An Evaluation of Dismantling Scenarios Using a Computer Simulation Technology for KRR-1&2

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ABSTRACT

A graphic simulation has been used to design and verify new equipment and has also been expanded to virtual prototyping technology [1~5]. In the nuclear decommissioning field, this technology has been utilized to validate the design of dismantling processes and to check the interferences and collisions in dismantling scenarios. However, a graphic simulation only provides us with visible result it just provides us with illustrative information of the decommissioning process. A scenario evaluation program has been developed using the computer simulation technology to create an efficient decommissioning plan.

In the D&D planning stage, it is important that the scenarios are evaluated from a engineering point of view because the decommissioning work has to be executed economically and safely following the best scenarios. Therefore, we need several modules to evaluate scenarios. We composed the systems like this:

1. Decommissioning DB module for managing the decommissioning activity information (nuclear facility data, worker's data, radioactive inventory date, etc.).
2. Dismantling process evaluation module
3. Visualization module for a radioactive inventory and a dismantling process using 3D CAD and virtual reality technology.
4. Analysis module for the evaluation results of a dismantling process.

The evaluation module's capabilities produce a dismantling schedule, quantify radioactive waste, visualize a radioactive inventory, estimate a decommissioning cost, estimate a worker's exposure, and check for interference/collisions.

After using the simulation results, the expert ranking system to evaluate scenarios for economics and worker's safety are implemented.

The expert ranking system is a powerful and flexible decision making process to help set priorities and make the best decisions when both the qualitative and quantitative aspects of a decision need to be considered. By reducing complex decisions to a series of one-on-one comparisons, then synthesizing the results, the experts ranking system not only helps decision makers arrive at the best decision, but also provides a clear rationale that it is the best. In the future this scenario evaluation system will be verified by being applied to the ongoing KRR-2 decommissioning project. We believe that it will also be useful to create a decommissioning plan for other nuclear facility decommissioning projects.

INTRODUCTION

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[6,7]. However, because of the deterioration of the utilities, and the change to the higher population area by the accelerated urbanization of the surroundings, a conversion to a comfortable and safe environment was required. Also because of HANARO that is a multipurpose research reactor, which started normal operation at the new site of KAERI, the outdated research reactors lost their usefulness. For these reasons, the decommissioning of the KRR-1&2 was decided. The decommissioning work of KRR-2 will be finished in 2005 and KRR-1 will start to be dismantled shortly afterward. 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 for the main dismantling process, the decommissioning data base system, remote dismantling equipment, and the automatic measurement system.

Since 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 decommissioning and decontamination (D&D) 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 have used physical mock-ups before 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. 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.

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.

