Study on the regulation improvement of domestic cyclotron decommissioning through the questionnaires on the current cyclotron operation status

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1. Introduction

In Rep. of Korea, 40 cyclotrons have been installed at a wide variety of location such as hospital, research institute and are being used for the purpose of medicine and research. In the case of cyclotron, activation occurs in target structures and concrete by neutron resulting from nuclear reaction of target part. Because of activation, surrounding structures and concrete are categorized as radioactive waste. Cost of intermediate and low-level radioactive waste (ILLW) disposal in 2015(about 12 million won) have been increasing about three times compared with cost of ILLW disposal in 2009(about 4.5 million won). Accordingly, the cost will be an important part in decommissioning cost [1, 2]. In case of nuclear facilities (such as nuclear reactor and related facilities, nuclear fuel cycle, nuclear material facilities), preliminary decommissioning plan report (PDPR) should be submitted in construction licensing stage. But, accelerator facilities (cyclotron) could be licensed to construct without PDPR [3]. Accordingly, decommissioning project managers and operators will have difficulty in determining cost of decommissioning. Therefore, we aim to draw improvements for preparation of regulation guidelines of domestic cyclotron decommissioning through the analysis of questionnaire.

2. Questionnaire on decommissioning in Europe [4]

In Europe, questionnaire on decommissioning was conducted to estimate the economical consequence of decommissioning the particle accelerator and build the database of the accelerator. Questionnaire contents include general information, accelerator data, irradiation and activation data, end of life of accelerator and decommissioning, and future plans. They surveyed 226 particle accelerators throughout the Europe, 91 particle accelerator operators responded to the questionnaire. The results of the survey are listed below.

- Radioactive nuclides involving the activation in concrete are mostly ^{152}Eu, ^{60}Co, and ^{134}Cs.
- Radioactive nuclides involving the activation in metal infrastructure are mostly ^{60}Co, ^{54}Mn, and ^{65}Zn.
- Radioactive nuclides involving the activation of machine parts are ^{60}Co, ^{54}Mn, ^{22}Na, and ^{57}Co.
- The cost of cyclotron decommissioning depends on the scenarios that are based on clearance level, waste management cost, and labor cost. (The minimum cost is 810 k€ (about a billion won), and the maximum cost is 7,700 k€ (about 10 billion won).)

3. A status report on domestic cyclotron operation

We conducted a survey of cyclotron operator to figure out the operation status of cyclotron throughout the country. General information (company / location, intended use, etc.) were collected to evaluate distributions and main purpose of cyclotron. Also, we looked into the licensing information (manufacturer, models, shield type (w, w/o self-shield), accelerating particle, beam energy and beam current, etc.) and operation information(number of cyclotron runs(per week), average operating time for a day, dose rate in shield wall surface and control room) for collection of data related to present condition of cyclotron and operation information. Additionally, decommissioning and disposal information (mounts of radioactive waste during operation, decommissioning plan, etc.) were surveyed to collect data related to radioactive waste disposal status (for operation period), future decommissioning plan. The details of each contents are given in Table I. Questionnaire is shown in the Fig. 1.

Table I. Questionnaire contents

Content	Details
General Information	Company, Location, Type of facility, Intended use, etc.
Licensing Information	Manufacturer, Models, Accelerating particle, Beam energy, Beam current, RF frequency, Plane of accelerator, Cyclotron weight, shield type (w, w/o self-shield), Weight / Size / Material of self -shielding, Installation year, Total operation period, etc.
Operation Information	Number of cyclotron runs (per week), Average operating time for a day, Average beam current, Amounts of ^{18}F production, Production per times, Stay time to cyclotron room after operation, Radiation dose rate before cyclotron operation and during the operation, Type of target foil, etc.
Decommissioning And Disposal Information	Mounts of radioactive waste during operation, The status of disposal of radioactive waste, Types of biological shield, With or without (heavy)metal in concrete, With or without neutron shield material between target and wall, Thickness of shield wall, Metal material contents in structure, Decommissioning plan, etc.

Fig. 1. Questionnaire on decommissioning

4. Survey Results

We surveyed thirty cyclotron of forty them installed all over the country, 25 cyclotron operators responded to the questionnaire. Survey results for each content are as follows.

