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Investigation of the Reactor Decommissioning Dose Field Calculation and Virtual Simulation Techniques: Preliminary Design for the Decommissioning of the First Heavy Water Research Reactor (HWRR) Reactor in China

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Abstract: The calculation and visualization of the dose field in the decommissioning of nuclear facilities is one of the important functions of the decommissioning virtual simulation system, which can provide accurate and intuitive radiation field distribution and play an important role in determining the demolition plan and protecting personnel during the engineering implementation process. This article investigates the development of dose field calculation and visualization in the reactor decommissioning virtual simulation systems, and preliminarily proposes a technical plan suitable for the development of the decommissioning dose field calculation and visualization display programs for the first Heavy Water Research Reactor (HWRR) in China. Besides, the applicability of the selected scheme is analyzed, the functional requirement and development direction of the HWRR reactor decommissioning dose field calculation and visual display module are preliminarily determined. Furthermore, the reactor vessel of HWRR reactor is modeled and the dose field distribution was calculated and visualized. This research can provide technical support for the development of the decommissioning simulation system for the first HWRR reactor in China.

Keywords: HWRR reactor; decommissioning; dose field calculation; visualization

1. Introduction

Nuclear reactor decommissioning is a measure taken when the reactor is shut down, with the purpose of permanently and explicitly improving its condition to meet safety protection requirements. The issue of decommissioning nuclear facilities has become an important issue facing the world. In the Level 3 decommissioning defined by the IAEA, it is required to remove all radioactive components and dismantled materials, so that the radiation levels in the factory reach or approach the environmental background, and can be opened for reuse. However, the cost is very expensive. At present, countries around the world have placed a special emphasis on developing suitable methods and approaches for retirement processes. Therefore, it is necessary to conduct pre analysis and simulation implementation of personnel control, nuclear facility item control, and environmental control in retirement projects [1].

The virtual simulation system for reactor decommissioning can become a powerful auxiliary tool for decommissioning engineering, providing a support platform for the determination of decommissioning implementation plans, process planning and optimization, analysis of construction key points, and personnel training [2]. The calculation and visualization of three-dimensional radiation fields in decommissioning scenarios is one of the important functions of the reactor decommissioning virtual simulation system. It can provide accurate and intuitive radiation field distribution for designers during the design of reactor decommissioning schemes, and plays an important role in personnel protection during the engineering implementation process [3].

The Heavy Water Research Reactor labeled 101 is the first research nuclear reactor in China, which was built in 1956, and was put into operation from June 1958 to December 2007. It has been

operating for nearly 50 years and has made historic contributions to the national defense construction, economic construction, and nuclear science and technology development of China. The transition period from 2008 to 2013 was the final safe shutdown stage, and preparations for retirement were officially carried out. At present, the first phase of retirement of the HWRR reactor has been approved, and related work is being carried out gradually, involving the dismantling of peripheral equipment, pipelines, etc.

This article conducts the progress on the development of dose field calculation and visualization tools for the reactor decommissioning. A preliminary technical solution for the dose field calculation and visualization program suitable for HWRR reactors is proposed. Besides, the outer shell of the HWRR reactor is modeled and the distribution and visualization of dose field are preliminarily calculated.

The content of this paper is organized as follows. The progress of the virtual simulation system for reactor decommissioning is presented in Section 2. Section 3 is the introduction about the technical scheme suitable for the development of dose field calculation and visualization module of the China HWRR reactor decommissioning system. The final conclusion is provided in Section 4.

2. Virtual Simulation System for Reactor Decommissioning

The research on the application of virtual simulation technology in the decommissioning of nuclear facilities in foreign countries started early and has made important contributions to the economy of decommissioning and various indicators of decommissioning plans. Studying the decommissioning technology of nuclear facilities through virtual simulation technology, verifying the feasibility of technical solutions, and optimizing the process have become an important direction for studying the decommissioning of nuclear facilities, and have become an essential technical means to solve the key problems of nuclear facility decommissioning.
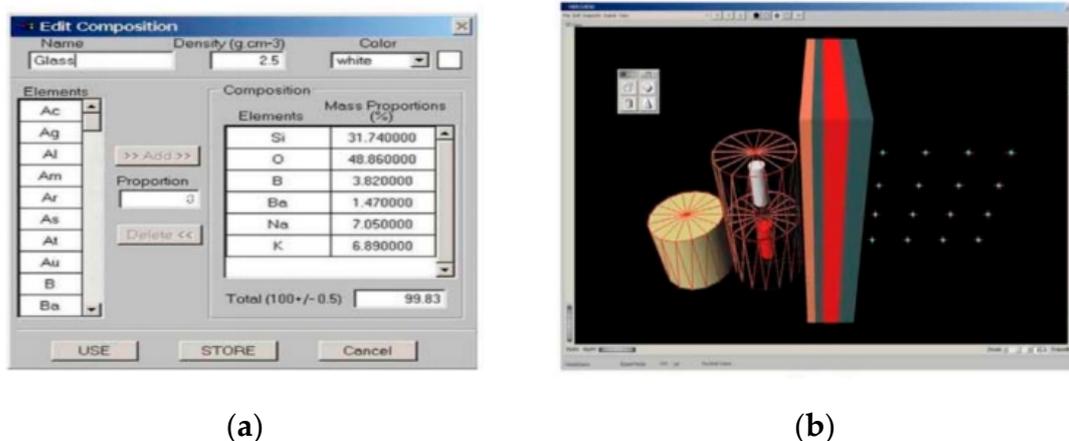

(**a**)   (**b**)

Figure 1. (**a**) Selection of Multilayer Shielding Materials in MERCURAD code; (**b**) Visualize display in MERCURAD code.

Since the 1980s, the French Atomic Energy Commission (CEA) has developed multiple simulation programs and software, including MERCURAD [4,5], CHAVIR [6,7], and NARVEOS [8,9]. MERCURAD is a three-dimensional dose field simulation program that uses the point kernel method to calculate dose rates. This program establishes several function modules such as shielding material library, cumulative factor calculation, energy group division, dose point definition, dose field calculation, and printing calculation reports. When calculating the dose fields, multiple layers of different shielding materials can be selected, which can be seen in Figure 2.1. The total cumulative factor of shielding for different materials can be calculated, the dose field calculation grid can be defined. Furthermore, the calculation of the dose field and the output of the dose field calculation results can be achieved, and the entire process can be visualized and displayed [5], which can be seen in Figure 2.2 [5].

