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Original Article

VERIFICATION OF ELECTROMAGNETIC EFFECTS FROM WIRELESS DEVICES IN OPERATING NUCLEAR POWER PLANTS

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ABSTRACT

Wireless communication technologies, especially smartphones, have become increasingly common. Wireless technology is widely used in general industry and this trend is also expected to grow with the development of wireless technology. However, wireless technology is not currently applied in any domestic operating nuclear power plants (NPPs) because of the highest priority of the safety policy. Wireless technology is required in operating NPPs, however, in order to improve the emergency responses and work efficiency of the operators and maintenance personnel during its operation. The wired telephone network in domestic NPPs can be simply connected to a wireless local area network to use wireless devices. This design change can improve the ability of the operators and personnel to respond to an emergency situation by using important equipment for a safe shutdown. IEEE 802.11 smartphones (Wi-Fi standard), Internet Protocol (IP) phones, personal digital assistant (PDA) for field work, notebooks used with web cameras, and remote site monitoring tablet PCs for on-site testing may be considered as wireless devices that can be used in domestic operating NPPs. Despite its advantages, wireless technology has only been used during the overhaul period in Korean NPPs due to the electromagnetic influence of sensitive equipment and cyber security problems. This paper presents the electromagnetic verification results from major sensitive equipment after using wireless devices in domestic operating NPPs. It also provides a solution for electromagnetic interference/radio frequency interference (EMI/RFI) from portable and fixed wireless devices with a Wi-Fi communication environment within domestic NPPs.

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1. Introduction

The use of wireless technology in nuclear power plants (NPPs) has numerous advantages. Generally, wireless communication technology can be associated with a traditional wiring connection sensor and has the additional advantage of reducing cabling costs. Despite these advantages, it is difficult to apply wireless technology in operational NPPs due to problems with cyber security and electromagnetic interference/radio frequency interference (EMI/RFI). For instance, a wireless communication network is more vulnerable to hacking than a wired communication network. It has not been verified that safety and non-safety systems under EMI/RFI conditions have no problems during operation. The application of wireless technology, hence, has only been utilized during the overhaul period of domestic NPPs on the basis of safety having the highest priority. All domestic NPPs are trying to achieve operational efficiency, safe operation, and reduction of human error by using Information Technology (IT). The commercial nuclear industry will need to invest in the necessary infrastructure to support mobile technology [1].

Currently Korea Hydro and Nuclear Power Co., Daejeon, Republic of Korea, is pushing to adopt wireless devices at Hanbit 5,6 (HBN 5,6) as a pilot operating NPP. It is also trying to change the plant designs in order to connect existing telephone and Wi-Fi wireless networks. This paper proposes a separation distance limit for operating wireless devices in front of the instruments and control (I&C) equipment. This decision is based on testing results from the test-bed and field susceptibility tests. As a simple and effective method for reducing EMI problems caused by wireless devices, an exclusion zone around the system cabinets and areas where I&C equipment was installed was set up. This restricted area (exclusion zones) for using wireless portable devices was obtained from calculations and experimental results based on the latest criteria and standards.

2. Review of electromagnetic wave verification requirements

In order to use wireless communication in operating NPPs, the performance of the main equipment should be protected from the electromagnetic waves generated from portable wireless devices. The applied electromagnetic wave validation criteria of domestic NPPs are diverse and different depending on the year of NPP construction. In the case of HBN 5, which has been operating since 1995, the application reference date of the plant construction and operation was approved in the 1990s. HBN 5 used the Military Standards 461A of the US Department of Defense as validation criteria of electromagnetic waves at the time of plant construction. The Regulatory Guide 1.180 was first issued in 2000 as the test guideline of electromagnetic waves for the safety I&C system of NPPs. As analogue instruments have been gradually upgraded to digital instruments, validation criteria for electromagnetic waves are also needed. Currently, U.S. RG-1.180 Rev1 (2003) and EPRI TR-102323 have been applied as the validation criteria of the electromagnetic waves in domestic NPPs. These standards are summarized in Table 1. The frequency band of electromagnetic validation requirements was changed as follows: 10 kHz~1 GHz⇒30 MHz~10 GHz, based on the environmental changes of digital equipment from the analogue equipment in NPPs. However, the electrical field strength (10 V/m) requirements have not changed. In addition, the latest regulatory requirements (Reg. 1.180, Rev1) require the gain margin (8dB) to be larger than the operating envelope (140dB) in order to use wireless devices at operating NPPs. The electromagnetic emission and immunity tests of the associated test criteria (EPRI TR-102323 and Regulatory Guide 1.180 standard) have been revised to reflect the characteristics and technical analysis of the plant equipment. The I&C equipment is small-powered and digitized in NPPs. Therefore, an emission test of equipment may be used as a basis to maintain or reduce the emission limit values, because the equipment may be vulnerable to electromagnetic waves. An immunity test has

Table 1 – The changes in trends of radiated electric field standards in domestic nuclear power plants.

