Virtual Reality-Based Simulation of ADS Spallation Target Maintenance

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INTRODUCTION

For As Low As Reasonably Achievable (ALARA) evaluation of an intervention in radiation working sites [1], the optimal scenario should be found to prevent the operators being too much exposed and integrating too much dose. However, due to the risks involved, work scenario is always designed based on experts' or past experiences, without considering faults in plant design, human wrong operation by unskillful handing, risks associated with unpredictable situation, the suggested work scenarios are always not the optimal scenarios according to ALARA principle.

Based on Virtual Reality (VR) technology and high-precision whole-body computational phantom named Rad-HUMAN [2], a virtual reality-based simulation system for nuclear and radiation safety named SuperMC/RVIS has been developed for organic dose assessment of interventions in nuclear or radiation working sites. The latest version is SuperMC/RVIS2.3 [3-5]. The improved features of our system are accurate evaluation of organic dose rates, which considered with the radiosensitive level of different organs, and advanced visualization of radiation on a graphical user interface (GUI).

FUNCTIONS OF SUPERMC/RVIS

SuperMC/RVIS is designed to be an integrated virtual reality-based simulation system for organ dose assessment of interventions in radiation working sites. Main functions are shown in Fig. 1.

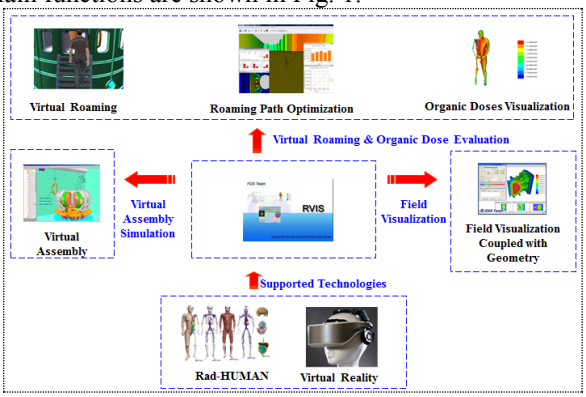

Fig. 1 The Main Functions of SuperMC/RVIS

a) **3D data field visualization coupled with geometry**

The output data of radiation transport simulation code can be automatically and intelligently visualized mixed with the input models according to users' interests. The calculation results can be visually analyzed with various styles such as mixed visualization with geometries, iso-surface and volume rendering. Besides, some normal visualization functions, such as curve plot, 2D map plot, mesh plot, geometry-coupled visualization and geometry-based data cutting, several new advanced visualization functions are supported, such as unified color mapping for various data maps, dynamical visualization in space. Now SuperMC/RVIS has directly supported of data post-processing for multiple codes, such as SuperMC, MCNP and TORT. Fig. 2 shows the visualization functions of SuperMC/RVIS.

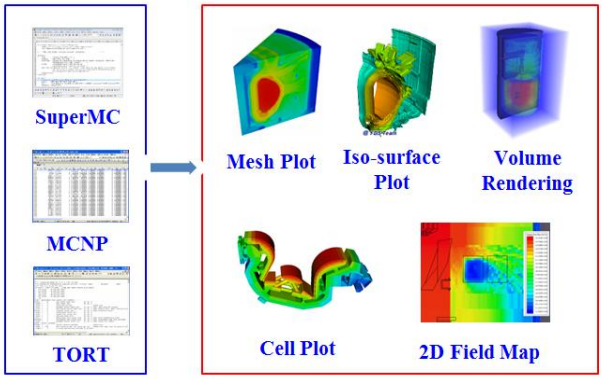

Fig. 2 The visualization functions of SuperMC/RVIS

b) **Virtual-reality based interactive simulation**

SuperMC/RVIS provides three-dimensional virtual interactive simulation function for nuclear complex facilities based on virtual reality hardware, which is shown in Figure 3. It can achieve accurate collision to parts' virtual assembly and disassembly, evaluation to assembly scenarios and optimization to assembly scenarios, and then it can verify the reasonability of nuclear facility model design to assembly's perspective, evaluate the assembly scenarios, and train the assembly workers and so on.

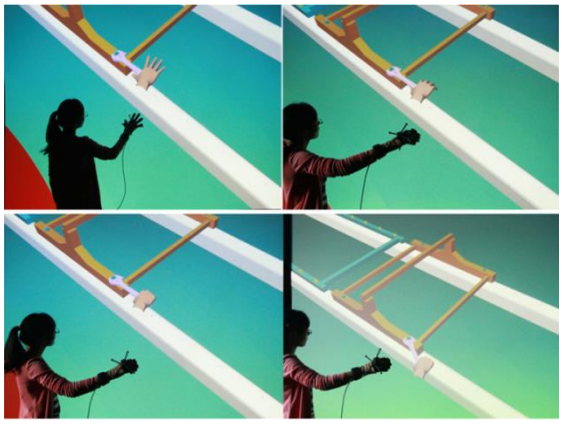

Fig. 3 Slide rails installation interactive simulation

c) Virtual roaming for organic dose assessment

After the modeling stage, paths can be defined, taking into account that the avatar can walk or stand at some locations for some time, during typical operations. Various doses vs. time have been calculated, for example, accumulated whole-body dose, effective dose rate, and equivalent dose rate of sensitive organs. The movement speed of a worker inside the nuclear working site can be assigned by users, taking account the realities of different tasks. Real-time dose assessment were displayed with the dose rate distribution with refresh rate of 50 Hz., which is shown in Fig. 4.