4.1 General Information

Among the type of cyclotron facility, there were seventeen of industries and eight of medical facilities. There were eleven of self-shield cyclotron and fourteen of non self-shield cyclotron according to the existence of the self-shield. Also, the distribution of cyclotron is shown in Fig. 2.

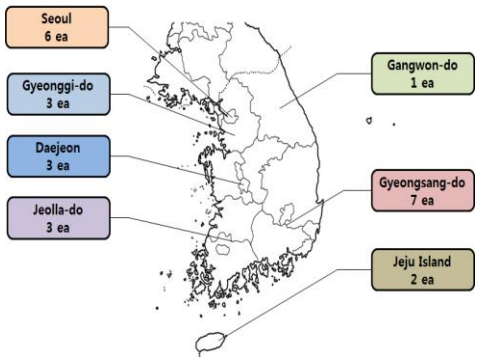

Fig. 2. Distribution of cyclotron in the Republic of Korea

4.2 Licensing Information

The number of cyclotrons according to manufacturers and models is tabled in the Table II and Table III. Also, accelerating particles are mainly H^-, other accelerating particles (such as deuteron, Optional D, Helium) are also used at some facilities.

Table II. The number of cyclotrons according to manufacturer

Manufacturer	Number
GE health care	5
IBA	6
KIRAMS	5
Siemens	6
Sumitomo	2
Others	1
Total	25

Table III. The Number of cyclotrons according to model

Model	Number
Cyclone 18/9	5
Cyclone-30	1
Eclipse HP Cyclotron	3
HM-7	1
HM-12S	1
KIRAMS-13	5
MC 50	1
PET Trace	2
PET trace 800(840/860/880)	3
RDS Eclipse	3
Total	25

4.3 Operation Information

Range of number of cyclotron runs (per week) is from 2 to 25, the most number of cyclotron runs (per week) is 5. Number of operating time for a day is mainly 1~2, maximum is 3. Also, the stay time to cyclotron room related to worker exposure during cyclotron operation is from 30 minutes to 24 hours. Distributions of radiation dose rate before cyclotron operation and during the operation (shield wall surface, control room) are given in Table IV.

Table IV. Radiation dose rate before cyclotron operation and during the operation

Standard		Radiation dose rate [μSv/hr]
Before cyclotron operation	Shield wall surface	background ~ 0.8
	Control room	background ~ 0.5
During the operation of cyclotron	Shield wall surface	0.2 ~ 4
	Control room	0.15 ~ 1.2

4.4 Decommissioning and Disposal Information

Disposal method of the consumable supplies related to cyclotron synthesizer and radiopharmaceutical production were surveyed. In most facilities, consumable supplies related to cyclotron synthesizer are stored in (high) activity waste container. After proper decay time, self-disposal is conducted. Also, consumable supplies related to radiopharmaceutical production are carried out in self-disposal after storage in (high) activity waste container. But, there are no plans for the shut-down in most of cyclotron facilities and there is no preparation for the decommissioning.

4. Conclusions

Through foreign cyclotron decommissioning practices, we verified the following [4,5].

- To perform cyclotron decommissioning, the preparation of the cost estimation, identification of radionuclide, and identification of activation concentration is necessary.
- According to categorization of radioactive waste, decommissioning waste disposal costs are changed.

In case of domestic cyclotron, Preliminary Decommissioning Plan Report (PDPR) is not submitted in construction licensing stage. But, the lifetime of cyclotron may be decreased because of the upgrade or the change of intended use. Even though the classification of radioactive waste (Very Low Level Waste, Low Level Waste, etc.) was adopted according to international standard, the disposal method of very low level waste has not yet been determined. If we dispose of radioactive wastes from decommissioning cyclotron, large amounts of intermediate and low level radioactive wastes will be produced. Accordingly, the costs of cyclotron decommissioning will be increase. However, as shown in the survey results, most of licensee are not preparing decommissioning fund. Because of the decommissioning cost, decommissioning manager and operators will go through confusion. Therefore, disposal plan of each radioactive waste according to the system of radioactive waste classification should be prepared. And cyclotron operation managers should prepare the decommissioning of cyclotron.

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Data for questionnaire is not released because information of institution contained questionnaire.

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