RO concentrated water treatment equipment for risk reduction of contaminated water stored in tank in Fukushima NPS – 16655

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ABSTRACT
At the Fukushima Daiichi Nuclear Power Station (NPS) site, concentrated waste water was stored in tanks, awaiting treatment to remove radionuclides using various multi-nuclide removal systems. To accelerate the treatment for risk reductions of radiation dose and tank leakage, we constructed reverse-osmosis (RO) concentrated water treatment equipment. The equipment consists of filters and five adsorbent vessels containing Cs-Sr simultaneous adsorbents with the removal ability of Sr being 1/1000(max) to 1/100(min), and the overall treatment capacity of 500 to 900 m^3/day. We developed a simulation code to calculate the Sr concentration of outlet water for each vessel in order to evaluate the bed life of the media. The simulation code makes it possible to plan when to change media in the vessels during the equipment operation. The successful treatment of concentrated waste water was conducted using the equipment from January to May 2015. Total amount of water treated was 82,194m^3.

INTRODUCTION
At the Fukushima Daiichi NPS, accumulated waste water in the reactor buildings and the turbine buildings has been treated by the adsorption removal of cesium (Cs) and RO desalination to allow water re-use for cooling the reactors. The RO concentrated water that contains strontium (Sr) with the concentration of 10^4 to 10^5 Bq/cm^3 and other nuclides including residual Cs has been stored in many tanks. To remove radionuclides from the stored water, three multi-nuclide removal systems have been installed at the Fukushima site [1].

To accelerate the removal of radionuclides from the stored RO concentrated waste water to reduce risks of radiation dose and tank leakage, Tokyo Electric Power Company (TEPCO) commenced removing Sr from the stored waste water with the following equipment: a Cs absorbing device (KURION), a second Cs absorbing device (SARRY), mobile-type Sr removal equipment, and RO concentrated water treatment equipment [2]. Fig. 1 provides a summary of them. Their Sr removal ability varied, being 1/1000 (max) to 1/10(min), and all contributed to completion of the treatment of stored water (except residual water in the bottom of the storage tanks) that TEPCO announced on May 27, 2015 [3].

