Future Treatment System of Radioactive Wastewater in Fukushima using Indigenous Algae
-- For Protecting our Oceans from the Pollution --

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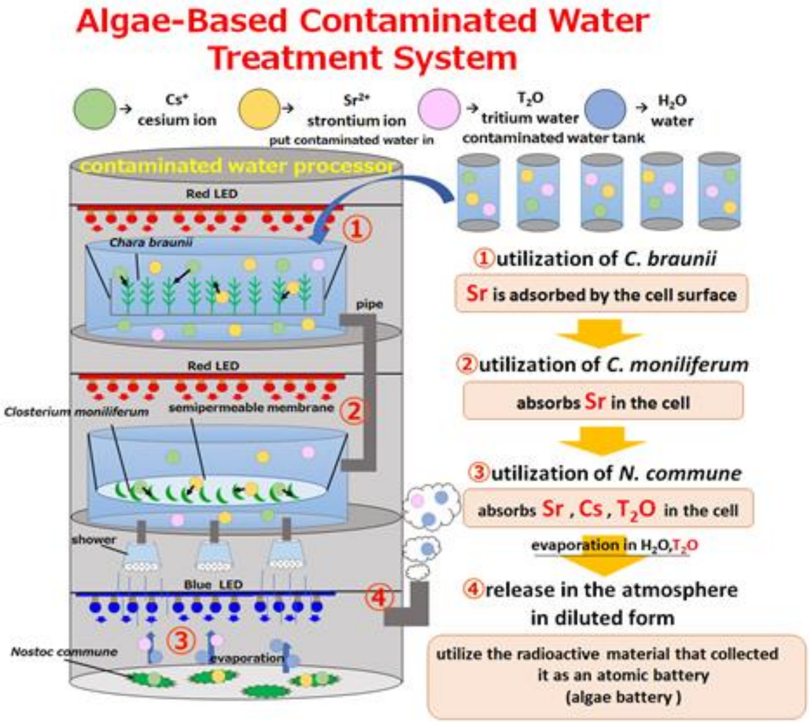
Abstract

The accident at the Fukushima Daiichi nuclear power plant 10 years ago still caused evacuation of 36 thousand people and generated a large amount of radioactively contaminated water that possibly cause adverse impact on marine ecosystem. My seniors conducted a survey of microorganisms in the vicinity of my high school, and found a green alga *Closterium moniliferum,* submerged plant, *Chara brunii,* and a cyanobacterium *Nostoc commune*. I took over the research from the predecessors and have attempted to develop a treatment system using these indigenous plants for the treatment of radioactively contaminated water, with the final goal of proposing a novel alternative to a current approach: discharge of treated water into the ocean. To achieve the final goal, the objectives of this study, I investigate the influence of irradiation time and the amount of *N. commune* on the evaporation of water. the water evaporation was found to be enhanced by the presence of *N. commune* and continuous irradiation of blue LED. Based on these research results, we propose a polluted water treatment system combining these three aquatic plants.



1. Background and motivation

It has been 10 years since the tsunami caused by Great East Japan Earthquake hit Fukushima Daiichi Nuclear Plant to cause the disaster including nuclear meltdowns and three hydrogen explosions. About 140 tons of tanks near Fukushima contaminated water per day have been generated from rainwater and groundwater Over 1000 tanks constructed near the plant will become completely full by the spring of 2023

Fig1 Satellite image of storage Daiichi Nuclear Power Plant (Google Earth**)**

On April 13, 2021, the government officially announced to discharge contaminated water into the sea after treatment in 2023, which might cause potential effect on coastal ecosystem surely cause reputational damage on fisheries. 10 years ago, just after the earthquake and nuclear power plant accidents, my seniors started a microbiology survey at Chaya-marsh near my high school with a thought that microorganisms might be susceptible to radiation. One of the microorganisms found in the survey was *Closterium moniliferum*. Another microorganism found during the survey was *Chara braunii*, **More recently, our research group focused on one of the terrestrial cyanobacteria, the stinging *Nostoc commune* We found a literature showing that *N. commune* was able to absorb and accumulate Sr and Cs in both cells and extracellular substrates. In addition, this cyanobacterium can absorb water 30 times as heavy as its own weight. Therefore, we thought that we can utilize this unique property of this bacteria to treat tritium that remains at the site of the nuclear power plant.**

2 . Experimental

2.1 Enhancement of water decrease by using *N. commune* under blue LED irradiation

(1) Methods

Experimental setup used to investigate the influence of the amount of *N. commune* on daily water loss was shown in **Fig. 2.**

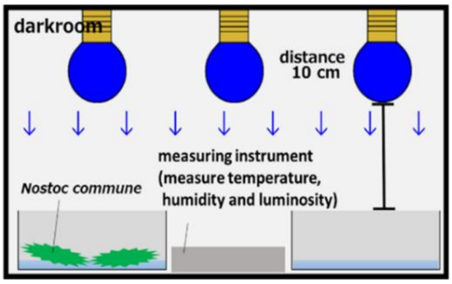


Fig. 2 Experimental setup used to investigate the enhancement of water decrease by using *N. commune* under

0.1 g of dried *N. commune* and 3 g of an aqueous solution containing 0.1 mM of $SrCl_2$ and CsCl were weighted in each container, and blue LEDs were irradiated 12 h per day. To avoid complete drying, 3 g of the solution was added in each container every day after measuring the weight of the container.

