Human Factors in Design, Engineering, and Computing, Vol. 159, 2024, 2335–2344
https://doi.org/10.54941/ahfe1005802

Prevention Through Innovation: Innovative method and tools for the effectiveness of experiential training for workers working in confined spaces

Luciano Di Donato[1], Marco Pirozzi[2], Andrea Cordisco[3], Massimo Spagnuolo[1], Daniela Freda[1], Antonia Biagi[1], Loriana Ricciardi[1]

1 National Institute for Insurance against Accidents at Work, Via R. Ferruzzi Roma, Italy

2 National Institute for Insurance against Accidents at Work, Via Fontana Candida Monte Porzio Catone (RM), Italy

3 National Institute for Insurance against Accidents at Work, Piazzale Pastore Roma, Italy

ABSTRACT

Examination of several accidents involving operators working in confined spaces has shown that the number of accidents is lower than the number of injured or that, for each cause of accident, more people are killed or injured.

In the case of the injured, if there has been contact with toxic products or the operator has remained too long without oxygen, it is very likely that the resulting damage remains permanent. The required performance of these workers and the safety compliances are very strict when it comes to confined spaces. In the analysis of which factors can influence the effectiveness of an operation in these spaces, not negligible human factors also come into play, psychological and specific to the individual, such as motivation, personal and interpersonal qualities, and tolerance for the mission. Education and training, in this sense, can reduce the negative impact of these factors through experience and knowledge of the operating modes, in order to manage not only the ordinary activity in these spaces, but also the management of high-risks and emergency situations for the individual. In light of these considerations, the idea has been consolidated that an experiential training, based on "learning by doing", that takes into account the psychophysical aptitude required to workers, is essential for the proper management of their own safety and that of their co-workers. Therefore, to meet the above, INAIL (National Institute for Insurance against Accidents at Work) researchers, in a logic of prevention through innovation, designed and built a physical simulator in order to replicate in a protected and effective way all types of risks to workers operating in these environments. The simulator 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.). The activity with the INAIL simulator, in Italy, is carried out throughout the national territory and there are agreements with the Italian firefighters that often participate in education and training activities, bringing the contribution of their direct experiences to the workers, integrating them with those of INAIL researchers. So far – data updated to July 2024 - 743 workers have been educated and 548 of them have also been trained using the simulator. In the article that follows some statistical data on the results of the training activities carried out through the use of the simulator are reported.

Keywords: Training, Injuries at work, Simulation

INTRODUCTION

A confined space is a place where maintenance, adjustments, mechanical parts installation, cleaning and other activities can be carried out, but it is not designed

to carry out continuous working activity. Italian legislation does not provide a definition of confined and/or suspected of pollution environments but there are European and international definitions that define them and which essentially agree in identifying three essential conditions as characteristic for their classification, i.e. a space:
• limited and not designed and built for the continuous presence of a worker;
• characterized by limited and/or difficult entry or exit routes;
• characterized by possible unfavourable ventilation and the potential presence of dangerous chemical agents (e.g. gases, vapours, dusts, mists) is to be expected.

The number of deaths 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 fundamental importance.

RISK FACTORS AND STATISTICS ON ACCIDENTS 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 sulfide, etc.) and/or formation/presence/introduction of gases that replace oxygen (nitrogen, carbon monoxide, etc.), entrapment in loose materials (cereals, granules plastics, catalysts, inert powdery supports);
- unfavorable microclimatic conditions due to high humidity, high or low temperature, use of PPE resulting in limited perspiration, type of work in progress, etc.;
- 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. ladder too short or not constrained), etc.;
- electrocution due to systems/tools not suited to the classification of the area, not complying with applicable legislation or in poor condition, maneuvering 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.;
- investment/crushing due to access from road areas, falling objects, maneuvering errors vehicles, lack of coordination during entry/exit.

The graph in Figure 1 clearly shows this phenomenon: it shows the numbers of workers who died or were injured in different types of confined and/or suspected of pollution environments (pits, tunnels, wells, tanks, silos, etc.), and the corresponding number of accident events, recorded in Italy from 01/01/2001 to 06/03/2024 (source: Italian media and Infor.Mo, an Italian database of accidents at work).

