Local Government Radiation Surveillance System for Nuclear Power Plants in China in the Post-Fukushima Era Postprint

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Abstract

After the Fukushima nuclear accident in 2011, improvement actions of the environmental radiation surveillance were carried out by Chinese government to deal with the possible nuclear accident in response to the rapid development of nuclear power in China. The local government radiation surveillance system, including the on-line radiation monitoring network and automatic sampling system, the off-site monitoring center laboratory, the radioactive effluent on-line monitoring system and the sampling inspection laboratory were regulated to establish for all operation and constructing nuclear power plant. This paper describes the general design of the system by taking Ningde nuclear power plant (NPP) for example. The main designs, including radiation monitoring and sampling equipment, data collection and the communication technology, and the surveillance management, are generally based on the experiences or lessons from Fukushima accident. The system is expected to act as a pivotal role to evaluate the environmental radioactivity from the operation of NPP, and to provide effective decision support in the event of possible nuclear accident.

Full Text

Preamble

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Local Government Radiation Surveillance System for Nuclear Power Plant in the Post-Fukushima Era in China

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Following the Fukushima nuclear accident in 2011, the Chinese government implemented improvement actions for environmental radiation surveillance to address potential nuclear accidents in response to the rapid development of nuclear power in China. The local government radiation surveillance system, comprising an on-line radiation monitoring network and automatic sampling system, an off-site monitoring center laboratory, a radioactive effluent on-line monitoring system, and a sampling inspection laboratory, was mandated for all operating and under-construction nuclear power plants. This paper describes the general design of the system using Ningde nuclear power plant (NPP) as an example. The main designs—including radiation monitoring and sampling equipment, data collection and communication technology, and surveillance management—are based broadly on experiences and lessons from the Fukushima accident. The system is expected to play a pivotal role in evaluating environmental radioactivity from NPP operations and providing effective decision support in the event of a possible nuclear accident.

Keywords: Radiation surveillance system, Post-Fukushima, On-line radiation monitoring network, Effluent monitoring inspection

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INTRODUCTION

After the Fukushima nuclear accident, the government, nuclear industry, and researchers extensively investigated the associated experiences and lessons in nuclear safety [1–3]. Both successful practices and failures in environmental radiation monitoring during the accident for the operator and Japanese government were summarized. For instance, deficiencies in communication and the lack of effective monitoring facilities resulted in an absence of supporting data for responding to the nuclear accident. These findings demonstrated that effective organization and reliable technical design of radiation monitoring systems play a vital role in nuclear emergency response [2]. The accident has awakened government requirements for improving environmental radiation systems, and effective surveillance of environmental radiation around nuclear facilities has become a public concern regarding nuclear safety. For example, in the United States, twenty percent of the US EPA's (Environmental Protection Agency) stationary radiation monitors in the nationwide RadNet system were out of service at the time of the Fukushima accident, revealing that the network was severely flawed and suffered from maintenance and reliability issues, which placed the US EPA under significant public scrutiny. Following the accident, the system was extensively evaluated and improved; for example, the US EPA procured a high-speed satellite system as the primary means of communication for fixed RadNet monitors [4].

In subsequent years, China also initiated a national safety inspection of NPPs. The reliability assessment and inspection of environmental radiation monitoring for nuclear emergencies were launched for both licensees and government. On May 5, 2012, the State Council of China issued a report on the comprehensive safety of the national civilian nuclear infrastructure and approved the recent five-year plan for nuclear safety and radioactive pollution prevention with a vision for 2020 [5]. The plan included goals for improving emergency response capacity, safety regulation, environmental safety, and radioactive pollution prevention and treatment. In February 2012, the Ministry of Environmental Protection and the National Nuclear Safety Administration (NNSA) released construction specifications for the off-site environmental radiation surveillance system of NPPs for local governments [6]. According to this document, the system should be established or complemented for all NPPs in operation and under construction. As of July 2013, systems for several NPPs had been established or were under construction through bids from private or public institutions, including Ningde NPP.

The first unit of Ningde NPP began commercial operation in April 2013, and the local government radiation surveillance system has been completed in accordance with regulatory requirements. The system design drew upon experiences and lessons learned from the Fukushima nuclear accident regarding security safety and data availability. The system for radiation monitoring equipment, data collection, communication technology, and surveillance management represents state-of-the-art implementation. This paper describes the system design based on the typical system implemented for Ningde NPP in China.

