Application of Dynamic Virtual Visualization Method for Modeling the Consequences of Nuclear Tests

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Abstract— **This paper considers an example of dynamic virtual visualization of physical fields in nuclear test sites and modeling of radiation environment parameters through interactive operation in virtual reality. The authors examine the possibility of applying mathematical framework to map radiation field propagation area in the area of nuclear tests, as well as to visualize built model using virtual reality technology. Application of software supplement for reconstruction of the shielding in area of explosion epicenter for experimental modeling is considered. Description of the physical equations that were used to prepare the calculation module is presented. The logical and software architecture of the solution are described. A 3D-scene of the nuclear test site was generated, for which an experiment was conducted using the parameters of the explosion specified by the interactive scale. The work is highly relevant due to the need to define an area and safe zone of deployment of personnel to carry out verification at the sites of the anticipated tests. In turn, there is a growing need to develop and implement information tools to support analysis of physical processes in the area of a nuclear explosion for Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization personnel training.**

Keywords— **Virtual reality, radiation field, nuclear tests, mathematical modeling.**

I. Introduction

On-site inspections are an essential element of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) nuclear test verification regime. The prompt dispatch of an inspection team to a suspected nuclear explosion site is important because evidence of a test can be obtained in the limited time available. In just 72 hours, a number of preparations for verification and the departure and deployment of the on-site expert team must be arranged. Nuclear test areas are zones of spreading radiation and radioactive decay products in the environment, and therefore an analysis of the terrain is needed to ensure the safety of personnel for verification [1]. There is a growing need for

the development of technology that allows the simulation of the consequences of a nuclear explosion, including the spread of the radiation field, on the basis of primary data on the nuclear explosion. At the same time, the interactive visualization of the event will make the analysis process dynamic and understandable under time constraints. The application of a mathematical system for calculating radiation field parameters together with the use of virtual reality will help in studying the radiation exposure volume received by the environment at the sites of nuclear explosions, which will provide a preventive analysis of the radiation situation for the placement of an expert group during on-site inspections.

II. General description of the system

The visualization of physical fields can be performed in three-dimensional space to increase the immersiveness of perception. This is necessary in time and resource-limited circumstances, as the understanding and reception of the results of analysis is enhanced by immersion in an artificially created environment. A strategy to visualize the data set in a virtual reality environment was chosen. In order to fulfill the objectives, it is necessary for the product under development to include the possibility of interactive adjustment of the experiment parameters. Therefore, in this regard the method of visualization of the physical field with the help of spheres was applied into the work. Each of them is represented as an indicator located in nodes of a three-dimensional grid. Step of a grid and its dimensions will be set during modeling as parameters. For example, you can specify transparency, size, and number of spheres. Measurements will be preliminary transferred into the 3D-scene of the virtual environment. At each point of the grid will be calculated the radiation load from the impact source, which is located within the grid.
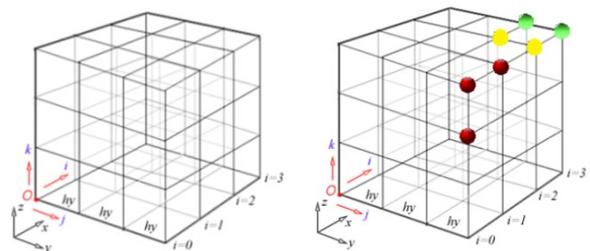

Fig. 1 – (a) Three-dimensional spatial grid with nodes. (b) Three-dimensional spatial grid with spheres arranged in nodes.

To demonstrate the possibility of application of the

developed method of dynamic visualization of the fields from a nuclear test the epicenter of its explosion is represented in the form of a simple point source.

For the model calculation the formula for the value of the scalar field at a point was used

$$F(x, y, z) = \frac{q_1}{(x-x')^2+(y-y')^2+(z-z')^2} \qquad (1)$$

Where F - scalar value of the field force from a point source at a point;

q_1 - emission rate;

x', y', z' - coordinates of point source;

x, y, z - coordinates of the point of calculation for the scalar value of the field force in the point.

At each point of the grid the dose load volume from the exposure source, located within the grid or outside it, is calculated. After the calculation in each node, the indicator is color-coded. Ranges of color indexing values are set optionally depending on the complexity of the subject field and parameters of the experiment. In the most basic case, an intuitive stepped "traffic light" coloring can be used, where:

1) Red color - the value is greater than or equal to the upper limit of the radiation dose absorbed per second.

2) Yellow color - the value is less than the upper limit of the radiation dose absorbed per second, but greater than or equal to its lower limit.

3) Green color - value is less than the lower limit of radiation dose absorbed per second.

