AN EXPERIMENTAL STUDY ON A DETERGENT-FREE LAUNDRY SYSTEM: APPLICATION TO CLOTHES CONTAMINATED WITH RADIONUCLIDES

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ABSTRACT

A new detergent-free laundry system was applied to wash clothes contaminated with radionuclides at the Radioactive Waste Treatment Facility (RWTF) of KAERI. The clothes were contaminated with soils and radionuclides which were mostly Cs-134, Cs-137 and Co-60. The maximum contamination of the clothes was β, γ-activity of 9,600~9,800 Bq/m^2. After washing them by using the system, the contamination of the washed clothes decreased to around β, γ-activity of 1,200~2,300 Bq/m^2 which is less than the permissible contamination level (β, γ-activity of 4,000 Bq/m^2) for re-use. Soils were also clearly removed from the clothes. The laundry wastewater from the system didn't cause foaming and its COD value was very low unlike the conventional laundry waste containing detergent. Because foaming by the detergent has been the main cause of decreasing the decontamination efficiency of the laundry wastewater treatment by evaporation at RWTF, it is expected that this detergent-free system would fundamentally solve the problem of the laundry wastewater treatment.

INTRODUCTION

The Radioactive Waste Treatment Facility (RWTF) has the responsibility for washing the clothes contaminated with radionuclides from its own use and the other nuclear research buildings of KAERI. Most of the clothes are washed and re-used when the contamination level after washing is decreased to less than the permissible contamination level. The clothes contaminated with radionuclides have been washed by using tap water and detergent. This washing process produces radioactive wastewater containing radionuclides, detergent, and suspended solids. The amount of laundry wastewater is greater than that of the laundry itself (clothing to be washed). The laundry wastewater was designed to be decontaminated by evaporation at the RWTF. However, because the detergent in the wastewater causes problems (for example, foaming which reduces the decontamination efficiency of the processes), the treatment of laundry wastewater is an important issue to be resolved as soon as possible. [1]

In this study, a new laundry system to wash clothes without using detergent (detergent free) was applied to wash clothes contaminated with radionuclides at the RWTF of KAERI. If the clothes contaminated with radionuclides and soil are decontaminated and cleaned by washing without using detergent, the problem caused by the detergent could be solved naturally. The experiment was performed in two stages. In the first stage, washability of the processed water from the

system was investigated with regard to its decontamination efficiency for the radionuclides and the detergency for the soil by using the test cloth specimens. In the second stage, real working clothes contaminated with radionuclides from the RWTF were washed by using a laundry machine equipped with a detergent-free system. Decontamination and detergency of the clothes were estimated after washing and the wastewater was also analyzed for pH, COD and foaming.

EXPERIMENTS

Materials

Test Cloth Specimen

A standard cotton fabric [2] was used to prepare the test cloth specimen artificially contaminated with radionuclides. A test cloth measuring 7 cm in width and 15 cm in length was contaminated by liquid radioactive waste obtained from the RWTF. The main radionuclides of the liquid radioactive waste were Cs-137 and Co-60. After contamination, they were dried naturally in a room for 3 days and used in the experiment. A standard artificially soiled cloth specimen was purchased from the Washing Science Association (Japan) and used to evaluate the detergency effects of the tap water, three kinds of commercial detergents (anionic and nonionic) and the processed water from the detergent-free laundry system, respectively.

Clothes Contaminated with Radionuclides

Through surveying the surface contamination of the clothes from the radiation control area at the RWTF, the clothes with a surface contamination level higher than β, γ-activity of 4,000 Bq/m^2 were collected and used in the experiment.

Detergent-free Laundry System

The main part of this system is an electrolytic cell that consists of a cathode with a special coating of nickel, an anode of nickel, and a cation exchange membrane between the two electrodes. The schematic of this system is shown in Fig. 1.

The electrolyte (12 % sodium carbonate solution) is filled into the anode and tap water is continuously supplied to the cathode. When electricity of 5 volts and 25 amperes is applied to the electrodes, a part of the water is electrolyzed and the processed water containing the materials produced by electrolysis continuously flows out from the cathode. It is believed that this processed water contains some active materials which are effective when washing the laundry.

