New Continuous Radon Monitoring in Nakaizu Observatory

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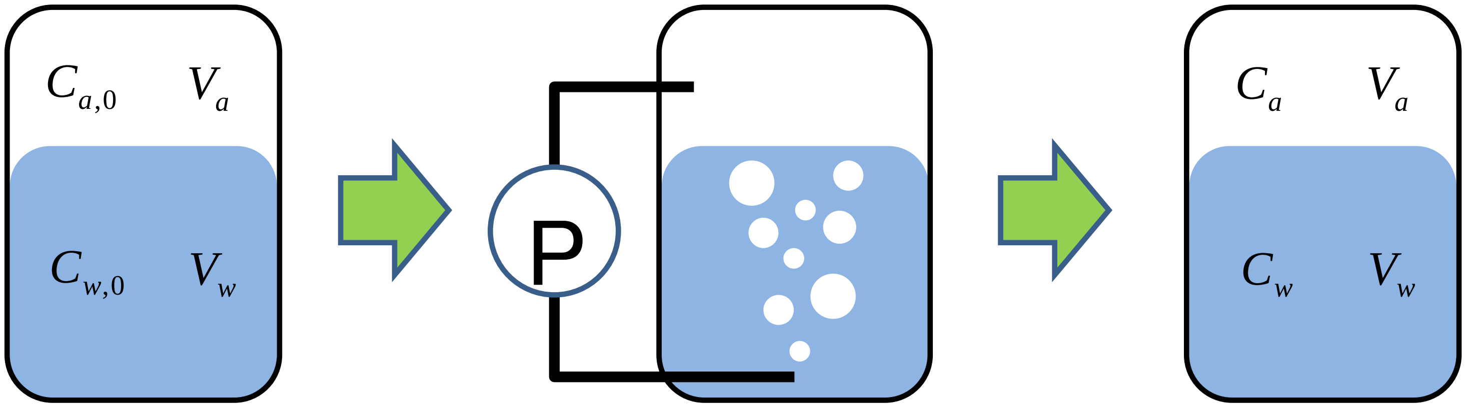
Goal of Research

- To reveal whether the precursory change of groundwater radon is a physical phenomenon or an unregulated one.
  - The anomalies occur in an aquifer.
  - Absolute radon concentration measurement is important because radon is generated from ^{226}Ra on the crack surface.
  - Hydrological parameters reflect the crack status in an aquifer.

Objective of This Talk

- To establish a flow extraction system to obtain radon from groundwater.
  - A flow extraction instrument is designed and installed.
  - A new equation to calculate a radon concentration taking into account the flow rate effect is required.

Bubbling Method



$C_{w,0}V_w + C_{a,0}V_{aa}$

$C_a = K_d C_w$

$C_w V_w + C_a V_a$

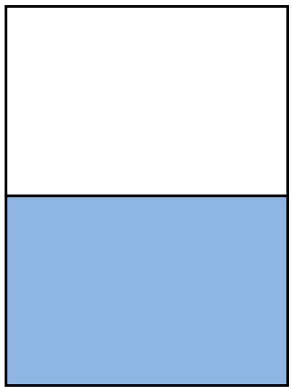
K_d : Partition coefficient

$$C_{w,0}V_w + C_{a,0}V_a = C_w V_w + C_a V_a \quad \Rightarrow \quad C_{w,0} = \left(C_a \frac{V_a}{V_w} + \frac{C_a}{K_d} \right) - C_{a,0}\frac{V_a}{V_w}$$

If $C_{a,0} = 0$, then $C_{w,0} = C_a \left(\frac{V_a}{V_w} + \frac{1}{K_d} \right)$

Simple physics without ambiguities.

