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Development of Groundwater Survey Methods Necessary for Safety Assessment Relating to the Geological Disposal of Radioactive Wastes

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ABSTRACT

In connection with groundwater surveys necessary for safety assessment of facilities for the geological disposal of radioactive wastes, this paper describes an ultra-low permeability test method for bedrock groundwater and a method for measuring the direction and velocity of groundwater flow, both developed by the Central Research Institute of Electric Power Industry (CRIEPI)

1. INTRODUCTION

To carry out safety assessment for geological disposal facilities for radioactive wastes, it is indispensable to investigate the conditon of groundwater flow. When constructing radioactive waste disposal facilities, a forecast is made of the leakage water during excavation of underground caverns.

Moreover, after the disposal has been made, the radioactive nuclides which migrate into the natural barrier through corrosion of the artificial barrier are carried into a sphere of life through the ground, thereby making it necessary, from the standpoint of safety assessment, to examine the condition of groundwater flow over a wide range from the vicinity of disposal facilities to the sphere of life and to forecast the underground migration of nuclides which are transported by the groundwater.

CRIEPI has been developing a method for evaluating the migration of radioactive nuclides which are tansported by the groundwater in the bedrock as shown in Fig.1. In the bedrock around the geological disposal facilities, it

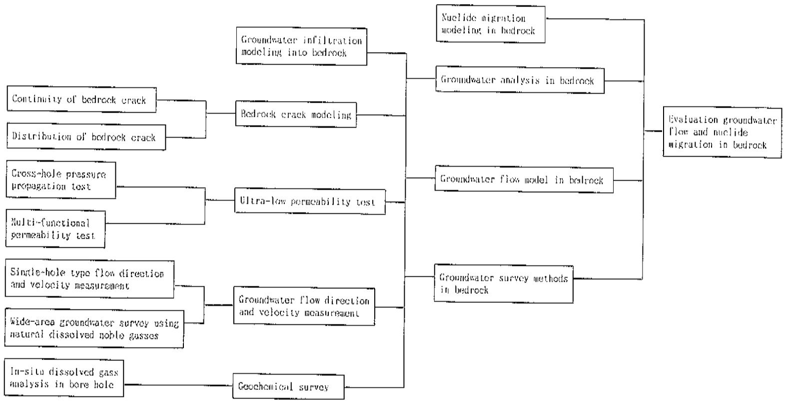


Fig.1 Resarch flow of evaluation groundwater flow and nuclide migration in bedrock at CRIEPI

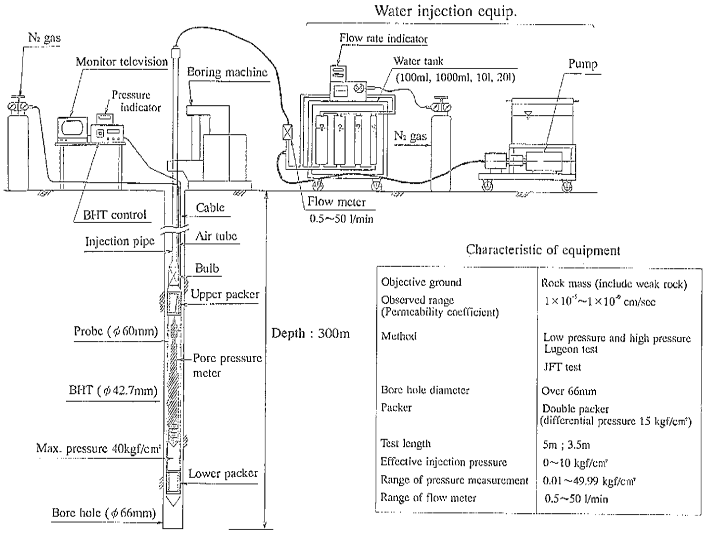
is estimated that the permeability of ground and the velocity of groundwater flow is both very low. To investigate these groundwater flow, therefore, it is necessary to develop a new groundwater survey technique because the conventional methods cannot make such a survey. This report describes, among these groundwater survey methods, an ultra-low permeability test method for bedrock groundwater and a method for measuring the direction and velocity of groundwater flow, both developed by CRIEPI in recent days.