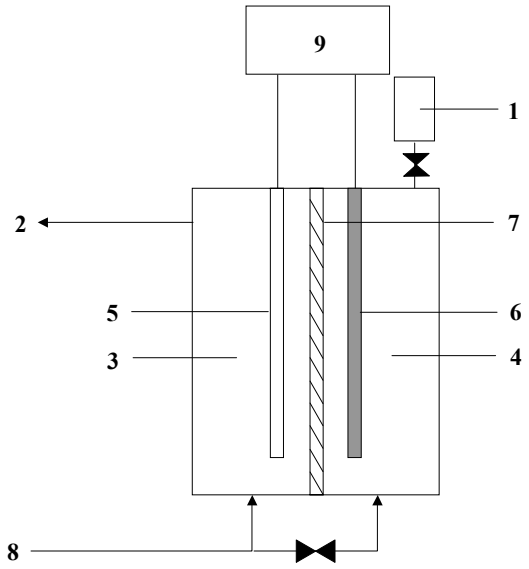


Fig. 1 Schematic of detergent-free laundry system

1 : Electrolyte Reservoir	2 : Processed Water Outlet
3 : Cathodic Flow Cell	4 : Anodic Flow Cell
5 : Cathode	6 : Anode
7 : Ion Exchange Membrane	8 : Tap Water Inlet
9 : Power Supply	

Reference Materials

The decontamination efficiency of the processed water from the detergent-free system for the radionuclides and the detergency for the soil were compared with those of some commercial detergents. An anionic detergent (A) and two nonionic detergents (D, F) were used as reference materials. One of the nonionic detergents (F) is known to have a 5% chelating agent.

Test Methods

Washing of the test cloth specimen

Washing of the test cloth specimens was performed by using a Terg-O-Tometer. Bath volume of the Terg-O-Tometer was 1 L and the bath ratio (weight of the bath to weight of the test cloths) was 100:1. The bath volume means the amount of aqueous solution to be used in the washing. Washing was operated for 10 minutes at 150 rpm and 25 ˚C. After washing, a sample of the aqueous solution was taken and analyzed for the concentration of the nuclides to determine the decontamination efficiency. Decontamination efficiency is expressed as follows:

$$\text{Decontamination Efficiency, \%} = \frac{\text{Activity (Amount) of Nuclide in the Bath}}{\text{Activity (Amount) of Nuclide in the Test Cloth}} \times 100$$

Detergency for the soil was determined by measuring the reflectance of the washed test cloths before and after removing the test cloths from the bath, drying and ironing them. Detergency for the soil is expressed as follows:

$$\text{Detergency, \%} = \frac{R_f - R_i}{R_o - R_i} \times 100$$

Where R_f is the reflectance of the soiled cloth after washing, R_o is the reflectance of the unsoiled cloth and R_i is the initial reflectance of the soiled cloth prior to washing.

Washing of the clothes from the RWTF

The clothes contaminated with radionuclides were washed by using an electric laundry machine equipped with a detergent-free laundry system. The washing operation was performed as follows.

1^{st} Washing → 1^{st} Wastewater Discharge → 2^{nd} Washing (Rinsing) →
2^{nd} Wastewater Discharge → Dewatering

The contamination of the clothes was measured by using β, γ-activity survey meter before and after washing. Detergency for the soil was visually evaluated by the laundry inspector because there is no appropriate method for this purpose.

The first and the second wastewater were collected after washing and analyzed for pH, Na^+ ion concentration, COD and foaming respectively.

RESULTS AND DISCUSSION

Washing for Test Cloth Specimen

The decontamination of the radionuclides on the test cloth was carried out by washing with tap water containing no additives, the processed water from the detergent free system, the aqueous solutions containing 0.13 wt% of the commercial anionic detergent (A) and nonionics (D, F) respectively. The results are shown in Fig. 2. For all the solutions, even in tap water, the decontamination efficiencies were more than 90 %. From these results, it is confirmed that the radionuclides on the test cloth can be decontaminated by washing without detergent. The processed water from the detergent-free system also has an ability to remove the radionuclides on the clothing as well as those of the tap water and the other solutions.

