Development of Wireless Data Transmission System for the Monitoring in Geological Disposal of Radioactive Waste - 12063

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ABSTRACT

The authors have been developing a wireless data transmission system to monitor the performance of a geological disposal system for radioactive waste. The system's concepts, advantages, and a recent development focused on reducing transmitter size to suit narrow spaces such as bentonite buffers and boreholes. A wireless transmitter with a built-in temperature sensor and a connector for external sensors has been developed, measuring 130 mm in length and 50 mm in diameter. The capability of the transmitter was confirmed by transmission tests on the ground and in a bentonite block.

INTRODUCTION

To confirm the performance of a geological disposal system, the authors have been studying the feasibility of monitoring the phenomenological evolution in and behind the bentonite seals emplaced in various locations in the underground facilities of a geological disposal site.

In 2001, the IAEA [1] noted that the benefits from gaining data on the behavior of the system components need to be balanced against any detriments resulting from the process of monitoring. The potential detriments may include the formation of pathways through the barriers due to the installation of monitoring equipment, leading to increased potential for radionuclide migration within or around the repository. Monitoring cables that pass through seals could affect the confinement performance of the seals. To solve this problem, the authors propose monitoring that uses wireless data transmission.

This paper presents the concepts, advantages, and recent development of the wireless data transmission system.

CONCEPT OF THE DEVELOPMENT OF WIRELESS TRANSMISSION SYSTEM

Frequency of Electromagnetic Waves for Transmission

Wireless communication applications such as radio and television broadcasting, and cellular phone communication use very high frequency (VHF, e.g. 30 MHz) and ultra high frequency electromagnetic waves (UHF, e.g. 3 GHz). However, in media with electromagnetic conductivity, such as rock masses and bentonite, high-frequency electromagnetic waves are excessively attenuated. Consequently, the authors have been developing a wireless data transmission system that can be used in media such as rock and bentonite by using a very low frequency (VLF, approximately 10 kHz) electromagnetic wave as the data carrier.

Table I. Applications of Electromagnetic Waves of Various Frequencies

Frequency	Wave length	Application
500 THz	Visible light, ca. 600 nm	Traffic signal
3 GHz	Ultra high frequency wave (UHF), ca. 10 cm	Mobile phone
30 MHz	Very high frequency wave (VHF), ca. 10 m	TV
300 kHz	Medium frequency wave (MF), ca. 1 km	AM radio
10 kHz	Very low frequency wave （VLF), ca. 30 km	Wireless transmission in the barrier or rock

Distance and Concept of Transmission

The authors performed feasibility testing to develop three concepts for wireless transmission monitoring of geological disposal, including the design and manufacture of an optimum wireless transmission system. The system was designed to deal with several conditions and meet specified requirements, such as the electrical conductivity of the media, transmission distance, transmission period, and sensor location. Following are some of the key design components:

1. ***Short-range transmission***: sensors and transmitters are installed in the bentonite buffer inside the disposal cell and data are transmitted to a receiver placed on the cap of the cell. The transmission distance for this concept is assumed to be less than 30 meters (m).
2. **Mid-range transmission between two tunnels**: the receiver is placed in a tunnel that is separated from the tunnel where the sensors and transmitters are installed. The transmission distance in this concept is less than 100 m.
3. ***Long-range transmission:*** data from sensors installed in the underground facility are transmitted directly to a receiver on the ground surface. The transmission distance is

greater than several hundred meters.

The authors have developed various types of transmitters. The development of a prototype transmitter for mid-range transmission was reported by Takamura et al. in 2009 [2]. This paper focuses on the development of a short-range transmitter.

SHORT-RANGE TRANSMITTER DEVELOPMENT AND INSTALLATION

Development of Short-range Transmitter

Recent research has focused on short-range transmissions and reducing the size of the transmitter to fit into narrow spaces such as bentonite buffers and boreholes. The transmitter has a built-in temperature sensor and a connector for external sensors, and is 50 millimeters (mm) in diameter and 130 mm long. Other specifications of the transmitter are:

