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Development of Evaluation Modules for Evaluating Decommissioning Scenarios Using Digital Mock-Up System

디지털 목업 시스템을 이용한 해체 시나리오 평가용 해체공정 평가모듈 개발

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Abstract

In the decommissioning and decontamination(D&D) planning stage, it is important that the scenarios are evaluated from an engineering point of views because the decommissioning work has to be executed economically and safely by following the best scenarios. Therefore, we need to develope several modules to evaluate the decommissioning scenarios. In this paper, the digital mock-up system is constructed in the virtual space to simulate the whole decommissioning process. The schedule evaluating equation and cost evaluation equation are derived to calculate the working time and the expected cost. And in order to easily identify the radiation level about the activated objects, the radiation visualization module is developed. Finally, on the basis of the obtained results from the Digital Mock-up and other important factors, the evaluating method of the scenarios that can indicate the best scenario is described.

Key Words : evaluation modules, digital mockup system, decommissioning and decontamination, radiation visualization

요 약

해체 작업은 최적의 해체시나리오에 따라 경제적이면서 안전하게 수행되어야 하기 때문에 제염해체의 계획단계에서 시나리오의 다양한 관점에서의 평가는 매우 중요하다. 따라서 사전에 해체 시나리오에 대한 평가 자료를 산출하기 위한 평가모듈개발이 필요하였다. 본 논문에서는 해체 시나리오의 전체적인 과정을 컴퓨터 가상공간에서 표현하여 해체과정을 이해하고 문제점을

파악하기 위해 디지털 목업 시스템을 구축하였다. 그리고 해체일정과 예상비용을 산출하기 위해 해체작업시간 및 예상비용 산출식을 도출하였다. 그리고 대상물의 방사화 정도를 쉽게 파악하기 위하여 방사화 가시화 모듈을 개발하였다. 마지막으로 전체적인 결과와 다른 여러 중요요소를 기초로 하여 해체 시나리오를 평가하는 방법론에 대해 기술하였다.

중심단어 : 평가 모듈, 디지털 목업 시스템, 제염 해체, 방사화 가시화

Ⅰ. 서 론

In Korea, KRR-1&2 (Korea Research Reactor 1&2), TRIGA Mark II&III, had been operated since 1962 and 1972 respectively until their planned shut down[1,2]. However, according to the deterioration of the utilities and the change to the population-massed-area by the accelerated urbanization of the surroundings, a conversion to a comfortable and safe environment is required. Also because of HANARO, a multipurpose research reactor, which started normal operation at the new site of KAERI, the superannuated research reactors lost their value in use. Because of these reasons, the decommissioning of the KRR-1&2 was determined. The decommissioning work of KRR-2 will be finished in 2006 and as soon as it is done KRR-1 will start to be dismantled. We are also promoting the decommissioning R&D programs as well as the KRR-1&2 decommissioning project. We carried out the development of a graphic simulation regarding the main dismantling process, the development of a decommissioning data base system, the development of remote dismantling equipment, and the development of an automatic measurement system.

As many of the world's nuclear reactors are aging, their safe decommissioning has emerged as an imminent task. Henceforth, the world's nuclear industries have initiated D&D (decontamination and dismantling) projects and relevant R&D programs since the mid 80's. Currently, many D&D technologies are commercially available. However, decommissioning a nuclear facility is still a costly and possibly hazardous project. To secure a worker's safety, many researchers have used physical mock-ups before they dismantlement. However, it was very expensive to make them and it was impossible to reuse them. Therefore using conventional mockups causes an abrupt increase in the decommissioning cost. But, as the computer graphic technology has been enhanced, a digital mockup has started to compete with conventional mockup systems[3~7]. Currently it is being used in many commercial companies such as the automobile, airplane, manufacturing industries, etc. to design and verify their products and for training and briefing of the staff.

In the nuclear decommissioning field, graphic simulation technology has also been used since a few years ago[8]. However, it has been limited to check the problems of dismantling scenarios and train workers. But we need to have a system that can evaluate scenarios quantitatively, effectively, and precisely before the real dismantling works. Therefore for this reason, we have been developing a digital mockup system with functions such as a dismantling schedule, decommissioning costs, wastes, worker's exposure dose, and a radiation distribution. This system also adopted a 3D virtual reality(VR) system and a data base(DB) system.

This paper presents the status of the

development of the dismantling digital mockup system for KRR-1&2.

