Studies in Systems, Decision and Control 346

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Volodymyr Artemchuk *Editors*

Systems, Decision and Control in Energy II

Springer

Application of Virtual and Augmented Reality at Nuclear Power Plants

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Abstract Development of nuclear energy is an important area of functioning of developed world countries. Nuclear power plants are objects of increased danger, so their development prospects are closely related to issues of safe operation and protection of territories, personnel, the environment on the territory of the station. Use of virtual and augmented reality technologies for energy sector received positive approval from the world's leading countries. The research examined publications on positive aspects of virtual and augmented reality technologies application for various industries, in particular for nuclear energy. Practical examples of application of virtual and augmented reality technologies for operation of nuclear power plants are described. As a result of the study, it is determined that currently virtual and augmented reality technologies for nuclear power plants are used in the following areas: modeling of various nuclear energy processes; operation, repair and maintenance of equipment; presentation of activities, construction of the station; staff training and education. Use of virtual and augmented reality technologies for nuclear power plants confirms its economic efficiency through the reduction of cost and time costs of staff travel to facilities; elimination of design errors before the beginning of the stage of construction and installation works; increasing the level of industrial safety; improving the management of nuclear power plants.

Keywords Energy · Virtual nuclear power plant · Augmented reality · Virtual reality · Digitalization · Advanced training · Staff training

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A. Zaporozhets and V. Artemchuk (eds.), *Systems, Decision and Control in Energy II*,
Studies in Systems, Decision and Control 346,
https://doi.org/10.1007/978-3-030-69189-9_14

1 Introduction

Development of nuclear energy is an important area of functioning of developed world countries. The publication [1] states that nuclear energy created new round in the history of human development. Unfortunately, three major nuclear accidents in the history of nuclear power plants (NPPs) (Tri-Mile Island, Chernobyl, Fukushima-1) caused global impact and led to significant radioactive contamination, causing significant damage to public health, natural and agro-environmental systems, etc. Therefore, safety is a necessary condition for the nuclear energy development [1, 2].

NPPs are objects of increased danger. So, their development prospects are closely related to issues of their safe operation and protection of territories, civilians and the environment on plant territory. Under various negative circumstances (violations of technological processes, safety and operating conditions, man-made accidents and incidents, natural phenomena, terrorist sabotage, hostilities, etc.), various emergencies can happen at NPPs. It pose a significant risk to environment, health of staff and population of the surrounding areas. Analysis of man-made emergencies by threat to human life, nature of action, scale of destruction of buildings, amount of material and economic damage, etc., shows that the most dangerous are emergencies causing radioactive and chemical contamination of the environment [2].

Currently, Ukraine has developed nuclear energy industry. It is based on four existing nuclear power plants: Rivne, Khmelnytsky, South Ukraine and Zaporizhia. It is planned to increase capacity of this industry for the next decades according to the "Energy Strategy of Ukraine until 2035" [2].

Development of most analog systems becomes impractical in the new technological era due to availability of digital alternative. Digital state becomes usual state of functioning and development of many systems, spheres, organizations, industries and economies. Main purpose of digitalization is to achieve digital transformation of existing and creation of new economy sectors, as well as the life spheres transformation into new more efficient and modern. Such growth is only possible when digitalization-related ideas, actions, initiatives and programs are integrated into national, regional, sectoral and development strategies. High-tech production and modernization of industry with the help of digital technologies, scale and pace of digital transformations should be priority of economic development. Sectors of the economy using digital technologies growths faster, cheaper and better [3]. So, digital technologies and successful projects of foreign developers need to be introduced more widely in the field of energy.

The work [1] state that NURESAFE7 simulation platform based on NURSIM was created after the Fukushima-1 nuclear accident. It is a platform for safety analysis, operation and engineering of nuclear reactor design. Virtual Nuclear Power Plant (Virtual4DS) is an integrated simulation platform covering NPP environment, based on digital reactor consisting of digital traffic, digital meteorology and data on processes in the earth's crust. Virtual NPP gives opportunity to perform modeling of multiactive operations, consider the evolution of nuclear accidents, use to support management decisions, anticipate emergencies and others based on big data, mobile

internet, artificial intelligence, cloud computing platform and other advanced digital technologies [1]. Therefore, issues of "nuclear energy safety" have gained new importance both for NPP personnel and for the training of future specialists in the energy sector thanks to digital technologies.

