Annals of Nuclear Energy 95 (2016) 161–167

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Technical note

Establishment of the framework to visualize the space dose rates on the dismantling simulation system based on a digital manufacturing platform

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ARTICLE INFO

Article history:
Received 22 October 2015
Received in revised form 20 April 2016
Accepted 10 May 2016
Available online 21 May 2016

Keywords:
Decommissioning
Simulation
Nuclear power plant
Dose rate
Visualization
Data processing
Computer-aided design
Digital manufacturing

ABSTRACT

A decommissioning plan should involve a comprehensive review of the feasibility of the safety measures, economics and so on. There is a variety of information required for the review of each decommissioning phase, ranging from the conformity of the dismantling process to radioactive waste management. The space dose rate of a nuclear facility is one of the major data points that must be obtained during the early planning stage for the decommissioning of a nuclear facility. We propose the framework for the visualization of the analyzed space dose rate on the dismantling simulation system with the solid modeling method, which is generally used for a CAD (computer-aided design)-based digital manufacturing platform. The visualization module applying this framework is implemented using the suitable software framework that can directly interface with the dismantling simulation system. The framework of the visualization module is composed of a pre-processing stage for creating an optimal data-structure of the analyzed space does rates and a configuration stage for a visualization of the 3-dimensional models of dose on the dismantling simulation system. As a result, the module in the dismantling simulation system can visualize both the 3-dimensional space dose rate and radioactive equipment model in the same virtual space and provides useful information to users in real time for planning the dismantling process.

1. Introduction

Nuclear power plant decommissioning involves various processes and technologies. Decommissioning should be performed after a comprehensive review of the information related to these processes and technologies. There are various means of prior examination and evaluation to ensure the feasibility and safety of the decommissioning process plan. In particular, a more careful review is essential before dismantling the highly radioactive core components, such as the reactor pressure vessel of the nuclear power plant.

The space dose rate is the quantity of radiation absorbed per unit time in the space. The space dose rate is a principal data point in the evaluation of the decommissioning process in the early planning stage to the final management of radioactive waste (Kim et al., 2014). The space dose rate is a major criterion used to determine the feasibility of the As Low As Reasonably Achievable (ALARA) principle of the nuclear dismantling process. The International Commission on Radiological Protection (ICRP) advises to limit the effective dose by the occupational exposure to 20 mSv per year, averaged over defined periods of 5 years in planned exposure situations (International Commission on Radiological Protection, 2007). Because this dose limit is also valid for the nuclear decommissioning tasks, for any decommissioning work involving exposure to radiation, it is necessary to plan the work after estimating the occupational exposure.

Digital manufacturing is a comprehensive approach for the preverification in the planning stage or in the strategic decision-making across all the manufacturing processes. Digital manufacturing uses integrated digital models created through the modeling of physical and logical components of a system and then uses a computer to make a precise simulation of their behaviors (Lee et al., 2011). This approach can be directly introduced in the nuclear decommissioning because the technologies of the digital manufacturing help to set up and verify specific processes for dismantling the highly radioactive core nuclear equipment and their facilities.

The present research involves the design and development of a real-time visualization framework of the 3-dimensional space dose

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http://dx.doi.org/10.1016/j.anucene.2016.05.013
0306-4549/

rate of a nuclear facility for our own dismantling simulation system based on a digital manufacturing platform. This dismantling simulation system has unique features in consideration of the processes for dismantling highly radioactive core equipment, which were developed using the CAD application programming interface (API) of the commercial digital manufacturing software, DELMIA by Dassault Systèmes (DELMIA Products, 2015). Our dismantling simulation system aims to simulate and evaluate whole processes related to the dismantlement of core equipment of nuclear power plant such as the device preparation, cutting operation, waste transfer, and so on. The visualization of the space dose rate on the dismantling simulation system can effectively support the evaluation and assessment related to the radiation exposure during the planning of the dismantling process of a nuclear power plant.

2. Related works

It is difficult to simply classify the research studies related to the visualization of a dose in a 3-dimensional space because each has a different purpose. We briefly describe these studies from the perspective of their implementation platforms using the following classifications:

- A dedicated scientific visualization platform.
- A real-time rendering platform for handling 3-dimensional objects and a 3-dimensional environment.

