Review of Technology Development Status of Mobile Radiation Monitoring Systems

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1. Introduction

To protect humans and the environment from radiation released from nuclear facilities at normal and/or abnormal conditions, IAEA recommends to monitor three types of radiation source, as shown in Fig. 1.

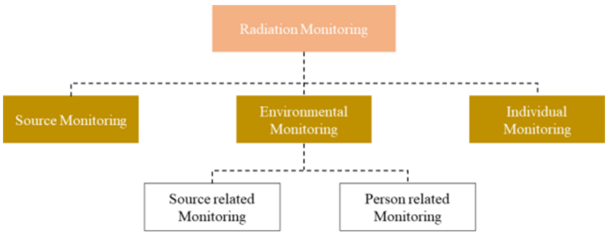

Fig. 1. Three types of radiation monitoring for the public[1]

To protect residents and the environment around nuclear facilities in our country, regulatory agency, nuclear reactor operator, and local governments have periodically checked the environmental radioactivity concentration and analyzed the samples taken around the facilities, in compliance with the Nuclear Safety and Security Commission Notice No. 2019-10 (Standards for Protection against Radiation, etc.).

The primary responsibility of the environmental monitoring around nuclear facilities is on the operators who install and operate the nuclear facilities, in compliance with Article 104 of the Nuclear Safety Act (Preservation of the Environment), Article 136 of the Enforcement Rules of the same Act (Measures for Prevention of Hazards and Reporting), and Notice 2017-17 of the Nuclear Safety Commission (Evaluation of Radiation Environment around Nuclear Facilities).

As the public are getting more sensitive about radiation since the Fukushima nuclear power plant (NPP) accident, the Korean government has spent lots of time and budget to improve our radiological emergency response system. For this, the regulatory agency has done lots of tasks, including continuous expansion of radiation monitoring systems around the nuclear facilities, establishment of an integrated information management system, and revision of the Act on Physical Protection and Radiological Emergency reflecting the lessons from the Fukushima NPP accident.

Although the environmental monitoring system has been continuously improved, there remains something that needs to be improved to aim for more effective protection of human beings and the environment. To identify what the things to be improved are, this paper reviews the current status of operation and development of the mobile (vehicle-mounted) radiation monitoring systems in the inside and outside of the country.

2. Status of operation and development of the mobile radiation monitoring system

2.1. Republic of Korea

Our country currently operates 21 nuclear power reactors, a nuclear research reactor, nuclear fuel fabrication facilities, and a low- and intermediate-level radioactive waste disposal facility. The KINS (Korea Institute of Nuclear safety) is sole a nuclear safety regulatory expert organization to protect the public and the environment from harmful effects of radiation which may arise from the use of nuclear power and radiation.

KINS, on behalf of the Korean government, monitors radiation that the residents around nuclear facilities encounter, and analyzes the samples taken from the area around the facilities. Also, local governments around the nuclear facilities have operated their own radiation monitoring systems. Information on environmental radioactivity collected from the national/local governments and a nuclear reactor operator is managed by and open to the public through IERNet (Integrated Environmental Radiation Monitoring Network).

To make up for limitation on mobility of the fixed monitoring post, KINS has operated mobile monitoring systems mounted on vehicles. The monitoring systems are run for the surveillance of surrounding areas of nuclear facilities at normal condition, and could be used for tracking radioactive plume that might be released from the nuclear facilities at accident condition.

In particular local governments have run their own radiation monitoring system and compared the monitoring results with those by KINS to ensure the reliability of their monitoring results. All the local governments, who hold NPPs within their administrative area, run the vehicle-mounted radiation monitoring system every week to every other month. Measurement data are open to the public, and provided as basic data to SIREN (System for Identifying Radiation in Environments Nationwide). Table 1 shows the specification of the mobile measuring system. Fig. 2 shows an example of the vehicle-mounted radiation monitoring system and measurement data displayed on a digital map.

2.2. Finland

Finland currently operates four NPPs and is constructing one NPP. The deep geological disposal facility for spent nuclear fuel (SNF) is under construction at Onkalo. The disposal facility is storing SNF below a 450 m depth.

Table 1. Specification of mobile measuring system

Dose range	0.01 ~ 1.0 μSv/hr
Energy range	80 keV ~ 3 MeV
Energy Resolution (at ^{137}Cs)	7.5 %
Operating temperature (°C)	- 25 ~ 55

Fig. 2. Vehicle-type mobile radiation monitoring system and measurement data in Gyeongju

Finland operates a mobile radiation monitoring system, SONNI (Sophisticated ON-site Nuclide Identification), to respond quickly against abnormal conditions at nuclear facilities. Once radiological emergency occurs, SONNI will be dispatched to the scene of the emergency for rapid and accurate measurement. The SONNI is equipped with two HPGe detectors, three NaI(Tl) detectors, air samplers, alpha-spectrometers, GPS, and communication equipment. The information measured by SONNI such as energy spectrum, precipitation, radiation dose rate, GPS information is transmitted to the data management system, shown in Fig. 3[2].