Indeed, new evolutionary stage of society is called technological era. For this era it is important to train professionals who will be competitive and will be able to quickly master the professions of the future. We believe that it is important to use digital technologies, in particular, virtual reality (VR) and augmented reality (AR) in specialists training for the new technological era [4].

Enterprises and large industries can't operate without digital technology in the digital era. So, process of staff training needs should be improved. VR and AR technologies are functional and affordable. It is possible to model complex tasks that require adaptive thinking and real skills by their help. Therefore, these technologies are an ideal tool for learning in the digital era. Today, global VR and AR spending will grow by 100% or more every year. Rising costs reflect willingness of companies to provide their employees with virtual environments for learning new skills and abilities. VR and AR technologies will become basis of training in an industrial environment, as training will become more effective, interesting and safe. Also, widespread use of immersion technologies requires cooperation between industrial companies and developers of VR and AR technologies, which must ensure their compliance with training and safety requirements for different organizations [5].

2 Literature Analysis and Problem Statement

Various problems aspects related to potentially dangerous objects functioning are considered in number of publications [2, 6–25]. Introduction of digital tools in energy companies work and in staff training is studied in [26–33]. Peculiarities of VR and AR technologies application for training were subject of consideration by many scientists [34–45]. VR and AR technologies are constantly improved and they are a powerful tool to ensure operation of NPPs and training/education of personnel. Therefore, there is a need to continue research on these technologies application for safe operation of potentially dangerous objects, including nuclear power plants.

The research aim—is to research features and best practices of using VR and AR technologies to support work and training of NPP personnel.

3 Research Results

The state policy of Ukraine [3] stipulates that it is important to encourage businesses and citizens to consume and use digital technologies, i.e. to make technologies available in Ukraine. Also, digital infrastructures should arouse the desire and motivation of people to connect to them and use them. It is important to modernize, optimize,

scale and accelerate development of own business using digital technologies. They are digital economy basis.

We agree with the work [46] that an important place is occupied by AR and VR technologies within the new stage of innovative development of society. It was named Industry 4.0. In essence, these technologies have both common and distinctive features, which are reflected in their use specifics by companies in process of relevant products creating. VR and AR technologies involve creation of thematic visualized content that can be used by target audience to meet specific needs with the help of modern electronic devices. Currently, AR and VR technologies are actively implemented in production processes, in the medical field, in educational processes, etc.

In publications [39, 45] the difference between the concepts of AR and VR is considered in detail. Humanity faced a problem called cognitive overload with improvement of digital technologies and the general digitalization of public life. That is, a situation when number of operations that need to be performed on the human brain exceeds its capacity. AR is technology that can unload human brain, release some of the cognitive effort and help optimize their use [47].

Using AR technology, you can project digital information off-screen devices and combine virtual objects with the real world. Device's processor, camera and screen will be used to combine virtual objects and elements with real ones. AR technology is easy to use, you just need to point the camera at a certain place and the result will appear on the screen. It can be three-dimensional object, an animation or something else [47].

We are impressed by the opinion expressed in the publication [34] that smart technology should be one of the main topics of research in modern conditions. It is important to meet society needs by means that do not harm environment and do not deplete natural resources. AR is new technology that combines three-dimensional virtual objects with reality. Also in the article [34] an analysis of the potential benefits of using AR technology in universities in Saudi Arabia is performed. Results of study show that of Saudi universities staffs believe that AR use in higher education has positive environmental and economic benefits.

AR technologies have great potential for many applications.

The publication [48] states that the US Navy tests AR goggles Magic Leap One for personnel training. "Tactically reconfigurable artificial combat enhanced reality (TRACER)" system was specially designed for military. This system includes directly Magic Leap glasses attached to processor in backpack behind military. It is a weapon model developed by Haptech (formerly known as StrikerVR) which supports simulation of recoil when firing, hand tracking system, as well as special software which provides various simulation scenarios. Great advantage of virtual training is less prediction for participants. It allows creating of learning scenarios much faster and cheaper than learning in the real world.