Test standards	Revision (yr)	Radiated emissions (RE102)		Radiated susceptibility (RS103)	
		Measuring frequency (MHz)	Allowable limit (dBμV/m)	Measuring frequency (MHz)	Allowable limit (dBμV/m)
EPRI TR-102323	Rev.1(1997)	0.01~1	80	0.01~1,000	140
		1~1,000	80~60		
	Rev.2(2000)	0.01~0.08	95~80	0.01(30)~10,000	140
		0.08~1	80		
		1~100	80~66		
		100~10,000[a]	66~80		
	Rev.3(2004)	2~100	44	0.01(30)~10,000	140
		100~10,000[a]	44~83.9		
Regulatory Guide 1.180	First Issue(2000)	0.1~2	95~59	0.01~1,000	140
		2~25	59		
		25~1,000	59~72		
	Rev.1(2003)	2~25	59	30~10,000	140
		25~10,000[a]	59~80		

[a] The test is performed up to 1 GHz in general. The test can be expanded up to 10 GHz by using a high frequency as necessary.

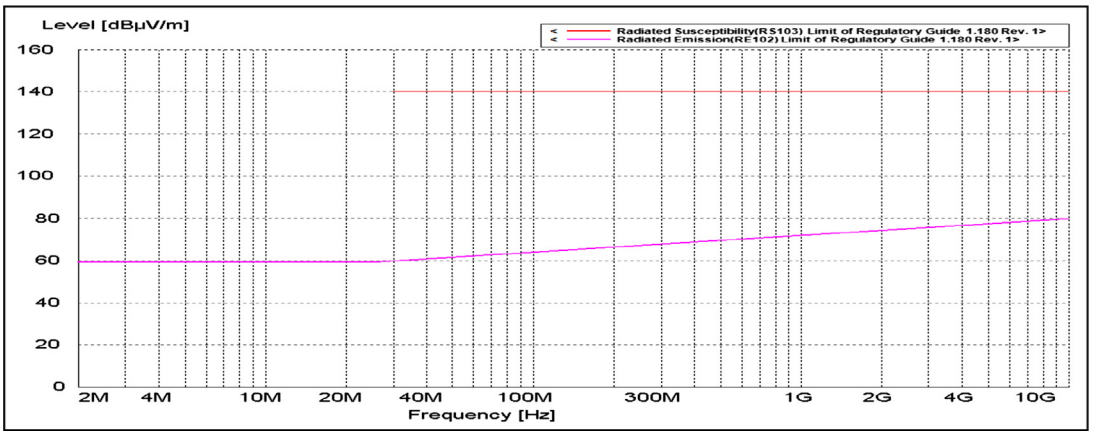

Fig. 1 – The noise emission limits and margin.

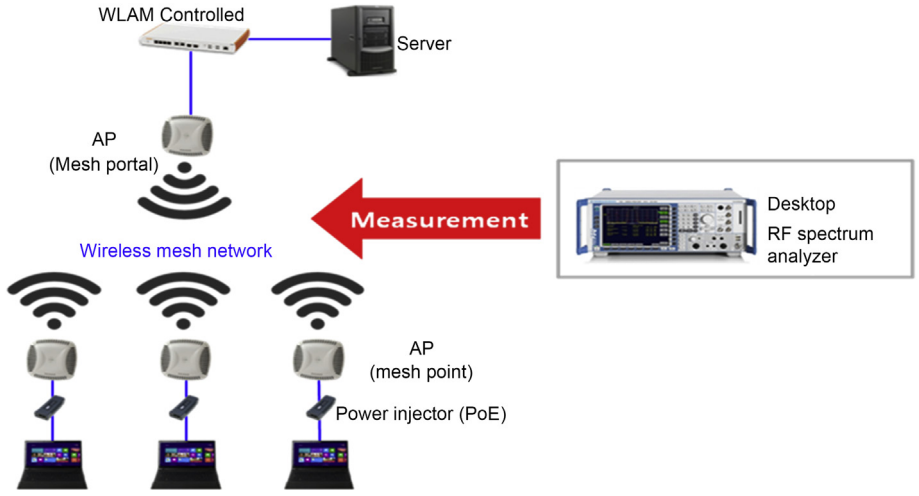

Fig. 2 – Test-bed configuration for measuring electric field strength of wireless devices.

also been applied to maintain the immunity level, but the test frequency range has changed directions in order to expand to a high frequency region. This reflects the use of high frequency for power plant equipment. Table 1 shows the changing trends of EPRI TR-102323 and the Regulatory Guide 1.180 standard associated with the radiated electric field tests of RS103 and RE102 [3, 6].

