NENE 2022
September 12-15
PORTOROŽ
SLOVENIA
31st International Conference Nuclear Energy for New Europe

Development of the evaluation method for the mobile radioactive contaminants for assessing public exposure risk in accidental events during decommissioning of nuclear power station

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ABSTRACT

In the risk assessment of the decommissioning phase, the inventory of radioactivity accumulated in filters and other materials changes with the progress of dismantling work under normal conditions, and a method that can evaluate the public exposure dose during an accident in which these changes are taken into account is required. The inventories (the mobile radioactive contaminants) include filters in which radioactive dust dispersed by equipment cutting work has accumulated and combustible waste generated by decontamination work. In this study, we developed a method to evaluate the accumulation of mobile contaminants in filters by calculating the amount of dust transferred into the air during equipment cutting operations using a model that evaluates the volume of the cutting kerf width and the dispersion ratio. Furthermore, the amount of the mobile contaminants that accumulates in local filters and building filters for each equipment was evaluated using this method, taking into account differences in cutting methods (underwater or in air) and work processes, and the equipment and work processes that should be focused on during regulatory inspections were studied preliminarily. It was suggested that the same level of mobile contaminants is generated in the dismantling of equipment using cutting in air in radwaste processing building compared to the mobile contaminants generated when core shroud (one of reactor internals) with high radioactivity is cut in underwater. This indicates that the mobile contaminant is one of the important indicators in nuclear regulatory inspections that influence the selection of inspection targets.

1 INTRODUCTION

A number of nuclear power plants are at the decommissioning stage. Unlike during power generation, although it is unlikely that neutron-activated radioactivity or contamination adhered to the inner surface of pipes would melt or evaporate and be dispersed into the work environment in the events of a fire or explosion due to an accident, dust generated by dismantling work and nuclides eluted in decontamination solutions could be released during an accident, and it is necessary to focus on these forms of contamination. These contaminants change spatially and temporally with the progress of dismantling work. In Japan, nuclear regulatory inspections have been newly introduced, and inspections are being conducted with the severity determined according to the impact on safety by risk informed, but a risk assessment method has not yet been developed for the decommissioning phase. Therefore, it is necessary to select equipment to be dismantled and work processes to be inspected in nuclear regulatory inspections during decommissioning according to risk, and it is necessary to develop a method for evaluating the risk of public exposure to radiation during an accident for decommissioning nuclear power plants. Risk in this study is the product of the frequency of an accident and the public exposure dose during an accident. In previous studies about risk assessment of nuclear power plants at the decommissioning stage, Mercurio et al. [1] showed Level 1 and Level 2 PSA results for the RPV and fuel pool for fuel damage frequency and so on at decommissioning stage. In addition, Iguchi [2] selected radioactive inventory, contamination status, dismantling method, and confinement system as factors to determine risk for the decommissioning phase, and evaluated the importance rank for each equipment. On the other hand, the study by Mercurio et al. evaluated the risk for specific equipment, and the study by Iguchi et al. did not take into account the frequency of occurrence, so there are still issues to be resolved in the selection of regulatory inspection targets.

In order to evaluate the public exposure dose during an accident in the decommissioning phase risk assessment, it is necessary to identify the radioactive inventories (hereinafter referred to as "the mobile radioactive contaminants") that are released during accidents (e.g., fires) and to quantify these mobile contaminants. In this study, assuming the case of a fire during cutting operations, the dust accumulated in local filters used for ventilation of the contamination control enclosure and building filters used for ventilation of the building were targeted. Since the mobile contaminants accumulated in filters changes with the progress of dismantling work under normal conditions, it is necessary to develop a method to evaluate the public exposure dose at the time of an accident that takes such changes into account. The purpose of this study is to develop a method to evaluate the mobile contaminants, which changes temporally and spatially according to the progress of decommissioning work, and to predictively evaluate the mobile contaminants as a preliminary step of risk assessment at decommissioned nuclear power plants.

2 ANALITICAL METHOD

We developed a method to evaluate the mobility contaminants that accumulates in each filter by calculating the amount of dust (weight and radioactivity) that is transferred into the air as dust during equipment cutting operations, using a model that evaluates the cutting kerf volume (neutron-activated contamination) or cutting kerf area (surface contamination) determined from the container dimensions and each dispersion ratio. In this method, the amount of dust generated is based on the dispersion ratio data organized from equipment cutting tests [3], and changes in the dispersion ratio depending on the cutting method and the material of the target equipment can be considered. In addition, from the amount of dust generated and the radioactivity concentration, the amount of each radioactivity that accumulates in local and building filters can be evaluated by considering the leakage from the contamination control enclosure and the collection efficiency of filters. Furthermore, the amount of mobile contaminant generated by each equipment considering the difference of cutting method (underwater, in air) and work process for each filter was evaluated by this method, and the equipment and work to be focused on during regulatory inspections were examined predictively. Note that the amount of mobile contaminant generated in this assessment is below the dose criterion for the assessment of public exposure dose during an accident.

