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Application of innovative methods and tools in experiential training of workers in confined spaces

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An examination of accidents involving workers in confined spaces has shown that for each accident that occurs there are often multiple injuries or victims. Furthermore, if the injured has been in contact with toxic products or has remained too long without oxygen, the resulting damage usually remains permanent. Education and training can reduce the negative impact of risk factors present in these kinds of environments through experience and knowledge of the operating modes, to manage not only the ordinary activity in these spaces, but also in the management of high-risk emergency situations for the individual. It is now established that an experiential training, based on learning by doing and that considers the psychophysical aptitudes required of workers, is essential for the proper management of the security of their own and their colleagues. Therefore, INAIL (Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro, i.e. National Institute for Insurance against Accidents at Work) researchers, in a logic of prevention through innovation, designed and built a physical simulator to replicate in an effective and protected way all types of risk and consequent danger to workers operating in these environments. The simulator is built to alter the cognitive conditions of the subjects who use it making them experience situations of risk and consequent danger extremely realistic and especially typical of confined environments (poor visibility, cramped spaces, communication difficulties, poor ventilation and emergency rescue). Additionally, to make training more realistic and immersive, INAIL researchers, in collaboration with professors of the Engineering faculty of the University of Naples, are working on the reconstruction of confined spaces in virtual and augmented reality, to train the operator to deal with potentially dangerous situations in an environment which, although virtually reconstructed, is as similar as possible to the one in which he will actually operate. A concrete example of the use of these techniques is the subject of this work.

Keywords: Confined spaces, Experiential training, Simulator, Virtual scenarios, Virtual reality, Augmented reality.

1. Introduction

Confined and/or suspected of pollution spaces are places where maintenance, adjustments, mechanical parts installation, cleaning and other activities can be carried out, but they are not designed to carry out continuous working activity. However, these environments are classified as workplaces with a high risk for the safety and health of workers.

The Health and Safety Authority (OSHA) published the "Code of Practice for Working in Confined Spaces", in accordance with section 60 of the Safety, Health and Welfare at Work Act 2005 (ISBN No: 978-1-84496-135-1). OSHA addresses confined spaces in specific OSHA standards for general industry, marine, and construction. (https://www.osha.gov/confined-spaces/standards). In Europe there are no specific community directives or regulations that deal with confined and/or suspected polluted environments.

In Italy, the legislative provisions on confined and/or suspected polluted environments can be found both in Legislative Decree 81/2008, in Articles 66 and 121, concerning work in suspected polluted environments, and in Annex IV, point 3, concerning work in confined environments, and in Presidential Decree 177/2011 'Regulation containing rules for the qualification of companies and self-employed workers operating in suspected or confined environments', in which, as the title suggests, the qualification criteria for companies and self-employed workers intended to work in this type of environment were defined. Table 1 shows the environments that Legislative Decree 81/08 explicitly defines as confined and/or suspected of pollution.

Art. 66	Art. 121	Annex IV
Work in environments suspected of pollution	**Presence of gas in excavations**	**Workplace requirements**
Cesspit Biological pit/cesspool Sewers Chimneys Tunnels Spaces and containers Pipelines Boilers and similar	Wells Biological pit/cesspool Underground passage Sewers Chimneys	Basins/tanks/pools Canalizations Piping Tanks Silos

Table 1. Confined and/or suspected polluted environments as referred to by L.D. 81/08

However, this list posed difficulties, as it excluded other types of environments that can also be considered confined and/or suspected of pollution. This problem was overcome with the release, in November 2024, of the national standard UNI 11958:2024 entitled "Confined and/or suspected polluted environments - Criteria for the identification of hazards and risk assessment" was published in Italy by *UNI* (National Unification Body); this standard provides a definition and initial description of a confined and/or suspected of pollution environment. Although a technical standard is not as binding as a legal provision, the definition of confined environment in it is an important step because it provides for the first time a reference for companies and workers who must work in this kind of environment. In it, the confined and/or suspected polluted environment is defined as a "circumscribed space not designed and constructed for the continuous presence of a worker, but of such dimensions as to allow his or her entry and the performance of the assigned work, characterized by limited and/or difficult entry or exit routes, with possible unfavorable ventilation, within which the presence or development of conditions dangerous to the health or safety of workers cannot be excluded".