Ⅱ. Dismantling Digital Mockup System Overview

The dismantling digital mockup system is composed of 4 different parts: a database part, visualization part, evaluation part, and an analysis part. Fig. 1 shows the conceptual diagram of the dismantling digital mockup system. The decommissioning DB system stores the data concerning the dismantling schedule, activity visualization system, cost evaluation system, 3D CAD, and so on. The visualization part has three sub-parts; a dismantling simulation, an activity visualization, and a virtual reality section. Dismantling simulation shows us an overview of the dismantling process. It is important to know which parts are highly radioactive. By using a graphic mapping technique, activity levels were visualized and contoured in a 3D modeling. This may contribute to an increase of the radiation awareness for workers and to provide planning information as to which items are going to be cut and treated as activated waste. VR technology has been used as a simulation technique because it is possible to move around during a playback, allowing the spectator to view the scenario from any angle [8,9]. In the evaluation section, there are: a dismantling schedule, waste estimation, dismantling cost, and worker's exposure subparts. The dismantling schedule offers the expected man-hours for each dismantling action and calculates dismantling costs of a scenario. The exposure dose part is a simulation system that can estimate a worker's exposure dose in a virtual space. The analysis part has collision interference and scenario evaluation subparts. The collision check can be used to find the best removal path [10,11]. The goal of this system is to find the best scenario that could be implemented from the estimated results.

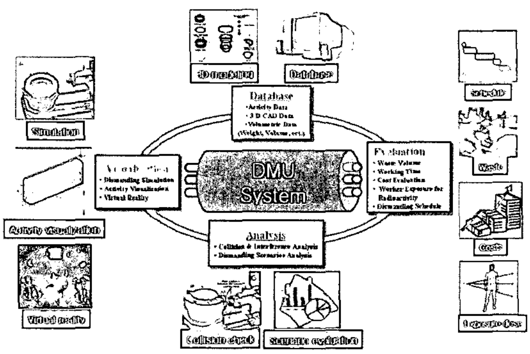

Figure 1. Conceptual diagram of dismantling digital mockup system

Ⅲ. 3D Modeling and Virtual Reality

The 3D modeling information is really important to understand dismantling items and dismantling processes. In order to construct the decommissioning DMU system, we built 3D models which are the main dismantling items such as the beam port, thermal column, core, and shield concrete, the environments of KRR-1&2, and the dismantling tools. The virtual environments of KRR-1&2 were built by using the EON studio which is made by EON Reality Inc.[12]. The left side picture of Fig. 2 shows the view of the virtual reality of KRR-1. In this position we can navigate the whole KRR-1 building in real-time. A specific area or opposite side of an object can be seen in on any area and rotated on a real-time basis. The Right side picture of Fig. 2 shows the snap shots for the core dismantling process of KRR-1. Once we review the snap shots we can understand the entire dismantling process.

Ⅳ. 3D Radiation Visualization

A 3D radiation visualization module is essential to classify the radioactive wastes and to define the

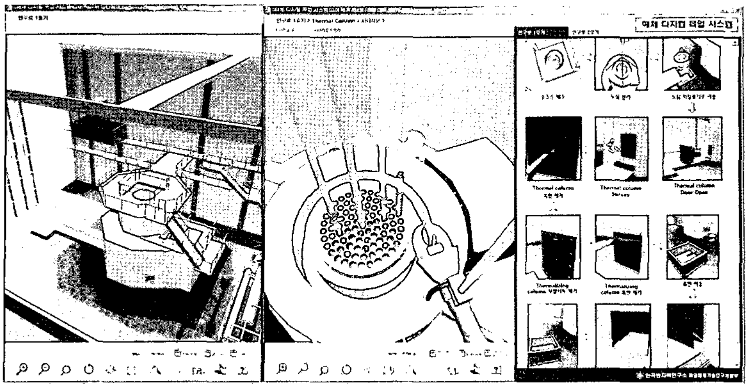

Figure 2. View of virtual reality of KRR-1 and visualization of core's dismantling simulation for KRR-1

cutting areas before making a dismantling scenario. It is very useful for worker's training before dismantling work as the radiation areas can be shown visually. The method of a 3D radioactivity visualization is like Fig. 3. Firstly 3D model is prepared. Secondly, the 3D model is divided into lots of nodes and then a radioactive data set is constructed. Thirdly the connect data is connected with the nodes of the 3D model. Finally we can visualize the 3D radiation level for activated items.