2.1 Decommissioning Safety Assessment Code "DecAssess"

Decommissioning safety assessment code "DecAssess" is a calculation code under development to assess the dose to workers under normal conditions, the dose to the public under normal conditions, and the risk of exposure to the public during an accident, based on data on the radioactive inventory and geometry for each piece of equipment and information on the dust dispersion ratio and working hours due to cutting. In this study, the evaluation of the public exposure risk in an accident was assumed, and amount of the mobile contaminants that could be released in an accident was evaluated. In this paper, local filters and building filters in which radioactive dust generated by cutting operations accumulates are evaluation targets. Figure 1 shows the developed evaluation procedure of the mobile contaminants.

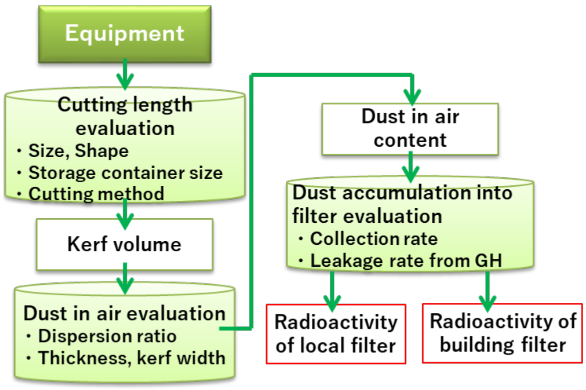

Figure 1: mobile contaminants evaluation

For all equipment to be dismantled, the shape of the equipment was classified as hollow rectangular, hollow cylindrical, and circular tube, and the size of the storage container containing the cut pieces and the size of the cut line relative to the storage container were set respectively, and the cut line length was evaluated using Shimada's model [4]. The time used for cutting was evaluated based on the evaluated cutting line length and cutting rate. The cutting rate was calculated using an evaluation formula developed from cutting time data collected during the decommissioning of JPDR, a Japanese research reactor facility whose decommissioning was completed in 1991. Additionally, in order to compare the effect of the different dispersion ratio of cutting methods on the occurrence of the mobile contaminants, it was assumed that the cutting rate in air and water are equal and that the time required for other preparation and post-treatment operations are also equal.

2.2 Equipment Data in BWR

The data on equipment were mainly from the reference BWR [5] in NUREG/CR-0672 vol. 2, published by the NRC. The reference BWR has a power output of 1155 MWe, and the size and radioactive inventories for each equipment are showed based on the assumption that the reactor will be dismantled after 30 years of full power operation. However, this report lacked data on the size of the reactor's major components, such as the core shroud. Therefore, for BWRs with a power output of 1000 MWe level, information published by each power company in Japan was surveyed and these used as size data [e.g., 6, 7]. For the percentage of nuclides of neutron-activated contamination, differences between stainless steel and carbon steel were taken into account. No distinction is made by material for the percentage of nuclides in surface contamination. The percentages of each species in the neutron-activated and surface contamination include Co-60, Ni-63, Fe-55, etc. As for the initial radioactivity, the core shroud has the highest amount of 2.33×10^{17} Bq. For some of the equipment, data on the internal surface area of the equipment is available, and this was used to evaluate the dispersion of surface contamination during cutting. For equipment for which no data on internal surface area was available, the internal surface area was calculated based on the specified shape and size.

In addition, fuel assemblies are assumed to be processed at a reprocessing facility and are not subject to the mobile contaminants source.

2.3 Analysis Condition

The decommissioning schedule was made as shown in Figure 2, referring to the decommissioning process in Japan. For the reactor pressure vessel (RPV) and the piping system connected to it, system chemical decontamination (DF = 30 [8]) is performed first, which reduces the surface contamination density in the system to 1/1000, and the radioactivity is transferred to the decontamination solution. Next, dismantling of the equipment and piping in the reactor building, dismantling of reactor internals such as the steam separator, and dismantling of the RPV are performed in this order. After the dismantling of the equipment and piping in the reactor building is completed, the dismantling of the equipment and piping in the waste processing building is shifted. For the dismantling of the biological shielding, the controlled blasting method was adopted in reference to the decommissioning of the JPDR [9], but this analysis did not reflect the accumulation of those mobile inventories because the study focused on the difference in the cutting method.