Also, NASA contractors use Microsoft AR HoloLens augmented reality headsets for quick and correct assemble of Orion spacecraft elements. Therefore, engineers began to use AR equipment on daily basis to perform their current work duties.

With help of the AR headset specialists can see holographic models of the spacecraft's elements, which are created for engineering design using a special software product Scope AR. Virtual models of details and schemes of marking are visually superimposed on already collected parts of design. Engineers from the American aerospace company Lockheed Martin use Microsoft HoloLens AR goggles for auxiliary purposes during assembling of crew cabin capsule elements. It saves a lot of time, as there is no need to read thousands of pages of paper instructions for preparation and production [49].

The study [35] emphasizes that technological progress through digitalization provides basis for a new format of human life. Focus on future work, automation and digitalization of many technological processes led to modernization of jobs, especially in industry. This changes requirements for employees with mandatory mastery of digital competencies. Various technologies, in particular AR, can be used to support employees in developing the necessary competencies. Also in [35] the potential of AR as an innovative learning environment was investigated. It can be applied to various professional cases in the work of industrial enterprises.

A similar conclusion was made in a study [36], namely that it is important to use AR applications in industry. They meet demands of industry, namely developed assistance system for maintenance of wind energy based on AR and welding simulator based on AR. Approaches and directions of application of AR solutions in industrial scenarios are outlined.

We will consider various aspects of AR and VR technologies application for energy sector, in particular for potentially dangerous objects operation.

Advances in immersion technology go far beyond consumer solutions. They have potential to turn complex industrial scenarios into "living and realistic experiences". AR and VR technologies were used for many years as part of dive technologies development with excellent results in following areas: pilot training, astronauts and military specialists. Advances in IT made creation of virtual worlds more accessible to a wide range of industries. Currently, such industries as oil refining, oil and gas, energy generating turned to AR and VR to learn how to work with hazardous systems [5]. These industries need to store and standardize knowledge and experience of their staff.

For example, Energoholding DTEK (Ukraine) has VR simulator to improve skills of DTEK Kyiv Electric Networks electricians. It was stated on the company's official website in 2019 [49]. This VR-simulator in real time simulates production and potentially life-threatening situations. So, workers can hone their skills and hone their skills without risking their lives. The company has serious training base and uses modern educational innovations for training with VR-simulator help. DTEK is one of the leaders in VR technology implementation in Ukraine's power industry. Energetics is considered as foundation of digital world future. The European Education Foundation is also interested in the VR complex developed by DTEK [50].

Also, in 2019 Energoholding DTEK (Ukraine) signed a cooperation agreement with the smart suit developer Teslasuit (Great Britain). Innovative development will provide opportunity to train employees using VR tools. It increases occupational safety in enterprises. The smart suit is equipped with special sensors. The system

transmits tactile and motor sensations, different temperature regimes and simulates vibration. Combined with VR technology (virtual reality glasses), Teslasuit allows you to create feeling of full presence in a thermal power plant unit. It allows the company's staff to learn new skills without being exposed to danger. Digital technologies can significantly increase the safety of employees. They include prevention of careless movements, a biometric system for analyzing performance and fatigue indicators. The Teslasuit smart suit (Fig. 1) today creates opportunities that were not previously used in industry. It takes occupational safety to a new level, which is one of DTEK's priorities [51].

Indeed, advanced industrial enterprises from near abroad also integrated AR and VR technologies into business projects. They develop full-fledged strategies for staff work and training based on these technologies. Currently, smart suits are promising solution for the industry. Such smart suits are interesting for staff training. Smart suits solve problems with tactile sensations, due to which the immersion in virtual reality is more complete. A person, for example, not only realistically sees fires and hears sounds, but also feels flame temperature. The smart suit has motion tracking, so it is possible to perform and analyze movement of whole human body. Biometrics allows you to get data on acceleration of respiration, heart rate, sweating. These signs may indicate onset of employee panic. Such simulations should become an integral part of personal protective equipment for large industrial companies. It is important to use smart suits during work with possible emergencies. Learning in regular VR-helmet can take wrong step back and not notice dangerous structure, hit or stumble. Of course, the cost of smart suits is still quite high, but when these projects become widespread, their cost should decrease [52].