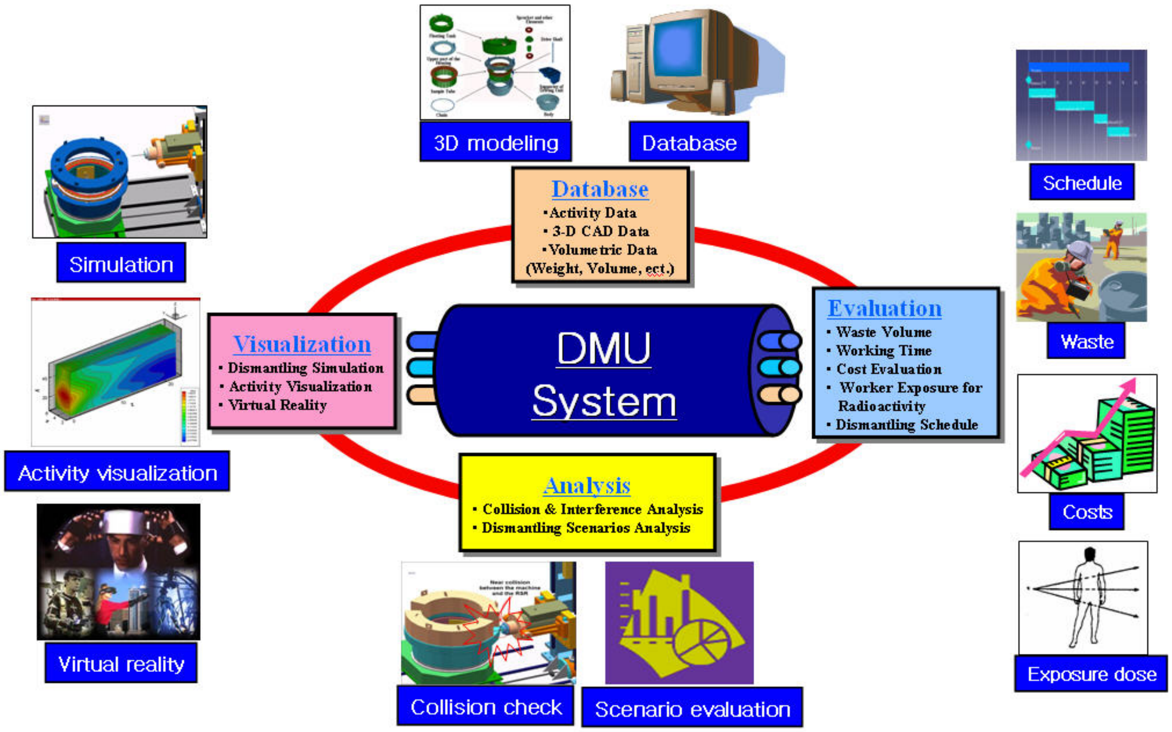


Fig. 1. Conceptual diagram of dismantling digital mockup system

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. The left side picture of Fig. 2 shows the view of the virtual reality of KRR-1. In this position we can navigate the KRR-1 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.

3D RADIOACTIVITY VISUALIZATION

A 3D radioactivity visualization module is essential to classify the radioactive wastes and to define the cutting areas before making a dismantling scenario. It is very useful for worker's training before dismantling work as the radioactive 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 radioactive level for activated items.

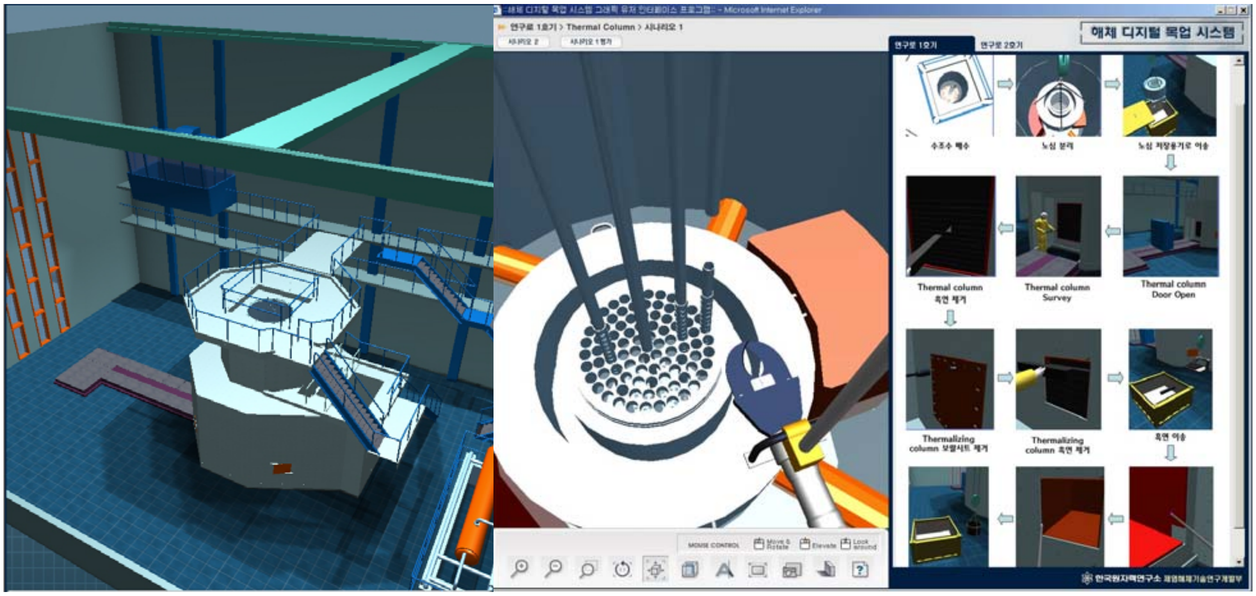


Fig. 2. View of virtual reality of KRR-1 and visualization of core's dismantling simulation for KRR-1