CHAVIR is a software used for nuclear facility maintenance and decommissioning, which can realize scene setting and fast calculation of radiation exposure. The scenario definition function of this software is established by the Dassault software package VIRTOOLS, and the dose calculation function is partially implemented using the algorithm and function modules in the MERCURE code package, such as material selection, cumulative factor calculation, energy group division, etc. The scene CAD model of CHAVIR software can be established from predefined basic objects within the software, or can be imported into other CAD models, with a complete interface to support the implementation of this function. CHAVIR software can calculate the radiation exposure of point source and body source. The point source uses the point kernel method to calculate the radiation exposure, and the body source uses the Monte Carlo method to calculate the radiation exposure by gridding the body source, which can be seen in Figure 2.3. The coupling calculation of the two methods can be realized simultaneously to simulate the dose field. However, because the Monte Carlo method takes a long time to calculate, the overall calculation time of the software will be long. This software can define measurement points in the scene, and then calculate the dose rate of each measurement point, which can be seen in Figure 2.4. At the same time, CHAVIR can achieve dynamic calculation of the dose field and calculation of staff exposure dose, which can guide the simulation calculation during the dismantling of retired facilities [7]. Figure 2.5 and Figure 2.6 show the Visualization Model of Nuclear Power Plants and equipment room in a certain post-treatment plant.
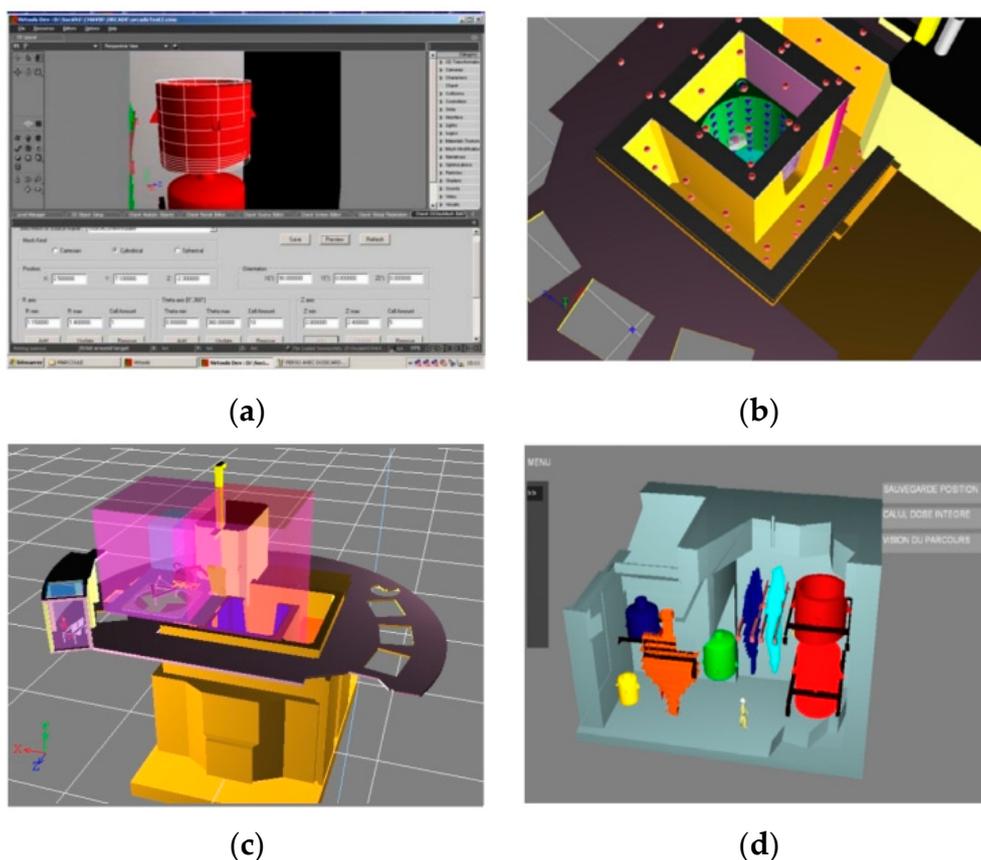

(a)

(b)

(c)

(d)

Figure 2. (**a**) Volume Source Meshing in CHAVIR code; (**b**) Selection of Dose Rate Measurement Points in CHAVIR code; (**c**) Simplified Visualization Model for Nuclear Power Plants in CHAVIR code; (**d**) Visualization model of equipment room in a certain post-treatment plant for CHAVIR code.

NARVEOS is a software system that combines virtual reality technology and point kernel method to calculate dose field. The software supports retirement scenario design and rapid dose calculation, which based on the principle of radiation assessment optimization (ALARA) to estimate the dose rates, simulate the operational feasibility, and optimize costs. This software can import 3DXML format files from CAD and use Dassault's 3DVia XM player to achieve virtual simulation of

retirement scenarios, which can be seen in Figure 2.7, so that the operating environment of personnel in dose scenarios can be visualized, which can be seen in Figure 2.8. Besides, Figure 2.9 shows the exposure dose in personnel operation paths, and then NARVEOS can provide optimization suggestions for personnel protection to reduce personnel exposure dose [9].
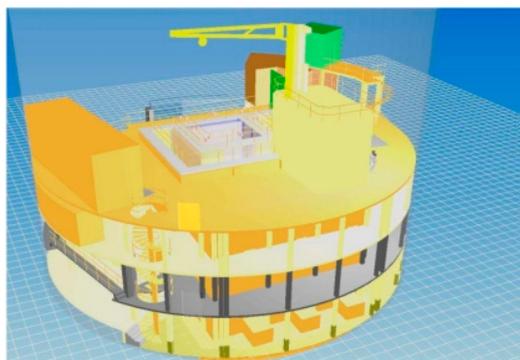
(a)
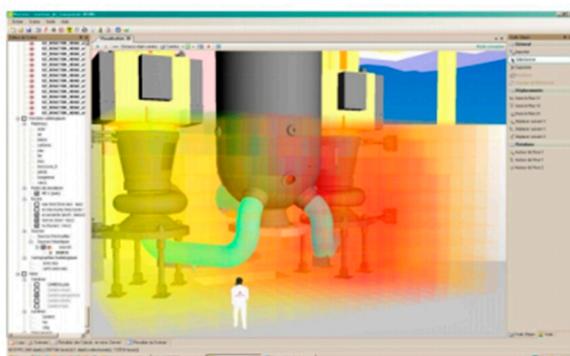
(b)

(c)

Figure 3. (a) Visualization display of a certain reactor model in NARVEOS code; **(b)** Visualization of the dose field in the personnel operating environment in NARVEOS code; **(c)** Dose rate display in personnel operation path in NARVEOS code.