The United States Nuclear Regulatory Commission (USNRC) Regulatory Guide 1.180 (Rev. 1) standard describes electromagnetic wave technology requirements, and the guidelines are prevalently applied to domestic NPPs, including newly built NPPs.

Among these tests, the limit values of radiated electric field measurements on high-frequency radiation (Radiated Emission, RE102) and radiated field resistant (Radiated Susceptibility, RS103) are described in Fig. 1.

The equipment used in NPPs should not radiate an electric field over the RE102 measurement reference. Malfunction or deterioration of equipment should not occur upon exposure to an electric field of the RS103 standard. Fig. 1 shows that the minimum margin is 60 dB (1,000 times) in the 10 GHz band of high frequency, which falls between the limit values regarding radiation and immunity.

This confirms that there is a proper margin and electromagnetic compatibility.

To address the concerns of EMI/RFI from portable and fixed wireless devices within NPPs, the Nuclear Regulatory Commission (NRC) provided guidelines for establishing

Table 2 – Given operation conditions of wireless devices.

Frequency	Antenna power (Pt)	Antenna gain (Gt)
2.4 GHz Band (2.400 GHz~2.4835 GHz)	6.25 mW/MHz (Setting value 21 dBm)	2.24 (3.5 dBi)
5.7 GHz Band (5.725 GHz~5.825 GHz)	6.25 mW/MHz (Setting value 21 dBm)	2.88 (4.6 dBi)

Table 3 – Maximum values of antenna power for wireless devices.

Frequency	Separation distance	Max. vertically polarized wave (dBμV/m)		Max. horizontally polarized wave (dBμV/m)	
		1.05 m Height	1.55 m Height	1.05 m Height	1.55 m Height
2.4 GHz band	0.1 m	129.28	127.27	112.29	112.78
	0.27 m	124.97	125.36	111.98	113.77
	0.5 m	121.08	119.69	107.41	106.87
	1.0 m	115.82	114.97	103.99	103.17
	2.0 m	112.41	109.69	100.44	102.15
	2.7 m	109.18	109.41	104.25	100.33
5.7 GHz band	0.1 m	126.22	127.78	129.22	125.79
	0.27 m	120.47	122.88	125.27	125.66
	0.5 m	114.71	116.19	119.49	120.14
	1.0 m	107.61	110.05	114.81	114.07
	2.0 m	104.29	104.91	109.40	107.88
	2.7 m	97.52	104.82	106.42	106.94

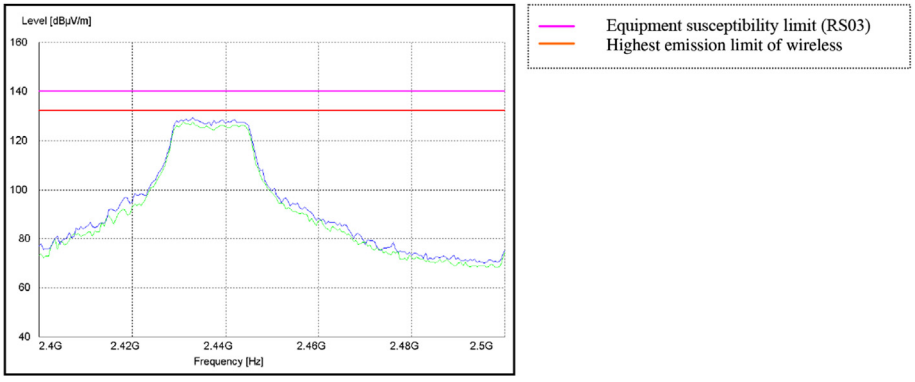

Fig. 3 – 2.4 GHz band/vertically polarized wave/0.1 m distance. Blue line, 1.05 m height; green line, 1.55 m height.

exclusion zones to prohibit the activation of portable EMI/RFI emitters (for example, welders and transceivers) in areas where safety-related I&C equipment is employed. The exclusion zone is the minimum distance allowed between a sensitive I&C system and EMI/RFI sources. The size of each exclusion zone is dependent on the electric field emissions allowed within a certain area. The size of the zone is determined using an 8dB difference between the susceptibility operating envelope and the allowable radiated electric field (E). For example, for the radiated electric field operating envelope of 10V/m (140dBμV/m), the resulting exclusion zone (D) would be based on an allowable radiated electric field of 4 V/m (132 dBμV/m):

$$D = \frac{\sqrt{30 P_t G_t}}{E} (meter) \quad (1)$$

where E = the allowable radiated electric field strength of wireless device (V/m), P_t = wireless output power (Watt), and G_t = antenna gain.

