Direct Inspection Technology of Buried Piping for Managing Tritium Contamination in Groundwater at Wolsong NPP (CANDU-6 Reactor)

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1. Introduction

As a result of analyzing the unplanned release [1] at NPPs reported so far, the commonly detected radioactive material was tritium, although it is not known that the leaked radioactive material affected the health of nearby residents.

On April 2019, a maximum of 713,000 Bq/L of tritium was detected in the stagnant water in the manhole of the turbine gallery at Wolsong Unit 3; On May 2019, a maximum of 28,200 Bq/L of tritium was detected in monitoring well of Wolsong Unit 2 [2]. Since it was known to public that the groundwater at Wolsong NPP site was widely contaminated with tritium of radioactive materials, controversy over the safety of NPP arose in Korea.

Tritium is a radioactive isotope of hydrogen, and its nucleus is made up of one proton and two neutrons, which is about three times heavier than hydrogen made up of one proton. CANDU (CANada Deuterium Uranium) reactors [3] produce more tritium than most other types of reactors because they use heavy water in their moderator and heat transport systems.

In-depth on-site investigation should be conducted including analysis of measurement data, along with site excavation of underground pipelines that are presumed to be the main leak source, non-destructive inspection of the pipes, and review of domestic and international references, etc. Furthermore, there are no codes or accepted regulatory guidance for using the inspection technology to examine the buried piping of Korean NPP.

This paper suggests the direct inspection technology of buried piping at Wolsong NPP (CANDU-6 reactor) to solve the pending issue of tritium contamination in groundwater.

2. Safety Issues and Status of Inspection Technology

2.1 Tritium contamination in groundwater

In 2012, during the geotechnical construction of containment filtered venting system (CFVS) facility for Wolsong Unit 1, seven steel pipes were installed, and two of them were belatedly confirmed that they had penetrated between the walls of the spent fuel bay (SFB) and the waterproofing wall as shown in Figure 1. As a result, it was confirmed that the waterproofing membrane (floor) installed on the outside of the structure was damaged.

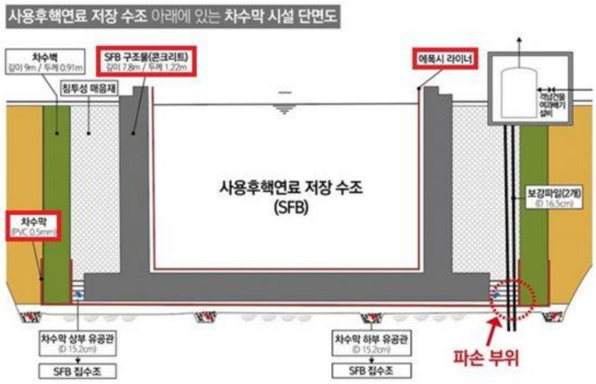

Fig. 1. Estimation of radioactive material leakage at Wolsong Unit 1.

After 2012, a maximum of 713,000 Bq/L of tritium was detected in the stagnant water in the manhole of the turbine gallery at Wolsong Unit 3 on April 2019. This high concentration of tritium would far exceed 40,000 Bq/L of KHNP's groundwater drainage system management standard [4].

In Wolsong NPPs, radioactivity is measured once a month in the sentry well and once a quarter in the surveillance well, and site boundary well to monitor unplanned outflow of radioactive material. On May 2019, the maximum concentration of tritium radioactivity measurements among 27 monitoring wells was reported up to 28,200 Bq/L in sentry wells near Wolsong Unit 2, up to 3,770 Bq/L in surveillance wells, and up to 1,320 Bq/L in site-bound wells as shown in Figure 2.

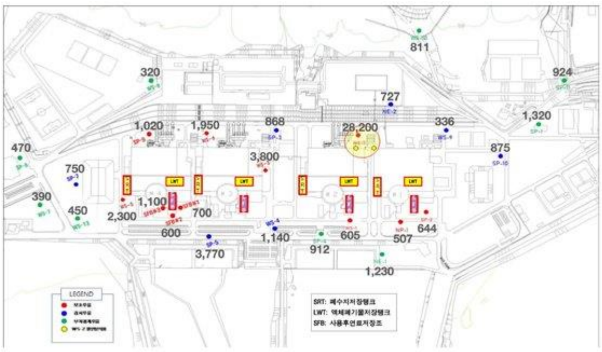

Fig. 2. Groundwater monitoring wells and maximum concentration of tritium on May 2019 at Wolsong NPPs (unit: Bq/L).

From the preliminary investigation report of Nuclear Safety and Security Commission (NSSC) [2], it has been confirmed that improving the aging management program for buried pipes and management of maintenance and discarded data of buried pipes is necessary. It is also suspected that radioactivity leakage is probably taking place in underground "buried pipes" that discharged contaminated water from experience of U.S. NPPs [5].