The effective dose is a value that is used to determine the risk of distant effects of radiation exposure. According to the Russian Federation Radiation Safety Standards (NRB-99/2009), the effective dose limits for the population are 1 mSv per year on average over any consecutive 5 years, but no more than 5 mSv per year [2]. However, events that occur during a nuclear explosion proceed over a short period, counted in seconds, and their duration depends directly on the parameters of the explosion. In this regard, there were calculated values of upper and lower limits of the effective dose rate in seconds, which were further used to estimate the color indication.

In order to implement shielding during the experiment, it is necessary to solve the problem of determining the run length in the material

$$R = aE^b + C \qquad (2)$$

Where a, b, C - constants;

E - Energy of the particle.

Calculation of shielding radiation attenuation in materials uses the law, which is described by the exponential dependence for non-scattered gamma rays and "narrow beam" neutrons

$$J_d = J_0 e^{-\frac{d}{\lambda}} \qquad (3)$$

Where J_d - Intensity of radiation at a given point with a shield;

J_0 - Intensity of radiation at a given point without the shield;

d - Range length;

λ - Thickness of the shielding material, attenuating the radiation in e=2.71 times, (relaxation length), depending on the radiation type, its energy and the shielding material.

Subsequently, by comparing the obtained intensity value

it is possible to determine the color of the sphere-indicator of the three proposed categories.

Therefore, it is possible to determine whether the radiation will be absorbed by the shield material. The value of the half attenuation layer is given by a global variable. The screen protection planes are represented as two parallelograms. In order to find the range, it is necessary to determine the points of radiation penetration through each of them. According to the found points a segment is constructed, the program function allows to calculate the length of the formed segment.
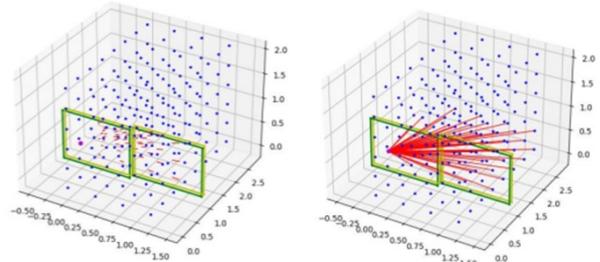

Fig. 2 – Visualization of the radiation range calculation. (a) The shield absorbs the propagating radiation. (b) The screen does not absorb the propagating radiation.

In the case when the radiation passes through 1 parallelogram, or does not pass through parallelograms at all, the construction of the segment does not proceed. Consequently, the screen has coped with the protective function. With a different outcome, namely when the radiation passes through both screens, the radiation exceeds the ability of the shielding. If necessary, this can be visualized by plotting the sections.

Afterwards when the resulting intensity value is compared it is possible to determine the color of the sphere-indicator from the 3 suggested categories [3].

III. THE USE OF VIRTUAL REALITY FOR DYNAMIC SIMULATION OF PHYSICAL PROCESSES

Dynamic virtual visualization of objects in the scene can be optimized depending on the specified parameters. The change of the radiation environment in the model can be set by interactive operation of the tools in the virtual scene. The principle of operation of the proposed solution can be described with the help of a logical scheme.
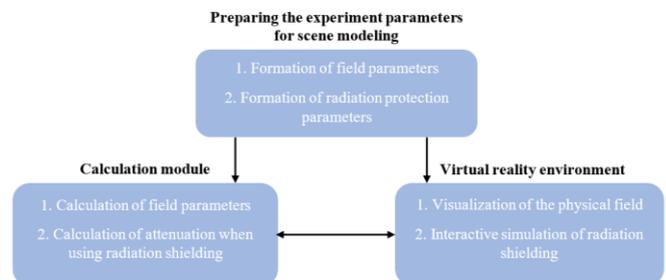

Fig. 3 – Scheme of interaction of the system's logical units.

Properties and parameters of a physical field are set by means of module of experience conditions for simulation of a scene. If it is necessary to add shielding elements to the scene, the values of the corresponding units are also determined at this stage. In the calculation module, the field parameters are computed. When shielding is used, the

attenuation calculation is performed. The virtual reality environment module is utilized for interactive simulation of radiation shielding, as well as for visualization of the physical field.

The calculation module interacts bi-directionally with the VR-environment. In the course of the experiment, a continuous flow of parameter data exchange is performed between them. From the virtual reality module the information flow is transmitted on spatial positioning and orientation of sources, as well as radiation protection units when they are applied. Information about instantaneous values of fields in the points of indicators location is transferred back in order to create dynamic visualization of radiation environment when the position of radiation sources or protective units is being changed. Relocation can take place both according to predetermined trajectories, and manually, by moving the objects by the operator in the virtual reality environment [4].