Électricité de France has developed a PANTHERE software [10], which uses the point kernel method to calculate the radiation exposure rate of complex source terms and a large number of observation points in a three-dimensional scene. At the same time, it can achieve custom geometry and import other CAD models, which can be seen in Figure 2.10 and Figure 2.11. The visual display of dose field distribution in PANTHERE is shown in Figure 2.12. Besides, a dose optimization system is embedded in PANTHERE and can be used for optimizing work dose in high radiation environments by scheduling tasks including combining with actual models, clarifying the distribution and source of source terms, and selecting certain protective measures to optimize the collective exposure dose, ultimately achieving the goal of reducing personnel exposure dose rates. The optimization process is shown in Figure 2.13 [10].
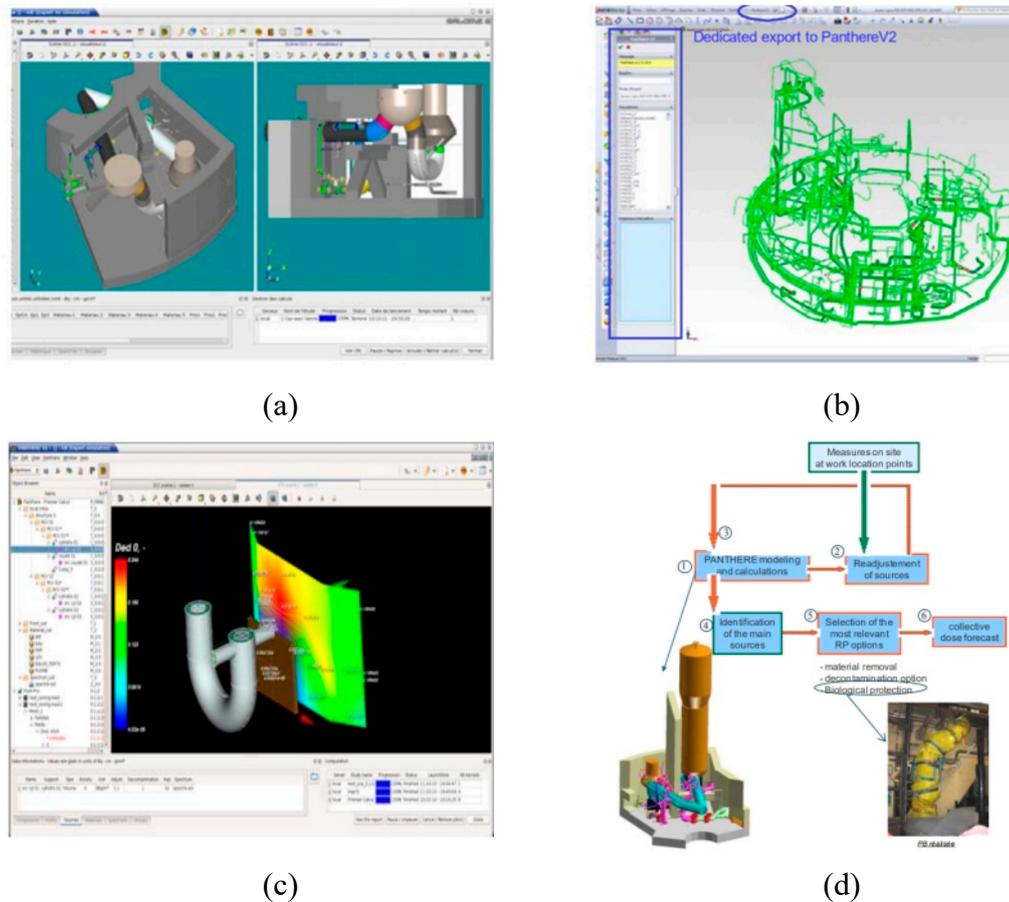
Figure 4. (a) Visualization Model of a Nuclear Power Plant in PANTHERE code; **(b)** Pipeline Layout Model for a Nuclear Power Plant in PANTHERE code; **(c)** Visualization display of dose field in PANTHERE code；**(d)** Radiation protection optimization process in PANTHERE code.

SCK·CEN in Belgium has developed a VISIPLAN 3D-ALARA software [11,12] that can be used to simulate dose distribution in decommissioning scenarios based on geometry, material, and source term information. This software adopts the point kernel calculation model, which can achieve dynamic calculation of the dose field in three-dimensional scenes. This software can take into account the changes in personnel operation positions and geometric and source terms in the work scene. The scene can be customized for modeling, and there is also an interface to import CAD models. By introducing different shielding structures in the model, the dose field distribution under different shielding materials can be calculated, and its effectiveness can be analyzed to achieve the development of shielding optimization plans. Detailed planning can achieve personnel work trajectory simulation and dose assessment, and flexible editing of radioactive environments and work trajectories can be used to optimize planned tasks, thereby achieving the radiation protection optimization [11], which can be seen from Figure 2.14 to Figure 2.17.
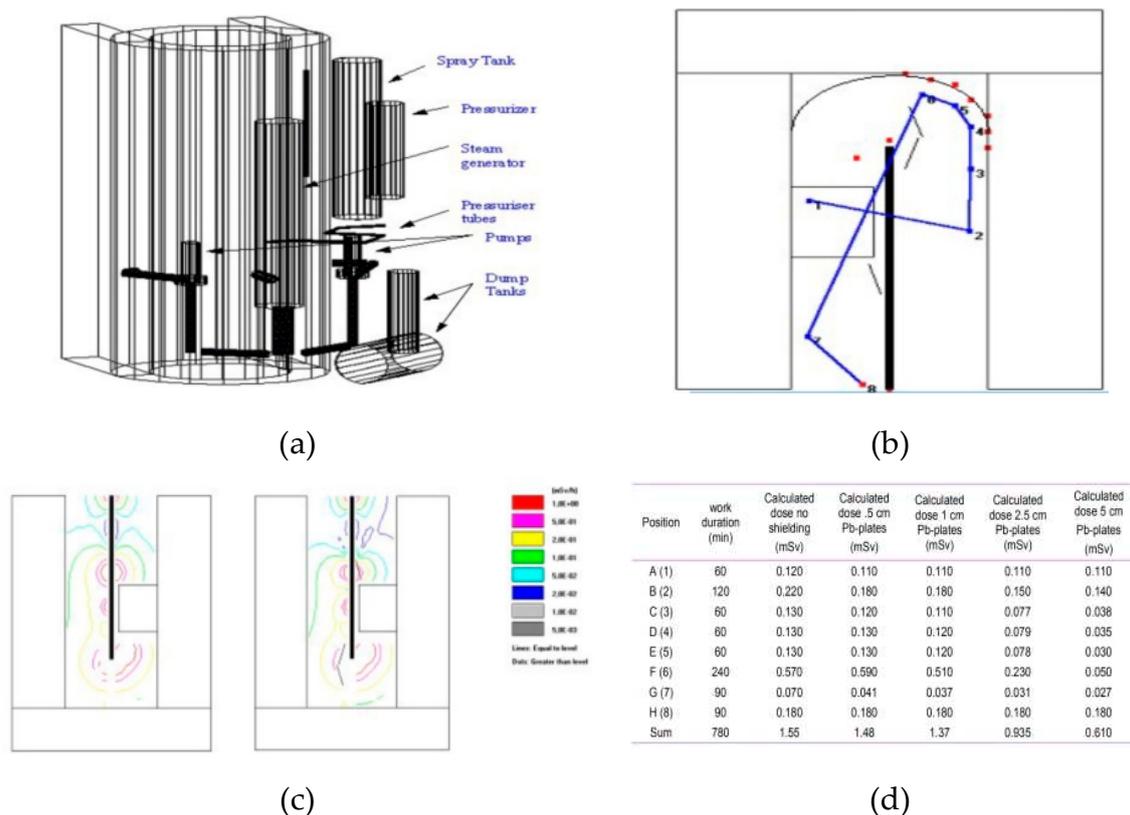
Figure 5. (a) Building the reactor model in VISIPLAN 3D-ALARA code; **(b)** Setting of personnel work trajectory in VISIPLAN 3D-ALARA code; **(c)** Dose field distribution when selecting different shielding materials in VISIPLAN 3D-ALARA code；**(d)** Calculation of the personnel exposure dose under different shielding materials in VISIPLAN 3D-ALARA code.