- Transmission distance: 15 m in rock and bentonite (depends on the ambient level of electromagnetic noise)
- Monitoring and transmission time: Preset control (one-way transmission from the transmitter to the receiver)
- Battery: Lithium battery: 3 years of 1 measurement/hour and 1 transmission/day
  10 years of 1 measurement /day and 1 transmission /week
  10 years of 1 measurement /week and 1 transmission /month
- Antenna type: Loop (coil) antenna with core
- Carrier frequency: 8.5 kHz
- Data bit rate: 75 bits per second (bps)
- Modulation: Phase modulation
- Number of sensors: 1 + installed thermometer
- Available sensor types: Linear Variable Differential Transformer (LVDT), potentiometer, strain gauge, (adaptor needed), DC voltage, DC current, vibrating wire etc.
- Antenna gain: - (Wavelength: ca. 30 kilometers (km) (8.5 kHz))
- Antenna pattern: Figure-eight
- Beam width: ± 45 °
- Major and side (minor) lobes: 0
- Front-to-Back ratio: Equivalence
- Aperture: 45 mm outer diameter, 40 mm inner diameter
- Area of coil is proportional to the power.

The internal construction is shown in Figure 1. A copper coil with an amorphous core is inserted in a pressure-tight PVC case. Sixty percent (60 %) of the interior space of the antenna is occupied by the lithium battery. A thermometer is installed inside the transmitter, 1 sensor can be connected outside the transmitter.

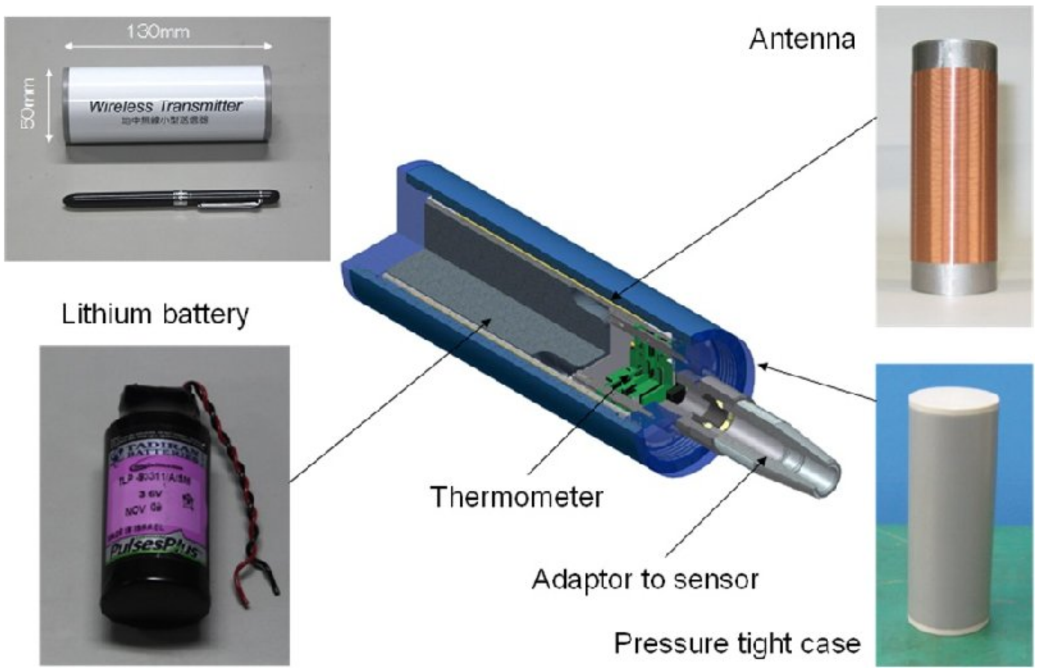

Fig 1. Internal construction of short-range transmitter.

Transmission Test on the Ground

A transmission test was carried out on the ground to confirm transmitter performance. In the test, the distance between transmitter and receiver ranged from 5 to 40 meters. The transmitter antenna was oriented either parallel (direction Y) or perpendicular (direction X) to the receiver antenna. Figure 2 shows the test results with design lines. As a reference, the received voltage of the prototype (for mid-range transmission) is also plotted in this graph. The graph shows that the received voltages matched the design line, meaning that the antenna performed as designed. The maximum transmission distance depends on the ambient level of electromagnetic noise. Figure 2 shows that the short-range transmitter can send data farther than 15 m against an electromagnetic noise background of 10 mV_{rms} (millivolt root-mean-square).

