Earthquake pre-seismic and co-seismic changes of the hot spring water in Central Part of Japan

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1. Observation system

Radon is a radioactive nuclei belonging to decay series of Uranium with a half life time about 3.8 days. It is inert and highly soluble in water and has served as a useful tracer for crustal strain changes associated with earthquake occurrences. The high sensitivity radon detector for water was developed.

Figure 1 shows a schematic view of the detector. This is composed of two sections. One is a radon gas extraction unit which transfers radon from water into air. The other is the electrostatic collection unit. Underground water is continuously introduced into extraction unit with a flow rate of several liters per minute. The high sensitivity radon detector enlarges the capacity of an electrostatic collection container from 1 l to 70 l, and has raised an electrostatic collection voltage from −120V to −1500V.

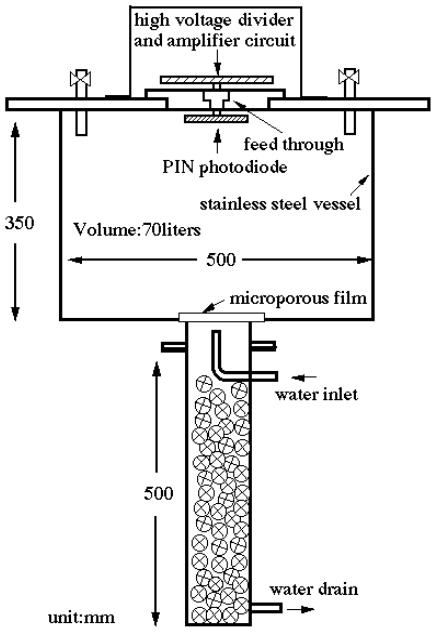

Fig.1 Schematic view of the high sensitivity radon detector for water.

The sensitivity of the new developed water radon detector has improved from the current detector by about 100 times. It is known that the daughter nuclei of ^{222}Rn become positively charged. Therefore, the basic principle of radon detection used in our detector collects the RaA (^{218}Po) daughter nuclei of ^{222}Rn in the gas state by an electrostatic field. Energy measurement of the alpha ray is carried out with a PIN photodiode.

The radon observation stations for underground water were placed on the active faults in Gifu Prefecture, Central part of Japan. Figure 2 shows the 16 observation stations for the underground water. The observation result of the underground water is displayed with the real time in the Web Page. These radon detectors have been installed in the 2 stations, the “Heisei hot spring (HEI)” in Fukui Prefecture on November 30, 2001, and “Wari-ishi hot spring (KAM)” in Gifu Prefecture on March 24, 2002. Amount of the hot spring water was measured by the electromagnetic flow meter, and the water temperature was measured by the precise thermometer with the accuracy of 0.01℃ in the water main pipe.

2. Heisei hot spring

1) Amount of the hot spring water

The "Heisei hot spring(HEI)" of Izumi-Mura, Fukui Prefecture, was dug from 1988 to 1989, and the water sprang up from 452.8 meters in the underground in July, 1989. The temperature of the water is 26.1℃, and amount of the hot water springs up at about 200 l/min.

Fig.3 is an observation result of the amount of the hot spring water from May 1, 1994 to February 24, 2002. The amount of the hot spring water from May 1, 1994 to March 8, 1998 were measured by the Izumi-Mura Office staff by the rotary flow meter. A continuous observation data of underground water were measured by the electromagnetic flow meter with the accuracy 0.1 l/min, on October 17, 1998 until February 24, 2002. The co-seismic and pre-seismic anomalous changes of the amount of hot spring water (water flow rate) were detected. The changes in the amount of the water with the earthquakes occurrence are showed by arrows.

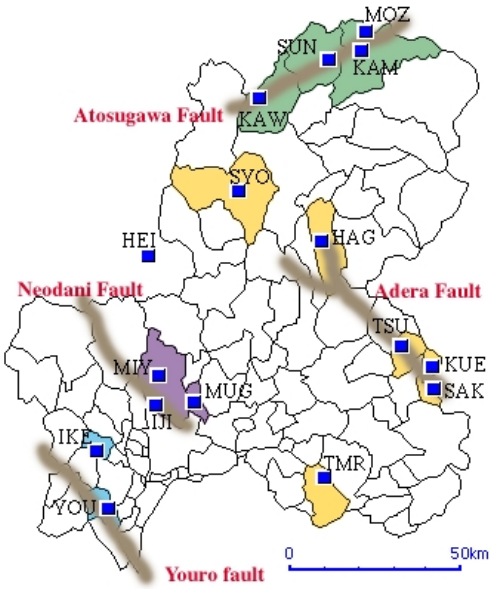

Fig.2 Observation stations in underground water on the active faults in Gifu Prefecture, Central Part of Japan.

