtual reality (VR) environments to support innovations in nuclear arms control, in particular, the role they could play in developing facility architectures and verification protocols for treaties that do not yet exist.

This paper builds on some of our earlier work,[1] and introduces our new environment (NuVR), which places a particular emphasis on gameplay elements, non-compliance scenarios and unexpected events and includes a variety of facilities that are potentially relevant in future arms-control inspection scenarios. We have used a prototype of NuVR as part of a course taught at Technische Universität Berlin, Germany, in the fall semester 2020/2021.

Architecture of the Virtual World

NuVR is being developed with *Unreal Engine*, a state-of-the-art game engine and collection of development tools for games and a wide range of other digital content. Developers have free access to the full source code.[2] *Unreal* uses C++ and a visual scripting system ("Blueprint"), which can be used separately or in tandem. NuVR is fully networked so that multiple players can participate (locally or remotely) and interact with each other in real time. The software captures movements of all relevant items, including containers, treaty accountable items and their components, sources, and equipment.

Geography. Figure 1 shows the geography of the virtual world. NuVR currently includes a briefing room, a naval base, a mobile missile base, a dismantlement facility, and a disposition facility. Users spawn in the briefing room, where they can familiarize themselves with the environment and the inspection scenario. The experience offers full-motion capabilities and "teleportation" features so that all sites and buildings can be accessed during an inspection exercise.

Networking. NuVR currently uses a cloud-based game-server solution offered by Amazon Web Services, called *GameLift*, which offers scalability and low latency, and is robust against connection issues that some remote players may experience. Depending on their importance for real-time gameplay, in-game events can run on the server, be multicast on both server and client, or run on the client alone.

State of the world. In order to begin the gameplay experience, one player from the host team creates a new session. The state of the world is defined in a JSON file that is provided by this player and read upon session launch. All other players can later join this session, either as part of the host or the inspector team. Only the player creating the session knows the "true" initial state of the world, which may include hidden objects and invalid items, for example, storage containers with weapon components that do not contain fissile materials and are flagged as "invalid" in the JSON file. As the events in the experience unfold, the state of the world can be saved to new JSON files so that future instances of the scenario can be restarted at later moments in the experience.

Avatars and non-player characters: Players are randomly assigned avatars upon launch of the experience. Avatars are chosen from a diverse and growing set of characters and,

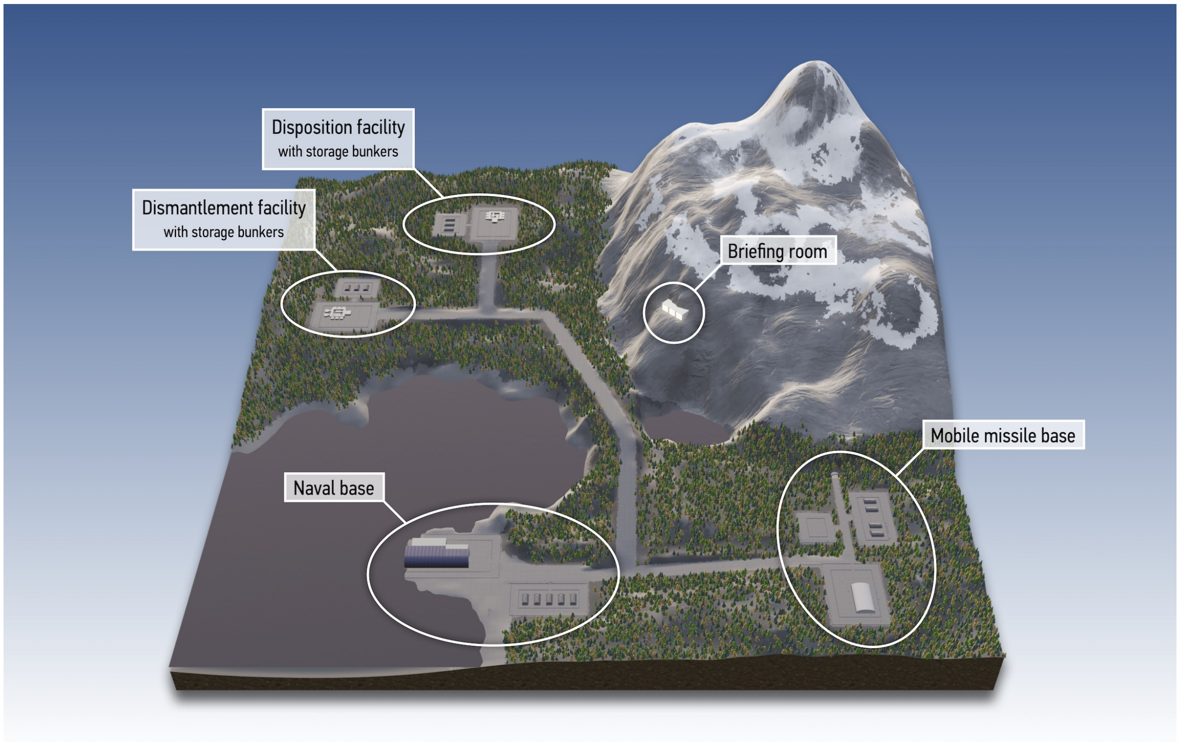

Figure 1. The Virtual Nuclear Weapon State. Accessible areas include a naval base, a mobile missile base, a dismantlement facility, and a disposition facility. A briefing room overlooking the region serves as a meeting point where the teams can discuss and familiarize themselves with the inspection scenario.