(2) Results and discussion

Daily water loss (measured by the change in overall weight of each container) during 28 days experiment with and without *N. commune* is shown in **Fig. 3**. Throughout 28 days experiment, the experimental system with *N. commune* showed higher daily water loss than the system without *N. commune*. This experimental data showed that water loss can be enhanced by adding *N. commune*, although responsible mechanisms were unknown at this stage.

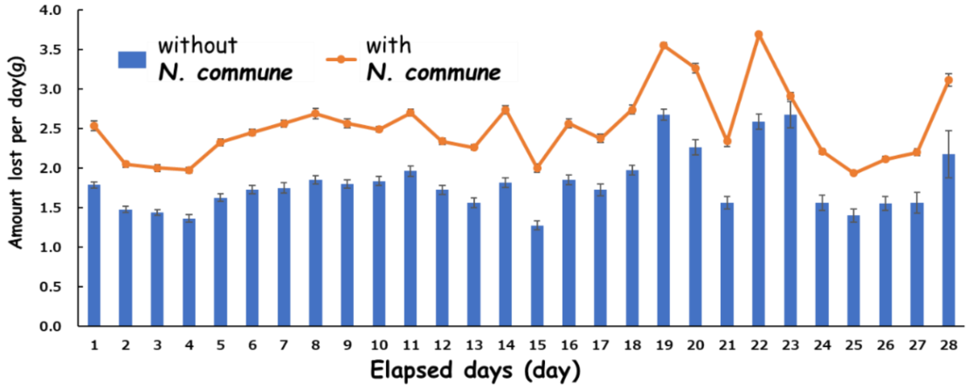


Fig. 3 Water loss during 28 days experiment with and without *N. commune*.

2.2 Comparison of the amount of water decrease by changing the amount of *N. commune*

(1) Methods

The *N. commune* samples were prepared with and without a stainless net to avoid the floating of the *N. commune* over the water surface. When *N. commune* was completely submerged in water, it was expected that the amount of water disappeared per day would increase with the increase in the dry weight of *the N. commune,* and the relationship between the dry weight of the *N. commune* and the amount of water loss was examined. Experimental procedures are described below. Experimental setup used to investigate the influence of the amount of *N. commune* was shown in **Fig. 4**. I weighed 0.1, 0.2, 0.3, 0.4, and 0.5 g of dried *N. commune* in each container, added 30 g of purified water, and placed a stainless steel net on top of flakes of *N. commune*. Blue LEDs were continuously irradiated at a distance of 10 cm. The weight of the whole container was measured every day for five days.

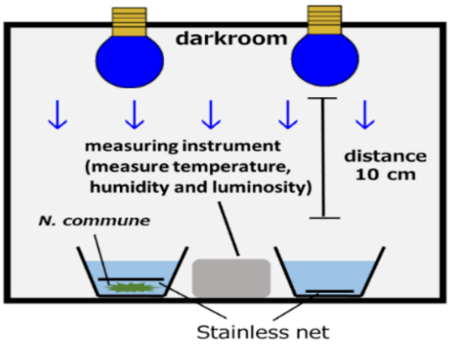


Fig. 4 Experimental setup used to investigate the influence of the amount of *N. commune*

(2) Results and discussion

The average decrease of water in five day with different addition of *N. commune* is shown in **Fig. 4**. As can be seen from **Fig. 5**, the amount of water decrease was the lowest (11.6 g) when *N. commune* was not added. However, the amount of water decrease increased by adding *N. commune*. This result was surprising because higher water decrease was expected for larger amount of dry weight of *N. commune*. However, it was found that the water loss for the 0.5 g was not the highest and no statistically significant difference in water loss on day 5 for 0.3, 0.4, and 0.5 g. Considering blue LED rights were located on top of container, this may be possibly because, in the samples of 0.2 g or more, *N. commune* spread by absorbing water covered the water surface and as a result, *N. commune* in the bottom of the container did not receive sufficient irradiation, and consequently the effects of blue LED (photosynthesis and/or heating) was not proportional to the amount of *N. commune* added in the container.