Temperature Dependence of K_d



$$\mu_a = \mu_a^* + RT\ln(x_a)$$

$$\mu_w = \mu_w^* + RT\ln(x_w)$$

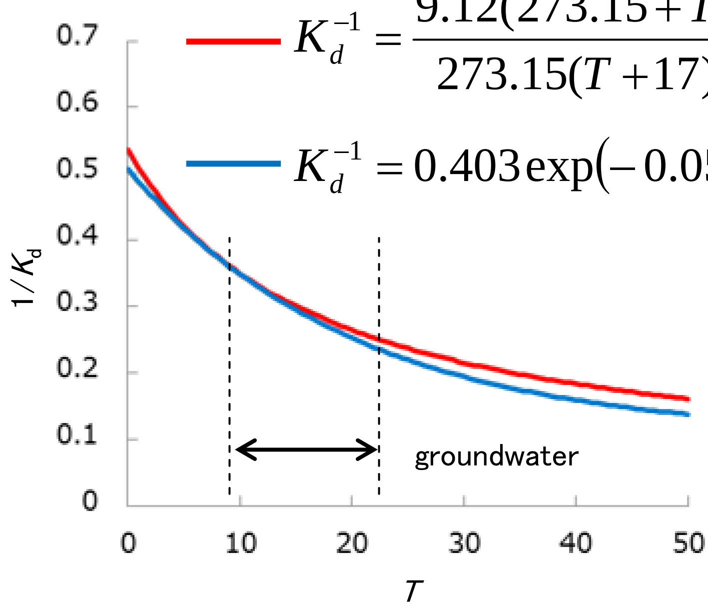
Under equilibrium state, $\mu_w = \mu_a$

$$\mu_a^* - \mu_w^* = \Delta\mu^* = RT\ln\left(\frac{x_a}{x_w}\right)$$

Therefore, $\frac{x_a}{x_w} = \exp\left(\frac{\Delta\mu^*}{RT}\right)$

$$K_d \equiv \frac{C_a}{C_w} \approx \frac{x_a}{x_w} = \exp\left(\frac{\Delta\mu^*}{RT}\right)$$

$$C_{w,0} = C_a\left(\frac{V_a}{V_w} + \exp\left(-\frac{\Delta\mu^*}{RT}\right)\right)$$

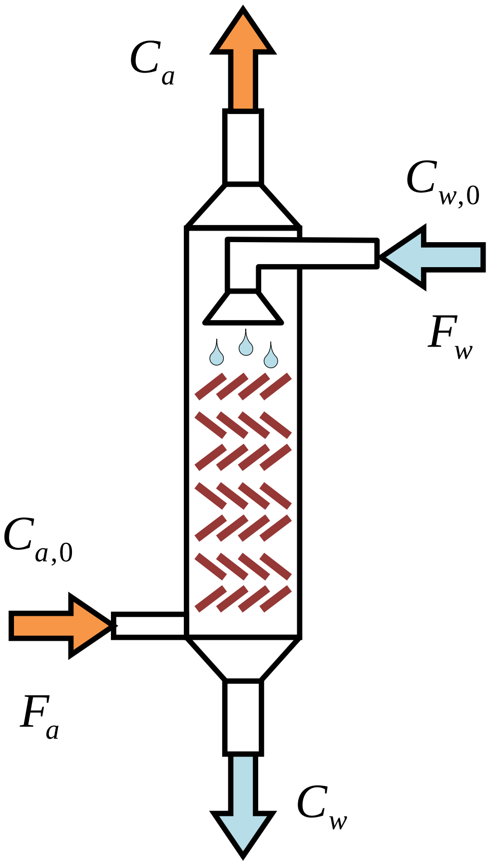


$$K_d^{-1} = \frac{9.12(273.15+T)}{273.15(T+17)}$$

$$K_d^{-1} = 0.403\exp(-0.0502T) + 0.105$$

Correction of temperature effect is very important.

Flow Method



For a continuous monitoring, a flow method has an advantage in robustness.

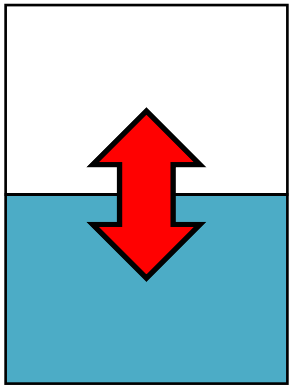
For an expedient formula, volume ratio is substituted with flow rate ratio.

$$\frac{V_a}{V_w} \approx \frac{F_a}{F_w}$$

$$C_{w,0} = C_a\left(\frac{V_a}{V_w} + \frac{1}{K_d}\right) \;\Rightarrow\; C_{w,0} = C_a\left(\frac{F_a}{F_w} + \frac{1}{K_d}\right)$$

This substitution might be valid **as long as equilibrium state is established** in an exchange instrument.