The number of deaths in these environments is often higher than the number of accidents, because fatal events affect not only those who are directly involved in the primary accident, but also those who intervene in the attempt to rescue them. Therefore, the training of those who work in confined and/or suspected of pollution environments is of critical importance.

2. Main risk factors in confined spaces

The main risk factors for those who work in confined and/or suspected of pollution environments are the following:

- asphyxia due to lack of oxygen caused by fermentation processes (formation of carbon dioxide, hydrogen sulphide, etc.) and/or formation/presence/introduction of gases that replace oxygen (nitrogen, carbon monoxide, methane gas, etc.), entrapment in loose materials (cereals, granules plastics, catalysts, inert powdery supports);
- unfavourable microclimatic conditions due to too low or too high humidity and temperature values;
- explosion/fire due to evaporation of flammable liquids, presence/formation of flammable gases, raising of flammable dust and presence of ignition sources of various kinds (electrostatic charges, use of tools and work equipment that produce sparks, electrical systems and appliances, operations of cutting and welding), etc.;

- intoxication due to the presence of residues, decomposition or biological reactions, ineffective insulation, etc.;
- fall due to failure or incorrect preparation of provisional works, failure to use PPE, use of unsuitable equipment or used badly (e.g. too short or not constrained ladder), etc.;
- electrocution due to systems/tools not suited to the classification of the area, not complying with applicable legislation or in poor condition, manoeuvring errors (lack of electrical insulation), failed coordination, failed electrical isolation, etc.;
- contact with organs in motion such as parts of the plant/machines not adequately protected, use of equipment unsuitable for the restricted environment, etc.

3. The INAIL training and education path for workers who operate in confined spaces

Operator performance and safety compliance are key factors when dealing with confined and/or suspected polluted environments. In particular, the effectiveness of operations in this type of environment must necessarily also consider human factors of a psychological nature, i.e. how the worker is likely to react when in that situation: the emotional factor, in fact, plays a fundamental role. Today, virtual reality (VR) and other new technologies may potentially enable immersive and interactive training experiences, allowing real-time physical and physiological feedback to improve situational awareness and decrease the risk of emotional reactions. In addition, new simulation techniques allow for repeated practice, enabling workers to become proficient in operational practices and improve their memory.

Italian legislation does not currently define what the contents of education and training for workers in confined and/or suspected of pollution environments should be. In this framework of legislative vacancy, INAIL researchers have conceived of an articulated path, starting with traditional classroom training, followed by a training phase using a simulator developed specifically for this purpose, and ending with a process that allows workers to be trained by reconstructing their real work scenarios in Virtual Reality and then in Augmented Reality. To date, the path has been fully implemented in terms of classroom and simulator training, and the first steps are being taken regarding the aspects of reconstructing real scenarios in virtual reality, as will be shown later.

3.1 Classroom and Simulator Training

The classroom and training course developed by INAIL researchers takes place over the course of one day and consists of a part to be carried out in the classroom and of a subsequent part that takes place inside a simulator. The frontal lesson part is mainly focused on providing information on:

- the qualification criteria of companies and self-employed workers intended to operate in confined and/or suspected of pollution environments that Italian law currently provides;
- a general overview of the types of risks that workers may encounter in these environments;
- the development of an effective work and emergency procedure to deal with these risks;
- the main personal protective tools and devices that workers must use.