V. Dismantling Scenario Evaluation Module

1. Schedule Simulation of the Scenarios

A schedule simulation of the scenarios is needed to find out how long this scenario will take until it is finished. The running time of the schedule is closely related with the calculation of the dismantling cost because the man-power which is required in any scenario is used to calculate the cost of personnel expenses. Eq. 1 is derived to calculate the working time. Abbreviations' meanings are BT_i is the dismantling basic unit time, which means the man-hours needed for each dismantling work. They were calculated by using a machine's specifications for instance, the cutting time of a hydraulic shear machine as different materials and by using decommissioning experience data of KRR-2 for instance, a machine's installation time, scaffolding installation time etc.. R_i is the number of dismantling works. Sometimes dismantling work becomes an iteration work. In this case the man-hours are calculated by multiplying a round time of a dismantling work by the iterating number of dismantling work. W_j means the weighting factors[13]. As shown in Table 1, weighting factors are divided into 5 different categories such as the height, respiratory protection, radiation/ALARA, protective clothing, and work breaks. In order to change the man-hours into days, the total man-hours are divided by and 8(8 means 8 hours per working a day).

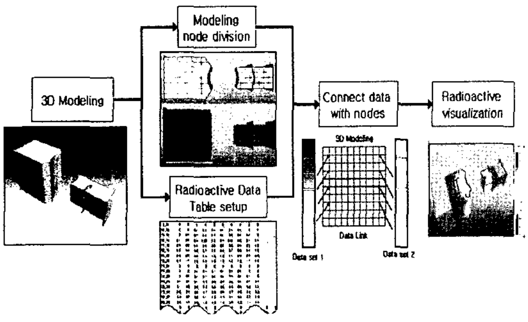

Figure 3. Method of 3D radioactivity visualization

$$T = \sum_{i=1}^{n} \frac{T_i}{N \cdot 8}, \quad T_i = BT_i \cdot R_i \cdot \left(1 + \sum_{j=1}^{m} W_j\right) \quad \cdots (1)$$

where, T = Total dismantling schedule (Days)

T_i = Calculated man-hour each dismantling work (Man-h)

N = Number of needed persons (Persons)

BT_i = Dismantling basic unit time (Man-h)

R_i = Number of works (Frequencies)

W_i = Weighting factors (%)

n = Number of scenario works

m = Number of weighting factors

2. Calculation of Waste

The quantity of waste is varied depending on each scenario because the cutting area should be changed when applying different dismantling methods. The amount of waste is also closely related to the decommissioning cost. As the amount of waste increases, the decommissioning cost also rises. It is significant to know the expected waste. A volume calculation function in a 3D CAD program is used to estimate the expected waste. First, the expected waste regions are classified through the 3D radioactivity visualization module. Then the volumes of the classified areas are calculated by using a volume calculation function in a 3D CAD program. Finally, the amount of waste was reclassified with different materials and different radioactive levels. Table 2 shows the example of the beam ports of KRR1 for both the diamond wire saw method and the core boring method. The left side picture of Fig. 4 shows the graphical user interface (GUI) depicting the calculated waste volume.

3. Estimation of Decommissioning Cost

As shown in Eq. 2, the decommissioning cost scenario can be expressed by summing the personnel expenses, tool expenses, and waste treatment expenses. Eq. 3 shows the equation of personnel expenses. The personnel expenses can be calculated as man-hours which are calculated in the schedule simulation module which multiplies average labor cost. Eq. 4 shows the equation of the tool expenses. The tool expenses can be calculated by multiplying the machine's unit cost with number of machines. Eq. 5 shows the equation of the waste treatment expenses. The waste treatment expenses can be

Table 1. Weighting factors for calculating the dismantling schedule

Work difficulty factors	Weighting (%)	Standards
Height	15	Work in the 2 m over/under
Respiratory Protection	38	Whether using mask or not
Radiation/ALARA	15	Whether working in radioactive area or not
Protective clothing	23	Whether wearing protecting cloth or not
Work break	9	Whether taking a break or not

Table 2. Waste volume of KRR-1's beam ports regarding the diamond wire saw method and core the boring method