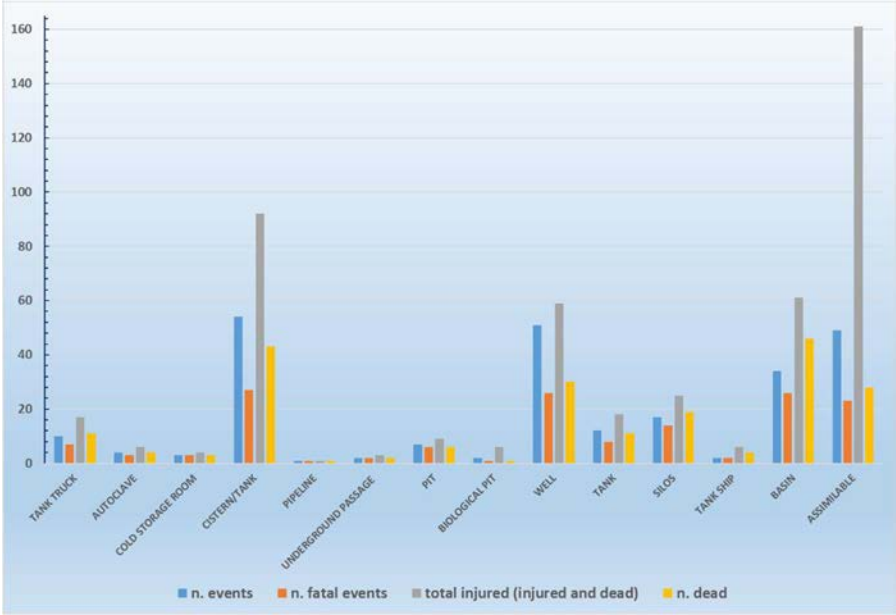

Figure 1: Accident events by type of confined and/or suspected of pollution environment

The graph in Figure 2 shows the numbers of accident events by type of accident recorded in Italy from 01/01/2001 to 06/03/2024 (source: the same as Figure 1).

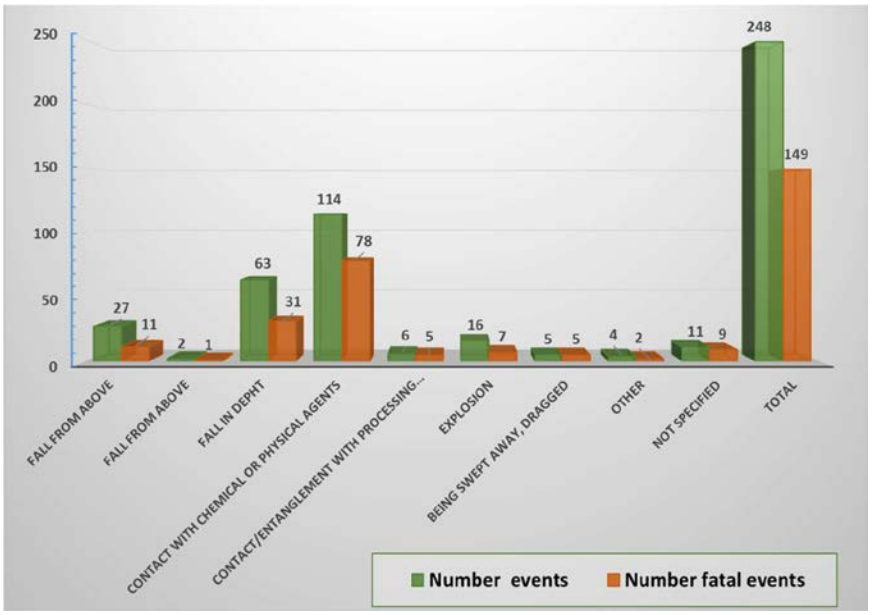

Figure 2: Number of events (total and fatal) by type of accident

THE INAIL MODEL OF EDUCATION AND TRAINING

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 has designed an education and training path, whichtakes place over the course of a day, consisting of a part to be carried out in the classroom and of a subsequent part that takes place inside the simulator. The frontal lesson part is mainly focused 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, on a general overview of the types of risks that workers may encounter in these environments, on the development of an effective work and emergency procedure to deal with these risks, and on 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 important phase of the training day, as well as the most appreciated one by the workers, is the one that takes place inside the 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 a rescue procedure for a supposedly injured worker 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 July 2024 - 743 workers have been educated and 548 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 of an emergency ambulance, with the implementation of a procedure which provided for the rescue of the fake injured by the firefighters and the subsequent intervention of the emergency ambulance staff to provide first aid. The designed and implemented training course is the result of a non-closed iterative process that takes into account 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.