It is clear that using low power will result in smaller exclusion zones and ultimately greater flexibility in the wireless system when installing wireless devices. The

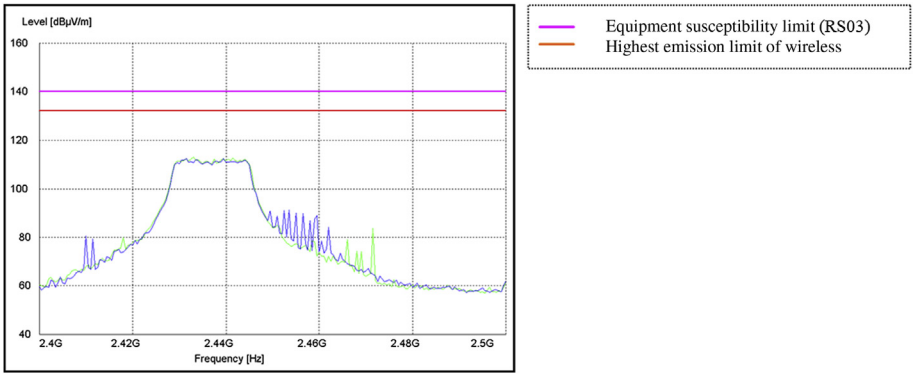

Fig. 4 – 2.4 GHz band/horizontally polarized wave/0.1 m distance. Blue line, 1.05 m height; green line, 1.55 m height.

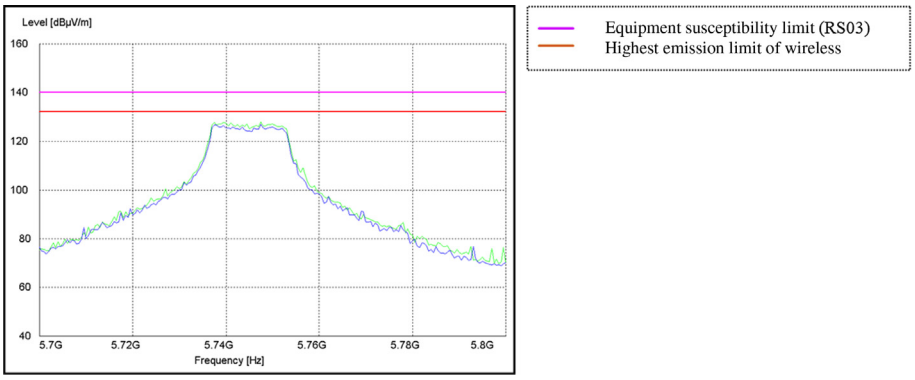

Fig. 5 – 5.7 GHz band/vertically polarized wave/0.1 m distance. Blue line, 1.05 m height; green line, 1.55 m height.

minimum exclusion zone of a wireless portable device from I&C equipment can be calculated as 27 cm from the above equation [Eq. [1]] [1].

3. The establishment of validation criteria for electromagnetic influence tests

3.1. *Overview of the test facility*

Measuring of the field intensity of wireless devices in Wi-Fi environments is necessary before performing a field test of the electromagnetic influence in order to consider using wireless devices in HBN 5,6. Domestic NPPs have not yet decided the kinds of wireless devices to be tested, but they have considered a Wi-Fi network as the communication standard (802.11a/b/g/n). Normally, Wi-Fi wireless communication technology uses a dual-band (2.4 GHz/5 GHz) while the maximum transmitted power of wireless portable devices is < 10 mW. In order to simulate the use of wireless devices in NPPs, we constructed a test facility that can maintain the maximum output of wireless devices, as seen in Fig. 2.

Generally, wireless devices do not generate a continuous radiofrequency for 10 minutes or longer. In addition, it is difficult to measure the electric field intensity for wireless devices because of the automatic changes in communication channels and frequency bands. Therefore, this test facility provides the following functions: (1) ensuring sufficient time; (2) having a fixed frequency band; and (3) generating a continuous maximum output for measuring the radiation level of wireless devices. The configuration of the test facility is shown in Fig. 2 [2].

To simulate the maximum output of wireless devices, large files were transmitted by the test-bed and a test was conducted under conditions of the maximum output being continuously generated at the fixed frequency band.

The antenna power (AP) program value of the antenna power for the repeater (mesh portal) and terminal (mesh point) is shown in Table 2.

The measurement of the electromagnetic radiation level for wireless devices was performed in an electromagnetic anechoic chamber as a preliminary test before the field test. The measurement results were used as comparison data in the field test. The experimental value was expected to be similar to the theoretical value, since there were no reflective waves except for those produced by the floor in the electromagnetic anechoic chamber. This interference effect of the wireless devices was tested according to the separation distance, quantity, and height.

