Systems Engineering for Decommissioning the Japan Power Demonstration Reactor*

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The Japan Power Demonstration Reactor (JPDR) decommissioning program is in progress: new technology for reactor decommissioning is being developed and a database is being established. Various data pertaining to dismantling of the JPDR have been accumulated in the database. The data collected in the program are being used for (1) managing ongoing dismantling activities, (2) verifying the code system for management of reactor decommissioning (COSMARD) developed for the forecasting of management information, and (3) planning future decommissioning of commercial nuclear power reactors. COSMARD and the database are expected to be particularly useful in the last of these three.

Key Words: Systems Engineering, Scheduling, Nuclear Reactor, Reactor Decommissioning, Work Breakdown Structure, Program Evaluation and Review Technique

1. Introduction

The decommissioning of nuclear facilities has been an important issue around the world, since there are a number of nuclear facilities for which decommissioning is planned or in progress. In anticipation of the decommissioning of the first Japanese commercial nuclear power reactor in the near future, research and development on decommissioning continues in Japan; the Japan Power Demonstration Reactor (JPDR) decommissioning program is the flagship program for the development of decommissioning technology. Systems engineering for decommissioning the JPDR is considered to be one of the important technologies requiring study in the JPDR decommissioning program.

In planning the JPDR decommissioning procedure, various project management information pertaining to cost, labor requirements, radiation exposure of workers and waste arisings should be evaluated with respect to various factors such as inherent plant conditions, decommissioning scenarios and waste management policy. A computer code system based on a logical and systematic methodology would be the best tool for efficient and precise estimation of the data for project management. To this end, the Code System for Management of Reactor Decommissioning (COSMARD) was first developed to meet the requirements of an optimization study regarding a site-specific decommissioning plan and the data on dismantling of the JPDR were estimated using COSMARD to design an efficient dismantling process. From the actual dismantling activities, various data have been collected and stored in the decommissioning database using the data collection and retrieval systems. Furthermore, the data collected from the dismantling activities were analyzed to characterize this procedure.

In this report, we describe the JPDR dismantling procedure, COSMARD, and data analysis relating to

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systems engineering for decommissioning the JPDR.

2. JPDR Decommissioning Program

2.1 JPDR

The JPDR, which was the first reactor to generate electricity in Japan, is a boiling water reactor that began generating electricity in 1963 and ceased operation in 1976. The JPDR provided a large amount of data for operation of successive commercial nuclear power reactors. Table 1 shows the main specifications, operation time, and radioactive inventory of the JPDR.

2.2 Outline of the JPDR decommissioning program

The JPDR decommissioning program consists of two phases. The objective of Phase I, started in 1981 and now completed, is the development of a set of techniques for reactor decommissioning. Phase II, the actual dismantling of the JPDR, followed Phase I and will be completed by 1994⁽¹⁾. The actual dismantling was started in December 1986. The primary objectives of this program are (1) to gain actual experience in the dismantling of a nuclear power reactor, (2) to test the techniques developed in the program, and (3) to collect data from the JPDR dismantling activities. The top priority of the dismantling procedure is to ensure safety of workers and to prevent radioactive materials from being released. Radioactive components and structures were removed in the early stage of the dismantling procedure, and the remote dismantling techniques developed in Phase I have been put to practical use to minimize the risk to workers.

2.3 Dismantling activities

In the first stage of the JPDR dismantling procedure, the machinery around the reactor in the reactor building was removed to provide necessary space for the installation and the operation of large remote-controlled cutting tools for the dismantling of the reactor itself. For example, the equipment in the forced circulation system was dismantled so that the space could be used as a packaging area. The equipment was cut with hand tools such as an oxygen torch and a band saw because the radiation dose rate in this area was low.

The main parts of the JPDR such as reactor internals and the reactor pressure vessel (RPV) were dismantled underwater by remote control. A plasma arc cutting technique, operated by either a mast-type or master-slave manipulator, was applied in cutting the reactor internals underwater⁽²⁾. Figure 1 shows a schematic diagram of the dismantling of the reactor internals. Together with the cutting devices, auxiliary apparatus such as underwater monitoring cameras, a contamination control envelope and gas collection

systems were used in the dismantling procedure.