Since the training course was provided to workers of companies of different production sectors (chemical, port, agricultural, wine, construction, etc.), this has made it possible to acquire through traditional tools (multiple choice questionnaires) a greater understanding of the actual level of knowledge as well as perception of the risk that workers experience during activities so as to modify the INAIL training model by adapting it to the actual needs of 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 aim of the entry post-it was to find out whether the workers were aware of the risk of confined and/or suspected of pollution environments and

whether they had ever had to deal with environments of this type 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.

The results of the 2024 education and training sessions of learners (data updated to July 2024) in confined and/or suspected of pollution environments, are reported below. The data refer to a sample of 275 workers who were administered the questionnaires via QR code. In particular, the knowledge gaps of operators clearly emerge, as well as the impact of psychological factors on the performance of work activities.

Thirty-four per cent of the learners states that they do not perform work activities in a confined and/or suspected of pollution environment, and subsequently 12% of the sample state that they do not know what a confined environment is (Figures 3 and 4).

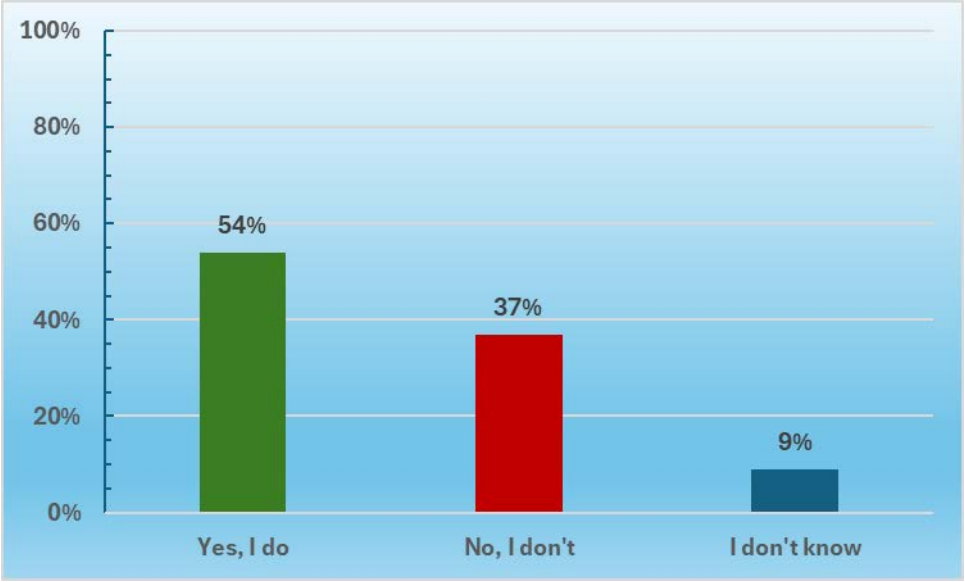

Figure 3: "Have you worked or do you work in a confined and/or suspected pollution environment?"