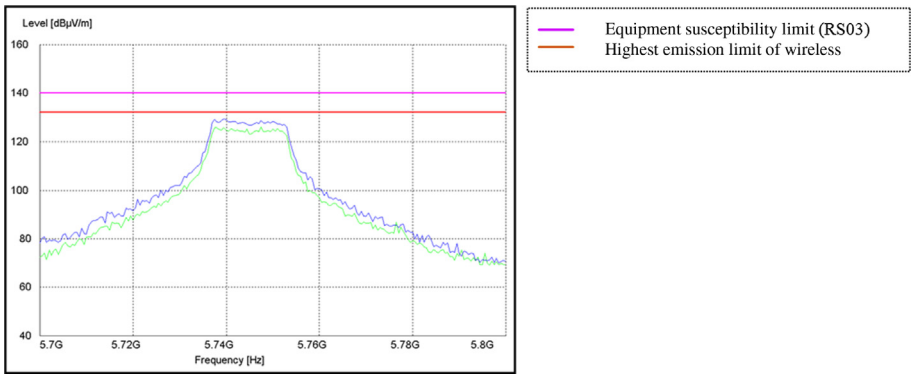

Fig. 6 – 5.7 GHz band/horizontally polarized wave/0.1 m distance. Blue line, 1.05 m height; green line, 1.55 m height.

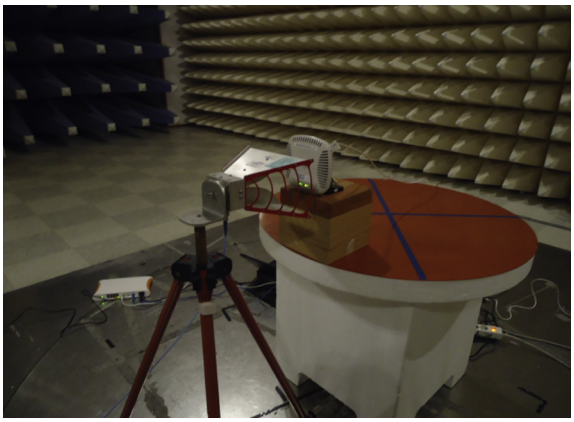

Fig. 7 – Measurement setup (AP1/1.05 m/vertically polarized wave).

3.2. *Measurement results of the wireless devices' electric field strength*

3.2.1. *Height effect of the AP for wireless devices*

The electric field strength was measured at different heights (1.05 m and 1.55 m) of AP for the wireless devices and frequency bands of 2.4 GHz and 5.7 GHz, respectively. The different heights were considered to simulate a user of a wireless handheld device in sitting and standing positions. The measurement results are shown in Table 3.

A slightly higher level of electric field strength was measured at a height of 1.05 m and a close separation distance as seen in the Fig. 7. These results may have been due to the frequency's higher linearity for a shorter wavelength.

Figs. 3–6 show a comparison of the received field strength of the 2.4 GHz and 5.7 GHz bands at a separation distance of 0.1 m.

4. Electromagnetic effect tests for using wireless devices

Generally, when measuring the radiated noise at an NPP, it is necessary to first look for the place where the strongest electromagnetic radiation occurs and also to select equipment that is the most sensitive to the emitted electromagnetic waves. I&C equipment can be extremely sensitive to electromagnetic effects in NPPs due to the abundant inclusion of semiconductor components. This equipment is mainly located in the main control room and ancillary equipment rooms. Therefore, the measurement of radiated noise for wireless devices was carried out in order to evaluate the impact assessment in the main control room and ancillary equipment room.

4.1. *Selection of sensitive equipment*

EMI/RFI sensitive equipment typically refers to devices receiving a response from electromagnetic radiation. The chosen sensitive equipment is expected to be the most sensitive to EMI in the main control room and ancillary equipment room. Twenty control cabinets, including the plant protection system and the turbine control system, were selected. These types of equipment contain a complex circuit with active elements inside as a main safety equipment for NPPs. If the cabinet of the same system is duplicated during the field test process, the performance of only one representative model is evaluated. Table 4 presents the results of an immunity test of 11 selected target systems that was carried out to measure the electromagnetic environment in HBN 5 [4]. The Table 5 is the result of immunity test.

4.2. *Field susceptibility test for sensitive equipment*

This test aimed to confirm whether degradation or malfunction of sensitive equipment performance by a generated electric field of high frequency occurred when using wireless devices in a Wi-Fi environment at HBN5.

The test measured the electric field strengths for three AP where the devices are operated 0.1 m, 0.27 m, and 0.5 m in front of the selected sensitive equipment.

The measurement procedure is as follows. The measurement setup (AP1/1.55 m) is shown in Fig. 8.

(1) The measuring devices and the target equipment for field tests are arranged as shown in Fig. 9.
(2) The meter is turned on and sufficient warm-up time is provided. The horn antenna is installed at a height of 1.05 m, which simulates the user of a hand-held

Table 4 – Details of selected sensitive equipment.