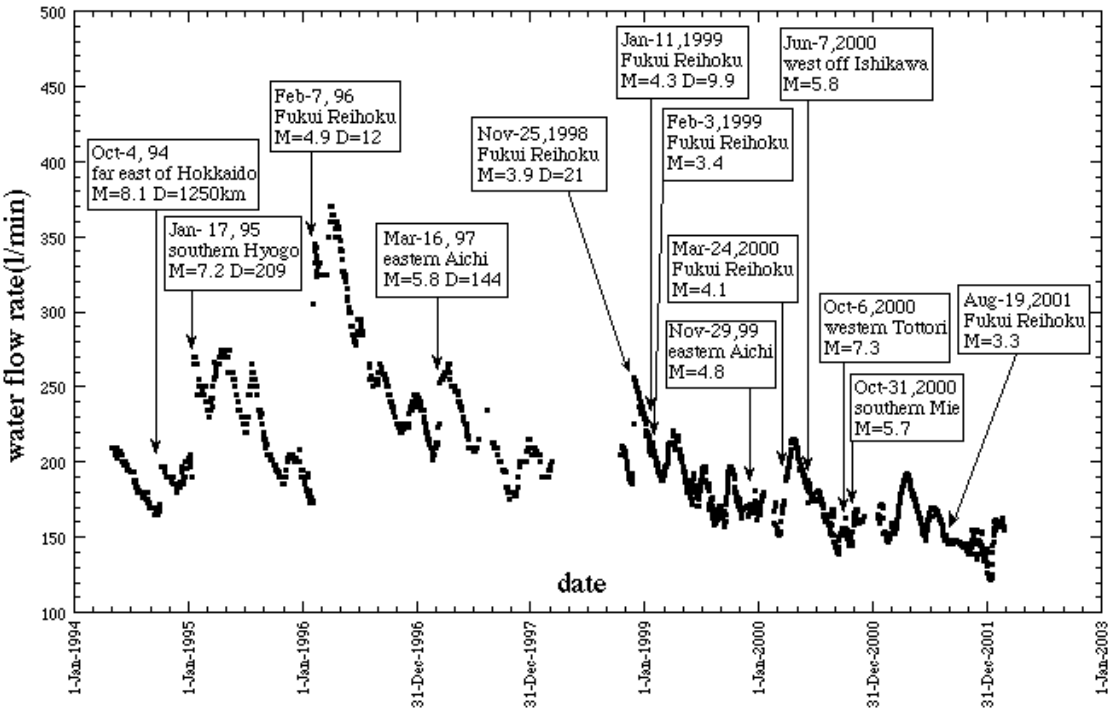

Fig.3 Observation results of the flow rate of the hot spring water from May 1, 1994 to February 24, 2002, in "Heisei hot spring(HEI)" of Izumi-Mura, Fukui Prefecture.

The co-seismic changes in the water flow rate with 10 earthquakes of M3.0 or more, and the pre-seismic changes with 2 earthquakes were observed at the observation period on December, 2002 from November, 1998.

2) Pre-seismic changes of accompanied to "West off Ishikawa Prefecture earthquake"

Figure 4 is the observation result of the flow rate and the standard deviation of the hot spring water on June 1 to June 10, 2000. The flow rate starts decreasing at 13:30 June 5, and the earthquake occurs in the point in which it decreased from 183 to 170 l/min. The water flow rate increased rapidly up to 188 l/min with the earthquake occurrence. The daily tidal change of the water flow rate was observed. The temperature of the water starts falling at 13:40 June 5, and the earthquake occurs in the point in which it fell from 27.72 to 26.15℃. The fountain temperature went up with the earthquake occurrence by 0.15℃. The number of RaA counts was decreased gradually after the earthquake occurrence. The hot spring is located about 120km from the epicenter.

