Subdrain Water Treatment Facility for Reduction of Accumulated Waste Water Amount at the Fukushima NPS Site – 17572

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ABSTRACT
At the Fukushima Daiichi Nuclear Power Station site, water treatment facility special for subdrain and groundwater drain has been constructed by Tokyo Electric Power Company Holdings, Inc. and Hitachi-GE Nuclear Energy, Ltd., and it has been operated to remove radionuclides from the pumped groundwater. The facility consists of three kinds of equipment for collecting, purifying and transferring. The purification equipment removes radionuclides contained in the pumped groundwater. The purification equipment consists of filters for removal of solids and colloidal particles, and adsorbents for removal of ionic radionuclides. Five adsorption vessels are installed into the equipment; three vessels have adsorbent to remove Cs and Sr simultaneously, the fourth vessel has adsorbent to remove Sb and for the last has adsorbent to remove heavy metals. The vessels for Cs and Sr are operating as a so-called “merry-go-round”. For the rational operation of the equipment, a simulation code has been developed to calculate the Sr concentration of outlet water which determines the replacement timings of the Cs-Sr adsorption vessels. The simulation code has been applied to planning of vessel replacement during the water treatment facility operation. The facility started operation in September 2015, and treated the pumped groundwater since then. As of October 2016, about 211,000 m^3 of groundwater had been treated.

INTRODUCTION
The amount of accumulated waste water has been increasing due to groundwater inflow and cooling water injection into the reactor buildings at the Fukushima Daiichi Nuclear Power Station (NPS). One of the countermeasures to reduce the accumulated water amount is use of a subdrain (Fig. 1). The subdrain is a well installed around the reactor and turbine buildings of the NPS which pumps out the groundwater, thus controlling the groundwater inflow into those buildings.

The groundwater includes low concentrations of radionuclides such as Cs-137 and Sr-90 due to contamination by radionuclides released into the environment right after the accident. The groundwater is also pumped up from the groundwater drain installed near the sea-side impermeable wall to prevent the inflow of slightly contaminated groundwater into the ocean. Water treatment facility special for subdrain and groundwater drain has been constructed by Tokyo Electric Power Company Holdings, Inc. and Hitachi-GE Nuclear Energy, Ltd., and it has been operated to remove radionuclides from the pumped groundwater. The treated water is released into the ocean after confirmation that the radionuclide concentrations

are lower than the upper limits, which is a stricter limit than that set by environmental standards.