Waste type	Waste volume(cm^3)	
	Diamond wire saw method	Core boring method
Steel	4.12×10^5	4.22×10^4
Aluminum	2.01×10^4	2.01×10^4
Concrete	1.43×10^7	9.51×10^5

calculated by multiplying the waste drum unit cost with a number of drums. A number of drums can be found by dividing the total volume of waste with the volume of drum and porosity.

$$C = PE + TE + WE \qquad \cdots\cdots(2)$$

where, PE, TC, and WC mean respectively the personnel expenses, tool expenses, and waste treatment expenses.

$$PE = \sum_{i=1}^{N} T_i \times ALC \qquad \cdots\cdots(3)$$

where, PE means the personnel expenses, Ti means the man-hours for each dismantling action, and ALC means the average labor cost.

$$TE = \sum_{i=1}^{N} M \times NOM \qquad \cdots\cdots(4)$$

where, TE means the tool expenses, Mi means the machine unit cost, and NOM means the number of machines.

$$WE = \sum_{i=1}^{N} D_i \times \frac{V_{totlal\,waste}}{V_{wastedrum} \cdot P} \qquad \cdots\cdots(5)$$

where, WE means the waste treatment expenses, Di means the waste drum unit cost, $V_{totlal\,waste}$ means the total radioactive waste for an object, $V_{totlal\,waste}$ means the waste drum which contains radioactive waste, and P means the porosity.

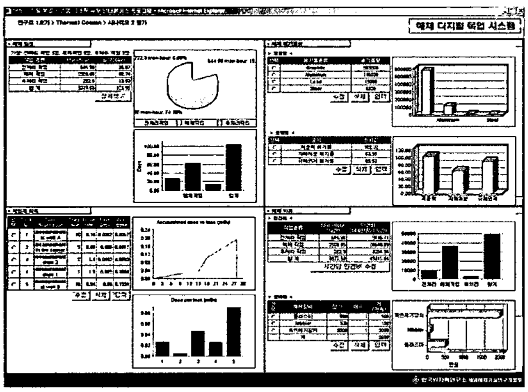

Fig. 4 . Graphic user interface of waste and worker's dose

4. Evaluation of Workers' Exposure

The evaluation of a worker's exposure for a dismantling activity is important from the aspect of the worker's safety. In order to select the best scenario, the evaluation of a worker's exposure should be performed with the radioactive objects. MCMP program was used to calculate the exposure regarding workers who work in the activated area. The right picture of Fig. 4 shows the GUI(Graphic User Interface) of the evaluation module of a worker's exposure. There are accumulated dose graphs for workers, dose charts at each position for worker, and their data table set in the GUI.

5. Evaluation of Scenarios

The evaluation of scenarios was based on selecting independent criteria and on expert's ranking the alternatives by the criteria with a specified ranking system. To make the evaluation of scenarios more realistic, the criteria were chosen and the alternatives ranked according to the feasibility of various technical decisions. The criteria were chosen and analyzed to classify the criteria by functional groups. The weighting factors were assigned by the experts for the criteria and their groups. The weighting factors indicate the significance of the criteria for the implementation of various decommissioning alternatives.

The decommissioning alternatives were analyzed using the criteria which were chosen by determining quantitative and qualitative features of a practical implementation of the alternatives. Depending on whether the implementation features are quantitative or qualitative, the criteria were assigned to "quantitative" or "qualitative" categories.

The decommissioning alternatives were analyzed and compared, with the following ranking system for each criterion:

- 5 very good
- 4 good
- 3 not good
- 2 bad
- 1 very bad

Groups of experts were interviewed independently and the results were averaged to rank each decommissioning alternative by the chosen criteria. The criteria were classified into the following categories chosen according to the current requirements for decommissioning activities:

- Category 1 economic efficiency criteria
- Category 2 safety criteria

A weighting factor was defined for each category, X_i (where: i=category). The weighting factors were defined by averaging the rankings of the independent experts. The weights were then normalized, i.e., $\sum X_i=1$. The following "weighted" sums were calculated for each decommissioning alternative:

$$S=\sum_i X_i \sum_j b_{ij} \qquad \text{……………(6)}$$

where i= category; j= criteria; b= ranking of criteria j in category i; and X_i = weighting factor for category i.