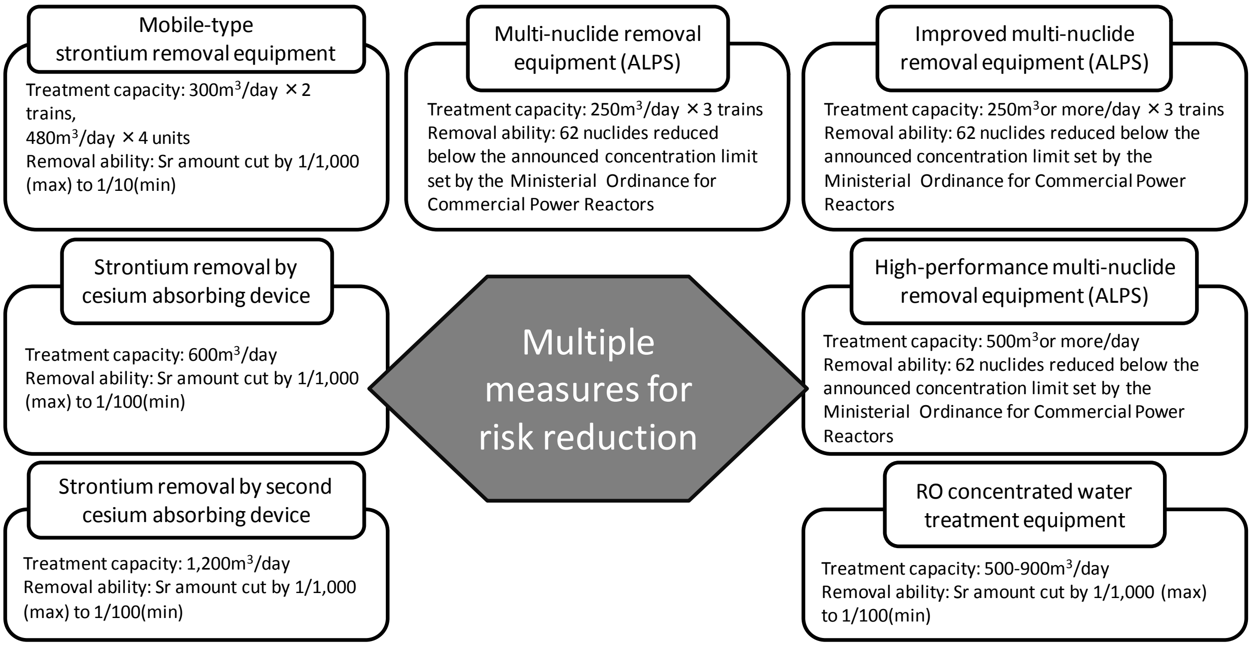

Fig. 1. Radionuclide removal equipment introduced at the Fukushima NPS [2].

Hitachi-GE Nuclear Energy constructed the RO concentrated water treatment equipment for Sr removal from the RO concentrated water stored in the tanks. Operation of the equipment for about 5 months resulted in treatment of about 82,000m^3 water with the Sr concentration being reduced by as little as 1/1000 to as much as 1/100. In this paper, we summarize the features of the equipment including the structure, capacity and operating procedures. A simulation code developed to evaluate the media life of the adsorbent is also shown.

METHODS

Outline of the RO concentrated water treatment equipment

Fig. 2 shows the schematic of the RO concentrated water treatment equipment. The equipment consisted of two main units, the pretreatment unit and the radionuclide adsorption unit, with the supply tank connected to the storage tanks of the RO concentrated waste water. The pretreatment unit includes vessels with filters to remove solid materials such as suspended solids and colloidal species. The radionuclide adsorption unit has five vessels containing Cs-Sr simultaneous adsorbent [4]. The radionuclide adsorption unit was operated with three to five vessels aligned depending on the concentration of Sr in the feed water and the operation history. A detailed description of the operation procedure for the adsorption unit is provided later. RO concentrated waste water from the storage tank was brought to the supply tank and then fed to the pretreatment unit and the radionuclide adsorption unit to remove Cs and Sr. Treated water with the Sr concentration reduced by 1/1000 (min) to 1/100 (max) was sent to the Sr treated water storage tanks. The treatment capacity of the equipment was 500 to 900 m^3/day.

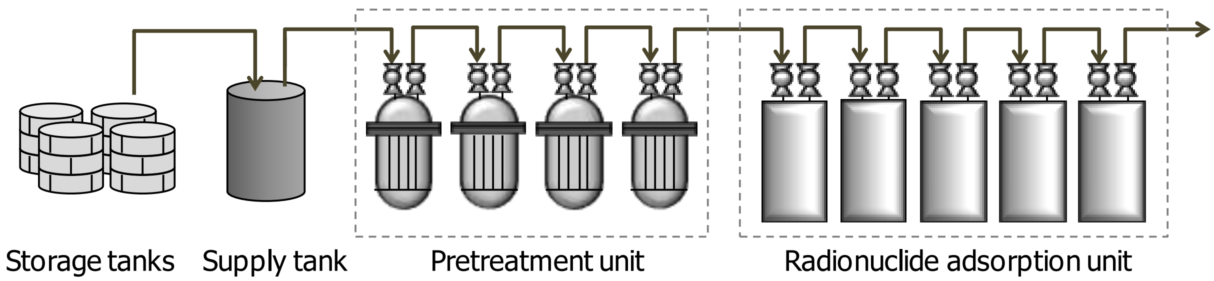

Fig. 2. Schematic drawing of the RO concentrated water treatment equipment.

Operation procedure

In the operation of the equipment, the filter vessels in the pretreatment unit were used in rotation: the feed water passed through a vessel until the differential pressure exceeded the defined value, and then the first vessel was isolated and the second one was aligned for operation. During the second vessel operation period, the spent filters in the first vessel were removed and new ones were installed to make that vessel ready for use.