independent of the true height of the user, all players are equally tall (170 cm) while in the experience. In addition to the avatars controlled by human players, non-player characters can be present in the experience, but their behavior has to be programmed separately. Non-player characters are currently used primarily as security guards, who are present at multiple locations across relevant facilities. As briefly discussed further below, these non-player characters can be used to assess the possible impact of misdirection techniques during an inspection.

User experience and immersion. Immersion is a major element of virtual reality applications since it is expected to influence the behavior of users in the experience.[3] Immersion is frequently referred to in VR research as a perceptual phenomenon that is reliant upon the individual user and the context.[4] For the optimal user experience and immersion, users can navigate freely through the environment and interact naturally with the elements therein. Items can be spawned, placed, and used in the environment, and radiation detectors can be handed over from one user to another. Communication between users is achieved with an always-on audio channel with directional sound to improve user engagement.[5] Dynamic shadows and ambient noise add to the authenticity of the experience. As many inspection scenarios involve treaty-accountable items with unique identifiers and declarations that an inspector may have to work with, we placed a particular emphasis on the readability of in-game text and documents.[6]

Scenes from the Virtual Inspection World

In order to illustrate the capabilities of our virtual environment, in the following, we briefly discuss a number of scenarios highlighting relevant aspects of the system and some possible use cases.

Confirming the Correctness of Declarations

Nuclear inspections often seek to confirm the correctness of a declaration made by the inspected party beforehand. This is true for both nuclear safeguards applied in NPT non-nuclear weapon states and for nuclear arms-control inspections. As this task represents a significant aspect of inspections, we wanted to include it as a routine activity in our scenarios. To facilitate this procedure, every major item in the environment has a visible serial number or unique identifier (UID) that can be accessed and read by the team of inspectors; when applicable, items also have characteristic radiation signatures. "Treaty accountable items" include storage containers for warheads and warhead components. As all other information relevant for the state of the world, serial numbers and materials are stored in the JSON file; in general, UIDs are randomly assigned when items are first placed in the world, and they cannot be modified during the experience.

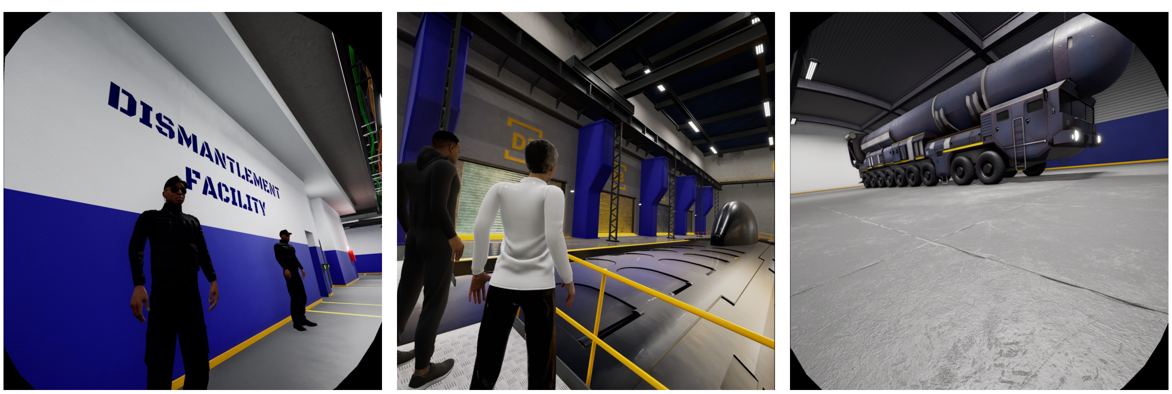

Figure 2. Views from the virtual world. Security guards can be placed throughout NuVR and perform pre-programmed tasks or actions that are triggered by certain in-game events (left). Overlooking a docked ballistic missile submarine (center). Transporter Erector Launcher in a garage at the mobile missile base (right).