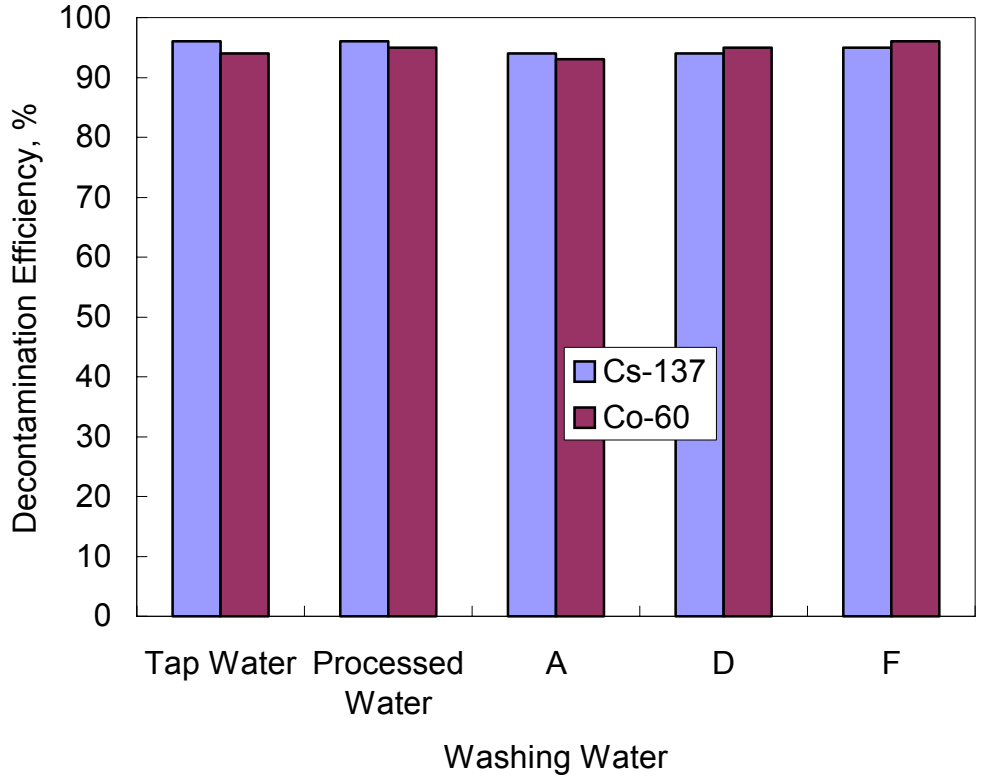


Fig. 2 Decontamination of the radionuclides by washing

Detergency on Soil

The clothes from nuclear facilities are also contaminated with soil in addition to radionuclides. Accordingly, the soil has also to be removed when washing. The detergencies for the soil were measured by washing with the tap water, the processed water from the detergent-free system, and the aqueous solutions containing 0.13 wt% of commercial anionic detergent (A) and nonionics (D, F), respectively. The results are shown in Fig. 3. The detergency of the tap water was obviously lower than those of the other solutions. It should be noted that the detergency of the processed water from the detergent-free system is similar to or better than those of the solutions containing the detergent. It is found that the processed water from the detergent-free system has an ability to simultaneously remove the radionuclides and soil from the cloth with a good efficiency.