Test location	I&C sensitive equipment	Cabinet no.
MCR	Plant protection system (PPS)	PM14
	Core protection calculator (CPC)	PM15
EER 'A'	Plant data acquisition system (PDAS)	PA19
	TBN control system (TCS)	PA16
	Seismic monitoring system (SMS)	PA14
EER 'B'	Plant control system (PCS)	PA02-15/09
		PA03B-12/12
	Plant data acquisition system (PDAS)	PA31
	NSSS control system (NCS)	PA34
TGB 100'	Feed water pump TBN control panel (FWPT)	526-LP02
TGB 135'	TGM panel	511-LP05

EER, electrical equipment room; TGB, turbine generator building.

Table 5 – Immunity test results for sensitive equipment.

Measurement location	System	Cabinet No.	Measured maximum field strength (dBμV/m)				Malfunction	Determination method
			2.4 GHz Band		5.7 GHz Band			
			Vertical	Horizontal	Vertical	Horizontal		
MCR (main control room)	Plant protection system (PPS)	PM14	129.59	123.17	124.72	129.14	N/A	Data recording
	Core protection calculator (CPC)	PM15	126.25	122.78	122.36	127.47	N/A	Data recording
EER (electrical equipment room) 'A'	Plant data acquisition system (PDAS)	PA19	129.59	125.49	133.36	131.59	N/A	Data recording
	TBN control system (TCS)	PA16	134.48	128.28	124.86	131.60	N/A	Data recording
	Seismic monitoring system (SMS)	PA14	133.63	128.81	125.17	131.63	N/A	Data recording
EER (electrical equipment room) 'B'	Plant control system (PCS)	PA02-15/09	130.16	121.98	128.97	134.41	N/A	Data recording
		PA03B-12/12	129.28	127.87	124.59	131.28	N/A	Data recording
	Plant data acquisition system (PDAS)	PA31	128.19	123.30	124.44	128.25	N/A	Data recording
	NSSS control system (NCS)	PA34	125.60	122.41	123.98	128.47	N/A	Data recording
TGB (turbine generator building) 100'	Feed water pump TBN control panel (FWPT)	526-LP02	136.06	129.16	134.33	132.49	N/A	Data recording
TGB (turbine generator building) 135'	TGM panel	511-LP05	126.06	125.49	133.74	134.79	N/A	Data recording

Common items
- The antenna power (AP) for the wireless device is 6.5 mW and immunity tests were carried out with three bonds.
- The test was performed in conditions with the door of the measured equipment open and closed.
- The minimum separation distance between the sensitive equipment and wireless devices for AP is 10 cm.
- The emission limit of the electric field for the wireless device is 132.00 dBμV/ m.

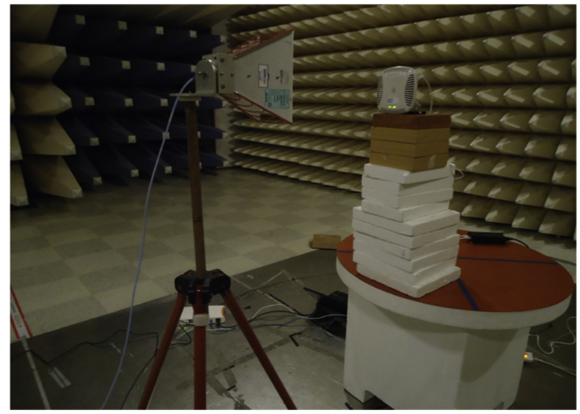

Fig. 8 – Measurement setup (AP1/1.55 m/horizontally polarized wave).

wireless device in a sitting position in front of the I&C cabinet.

(3) The setting values of the instrument, the correction coefficient of the antenna, and the loss of cable inputs to the program is checked.

(4) The measurement mode of the frequency band (2.4 GHz~2.5 GHz and 5.7 GHz~5.8 GHz) to the EMI Receiver is set to "SCAN" and "Maxhold". The vertical and horizontal polarizations are measured repeatedly (10 times) to obtain the maximum value.

(5) This test was performed by changing the distance (0.27 m, 0.5 m) between the receiving antenna and the wireless devices to 0.27 m. The process of (4) is repeated.

(6) The wireless devices can be 10 cm from the sensitive equipment. This is to verify the performance of the equipment. The door of the equipment is also evaluated in both opened and closed conditions at this time.

(7) The measurement and resistance evaluation results are recorded.