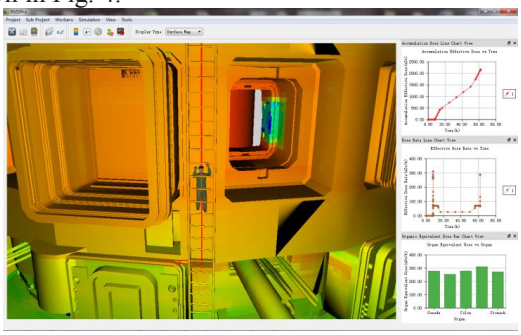

Fig. 4 Real-time dose assessment and visualization of dose rate distribution in radiation working site

APPLIACATION OF SUPERMC/RVIS ON ADS SPALLATION TARGET MAINTENANCE

The case study chosen to optimize the proposed development for dose assessment in nuclear and radiation environment was the modeling and simulation of ADS spallation target maintenance. China LEAd-based research Reactor (CLEAR-I)[6-7] was selected as reference reactor for the first stage of China Accelerator Driven Subcritical System (ADS) project. Spallation target is a key component to connect the accelerator and subcritical reactors in ADS system. It was bombarded by high-energy protons and spallation neutrons, while a large number of nuclear heat deposition produced. Therefore, target window is designed to replace at regular intervals and should be carried out by manual.

Real-Time Organic Dose Assessment

Various exposed doses and working time could be on-line calculated and shown on the screen, for example, accumulated dose, effective dose rate, and equivalent dose rate of sensitive organs. Various organ dose Rate results at location (-710， -744, 633) are shown in Figure 5. The maximum dose rate during this maintenance activity was 0.914 μSv/hr. The accumulated dose of a maintenance person was 0.213 mSv.

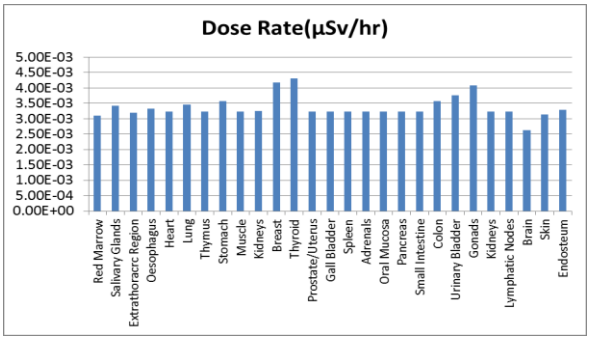

Fig. 5 Various organ dose Rate results

Virtual training for manual inspection and repair

A virtual environment for CLEAR- I Spallation target maintenance had been established based on RVIS and VR hardware in FDS Team for operator training. The virtual environment for CLEAR- I Spallation target maintenance was shown in Fig.6. The simulation allowed an immersive experience. Users could navigate the virtual environment by controlling an avatar to walk the way they wanted, visualizing the reactor rooms and radiation field, and experiencing the repair procedure. The dose information was computed in real-time and displayed, allowing them to evaluate the dose received by the avatars while walking.

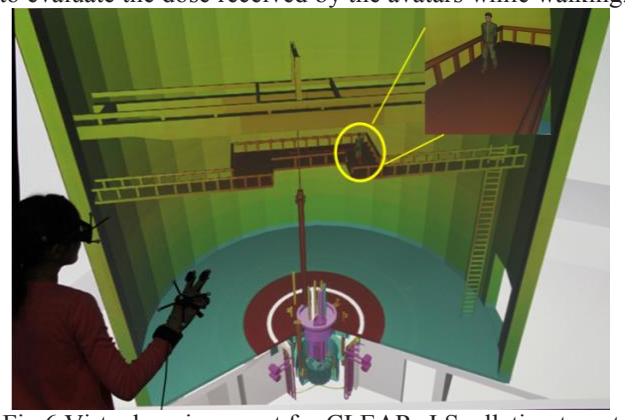

Fig.6 Virtual environment for CLEAR- I Spallation target maintenance

CONCLUSIONS

Based on VR technology and high-precision whole-body computational phantom named Rad-HUMAN, a virtual reality-based simulation system for nuclear and radiation safety named SuperMC/RVIS has been developed for organic dose assessment and ALARA evaluation of work scenarios in radiation environment. In this paper, the system architecture, ALARA evaluation strategy, advanced visualization methods and VR technology used in SuperMC/RVIS are described. Virtual reality-based simulation during CLEAR-I spallation target maintenance has been demonstrated to validate the feasibility and effectiveness of the system. SuperMC/RVIS makes it possible to safely perform the designs and optimization of work scenario in the risky areas taking into account the radiosensitive level of different organs.

ACKNOWLEDGMENTS

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