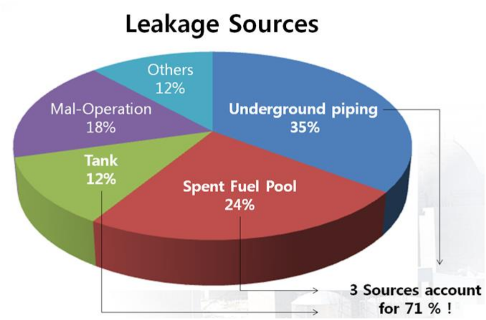

Fig. 3. Leakage sources of groundwater contamination at U.S. nuclear power plant [5]

2.2 The Buried Pipe Lines Issued at Wolsong NPP

The NSSC conducted the first-phase investigation at the Wolsong NPP site on April 2021. Figure 4 shows the buried pipe lines tested by civil investigation team [2]. The buried pipe lines that have become a major concern are as follows:

Point A:
- Pipe No. 5 (red) is a pipe buried at the time of construction of Unit 3, which supplies fire-water in the event of a fire.

Point B:
- Pipe No. 2 (black) is presumed to be a sewage pipe.
- Pipe No. 3 (yellow) is the drain pipe of Unit 3 turbine gallery newly buried in 2020. Originally, pipe No. 1 was used, but it was discarded and newly replaced with pipe No. 3.
- Pipe No. 4 (blue) is a drain pipe in the neutralization tank and is made of PVC.

Point C:
- This is where a separate excavation for investigating three pipes.

Point D:
- This area is excavated for removal of the CFVS facility at Unit 1. Due to excavation, the cooling pipe of the SFB is exposed to the outside.

Point E:
- This is the point where 28,200 Bq/L of high-concentration tritium was detected. Pipe No. 1 (red) is not in use now, but inspected.

Fig. 4. The buried pipe lines at Wolsong NPP site (by civil investigation team on April 2021 [4]).

2.3 Status of the Buried Pipe Inspection Technology

As the operation period of NPP has increased, the buried pipes faces an increase in defects due to aging, and a considerable amount of cost is required on repair and replacement. Accordingly, it is necessary to establish and perform an aging management program capable of systematically inspecting and managing buried pipes [6]. In the case of U.S. NPPs, EPRI has long developed a technology that can inspect buried pipes, and based on this, systematic management programs are presented and technical reports are prepared to support industrial guidelines of aging management program for the buried pipe [7]. However, there is no such activity in Korea yet. In order to establish this aging management program applicable to domestic NPPs, first of all, inspection technologies applicable for actual buried pipes at NPP must be investigated.

The inspection technologies applicable for buried pipe of NPPs can be divided into several methods, but in this paper, they are simply divided into indirect inspection method and direct inspection method. The indirect inspection method indirectly inspects internal flaws by excavating soil around the buried pipe and attaching an inspection device outside the buried pipe. While the direct inspection method directly inspects internal flaws by inserting an in-line vehicle (or Pipeline Inspection Gauge “PIG”) inside the buried pipe (Fig. 5).

There may be various indirect inspection methods, but the most practical is guided wave technology. However, the direct inspection is known to be the best way to directly investigate the inside of a pipe by mounting a camera, various non-destructive inspection devices, and sensors. In this paper, after grasping the current status of buried pipe inspection technology, introducing inspection technology, inspection device, and inspection method according to piping structure, we came up with a plan to directly inspect buried pipes by overcoming bend, pipe size change, valves, and branches.

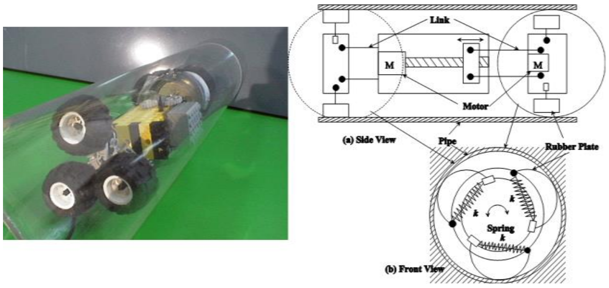

Fig. 5. The crawler inside the pipe.

3. Inspection Technologies for Buried Piping

3.1 Indirect Inspection Technology

The most applicable external (indirect) inspection technology is guided wave technology [8]. Guided ultrasonic waves vibrate the thickness of the tube at the boundary of the pipe wall and measure the reflection and return of a signal proportional to the rate of change in the pipe cross-section, and measure the thickness and position of the subject by detecting the reflected signal. Therefore, it is used for a long-distance pipe inspection from the probe location, and an area having difficulty in access may be inspected. However, it depends a lot on the condition or surrounding environment of the pipe, and detailed defects cannot be identified. Therefore, it is not an inspection method for quantitative evaluation, and can be applied for screening inspection.

