Variation of the Radon Content in Two Display Springs and the Reservoir of the Hot Springs National Park in Arkansas*

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ABSTRACT

On the Display Springs Nos. 1 and 2, and the reservoir of Hot Springs National Park the author daily examined the rate of flow, water temperature, and the radon, free carbon dioxide, the sum of calcium and magnesium, alkalinity and bicarbonate contents during the time of Oct. 24 to Nov. 25, 1961 and Mar. 19 to Apr. 17, 1962.

The results were as follows :

1) Display Spring No. 1 : Water temperature 57.1 - 52.8℃ ; rate of flow 23.4 - 30.5 l / min ; radon 0.18 - 0.63×10^{-9}curie / l ; free carbon dioxide 18.5 - 29.0 mg / l ; Ca+Mg 2.70 - 2.74 meq / l ; alkalinity 2.65 - 2.70 meq / l ; bicarbonate 162 - 165 mg / l.
2) Display Spring No. 2 : Water temperature 52.2 - 54.7℃ ; rate of flow 18.8 - 40.6 l / min ; radon 6.09 - 13.8×10^{-9}curie / l ; free carbon dioxide 10.9 - 19.2 mg / l ; Ca+Mg 2.55 - 2.64 meq / l ; alkalinity 2.47 - 2.59 meq / l ; bicarbonate 151 - 158 mg / l
3) Thermal water from the drinking tap at the National Park Headquarters :
Radon 1.70 - 2.09×10^{-9}curie / l ; free carbon dioxide 21.0 - 24.5 mg / l ; Ca+Mg 2.67 - 2.75 meq / l ; alkalinity 2.61 - 2.67 meq / l ; bicarbonate 159 - 163 mg / l.
4) The radon content of Display Spring No. 2 remarkably increased when a heavy rainfall of 96 mm occurred on November 22, 1961.
5) It is supposed that the radon accumulated in the porous radioactive deposits, probably tufa dissolved into the thermal water rising from the depths at the shallow places under the ground.
6) The radon content of thermal water from the drinking tap at the National Park Headquarters clearly showed a periodic change and higher value on Fridays than other days.

I) Introduction

As stated in the previous report[1], it is clear that hot spring waters of Hot Springs National Park, Arkansas are created by mixing of the thermal water rising from depths with the shallow ground water.

If rainfall occurs, it is expected that the thermal water is diluted with rain water or ground water increased by the increasing of the hydrostatic pressure caused by the rising of the ground water level.

It is the purpose of the author to elucidate the mechanism of variation of the radon content in two display springs and the reservoir of the Hot Springs National Park.

* This work was done by the author during his stay in the University of Arkansas as a Visiting Professor from September 1961 to August 1962.

** The author retired from the Professorship of Tokyo Metropolitan University in March 1969 and was granted the title of Emeritus Professor of the same university.

From October 24 to November 25, 1961 water temperature, rate of flow and the contents of radon and carbon dioxide were measured on the Display Springs Nos. 1 and 2 every day. From March 20 to April 17, 1962 water temperature, rate of flow and the contents of radon, carbon dioxide, bicarbonate, alkalinity and the sum of calcium and magnesium were measured on the Display Springs Nos. 1 and 2 and the reservoir every day.

II) Analytical procedures

1) For the determination of radon in water a fontactoscope of the IM type was used.
2) As for the determination of free carbon dioxide content in water, a water sample was collected in a 100 ml graduated cylinder with care that the gas in the water did not escape. Then, at the orifice of the spring the water sample was titrated with 1 / 22 N sodium carbonate solution, using phenolphthalein as an indicator.
Then, a water sample was collected again and titrated with the same reagent after free carbon dioxide in water was completely expelled by vigorous shaking in air. A free carbon dioxide content was calculated from the difference between two titration values.
3) The sum of calcium and magnesium contents in water was determined by the titration method, EDTA being used.
4) As for the determination of alkalinity, methylorange was used as an indicator.