Mass Transfer



$$\frac{dR}{dt} = -kS(R - K_d)$$

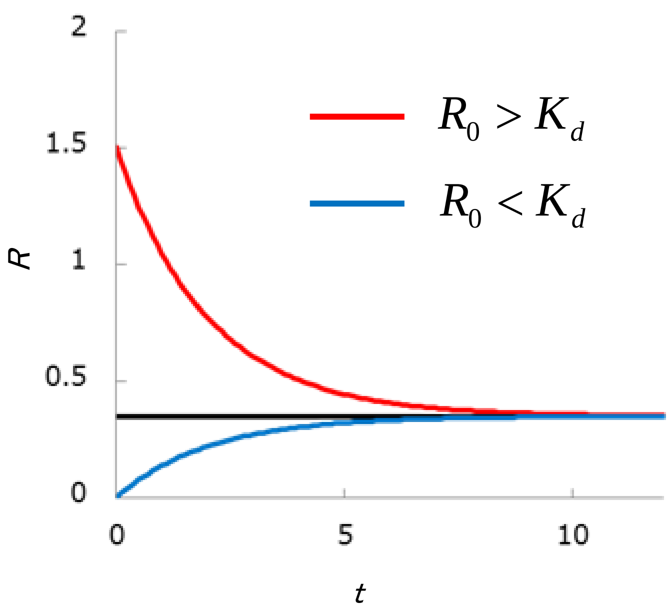
$$R(0) = R_0,\ R(\infty) = K_d$$

$$R(t) = (R_0 - K_d)\exp(-kSt) + K_d$$

R : Concentration ratio

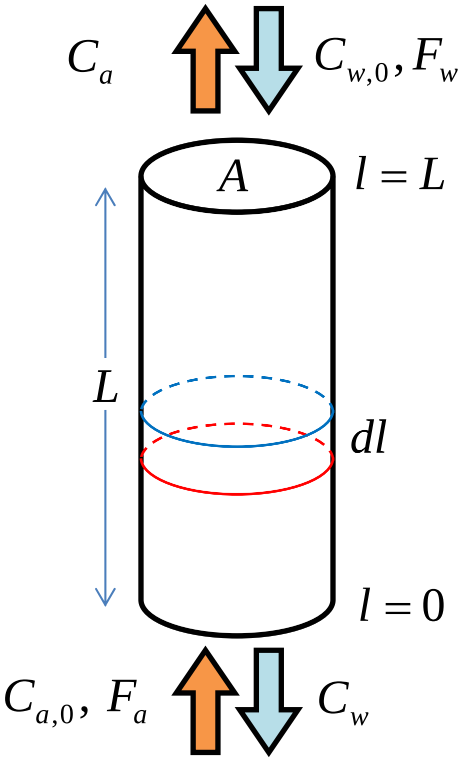
k : Mass transfer rate

S : Interface area



- The bubbling time should be longer than the mass transfer time ($1/k$).
- To achieve the equilibrium state, the **long time** of the exchange operation and/or the **effective mass transfer** are required.