The use of case studies and demonstration videos is also included in this training part. However, the most relevant part of the training day, as well as the one most appreciated by the workers, is the one that involves the use of the physical simulator. Since the importance of living an experience similar to reality for the purpose of developing skills is known, the model developed by INAIL includes a training phase with a simulator specifically designed to create a protected environment where the main critical situations for workers operating in confined and/or suspected of pollution environments can be reproduced. The simulator training phase also includes the simulation of rescue procedures for supposedly injured workers by other workers. For this reason, they are all equipped with the appropriate personal protective equipment, including harness, restraint lanyards, protective helmet, gloves and safety shoes. So far – data updated to September 2024 – 790 workers have been educated and 615 of them have also been trained using the simulator. In some cases, an exercise was also carried out with the direct participation of the firefighters and an external rescue team with the use of the necessary means and equipment. This activity included the implementation of a procedure that provided for the rescue of fake injured people by firefighters and the subsequent intervention of rescue personnel to provide first aid. The designed and implemented training course is the result of a non-closed iterative process that considers the data collected in each edition relating to the level of knowledge of workers on the topic of confined and/or suspected of pollution environments. The provision of the training course to workers of companies in different production sectors (chemical, port, agricultural, wine, construction, etc.) has made it possible to acquire, through traditional tools (multiple choice questionnaires), a greater understanding of both the actual level of knowledge of the workers and the perception of the risk that they experience during the activities, so as to modify the INAIL training model by adapting it to the actual needs of the workers operating in the various sectors mentioned above. During the course, the learners filled out, in addition to the learning test, post its upon entry, before the start of the education phase, and upon exit, at the end of the training phase; the purpose of the entry post it was both to find out whether they knew what confined environments were and, if so, what they knew about them and whether they had ever had to deal with this kind of environments during their normal working activity. At the end of the day, two further post it notes were given to the workers to get feedback on the overall level of satisfaction with the followed course as well as suggestions to improve the training path. As the aim was to summarize the answers obtained through the post it notes into statistical data that would allow to have an overall picture of the workers' prior knowledge, as well as their suggestion about the training and education offer, the difficulty in obtaining homogeneous clusters of data from post it notes advised us to use a pre-training and a post-training questionnaire, administered via QR code. In addition to the questionnaires, a digital check list has been prepared to detect and report in real time, by teachers, the critical issues and any errors most frequently encountered during training.

3.2. The INAIL simulator

In more recent times, numerous studies have contributed to explain how immersive education and training experiences constitute an optimal methodology to improve the efficiency and validity of training. It is now well established that an "experiential" training has become more and more necessary to have a positive and effective impact on workers.

For this reason, INAIL (National Institute for Insurance against Accidents at Work) researchers from the "Safety of processing and production plants Laboratory", in a logic of prevention through innovation, designed and built a physical simulator to replicate in a protected and effective way all types of risks for workers operating in these environments. The simulator (fig. 1) has been designed to alter the cognitive conditions of those who use it, making them experience situations of danger and consequent extremely realistic risk, typical of confined environments (poor visibility, cramped spaces, communication difficulties, poor ventilation and emergency rescue difficulties, etc.). It is transportable; it can be connected to the electricity grid of the host company or organization and is equipped with structures and systems that allow it to be safely used. Access to the upper part of the simulator is via a ladder that can be anchored to the external wall, protected from falls by a retractable perimeter metal parapet. The same is useful for practicing the descent through a vertical manhole. It is also equipped with:

- a control room with control system in order to record the events of the training activity;
- a horizontal manhole;
- colored pipes and valves and four different locks (each with its own key) to simulate LOTO (Lock-Out Tag-Out) conditions;
- internal movable walls;
- systems that influence sensory capabilities, such as various types of noises reproduced via a speaker, harmless fumes of different colors, etc.;
- camera systems to provide videos of the implemented operations, to analyze and eliminate any critical issues that may arise.

Another advantage is the awareness of the difficulty of emergency recovery of non-cooperating personnel, which leads to greater attention in the application of work procedures to facilitate the possible intervention of rescue workers. The INAIL simulator has been patented until now in Italy, USA, China, Canada, Brazil, India and is currently being examined by the European Patent Organization (EPO) for a future patent.

Fig. 1. The INAIL simulator

3.3 The reconstruction of confined spaces for the implementation of training activities in virtual reality

To further minimize the risks that workers may encounter in confined spaces, training workers on the actions to be performed, using virtual reality, can be very helpful. To this end, as part of a research project financed by INAIL in which the Department of Industrial Engineering of the Federico II University of Naples and the Department of Computer Engineering of the Sapienza University of Rome participate, we are working on the virtual reconstruction of real confined spaces. The goal is to integrate physical training on the field and virtual reality activities as much as possible, so that the two can coexist and support the worker both in normal work activities and in training ones. For this purpose, we reconstructed an underground manhole located near the runways at Fiumicino Airport in Rome. The manhole is used to contain a preconditioning pipe to be connected to a nearby aircraft to provide hot or cold air to the interior spaces, thus allowing the jet to remain with the internal air conditioning and heating system turned off to avoid wasting fuel. The cockpit corresponds to the description of a typical confined space: in fact, it is characterized by a narrow space, with limited access and exit route, not intended to be continuously occupied by workers, but where workers occasionally access to perform maintenance or control operations. In fig. 2 an actual photo of the area outside the sump and a glimpse of the inside of the sump.