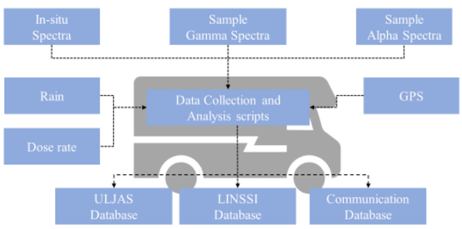

Fig. 3. Data management concepts in SONNI

2.3. Sweden

Sweden is operating seven NPPs and is planning to dispose of SNF in a deep disposal facility, like Finland. The regulator agency to supervise and monitor those facilities is Strålskerheetsmyndigitalen (SSM).

SSM is operating a national radiation monitoring network consisting of 28 monitoring posts all over the Sweden, and 30 monitoring posts at the three nuclear facility sites in Sweden.

To prepare against a radiological emergency, SSM also operates a mobile radiation monitoring system that is capable of measuring radiation dose rate and radioactivity concentration. The vehicle-type monitoring system consists of 2 × 4 liter NaI(Tl) and HPGe, as shown in Fig. 4. Bag-type monitoring systems consists of a 1.5" × 1.5" $LaBr_3$ detector that can be used by foot or mounted vehicles, as shown in Fig. 4[3].

(a) (b)

Fig. 4. Mobile radiation measuring systems in Sweden (a) vehicle-type gamma spectroscopy, (b) backpack-type monitoring system

2.4. Czech Republic

The Czech Republic (Czech) currently operates six NPPs on the two sites. The Radiation Monitoring Network (RMN), which is monitoring nuclear facilities in the country and neighboring countries, has been operated by SÚJB (Státní úřad pro jadernou bezpečnost, The State Office for Nuclear Safety) since the Chernobyl NPP accident. The Czech is also preparing against abnormal situations by running RMN and mobile radiation monitoring systems.

The SÚJB itself has no radiation monitoring vehicles, but each regional center has hand-held and vehicle-type radiation monitoring systems. The hand-held monitoring systems consists of two energy compensated GM detectors that covers energy ranges from 50 nSv/h to 400 mSv/h of GDER (Gamma-Dose Equivalent Rate)[4]. It can detect dose equivalent rates on pre-defined routes and collects gamma energy spectra and concentrations of aerosol and radioiodine in the atmosphere.

Ground monitoring is usually performed by a vehicle-type monitoring system driving at a speed of 40 km/h on a pre-defined route that is about 50 km. The monitoring system collects and saves the radiation information on the routes along with the information on the measurement locations and times. The ground monitoring is done once a month. The information on the vehicle locations and radiation measurements are collected every 10 seconds during the monitoring, the distance between the measurement points could be determined considering the vehicle's speed. The error range of the measurement location coordinates by the GPS is about 5-20 meters. The measurement data are open to the public through MonRas, as shown in Fig. 5.

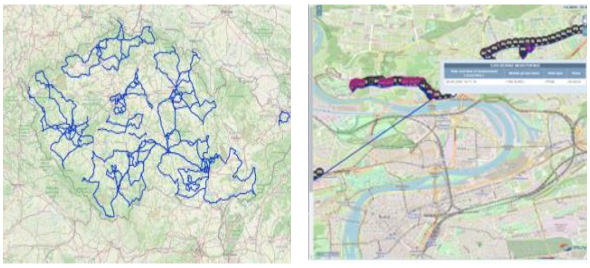

Fig. 5. Vehicle's moving path and radiation measurement data on the digital map in Prague, Czech

2.4. Germany

Germany has permanently shut down most of its own NPPs since the Fukushima NPP accident, and currently operates only six NPPs.

Germany monitors the leakage of radioactive material in three phases. Before and during the dispersion phase, the BfS (Bundesamt für Strahlenschutz, Federal Office for radiation protection) monitors the ambient gamma dose rate every 10 min at the monitoring post. Immediately after dispersion, the monitoring phase changes from phase 1 to phase 2, and mobile monitoring systems, including vehicles and helicopters, would be used, along with the existing monitoring systems.

Germany uses CBRN exploration vehicles for monitoring, sensing, and recording of radioactive and nuclear contamination. Table 2 shows the specification of the monitoring system. A total of 14 monitoring vehicles are in Berlin[5].

Table 2. Specification of the radiological monitoring system on the CBRN vehicle in Germany

Detector	FH 40G-10	FHZ672-2 (Background rejection)
Monitoring range	500 nSv/h ~ 1 Sv/h	10 nSv/h ~ 100 μSv/hr
Energy Range	30 keV ~ 4.4 MeV	60 keV ~ 2 MeV

Measurement data is transmitted to the central server via wireless communication network. Fig. 6 shows a measurement results by using GeoFES package.

Once an emergency occurs, monitoring and analysis vehicles would be urgently deployed. Vehicles from Helmholtz center will analyze the concentrations of ^{131}I and radioactive aerosol and transmit the analysis results through wireless transmission network. Table 3 shows the specification of the mobile monitoring system in the Helmholtz center.