Conducting Absence Measurements

The use of radiation-detection equipment in nuclear arms-control verification has so far been rather limited.[7] Under New START, the bilateral agreement between Russia and the United States capping the number of deployed strategic weapons,[8] parties are allowed to make neutron measurements to confirm the non-nuclear nature of objects, i.e., to confirm the absence of additional nuclear weapons. Concepts have been developed to also consider gamma measurements for such absence measurements.[9] Even future agreements limiting the total number of nuclear weapons, both deployed and non-deployed, could envision absence measurements as a key inspection procedure.

In NuVR, warheads and their components can contain several materials, including plutonium, highly enriched uranium, natural uranium, as well as certain non-nuclear materials. These materials are specified in the JSON file for each object. The presence of any one of the nuclear materials will trigger the gamma counter; the presence of plutonium will also trigger the neutron counter, which is modeled after the modified Eberline ESP-2 previously used under New START.[10] NuVR currently uses a simplified radiation model with an adjustable source strength and radiation fields dropping off with distance following a $(1/r^2)$-dependency. Background radiation levels in the facilities can be set within specified ranges for each area. Radiation detectors display measurements that are consistent with the total radiation level at the detector's current position, taking into account the stochastic nature of the process.

In a standard absence measurement scenario, the inspector would first identify an object for inspection that has been declared "non-nuclear" by the host. This item is then moved to a separate part of the facility, where radiation levels are low and measurements can be conducted without interference from other objects. The inspector can then confirm that emissions are indeed below an agreed level following the procedures defined in the relevant inspection protocol. As discussed below, there are various strategies for the host to misdirect the inspector in anticipation of an absence measurement.

Setting-up Non-compliance Situations

Ultimately, we want to help devise effective verification approaches. Exploring a variety of non-compliance situations can be an important strategy to assess the robustness of proposed or possible approaches. Here, the use of virtual reality can offer a powerful tool as inspections can be repeated numerous times under carefully controlled conditions. While arbitrarily complex scenarios can be constructed in the virtual environment—including, for example, trapdoors, double walls, and hidden areas with secret entrances—here, we focus on basic scenarios where the host party has available additional containers with invalid items that can be used to substitute containers with valid items. During the dismantlement stage, without the inspectors present, the host may then have the opportunity to divert weapon components or fissile materials. In order to streamline such activities, items can be moved individually or, when palletized, in groups. In particular, the dismantlement of a nuclear warhead results in four separate containers (primary, secondary, high explosive, and non-nuclear components), which are automatically placed on one pallet. The host can rearrange and "re-palletize" the containers before the inspector team is allowed to access these items.

Assessing the Relevance of Forcing and Misdirection

Our project currently places an emphasis on the relevance of forcing and misdirection techniques and their possible impact on the effectiveness of different verification approaches. As an example, we focus on the situation in a storage facility (bunker) where reserve warheads may be stored. We consider a simple scenario, where some of the items are invalid, and the host seeks to avoid their selection for inspection, which may involve radiation measurements revealing the non-compliance situation.

Forcing Techniques

The last decade has seen a sharp rise in scientific research using magic tricks as a tool to investigate classical psychological and cognitive processes such as attention, problem-solving, or perception.[11] More recently, a new research program has emerged, investigating magicians' mind control tricks: forcing techniques, also called forces.

Although we like to think we are in charge of our decisions, research in psychology consistently shows that many of our behaviors are unconsciously influenced by external stimuli. Magicians have exploited this illusory feeling of freedom for centuries and have developed a wide range of psychological tricks to covertly influence spectators' choice, and these forces are often extremely effective. Scientific research using magicians' forces shows that participants report high feelings of freedom over their choice even though they ended up with the predetermined target card or object.[12] Many of the psychological principles that are the foundation these techniques can be applied to many domains outside magic performances.

In an inspection setting involving a non-compliance situation, we can assume that a "dishonest" host could take on a role similar to that of a magician using forcing techniques, and the inspector (or the team of inspectors) would represent the audience. The host could try to use subtle psychological tricks to covertly guide the inspector(s) to examine only desired items or to neglect other ones.

A successful force has two key components.[13] First, the technique has to significantly affect the inspector's decision or the outcome of their choice. Second, the inspector must feel free in their choice and in control of the outcome they obtain. Two main types of forces have been distinguished, namely outcome forces and decision forces.

In the case of outcome forces, the spectator makes a completely free and deliberate decision, but this decision has no impact on the outcome of the trick or procedure; in other words, non-compliance will never be detected during an inspection.[14] For example, a magician can ask a spectator to select a playing card from a deck where all cards are identical. A key principle here is that the spectator does not understand that their choice cannot affect the outcome of the procedure.

In the case of decision forces, the magician directly manipulates the person's decisions. These techniques allow the performer to increase the odds that the target item is selected, without guaranteeing its choice. Decision forces typically either rely on using psychological biases or restrictions of the spectator's choice.[15] Decision forces often rely on the fact that people tend to choose the item that involves the minimum amount of effort. In the following, we consider decision forces only.