The Japanese Nuclear fuel cycle Development Agency (JNC), the Japanese Atomic Energy Research Institute (JAERI) and the Norwegian Energy Technology Institute (IFE) developed a decommissioning engineering support system DEXUS [13] using 3D-CAD, virtual reality (VR) and visualization technology, the system functional module composition of DEXUS is shown in Figure 2.18. This system is mainly used for the Fugen NPS decommissioning project in Japan. The DEXUS system consists of a database system, evaluation and optimization system, virtual reality and visualization system, and data management system. It can achieve functions such as loading CAD models, dose field calculation, data storage, and visualization display. In addition, the software can also use virtual reality technology to achieve workload simulation for decommissioning plans and demolition plans, worker simulation, safety inspection evaluation and optimization functions. Among them, VRDose [14] is the main module of the system, which considers personnel exposure dose, workload, etc. in the implementation and formulation of nuclear facility retirement plans, and VRDose can achieve functions such as dose assessment and optimization of retirement plans, which can be seen in Figure 2.19.
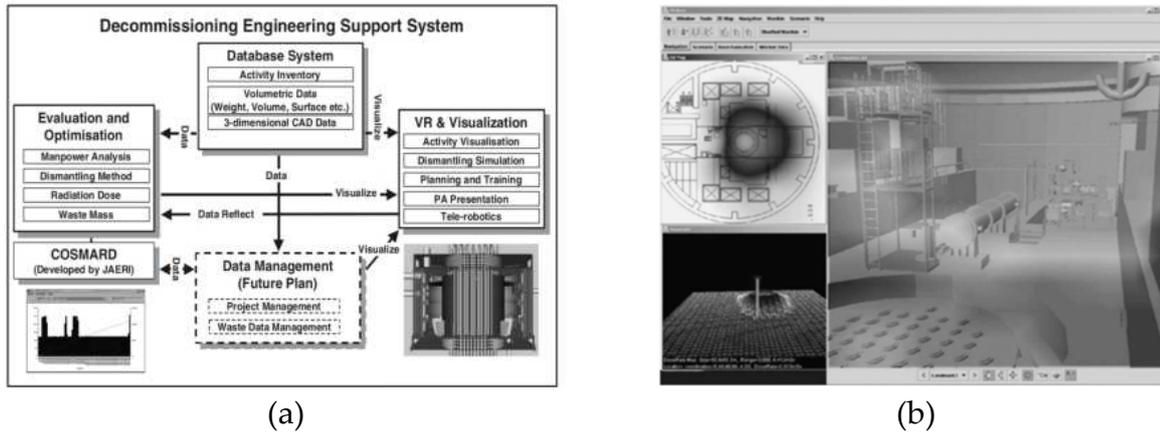
Figure 6. **(a)** System functional modules in DEXUS code; **(b)** S Visual display of a certain scene in DEXUS code.

In addition, the Korean Atomic Energy Research Institute (KAERI) has developed the decommissioning digital simulator system DMU (Digital Mock Up) [15], which is mainly used for simulating the decommissioning and dismantling of the KRR-1 reactor, and DMU can achieve visual display of simulated decommissioning processes and radiation fields. The DMU system uses the Monte Carlo method to calculate the dose field, including the decommissioning database system, demolition simulation, and data calculation modules, which can be seen in Figure 2.20. DMU can import models established by SE (Solid Edge) software and 3DSM (3D Studio Max) software, which can be seen in Figure 2.21. Besides, DMU can achieve virtual simulation of the decommissioning process in specific scenarios and it can calculate the demolition time, estimate the demolition cost, optimize the demolition plan, display the dose field in 3D in Figure 2.22.

(a)
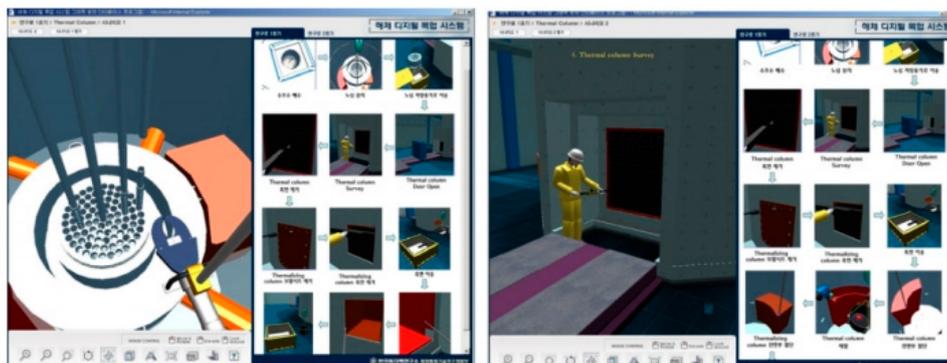
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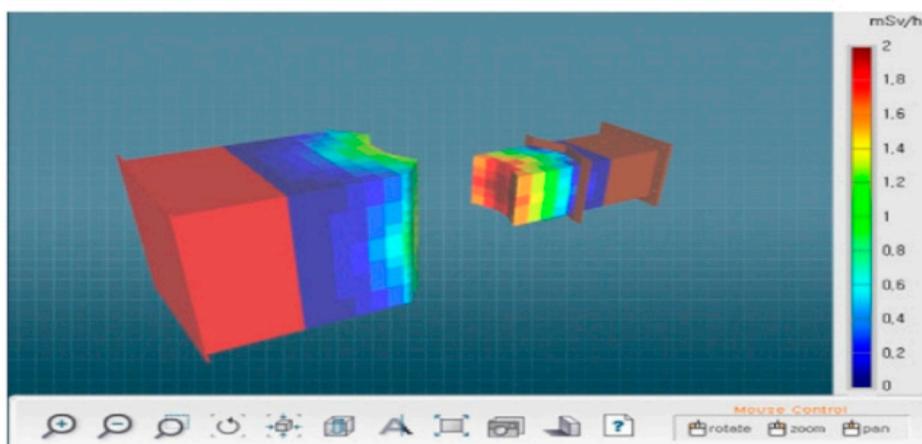
(c)