2. ULTRA-LOW PERMEABILITY TEST METHOD FOR BEDROCK GROUNDWATER

To make safety assessment of geological disposal facilities, it is necessary to analyze numerically the groundwater flow. For this purpose, the permeability coefficient which indicates the permeability of the ground must be measured with a high accuracy in situ. CRIEPI has developed the following two devices capable of measuring a very low permeability coefficient.

(1) Multi-functional permeability test device with built-in TV camera

CRIEPI has developed a multi-functional permeability test device with built-in TV camera as shown in Fig.2. (Osumi et al. 1990) This device is aimed at measuring simultaneously the permeability coefficient of bedrock at prescribed depth and the pore water pressure in the boring hole of more than 66 mm in diameter. Also, using a TV camera, the condition of groundwater flow in the test section as well as the condition of boring hole walls can be observed.



Characteristic of equipment

Objective ground	Rock mass (include weak rock)
Observed range (Permeability coefficient)	$1\times10^{-5}\sim1\times10^{-9}$ cm/sec
Method	Low pressure and high pressure Lugeon test JFT test
Bore hole diameter	Over 66mm
Packer	Double packer (differential pressure 15 kgf/cm²)
Test length	5m ; 3.5m
Effective injection pressure	0~10 kgf/cm²
Range of pressure measurement	0.01~49.99 kgf/cm²
Range of flow meter	0.5~50 l/min

Fig.2 Multi-functional permeability test device

This device has the following features:

1) Using a single boring hole, the permeability test can be performed by the injection method (low-pressure Lugeon test; high-pressure Lugeon test) and the recovery method (JFT method).

2) A wide range of permeability coefficients (1×10^{-5} to 1×10^{-9} cm/sec) can be measured.

3) The packer can be installed while observing the condition of pore walls with a TV camera, to mitigate the danger of a water leakage through the packer during testing.

4) The characteristics of cracks in the permeability section can be observed by means of a TV camera, and the relation between cracks and permeability coefficients can be clarified.

5) The permeability test section can be shortened and the test can be

conducted on specific cracks.
An example of permeability test results obtained by using this device in two boring holes in granite is shown in Table 1. Permeability coefficients obtained by the test were in the range of 2.4 $\times 10^{-4}$ to 7.2 $\times 10^{-8}$ cm/sec. The difference between the permeability coefficient obtained by the injection method and that obtained by the recovery method was below the 1/2 order, which indicates that the device can measure a very low permeability coefficient.

boring No.	depth (m)	pore pressure (kgf/cm²)	K by injection method (cm/sec)	K by JFT (cm/sec)	
				Hvorslev method	Cooper method
No.2	-20.0～-25.0	2.08	4.3×10^{-7}	3.0×10^{-7}	1.6×10^{-7}
	-27.3～-32.3	2.63	2.4×10^{-4}	1.6×10^{-4}	2.3×10^{-4}
	-45.0～-50.0	4.28	9.3×10^{-8}	7.2×10^{-8}	1.1×10^{-7}
No.3	-21.5～-26.5	2.00	1.1×10^{-5}	1.1×10^{-6}	1.1×10^{-8}
	-33.0～-38.0	3.15	5.5×10^{-8}	6.5×10^{-8}	1.3×10^{-5}
	-50.0～-55.0	4.78	3.2×10^{-8}	3.2×10^{-8}	2.5×10^{-8}

Table 1 An example of permeability test in granite

(2) Cross-hole pressure propagation test device
To measure ultra-low permeability in bedrock, CRIEPI has developed a cross-hole pressure propagation device utilizing several boring holes as shown in Fig.3(Motozima et al. 1990).