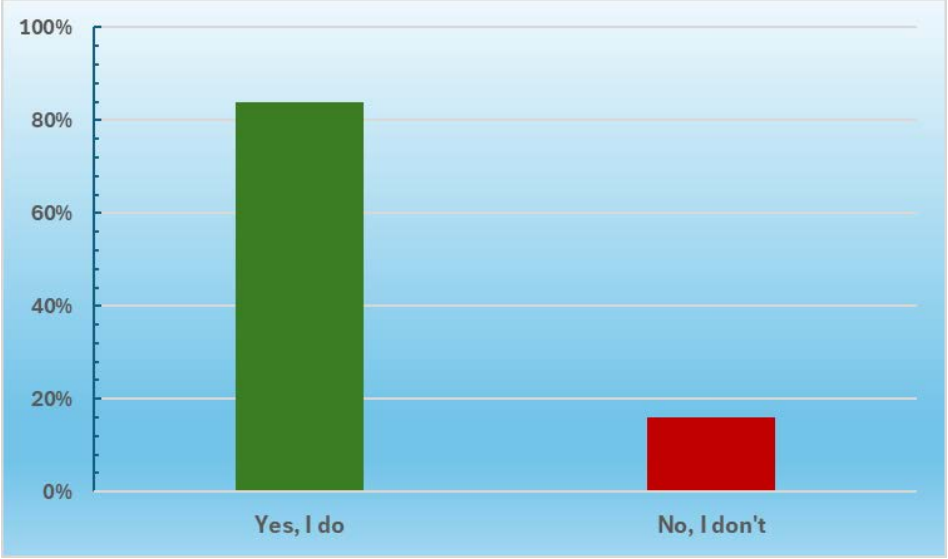

Figure 4: "Do you know what a confined and/or suspected of pollution environment is?"

It also emerges that 14% of the sample considers working in confined and/or suspected of pollution environments as minimally dangerous, and only 25% consider it very dangerous; a further 2% of workers do not consider it dangerous at all (Figure 5).

Figure 5: "How potentially dangerous do you think your work is for your health and safety?"

Together with the education/training activities, a plan was launched which saw the involvement of students from high schools (mainly agricultural and industrial institutes) through training meetings lasting at least two hours and regarding the risks associated with activities in confined environments and /or suspected of pollution. To date, approximately 220 students have been educated. Through the experience acquired, it was decided to design an innovative study-work alternation system for students facing these risks. The project aims not to be limited to classroom training but to allow students of the last two years to participate in training activities.

PSYCHOLOGICAL FACTORS IN EDUCATION AND TRAINING

Operator performance and safety compliance are key factors when dealing with confined and/or suspected of pollution environments. In particular, the effectiveness of the operations in these environments must necessarily consider not negligible human factors of psychological nature, such as motivation, personal and interpersonal qualities, and tolerance to the mission. Studies have emerged in the 1970s which show that education and training can reduce the negative impact of psychological factors through experience and knowledge of operating practices, in order to ensure the proper management of both ordinary activities and high-risk emergency situations for the individual.

Nowadays, virtual reality (VR) and other new technologies have enabled immersive and interactive training experiences by experimenting with real-time physical feedback to enhance situational awareness and decrease risk in these spaces. In addition, new simulation techniques make it possible to practice repeatedly, thus enabling workers to become proficient in operating practices and to improve their memory.

In more recent times, in fact, numerous studies have contributed to explain how immersive education and training experiences constitute an optimal methodology to improve the efficiency and validity of training. Due to these considerations, an "experiential" training has become necessary that can have a positive and effective impact on the factors mentioned above to learn how to manage the psychological aspects in the most suitable way for safety. Therefore, the research has led to structure a complete training path even more necessary in the absence of clear legal directions. In fact, from the results of the questionnaires mentioned above, it emerges how psychological factors (inattention, distraction, physical and mental fatigue) affect performance: in particular, 16% of the sample states that they feel inattentive, distracted or tired while performing work activities, and more than half (59%) confirm this, though at a lower level ("little inattentive, distracted or tired") (Figure 6).