Figure 7. (a) Data management and calculation module of DMU code system; **(b)** Visualization display of model loading and simulation operations in DMU; **(c)** Visualization display of dose field distribution in a certain thermal column in DMU.

In the 1970s, China gradually began to use computer virtual simulation technology in the field of nuclear energy to carry out some related technical research. In recent years, with the rapid development of China's nuclear energy industry and related technologies, more standardized and professional requirements have been put forward for the technical research and engineering preparation of nuclear facility retirement. Currently, some domestic nuclear industry related units have conducted in-depth research on the development of virtual simulation technology for nuclear facility decommissioning, including the calculation of decommissioning dose field and the development of visual display software. Some technologies have also been applied in practice.

The Department of Computer Science and Engineering of Beijing Institute of Technology carried out the research on the reactor decommissioning simulation system based on virtual reality [1], and determined the stage goals: initially realize the simulation of the reactor body and surrounding environment, decontamination process, disassembly process, and radiation dose distribution; In the mid-term, the main research focuses on waste management, remote operation, and cost estimation for decommissioning; The long-term goal is to achieve the optimization and comparison of retirement plans. The scene construction of this system can preliminarily achieve the conversion between VR models, CAD models, and CAE models. Virtual demolition operations can achieve non-destructive and destructive demolition. Virtual decontamination can simulate the operation process and decontamination effect. Virtual operations can enable operators to evaluate workload and exposure dose while walking and operating, the exposure dose is calculated using the point kernel method.

The FDS team of the Institute of Nuclear Safety Technology, Chinese Academy of Sciences, has developed a universal, intelligent, and accurate nuclear design and radiation safety evaluation software SuperMC [16–18]. The software uses Monte Carlo and deterministic methods to support radiation transport, including calculation functions such as burnup, radiation source term, dose, biological hazards, material activation and transmutation. SuperMC can achieve the automatic and accurate conversion from complex engineering CAD models to Monte Carlo computational models. At the same time, it supports automatic modeling of computational physical properties, achieving the establishment of a complete computational model. SuperMC includes the universal nuclear and radiation safety simulation system Super MC/RVIS2.3 [19]. SuperMC can achieve complex system modeling and virtual assembly simulation, 3D dynamic data field and model superposition visualization analysis, personnel virtual roaming simulation in nuclear radiation environment. At present, the Super MC software system has been applied to the international thermonuclear experimental reactor program ITER, the lead based reactor ADS-CLEAR of China, the U.S. fusion nuclear science device FNSF, the HPR1000 of China etc [19].
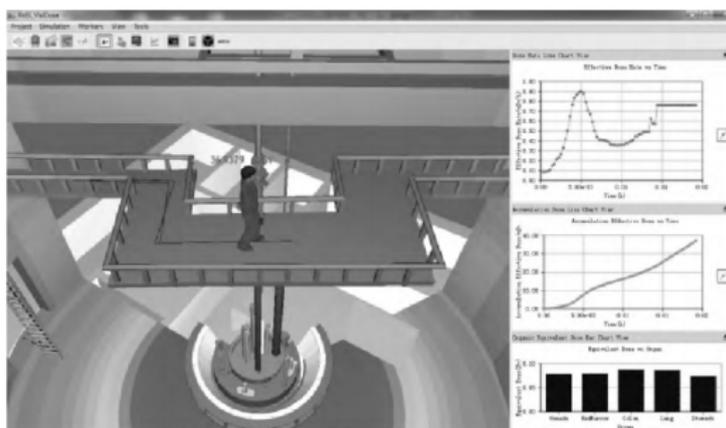
Figure 8. Virtual Simulation of Dose Field in SuperMC.

China Nuclear Power Research and Design Institute has developed a reactor decommissioning simulation system based on the DELMIA and VIRTOOLS software platforms [3,20]. The overall structure of the system is shown in Figure 2.27. This system is based on a comprehensive database and consists of subsystems such as virtual scene, retirement process simulation, engineering management, and evaluation and expert support. It has functions such as 3D scene roaming, virtual cutting and demolition process simulation, 3D radiation field visualization display, personnel exposure status display, engineering plan and process management, real-time tracking management of radioactive waste, retirement plan evaluation and expert support. The developed 3D simulation prototype system for reactor decommissioning [3] proposes a 3D radiation field calculation and visualization technology scheme with independent and integrated simulation systems, databases, and kernel methods. The point kernel integration algorithm is used to establish the 3D radiation field calculation model, and the VS language and SQL server software platform are used to prepare the 3D radiation field calculation program. The real-time computing and data update of the 3D radiation field in the retirement scene are realized, and the visual display is realized in Figure 2.31. At the same time, the calculation method of the radiation dose of the personnel based on the walking path is proposed. At present, the radiation field calculation results of this program have significant errors, but the developed 3D radiation field calculation program and the visualization display technology of radiation field and personnel exposure dose have made initial breakthroughs.

Figure 8. Display of radiation field distribution in retirement scenarios for reactor decommissioning simulation system developed by CNPRI.

The Radiation Safety Research Institute of China Institute of Atomic Energy has established a three-dimensional radiation field calculation software system [21–23], which uses the FLUKA Monte Carlo code and the point kernel integration method, which includes CAD based 3D automatic

modeling, radiation source term and radiation field distribution, radiation field calculation system, dose simulation and optimization system.