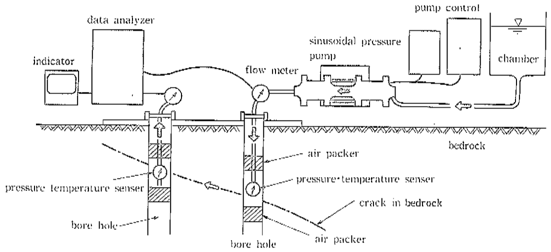


Fig.3 Cross-hole pressure propagation test device

This device has been developed with attention paid to the fact that in the saturated ground with low permeability, the water pressure propagation shows more sensitive reaction than the change of groundwater flow rate. The periodic change of water pressure generated in one boring hole is measured in another boring hole, while permeability coefficient and specific storage between two holes, are determined from the pressure damping or phase lag resulting from hydraulic characteristics between these boring holes.
This device is composed of a hole measuring unit, an on the ground measuring unit, a test pressure generator controller unit, and a processing and analytical unit. This device uses pressure sensors with high resolution (minimum 0.002 kgf/cm²) and micro flowmeters (minimum 0.5 1/min) as well as packers (5m length) for setting test sections, to prevent a leakage of water from hole walls, thus making it possible to conduct highly-accurate permeability tests in bedrock with very low permeability (10^{-10} cm/sec order). Moreover, sinusoidal pressure is automatically controlled at maximum 50 kgf/cm² and the maximum period of 1000 sec.
When the device was applied to the granite in the deep underground part of G.L. -400m with the layout of boring holes as shown in Fig.4, the following results were obtained.
1) In the sinusoidal pressure test, the pressure damping due to distance is very large as shown in Fig.5, and a different response is given as the pressure receiving hole varies by 1m. It was confirmed that the propagation of that pressure agreed with the direction with predominant bedrock joint.
2) The permeability coefficient is 1.4×10^{-9} cm/sec and the hydraulic diffusivity is 1 to 10 cm²/sec. These values are low in the same way as the results of conventional laboratory tests using boring cores.
3) As shown in these test spots, it was clarified that the permeability coefficient and hydraulic diffusivity of bedrock located in the deep underground part were very low, indicating a possibility that these values are much smaller than laboratory test results. These are important phenomena because they suggest the validity of geological disposal for high-level radioactive wastes.

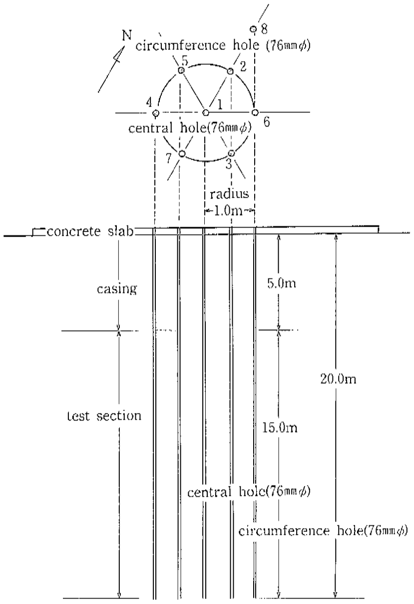


Fig.4 Layout of boring hole at cross-hole pressure propagation test

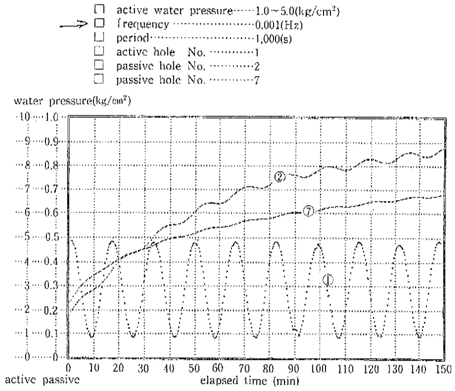


Fig.5 An example of the result of sinusoidale test

3. METHOD FOR MEASUREMENT OF GROUNDWATER FLOW DIRECTION AND VELOCITY

When making safety assessment of geological disposal facilities, it is necessary to grasp the direction and velocity of groundwater flow. For this purpose, CRIEPI has developed a single-hole method to measure local flow direction and velocity and a method of measuring a wide-area of values by the use of natural dissolved gas.