Modeling



We define the reduced flow rate indicating a relative flow rate of water to gas.

$$f = \frac{1}{\frac{1}{F_{w,act}} + \frac{1}{F_{a,act}}}$$

$F_{x,act}$: actual flow rate of x in the chamber

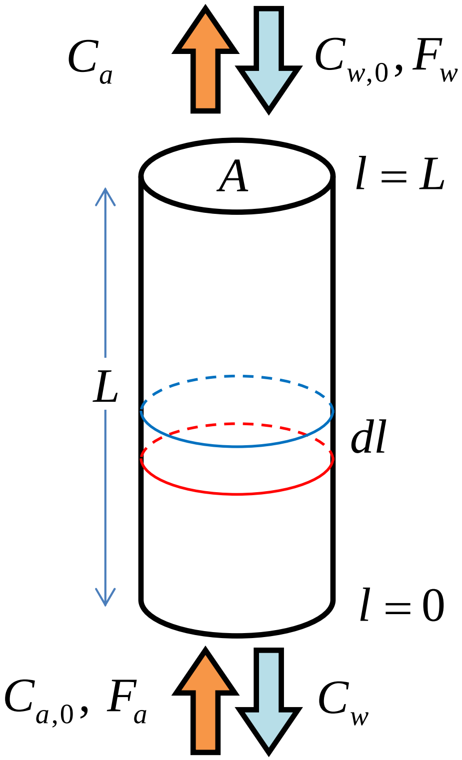
$$f = \frac{1}{\frac{r}{F_w} + \frac{(1-r)}{F_a}}$$

r : volume ratio of water in the chamber

The apparent transit time dt of water in dl region is …

$$dt = \frac{Ar}{f} dl$$

Modeling



The small change of the concentration ratio of gas in *dl* region depends on the apparent transit time *dt* via water–air interface (S).

$$\frac{dR}{dt} = kS(K_d - R) \qquad dt = \frac{Ar}{f} dl$$

$$K_d \equiv \frac{C_w}{C_a}$$: partition coefficient of gas in equilibrium

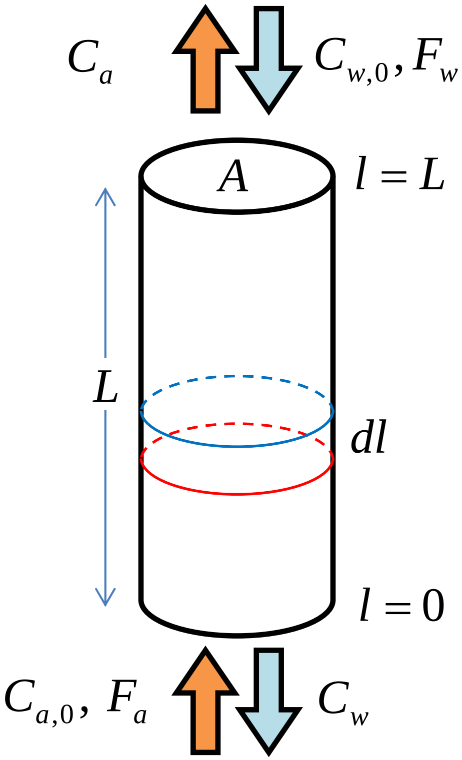
$$R(l) \equiv \frac{C_{w,0}}{C_a}$$: concentration ratio

$$\frac{dR}{dt} = \frac{dR}{dl}\frac{dl}{dt} = \frac{dR}{dl}\frac{f}{Ar} = kS(K_d - R)$$

Eventually, the small change of R in dl region is expressed as …

$$\frac{dR}{dl} = \frac{Ar}{f} kS(K_d - R)$$

Modeling



Solve the differential equation with conditions as follows …

$$\frac{dR}{dl} = \frac{Ar}{f} kS(K_d - R)$$

$l \to \infty,\ R \to K_d$ and $l = 0,\ R = C_{a,0} / C_w$

$$\frac{C_a}{C_{w,0}} = K_d - \left(K_d - \frac{C_{a,0}}{C_w} \right) \exp\left(-\frac{ArkS}{f} L \right)$$