III) Results

A) Water temperature, rate of flow, free carbon dioxide and radon contents of Display Springs Nos. 1 and 2 were measured daily from October 24 to November 25, 1961. The results obtained are shown in figs. 1 and 5.
1) Display Spring No. 1
The orifice of this spring is a small cave which is one meter deep and 50 cm wide. The water in the cave is 75 cm in depth.
On November 22, the rate of flow was very remarkably increased by the heavy rainfall of 96 mm, while the radon and free carbon dioxide contents of this spring observed on the same day were not so varied as shown in **fig. 1.**
The data are summarized as follows :
Water temperature 57.5 - 58.2℃, rate of flow 23.4 - 30.5 1 / min, pH 7.4, free carbon dioxide 18.5 - 24.0 mg / 1 and radon 0.18 - 0.63×10^{-9}curie / 1.
There exists a linear relationship between water temperature and air temperature as shown in **fig. 2.** The rise of water temperature caused by the rise of 4℃ of air temperature is about 0.1℃.
The result obtained by statistically treating the data of free carbon dioxide content and water temperature is shown in **fig. 3.**
The content of carbon dioxide is decreasing as water temperature rises.
The result obtained by statistically treating the data of radon content and water temperature is shown in **fig. 4.**

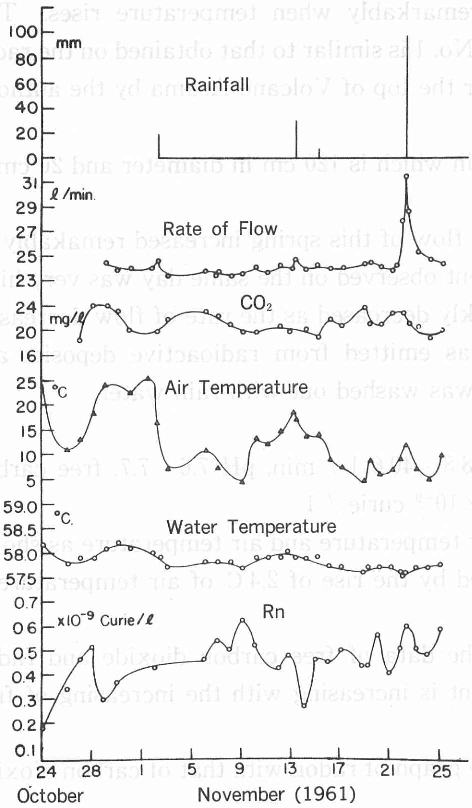

Fig. 1 Variation of the rate of flow, water temperature and the free carbon dioxide and radon contents of Display Spring No. 1

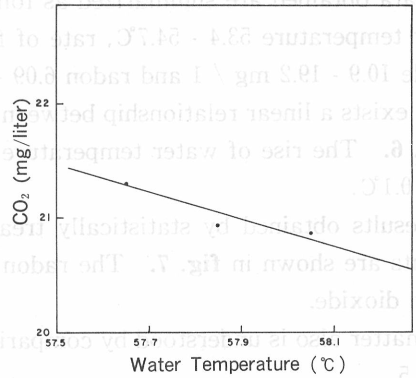

Fig. 3 Relationship between the free cabon dioxide content and the water temperature of Display Spring No. 1, when the data were statistically treated.

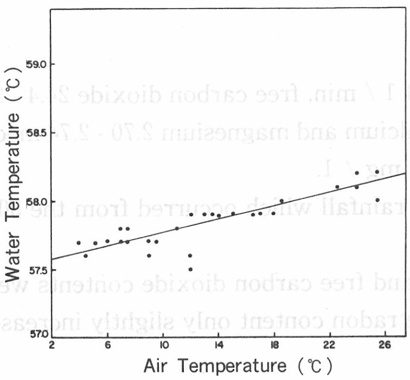

Fig. 2 Relationship between the water and air temperatures of Display Spring No. 1