After removal of the reactor internals, a cylindrical tank was temporarily installed in the cavity between the RPV and the concrete biological shield to cut the RPV underwater. The RPV was cut into a total of 65 blocks, 70–90 cm wide. The blocks were placed into either 1 m³ steel containers or shielded containers depending on their radioactivity. Following this dismantling procedure, the activated portion of the concrete biological shield was dismantled using both diamond sawing/coring and abrasive water jet

Table 1 Major specifications, operation history and radioactive inventory of JPDR

Specifications	
Pressure vessel	
material	ASTM-A302-56GrB
inner diameter	2.1 m
height	8.1 m
thickness	0.07 m
Biological shield	
material	reinforced concrete
thickness	1.5 to 3 m
Reactor containment	
inner diameter	15 m
height	38 m
Operation history	
Operation time	17,000 hours
Output of electricity	1.4×10^6 KWH
Radioactive inventory	131 TBq
	(as of April, 1988)

Fig. 1 Schematic view of the master-slave manipulator cutting system

cutting techniques. First the upper half of the activated concrete biological shield was cut using diamond sawing/coring, and the lower half was cut using an abrasive water jet. Controlled blasting was used to demolish the rest, which was only slightly activated. After confirmation that there is no radioactivity, all building structures will be demolished, and the site will then be renovated and landscaped.

3. COSMARD

3.1 Methodology

The data for project management for decommissioning a nuclear power reactor are generally grouped into three basic categories, each of which requires a slightly different analysis. In COSMARD, the grouped categories are as follows :

- (1) activity-dependent data,
- (2) period-dependent data, and
- (3) collateral data.

The activity-dependent data are related to repetitive events such as cutting pipes and tanks and transporting containers. Data regarding labor requirements which are activity-dependent are analyzed by multiplying a unit factor by certain inventory units such as weight and volume. The data for labor requirements of most manual tasks and remote-controlled cutting are considered to be activity-dependent. The period-dependent data include those of the decommissioning project administration, site maintenance, equipment rental and energy consumption during the period of the decommissioning project. For example, the staff size for the project administration is first determined depending on the project scale, and then administrative costs are estimated based on the duration of the project and unit rates of staff salaries. The collateral data are estimated using the estimated values of activity-dependent and period-dependent data. These are estimated by multiplying the values obtained in the other groups by suitable percentages. Contingency costs for unexpected events are included

in the collateral data. In the estimation of the data for project management by COSMARD, all types of decommissioning work can be categorized into the three groups by processing of a set of input data.

496 3.2 Outline of COSMARD

Figure 2 shows the basic principle of COSMARD calculations. As indicated in the figure, the estimation of the data for project management for reactor decommissioning is based on the following factors.

- plant inventory
- models for estimating the data for project management
- work breakdown structure (WBS)

The input data for the COSMARD calculations are prepared as a set of descriptions of a work package for decommissioning formed using the WBS. These include titles of grouped work items, specifications of target codes of components to be dismantled, network relations among tasks in the dismantling procedure, productivity loss factors, and so on. Data on components to be dismantled are stored in the plant inventory database and identification codes are used to refer to data in the calculations. Productivity loss factors are determined by work conditions such as respiratory protection, protective clothing, scaffolding and congestion of the work area. According to the input data, necessary unit factors and unit component data for the calculations are retrieved from the databases, and these values are processed according to calculation models which are associated with the unit activities. The output consists of results calculated with respect to the input WBS.

3.3 Calculation models

As described previously, the data evaluations for project management are based on the plant inventory data and calculation models prepared as unit activities in the unit activity database. The arithmetic formulas derived from the calculation models are placed at the bottom of the WBS. The input WBS is prepared in such a way that each work activity on the

Fig. 2 Principle of COSMARD calculations

bottom level should correspond to the model of its calculation in the unit activity database, as shown in Fig. 3. Simple arithmetic, logical operations and "if ... then ... else" rules are used in the models. The evaluated data are summed according to the input WBS. An example of evaluations of the labor hours for the dismantling of a pump is shown below.

```

ACT.METH : PUMP.GEN
IF(WEIG>=1)
  DMMHSUM=35 * WEIG * NUMB
IF(WEIG>=0.5)
  DMMHSUM=25 * WEIG * NUMB
IF(WEIG>0)
  DMMHSUM=15 * WEIG * NUMB
ENDIF
ENDIF
ENDIF
END
  
```

A calculation model is inserted between the name ("ACT.METH : PUMP" in this case) and the END statement. If the data stored in the plant inventory database are necessary, variables such as WEIG and NUMB, which denote weight and quantity, respectively, are used to refer to these values in the database. Models are prepared for all activities, including the dismantling of components such as pumps and tanks, preparation, packaging and cleanup activities.

3.4 Data for management of JPDR dismantling procedure

Before the dismantling procedure was begun, various data for project management were evaluated under actual operational conditions⁽³⁾. The major sources of data pertain to labor requirements, radiation exposure of workers and costs associated with the dismantling procedure. The total manpower was estimated to be 83,240 man-days with exposure of workers to radiation of about 0.8 man·Sv. The total

cost is estimated to be approximately 11 billion yen, excluding period-dependent items such as administration costs of the project. The work in the reactor building accounts for approximately 40% of the labor required for the dismantling procedure and about 80% of the total radiation exposure of workers.