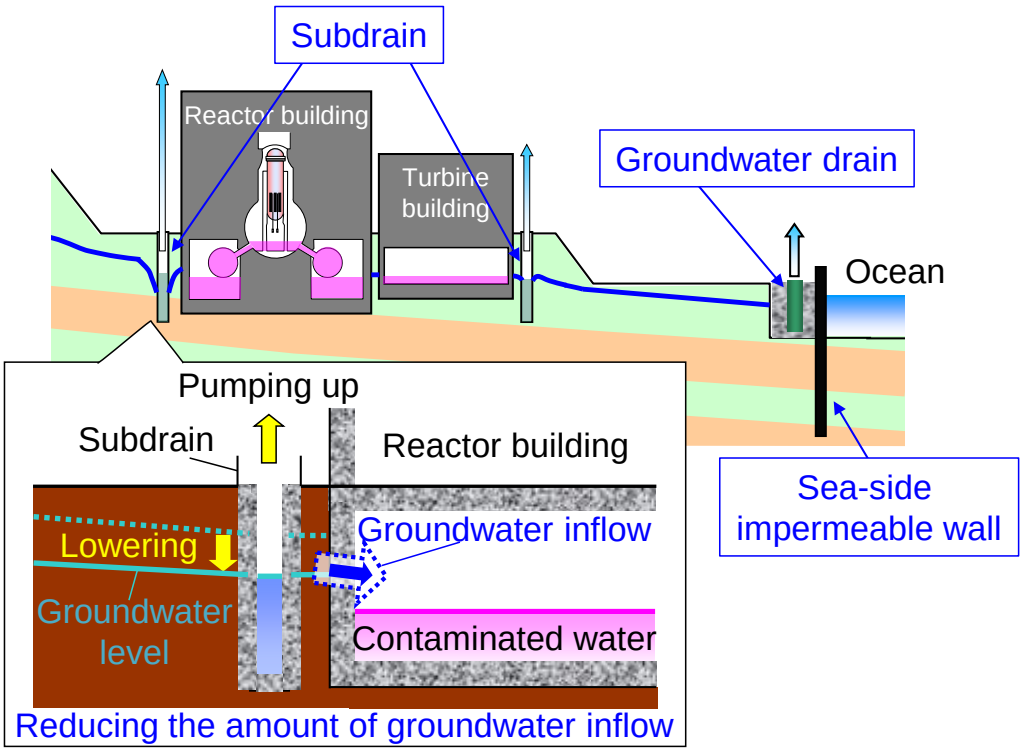

Fig. 1. Scheme of the subdrain and groundwater drain[1].

This paper describes the features of the facility, including its structure, capacity, operating procedures, and recent operation results, and it also describes a simulation code developed for replacement cycle planning for the adsorption vessels used to remove the radionuclides.

OUTLINE OF WATER TREATMENT FACILITY

The pumped groundwater includes dissolved radionuclides, dissolved component ions of seawater, and various solids from the soil and structural materials. The radionuclide concentrations of the pumped groundwater have been reported as about 100 Bq/L for both Cs-137 and Sr-90[2]. The upper concentration limits of Cs-137 and Sr-90 in the outlet treated water for the facility are less than 1 Bq/L for each[1].

As shown in Fig. 2, the facility consists of three kinds of equipment [1] for collecting, purifying and transferring. The collecting equipment pumps up groundwater from each subdrain and groundwater drain to collect groundwater into the water collecting tanks. The purification equipment removes the radionuclides contained in the pumped groundwater. The transfer equipment transfers the treated water to the sampling tanks, and after confirmation that the radionuclide concentrations in the treated water satisfy the upper limits, discharges the water to the ocean.