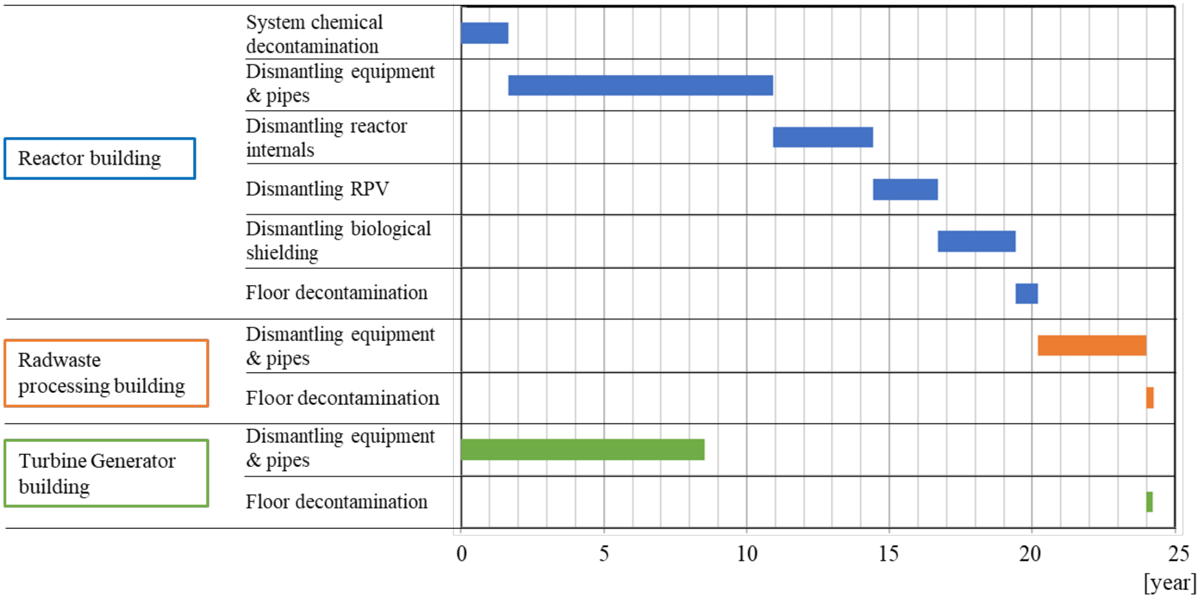

Figure 2: Progress schedule of decommissioning

For the dust dispersion ratio when cutting the equipment, we referred to a research report [3]. In this analysis, the cutting method is plasma cutting, which can handle a wide range of plate thicknesses from 0.5 mm to 100 mm. The dispersion ratio represents the amount of radioactive material transferred in air per the amount of radioactive material lost by cutting the object to be dismantled. The dispersion ratio was obtained from cutting tests of stainless-steel plates and other materials. The dispersion ratio of neutron-activated contamination by cutting in air is 10.7%, and that of surface contamination is 70%. The dispersion ratio of neutron-activated contamination in underwater cutting is 0.0036%. However, since the dispersion ratio of surface contamination in underwater cutting was insufficient, 0.0236% was assumed based on the ratio of the dispersion ratio of neutron-activated contamination in air cutting to the dispersion ratio of surface contamination. In this study, however, the maximum value of the test results was conservatively adopted for the dispersion ratio when cutting neutron-activated materials. Although the kerf width varied depending on the plasma output and other factors, it was assumed to be 1 cm for all equipment and methods in order to simplify the comparison of the mobile contaminants for each cutting method.

For cutting operations, it was assumed that contamination control enclosures were used to control dust dispersion, and the leakage rate for contamination control enclosures was assumed to be 0.5% from the report [3]. The leakage rate represents the amount of radioactive material leaking from the contamination control enclosure per amount of radioactive material generated in the contamination control enclosure.

Filters that collect dust are generally used in combination with corresponding filters depending on the particle size of the dust. For example, coarse dust filters are used for larger particles and HEPA filters for smaller ones. In this study, on the other hand, it is assumed that the dust is fine particles, and HEPA filters are used for both local filters and building filters. For building filters, multiple filters are usually connected and used as a single system, but in this study, for simplicity, only one HEPA filter was used for the building filter. The collection efficiency of these filters was assumed to be 99.99% [3], with a maximum dust accumulation of 2 kg [10]. When the accumulated dust in the filter exceeds 2 kg, the filter is replaced with a new one.

Cutting in underwater is usually the method used for reactor internals, while cutting in air is used for the rest. However, in this analysis, both cutting methods were assumed to be applied to all equipment and structures.