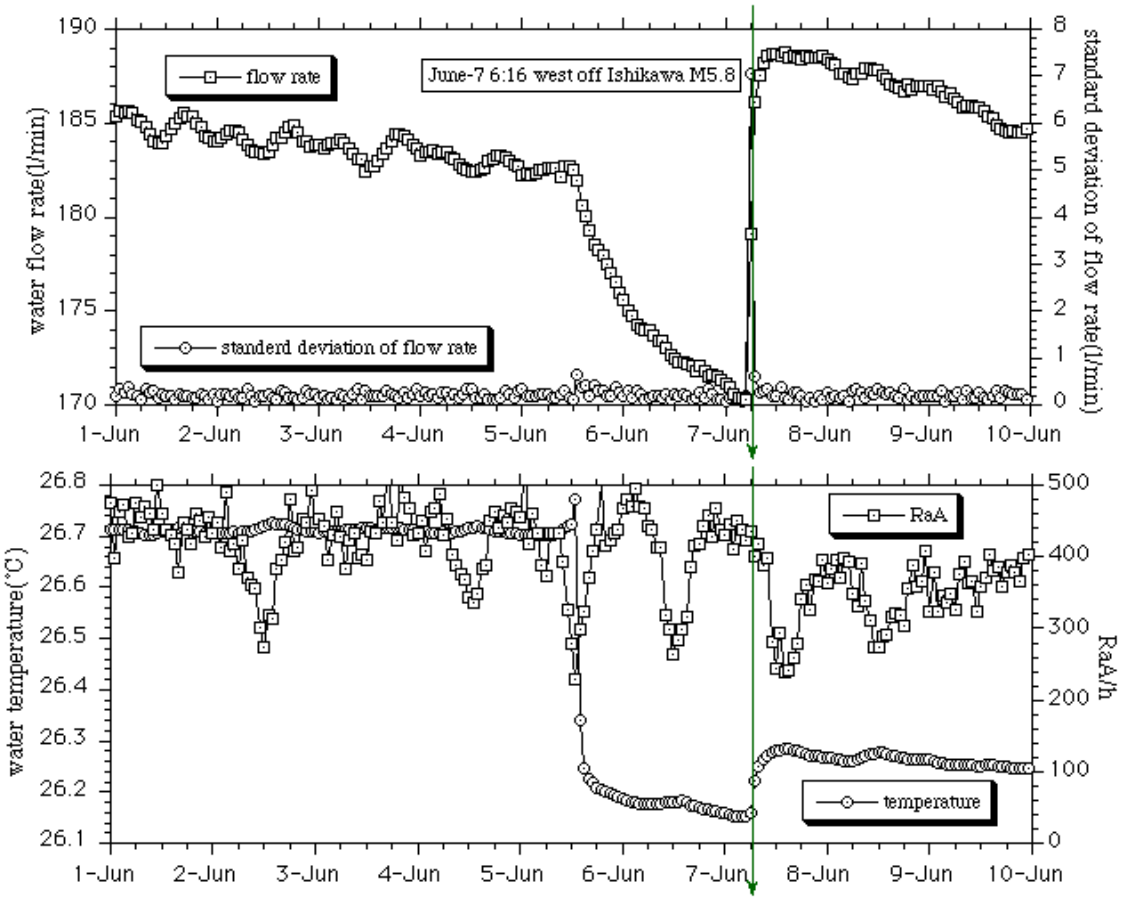

Fig.4 Pre-seismic change of the water flow rate and the temperature of the hot spring water of accompanied to "West off Ishikawa Prefecture earthquake" on June 7, 2000.

3) Pre-seismic changes of accompanied to "Western Tottori Prefecture earthquake"

Figure 5 is the observation result of the amount of the hot spring water, the temperature of the fountain and the number of RaA counts. The observation point is away from the hypocenter region of the earthquake at about 260km.

The amount of the hot spring water has increased from 151.5 to 153.5 l/min before 2.5 hours of the earthquake occurrence. In addition, it has increased from 153.5 to 163.6 l/min at the same time as the earthquake occurrence. The fountain temperature went up from 26.35 to 26.56℃ before 2.5 hours of the earthquake occurrence. It went up to 26.62℃ further at the same time as the earthquake occurrence. The number of RaA counts decreased for the period of October 3 to October 4.

The standard deviation of the flow rate was 0.7 l/min before the earthquake, and has decreased 0.2 l/min, after the earthquake among a day. This phenomenon is thought to be a decrease of the amount of the gas in the hot spring water as described in the next paragraph.