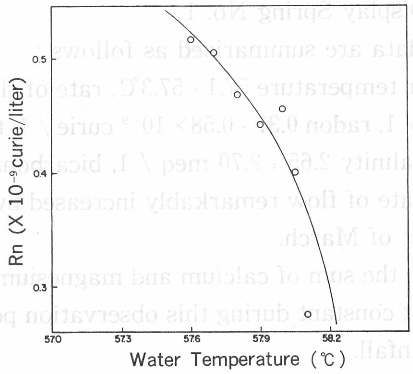

Fig. 4 Relationship between the radon content and the water temperature of Display Spring No. 1, when the data were statistically treated.

The radon content of this spring decreases remarkably when temperature rises. This tendency of the radon content of Display Spring No. 1 is similar to that obtained on the radon content of the mineral spring at Jigokudani near the top of Volcano Asama by the author[2].

2) Display Spring No. 2

The orifice of this spring is a small shallow basin which is 120 cm in diameter and 20 cm in depth.

As shown in **fig. 5,** on November 22 the rate of flow of this spring increased remakably by the heavy rainfall of 96 mm and the radon content observed on the same day was very high. When it stopped raining, the radon content quickly decreased as the rate of flow decreased. It is possible to suppose that radon which was emitted from radioactive deposits and accumulated in the porous rocks, possibly tufa was washed out with rain water.

The data obtained are summarized as follows :

Water temperature 53.4 - 54.7℃, rate of flow 18.8 - 40.6 1 / min, pH 7.6 - 7.7, free carbon dioxide 10.9 - 19.2 mg / 1 and radon 6.09 - 13.8×10^{-9} curie / 1

There exists a linear relationship between water temperature and air temperature as shown in **fig. 6.** The rise of water temperature caused by the rise of 2.4℃ of air temperature is about 0.1℃.

The results obtained by statistically treating the data of free carbon dioxide and radon contents are shown in **fig. 7.** The radon content is increasing with the increasing of free carbon dioxide.

This matter also is understood by comparing the graph of radon with that of carbon dioxide in fig. 5.

B) From March 19 to April 17, 1962 the author stayed again in Hot Springs National Park and measured the rate of flow, water temperature and chemical components such as free carbon dioxide, radon, sum of calcium and magnesium, and alkalinity of Display Springs Nos. 1 and 2 and Drinking Tap at National Park Headquarters. The results obtained are shown in **figs.** 8, **9 and 10.**

1) Display Spring No. 1

The data are summarized as follows :

Water temperature 57.1 - 57.3℃, rate of flow 23.6 - 29.4 1 / min, free carbon dioxide 24.4 - 29.0 mg / 1, radon 0.37 - 0.58×10^{-9} curie / 1, the sum of calcium and magnesium 2.70 - 2.74 meq / 1, alkalinity 2.65 - 2.70 meq / 1, bicarbonate 162 - 165 mg / 1.

The rate of flow remarkably increased by 42.5 mm of rainfall which occurred from the 30th to 31st of March.

While, the sum of calcium and magnesium, alkalinity and free carbon dioxide contents were almost constant during this observation period and the radon content only slightly increased by rainfall.

On comparison with the data obtained in October, 1961, water temperature slightly decreased and free carbon dioxide content increased, as shown in table 1.

2) Display Spring No. 2

The data obtained are summarized as follows :

Water temperature 52.2 - 52.9℃, rate of flow 26.4 - 33.3 1 / min, free carbon dioxide 12.4 - 17.