3 RESULTS AND DISCUSSION

Figure 3 shows the results of the evaluation of the mobile contaminants generated by each building and equipment when each cutting method (in air and in underwater) was used. Assuming that the fire started in a local filter and spread to a building filter, these mobile contaminants represent the total amount of radioactivity accumulated in a local filter and a building filter. Filters are set to be replaced with a new filter when the accumulated amount of dust exceeds 2 kg through differential pressure control, and for dismantling of equipment with dust accumulation exceeding 2 kg, the radioactivity amount at the time of dust accumulation of 2 kg is output. For both cutting methods, the largest mobile contaminants were generated by cutting the reactor internals in the reactor building. Since underwater cutting is commonly used for reactor internals, focusing on the maximum mobile contaminants (core shroud) in underwater cutting indicated a similar level of mobile contaminants in the radwaste processing building (e.g., Condensate phase separator tank). This indicated the importance of assessing the contamination that could be released during an accident as mobile contaminants, rather than the risk of the decommissioning stage being determined by the initial radioactive inventory of the equipment.

As mentioned above, in this analysis, in addition to setting an upper limit to the amount of dust accumulated on the filters, spatial movement of filters that have reached the upper limit of dust accumulation (movement to a storage area) is not taken into account. Other possible mobile contaminants include combustible waste generated by wiping equipment with surface contamination and filters that remove nuclides in ionic state and dust that have migrated into the water resulting from underwater cutting. In the future, it is necessary to add the functions that can evaluate these contaminants in order to assess the temporal and spatial variation of the mobile contaminants inventory in more detail.

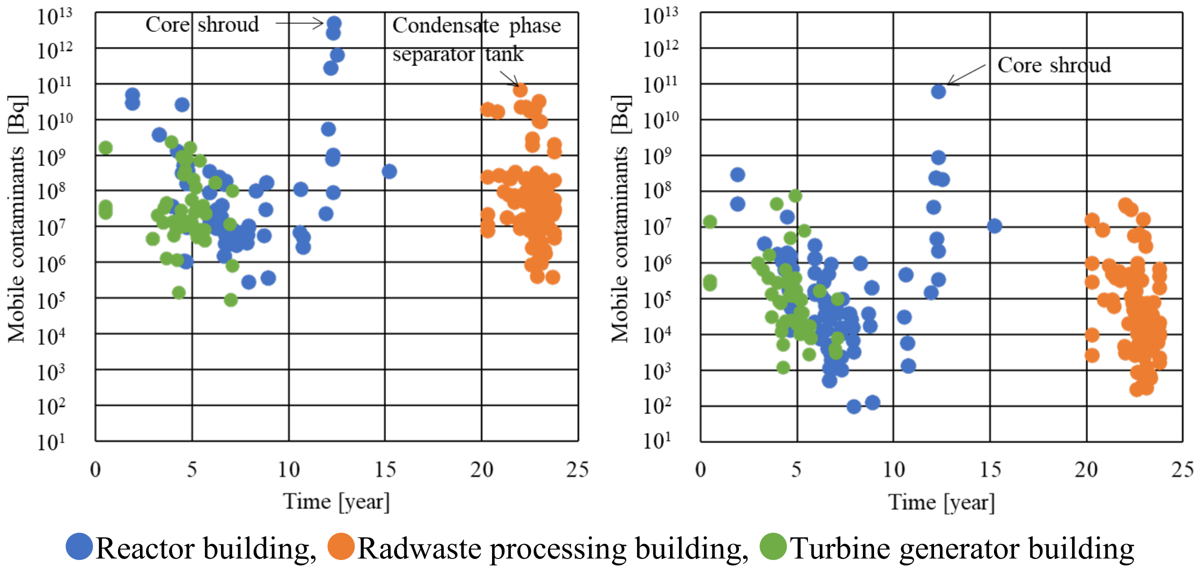

Figure 3: The mobile contaminants (left: in air, right: underwater)

4 CONCLUSION

In order to assess the risk of public exposure at nuclear power plants at the decommissioning stage, we have developed a method to evaluate the mobile contaminants (the amount of radioactive dust accumulated on the filter caused by cutting operations) that could be released in an accident.

The results of the evaluation of mobile contaminants by different cutting methods using the developed method suggest that the same level of mobile contaminants is generated in the dismantling of equipment using cutting in air in radwaste processing building compared to the mobile contaminants generated when core shroud (one of reactor internals) with high radioactivity is cut in underwater. This result indicate that the mobile contaminants are one of the important indicators that influence the selection of inspection targets in nuclear regulatory inspections.

In the future, a risk assessment method will be developed by combining the frequency of accident events and the evaluation of public exposure doses using the evaluation method of the mobile contaminants.

ACKNOWLEDGMENTS

This research was conducted as part of the "Study on Decommissioning Risk Assessment (2021)" entrusted by the Nuclear Regulation Authority of Japan (NRA).

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