II. GENERAL DESCRIPTIONS

C. Surveillance Role of Local Government

In China, surveillance of environmental radiation from NPPs is undertaken by the local monitoring and management office, a public institution attached to the local environmental protection authority. Such offices have been established in most provinces to date. The radiation monitoring capability of offices in provinces with NPPs is generally required to be more robust. For Ningde NPP, the surveillance office is the Fujian Radiation Environmental Supervision Station. The scope of supervision activities for environmental radiation generally covers the following areas: radiation and radioactivity in the environment within the regulatory scope; radiation sources, including radioactive waste; environmental radiation assessment; education and training; and public outreach.

B. General Description of Ningde NPP

Ningde NPP is located in Fuding, Ningde City, Fujian Province, 32 km south of Fuding, facing the East China Sea to the east, with Taiwan situated to the southeast across the Taiwan Strait. [Figure 1: see original paper] shows the site location of the NPP. The first stage of the NPP involves constructing four pressurized water reactors of CPR 1000 (Chinese Pressure Reactor 1000), with the first reactor having begun commercial operation on April 18, 2013.

Surveillance of environmental radiation from operating NPPs for local government is specified in the environmental protection standard HJ/T 61-2001 [7]. The monitoring items and sampling frequency for environmental samples and effluent are generally listed in this standard according to the transport mode of radioactive release via gaseous and liquid effluent for both terrestrial and aquatic regimes. For Ningde NPP, the environmental radiation monitoring plan was designed prior to NPP operation. shows the environmental radiation surveillance plan for Ningde NPP. Monitoring of gamma dose rate, along with meteorological parameters, is designed with advanced probes and redundant communication networks, with data transferred on-line to the off-site center laboratory. Analytical items for air, aerosol, fallout, and rainwater rate are generally related to the frontier station. Other items are carried out through off-line sampling and analysis at the off-site center laboratory. All analytical methods are adopted from national standards or standards released by environmental protection and nuclear industry agencies.

Surveillance of radioactive effluent release is performed through on-line monitoring of radioactivity in the stack, outlet of the waste gas treatment system, and liquid tanks of the nuclear power plant, as well as through on-line sampling and off-line analysis at the inspection laboratory. On-line monitoring items for gaseous effluent include radioactive aerosol, iodine, and noble gas, while for liquid effluent only gross gamma is monitored. Data are collected on-line and transferred to the local government office and NNSA. Off-line analysis of tritium, gross gamma, and gamma radionuclides is performed for liquid effluent from the nuclear island and conventional island of the NPP, while tritium, 14C, and gamma radionuclides are analyzed for aerosol (with filters), inert gas (with sampling bottles), and iodine cartridges for gaseous effluent from the waste gas treatment system. The intervals for off-line analysis depend on effluent release and the NPP's own schedule.

III. DESIGN OF THE SYSTEM

A. General Description

The system can be divided into five elements: the on-line radiation monitoring system, the automatic sampling system, the off-site center laboratory, the effluent on-line monitoring system, and the effluent sampling inspection laboratory. The on-line radiation monitoring system and automatic sampling system are designed as off-site stations that receive control signals from and send monitoring data to the off-site center laboratory through a communication network. The off-site center laboratory serves as the data center for the network and as an analytical laboratory for environmental samples. The effluent on-line monitoring system is designed to receive on-line data from effluent monitoring at the supervised NPP and transmit it to the local government office and NNSA. The effluent sampling inspection laboratory is established independently of that for the NPP. Both analyses are similar, but the inspection laboratory serves as government supervision. In summary, the system is constituted based on regulations for the release of radioactive materials and environmental radiation quality, which enables the government to obtain and provide reliable data to the public.

[Figure 2: see original paper] shows the configuration of the surveillance system. As indicated, two monitoring types are included: environmental radiation and radioactivity effluent from the nuclear power plant, with three and two elements designed for each type, respectively.

B. Elements Description of the System

1. On-line Radiation Monitoring System (1) Monitoring Sites

According to the specification of the on-line radiation monitoring network, monitoring stations are generally required to be set with equal coverage per 22.5° sector at a distance of 10 km within the plume emergency planning zone (PEPZ), meaning at least one station should be installed in each sector. For coastal NPPs, monitoring points toward the sea may be set according to actual requirements. The density of monitoring points should be increased in downwind directions based on on-site atmospheric conditions and in densely populated areas. Additionally, a control point should be set outside the PEPZ. Meanwhile, conditions related to electricity, communication, and geological environment are important considerations. For Ningde NPP, ten stations were identified for on-line radiation monitoring and approved by the local government and NNSA. As shown in [Figure 1: see original paper], Z1 to Z9 were set within the PEPZ, and one control point was established in Fuding, Fujian Province.