The dedicated scientific visualization platform classification refers to the tools or application used to visualize a variety of a large analysis dataset. This classification includes a number of visualization platforms, such as VisIt and ParaView, which were used for visualization of the massive dataset for the space dose (Frambati and Frignani, 2012; Para View [Internet], 2015; VisIt [Internet]., 2015). VisIt was applied to visualize a shutdown dose rate in a neutral beam cell, and ParaView was used to render the analysis results through the geometry conversion tool (Serikov, 2011; Große et al., 2013). Generally the visualization of dose with a scientific visualization platform required a process for data conversion, and it could be difficult to integrate additional functionalities of user demand with this platform.

A real-time rendering platform for handling 3-dimensional objects and the environment is also applied to visualize the space dose. This platform is intended to create and display a 3-dimensional environment in real time by providing the general functionalities for the processing and visualization of a 3-dimensional geometry. Therefore, a real-time rendering platform supports the implementation of a specialized application in various fields that demand the capability of real-time visualization, e.g., a game engine or a geometry kernel used for handling 3-dimensional objects. An authoring tool with its own script or a standard language for developing interactive 3-dimensional applications is also treated as this type of platform. Chaput et al. and Park et al. used a light 3-dimensional authoring tool to display the geometries of the dose (Chaput and Waller, 2010; Park et al., 2008). Iguchi et al. proposed the nuclear decommissioning support system that visualized a 3-dimensional space including the dose rate with the JAVA3D and virtual reality modeling language (VRML) Iguchi et al., 2004; Java SE Desktop Technologies - Java 3D API [Internet], 2015; ISO/IEC, 1477. Szőke et al. also used VRML to develop the 3-dimensional radiological protection planning tool (Szőke et al., 2015; Institute for Energy Technology Halden Virtual Reality Centre, 2013). Mol et al. applied the game engine to the online dose rate monitoring and assessment system for visualization of the dose information (Mol et al., 2011). Thevenon et al. developed a VR-based simulation tool for the evaluation of the work in a nuclear radiating field based on the 3DVIA platform (Thevenon et al., 2009; 3DVIA [Internet], 2015). This tool embedded the dose rate evaluation feature and visualized the 3-dimensional virtual environment, including the space dose. Tang et al. developed the dose evaluation and visualization application based on Virtools to display the derived space dose in a 3-dimensional virtual environment (Tang et al., 2010; 3DVIA Virtools [Internet], 2015).

There are a few cases of directly interfacing and visualizing the space dose rates using 3-dimensional CAD-based tools. The aims of this study are to establish the framework for directly visualizing the 3-dimensional space dose rates on our own dismantling simulation system which is operated on a CAD-based digital manufacturing platform using the solid modeling. This dismantling simulation system can simulate and evaluate the various dismantling procedures, such as the device preparation, cutting operation for highly radioactive equipment, and waste transfer. In particular, this dismantling simulation system provides unique functions that can be used to flexibly simulate cutting processes via the solid modeling method using the CAD-API. If the other visualization platform like the 3DVIA platform is used, it is difficult to implement such functionalities due to the limitation of their methods for representing model, even though its appearance is similar to our simulation system. The dismantling simulation system can be improved and its functionalities extended by adding the dedicated modules for the users' intent. The purpose of the visualization of the space dose rate on the dismantling simulation system is the intuitive support for the process evaluation related to the radiation exposure rather than just an illustration of the space dose rate in the space.

3. Framework for visualization of the space dose rates on the dismantling simulation

3.1. Setting the conceptual procedure for the space dose rate visualization on the dismantling simulation system

The measurement of the space dose rate is typically performed by the direct field estimation. However, it is often difficult or even impossible to obtain the dose information for the core parts of the nuclear reactor because the access to the measuring equipment is limited due to the extremely high radiation environment. Therefore, the space dose rates of such an area must be predicted via computational analysis based on dose rate modeling. Such analysis is often effective in the case of evaluation over a long period of time for a wide variety of complex works, such as nuclear dismantling processes. The procedure was designed to consider the utilization of external dose analysis data by a scalar filed within the dismantling simulation system based on a CAD-based digital manufacturing platform. To realize the conceptual procedure, more detailed steps was established according to the following requirements:

- The analyzed space dose rates should be directly input into the simulation system.
- All process must be handled in internal modules on the dismantling simulation system.
- The system should be able to visualize the space dose rates in real-time.
- Users should be able to observe simultaneously the space dose rates and the corresponding radioactive equipment on the 3-dimensional virtual space.

The procedure for a real-time visualization of the space does rates in our dismantling simulation system is illustrated conceptu-