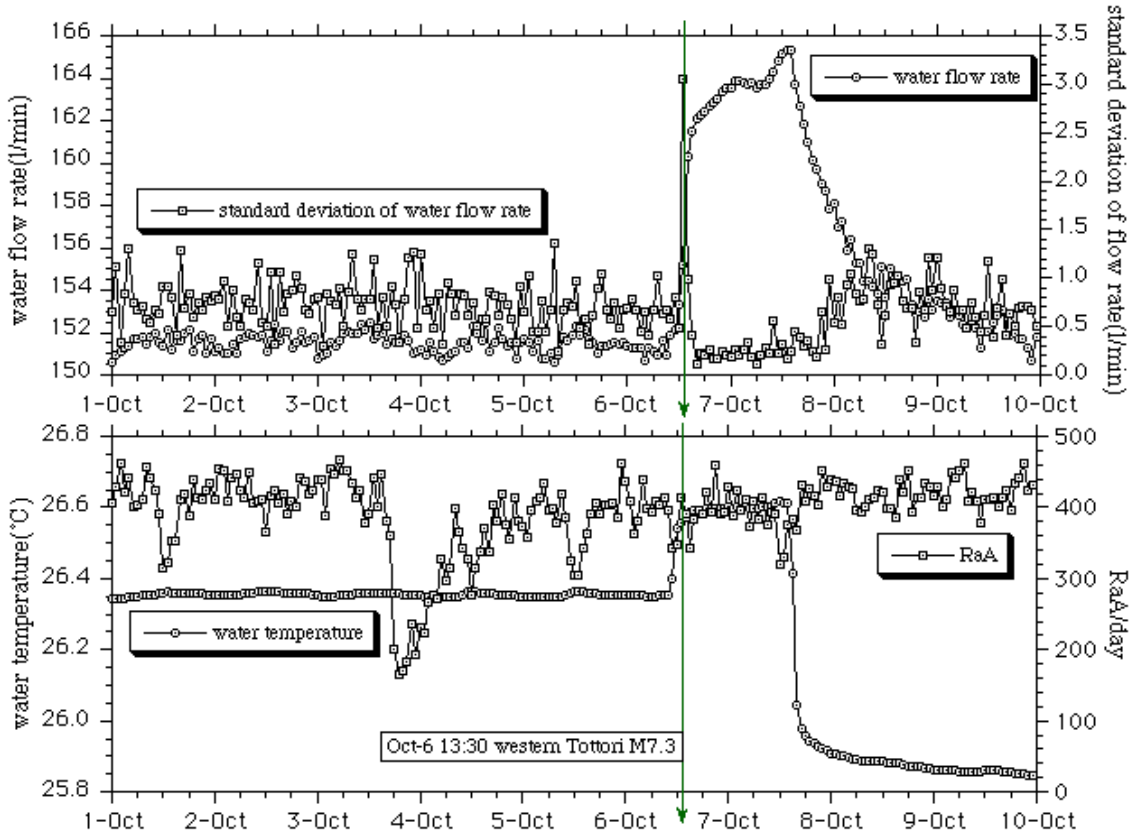

Fig.5 Pre-seismic changes in the water flow rate and the standard deviation of flow rate, temperature and the count rate of RaA of the hot spring water of accompanied to "Western Tottori Prefecture earthquake" on October 6, 2000.

The computer for the measurement accesses the NTP server at intervals of 12 hours and is doing the time match. The time of the computer has accurately synchronized with a Japanese Standard Time.

4) Amount of the gas in the hot spring water

The amount of the gas in the hot spring water has increased rapidly from November, 2001. When the ear was applied to the pipe, it heard of a big sound to which the gas gushed in water.

To measure the amount of the gas in the hot spring quantitatively, the standard deviation of the flow rate measured with an electromagnetic flow meter was analyzed. In view of the measurement principle of an electromagnetic flow meter, the fluctuations of the flow rate should be proportional to the amount of the gas in underground water.

Figure 6 shows an analytical result of the standard deviation of the flow rate for the observation period of March 30, 2003 from January 1, 2002. It turned out the amount of the gas in underground water that there were three stages, the maximum period (flowing quantity change of ±10 l/min), the middle period (flowing quantity change of ±4 l/min), and the minimum period (flowing quantity change of ±0.5 l/min). The maximum, middle and minimum period of the amount of the gas in water appear repeatedly. The amount of hot spring water was decreased for the minimum period. The maximum period was a period of July 4 to July 19, and a period of October 12 to November 9, 2002.

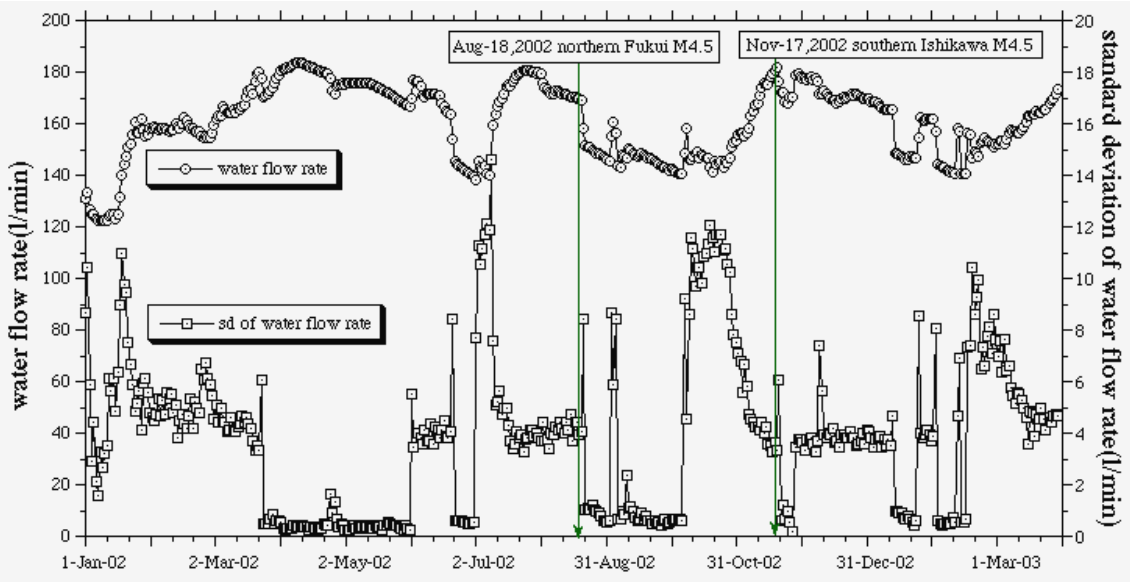

Fig.6 Water flow rate and the standard deviation for the observation period of March 30, 2003 from January 1, 2002, in "Heisei hot spring".