4. Data Collection and Analysis

4.1 Data collection and retrieval systems

Various kinds of data for the JPDR dismantling procedure have been accumulated in the decommissioning database. The database is to be used for (1) management of ongoing dismantling procedure, (2) verification of the developed code system, and (3) planning of future decommissioning of commercial nuclear power reactors. These data, which include dismantling procedure specifications, labor requirements, radiation exposure of workers and waste arisings, have been collected by the data collection and retrieval systems developed using the mainframe JAERI (FACOM-M 780) and minicomputers. In addition, data on machine performance and operability were collected when newly developed decommissioning techniques were applied during the dismantling procedure. All data collected through the JPDR dismantling procedure have been stored in the decommissioning database.

Figure 4 shows the concept of the developed data collection and retrieval systems. Data for dismantling the JPDR are basically grouped into three categories: radiation control data, dismantling operation data and waste management data. The radiation control data, which include labor hours and radiation exposure of workers, are collected using magnetic identification cards and pocket dosimeters, respectively. When passing through the gate of the radiation control area, each worker is required to record entering/exiting time and external dose by inserting his/her magnetic card and pocket dosimeter into the magnetic reader, which is connected to a computer. The other data have been collected through descriptions made by supervisors of workers. All reports made by supervisors are submitted daily to the staff of the systems engineering group in the JPDR decommissioning program. Then, relevant data for ongoing management and for future decommissioning are selected according to a predesignated format and stored in the decommissioning database through computer terminals. Other data pertaining to such factors as machine performance and unexpected occurrences have been stored in document form.

4.2 Use of collected data for project management

The data collected during the dismantling proce-

Fig. 3 Calculation process and the role of the unit activity database in COSMARD

cedure are used for project management as follows.

a. Radiation control data: Cumulative doses and other information, for example, dates of medical examinations, are checked to ensure that they conform to regulations. When the collective dose, itemized by the work permission number, exceeds a set value, the reason will be determined. The analyzed results will be used to modify the proposals of other dismantling procedure if necessary.

b. Dismantling operation data: To perform dismantling tasks efficiently, it is necessary that the plans for subsequent decommissioning procedure be re-examined using collected data pertaining to working hours, number of workers, task completion, and so on.

c. Waste management data: Dismantled components are placed in containers with identification

numbers, which are linked to information such as source and quantity of waste, transportation, storage, radioactivity level and processing method.

Figure 5 shows a histogram of the main management data collected from the dismantling procedure in the reactor building along with the estimation.

4.3 Data analysis

Data for manual work were collected on the basis of work permission numbers. Among the data collected, the number of labor hours required for the dismantling procedure is useful in the evaluation of unit factors for the estimation of labor hours. Before estimation of labor requirements is performed using COSMARD, a number of unit factors for the estimation of labor hours were prepared based on actual field experience. However, since this is the first decommis-

Fig. 4 Concept of data collection and retrieval system

Fig. 5 Data for labor requirements and radiation exposure of workers collected from the dismantling procedure in the reactor building along with the estimation

Fig. 6 Relationship between weight of dismantled components and labor hours required in the dismantling of cables, pumps and piping

sioning of a nuclear power reactor in Japan, the unit factors prepared are not always reliable for the estimation of labor requirements in the JPDR dismantling procedure. The reliability of the unit factors has therefore been examined through the analysis of manpower data collected during the dismantling procedure. Figure 6 shows the relationship between weight of dismantled components and labor hours required in the dismantling of cables, pumps and piping. The unit factors which differ with respect to component type were evaluated based on these kinds of relations and other information, including dismantling work specifications.

Dismantling tasks are very site-specific, and many alternatives are acceptable depending on work conditions. It is therefore important to evaluate productivity of workers under specific conditions, because evaluated unit factors will be applied to the estimation of labor requirements under various conditions. As indicated in Fig. 6, the work performed in congested areas requires a greater number of labor hours than work in other areas. This is because the dismantling work was performed with the use of respiratory protection and protective clothing in a limited space. A number of productivity loss factors can be derived from these data. The data on the JPDR dismantling procedure will contribute markedly to the verification of the unit factors and the evaluation of productivity loss factors.

5. Concluding Remarks

The JPDR decommissioning program is success-

fully under way, and useful data for future decommissioning of commercial nuclear power reactors are being accumulated. It has been recognized that the precise estimation of the data for project management is of great importance in creating an economical and safe decommissioning plan for a nuclear power reactor. However, much effort is required to establish a project-specific database because the data vary with the selected decommissioning scenario, the location and other inherent plant characteristics. COSMARD has been developed to enable estimation of the data for project management with respect to various decommissioning scenarios, and it provided accurate estimation of data for the JPDR dismantling procedure. Furthermore, data are being collected on an ongoing basis from the JPDR dismantling activities to validate COSMARD. COSMARD and the database will contribute to the development of an optimum plan for future decommissioning of commercial nuclear power reactors.

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