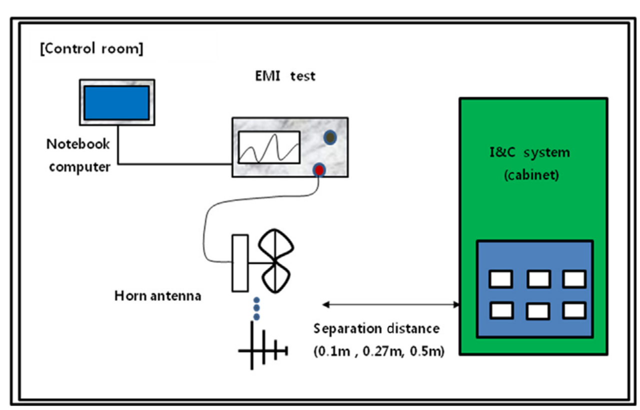

Fig. 9 – Field tests for wireless portable devices. EMI, electromagnetic interference; I&C, instruments and control.

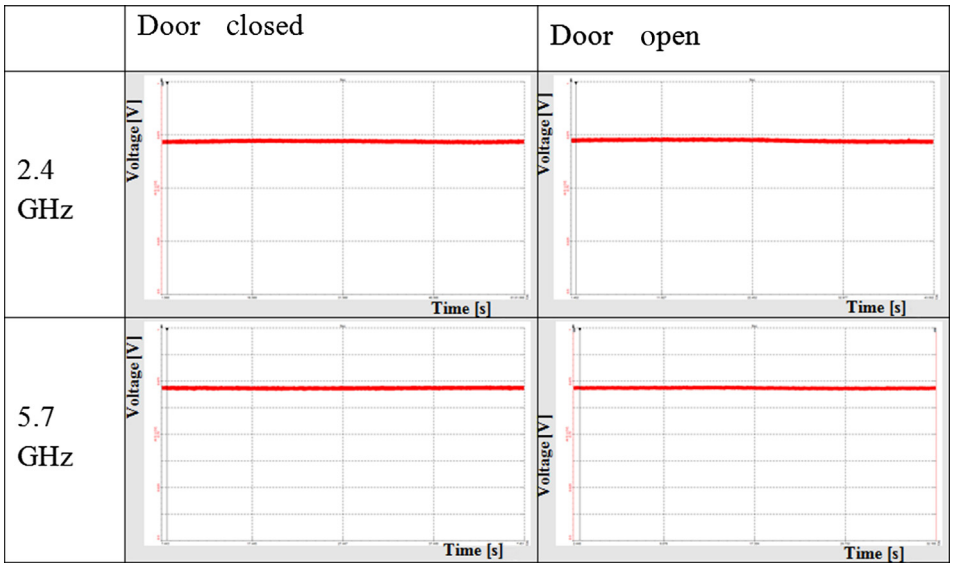

Fig. 10 – Output data of the plant control system (PCS) cabinet for immunity evaluation.

Table 6 – Detailed environmental information of measurement locations.

Measuring point	Measuring space	Environmental features of the measuring points
1	MCR	Measuring antenna (front), metal (right), concrete (left), metal (back)
2	EER 'A'	Measuring antenna (front), some metal in an open concrete surface (right), some metal in an open concrete surface (left), concrete (back)
3	EER 'B'	Measuring antenna (front), metal (right), metal (left), concrete (back)
4	TGB 100'	Measuring antenna (front), metal (right), metal (left), metal (back)

EER, electrical equipment room; MCR, main control room; TGB, turbine generator building.

4.3. *Field immunity test evaluation results for sensitive equipment*

Field immunity test for the electric field exposure of wireless devices was carried out under conditions of closed and open doors of sensitive equipment. The intensity of the electric field is generally different between the vertically polarized waves and horizontally polarized waves that occur due to the wireless device. This intensity was tested by exposing the sensitive equipment to vertical and horizontal polarized electric fields of the wireless devices. The maximum electric field strength was measured to be 134.79 dBμV/m in a 5.7 GHz band and up to 136.06 dBμV/m in a 2.45 GHz band during the immunity test. The measured value exceeded the 132 dBμV/m electric field intensity threshold level of the radio devices specified in the guide. This occurred when the three APs for wireless devices were adjacent at a distance of 10 cm. All target sensitive devices were exposed to such conditions, even the electric field strength, to ensure that there was no malfunction or performance degradation [5]. Fig. 10 shows an analogue variable of containment humidity obtained from the plant control system (PCS) cabinet (PA02-15) during the field immunity test. It was confirmed that the value of this variable was maintained at a constant level during the test performed with the door of the cabinet opened and closed. The major components of the most sensitive equipment are constructed primarily of analogue