5) Radon observation results

The high sensitivity water radon detector has been installed on November-30, 2001, thinking that sensitivity was insufficient in the small water radon detector. Fig.7 is an observation result of the radon concentration for the period on March, 2003 from March, 2002. This figure indicates the standard deviation value of the water flow rate together. Number of RaA counts increases at the period of July 18 to August 5 of 2002, and the period of November 10 to November 19 of 2002.

The earthquake of M4.5 occurred from the observation point within about 50km in the northern part of Fukui Prefecture on August 18, 2002. Moreover, the earthquake of M4.5 occurred in the southern part of Ishikawa Prefecture on November 17, 2002. The maximum period of the amount of the gas was a common phenomenon of the pre-seismic signals of earthquakes before about one month the earthquake occurrence, and a rapid increase in the RaA counts rate was observed afterwards.

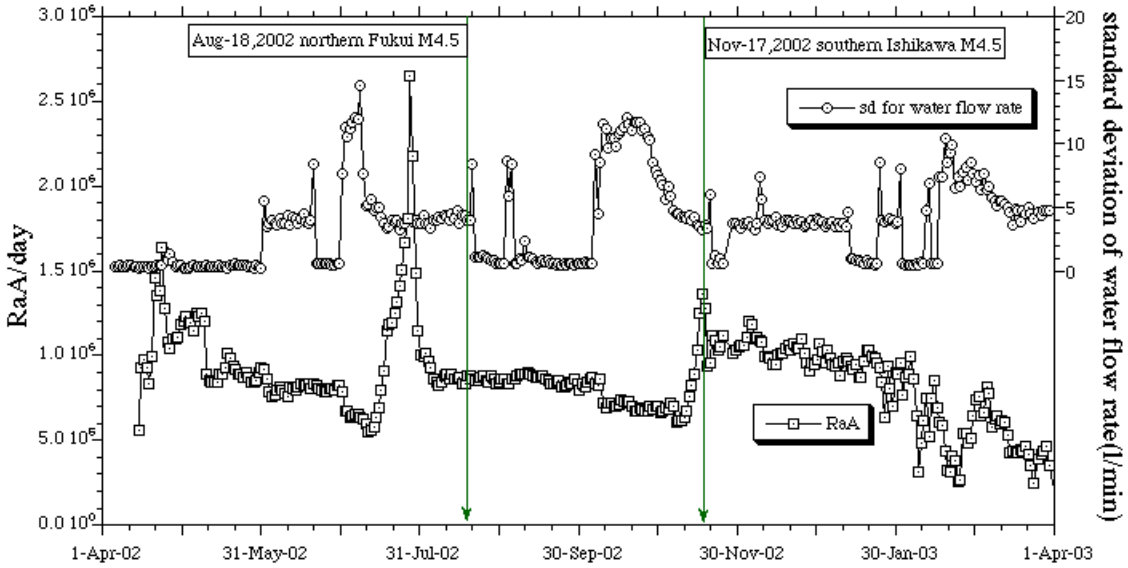

Fig.7 The number of RaA counts and the standard deviation of the water flow rate for the period on March, 2003 from March, 2002.

3. Wari-ishi hot spring

1) Amount of the hot spring water

The "Wari-ishi hot spring (KAM)" is located on the Atotsugawa Active Fault, where is Kamioka-Town in the north of Gifu Prefecture. The hot spring, with a depth of 850 meters, is an artificial well which emits water at about 40 l/min. The Kamioka-Town office persons who manages the hot spring, had measured the water temperature using a bulb thermometer and the water flow

rate using a water bucket, on every Monday over a period of 20 years. There have been three co-seismic and pre-seismic phenomena associated with seismic activity over the last 20 years. Figure 8 shows the observational result from May 1977 to December 1997. The amount of the hot spring water had decreased by about 70% before 17 days of the occurrence of the Central Japan Sea earthquake in 1983. This observation result might be a pre-seismic change of the earthquake.

(1)Water flow rate decreased by 60% before the 1983 Central Japan Sea earthquake (M7.7)

(2)Water flow rate increased by 20% after the 1984 Western Nagano earthquake (M6.8)

(3)Water flow rate increased by 20% after the 1993 Offshore Noto Peninsula earthquake (M6.6)

