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# Proof of Concept for a Virtual Reality Intervention Evaluation and Training Platform for Highly Radioactive Environments

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## Abstract.

This paper presents a novel way to predict radiation dose using immersive Virtual Reality (VR). The platform allows an assessment of proposed interventions in as much detail and time as required. Its purpose is to give users the maximum amount of agency while in the environment. Workers get a realistic experience practising jobs and supervisors can oversee the expected radiation doses for each intervention.

A proof of concept performed and showed the platform returned a comparable result to the real radiation exposure for a predefined route. The errors of the system are dependant on the dose map. With an accurate dose map, the system will produce reliable results.

## 1. Introduction

An important concept in radiation protection (RP) is the ALARA (as low as reasonable achievable) principle. The likelihood of negative biological effects increases with dose. Therefore, exposure should be minimised wherever possible. However, human presence inside a radioactive area are sometimes required. The ALARA principle requires radiation exposure be as low as possible, while still allowing workers the ability to carry out important tasks. For this reason, human intervention in radioactive areas requires careful planning.

This paper will present ongoing work for the creation of an integrated system for radiation personnel intervention planning. The system is a Virtual Reality (VR) environment with integrated dosimeters that can be applied for various radiation critical interventions, where detailed CAD drawings and dose maps are readily available. It gives users a realistic experience within the target environment without the associated radiation exposure. A virtual dosimeter follows all personnel within the setup, tracking movements and integrated radiation dose. As a result, workers are able to practise the required tasks, and anticipate their exposure to radiation. This allows a proper assessment of how best to complete the work without exposure, and helps optimise a worker's approach to tasks, especially if they are infrequent and/or repetitive such as general maintenance tasks. It is also an effective way for RP to assess the exposure risk of proposed interventions before they are carried out. A complementary application of the system is the review of existing location data. An animated worker follows the 3D-motion path given by these coordinates, and the system tracks and records their radiation exposure. This allows for a 3rd person assessment, giving an alternate viewpoint to the 1st person headset operation. It grants an intuitive identification of high risk areas, and a offers a confirmation for other RP analyses.



A proof of concept will be demonstrated, where the radiation exposure for a predefined route is compared with the prediction of the VR platform.

## 2. Related Work

Using Virtual Reality to train for high radiation exposure procedures has been investigated as early as 2003. The CIPRES (Calculós Interactivos de Protección Radiológica en Entorno Simulado) project, developed by developed jointly by IBERINCO and the Nuclear Engineering Department of the Polytechnic University of Valencia, aimed to create a simulation of refuelling operations for nuclear power plants, and developed a database of radiation doses for the different stages of the refuelling process. The desktop application shows a Sims-like [1] environment, where the user can move and/or change operators around the virtual nuclear plant. Different refuelling stages can be simulated, and the software can show both instantaneous and accumulated doses. However, the software suffered from lack of accuracy due to poor data. Increasing the data for interpolation came with the risk of compromising the plant operations [2].

A similar system was created in 2008 to simulated the dismantling of the decommissioning of the Korea Research Reactor (KRR) 1 & 2. This used the MCNP4 nuclear interaction simulation software to calculate dose rate [3].

In 2011, it was proposed to use neural networks to interpolate a radiation dose rate map for nuclear plants. Like the CIPRES VR software, it is a desktop application that shows both dose rate and accumulated dosage for an individual moving around virtual space [4].

More recently, in 2014, a virtual simulation prototype has been created for the refuelling process of the China Lead-based Research Reactor (CLEAR-I). The refuelling system was being developed, and design scenarios were in a state of flux. The application shows a CAD like model of the refuelling system, and users can perform the refuelling operation in the virtual environment. This setup was designed to train users on the refuelling process; it was not optimised to produce data on the expected radiation dosage of the procedure [5].

These Virtual Reality applications were all desktop orientated, and did not use Virtual Reality headsets to increase the realism of the training program. It was highlighted that the development of VR headsets would present a more immersive experience in a review of Brazilian research into Virtual Reality applications in the nuclear sector [6].

The use of networked VR headsets navigating a shared environment was developed to train workers for a nuclear industrial accident [7]. The system is used to anticipate specific predefined scenarios, using MCNP to estimate dose. The system is similar to the one laid out in this paper, however their focus was to familiarise workers with a new environment and prevent accidents; accuracy of the dose estimation was not assessed.