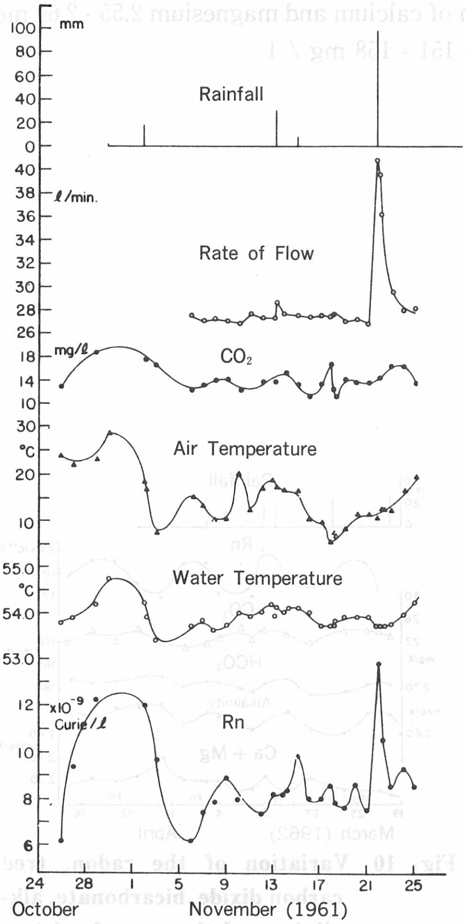

Fig. 5 Variation of the rate of flow, water temperature and the free carbon dioxide and radon contents of Display Spring No. 2

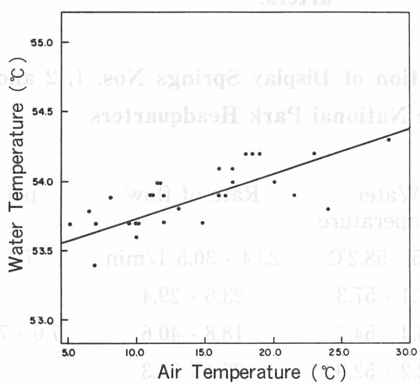

Fig. 6 Relationship between the water and air temperatures of Display Spring No. 2

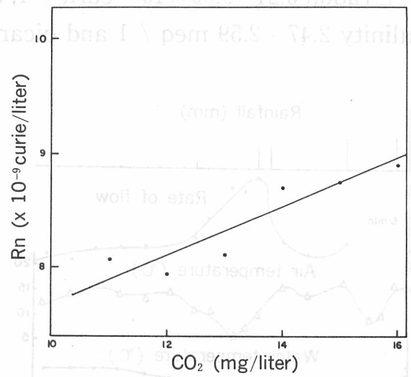

Fig. 7 Relationship between the radon and free carben dioxide contents of Display Spring No. 2, when the data were statistically treated.

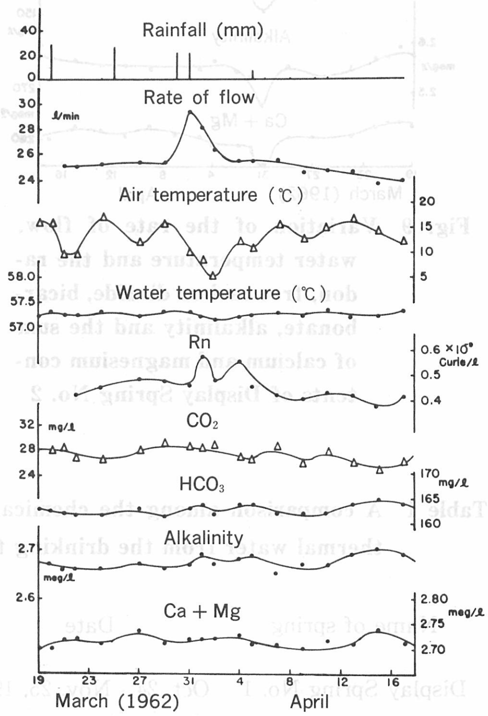

Fig. 8 Variation of the rate of flow, water temperature and the radon, free carbon dioxide, bicarbonate, alkalinity and the sum of calcium and magnesium contents of Display Spring No. 1

2 mg / 1, radon 6.21 - 9.00×10^{-9} curie / 1, the sum of calcium and magnesium 2.55 - 2.64 meq / 1, alkalinity 2.47 - 2.59 meq / 1 and bicarbonate 151 - 158 mg / 1.