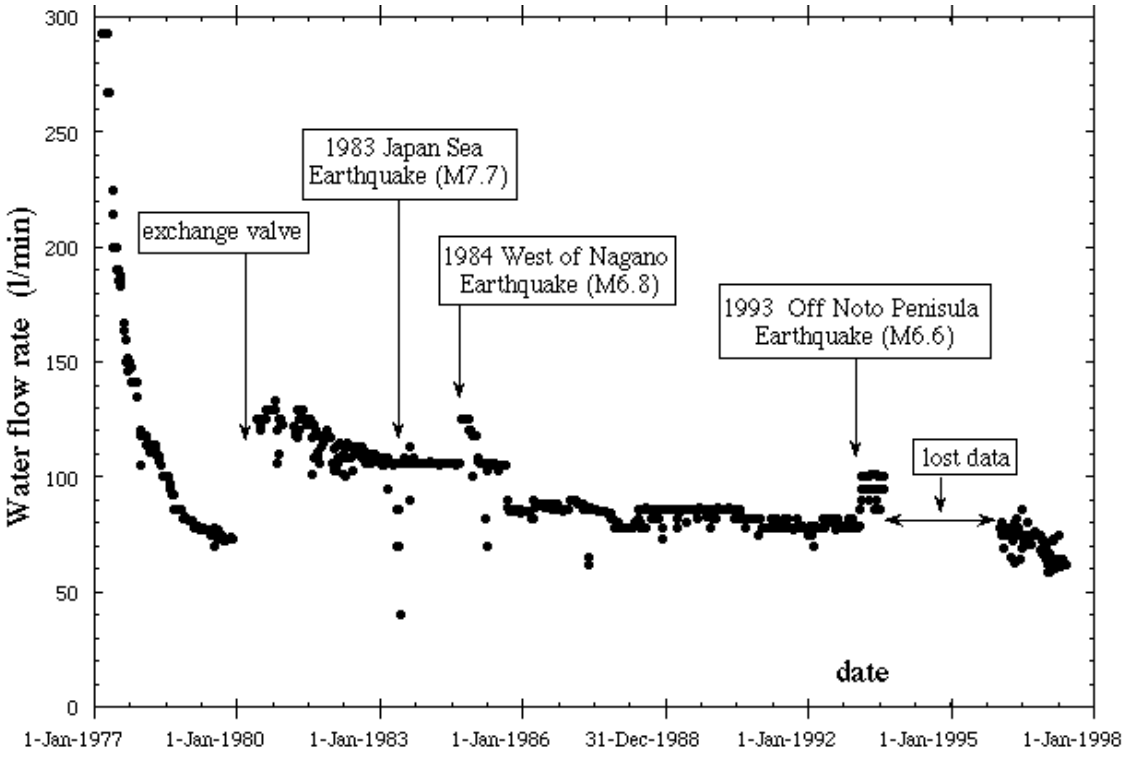

Fig.8 Observational results from May 1977 to December 1997. The water flow rate was measured at Wari-ishi hot spring with a bucket by the persons for the maintenance.

Since Wari-ishi hot spring is suitable for the observation of groundwater, we have carried out continuous monitoring of the radon concentration, the water temperature and the water flow rate of the groundwater. We began the research of the observation of the survey of the hot spring on July 7, 1998. Figure 9 shows the observation result of the amount of the hot spring water of 3.5 years until March, 2002.

The co-seismic and pre-seismic changes in the amount of the hot water by the electromagnetic flow meter were observed for this observation period, as the following four earthquakes.

(1) Hida region of Gifu Prefecture earthquake on August 16, 1998 (M5.4)

(2) West off Ishikawa Prefecture earthquake on June 7, 2000 (M5.8)

(3) Western Tottori Prefecture earthquake on October 6, 2000 (M7.3)

(4) Central part of Shizuoka Prefecture earthquake on April 3, 2001 (M5.3)

The standard deviation of water flow rate is related with the amount of gas in hot spring water. Pre-seismic and co-seismic changes of the standard deviation were observed in the three earthquakes in Fig.9. Decrease of the amount and the deviation of hot spring water were observed before about a month in Western Tottori Prefecture earthquake, and in Central part of Shizuoka Prefecture earthquake. The pre-seismic change of the amount of gas in the water is one of the important information from the crustal strain changes associated with earthquake.