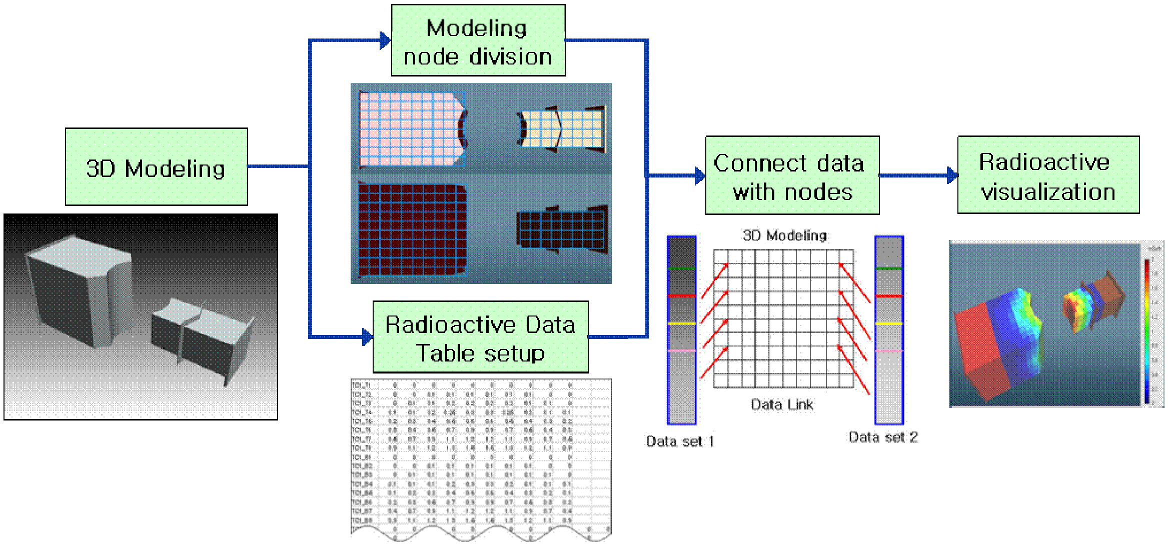


Fig. 3. Method of 3D radioactivity visualization

DISMANTLING SCENARIO EVALUATION MODULE

Schedule Simulation of the Scenarios

A schedule simulation of the scenarios is needed to calculate the scenario duration. The running time of the schedule is closely related with the calculation of the dismantling cost. The man-power required in any scenario is used to calculate the cost of personnel expenses. Equation 1 (Eq. 1) is derived to calculate the working time. Abbreviations' meanings are; BT_i is the dismantling basic unit time, which equals 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 for different materials and 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 activities. Sometimes dismantling work becomes an iterative activity. In this case the man-hours are calculated by multiplying an amount of time for activities by the iterating number. W_j equals the weighting factors. As shown in Table I, 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 N and 8(8 means 8 hours per working a day).

$$T = \sum_{i=1}^{n} \frac{T_i}{N \cdot 8}, \qquad T_i = BT_i \cdot R_i \cdot \left(1 + \sum_{i=1}^{m} W_i\right) \qquad \text{(Eq. 1)}$$

where, T = Total dismantling schedule (Days)

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

N = Number of needed person (Persons)

BT_i = Dismantling basic unit time (Man-h)

R_i = Number of work (Frequencies)

W_i = Weighting factors (%)

Table I. 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 respirator 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

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 II 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.

Table II. Waste Volume of KRR-1’s Beam Ports for the Diamond Wire Saw Method and Core the Boring Methods

Waste type	Waste volume(cm^3)	
	Diamond wire saw method	Core boring method
Steel	$4.12\text{x}10^5$	$4.22\text{x}10^4$
Aluminum	$2.01\text{x}10^4$	$2.01\text{x}10^4$
Concrete	$1.43\text{x}10^7$	$9.51\text{x}10^5$

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 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.

$$C = PE + TE + WE \qquad \text{(Eq. 2)}$$

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

$$PE = \sum_{i=1}^{n} T_i \times AMC \qquad \text{(Eq. 3)}$$

where, PE means the personnel expenses, T_i equals the man-hours for each dismantling action, and AUC equals the average labor cost.