VR technology became a global tool for nuclear power plants studying. In 2019, a large-scale VR simulation of the Fukushima-1 emergency power plant was presented to the world public. With its help engineers and scientists can assess requirements for

Fig. 1 The Teslasuit smart suit for a thermal power plant [51]

work to be carried out in the area of radiation contamination. Canadian university has virtual nuclear reactor simulator. It is used to train emergency response personnel. Ability to simulate different situations and stop events allows lecturers to adjust and objectively evaluate staff and students actions [53].

Chinese scientists at the Chinese Academy of Sciences developed Virtual4DS simulator with virtual reality support to simulate the life cycle events of nuclear power plants and extreme scenarios such as reactor destruction. Using this platform, you can analyze new reactors safety, predict changes in radiation levels and long-term environmental impacts. Virtual4DS can also be connected to new NPP management system for training, staff training, accident simulation. It can test effectiveness of contingency plans. The developed software use will be carried out for design and safety assessment of object through the analysis of large data from digital reactor along with information about the climate, tectonic movement in certain areas [53].

The "digital reactor" (VisualBUS) was developed to provide high accuracy integrated modeling of multiphysical processes for nuclear energy [1]. VR and high computing performance, the operation of the digital reactor is aimed at achieving full range and integrated modeling of reactor behavior in full cycle mode due to integration of digital technologies such as big data, cloud platforms, visualization. Virtual NPP is based on a digital reactor. It is an integrated simulation platform for entire NPP environment.

Virtual4DS is an integrated simulation platform for modeling accidents and emergency situations at NPPs. It performs following tasks: modeling reactor design and operation, accident modeling and warning, full-scale migration of radionuclides and environmental impact assessment, public health risk assessment. Virtual4DS can be connected to NPP information system and get access to its status in real time. Also, Virtual4DS has wider application. It is used during wells drilling, testing nuclear weapons and nuclear power plants and more. It was accredited by The Nuclear Energy Agency of the Organization for Economic Co-operation and Development [1].

Let's consider more detailed tasks of Virtual4DS [1]:

- large-scale diffusion of radionuclides in the environment. Research of long-term diffusion processes, forecasting of consequences, estimation of dose load of radiation on population health and environment;
- accident warning and simulation of various accidents. It is possible to predict the risks of emergencies at NPPs based on forecasting of NPP equipment malfunctions and changes in the external environment. Thus it is possible to predict the most probable accidents;
- nuclear emergency and personnel training. Timely and correct rescue plays an important role in overcoming consequences of nuclear accident. Nuclear accidents are very dangerous and cannot be simulated in the laboratory. It is possible to simulate different scenarios of nuclear accidents and perform training and education of personnel in near-real-world environments due to VR technologies. Training effect in the simulation scene for NPP personnel is important and has advantages of safety, savings (money and time) and repeatability possibility.

Virtual Fusion Reactor (FUSION-V) is customized applications of Virtual4DS for fusion reactor design and safety assessment. It supports simulation and prediction of new phenomena based on multiphysics coupling with neutron transport in media of high-gradient attenuation radiation, new coolant, tritium breeding and cycle, etc. Safety design and evaluation in the whole space with high fidelity can be done including radiation safety design and evaluation, operation and control safety, repair safety, accident evolution, etc. FUSION-V is a collaborative research platform, supporting collaboration-based research tasks management, cloud-based research such as co-design, intelligent analysis-based performance evaluation, and decision support. FDS team developed virtual reactor (CLEAR-V) based on Visual4DS (Fig. 2). It is possible to anticipate potential problems during the design, construction and operation of the reactor to speed up the design and construction of the reactor and provide operator training [1].

Augmented Reality APP—Chornobyl NPP ARCH AR application was officially launched in 2018. According to the State Agency of Ukraine on Exclusion Zone Management, this application allows to visit new safe confinement and look in detail at the design of the Arch and the Shelter by smartphone. With this tool you can see absolutely all details to the size of the exhibition stand. It is possible to get real picture of object "Shelter" details without risk to human health [54]. In the future, applications of this type can be used to improve efficiency of emergency preparedness and response system and emergencies at potentially hazardous sites. But this requires development of new methods, approaches and information systems to address emergency prevention. These systems should be based on adequate mathematical models of development of various emergencies and meet modern requirements in the field of civil protection [4].