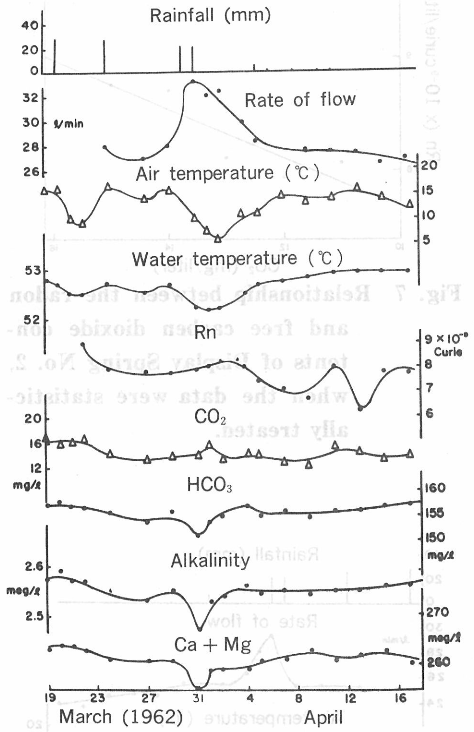

Fig. 9 Variation of the rate of flow, water temperature and the radon, free carbon dioxide, bicarbonate, alkalinity and the sum of calcium and magnesium contents of Display Spring No. 2

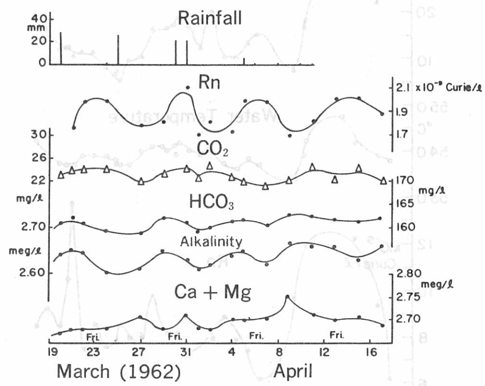

Fig. 10 Variation of the radon, free carbon dixide, bicarbonate, alkalinity and the sum of calcium and magnesium contents in the thermal water from the drinking tap at the Park Headquarters.

Table 1 A comparison among the chemical composition of Display Springs Nos. 1, 2 and the thermal water from the drinking tap at the National Park Headquarters

Name of spring	Date	Water Temperature	Rate of flow	pH
Display Spring No. 1	Oct. 24 - Nov. 25, 1961	57.5 - 58.2℃	23.4 - 30.5 1/min	7.4
〃 〃 〃	Mar. 19 - Apr. 17, 1962	57.1 - 57.3	23.6 - 29.4	—
Display Spring No. 2	Oct. 24 - Nov. 25, 1961	53.4 - 54.7	18.8 - 40.6	7.6 - 7.7
〃 〃 〃	Mar. 19 - Apr. 17, 1962	52.2 - 52.9	26.4 - 33.3	—
Thermal water from the drinking tap at the National Park Headquarters	Mar. 19 - Apr. 17, 1962	—	—	—

The rate of flow remarkably increased by 42.5 mm of rainfall which occurred from the 30th to 31st of March, while the contents of bicarbonate, the sum of calcium and magnesium, and alkalinity decreased on the same day. In this case, it is reasonable to conclude that thermal water was diluted with rain water.

In November, 1961 the radon content of Display Spring No. 2 remarkably increased in accordance with the increasing rate of flow by heavy rainfall, but in March, 1962 the amount of rainfall was not so much and only a slight increase of radon content was caused by rainfall.

3) Thermal water from the drinking tap at the National Park Headquarters.

As stated before, all the thermal waters in the Hot Springs area except two display springs were collected in a large reservoir and from there sent by pump to a tank located at a higher position on the mountain.