Harbin Engineering University (HEU) has established a set of virtual simulation system for nuclear facility decommissioning [2], the Unigraphics three-dimensional modeling software is used to establish three-dimensional models of retired personnel, tools and nuclear facilities. On this basis, C # 4.0 language and WPF (windows presentation foundation) are used to achieve three-dimensional simulation, scene layout. The system provides two work plan planning methods based on manual simulation and optimized path simulation using local navigation algorithm to search the optimal path. This system can achieve virtual simulation of three-dimensional scenarios for nuclear facility decommissioning [24], which can be seen in Figures 2.36 and 2.37.
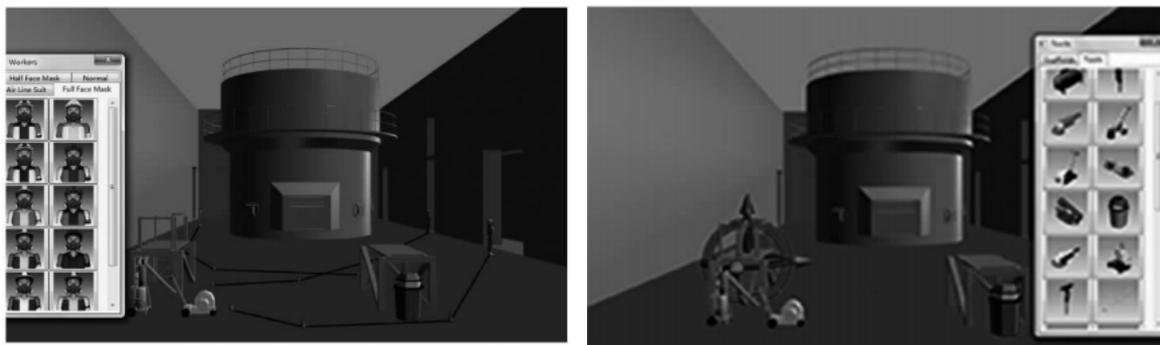

Figure 9. Virtual path setting and simulation scene display in HEU virtual simulation system for nuclear facility decommissioning.

University of South China has developed a rapid and accurate calculation MCPK program for three-dimensional radiation fields and visualization display. This program uses the coupled MCNP5 Monte Carlo code and point kernel method to calculate the dose fields distribution [25], solving the shortcomings of long calculation time and insufficient calculation accuracy in shielding calculations. It can achieve rapid and accurate calculation of dose fields. The MCPK program mainly includes a database module (capable of customizing information such as scenes, devices, and source items), a radiation field calculation module (using Monte Carlo method and point kernel methods), a visualization display module (visualizing geometric scenes and dose fields), and an interface program module (realizing the connection of all calculation processes). The core module of MCPK is the self-developed point kernel calculation program, which establishes various material accumulation factors based on ICRP data, the database of line attenuation coefficient, photon fluence and conversion coefficient from air kerma in free air to ambient dose equivalent of rays in some elements and materials. At the same time, in terms of shielding of different materials, the geometric identification process of shielding materials and thickness through which rays pass (Brep, the Boundary representation method) is considered, which ensures the accuracy and speed of radiation field calculation. The 3D visualization module is mainly developed based on the AnyCAD platform. AnyCAD is a visualization plug-in developed based on Open CASCADE, which is responsible for the display of 3D models and the rendering of radiation exposure fields during the visualization operation. At the same time, the MCPK code can achieve dynamic calculation of decontamination and dismantling dose fields, which can be seen in Figure 2.42.
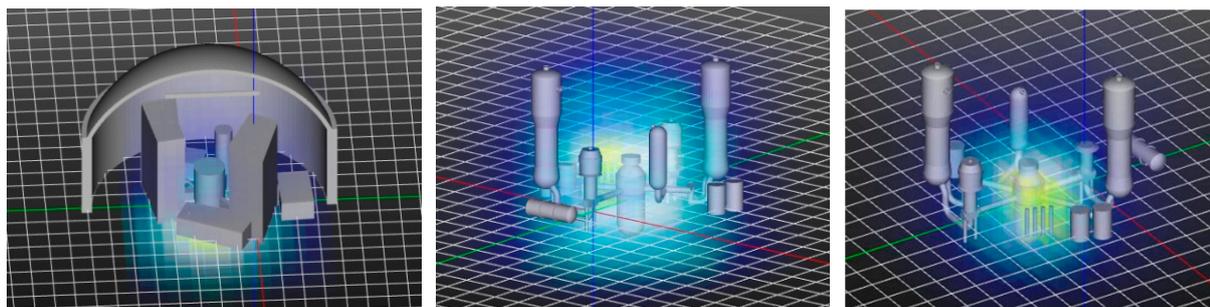
Figure 10. 3D radiation field display in MCPK code system.

In addition, North China Electric Power University has developed a TORT-MCNP three-dimensional coupling program system [26–28], which is based on the discrete ordinate method (SN) and Monte Carlo method (MC) coupling to calculate the dose field. Combining the advantages of SN method in solving deep penetration problems and the advantages of MC method in simulating complex geometry, the TORT-MCNP program system is divided into four main modules: SN calculation module, SN-MC interface module, MC custom source sampling module and MC calculation module.

3. Preliminary design and application of dose field and virtual simulation system for the decommissioning of China HWRR reactor

3.1. Calculation Method and Code Development of Radiation Dose Field

The dose field calculation program for the decommissioning of HWRR reactor is mainly used to calculate the radiation field in simulation scenarios, displaying the decommissioning 3D dose field and estimating personnel exposure dose. Furthermore, the program should provide data support for subsequent decommissioning work and data basis for personnel protection, demolition plans, etc.

3.1.1. Dose field calculation method

Through the preliminary investigation in Section 2, we can see that the most commonly used methods for calculating the decommissioning dose field are Monte Carlo method, discrete ordinate method, and point kernel method, but each of the three methods has its own advantages and disadvantages, which can be seen in Table 1.

Table 1. Classification of Calculation Methods for Dose Fields.