For the radionuclide adsorption unit, three vessels were used to treat the feed water while the remaining two vessels were on standby at the beginning of operation. The Sr concentration in the outlet water of the third vessel was monitored, and when the Sr concentration of the outlet exceeded the specified value the fourth vessel was put into operation. The same was repeated for the fifth vessel. This operation procedure enabled us to use up the adsorption capacity of the adsorbent in the first and second vessels, and prevent the capacity of the adsorbent in the fourth and fifth vessels from unnecessary water flow and the degradation of the adsorbent.

When the Sr concentration in the outlet of the fifth vessel exceeded the defined value, three vessels from the front were removed and the remaining two vessels were moved to the front. Three new vessels with fresh adsorbent were installed at the end of the train, and then the three vessels from the front (two used vessels and one new) were used to treat the feed water.

Simulation code

In order to determine the timing of switching the operation and exchanging the vessels, a simulation code was made to calculate the Sr concentration of outlet water for each adsorbent vessel in the radionuclide adsorption unit. Fig.3 shows the adsorption model in the adsorbent vessel used for the simulation. The adsorbent used in the RO concentrated water treatment equipment adsorbs Sr by the exchange reaction with Na ion. On the other hand, the adsorbent also adsorbs Ca and Mg in competition with the adsorption of Sr. In the simulation code we took into account the adsorbed concentration of each element as the function of time in the advection-diffusion equation (Eq.1).

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

Here u_0 is the linear velocity, c is the concentration of an element in the liquid phase, cp is the average concentration of an element in the adsorbent, ε is the void fraction in the packed bed of the adsorbent, and λ is the mean free path. In Eq.1, the second term on the right side shows the adsorption reaction. In the simulation code we calculated the exchange reaction of Sr and Na in the adsorbent using the relationship that the reaction rate is proportional to the distribution coefficient Kd. The Kd value is determined by fitting of the data obtained in the early stage operation of the RO concentrated water treatment equipment. In addition, the Kd of Sr adsorption is assumed to have an inverse relationship with Ca concentration in the liquid phase within the water conditions of the RO concentrated water. We took into account the above relationship of Kd to calculate Sr concentration in the outlet when the concentration of the element in the feed water was altered.

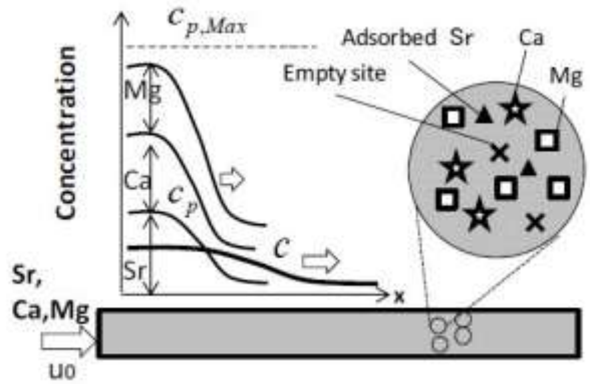

Fig. 3. Adsorption model used in the simulation code.

RESULTS

Fig.4 shows part of the operation data of the RO concentrated water treatment equipment with the results of the simulation. The observed data of Sr-90 concentration in the outlet are shown as symbols and calculated results are shown as lines. The labels "Vessel change" mark the times when three vessels from the front were removed and three new vessels were added to the end of the train as described above. At the points "A" and "B", the Sr-90 concentration of the third and fourth vessels exceeded the defined value and the fourth and fifth vessels were placed in operation, respectively.

At the early stage of operation after the exchange of the towers and the addition of the fourth and fifth vessels, the Sr-90 concentration of the last vessel was about 2×10^1 Bq/cm^3.That means the decontamination factor (DF) of Sr-90 in the equipment was around 10^3. Since the outlet Sr-90 concentration was the same as the defined value, the DF at the outlet was about 10^2. The equipment showed the ability to reduce the Sr-90 concentration of the treated water to the extent of 1/1000 to 1/100.