Tables 3 and 4 show the evaluation results of the economical efficiency category and the safety category regarding two scenarios of the thermal column in KRR-1. Table 5 shows the weighting factors which were derived from Tables 3 and 4. Finally Table 6 shows the scenario evaluation results by considering the economic and safety aspects. According to the final results, the scenario 2 just got the slightly higher

Table 3. Analysis of the alternatives by the economic efficiency criteria

Criteria	Scenario 1 b_{ij}	Scenario 2 b_{ij}
1. Costs of dismantling activities	4	3
2. Costs of special equipment and expendables	3	2
3. Costs of radioactive waste handling	3	3
4. Costs of personnel training	3	2
5. Rate of recycling materials return	1	1
Total	13	11

Table 4. Analysis of the alternatives by the safety criteria Criteria

Criteria	Scenario 1 b_{ij}	Scenario 2 b_{ij}
1. Personnel safety (minimization of personal dose rate)	4	3
2. Safety of the environment	4	4
3. Continuity of personnel work	2	5
4. Necessity to use unique equipment	3	4
5. Rate of recycling materials return	3	3
Total	16	19

Table 5. Weighting factors by categories

Criteria	x_i
1. Economic efficiency	0.407
2. Safety	0.593

Table 6. Results of the scenario evaluation

Scenarios / Criteria	Scenario 1	Scenario 2
Economic efficiency	5.291	4.477
Safety	9.488	11.267
Total	14.779	15.744

score than the scenario 1. Therefore we can say the scenario 2 was more suitable to apply to dismantle the thermal column in the KRR-1.

Ⅵ. Conclusion

A digital mock-up system which can evaluate the scenarios for KRR-1&2 was developed and the dismantling schedule simulation module, waste calculation module, decommissioning cost module, worker's exposure module and virtual reality module were also developed. Finally on the basis of the evaluation results, the scenarios can be quantitatively compared and evaluated. Hereafter this system will be applied to KRR-1 to obtain the best scenario and moreover we expect to use it as a system engineering tool for decommissioning of a nuclear power plant in the future.

In the next term, this system will be upgraded to be able to organically obtain data from the decommissioning DB system. We believe that this system can lead to decrease the decommissioning cost and the improve the worker's safety.

Acknowledgement

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References

[1] K. J. Jung, "Decommissioning of TRIGA Mark 1&2", KAERI/RR-1798/97(1997).

[2] J. H. Park, "Decontamination and Decommissioning Project for the Nuclear Facilities", KAERI/RR-2304/2002 (2003).[3] J. A. Stone, "Vol-oxidation Studies with UO_2 Reactor Fuels", ANS, Meeting on Fuel Cycles for Eighties, DP-MS-80-9, Sep.-Oct. (1980).

[3] J. J. Fisher, "Applying Robots in Nuclear Applications", RI/SME Robots Conference (1985).

[4] A. R. Gregory, "The Use of Remote Handling Equipment for Gas Cooled Reactor Inspection", Proceeding of Remote Handling in Nuclear Facilities, pp. 534-555 (1984).

[5] G. Clement, "Remote Handling and Transfer Techniques in Dismantling Strategy", Proceeding of Remote Handling in Nuclear Facilities, pp. 556-569 (1984).

[6] A. Baker, "Remote Handling Equipment for the Decommissioning of the Windscale Advanced Gas Cooled Reactor", Proceeding of Remote Handling in Nuclear Facilities, pp. 581-597 (1984).

[7] L. Costa, "Remote Operation in Decommissioning", Decommissioning of Nuclear Power Plates, (1989).

[8] C. P. Baker, "Parametric Design Using IGRIP", Proceeding of the DENEB User Group Conference, pp. (1994).

[9] H. D. Clifford, S. Ekdahl, and J. S. Tulenko, "Virtual Reality for Mobile Robot Control", Proceeding of the DENEB User Group Conference, pp. 91-98 (1994).

[10] M. Salminen, R. Tuokko, and J. Sulkanen, "Development, Experiments and Experience in Telerobotics and VR Using the TELEGRIP Software", Proceeding of the DENEB User

Group Conference, pp. 55-64 (1995).
[11] J. B. Barnaby, "The Use of Real-Time Computer Graphics to Assist Remote Reactor Inspection", Proceeding of the DENEB User Group Conference, pp. 27-3130 (1999).
[12] EON Studio 7.0 Manual, EON Reality Inc.
[13] ATOMIC INDUSTRIAL FORUM - NATIONAL ENVIRONMENTAL STUDIES PROJECT, Guidelines for Producing Nuclear Power Plant Decommissioning Cost Estimates, AIF/NESP-036, Washington (1986).