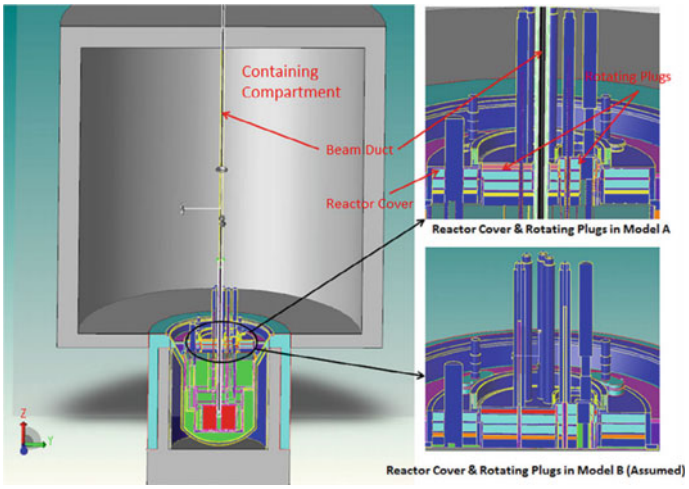

Fig. 2 Three-dimensional neutronics accelerator driven subcritical system model [1]

Virtual tour or interactive 3D application is a software product that allows you to visualize, navigate, interact with a 3D model. It allows you to move on three-dimensional model representing real or projected object, to perform various actions. High degree of 3D model realism contributes to effect of user immersion in presented object. Such objects can be industrial sites, buildings, oil rigs, nuclear power plants, etc. Interactive 3D applications can be effectively used at all stages of the life cycle of an industrial facility: from design to dismantling. Also, applications can be used to solve highly specialized problems or be a part of automated enterprise management system. It can be used by different groups of professionals: engineers, operators, firefighters, repair specialists, security service. Using of 3D-applications provides managers of industrial facility with ample opportunities to monitor progress of various processes at the enterprise, assess the current state of the object, forecast possible accidents [55].

Let's analyze various aspects of 3D applications use in the operation of nuclear power plants [55].

1. *Operation, repair and maintenance.* Carrying out repair work on complex and dangerous man-made objects is associated with risk of abnormal situations. For this reason, great attention is paid to careful planning of such works. Safety is a priority for operation of industrial facilities. An interactive 3D application based on an up-to-date and accurate three-dimensional model allows you to easily plan repairs, in particular, assess the possibility of safe work, plan the placement and movement of personnel and equipment taking into account safety zones, work with maintenance engineers to perform technological operations.
2. *Forecasting and elimination of emergencies.* Use of interactive 3D applications increases level of industrial safety, especially on dangerous objects. Such applications can be a system part for monitoring and managing engineering systems of buildings and structures used in potentially hazardous, especially hazardous, technically complex and unique objects. Virtual tour allows to estimate conformity of object to norms of chemical, fire, radiation safety, to develop such documents, as the plan of localization and liquidation of emergency situations. The 3D application allows not only to simulate the development of an emergency situation, but also to assess possible consequences. Also, the user can observe the process both from the side and from inside the virtual object to increase efficiency. For example, assess extent of smoke spread at specified time after the start of the fire or check capacity of emergency exits when playing scenario for the evacuation of personnel.
3. *Safety*. Presence of 3D model of NPP contributes to effective development of protection scheme. It takes into account individual infrastructure of industrial facility. It is determined by the size and configuration of production site, geometric characteristics of buildings and structures, peculiarities of their location on the territory. Using interactive 3D-application it is possible following: to choose means and schemes of protection and control of situation on object, effectively to place cameras of video surveillance systems, to organize pass mode,

to provide physical and antiterrorist protection of objects. Also it is possible to visualize in real time.

4. *Visualization of processes.* Interactive 3D application allows you to visualize modeling results—from spread of smoke in case of fire to assess convenience of repair work in terms of staff access to object. Online visualization involves demonstration of real-time events; offline visualization shows calculations results, such as spread of toxic substances in the event of an emergency. Online visualization involves use of sensors system. It is based on information from which mathematical model of technological process is built and its state at current time is visualized. This visualization helps control the process. Alternative is to visualize different states in pre-determined scenario. Therefore, we emphasize that AR and VR technologies application at nuclear power plants, where the human factor and staff training play a significant role, has significant potential.