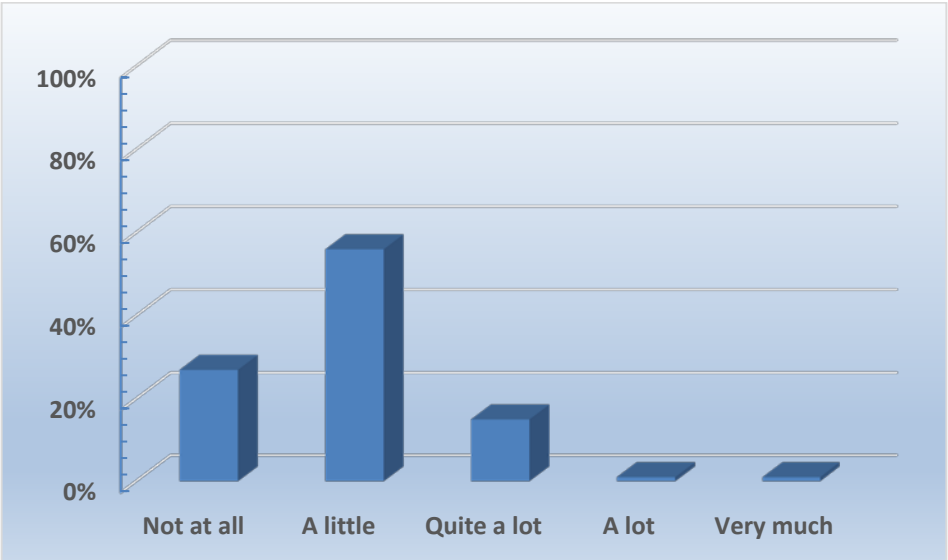

Figure 6: "Do you find yourself feeling inattentive/distracted/tired at the workplace?"

The graphs showing the causal factors of this psychological state show that environmental factors (e.g., noise, temperature) have the greatest impact, followed by prolonged physical exertion (e.g., lifting weights, prolonged use of Personal Protective Equipment) and organizational aspects (e.g., relationship with coworkers, work shift management) (Figure 7).

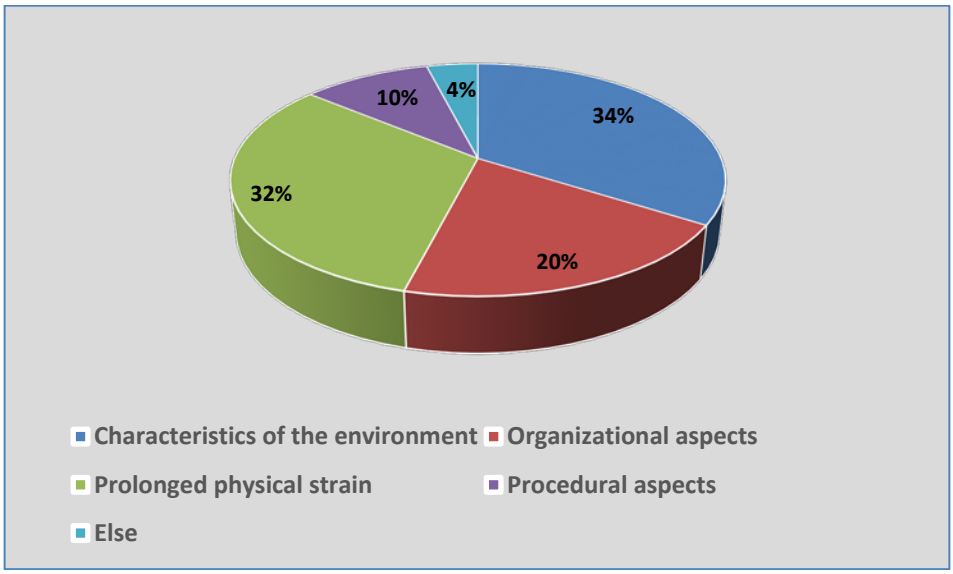

Figure 7: "What is it that makes you inattentive/distracted/tired at the workplace?"

The results are also confirmed when asking the remaining learners of the sample (who responded negatively) to imagine hypothetical scenarios ("Imagining feeling inattentive, distracted or tired, what would cause this feeling?") (Figure 8).