## 3. Virtual Reality Intervention Platform

The VR Intervention Evaluation platform was created in Virtalis Visionary Render 2.1.0. This software can restrict users and objects to the laws of classical mechanics. It also has a networking function to allow multiple users to connect to a master server and interact within the same virtual environment, or scene simultaneously.

HTC Vive headsets are used with the Steam VR interface to immerse the users inside the environment. The headset can track the user around an unobstructed physical area using two base-station towers that scan in infrared. For movements that would be too large for natural movement inside the delimited area, the HTC Vive hand controllers can translate or teleport the user inside the virtual world, as well as interact with virtual objects.

### 3.1. The Environment

The Visionary Render software creates a 3D space with a basic physics engine which can then be populated with CAD models. It has a limited capability to modify the CAD objects inside the

environment as well as create basic geometric volumes.

Certain properties of these assemblies can be altered to the user's specifications, such as the colour, visibility, mobility, and solidity of an object (where the object can be always solid and always causes collisions, or collides only with other specified objects, or is completely intangible).

Collision-enabled objects are useful to determine logistics of an intervention. If moving an object is trickier than first anticipated, (e.g. it is too long and will get stuck around a corner), it is better to realise within an accurate simulated environment, rather than in the field while workers' doses accumulate.

Extra information can be transferred to and from the environment as a set of comma-separated values (csv) files. The data for regarding the radiation maps is contained in one of such files. When the scene is opened, the first recorded map is loaded. During run-time other maps can be loaded and swapped to the scenario. A change of radiation map can be set by any single or combination of events, such as a timers or objects being moved.

User tasks are stored in a different file. Dynamic workstations are created in predefined locations of the environment depending on the task setup. They appear as green disc markers, with relevant information regarding the task (activity, available time, average radiation in that spot, a potential prediction of the dose, etc) floating above them. When a user reaches a workstation, an invisible timer starts. When the timer runs out the station disappears, and the next station becomes visible. There are no restrictions on whether a user remains at the station, however the current timer cannot be paused or reset once it has been triggered. Workstations can be changed and their settings updated to tailor a situation, and give as much or as little guidance for workers as needed. An operational diagram of different user interactions is shown in Figure 1.

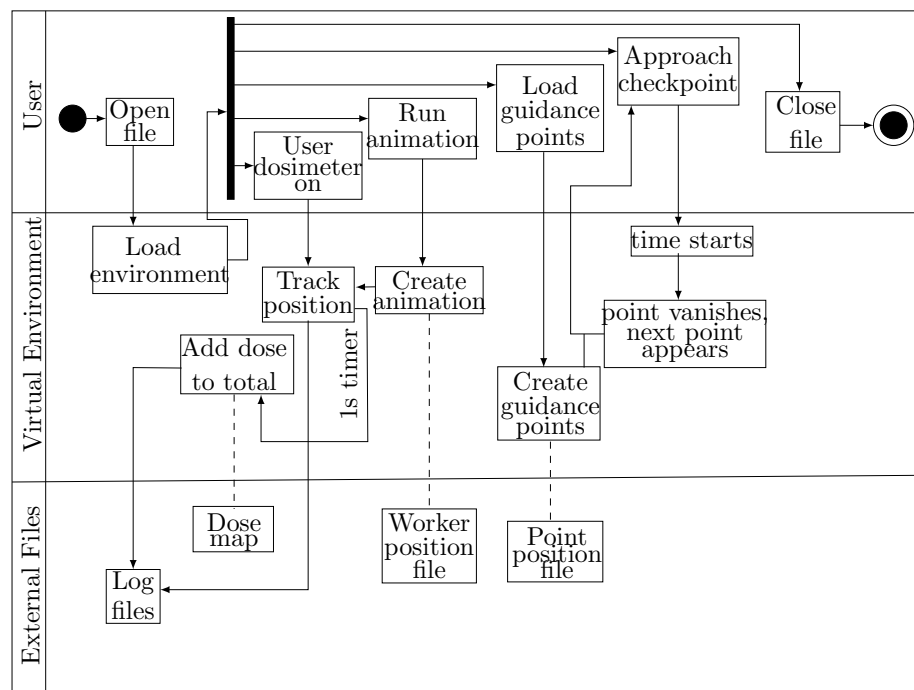


Figure 1: Non exhaustive operational diagram of user actions in the software.