IV. PROTOTYPE ARCHITECTURE OF THE SOFTWARE IMPLEMENTATION FOR INTERACTIVE VIRTUAL TECHNICAL REALITY

The VR Concept software [5] was used for the operation in the virtual reality environment. A SimulationManager plugin is used to interconnect the computational module, which is implemented by a C++ program code, with the VR Concept visualization environment. The interaction is performed using a plugin from the vrcSimulationPlugins block. VR Concept-0.25.1 software version is used in the given study. The information exchange is implemented bi-directionally using the UDP interaction datagrams protocol together with the external modules.

Script written in the Python programming language is used to prepare the scene, which changes the file structure in the ".vrcp" format, generating the required number of indicator spheres and immediately giving them the necessary simulation commands to place in the coordinate grid of the virtual scene and change the color of the indicators themselves. As a result, the following functions have been implemented to interact with the VR Concept virtual reality environment:

- Function for placing the indicators;
- Function for calculating field parameters;
- Function for transferring data to VR Concept;
- Function for obtaining the orientation of objects from VR Concept;
- Function for calculating shield attenuation;
- Function for color indexing of indicators.

For the operation of the presented functions, geometric classes with corresponding fields and methods have been defined, such as:
- "Point" with x, y, z coordinate fields and constructor;
- "Vector" with the coordinate fields dx, dy, dz, constructor and overloaded operators +, -, * and ==;
- "Line" with Point 1 (Point) and Point 2 (Point)

fields, constructor and method of its length calculation;
- "Parallelepiped" with Vector 1 and Vector 2 fields and a constructor.

The architecture of the information product is shown in Figure 4. The system consists of two programming modules: visualization, which is VR Concept software, and calculation module in C++ programming language. Using 3D-object files, a virtual scene (project.vrcpa) with indicators and required objects in it is formed. VR Concept and the calculation module exchange information in real time via the UDP protocol.
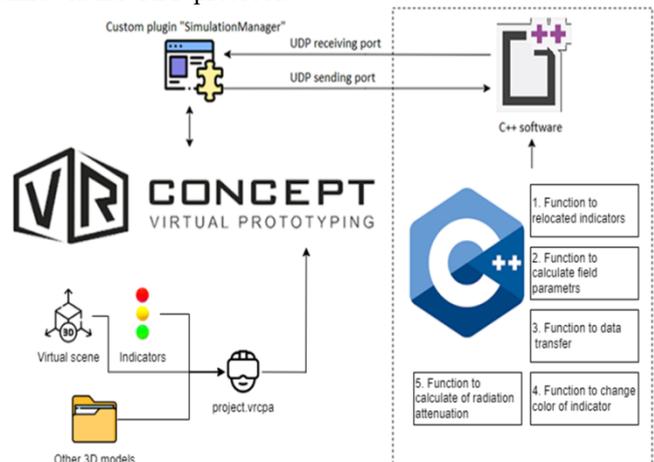

Fig. 4 – Software architecture of the information product.

Generated data packets must comprehensively describe the state of the point in the coordinate system at each point in time. The bi-directional interaction between VR Concept and the external calculation module is therefore synchronized with the transmitted parameter values for the simulation. The external software module is presented as a console application in C++. The source and header files (vrcsimapi, vrcsimulationclient, vrcupdsimserver) were used to organize the flow of information between the visualization modules and the computation modules in a correct bilateral way using the UPD protocol. They provide a programming interface for the exchange of datagrams and information between the software modules.

The exchange of information is performed using a pair of index and value, where index is the simulation command in VR Concept, and the value is the required figure calculated in the module. To transfer the data the client class is implemented, which uses the setData() method with the index and value parameters presented above to set values in the visualization module. The SimulationManager plugin builds the coordinate grid of indicators and sets their respective colors by RGB value according to the received data (index and value).

V. RESULTS OBTAINED IN THE STUDY

In the VR Concept virtual environment, a 3D-scene depicting a test pit was generated in which the indicator spheres were formed.
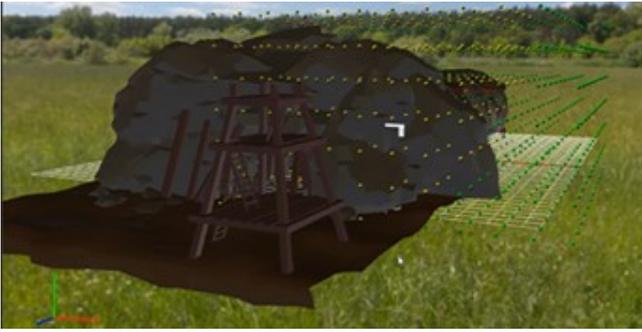
Fig. 5 – An overall view of the recreated 3D-scene of the event.