The reconstruction of the environment was carried out using a laser scanner with which 4 scans of the indoor space and 2 scans of the outdoor environment were acquired, which allowed us to obtain the complete point cloud of the site.

Fig. 2. Actual photo of the area outside the cockpit with open hatch (above) and a glimpse of the inside of the cockpit (below)

A mesh model of the reconstructed manhole was then created from the processed point cloud. The latter served as the basis for subsequent three-dimensional modelling of the environment and the actual facility.

Some of the images from inside and outside the well resulting from this reconstruction are shown below.

In fig. 3, the image of the working environment outside the virtually reconstructed well.

Fig. 3. The virtually reconstructed working environment outside the well

In fig. 4, the virtually reconstructed image of a multigas detector, used to sample the air quality. The atmosphere outside and inside the manhole has to be sampled by the multi-gas detector. The latter is a device equipped with sensors capable of verifying both the sufficient presence of oxygen (normally the oxygen level in the atmosphere is 20.8 percent) and the possible presence of hazardous gases. In addition to sampling on the outside of the sump at the edge of the access door, air quality sampling shall always be carried out on 3 levels inside the sump: the reason why the air sampling procedure inside the well is done on 3 levels - top, middle, and bottom - is related to the ability of gases to stratify on different levels due to their different weights, so some gases may be, for example, at the bottom of the confined space and only surface sampling may not be able to detect it.

Fig. 4. Virtually reconstructed image of a multi-gas detector

Fig. 5 shows the sampling sequence: from left to right clockwise, first outside with the tailgate closed and then inside on 3 levels, top, middle and bottom level respectively. The dashed yellow circle indicates the location of the multi-gas detector.

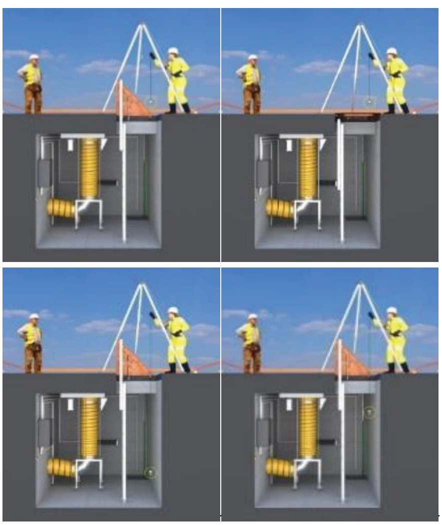

Fig. 5. Virtually reconstructed image of the sampling sequence, outside and inside the well. The dashed yellow circle indicates the location of the multi-gas detector

This reconstruction, whose images shown are a non-exhaustive example, has been preliminary to the virtual reality reproduction of the working environment: in fact, as previously said, one of the goals of this project is to allow operators to perform in virtual reality, through visors or other tools, exactly the same operations that they will have to actually perform when they will be physically operating in these environments, so that before physical access they will become familiar with the type of environment they will be dealing with through its virtual reconstruction.
In this case, a virtual reality headset was used to give the operator the feeling of being immersed in the real work scenario. Virtual Reality headsets (fig. 6) are devices designed to immerse users in a completely digital environment, typically by displaying 3D visuals and using sensors to track head movements. These headsets are for example used for gaming, entertainment, training simulations, and even educational purposes.

Fig. 6. A Virtual Reality headset

VR headsets work by providing separate screens (or lenses) for each eye, creating a stereoscopic effect, which simulates depth and enhances the feeling of immersion. Many VR headsets also include additional features such as spatial audio, motion tracking, and controllers to allow for full interaction within the virtual environment.
One of the activities to be performed by the operator accessing the inside of the well is to check the proper attachment of the clamp (indicated by the arrow in fig. 7) that stabilizes the tube in its housing.