The system was conceived and designed to give users the maximum amount of agency while in the environment. Workers get a realistic experience and can practise jobs without physical consequences; supervisors can oversee the expected radiation doses for each intervention; and

planning one-time interventions where there is a significant dose risk, and no previous similar circumstance to exploit.

### 3.2. Agency of Workers

The system has two distinct types of user. The trainee or worker and the trainer or supervisor. In every environment there can be multiple workers immersed in the VR but only one supervisor that is either inside the VR as well or as a common user with a 3D mouse and a PC.

The supervisor controls the environment, task allocation, trainees' starting conditions, and monitors the whole environment. They can control the environment using script enabled buttons on their screen. Some of the most common actions from a supervisor are: reset the simulation, modify the current environment geometry, save the modified geometry, locate every worker to a starting point and/or modify their dosimeters and logging scripts. The supervisor can start, pause and reset all dosimeters and logging activities.

Each worker has a head's up display (HUD), which are physical objects that are programmed to appear just in front of each worker's line of sight. They are customized to the type of user, where the worker can see their own stats and control their own dosimeter, but cannot access the supervisor's scene or alter any scripts. A diagram of the physical hardware setup is shown in Figure 2.

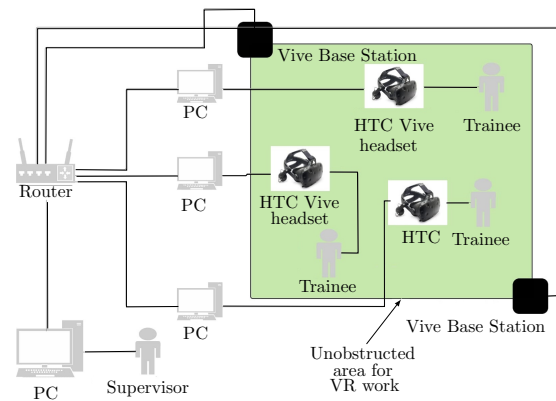


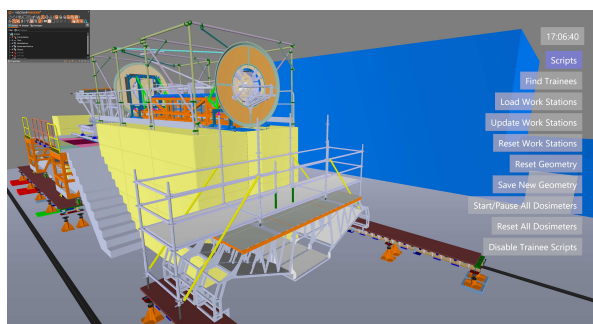
Figure 2: Diagram of the hardware setup

## 4. Experimental Setup

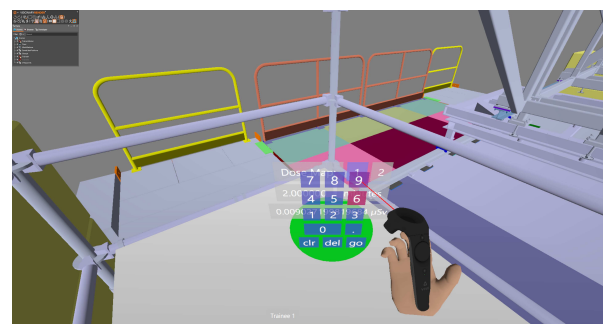
Two different environments were used. A Mock-up of the ATLAS Inner Detector at the CERN particle collider, and the Medical Physics MC40 cyclotron at the University of Birmingham.

### 4.1. ATLAS Mockup Model

The first application of the system is in preparation for the decommissioning of the ATLAS Inner Detector (ID) in 2024 Long Shutdown (LS3), which will be replaced by the new ATLAS Inner Tracker (ITk) [8].



(a) The ATLAS Mockup from the Supervisor's point of view



(b) Working inside the VR using a HTC Vive headset

Figure 3: Screenshots of the different perspectives of the VR system

As CERN prepares for the High Luminosity LHC upgrade (HL-LHC), several detectors & components of the experiments need to be replaced with upgraded versions, designed to take full advantage of the increased luminosity. The ATLAS ID has been exposed to intense high energy beams for several years, creating a challenging radiation environment for personnel. It will require significant manpower over several months for a complete removal of the detector and its associated services.

Instead of using the detector itself, the first environment created in the system was the CERN ATLAS Mockup Model. The mockup exists physically at the Rutherford Appleton Laboratory and in Geneva at CERN. The model was created to train for the installation and assess wiring the inner pixel detector.