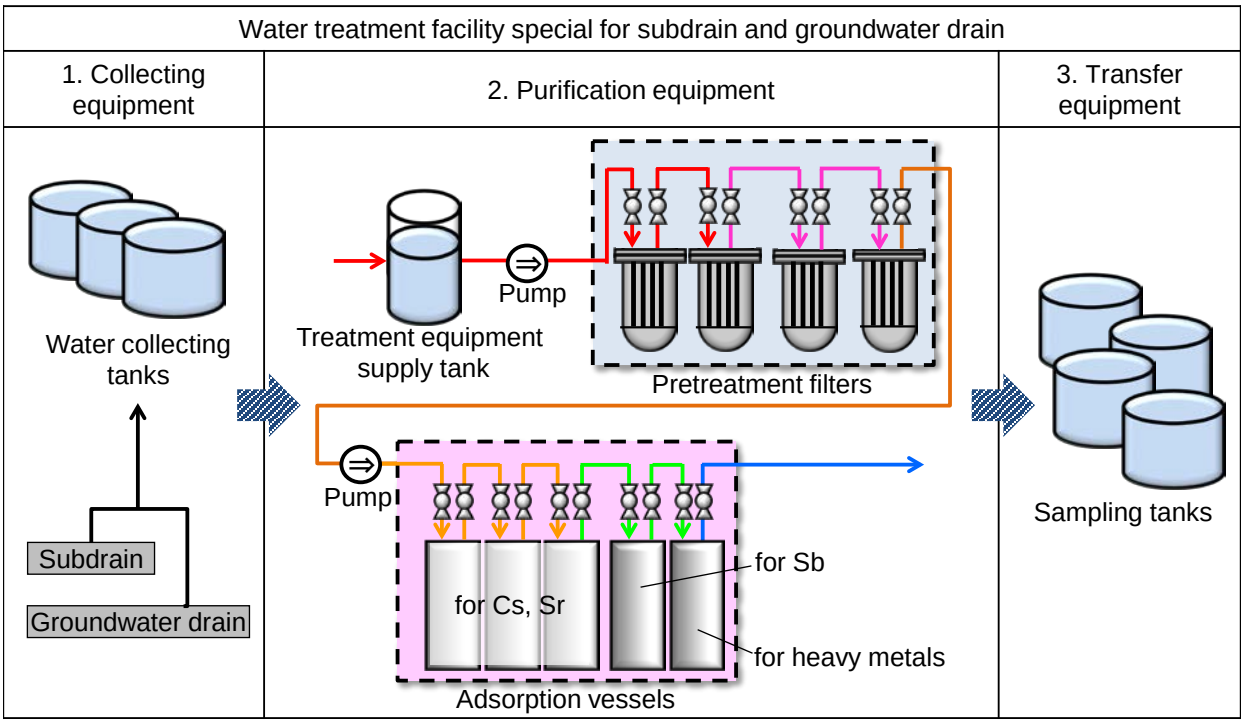

Fig. 2. Outline of the water treatment facility special for subdrain and groundwater drain[1].

The purification equipment consists of filters for removal of solids and colloidal particles, and of adsorbents for removal of dissolved ionic radionuclides, with the treatment capacity of 1,200 m^3/day[1].

Four filter vessels are installed into the equipment; two vessels with different filter diameters for suspended solids and two vessels to roughly remove Cs and Sr. When the differential pressure of the filter vessel exceeds the defined value, the vessel is replaced with a new one.

Five adsorption vessels are installed into the equipment; three vessels with the adsorbent for simultaneously removing Cs and Sr[3], one vessel for removing Sb and one for removing heavy metals. The vessels for Cs and Sr are operated as a so-called “merry-go-round” to utilize the adsorption capacity more efficiently. During the operation, the Sr concentration in the outlet water of the first or second vessel is monitored. When the Sr concentration in the outlet of the first or second vessel exceeds the defined value, the first vessel is removed and the remaining two vessels are moved to the front. One new vessel with fresh adsorbent is installed at the end of the train.

SIMULATION CODE

The adsorbent has a higher adsorption capacity for Cs than Sr[3]. Sr-90 breaks through the adsorption vessels faster than Cs-134 and Cs-137. The replacement timings of the Cs-Sr adsorption vessels are determined by the Sr-90 concentrations in the outlets of the vessels. For the rational operation of the equipment, a simulation code has been developed to calculate the Sr-90 concentration of outlet

water for each vessel. A model of Sr behavior in the adsorption vessels for the simulation is shown in Fig. 3. This model is based on the advection-diffusion equation [4] with consideration of the adsorption reaction of and hydrological dispersion [5]. Sr in the adsorption vessels moves according to the advection of the groundwater flowing through the vessels. While the groundwater passes through the adsorption vessels, the Sr adsorption into the simultaneous Cs-Sr adsorbent results in a decreased Sr concentration in the liquid phase. The diffusion of Sr and hydrological dispersion leads to a broadening of the Sr concentration distribution. The Sr concentration of the outlet water in this model is decided by the advection, adsorption, diffusion and hydrological dispersion.