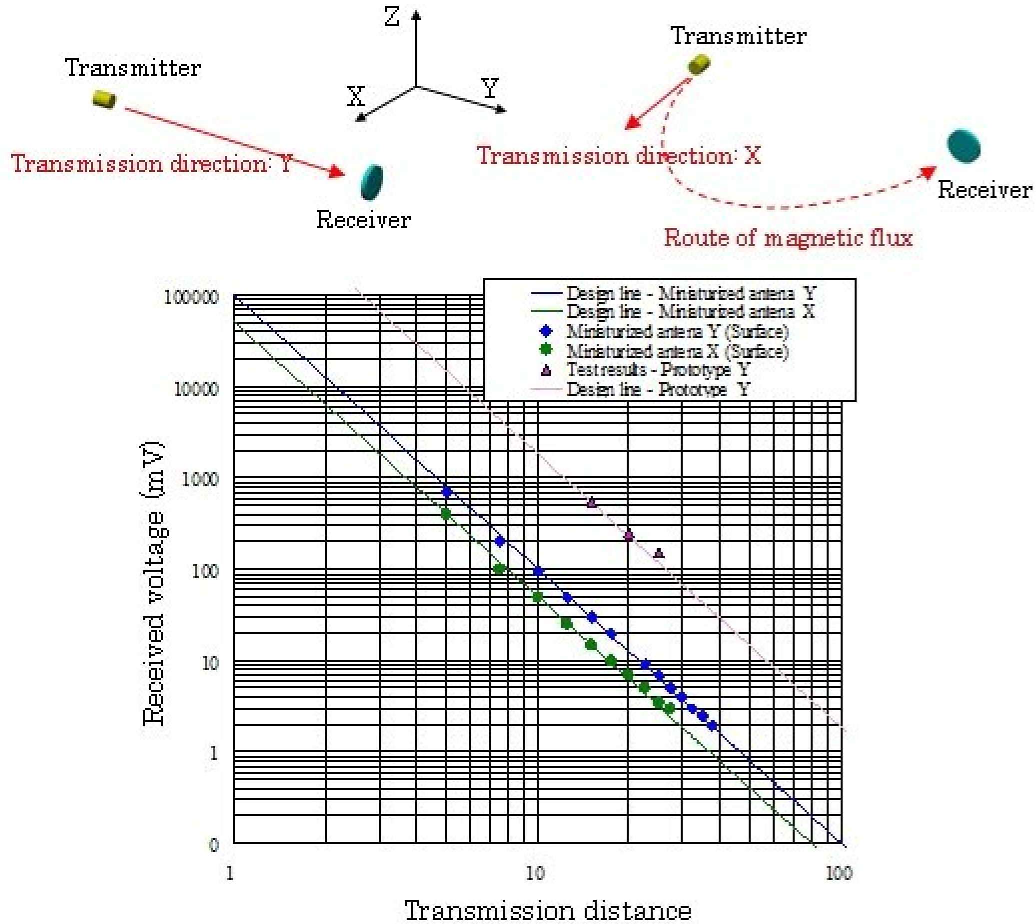

Fig 2. Results of the transmission test on the ground.

Installation of Short-Range Transmitter

When regions inside engineered barrier systems are monitored using conventional electric or fiber-optic cables, the cable routes passing through the seals can compromise the quality and performance of the seals. This disturbance may occur also in backfilling materials in drifts and bentonite plugs. Wireless monitoring can solve this problem.

A wireless transmission system can be installed with less impact on the quality and performance of the seals, using the “shot-clay method”. This method also simplifies the installation of the monitoring equipment. The shot-clay method allows engineered bentonite barriers to be constructed by spraying a mixture of powdered ice and chilled bentonite [3].

The authors demonstrated how to install the short-range transmitter in the bentonite block, using the shot-clay method. Figure 3(a) shows the set-up of the installation. The miniaturized transmitter was successfully installed in the bentonite block. Alongside the transmitter, the dry density of the bentonite was 1.6 Mg/m^3 (1600 kg/ m^3) as same as the designed value. No gap or potential water pathway was found between the transmitter and the surrounding bentonite (Figure 3(b)).

(a) Installation using the shot-clay method.

(b) Cut bentonite block around the transmitter

Fig 3. Installation of short-range transmitter in bentonite block.