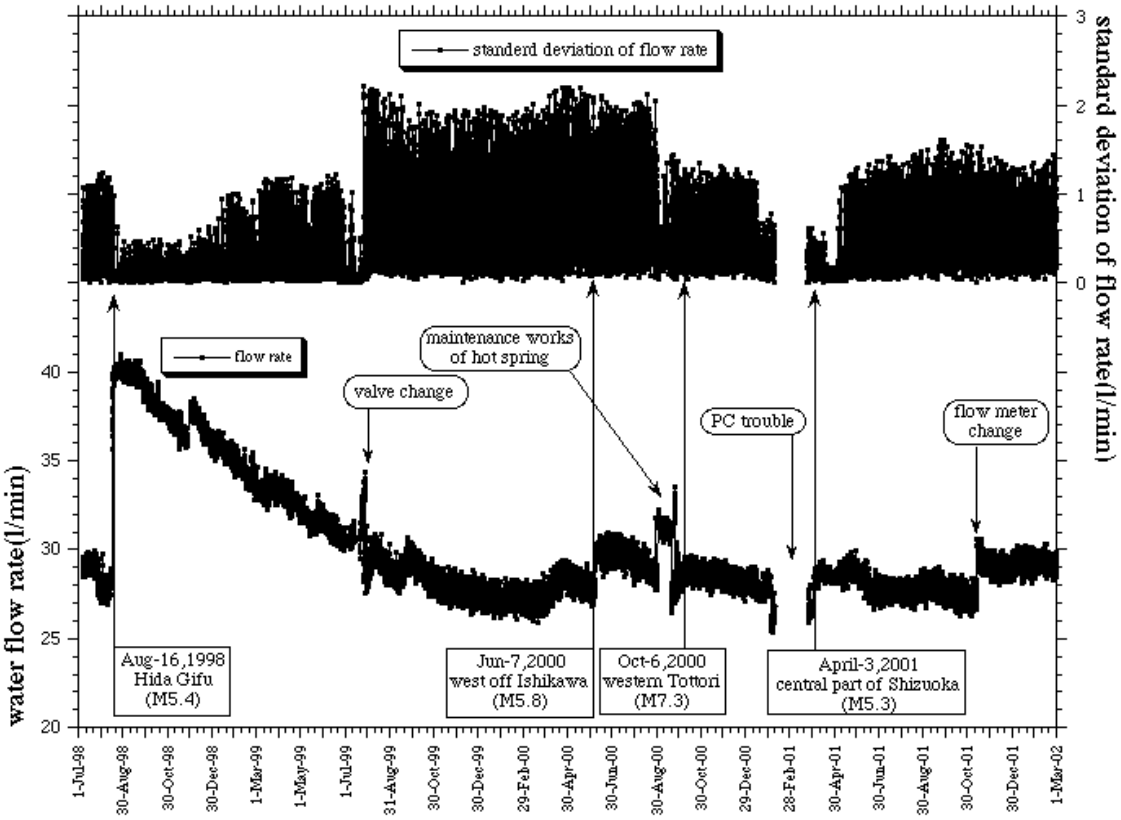

Fig.9 Observational results of the co-seismic and pre-seismic changes in the amount of the hot spring water and the standard deviation by the electromagnetic flow meter from July 1998 to March 2002.

2) Pre-seismic changes of accompanied to "Hida region of Gifu Prefecture earthquake"

The water flow rate at Wari-ishi hot spring has periodic fluctuations mainly induced by the earth's tides. There were pre-seismic phenomena of the series of earthquakes at Hida region of Gifu Prefecture from August 7, 1998. The hot spring is located about 30km from the epicenter.