The radiation source is placed as a blue sphere with a large diameter. For this work it corresponds to the epicenter of the test explosion.
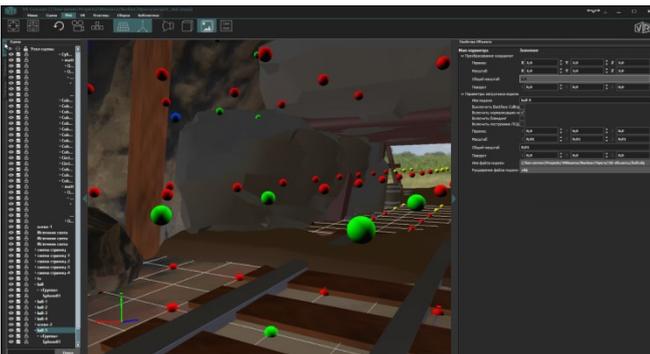

Fig. 6 – Modelling of radiation field propagation from a source with shielding application.

To set the parameters of the radiation field a window with an interactive scale designed. The operator can adjust the values for the emission rate (q), its radius (r) and coordinates (x, y, z) automatically.
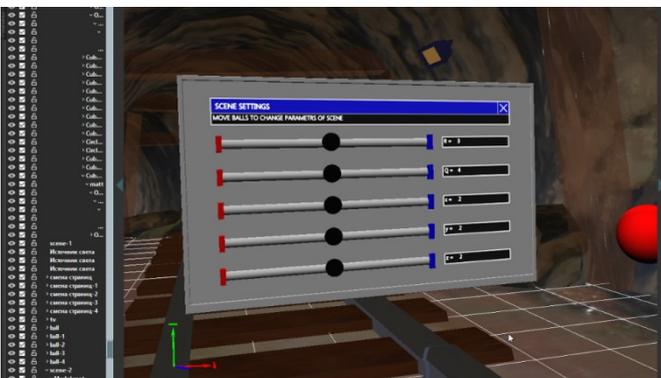

Fig. 7 – Interactive window for setting the source parameters.

The protective shielding was also applied. Its parameters are set programmatically in the block of the calculation module.

VI. CONCLUSION

Results obtained demonstrate possibilities of modeling physical processes in virtual reality environment. For experiments on reconstructing the consequences of nuclear tests it is possible to specify parameters with the help of interactive tools of 3D-scene on the explosion site. Thus it permits to forecast promptly the radiation situation in the places of nuclear tests, which facilitates early calculation of safe zones for the location of the team of experts. In turn, modeling by the suggested method will allow the observation of the propagation of physical fields in the environment as one of the consequences of the tests to study the nature of the explosion. By changing the parameters of the physical field visualization model, size, grid spacing, dimensions and properties of the spheres, it is possible to adapt the immersiveness of perception in the virtual environment for the user. Quality and realism of the virtual environment and, most importantly, its safety allow to apply the technology for education and training of personnel for on-site inspections. This enables the analysis and subsequent investigation of the acquired exposure dose rate of the environment at the nuclear test sites. In addition to the prediction of dose rates, the mechanics of buildup, it is possible to create radiation protection and allocate zones at the test site with appropriate exposure rates not exceeding a certain threshold.

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REFERENCES

[1] ON-SITE INSPECTION. CTBTO Preparatory Commission: [Online]. Available: https://www.ctbto.org/our-work/on-site-inspection.
[2] Head State Sanitary Doctor of the Russian Federation Regulation №47 On Approval of SanPin 2.6.1.2523-09 dated July 7, 2009. Electronic Foundation of Legal and Regulatory and Technical Documents. [Online]. Available: https://docs.cntd.ru/document/902170553.
[3] M.A. Utkin, "Development of visualization model of dynamic change of radiation load intensity at interactive simulation of protection in virtual reality environment" Master's thesis, National Research Nuclear University MEPhI, Moscow, Russia, 2022.
[4] M.A. Utkin O.V.Boyko, .M.G. Zhabitsky, "Method of dynamic virtual visualization of physical fields and optimization of parameters of radiation environment by means of interactive operation in virtual reality", *International Journal of Open Information Technologies*, vol. 10, August 2022. pp. 46-50.
[5] VR Concept. Concept Virtual Prototyping: [Online]. Available: https://vrconcept.net/vr/.