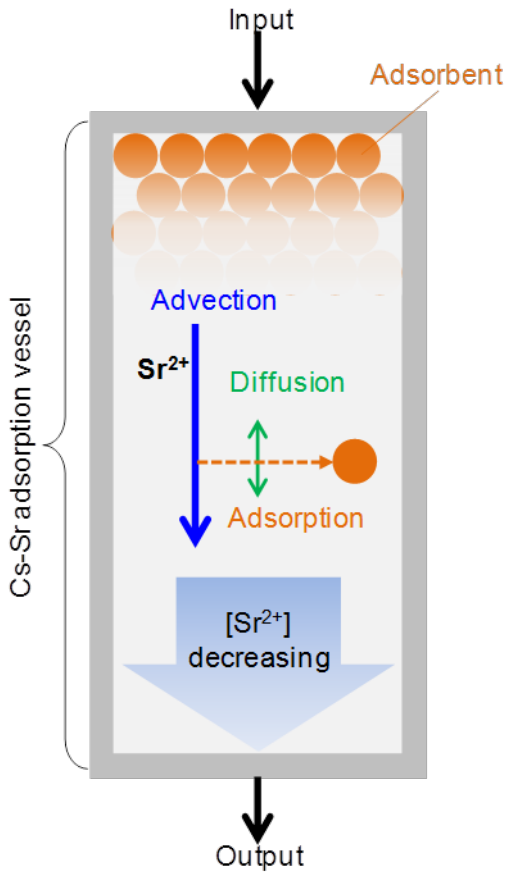

Fig. 3. Model of Sr behavior in the adsorption vessels for the simulation

The model is expressed as Eq. 1 which is a modified equation based on the advection-diffusion equation[4].

$$\frac{\partial c}{\partial t}+\left(\frac{u_0}{\varepsilon}\right)\frac{\partial c}{\partial x}=\left(D+\frac{u_0\lambda}{\varepsilon}\right)\frac{\partial^2 c}{\partial x^2}-\left(\frac{1-\varepsilon}{\varepsilon}\right)\frac{\partial c_p}{\partial t} \qquad \text{(Eq. 1)}$$

Here c is the Sr concentration in the liquid phase (mg/L), t is time (s), u_0 is the linear velocity (m/s), ε is the void fraction in the packed bed of the adsorbent (-), x is the position along the column length (m), D is the diffusion constant of Sr in water (m^2/s), λ is the length of hydrological dispersion (m)[5], and c_p is the

average Sr concentration in the adsorbent (mg/kg). The left side of Eq. 1 shows the advection, and the first and second terms on the right side show the diffusion and adsorption reaction, respectively.

The adsorption reaction of Sr in Eq. 1 is calculated by Eq. 2[6] in which it is defined as a function of the Sr concentration with the mass transfer coefficient and the distribution coefficient.

$$\frac{\partial c_p}{\partial t} = a_p\left(K_d c - c_p\right) \qquad \text{(Eq. 2)}$$

Here a_p is the mass transfer coefficient (m^2/s), K_d is the distribution coefficient (L of solution treated / kg of media) expressed in Eq. 3.

$$K_d = [Sr]_{Ad} / [Sr]_{Lq} \qquad \text{(Eq. 3)}$$

Here $[Sr]_{Ad}$ is the equilibrium concentration of Sr in the adsorbent (mg/kg) and $[Sr]_{Lq}$ is the equilibrium concentration of Sr in the liquid phase (mg/L).

RESULTS

Fig. 4 shows some operation data of the water treatment facility and simulation results. The timings of vessel replacement in merry-go-round operation are shown as vertical dotted lines. The Sr-90 concentrations in the outlets of the second and third Cs-Sr adsorption vessels are below the detection limit (1 Bq/L) during this period, and are not shown in Fig. 4.