We can note following regarding the cost-effectiveness of using interactive 3D-applications on dangerous objects: reduction of cost and time for staff travel to object; design errors elimination before beginning of construction and installation works stage; increasing level of object industrial safety; improving efficiency of dangerous objects management [55].

Rapid development of VR and AR technologies and their scope expansion led to number of scientific and technical studies on VR and AR technologies development. It is also important to analyze best practices in VR and AR technologies use for NPP personnel training and education. It is necessary to introduce such best practices in higher education institutions, where future specialists are trained to work at nuclear power plants.

In [56] it was emphasized that reliable training is a key to safe and productive activities of NPP personnel: “cost of the slightest mistake in the energy sector can be incredibly high!”. In order to minimize risks, special attention should be paid to training for work at NPPs. VR technology is a reliable and effective simulator, with which you can easily design any situation and work out procedure to solve possible problems. By means of VR-system: actions order in the emergency mode is fulfilled; optimization of temporary costs for urgent repairs is achieved; dismantling/installation of equipment elements, etc. is being worked out. Using VR technology you can visualize project for collective acquaintance, further adjustment and joint decision-making in the framework of corporate activities [56].

There is no doubt that energy infrastructure is critical. So, reliability and safety of its facilities, and hence the training of the highest requirements is also critical. VR technology allows you to safely organize such training in conditions close to real. Interactive 3D applications allow you to organize training for remote or hazardous industries. Having 3D model of NPP, there is no need to go to facility for training: training can be done in the office, staff will not only be able to virtually explore the facility, but also with the instructor to play different scenarios [55].

The American Electric Power Research Institute (EPRI), namely the Nuclear Maintenance Applications Center, prepared interactive manual with VR interface

for working with the Terry Turbine pump turbine. Wearing VR helmet connected to the computer and running the program (Figs. 3, 4 and 5) user enters learning environment [57].

There the user has access to following modes: (1) arbitrary—you can in any order remove and replace pipeline nodes; (2) workshop—the user disassembles and assembles unit with help of prompts, rogram alternately highlights nodes; (3) instruction—an animated video is launched, which shows the procedure for disassembly

Fig. 3 EPRI virtual reality training for terry turbine maintenance (Example 1)

Fig. 4 EPRI virtual reality training for terry turbine maintenance (Example 2)

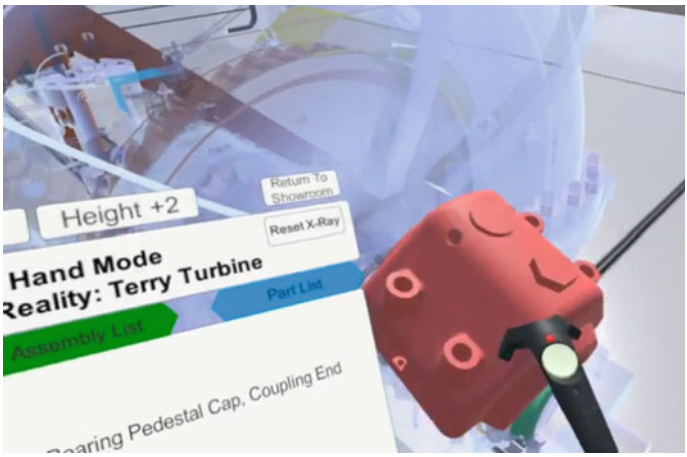

Fig. 5 EPRI virtual reality training for terry turbine maintenance (Example 3)

and assembly of the pipeline; (4) test—only text instructions are available. The Terry Turbine was handed over to energy company Dominion Energy, which tested it at three of its nuclear power plants and also praised it. NPP management hopes that virtual training will interest young people in working at NPPs and thus help to improve the staffing situation [57].