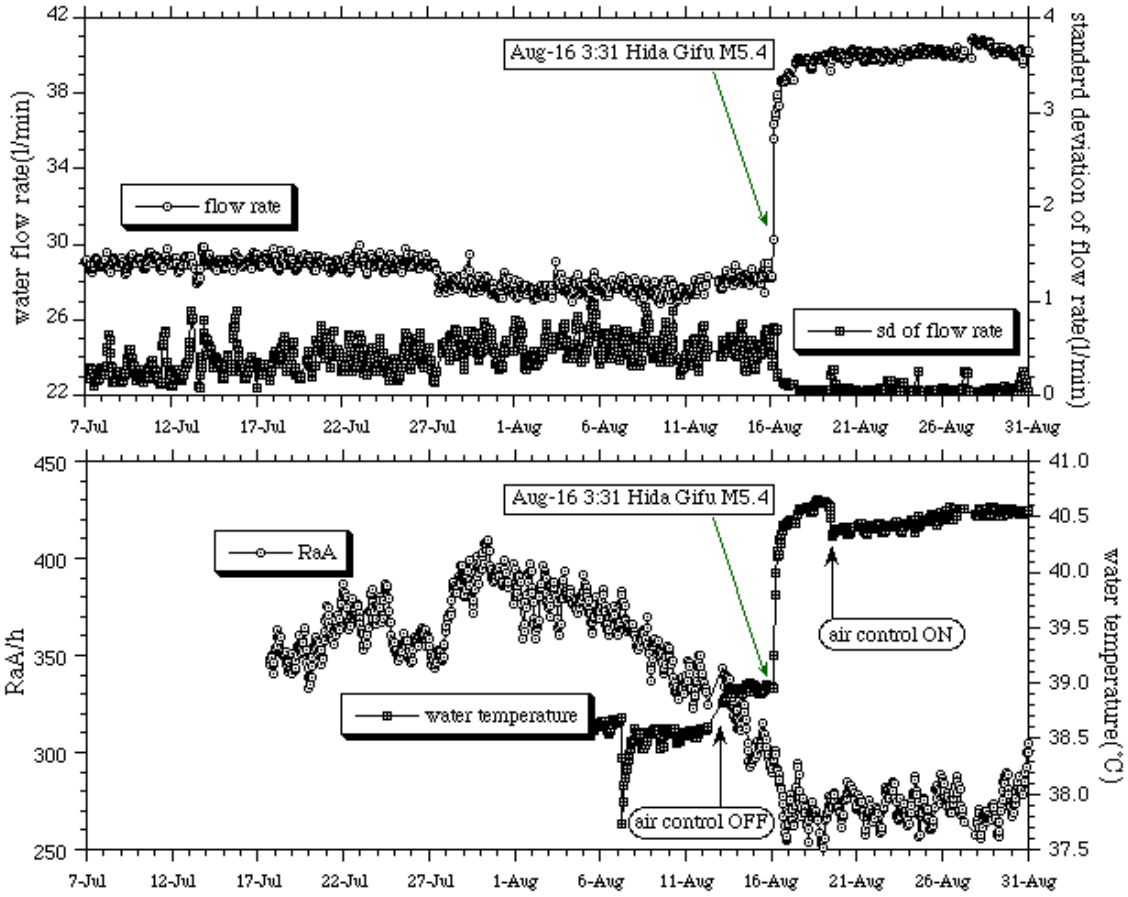

Fig.10 Pre-seismic changes in the water flow rate, the standard deviation of flow rate and the number of RaA counts of the hot spring water of accompanied to "Hida region of Gifu Prefecture earthquake" on August 16, 1998.

Figure 10 is the observation result of the amount of the hot spring water, the temperature of the fountain and the number of RaA counts. The amount of the hot spring water has decreased from 29 l/min to 27.3 l/min, and the number of RaA counts decreased before 3 weeks of the earthquake occurrence. The standard deviation of the flow rate was 0.2 l/min on July 7 when the measurement began. It increased up to 0.5 l/min on July 6 immediately before the earthquake, and has become 0.05 l or, less per minute for two weeks after the earthquake occurrence. There was the co-seismic change at Wari-ishi hot spring, where the water temperature went up about 1.5℃ and the water flow rate increased by 41 l/min, from 28.3 l/min, on Hide region of Gifu Prefecture earthquake of a magnitude of 5.4 at 3:31 August-16, 1998. The amount of the water decreased to 30 l/ min before the occurrence of the earthquake one year later.

4. Summary

We have observed the radon concentration, the flow rate and the temperature of the underground water in the 16 observation stations on the active faults in Gifu Prefecture, Center

Part Japan from August 1998. The high sensitivity radon detectors for water were installed in the "Heisei hot spring" in Izumi-Mura, the east of Fukui Prefecture, and "Wari-ishi hot spring" in Kamioka-Town, the north of Gifu Prefecture. Amount of the hot spring water was measured by the electromagnetic flow meter with the accuracy of 0.1 l/min, and the water temperature was measured by the precise thermometer with the accuracy of 0.01℃ in the water main pipe. The observation results in the underground water were displayed with the real time in the Web Page.

The many co-seismic and three pre-seismic changes were detected on Heisei hot spring and Wari-ishi hot spring. The pre-seismic anomalous changes accompanied to the three earthquakes, Hida region of Gifu Prefecture earthquake, west off Ishikawa Prefecture earthquake and western Tottori Prefecture earthquake, were summarized in this report.

Anomalous changes in the flow rate, the deviation of flow rate and radon concentration were observed at Wari-ishi hot spring, before 3 weeks of Hida region of Gifu Prefecture earthquake (M5.4) on August 16, 1998: decrease of water flow rate from 29 to 27.4 l/min, and increase of deviation of flow rate from 0.2 to 0.5 l/min, decrease of the number of RaA counts of about 40%, daughter nuclei of ^{222}Rn. The deviation of flow rate became 0.05 l/min or less among two weeks after the earthquake occurrence. The amount of gas in the hot spring water showed anomalous change before and after the earthquake occurrence.

The decrease of water flow rate from 183 l/min to 170 l/min, and temperature from 27.72 to 26.15℃ were observed at the Heisei hot spring, before 42 hours of west off Ishikawa Prefecture earthquake(M5.8) on June 7, 2000. The number of RaA counts was decreased gradually after the earthquake occurrence.

The increase of water flow rate from 151.5 l/min to 153.5 l/min, and temperature from 26.35 to 26.56℃ were observed at Heisei hot spring, before 2.5 hours of western Tottori Prefecture earthquake(M7.3) on October 6, 2000. The number of RaA counts decreased for the period of October 3 to October 4 before the earthquake. The standard deviation of the flow rate was 0.7 l/min before the earthquake, and has decreased 0.2 l/min after the earthquake among a day. This phenomenon is thought to be a decrease of the amount of the gas in the hot spring water.

Co-seismic and Pre-seismic changes of the amount of gas in hot spring water were observed with 5 earthquakes, Western Tottori Prefecture earthquake, northern part of Fukui Prefecture earthquake (M4.5), southern part of Ishikawa Prefecture (M4.5) in Heisei hot spring, and Hida region of Gifu Prefecture earthquake, Western Tottori Prefecture earthquake, Central part of Shizuoka Prefecture earthquake (M5.3) at Wari-ishi hot spring. The pre-seismic change of the amount of gas in the hot spring water is one of the important sign from the crustal strain changes associated with earthquake.