Fig. 7. Image of the clamp securing the pipe

In the event of a negative result, i.e. the instability of the tube, the clamp that holds the tube in place should be tightened. Obviously, this specific task is part of a much more comprehensive procedure involving a few steps prior to entering the well and subsequent to the operation to be performed inside the well. More specifically, the procedure to be followed, which was then reconstructed in virtual reality mode, is articulated as follows:

- Step 1: workers demarcate the access area to the shaft, represented externally by the surface hatch. This can be done using cones or other devices such as stakes or two-colour posts;
- Step 2: prior to opening the hatch, check the air quality around the perimeter of the hatch using a multi-gas detector (fig. 8);

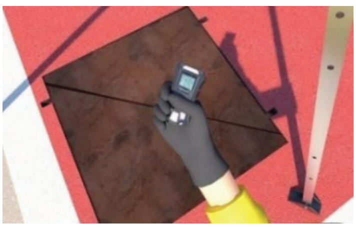

Fig. 8. The multi-gas detector as reproduced in VR

- Step 3: in the absence of any danger signals from the multi-gas, the door (which opens outwards) is opened;
- Step 4: the air inside the sump is detected by the multi-gas detector; the detection must be made at three levels: at the horizontal access plane of the hatch, at mid-height and at the bottom of the sump, in order to verify the absence of any gas stratification at the surface (light gases) or at the bottom (heavy gases);
- Step 5: mount and install the tripod or other suitable device at the manhole opening for handling the worker who, properly harnessed, must be lowered from the manhole opening;
- Step 6: the worker who is to physically enter the sump wears a harness with a sternal and dorsal hook, a hard hat, gloves suitable for the activity and safety shoes;
- Step 7: the operator entering the sump positions the multi-gas detector at chest height so that the presence of hazardous gases or oxygen deficiency can be signalled as he or she moves within the sump;
- Step 8: the harnessed worker sits on the top edge of the cockpit and hooks onto the tripod winch rope using the sternal hook of the harness;
- Step 9: the harnessed worker is slowly lowered into the cockpit. The operation is carried out by another operator who operates the winch by means of a crank for the descent of his colleague;
- Step 10: the worker reaches the bottom of the sump and disconnects from the tripod winch;
- Step 11: the operator continues with the task that required his presence inside the chamber; in this case, he must check the stability of the pipe in its casing by trying to move it;
- Step 12: assuming that the pipe is moving slightly upwards and that the clamp that is supposed to hold the pipe is not tight enough, the operator uses a wrench to tighten the 2 screws at the end of the clamp (fig. 9);

Fig. 9. The operation of fixing the clamp reproduced in VR mode

- Step 13: the worker, having completed the task for which he had to enter the shaft, hooks himself back onto the tripod rope, again using the sternum hook, and is hoisted outside by the worker who "operates" the tripod winch;
- Step 14: having reached the outer edge of the cockpit opening, the operator sits on this edge and is helped to unhook the rope and stand;
- Step 15: the cockpit door is closed;
- Step 16: the worker removes the harness and the tripod is dismantled;
- Step 17: the cones are removed. Work completed.

The presence of other workers outside the manhole is due to the need to maintain continuous contact with the worker inside the confined environment: in fact, the correct procedure requires that there should always be at least one figure operating as a supervisor who is outside the confined environment, possibly also ready to activate help in case of emergencies.

4. Conclusions and future developments

Working in confined spaces is dangerous and, to date, there are still too many injuries, often with a high death toll. The new national standard UNI 11958:2024 clearly defines what a confined space is and this is an important step because it provides for the first time a reference for companies and workers who must work in this kind of environment. However, a specific rule on how to do the training is still lacking, even though it is known to be a key element.

New technologies make it possible to train a worker by allowing him to carry out, in a controlled and safe manner, the same operations that he will later have to perform on the field, in reconstructed environments that reflect the real work scenario. The one presented in this paper, which relates to a specific work activity in a confined environment such as the cockpit of an airport runway, is a concrete example of what is possible with VR. The next steps that INAIL researchers propose to implement concern the virtualisation of other work scenarios, of other confined and/or polluted environments, with also the possibility of implementing elements of augmented reality, that is to say the addition of digital information superimposed on the real world, so that this information allows the operator to be trained in the actions that he will have to carry out directly on the field.

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