Container Selection Scenario

Any arms-control verification regime is likely to rely, at least partly, on random selection to confirm the correctness of declarations and other information provided by the parties. This could be the case, for example, in a situation where serial numbers are verified or confirmation measurements made.

In one of our notional baseline scenarios, the host and the inspector enter a storage facility, where numerous treaty accountable items are held. The inspector is allowed to select a very limited number of items, perhaps only one, for further inspection. We are currently using NuVR to examine a variety of environmental conditions and unexpected circumstances to understand the extent to which inspection outcomes can depend on these factors. NuVR can be used to examine position forces, visual saliency, and perceptual restrictions among other concepts that could be relevant in this context. We also explore the possible role of non-player characters—in practice, for example, additional host personnel—in steering inspection activities or outcomes in directions preferred by the host. Some of these situations are highlighted in Figure 3.

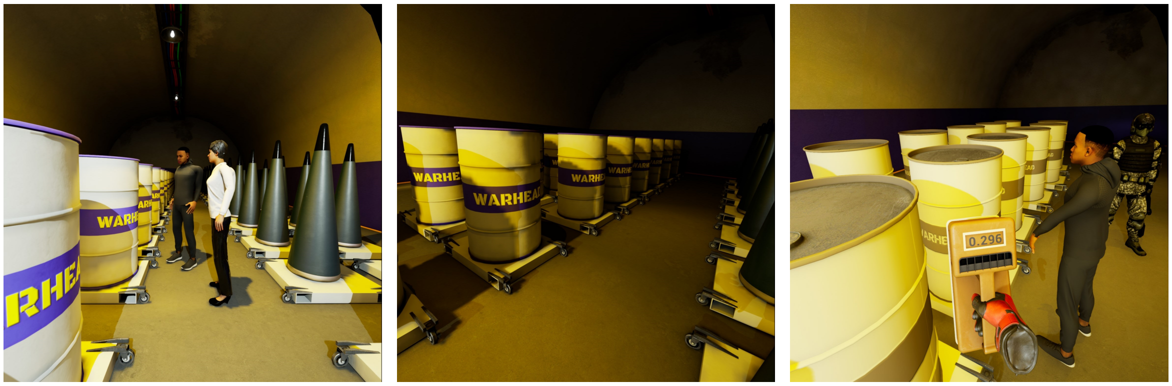

Figure 3. Views from the virtual world. Personnel from the host and the inspector team during a visual inspection of treaty accountable items (left). Storage bunker with uneven lighting (center). Radiation measurement using the neutron detector with a security guard standing nearby (right).

Conclusion and Outlook

There are many unanswered questions surrounding verification options for future nuclear arms-control measures at lower numbers, including whether reductions should emphasize warhead counting or fissile material inventories, how states will balance transparency and security, and how future measures will be implemented in cohesion with existing nonproliferation and arms-control agreements. Accordingly, as researchers and policy makers work to design verification approaches, there is a significant need for frameworks and toolsets to facilitate orientation, design, and testing. States will eventually need to reach compromises in terms of balancing transparency and security, and each may have different views on the feasibility of various options. This situation can be improved by having a greater number of viable options available.

Immersive virtual environments, such as NuVR, can support this process in providing a flexible and powerful new way to extend the research community's ability to examine larger numbers of verification approaches and to assess their viability. Virtual environments can also offer levels of accessibility typically much more difficult to achieve in actual facilities, given security and resource concerns. Accordingly, they can allow for more substantial collaboration amongst research groups and governments working to find solutions to existing verification challenges. In addition, these environments can be used to examine the possible role of psychological tricks deployed to compromise inspections and to assess different strategies to make inspections more robust against such interference. Virtual environments can therefore serve as a tool for the international academic and NGO community to develop new approaches relevant to nuclear arms control and verification, but also as a way to engage the public and grow public sensibility about nuclear weapons.

To make NuVR more useful to experts, we plan to expand the range of inspection equipment, add additional possibilities for interactions within the environment (for example body-movement), and integrate more complex radiation signatures and detector response functions. To make NuVR more useful for research, including a better understanding of techniques using psychological constructs such as misdirection and forcing, we also plan to leverage recent advances in VR technologies, for example by using new VR headsets that offer eye-tracking, heart-rate monitoring, and pupillometry.

It is worth noting that the International Partnership for Disarmament Verification (IPNDV) recently noted that it "may, with support from the academic and NGO community, explore development of a virtual digital environment to explore and change variables to assess consequences and test verification approaches."[16] We hope that NuVR can contribute to this and other efforts advancing verification concepts and applications.

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Endnotes

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[2]*Unreal* is free to use for internal or free projects, but there is a royalty model for commercial use; www.unrealengine.com/en-US/faq.

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