(1) Single-hole type flow direction and velocity measuring device

The direction and velocity of groundwater flow are generally estimated from the results of groundwater level measurements conducted in a large number of wells and tracer tests. To improve accuracy in these methods and economy as well, CRIEPI has developed a device which tracks the tracer injected in the goundwater crossing the single observation well and directly measures the direction and velocity of groundwater flow (Kawanishi et al. 1988). As a principle of measurement, the device performs measurement in the process where the distilled water used as a tracer which moves by the groundwater flow changes the specific resistance between electrodes arranged on a straight line bisymmetrically with the center electrode, in the boring hole of about 10 cm in diameter as shown in Fig.6.

The features of this device are as follows:

1) The direction and velocity of groundwater flow can be measured simultaneously in a single hole.

2) The flow velocity of 10^{-2} to 10^{-6} cm/sec order can be measured.

3) Continuous and repeated measurement at any depth can be performed efficiently.

Fig.7 shows an example where the direction and velocity of groundwater flow in the granite bedrock up to about 300m in depth were measured using this device.

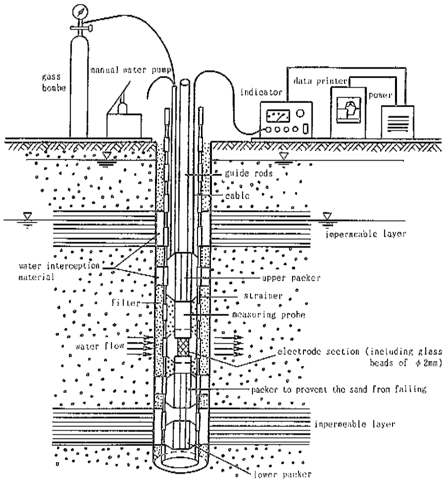


Fig.6 Sigle-hole type flow direction and velocity measuring device

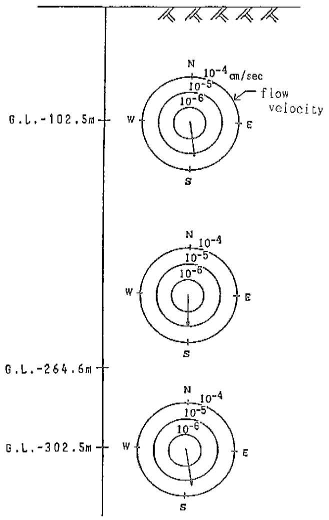


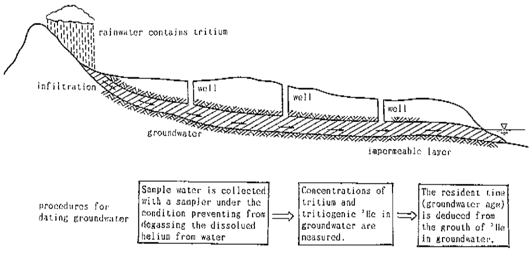
Fig.7 An example of the result of direction and velocity of groundwater flow measurement

(2) Wide-area groundwater survey method using natural dissolved noble gases

To conduct environmental impact assessment relating to the geological disposal of radioactive wastes, it is necessary to determine the flow of groundwater over a wide area. As one of these methods, a new technique is being developed to measure the flow of groundwater by tracking natural radioactivie materials dissolved in the groundwater, such as ^{3}H, ^{14}C, ^{36}Cl and ^{129}I. By measuring the change of the concentration of these materials in the groundwater with the lapse of time, it will be possible to estimate the time elapsed after the rainwater has infiltrated into the ground, that is, resident time. Among these radioactive nuclides, only ^{3}H (tritium) has been actually used so far. However, with recent decrease in the concentration of ^{3}H in the rainwater, there is an increasing difficulty in measuring the resident time. Therefore, to make up for the defect of this ^{3}H method and permit the estimation of resident time up to maximum 120 years in one measurement, the ^{3}H-^{3}He measuring method has been developed (Mahara, et al. 1991). It can be considered that in the confined groundwater layer as shown in Fig.8, the rainwater having an intrinsic ^{3}H concentration infiltrates into the ground.Also, in the rainwater which has infiltrated into the ground once, the supply of ^{3}H from the surrounding stratum is almost negligible, and the groundwater flows like a piston.
It can, therefore, be considered that the mixed diffusion due to groundwater flow is small. Under these condition, ^{3}H and ^{3}He (helium-3) which is produced by the β-decay of ^{3}H are measured simultaneously in respect to the same sample water, so that the groundwater resident time T can be determined by the following equation:

$$T = 17.69 \ln (4.01 \times [^{3}He]tri \ / \ [^{3}H] \ 10^{14} + 1)$$

$[^{3}He]$: Concentration of tritium in groundwater (T.U.)