By combining existing CAD models with dose maps from an improved radiation simulation (using the FLUKA simulation package) [9], a 3D virtual environment was created which monitors the instantaneous dose rate with respect to position within the environment.

The dose map was created by data provided by CERN's radiation protection team. Per ATLAS detector nomenclature, location and orientation information is given in cylindrical coordinates ( $R$ ,  $\phi$ ,  $Z$ ), with the origin at the collision point. The detector is symmetrical along the  $Z$  axis, so the given dose map has 5 cm resolution in  $R$  and  $Z$ , with the dose smeared around  $\phi$ . The dose maps are created from FLUKA simulations, which are then backed up by in-situ measurements. The software dynamically changes the dose map based on triggers such as elapsed time and removal of pre-established parts of the detector.

Figure 3a shows the supervisor scene of the ATLAS mockup. The supervisor is not restricted to obey Newtonian physics, and the buttons along the right-hand side of the image control the different scripts.

Figure 3b shows a workpoint being modified by a worker inside the ATLAS Mockup platform. The hand controller is visible, and the worker/trainee HUD is collapsed out of the way at the bottom of the image.

#### 4.2. Birmingham Cyclotron Vault

The vault housing the cyclotron at the University of Birmingham was used to demonstrate proof of concept. The room is 8.9 x 8.1 m, and the interior was modelled using the Microsoft Hololens spatial mapping, backed up by physical measurements and simplified geometry.

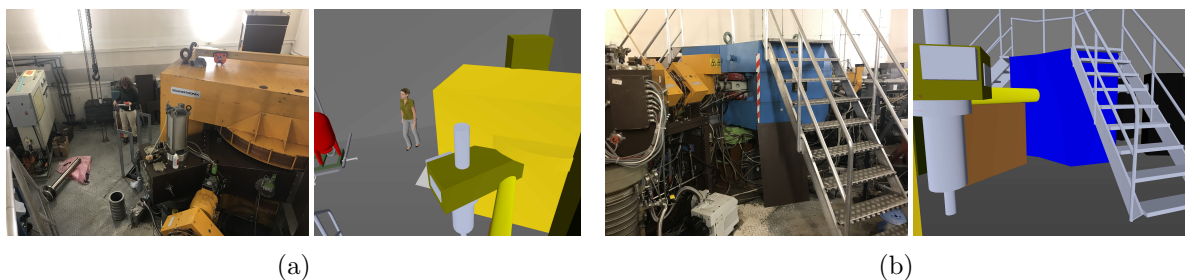


Figure 4: Comparison of the Vault with its virtual double. a) From the gantry above the beam lines towards the cyclotron b) From the back of the cyclotron towards the gantry

Figure 4 shows a comparison of photos taken from inside the vault with screen-caps taken from the VR software (Visionary Render). Anything that didn't impede human movement, such as the wiring, was deemed trivial to recreate. Inaccessible areas such as the area above the hole in the floor in Figure 4a, were made deliberately impenetrable in the virtual environment.



4.2.1. *Birmingham Radiation Map* The School of Physics and Astronomy at the University of Birmingham take monthly measurements of the background radiation inside the cyclotron vault, however the location of the measurements is strategic to monitor particle backscatter from the cyclotron, rather than to map the whole vault, as shown in Figures 5, 6. Therefore, a dose map was created with a new set of measurements.