Method	Advantages	Disadvantages
Monte Carlo method	Complex radiation sources and geometry	Reliable calculation results cannot be provided in a reasonable time for the problem of thick shielding in large spaces
Discrete ordinate method	Suitable for deep penetration problem	Not suitable for complex source terms and geometric regions, not suitable for fast calculations
Point kernel method	Fast speed, suitable for deep penetration	Not suitable for complex source terms and geometric regions, accumulation factor estimation may bring significant errors

In response to the complexity of the HWRR reactor decommissioning scenario, the diversity of decommissioning facilities, the uncertainty of source term conditions, and the shortcomings of a single dose field calculation method, this research intends to develop HWRR reactor decommissioning dose field calculation program by combining mature and user-friendly methods such as the Monte Carlo method, point kernel method, and method of coupling Monte Carlo with point kernel integration. The considerations are as follows:

(1) Through the investigation, it has been found that there are mature calculation programs and methods for retired dose fields, and most dose field calculation programs are developed using the Monte Carlo method or point kernel method. This indicates that these two methods have strong universality and applicability;

(2) For the development of technical support system for decommissioning engineering of China HWRR reactor, the focus of dose field calculation subsystem is to make sexual selection for the existing general calculation methods, select the calculation methods that can achieve the overall calculation effect and meet the requirements for calculation accuracy and speed of different decommissioning scenarios, facilities and equipment, rather than developing new methods. Therefore, the Monte Carlo method and point kernel method meet the requirements;

(3) The dose field calculation program of the HWRR reactor is planned to create an independent calculation module. The Monte Carlo method is used to achieve accurate dose field calculation for complex source term with no deep penetration problem, the point kernel method is used to achieve fast calculation of simple source term with thick shielding, and the coupling method is used to achieve fast and accurate calculation of complex source term with deep penetration problem.

(4) For the development of the dose field calculation program, more emphasis needs to be placed on the point kernel method in the overall development. The Monte Carlo programs are mature calculation programs and can be used directly.

3.1.2. Design and development of code system

The main functions of the decommissioning dose field calculation code system for HWRR reactor include source item data, scene information, facility equipment, and radiation field calculation etc. Users can update the database according to their computational needs. The updates of source item data should include the source data input, modification, and viewing of source item data, while the scene information updates should include scene selection, modification, and viewing. Besides, the facility and equipment updates should include facility and equipment selection, modification, and viewing. As for different retirement scenarios such as source terms, facilities and equipment, radiation field calculation should include the selection of calculation methods (Monte Carlo method, point kernel method, coupling method), the input of calculation information, the initialization of dose field, the calculation of dose rate, as well as the storage and output of calculation results, etc., which can be seen in Figure 4.1.
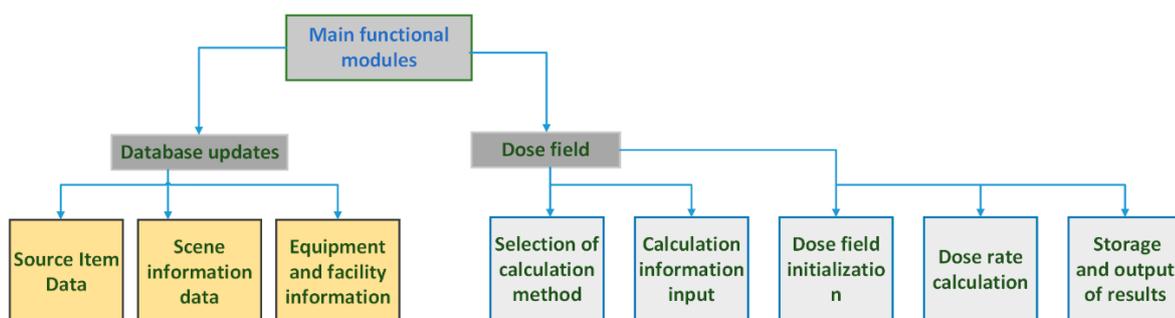

Figure 11. The main functions and module structures of the decommissioning dose field calculation code system for HWRR reactor.

For the different retirement scenarios such as source terms, facilities and equipment, different calculation methods should be chosen to calculate the dose rates of all equipment in their respective spaces. Firstly, the dose field program initializes and calculates the dose rates of all source term devices in all spaces. During the decommissioning simulation process, the main focus is on updating the dose field for the changed scenarios, and also initializing the dose field for scenarios with significant changes as needed. The calculation process of the dose field calculation program is shown in Figure 4.2. After receiving the calculation instruction of the simulation system, the calculation program calls the database information, judges the source items, facilities and equipment of the calculation scene, selects the appropriate calculation method, calculates the scene, and stores the calculation results in the database. If the instruction given by the simulation system is to calculate the changes in the dose field during a certain demolition process, the program needs to determine the impact of the demolition equipment on the overall spatial dose rate, then subtract the demolition dose rate from the initial dose rate, and store the calculation results in the database for subsequent calls.
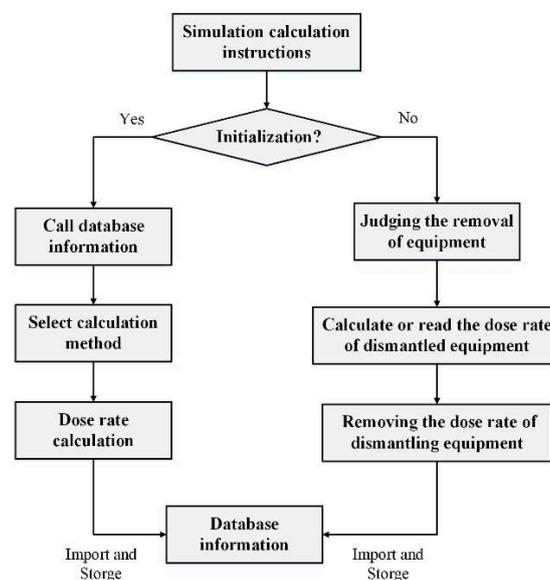

Figure 12. The calculation process of the dose field calculation program for HWRR reactor.

3.2. Visualization implementation

Unity 3D is a virtual reality engine mainly used for realistic display of scene models and data. We use the Unity 3D software for secondary development, and the dose field visualization display module is developed, so that it is easy for users to operate and use. It can perform visualization display of retired dose fields. The dose field visualization module is intended to consist of a menu bar and a visualization window, which includes files, views, windows, and help button.

The visualization of dose field is divided into two steps. Firstly, the users should import the STL and STEP files of the scene and then import the TXT or EXCEL data files of the dose field data. After the program successfully read the dose field file, the dose field will present in the visualization interface. If the displayed color of the dose field does not meet the needs, the chromatography tool should be used to set, the interface of chromatography tool is shown in Figure 4.3.
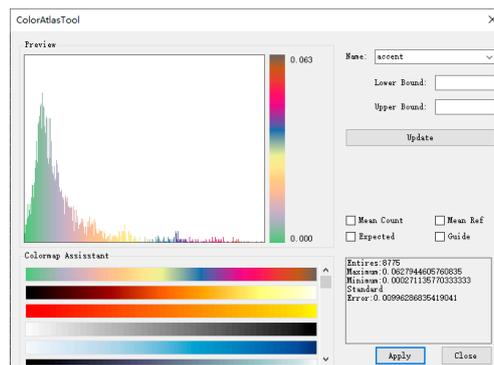
Figure 13. The interface of chromatography tool for dose field and virtual system of HWRR reactor.