(2) Radiation Monitoring Probes

The monitoring probes selected include both high pressure ionization chamber (HPIC) and NaI-detector. The common Geiger-Muller Counter with two or three identical counters was not selected for the system due to its low accuracy. Generally, the gamma dose rate is adapted from HPIC during normal NPP operation, while the NaI-detector serves as an identification tool providing on-line gamma spectra of artificial radionuclides released from the NPP. The HPIC reading interval is every 1 minute and the NaI-detector at least every 5 minutes. The HPIC is required to be installed at least 1 meter above ground with a measurement range of ambient dose rate from 10 nGy/h to 1 Gy/h, enabling measurement in both normal background and serious nuclear accident situations. The NaI-detector allows recording of in-situ gamma spectra with at least 1,024 channels for the multi-channel analyzer (MCA), and automatic calibration to the naturally present 40K peak (1,460 keV) is basically required to stabilize energy calibration against gain fluctuations induced by temperature changes.

The efficiency calibration relating nuclide-specific count rates to different concentrations in units of Bq/m^3 and Bq/m^2 and the minimum detection activities (MDA) would be further established based on current equipment design and installation environment [8].

(3) Meteorological Gauges

At each site, gauges for rain intensity, wind direction and speed at a height of 10 m, and other related meteorological parameters are installed, enabling operators to screen possible influences on gamma dose rate. In potential nuclear accident situations, the gauges can also serve as tools for wind field simulations in accident consequence assessment.

(4) Data Process and Communication

In a monitoring cabinet or house, a data acquisition unit is installed to record data from the HPIC gamma dose rate, NaI-detector gamma spectrum, meteorological parameters, and sampling device status. The data is then transferred to a microprocessor and automatically transmitted to the remote server located at the off-site center laboratory for each NPP, and subsequently to the local government office. Operators can also view data through the on-line display unit. Data communication modes are required to have redundant wire and wireless capabilities. Wire communication is used as the main channel due to its high bandwidth characteristics, with fiber optic communication generally adopted. When the wire channel is terminated, the wireless channel is activated to guarantee data availability 24 hours per day, using public wireless telephone networks such as GPRS (General Packet Radio Service) or 3rd Generation (3G) networks. In the Ningde project, the WCDMA (Wide Band Code Division Multiple Access) network is used. Selection is flexible according to local government requirements and actual designs. [Figure 2: see original paper] shows the block diagram of the system for Ningde NPP as a typical design.

(5) Infrastructure Design

For the Ningde NPP system, a UPS system or a system with battery and inverter controller should be designed to supply monitoring probes and communication devices for more than 72 hours at each station to meet data availability requirements during external power loss. A hot-standby system and cluster technique for network servers were designed to ensure monitoring data safety.

Management software for different on-line data was developed with user-friendly interfaces. Functions include data acquisition, display, analysis, and reporting, as well as alerts for abnormal increases in gamma dose rate and possible detection of artificial radionuclides. Based on emergency monitoring experience from Fukushima, the safety design of the entire system should be improved to guarantee monitoring and communication capabilities, including resistance to typhoons, earthquakes, storms, and lightning. The infrastructures are sufficiently reliable. A three-level lightning protection system was designed to protect the power supply, monitoring probe, and communication unit. Ground resistance is below 4 Ω through methods of improving ground mesh or other grounding equipment.

[Figure 3: see original paper] (Color online) Block diagram of on-line monitoring station for the Ningde NPP project.

2. Automatic Sampling System It is regulated that air automatic sampling systems should be installed at least 30% of on-line radiation monitoring stations. The sampling program at each station involves aerosol and gaseous iodine, airborne tritium and carbon-14, and atmospheric deposition (fallout and rainwater). All samples can be obtained automatically and transferred from the field to the laboratory for analysis.

The general sampling flow-rate for air particulate matter is required to be no less than 60 m^3/h, and at least one high-volume air sampler should be installed in one of the stations with a flow rate no less than 600 m^3/h, similar to that adapted at stations of the global Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) [9]. For the Ningde NPP systems, the JL-900 SNOW WHITE was installed with flexible capability to change volume flow through pump control with a frequency converter. The minimum requirement for total volume of airborne particulate matter or aerosol for gamma spectrometry is about 10,000 m^3, which can be obtained within 7 days (one week) for the general sampler and within one day for the high-volume sampler. For gaseous iodine measurement, the sampling volume is not explicitly regulated. The high-volume air sampler can guarantee rapid air sampling as a powerful tool in potential nuclear accident situations based on experience from the Fukushima accident. Based on the current design, unattended sampling and activity monitoring apparatus for air with high volume would be considered a more effective tool for surveillance of environmental radiation of NPPs in the future [9, 10].