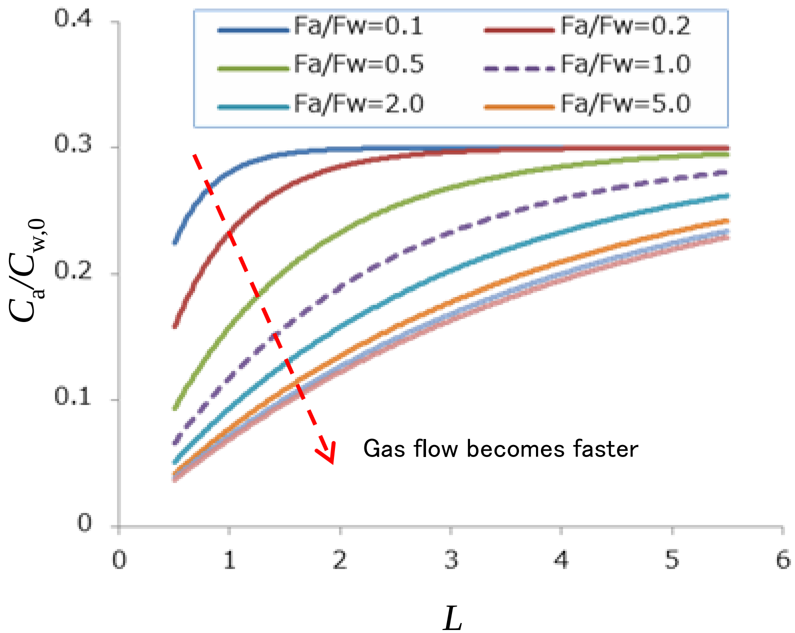
If $C_{a,0} = 0$, then

$$\frac{C_a}{C_{w,0}} = K_d \left[1 - \exp\left(-\frac{ArkS}{f} L \right) \right]$$

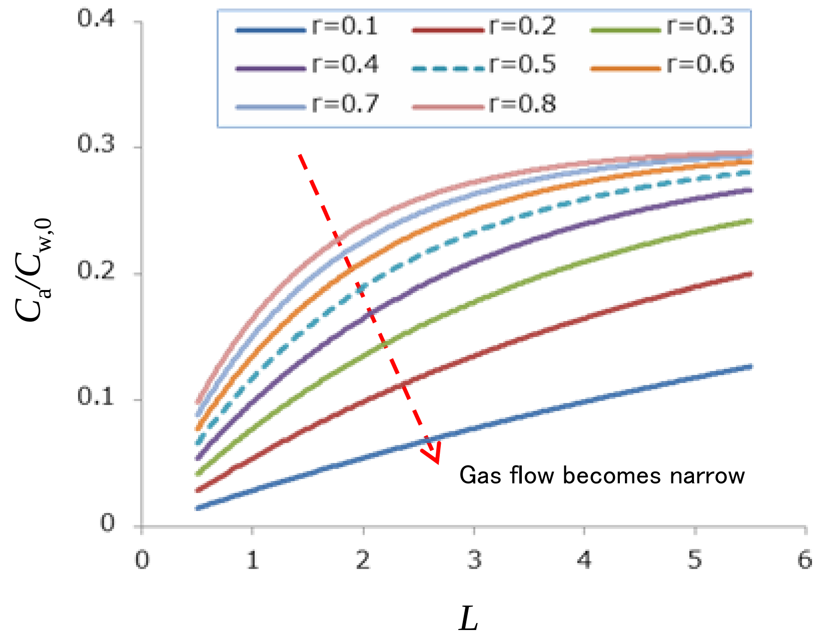
Modeling

$$C_{w,0} = C_a \frac{1}{K_d}\left[1-\exp\left(-\frac{ArkS}{f}L\right)\right]^{-1}$$