3.3. Calculation and Visual Display of the Dose Field for Outer shell of HWRR reactor

3.1.1. HWRR reactor

The Heavy Water Research Reactor is the first large research reactor to be decommissioned in China [31–38]. The main body of HWRR reactor adopts the multi-layer canister structure. The Figure 1. shows the main structure of HWRR reactor, the central area is the active zone of the reactor body, where the fuel assemblies are loaded. The graphite reflection layer, shielding water tank, packing sand layer and shielding layer are arranged outward successively [3,4].
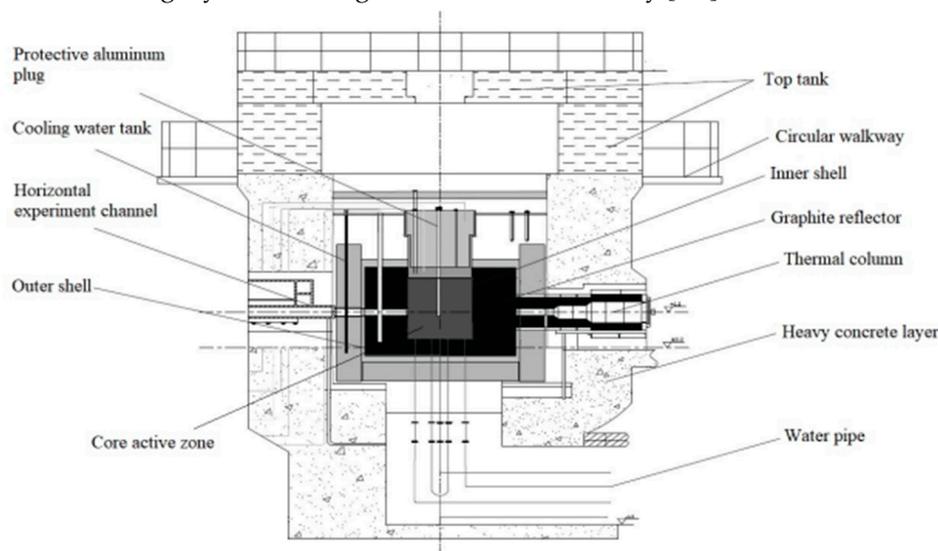

Figure 1. The main structure of the HWRR reactor.

The outer shell of HWRR reactor consists of three cylinders of different diameters welded together with two ring plates, a bottom plate and a flange. There are 44 screw holes on the end face of the cylinder for installing the sealing flange, and another through hole for installing the vertical test hole of the graphite layer. The size of the upper barrel is 1675mm in outer diameter and 15mm in wall thickness, the size of the middle barrel is 1470mm in outer diameter and 20mm in wall thickness. A stiffener plate is welded around the middle barrel to improve the overall rigidity of the shell. The size of the lower barrel is 2690mm in outer diameter and 15mm in wall thickness. The bottom of the outer shell is made of two layers of welded steel plates, the two layers are supported by steel beams.
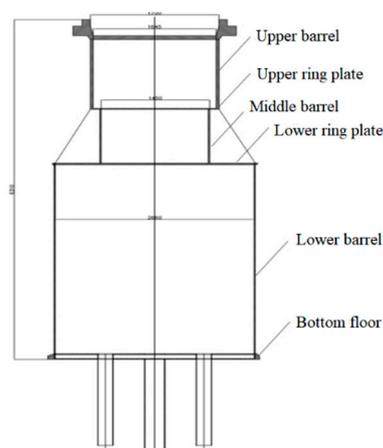
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Figure 2. The structure of the outer shell of HWRR reactor.

Based on the historical operation data of the HWRR reactor, the source term data of outer shell is calculated. The dose field distribution of the HWRR reactor shell is calculated by using the coupling method of Monte Carlo method and point kernel method. The preliminary designed virtual simulation program of HWRR reactor uses Pro/E to build the 3D model, the visualization of dose field can be displayed after loading the dose field data. Figure 2 shows the visual display of the dose field of the HWRR reactor outer shell.
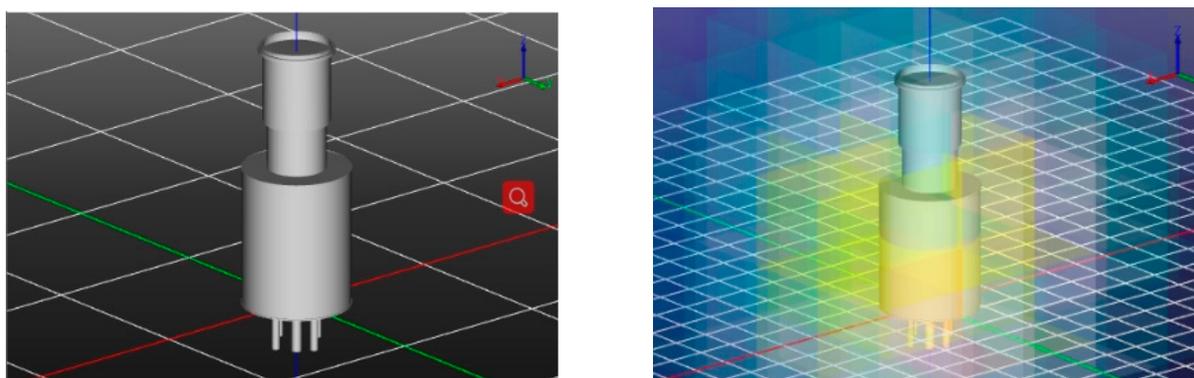

Figure 2. (a) Outer shell model of HWRR reactor; **(b)** Visualization display of dose field of HWRR reactor.

4. Conclusions

Reactor decommissioning virtual simulation system is a powerful auxiliary tool for the decommissioning engineering, which can provide a support platform for the determination of decommissioning implementation scheme, optimization of the process planning and personnel training, etc. The calculation and visualization of 3D radiation field in the decommissioning scene is one of the important functions for the reactor decommissioning virtual simulation system. This kernel module can provide accurate and intuitive radiation field distribution in the design of decommissioning scheme, and play an important role in the protection of personnel in engineering implementation. Therefore, this paper investigated and summarized the progress of relevant technologies in the virtual reactor decommissioning simulation system, and initially proposed the technical scheme suitable for the development of dose field calculation and visualization module of the China HWRR reactor decommissioning. The applicability of the technical scheme was analyzed, and the outer shell of the HWRR reactor was modeled and the dose field distribution was visualized. This work can provide technical support for the subsequent development of virtual simulation system for decommissioning HWRR reactors.

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