In [58] it is noted that VR complex served several purposes. It was created at the Rostov NPP during the construction of its third and fourth power units. According to the developer, VE Group controls (supports) station construction, presentation and staff training. The complex was used primarily as visualization tool in solving complex optimization problems, such as schedule adjusting to minimize delays caused by late deliveries of equipment from contractors and subcontractors. VR-system belongs to the CADWall type. Image (stereoscopic or normal) is projected on a flat screen. The VE Group solution implements Blending, i.e. stitching images where joints are invisible. Switching and control system allows both in normal and stereo mode to display on top of background image windows of various applications, scaling them as needed. For training, the complex includes system of interactive interaction (tracking). It monitors movement of person in special suit in front of virtual stage. To Developers increased number of infrared cameras from the standard four to ten to increase the accuracy of tracking. Special VR-gloves allow users to work out installation processes on virtual objects, check assembly level of structures and interchangeability of their parts. The complex also includes video conferencing system and acoustics for conferences and meetings [58].

Currently, there are various organizations, such as NPP "Educational Technology"—a research and production company [58] with 40 years of experience that develops and manufactures components of modern high-tech educational environment for most sectors of Russia's industrial economy. Transition of nuclear energy to higher technological way contributed to the creation in the system of vocational

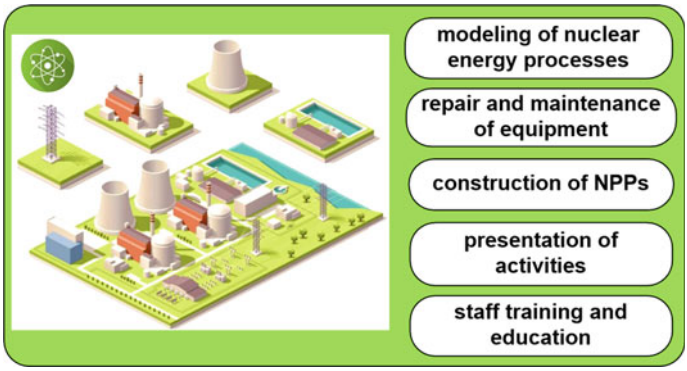

Fig. 6 Areas of use of VR and AR technologies for nuclear energy

education of high-tech educational tools (simulators, simulators) as the most effective tools for the formation of knowledge and professional competencies. Such interactive educational equipment and visual aids allow with minimal material and resource costs to identify and consolidate in student appropriate causal links in studied objects, phenomena and processes. On the web site [58] in the section "Training equipment for nuclear energy" it is presented following: nuclear power plants (blocks of nuclear power plants); facilities and complexes with industrial nuclear reactors. Atomic energy training equipment complete with digital tools and VR technologies are designed to comprehensively support all forms of educational process [58].

Thus, based on the analysis of the scientific literature [1, 31, 32, 43] and publications on the Internet [5, 50–58], it is determined that currently VR and AR technologies for nuclear energy are used in the following areas (Fig. 6): modeling of various nuclear energy processes; operation, repair and maintenance of NPP equipment; presentation of activities, NPP construction; staff training and education.

4 Conclusions

Analysis of the world experience of VR and AR technology for nuclear energy defined that powerful energy companies actively use these technologies for various needs of industry, namely: staff training, presentation of new equipment (exhibition complexes), etc.

It is determined that currently VR and AR technologies for NPPs are used in the following areas:

- modeling of various nuclear energy processes. Digital reactor and virtual NPP is used for high-precision integrated modeling of multiphysical processes of nuclear energy. It can analyze new reactors safety, predict changes in radiation levels and long-term environmental impact;

- operation, repair and maintenance of NPP equipment. Application of VR and AR for planning of repair works on the basis of actual and exact three-dimensional model for estimation purpose of possibility of safe carrying out of works, planning of placement and personnel and equipment movement taking into account safety zones, to work with maintenance engineers;
- presentation of activities, construction of NPPs. Application of VR and AR technology for developments or projects visualization. It can be used as a visualization tool in solving complex optimization tasks, such as calendar plan adjusting to minimize delays caused by late deliveries of equipment from contractors and subcontractors during the NPPs construction;
- staff training and education. VR and AR technologies can be the most effective tool for skills and professional competencies developing of NPP personnel. Employees can improve their skills (simulating accidents to test the effectiveness of contingency plans) and hone their skills without risking their lives. Thus, various aspects of training and advanced training of NPP personnel using AR and VR technologies are considered.

Also, use of VR and AR technology confirms its cost-effectiveness due to the reduction of cost and time spent on business trips to facilities; elimination of design errors before beginning of construction and installation works stage; increasing the level of industrial safety; improving the efficiency of NPP management.

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