$$\frac{1}{f} = \frac{F_w(1-r)+F_a r}{F_w F_a}$$



Effect of flow rate ratio



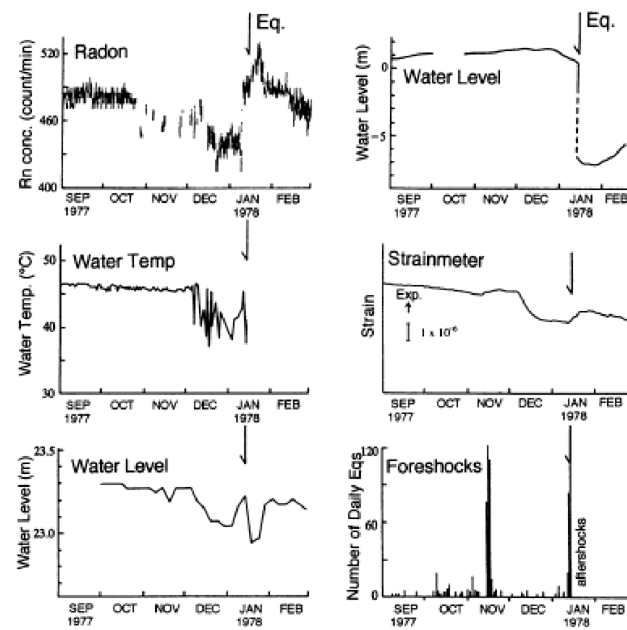
Effect of flow volume ratio

~~$$C_{w,0} = C_a\left(\frac{F_a}{F_w}+\frac{1}{K_d}\right)$$~~

The conventional equation is … not correct.