As shown in Fig.4, the calculated results using the simulation code we developed agreed well with the operation data. Using the simulation code we were able to plan when to switch the vessels during the system operation.

The operation of the RO concentrated water treatment equipment was started in January 2015, and the waste water treatment was successfully conducted for five

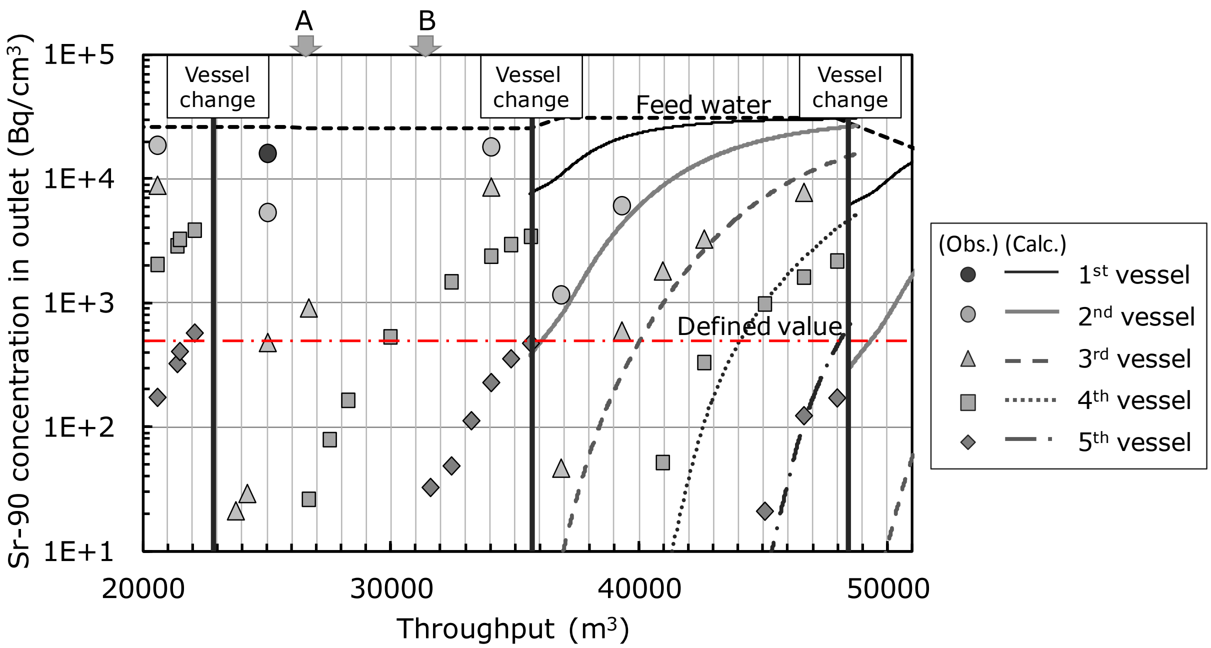

Fig. 4. Sr-90 concentration at the outlet of each adsorbent vessel during the operation of the RO concentrated water treatment equipment. (Symbols: observed data, lines: calculated results)

months. The equipment treated 82,194m^3 of waste water in total[5], thus contributing significantly to completion of the stored water treatment at the Fukushima Daiichi NPS.

CONCLUSIONS

The RO concentrated water treatment equipment, consisting of the pretreatment unit with filters and the radionuclide adsorption unit with Cs-Sr simultaneous adsorbent, was introduced into the Fukushima Daiichi NPS to treat the stored RO concentrated waste water. The equipment showed the ability to reduce Sr-90 concentration of the treated water by a little as 1/1000 to as much 1/100. The results obtained by the developed simulation code for the Sr-90 concentration in the outlet water of each vessel were in good agreement with the results measured for the actual equipment performance, and enabled us to plan when to switch the vessels to be used in the operation. The equipment started operation in January 2015, and the waste water treatment was successfully conducted for five months. The equipment treated 82,194m^3 of waste water in total which contributed to the complete treatment of stored water at the Fukushima Daiichi NPS.

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