3.2 Direct Inspection Technology

The direct inspection technology of buried piping is to determine the degree of defects on the pipe by attaching a non-destructive device to a crawler or robot driving inside the pipe and analyzing the signal obtained from the non-destructive device attached while the robot driving inside the pipe. Since the robot travels along the pipe, it is also referred to as In-Line Inspection (ILI).

To this end, it is important to select a non-destructive evaluation (NDE) technology that can be implemented to the robot inspecting flaws in buried pipes, and to design/manufacture the devices to be attached to the robot.

For the NDE devices developed in the United States, it is evaluated that SLOFEC devices have better flaw detection capabilities than MFL devices [9]. RFEC, PEC [10] or EMAT [11] devices may be attached to the crawler and used depending on the diameter or characteristics of the tube. The NDE technologies are compared in table I. These methods can be chosen depending on the aperture of the pipe, and in the case of medium and large pipes, various NDE devices are mounted mainly on a moving crawler, to inspect the flaws inside the pipe. This method has been used mainly in the oil and gas industries for decades, and many studies and experiences have been accumulated in foreign countries. However, in the case of buried pipes, changes in size of bend pipes, valves and branches should be considered, and additionally, cleaning of pipes is required. Therefore, there may be many practical limitations on application of the ILI systems to the buried pipes of NPP, which are currently used in the oil and gas industries.

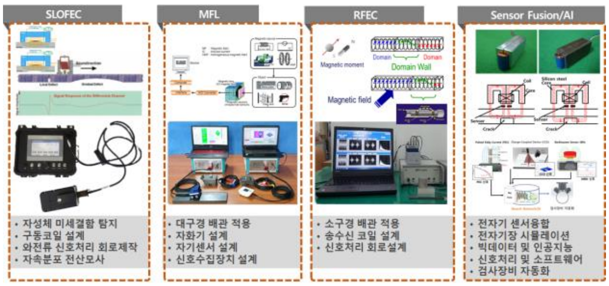

Fig. 6. The NDE technologies for direct inspection of buried piping of NPP.

In general, Remote Field Eddy Current (RFEC) technology can be applied to small-diameter pipes, and a device using Magnetic Flux Leakage (MFL) is attached to medium to large-diameter pipes. Recently, there has been a tendency to employ Saturated Low Frequency (SLOFEC) technologies with superior resolution than MFL. Regardless of the diameter sizes of the buried pipe, a crawler or robot is used for inline inspection. Therefore, a CCD camera is attached to the front of the crawler to conduct a visual inspection. If there are more than two attached sensors, it is necessary to bring together inputs from multiple sensors to obtain more accurate results, which is called sensor fusion technology. In particular, in environments isolated from human five senses, such as buried pipes, there is a very high risk of causing judgment errors when measuring objects or defects with only a single sensor. In this case, sensor fusion technology that reduces errors as much as possible by integrating information obtained from two or more sensors at the same target is very important. In addition, Artificial Intelligence (AI) defect identification technology should be introduced to continuously learn numerous data obtained from multiple sensors and to judge defects correctly. Figure 6 shows the NDE technologies applicable for direct inspection of the buried piping of NPPs. The main characteristics of the NDE devices are compared in Table I.

Table I: Comparison of Non-Destructive Evaluation Technologies

	RFEC	MFL	UT
Drag force	Weak	Strong	Mild
Inner/outer flaw detection	Inner/outer	Inner	Inner/outer
couplant needed?	no	no	yes
fill factor sensitivity (Passing through the diameter change or curved parts)	small (possible)	large (Special design needed)	large (Special design needed)
Signal processing	simpler	simple	more complex
on-line inspection	possible	Additional study needed	possible

4. Conclusions

From the investigation on tritium found at Wolsong NPP site by support of NSSC in 2021, it has been confirmed that improving the aging management program for buried pipes and management of maintenance and discarded data of buried pipes is necessary. We suggest the Non-Destructive Evaluation (NDE) technologies of buried piping to solve this pending issue of tritium contamination in groundwater.

NDE technologies for buried pipes include indirect measurement methods such as measuring electrical resistance of soil or direct method such as In-Line Inspection (ILI) methods that measure directly by inserting intelligent vehicles or crawlers into the pipes. Since the external inspection method requires excavation of the inspection site, it costs more to excavate the soil than the cost required for inspection, and in reality, it is impossible to excavate the entire section, so there is a limit to the actual buried pipe inspection. In addition, reliability is insufficient in terms of flaw detection. However, among them, guided wave technology is useful as a regular inspection that periodically inspects a screening test or a probe with it attached to a pipe. On the other hand, the ILI method, which is similar to applied in gas pipe inspection, is a most reliable technology at present even though relatively high cost.

Among NDT technologies applied in the ILI inspection, MFL and SLOFEC is adequate for medium and large pipe, and RFEC is more adequate for small and medium pipes. But, ultrasonic technology has to solve the couplant problems in order to apply in the squalid environments such as buried pipe.

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