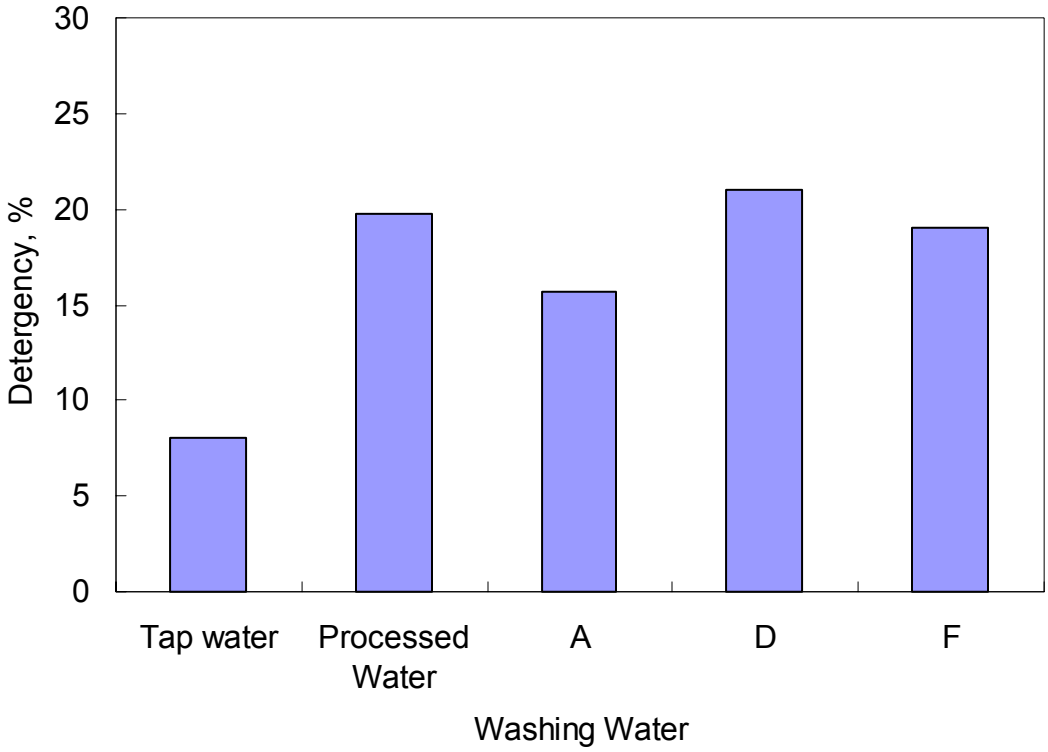


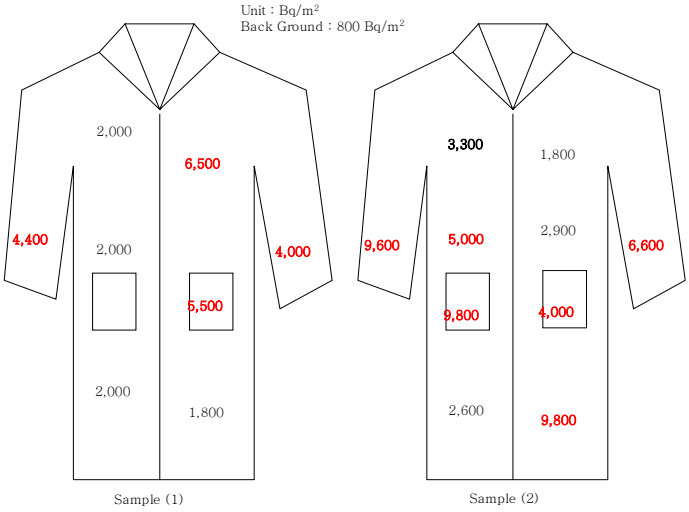
Fig. 3 Detergencies for the soil with various washing solutions

Washing for the Clothes from the RWTF

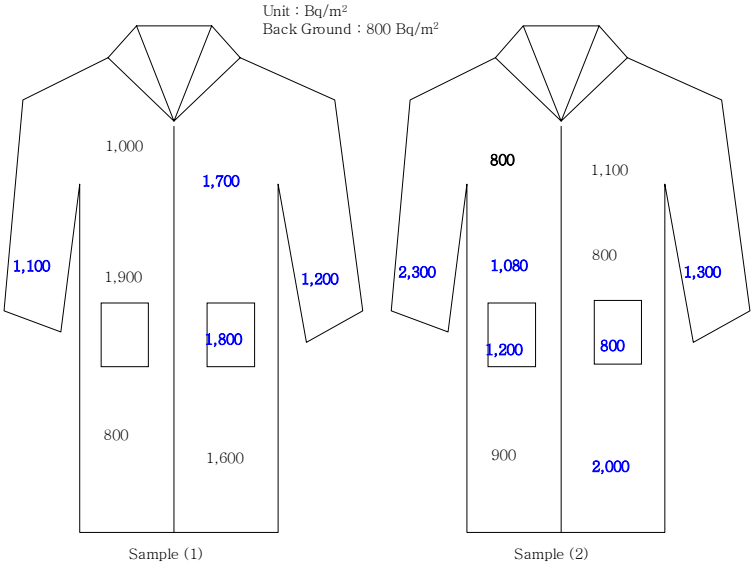
According to the radiation management procedure of KAERI, the clothes which have a contamination level higher than β, γ-activity of 4,000 Bq/m^2 have to be decontaminated for re-use by washing. If their contamination level is still higher than β, γ-activity of 4,000 Bq/m^2, they cannot be re-used and should be discarded.

Two samples among the clothes used in this experiment are shown in Fig 4-(a). The samples were partially contaminated to be higher than β, γ-activity of 4,000 Bq/m^2 before washing. Therefore, they had to be decontaminated below β, γ-activity of 4,000 Bq/m^2 for re-use. The result after washing by using the detergent-free laundry system is shown in Fig. 4-(b). The clothes have no area contaminated higher than β, γ-activity of 4,000 Bq/m^2. In particular, in the case of sample (2), the parts with β, γ-activity of 9,600~9,800 Bq/m^2 were decontaminated to β, γ-activity of 1,200 Bq/m^2 ~ 2,300 Bq/m^2. These values are slightly higher than that of the background (800 Bq/m^2) but are as low as a half of the permissible contamination level for re-use.