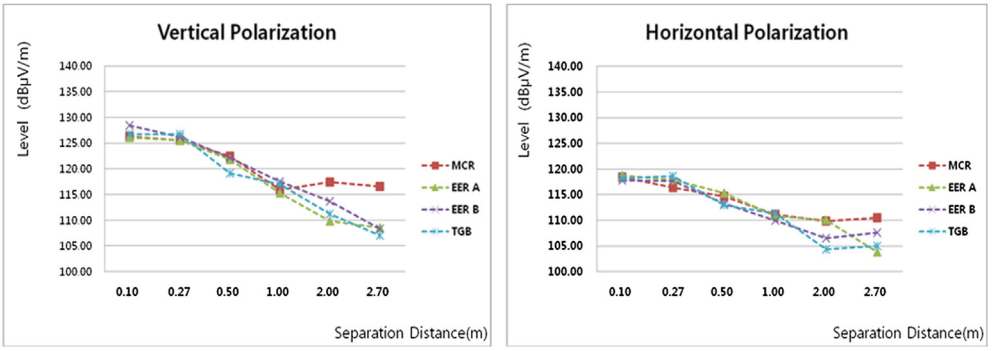

Fig. 11 – Comparison of the measured values in 2.4 GHz. X, separation distance; Y, measured electric field strength.

elements and were not affected by the frequency used in radio equipment using 2 GHz or higher frequency.

It was determined that the use of wireless devices in NPPs met the national radio law.

4.4. *Comparison of measurement results and the theoretical values*

The exclusion zone formula between the sensitive equipment and a wireless device can be used to confirm the similarity of the measured values through anechoic chamber tests. However, a field test is needed to apply the actual plant conditions because the anechoic chamber does not have top or side reflection.

According to the USNRC Reg. Guide 1.180, when using a wireless device that generates strong electromagnetic waves in the interior of a power plant, it is possible to calculate the separation distance, d, from sensitive equipment. Therefore, it is necessary to verify the minimum exclusion zone of the wireless devices from the sensitive equipment through the measured values of the power plant environment. In this study, the theoretical values and field strength measurement values in four places, the main control room (MCR), and electrical equipment room (EER) 'A' and 'B', and turbine generator building (TGB), were compared and analyzed.

The results of the analysis are shown in Table 6. Fig. 11 shows the measurement results of the test facility in plant environments where the use of wireless devices may be considered. It was confirmed that the electromagnetic strength of the wireless device was much lower than the highest emission limit (132 dBμV/m) along with the separation distance.

5. Conclusion

A verification test of electromagnetic waves was carried out in order to evaluate the use of wireless devices in operating NPPs. This test aimed at verifying and evaluating the effects of the existing installed I&C sensitive equipment caused by electromagnetic waves from radio repeaters and wireless devices in HBN 5.

To measure the electric field strength of wireless devices, the effects of the number of wireless devices, the distance between the devices and sensitive equipment, and the height were evaluated in an electromagnetic anechoic chamber before field tests. A frequency immunity evaluation was performed on 11 sensitive cabinets that were expected to be sensitive to EMI, including the plant protection systems. This test was carried out conservatively with opened door and closed door conditions for I&C sensitive equipment. The exclusion zone for wireless devices in front of the main cabinet was presented based on the USNRC standard (Reg. Guide 1.180).

It was confirmed that malfunction of subject facilities did not occur when the wireless devices were used. This is due to the main cabinets being mainly composed of analogue devices. It is thus believed that wireless devices with frequency > 2 GHz will not influence the main systems of NPPs. It was also confirmed that the use of wireless devices that have small outputs does not negatively impact any major measurements or control equipment in operating NPPs with a Wi-Fi environment.

When applying the latest reference criteria and standards, a minimum exclusion zone (27 cm) from I&C sensitive equipment must be maintained when using wireless devices, based on the testing results. It is also necessary to maintain a conservative separation requirement to apply wireless devices in operating NPPs.

Conflicts of interest

All authors have no conflicts of interest to declare.

REFERENCES

[1] H.D. Medema, R.K. Farris, Guidance for Deployment of Mobile Technologies for Nuclear Power Plant Field Workers, INL/EXT-12–27094, Idaho National Laboratory, September, 2012.
[2] S.H. Ye, Y.S. Kim, H.S. Lyou, M.S. Kim, J. Lyou, The Applications of Wireless Technology for Operating Nuclear Power Plants, The 14th International Conference on Control, Automation and System, ICCAS, KINTEX, Gyeonggi-do, Korea, October 22–25, 2014.
[3] Nuclear Regulatory Committee, Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation, Regulatory Guide 1.180 (Rev.1), October, 2003.
[4] ABB-Electro-Mechanics, Qualification Report for Plant Protection System Cabinet Assembly and PPS Remote Control Module Assembly for YONGGWANG Nuclear Power Plant, Units 5&6, QS 11753–1, 1999.
[5] Department of Defense, Electromagnetic Interference Characteristics Requirements for Equipment, MIL-STD-461A, USA, August, 1968.
[6] Electric Power Research Institute, Guidelines for Electromagnetic Interference Testing of Power Plant Equipment, EPRI TR-102323(Rev. 3), November, 2004.