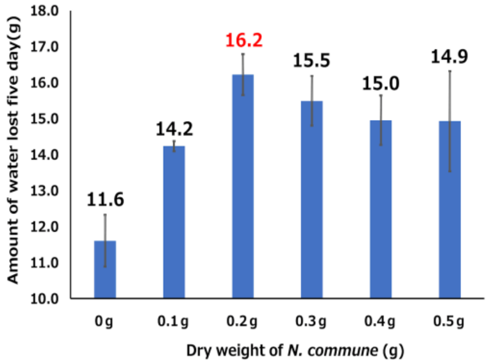


Fig. 5 Relationship between amount of lost in five days and the amount of dry *N. commune*

2.3 Effect of irradiation time of blue LED on water loss

(1) Methods

I irradiated *N. commune* with blue LED for 12 h and added the mixed solution (0.1 mM $SrCl_2$, 0.1 mM CsCl) every day to confirm the loss of water stably occurs. After 4 weeks, the blue LED was changed from 12 h irradiation per day to 24-hour continuous irradiation, and the weight of the whole container was measured every day for another 28 days, and 3 g of the mixed solution was added every day after the measurement.

(2) Results and discussion

When comparing the samples with and without *N. commune*, the amount of water lost per day was higher in all samples with *N. commune* than without. Although the reason is not clear, it is reasonable to conclude that continuous irradiation *N. commune* for 24 h enhances the water loss (**Fig. 6**).

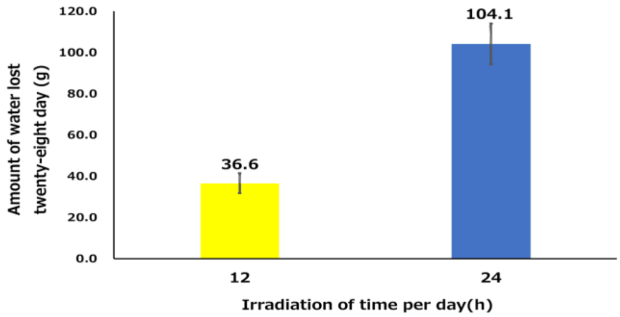


Fig 6 Difference in the amount of loss by *N. commune* in changing the irradiation time per day.

The color of the *N. commune* gradually changed from the initial dark black to a light brown (**Fig. 7**). Optical microscopy revealed that the cell clusters of spherical cells connected in a bead-like pattern observed in the initial stage gradually broke apart, and sparse spherical bead-like cells were observed (**Fig. 7**). Therefore, it seems the condition of the *N. commune* may not have significant impact on the loss of water. We observed that the amount of water loss increased by adding *N. commune* to the water and irradiating with blue LED, but could not fully elucidate the mechanism of this phenomenon in this study. However, It is important to mention that I performed the experiments with black-colored sponges, but I found the water loss was much higher with *N. commune*. Therefore, it is clear that this enhancement of water loss is unique for this organism.

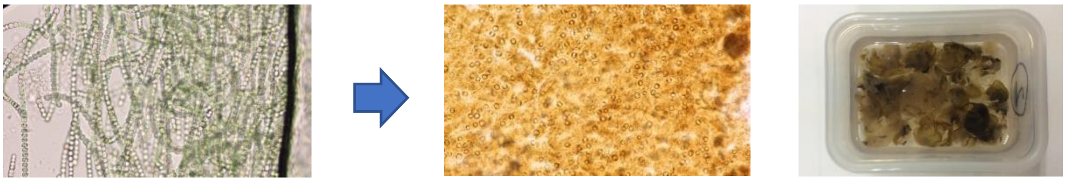


Fig. 7 Pictures of *N. commune* before experiment (left picture) and after 56 days experiment (middle and right pictures)

3. Future view

Based on the research I took over from predecessors, I would like to reduce the volume of ALPS treated water on the site of the nuclear power plant using our future contaminated water treatment system with various algae.

I confirmed that continuous irradiation of blue LED was effective as an ideal condition for the disappearance of water in terrestrial cyanobacteria, *Nostoc commune* used in the third stage. In this stage, all of the radioactive material had to be recovered and partly tritiated water had to be reduced, so *N. commune*, which can absorb and decrease water efficiently, was considered to be suitable. However, radioactive materials collected by the *N. commune* must be further managed in a safe manner. It is not an immediate solution, but if there is enough storage space, I think it is important to reduce the volume and attenuate it sufficiently by allowing *N. commune* to absorb it.

4. Reference

1) Sasaki Y, Funaki H, Iri S, Dohi T, Hagiwara H. Fate of radiocesium in freshwater aquatic plants and algae in the vicinity of the Fukushima Daiichi nuclear power plant. *Limnology*. 17(2016) 111-116.