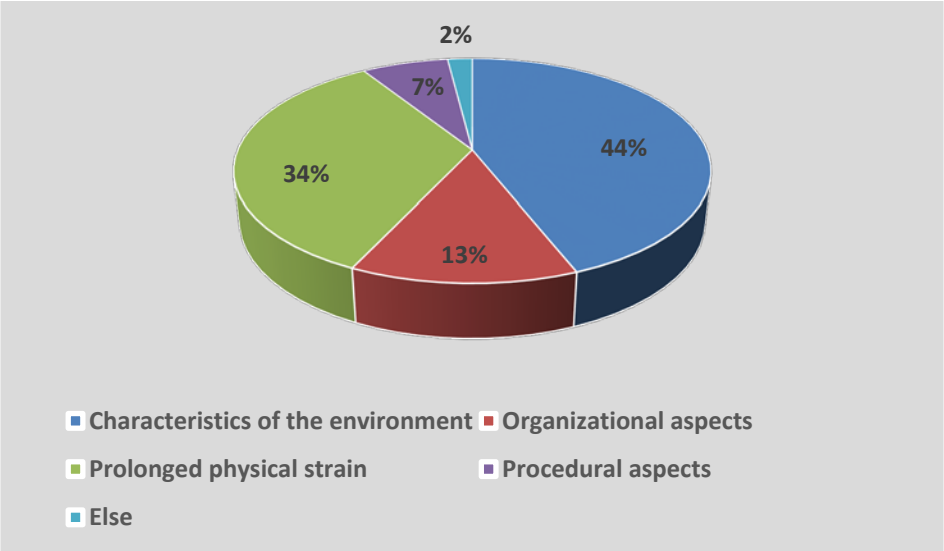

Figure 8: "Do you find yourself feeling inattentive/distracted/tired at the workplace?"

Thus, it becomes clear that education and training activities are necessary to increase workers' awareness in order to make them properly educated and trained as well as aware of what working in confined environments entails, in terms of responsibilities, risks to their own health and safety, and operating practices.

Finally, these results confirm the importance and non-negligible impact of psychological factors on the performance of activities, whether environmental, organizational, relational, or originating from physical exertion.

THE INAIL SIMULATOR

As previously said, the INAIL simulator (Figure 9) recreates, in a protected form, an environment in which to reproduce the main critical situations for workers who operate in confined and/or suspected of pollution environments. The simulator 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 inside via a speaker, harmless fumes of different colours, 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 in order to facilitate the possible intervention of rescue workers.

The INAIL simulator has been patented until now in Italy, Usa, China, Canada, Brasil, India and is currently being examined by the European Patent Organisation (EPO) for a future patent.

Figure 9: Inail Simulator

CONCLUSION

A confined space is a space whose configuration and/or contents may present special dangers not found in normal work areas. Training is mandatory and necessary. INAIL researchers designed a model of education and training including the use of a physical simulator in order to replicate, in a protected and effective way, all types of risks for workers operating in these environments. The simulator has been designed by Inail researchers and it has been patented in Italy, Usa, China, Canada, Brasil, India and is currently being examined by EPO for a future patent. About future applications of the simulator, in a logic of efficiency and improvement of activities, Inail researchers are working to provide its integration within Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR) systems to create a fully immersive multisensory system that adapts to the cognitive and emotional state of the operator in order to maximize the effectiveness of training in high-risk work environments.

ACKNOWLEDGMENT

The authors would like to thank Carla Console, Fabio Cassandra, Elisabetta D'Alessandri, Giulia Di Ferdinando and Alessio Di Filippo who collaborated and collaborate on the course activities.

REFERENCES

L. Di Donato, F. Longo, A. Ferraro, M. Pirozzi (2020) An advanced solution for operators' training working in confined and /or pollution suspected space - Procedia Manufacturing 42 (2020) 254–258

S. Mosconi, A. Bacchetta, L. Di Donato; R. Melloni, M. Oliva, L. Botti (2020) Web aided confined spaces risk assessment: Development of a web portal supporting the risk assessment of work in confined spaces. Proceedings of the Summer School Francesco Turco2020 25th Summer School Francesco Turco, 2020Virtual, Online

G. Landucci, L. Ricciardi, L. Rossi, F. Ovidia, L. Di Donato (2020) Quantitative methodology to support the hazard assessment of confined space operations in the process industry. Chemical Engineering Transactions Volume 82, Pages 1 – 6

F. Longo, A. Padovano, L. Gazzaneo, G. Mirabelli, M. Pirozzi, L. Di Donato (2021) Integrating physical and virtual game-based simulation for operators' training to enhance learning effectiveness: An application in hazardous industrial spaces. International Journal of Simulation and Process Modelling Vol. 16, Issue 2, Pages 130 – 146

X. Zhuo, M. Xu, Q. Dong, H. Zhang, Y. Chen (2024) Design and Development of Digital Teaching Resources for HSE Training on Safety Management of Confined Space Operations Based on VR Technology. Proceedings of the International Conference on Industrial Design and Environmental Engineering, IDEE 2023, November 24–26, 2023, Zhengzhou, China.