After the installation of the transmitter, thermal data was transmitted continually for 10 days. Figure 4 shows the thermal data measured. The temperature inside the bentonite block, as measured by built-in thermometer in the short-range transmitter, shows a smaller range of fluctuation than that reported by a wired thermometer. The fluctuations were caused by the cyclic change of room temperature. The temperature of the wired thermometer seemed to be affected by heat conduction not only through the bentonite but also through the cable connected to the thermometer.

In this demonstration, the transmission distance was very short because the block size was 70 centimeters, so the received voltages were not measured.

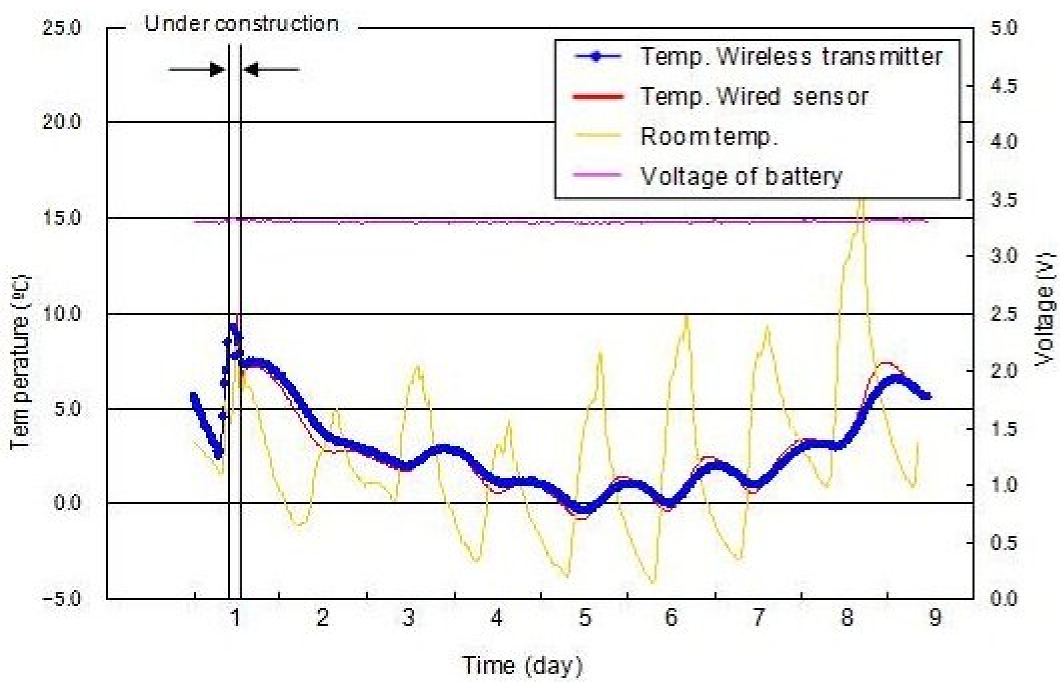

Fig 4. Thermal data measured by the miniaturized transmitter.

DISCUSSIONS

Advantages and Technical Challenges of Wireless Monitoring System

An advantage of the wireless data transmission system is that cables are not needed. As mentioned above, monitoring cables that pass through the seals can affect the confinement performance of the seals. The cables passing through the seals can form pathways for radionuclide migration within or around the repository. Additionally, as shown in the previous chapter, the cable connected to a sensor affects the monitored temperature by acting as a heat conductor. If a pathway for water is formed between the cable and the seals, other parameters such as pressure will also be affected. A wireless data transmission system will eliminate these problems.

However, there are several technical challenges for the wireless transmission system, such as increasing the data transmission rate, reducing the size of the receiver, ensuring pressure resistance, and the need to consider battery life as well as the service life of the sensors. Radiation resistance and heat resistance will also be challenges in the case of monitoring near high-level radioactive waste.

Future Research

Future research should focus on the technical challenges mentioned above. Recently, the authors have focused on reducing the size of the receiver for application in boreholes, and the results will be reported in the immediate future. The next challenges will be to increase the durability of transmitters and receivers in a high-pressure environment, and to integrate the monitoring system with its various sensors and its wireless transmission into a network. Development of long-lived energy sources is also an important issue for the wireless transmission system. Development of radiation-hardness and resistance to high temperatures will be performed on demand.

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ACKNOWLEDGEMENT

This R&D has been done under contract with the Ministry of Economy, Trade and Industry (METI) of Japan.