$$TE = \sum_{i=1}^{n} M_i \times NOM \qquad \text{(Eq. 4)}$$

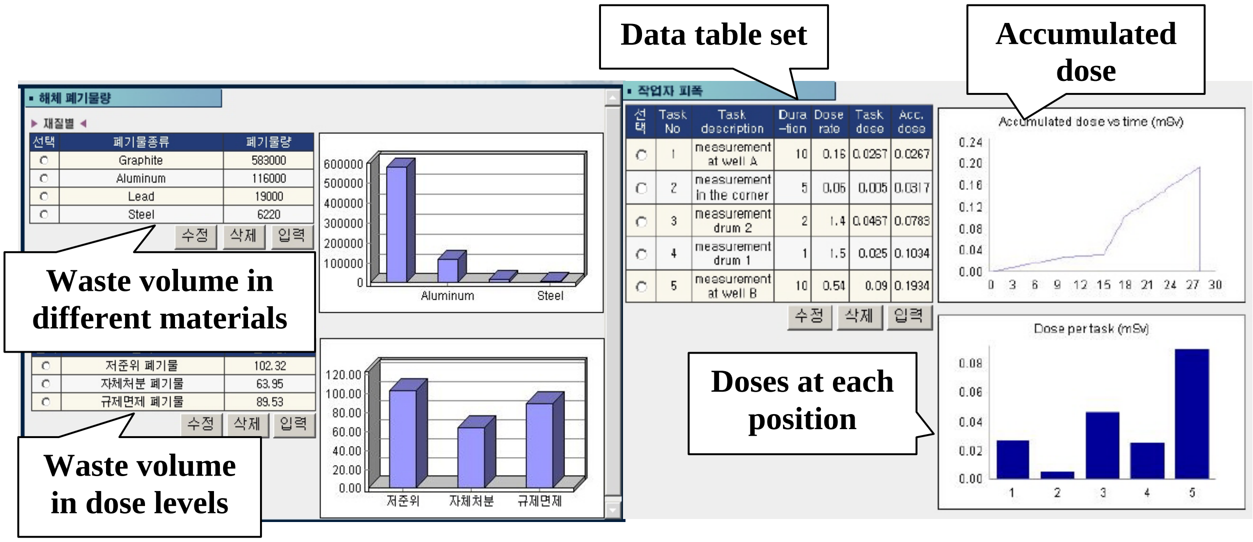
where, TE means the tool expenses, M_i equals the machine unit cost, and NOM equals the number of machines.

$$WE = \sum_{i=1}^{n} D_i \times \frac{V_{total\ \ waste}}{V_{waste\ \ drum} \cdot P} \qquad \text{(Eq. 5)}$$

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

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.



선택	폐기물종류	폐기물량
○	Graphite	583000
○	Aluminum	116000
○	Lead	19000
○	Steel	6220

○	저준위 폐기물	102.32
○	자체처분 폐기물	63.95
○	규제면제 폐기물	89.53

선택	Task No	Task description	Dura -tion	Dose rate	Task dose	Acc. dose
○	1	measurement at well A	10	0.16	0.0267	0.0267
○	2	measurement in the corner	5	0.06	0.005	0.0317
○	3	measurement drum 2	2	1.4	0.0467	0.0783
○	4	measurement drum 1	1	1.5	0.025	0.1034
○	5	measurement at well B	10	0.54	0.09	0.1934

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

Evaluation of Scenarios

The evaluation of scenarios is based on selecting independent criteria and on expert's ranking of the alternatives within 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, χ_i (where: i=category). The weighting factors were defined by averaging the rankings of the independent experts. The weights were then normalized, i.e., $\sum \chi_i = 1$. The following “weighted” sums were calculated for each decommissioning alternative:

$$S = \sum_i \chi_i \sum_j b_{ij} \qquad \text{(Eq. 6)}$$

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

Table III. 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 IV. Analysis of the Alternatives by the Safety 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 V. Weighting Factors by Categories

Criteria	χ_i
1. Economic efficiency	0.407
2. Safety	0.593

Table VI. 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

Table III and IV show the evaluation results of the economical efficiency category and the safety category regarding two scenarios of the thermal column in KRR-1. Table V shows the weighting factors that were derived from Tables III and IV. Finally Table VI shows the scenario evaluation results by considering the economic and safety aspects.

CONCLUSION

A digital mock-up system which can evaluate the scenarios for KRR-1&2 was developed along with the dismantling schedule simulation module, waste calculation module, decommissioning cost module, worker’s exposure module and virtual reality module. On the basis of the evaluation results, the scenarios can be quantitatively compared and evaluated. This system will be applied to KRR-1 to obtain the best scenario and we expect it to be used as a future systems engineering tool in other nuclear power plant decommissioning.

This system will be upgraded to obtain data from the decommissioning DB system. This can lead to a decrease of the decommissioning cost and the improvement of a worker’s safety.

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