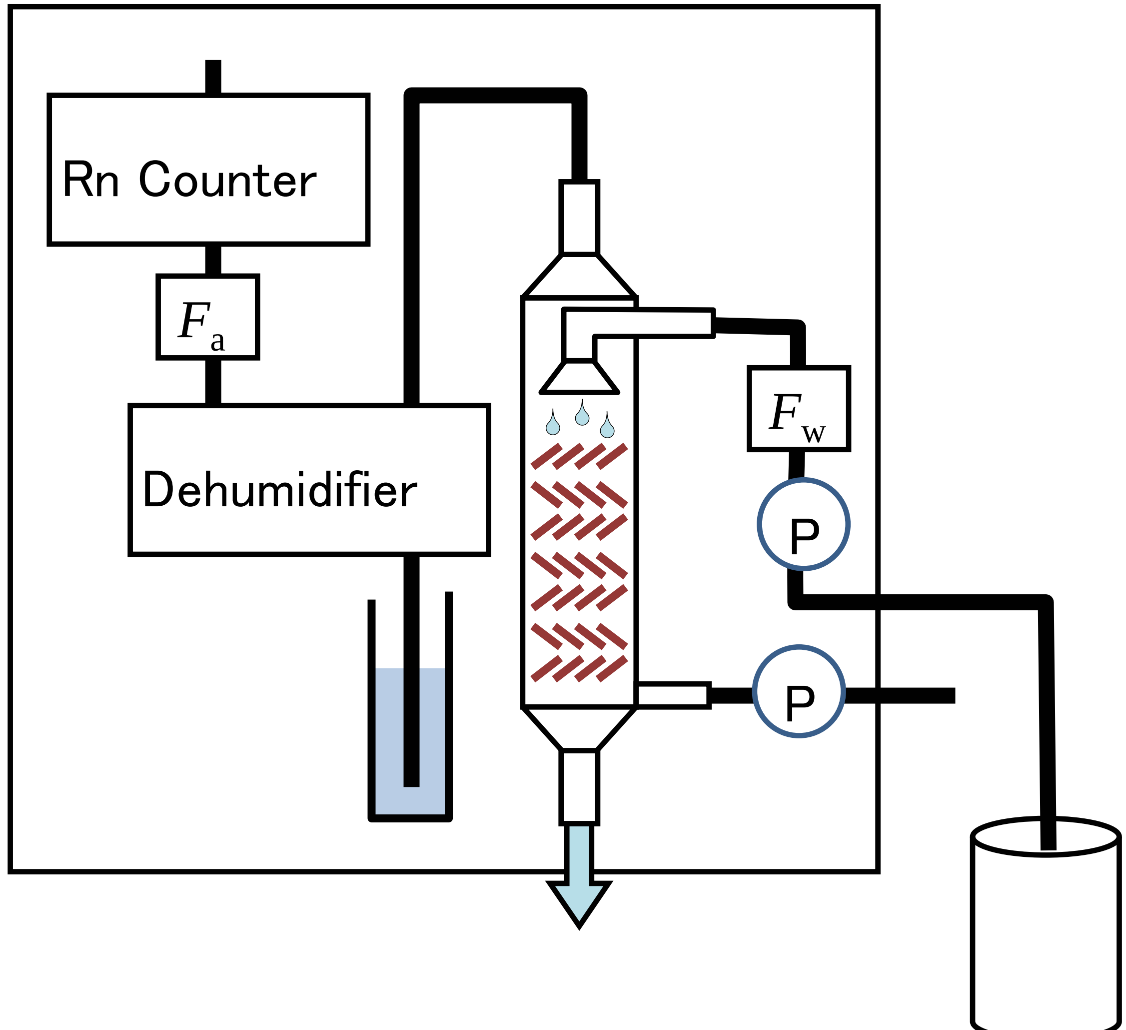
Nakaizu Observatory

- It is located in the Izu peninsula.
- The well recorded a precursory radon change before Izu-Oshima Kinkai Earthquake, 1978.