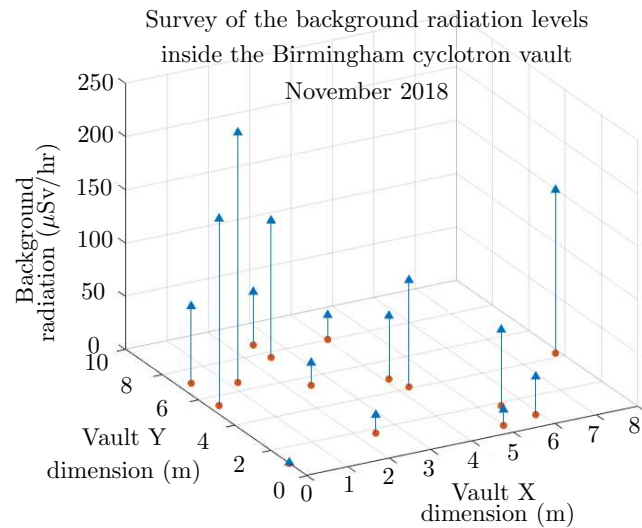
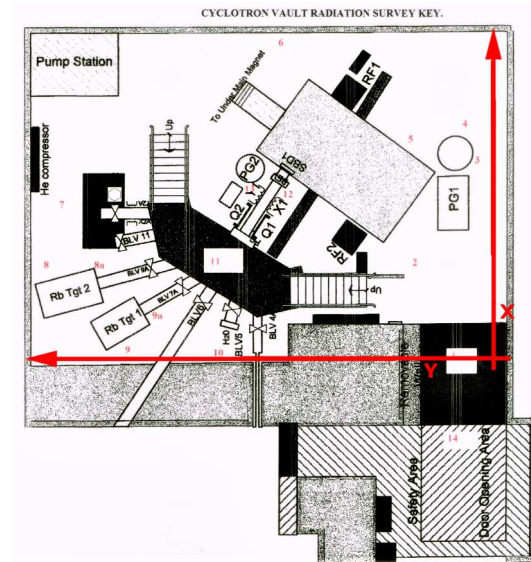


Figure 5: 2D map of the vault, with survey measurement locations

Figure 6: Background radiation levels from the November 2018 survey

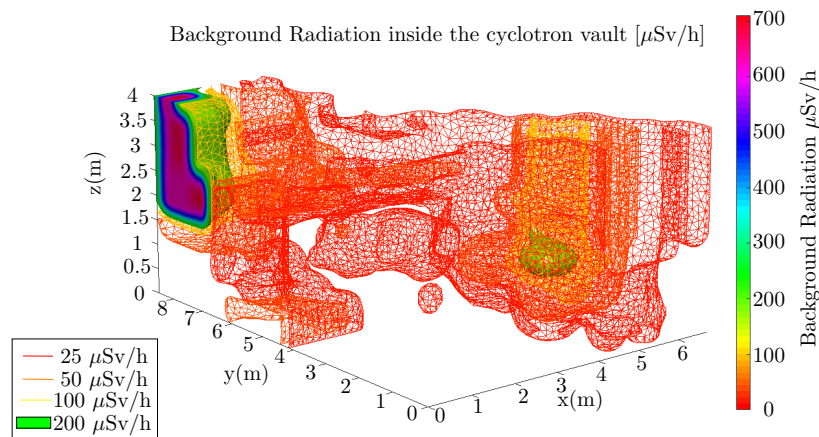


Figure 7: Final dose map, resolution 5 cm

The measurements were taken manually using a Tracerco Personal Electronic Dosimeter (PED) Blues [10], following a grid system of 0.5 m across the accessible areas inside the vault, from floor level to 3.8 m high. The measurements were taken up to 2 m from the floor, the extra height of the grid coming from the bridge, which is 1.8 m tall. The raw data was then interpolated. The first interpolation used the nearest neighbour method first to fill in the gaps in the grid.





## 6. Conclusion

VR removes many of the constraints around the exploration of harsh environments by providing an accurate facsimile of the situation without the associated risk. A Virtual Reality platform with virtual dosimeters was created to aid in the planning and assessment of human interventions in a radioactive environment. The system allows for 1st person immersive experience, and well as 3rd person review of the movements within a radioactive area. It can be used by a trainer supervising workers on a specific scenario, with updateable guidance checkpoints. Agency and natural movement are the biggest benefits to using the setup.

A proof of concept was performed using the Birmingham cyclotron vault. The vault was rendered in the Virtual world, and its background radiation mapped for the system. It showed the VR platform returned a comparable result to the real radiation exposure for a predefined route through the vault. The errors of the system are dependant on the dose map. With an accurate dose map, the system will produce reliable results.

## 7. Future Work

Further investigation and development of this technology will be crucial to future time and location sensitive projects.

Timescale of interventions can differ from hours to months, in which case a normal time-flow is ill-suited for intervention planning or training. It is also true that for trivial actions such as (un)bolting, cutting, and moving objects take time that VR does not currently realistically reproduce. In some scenarios, time in VR should be elasticated. This would improve suitability for applications planning lengthy interventions, and would better reflect the time cost of the task in reality, while also giving a more accurate dose prediction. Work on this issue is currently in progress.

The platform can also be adapted to the specific needs of other sectors such as nuclear, construction, and oil and gas.

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