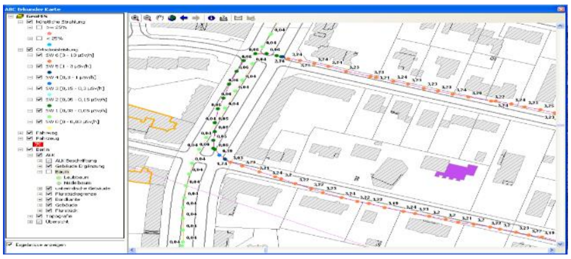

Fig. 6. User interface of the GeoFES package

Table 3. Specification of the mobile gamma spectroscopy system in the Helmholtz center

Efficiency	Relative efficiency 20 ~ 44%
FWHM (at 1332 keV)	1.8 keV
Dose rate sensor	NBR sensor

2.5. Japan

Japan is monitoring the environmental radioactivity on prefecture-level. Each prefecture establishes and operates an environmental radioactivity monitoring facility and transmits measurement data to the central government. After the Fukushima NPP, more than 4000 monitoring post has been added all over Japan.

In addition to the fixed monitoring posts, Fukushima Prefecture uses the Kyoto University Radiation Mapping (KURAMA) system which is a GPS-linked space dose rate automatic recording system. The KURAMA consist of NaI or CsI scintillation detectors. For continuous measurement in high dose area such as those above 30 μSv/hr, the ionization chamber is also equipped. The information on gamma dose rate and measurement location are simultaneously recorded, and transmitted to the central server. Measurement results could be displayed on 3D map, as shown in Fig. 7. The KURAMA is compact, and it is able to make measurements even at places where it is difficult for a vehicle to go into.

Fig. 7. Measurements by KURAMA on 3D map

Japan upgraded KURAMA into KURAMA-II, shown in Fig. 8 and Table 4[6]. The KURAMA-II can measure and transmit the information on dose rates and measurement locations every 3 seconds. The distance between measurement points is determined by considering the vehicle's speed. The information is usually stored at distance of 5 to 10 m.

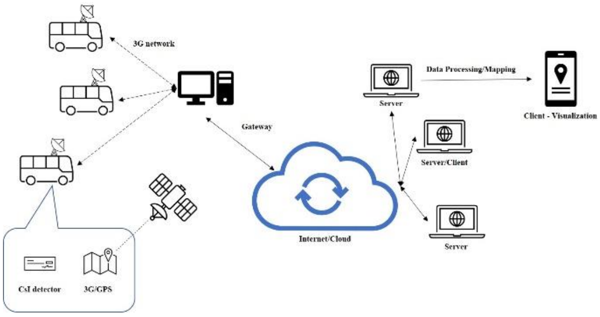

Fig. 8. Outline of KURAMA- II

Table 4. Specification of KURAMA- II

Type	C12137-00	12137-01
Scintillator	CsI(Tl)	
Scintillator size	13×13×20 mm	38×38×25 mm
Energy resolution (at 662 keV)	8%	8.5%
Counting efficiency (662 keV, 0.01 μSv/h	40 cpm	400 cpm
Detecting device	MPPC	

KURAMA-II is being upgraded to identify radionuclide by resolving the incident gamma energies. Fukushima Prefecture is conducting an experiment to measure radiation dose rate by KURAMA-II mounted on local circular buses running on National Route 6. Fig.9 shows measurement results by KURAMA-II mounted on local circular buses.

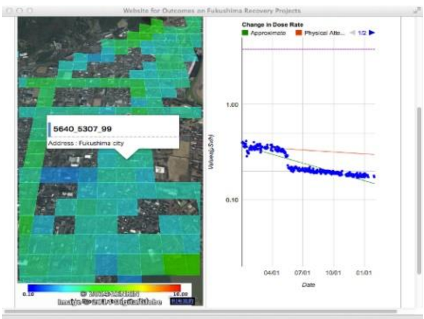

Fig. 9. Measurements by KURAMA- II mounted on local circular buses in Fukushima Prefecture

3. Conclusions

The countries that operates NPPs, including our country, have run the environmental radioactivity monitoring systems to identify long-term behavior of radioactive material in the environment around NPPs, and check if the radioactivity concentrations and/or radiation dose rate is within a normal range that might be expected at normal situation. The real-time monitoring and sample analysis results are usually used to identify the occurrence of abnormalities and locate radioactive leaks in nuclear facilities as early as possible.

In several countries such as Finland, Sweden, Czech, Germany, and Japan, the mobile radiation monitoring system installed on a vehicle or a helicopter is used for the environment monitoring against a radiological emergency. Due to a long interval of monitoring, however, the effectiveness of the mobile radiation monitoring systems, in terms of protecting local residents from radiation, could not be guaranteed.

Japan is developing an automatic measurement system that utilizes public transportations along with the operation of the existing mobile measurement system, which can make up for the limitation of the fixed monitoring system.

It could be more helpful to protect people from accidental radiation release if a mobile radiation monitoring system to utilize public transportations and supplement for a mobile measurement system with a long period of monitoring is developed.

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