The airborne tritium sampler can be used to collect air moisture (i.e., HTO), generally with a dehumidifier, while the airborne 14C sampler is used to collect organic and inorganic carbon through catalysis of organisms in the air. The design for sampling airborne tritium and 14C is required by supervisors in China as both are present in top amounts during normal NPP operation.

Dry and wet deposition samplers were installed in this system, enabling automatic collection of wet precipitation and dry fallout for analyzing radioactive atmospheric materials. Device status and sampling data were designed to be recorded and transferred to the server at the off-site center via the on-line network. A sensor was designed to trigger a lid to open or close to obtain both dry and wet samples.

3. Off-site Center Laboratory The off-site center laboratory serves as a facility for environmental radiation surveillance by local government during normal NPP operation and for local nuclear emergency response. The server for the on-line radiation monitoring system is situated in the center. During normal

NPP operation, the center analyzes environmental samples within 30 km of the NPP, independent of the operator's monitoring program, to evaluate radioactivity levels resulting from NPP operation. The center is equipped with low-background analytical instruments such as high-purity germanium spectrometers, liquid scintillation spectrometers, and alpha/beta counters, along with auxiliary equipment such as balances, muffle furnaces, drying ovens, and other sample pretreatment equipment, enabling analysis of radioactive isotopes such as 90Sr, 137Cs, 3H, 14C, and other possible artificial radioisotopes in various samples including airborne particles, fallout, rainwater, soil, sediment, and biota according to respective monitoring programs.

During local nuclear emergency response, the center serves as an off-site emergency monitoring center, with mobile measurement vehicles for nuclear emergency response deployed.

As regulated for the off-site center, different types of laboratory rooms are required, such as sample pretreatment and preparation rooms and radiochemical analysis and measurement rooms. The center is generally located outside the PEPZ, providing convenience for sampling and analyzing environmental samples from the NPP even during nuclear emergency response.

For the Ningde NPP system, the off-site center is located 30 km north-northwest of Fuding, a prefecture-level city. The main detectors configured in the center are shown in .

4. Effluent On-line Monitoring Surveillance of radioactive effluent discharge from the NPP is also required in the system. It is regulated that on-line monitoring data and alert signals for liquid and gaseous effluent discharge should be transferred simultaneously to the server at the off-site center through independent transmission and communication equipment. On-line monitoring items for gaseous effluent discharge include air particulates, iodine, and radioactive inert gases, while those for liquid effluent discharge include liquid waste from the nuclear island and conventional island. All NPPs should provide data transmission interfaces for effluent monitoring and accept government supervision.

5. Effluent Sampling Inspection Laboratory To supervise NPP effluent discharge, an analyzing laboratory for effluent inspection should be established. The location is generally required to be near the off-site center laboratory with an independent layout to avoid possible cross-contamination of environmental samples, or at the NPP site for sampling convenience.

Inspection items are similar to those of the NPP licensee but with relatively lower sampling frequencies. The laboratory is used to monitor discharge of radioactive materials from gaseous and liquid effluents. The primary measurement instruments for effluent inspection are similar to those listed in .

IV. SUMMARIES

In the post-Fukushima era, requirements for environmental radiation surveillance of NPPs have led to enormous development for local government in China. On-line radiation monitoring networks and off-site center laboratories are regulated for construction at every operating and under-construction NPP, with supervision extending even to radioactive gaseous and liquid effluent. Experiences and lessons have been drawn from emergency monitoring of the Fukushima accident in Japan regarding security safety and data availability.

The system should be designed according to Chinese standards and experience from the Fukushima nuclear accident. Safety performance and data availability of the system are required to improve based on infrastructure construction for disaster prevention, including lightning protection, power supply, technical design of communication, radiation probe selection for radiation monitoring networks, and installation of automatic air sampling systems. Typical designs of the entire Ningde NPP system were introduced.

It should be noted that with comprehensive improvement of the system, management requirements and operational mechanisms should be simultaneously enhanced to take full advantage of the design and funding. More unified, practical, and standardized monitoring systems and methods should be improved concurrently with the development of nuclear power and regulatory requirements.

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Table 2. Main equipment for environmental radiation analysis in off-site center of Ningde NPP

Instrument	Manufacturer and model	Number	Applications
Ultra low level liquid scintillation counter (LSC)	PerkinElmer Quantulus 1220	1	^{3}H, ^{14}C analysis
Low background broad Energy Ge Detector (HPGe)	Canberra BE3830	1	γ nuclides analysis

Instrument	Manufacturer and model	Number	Applications
Low background Alpha/Beta detector	Ortec Protean MPC9604	1	Measurement of total α, total β, ^{90}Sr, ^{137}Cs

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Note: Figure translations are in progress. See original paper for figures.