Sample water is collected with a sampler under the condition preventing from degassing the dissolued helium from water

Concentrations of tritium and tritiogenic ^{3}He in groundwater are measured.

The resident time (groundwater age) is deduced from the grouth of ^{3}He in groundwater.

Fig.8 Wide-area groundwater survey by measuring method

$[^3He]tri$: Amount of ^3He produced by the β decay of tritium (cc STP/g)

To make practical application of this survey method, it will be necessary to develop an analytical device which can accurately measure a very small amount of gas dissolved in the groundwater and a device which can sample the groundwater in such a way that a very small amount of ^3He gas which is dissolved in the groundwater will not escape.

CRIEPI has imported a high-performance mass analytical device which can perform measurement up to 10^{-15} cc STP/g) (STP/g: amount of gas dissolved in the water of 1 g converted into cubic volume at 0℃ and 1 atmospheric pressure). Moreover, CRIEPI has developed a device which can sample water by lowering it to the prescribed depth in the boring hole and activating the two pressure-type cut-off valve located in the upper and lower parts of the sampling tube (ϕ = 10 mm, ℓ = 540 mm).

This ^3H-^3He groundwater resident time measuring method was applied to the groundwater in the Mishima lava layer located near Mishima City in Japan as shown in Fig.9, where the velocity of groundwater flow was measured by detailed hydro-geological survey, etc. in the past. As a result, it was found that the velocity of groundwater flow was 6 to 20 km/year (16 to 55 m/day). On the other hand, the flow velocity which was measured previously at the same spot by Ochiai et al. by using radioisotope flowmeter, etc. was 0.01 to 44 m/day. Accordingly, it can be said that the velocity of groundwater flow measured by the ^3H-^3He groundwater resident time measuring method is not so different from the value obtained by the conventional flow velocity measuring methods, and a good prospect has been obtained with regard to its application to the field.

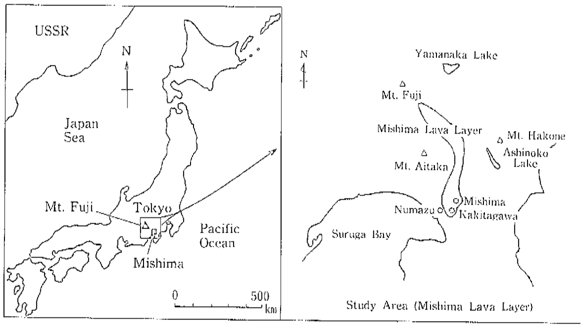


Fig.9 Groundwater flow which method was applied to

4. CONCLUSION

The survey methods developed by CRIEPI for safety assessment relating to the geological disposal of radioactive wastes have been discussed. Based on the results of these bedrock groundwater surveys, CRIEPI is to develop a bedrock groundwater flow model for further analysis of groundwater flow.

REFERENCES

Osumi, et al (1990). Development of in Situ Permeability Test Apparatus Equipped with Borehole TV Camera, 1990 Fall Meeting of the Atomic Energy Society of Japan. p724

Motozima et al (1990). Development of Cross-Hole Permeability Test Equipment, CRIEPI Report U90002.

Kawanishi et al (1988). Application of Groundwater Flow Meter with Single Well to Groundwater Flow Survey in Fractured Rock (1), CRIEPI Report U88014.

Mahara et al (1991). Survey of Groundwater Using ^3H ÷ ^3He Dating Method, Proceedings of the 3rd International Symposium on Advanced Nuclear Energy Research.