Then, the thermal water was distributed to each bath house and the drinking tap at the National Park Headquarters by using hydrostatic pressure, after it had been cooled by heat exchange to a suitable temperature for bathing. The author collected water samples from the drinking tap at the National Park Headquarters and analyzed them.

The analytical results are summarized as follows:

Free carbon dioxide 21.0 - 24.5 mg / 1, radon 1.70 - 2.09 $\times 10^{-9}$ curie / 1, the sum of calcium and magnesium 2.67 - 2.75 meq / 1, alkalinity 2.61 - 2.67 meq / 1 and bicarbonate 159 - 163 mg / 1.

The author did not take temperature measurement of this water, because the water temperature was lowered by heat exchange and air cooling.

According to the temperature record taken by the staff of National Park Service, the temperature of water in the reservoir was 61℃ and almost constant during the above mentioned period.

No noticeable change occurred in radon, free carbon dioxide, bicarbonate, the sum of calcium and magnesium contents by 42.5 mm of rainfall.

But, the radon content clearly showed a periodic change and higher content on Fridays than other days. It is reasonable to suppose that this change was caused by pump stopping from Saturday afternoon to Sunday and being operated from Monday through Friday for sending thermal water to bath houses.

C) A comparison among the chemical compositions of Display Springs Nos. 1, 2 and the thermal water from the drinking tap

As shown in **table 1,** if the chemical composition of Display Spring No. 1 is compared with

Radon 10^{-9} curie/1	mache	Free carbon dioxide mg/1	Ca+Mg meq/1	Alkalinity meq/1	HCO_3 mg/1
0.18 - 0.63	0.50 - 1.73	18.5 - 24.0	—	—	—
0.37 - 0.58	1.02 - 1.59	24.0 - 29.0	2.70 - 2.74	2.65 - 2.70	162 - 165
6.09 - 13.8	16.75 - 37.95	10.9 - 19.2	—	—	—
6.21 - 9.00	17.08 - 24.75	12.4 - 17.2	2.55 - 2.64	2.47 -2.59	151 - 158
1.70 - 2.09	4.67 - 5.75	21.0 - 24.5	2.67 - 2.75	2.61 - 2.67	159 - 163

that of Display Spring No. 2, the former was slightly higher in temperature and in free carbon dioxide, the sum of calcium and magnesium, alkalinity and bicarbonate contents than the latter.

It means that the former is slightly richer in thermal water rising from the depths of the earth than the latter.

As for the water temperature of Display Springs, in the case of Display Spring No. 1 the rise of water temperature caused by the rise of 4℃ of air temperature was 0.1℃, while in the case of Display Spring No. 2 the rise of water temperature caused by the rise of 2.4℃ of air temperature was 0.1℃. Therefore, the water temperature of the latter is more easily affected by air temperature than that of the former.

The radon content of the former was 0.18 - 0.63×10^{-9} curie / 1 in 1981 and 0.37 - 0.58×10^{-9} curie / 1 in 1962. Those values are not so high and almost equal to the radon content of ordinary spring waters such as spring waters in the neighbourhood of Mt. Asama and the well waters in the campus of the University of Tokyo.

While, the latter is remarkably higher in radon content than the former.

It is supposed that the radon accumulated in the porous radioactive deposits, probably tufa dissolved into the thermal water rising from the depths at the shallow places under the ground. This interpretation on the origin of radon in the spring waters will be supported by the fact that the radon content of Display Spring No. 2 was very remarkably high on the day of heavy rainfall of 96 mm in November, 1961.

The thermal water from the drinking tap at the National Park Headquarters was almost the same in the free carbon dioxide, the sum of calcium and magnesium, alkalinity and bicarbonate contents as the thermal waters of Display Springs Nos. 1 and 2. But, as for radon content it was larger than Display Spring No. 1 and smaller than Display Spring No. 2, as shown in table 1.

Acknowledgments

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