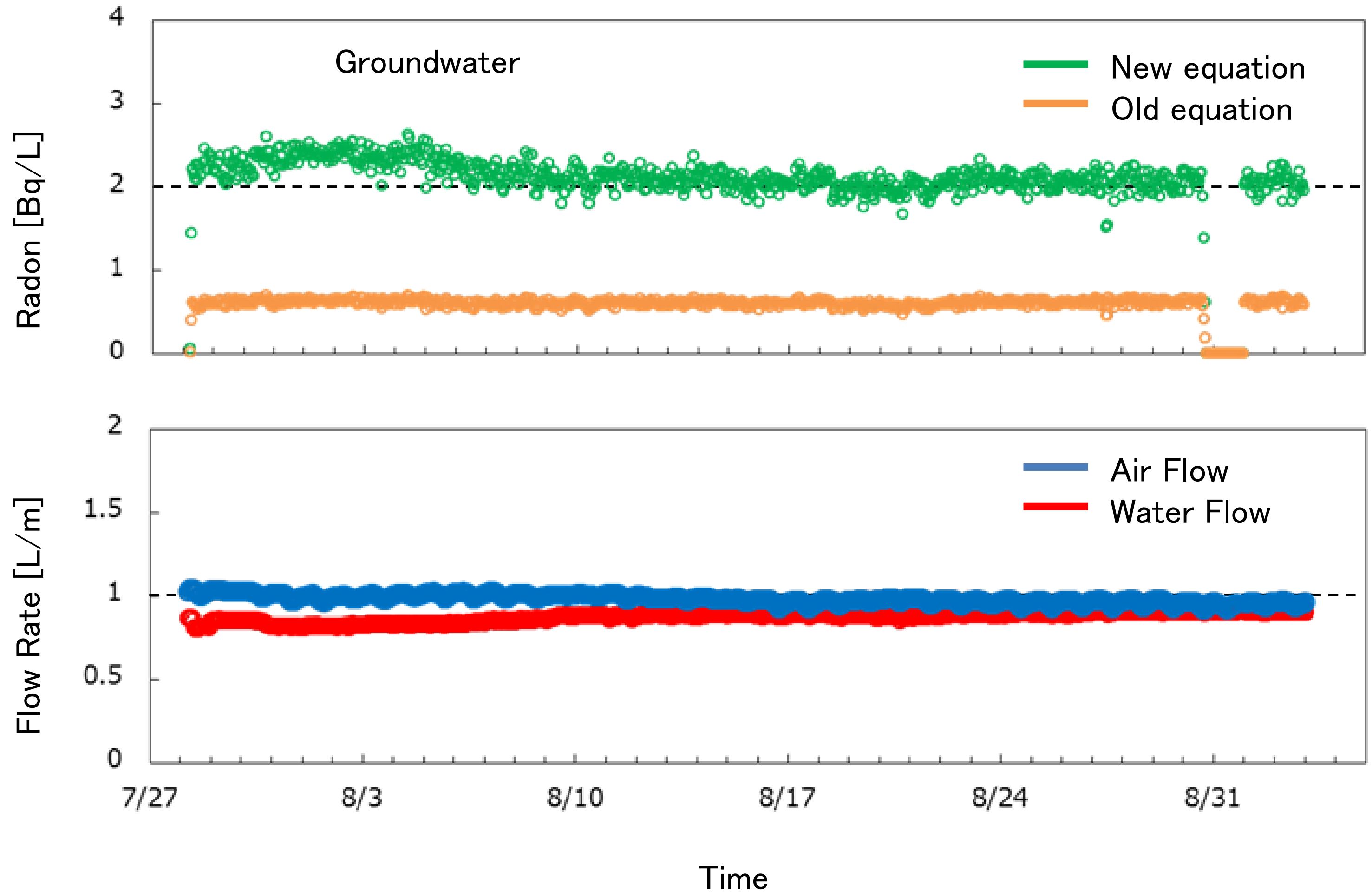


Wakita et al. (1980,1996)

Observation Setup



Observation Records



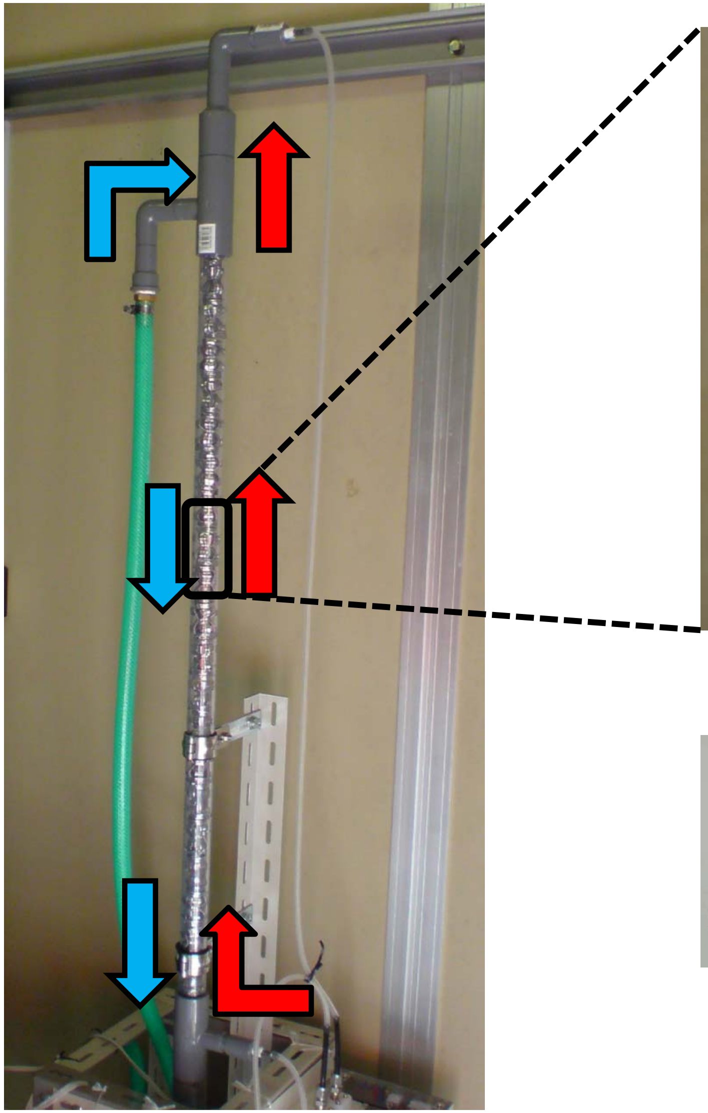
The absolute concentration of radon in groundwater is correctly obtained by the new equation.

Conclusions

- A radon extraction chamber was developed and installed in the Nakaizu observatory.
- A new equation to calculate the absolute radon concentration has been proposed as a substitute for the conventional equation.

$$C_{w,0} = C_a \frac{1}{K_d}\left[1 - \exp\left(-\frac{ArkS}{f}L\right)\right]^{-1} \qquad \frac{1}{f} = \frac{F_w(1-r) + F_a r}{F_w F_a}$$

Gas Extraction Chamber



Folded shape

Stainless plate

Rn Counter & Dehumidifier