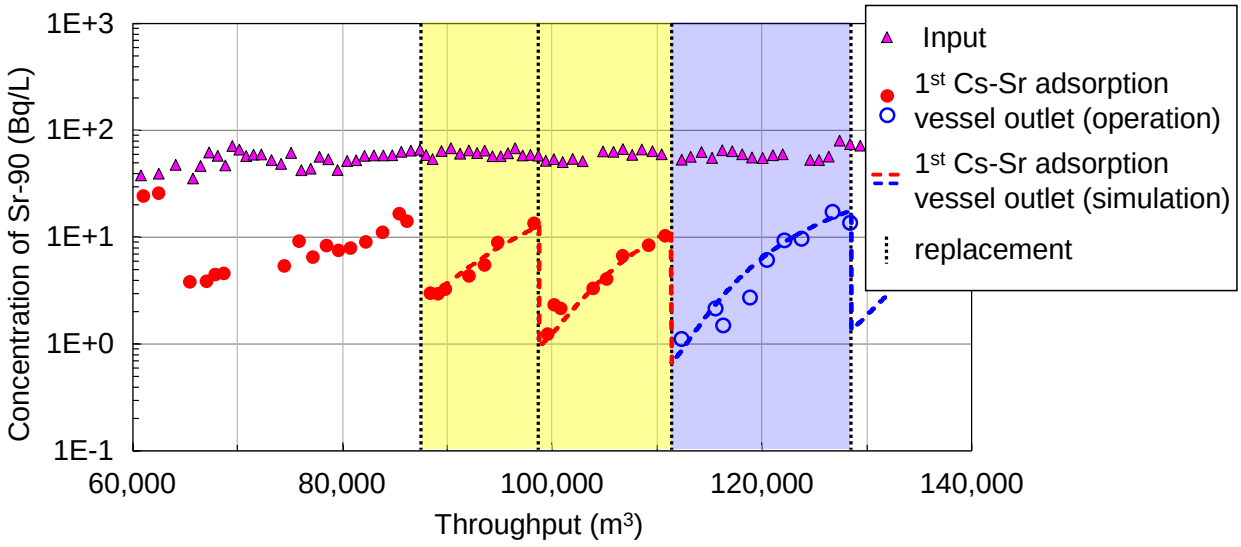

Fig. 4. Comparison of the operation data and the simulation results of the water treatment facility.

During the operation period shown in Fig. 4, the Sr-90 concentration in the inlet of the facility was maintained between 60 and 80Bq/L after about 88,000 m^3 had been treated. The Sr-90 concentration in the outlet of first Cs-Sr adsorption vessel was increased from 1 to 20 Bq/L, however that in the outlets of the second and third Cs-Sr adsorption vessels were below 1 Bq/L. Purification performance of the facility satisfied the regulation. The facility started operation in September 2015, and has continued to treat the pumped groundwater. As of October 2016, about 211,000 m^3 of groundwater had been treated to remove radionuclides for the upper concentration limit (1 Bq/L for Cs and Sr each)[7] and the treated water was discharged to the ocean.

The results of the operation and simulation have been compared since about 88,000 m^3 when all the adsorbents for Cs and Sr were made same kinds as currently used. In the simulation, the values of λ and a_p were determined by the results of laboratory tests[8]. The value of K_d was temporarily determined by the results of laboratory tests[8], and adjusted to match the measured Sr concentrations in the outlet of the first Cs-Sr adsorption vessel between about 88,000 m^3 and about 116,000 m^3 shown as solid red circles. The Sr-90 concentration in the outlet of the first Cs-Sr adsorption vessel calculated using the adjusted K_d value is shown as the broken red line. After about 116,000 m^3 had been treated, Sr concentrations in the outlet were predicted using the adjusted K_d value with the assumption that operating conditions were constant. The predicted Sr concentration is shown as the broken blue line. After that, operation data were updated as open blue circles and compared with the predicted Sr concentration. The predicted Sr concentration agreed well (the coefficient of determination (R^2) > 80%) with the operation data.

The simulation code has been applied to plan replacement of the vessels during operation of the water treatment facility.

SUMMARY

The water treatment facility special for subdrain and groundwater drain has treated the groundwater to reduce the accumulated waste water amount and to prevent the inflow of groundwater into the ocean. The simulation code has been developed to predict the Sr concentration of outlet water which determines the replacement timings of the Cs-Sr adsorption vessels. The main points of this paper are summarized below.

1. The facility started operation in September 2015, and it has continued to treat the pumped groundwater. As of October 2016, about 211,000 m^3 of groundwater had been treated to remove radionuclides to below the upper concentration limit and the treated water was discharged to the ocean.

2. The Sr concentration predicted by the simulation code agreed well with the operation data. The simulation code has been applied to plan replacement of the vessels during operation of the water treatment facility.

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