The laundry inspectors estimated the detergency for the soil of the clothes through visual inspection and experience. They confirmed that the clothes were clean enough for re-use.



(a) Before Washing



(b) After Washing

Fig. 4 Examples of the surface contamination of the clothes from the RWTF

Laundry Wastewater after Washing

pH

The pH of the 1st wastewater by using the detergent-free system was around 10.7 and that of the 2nd wastewater was in the range of a pH of 8~9. Because the 1st wastewater and 2nd wastewater are actually collected in the same waste storage vessel at the RWTF, the pH of the laundry

wastewater from a washing operation averaged in the range of 9~10. The treatment of the wastewater by evaporation at the RWTF is not affected at this range of pH .

COD (chemical oxygen demand)

The wastewater is treated by evaporation at the RWTF. The concentrate is finally solidified by bitumen. Organic materials contained in the concentrate degrade the quality of the final bitumen waste form since they can be easily decomposed. And the concentration of the organic materials in the wastewater should be controlled to be as low as possible. The COD of the wastewater can be used as an indicator for the concentration of the organic materials in the wastewater. As the wastewater has a higher COD value, it contains a higher concentration of the organic materials.

The COD of the 1st wastewater by using the detergent-free system was 50~150 mg/L. Since the COD of the processed water from the detergent-free system was low, in the range of 1~4 mg/L, the COD of the 1st wastewater depended on the organic materials(soil) removed from the working clothes. This means that much of the soil on the clothes was removed by the processed water from the detergent-free system. The 2nd wastewater was rinsing water so the COD was as low as 15~20 mg/L. The COD of the actual wastewater collected in the wastewater storage vessel averaged in the range of 30~80 mg/L.

On the other hand, when washing by using the commercial detergents (A, D, F), the COD values of the wastewater were very high in the range of 450~910 mg/L.

Foaming

Foaming is the most important factor when treating the laundry wastewater by evaporation because it causes entrainment and reduces the decontamination efficiency of the evaporation.

To observe the foaming of the laundry wastewater, the height of the foam was measured after shaking a mess cylinder containing laundry wastewater. The results of the foaming test are listed in Table I. The foaming of the laundry wastewater from the detergent-free system was insignificant when compared with those of the laundry wastewaters containing detergent. And the foam of the laundry wastewater from the detergent-free system disappeared rapidly when left to stand while those of the laundry wastewater containing detergent remained for a long time.

Table I. Foaming of the Laundry Wastewater

Wastewater	Height of Foam, cm	
	After 1 sec.	After 10 sec.
Tap Water	(0)	0
Processed water from Detergent-free System	(0)	0
1st Wastewater from Detergent-free System	1.1	0.3
2nd Wastewater from Detergent-free System	(0)	0
Wastewater Containing Detergent A (0.1 wt%)	12.2	10.5
Wastewater Containing Detergent A (0.1 wt%)	10.5	8.7
Wastewater Containing Detergent A (0.1 wt%)	10.5	9.2

SUMMARY

An experimental study was performed in two stages to estimate whether or not, a new detergent-free laundry system could be applied to wash the clothes contaminated with radionuclides from the RWTF. In the first stage of the experiment, by using the processed water from the detergent-free laundry system and the artificially contaminated test specimens, the results indicated that the processed water from the detergent-free laundry system has an ability to simultaneously remove the radionuclides and soil from the cloth. In the second stage of the experiment, real clothes contaminated with radionuclides and soil from the RWTF were washed using an electric laundry machine equipped with the detergent-free laundry system. The maximum contamination of the clothes was β, γ-activity of 9,600~9,800 Bq/m^2. After washing by using the system, the contamination of the washed clothes decreased to around β, γ-activity of 1,200~2,300 Bq/m^2 which is less than the permissible contamination level (β, γ-activity of 4,000 Bq/m^2) for re-use. Soils were also clearly removed from clothes. Therefore, it confirms that the clothes contaminated with radionuclides and soils could be decontaminated and cleaned using the present system without using detergent. The laundry wastewater from the system didn't cause foaming and its COD value was very low unlike the laundry waste containing detergent. Because foaming by detergent has been the main cause of decreasing the decontamination efficiency of the laundry waste treatment by evaporation at the RWTF, the use of the detergent-free laundry system would fundamentally solve the problem of the laundry wastewater treatment. Consequently, based on the results, it is concluded that the application of the detergent-free laundry system to the washing at the RWTF would be successful in the washing of the clothes and the wastewater treatment.

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