Research and Application of Standardized Technology for Physical Characteristics Risk Monitoring and Assessment of Nuclear Power Plant

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Abstract. Environmental risks generally exist in various production activities. Based on existing research foundation, in order to solve the related problems in the field of environmental risk of nuclear power plants, this paper conducts in-depth research and discussion on the monitoring and assessment of environmental risks of nuclear power plants. This paper proposes a set of standardized technical framework, based on this framework, an application platform is designed and implemented and applied to the environmental risk monitoring, assessment, and management of nuclear power plant.

Keywords: Environmental risk, monitor, assessment, nuclear power plant.

1. Introduction
Environmental risk is the degree of harm to the environment (or health) caused by accidents, which are widely present in production and other activities. At present, a lot of research work has been carried out in the field of environmental risk. Existing research mainly focuses on two aspects. One is the research on the identification method of environmental risk sources, and the research focus is on the methods and technologies for identifying and grading of risk sources in various professional fields [1][2][3][4][5]. The other focuses on the risk monitoring and assessment technical framework and corresponding application [6][7][8][9][10].

As a special enterprise, the environmental risks of nuclear power plant include not only conventional risks, but also radiological risks. During production and operation, nuclear power plants will generate a large amount of environmental dynamic data, such as environmental monitoring data, survey sampling data, pollution discharge data, meteorological observation data, etc. These data are scattered and stored in the systems or files of various departments, and there is no efficient information sharing channel, resulting in a low comprehensive utilization rate of data. There are relatively few studies on a set of methods and technologies for the identification, monitoring, and assessment of environmental risks of nuclear power plant [11], and a unified technical framework and system have not been established.

Therefore, it is necessary to conduct in-depth research on the fields and contents mentioned above, including how to identify the environmental risks of nuclear power plant, establish a standardized risk monitoring and assessment technical framework, and design and implement an application platform for environmental risk monitoring and assessment.
2. Environmental Impact and Risk Identification

2.1. Environmental Impact
The main environmental impacts of nuclear power plant can be divided into two categories: radioactive and non-radioactive.

2.1.1. Radioactive Impact. The main radioactive impact on the environment under operating conditions of nuclear power plant comes from radioactive effluents, that is, radioactive substances which are discharged into the environment in the form of gas, aerosol, dust, and liquid, and are diluted and dispersed in the environment. Among them, the airborne radioactive effluent is mainly inert gas, iodine, particles, C-14, tritium, etc., and the liquid radioactive effluent is mainly tritium and C-14.

2.1.2. Non-radioactive Impact. Thermal drainage is the main non-radioactive environmental impact of nuclear power plant. The waste heat generated by the cooling system of the nuclear power plant is discharged into the sea nearby through the circulating cooling water.

Environmental impacts also include non-radioactive effects such as chemical substances in circulating cooling water, oily wastewater, domestic sewage, solid waste, and concentrated brine discharged from seawater desalination system.

2.2. Existing Online Monitoring System
In order to monitor various environmental impacts, a series of online monitoring systems have been built for nuclear power plant.

a) Online monitoring system of effluent (KRT): The chimney is equipped with an on-line monitoring and sampling device for airborne effluent. The gas sample is drawn to aerosol, iodine, and inert gas monitors for monitoring or sample collection. The liquid effluent monitoring subsystem consists of two online monitoring channels, which respectively monitor the radioactivity of waste liquid discharge line on the nuclear island and conventional island.

b) Continuous monitoring system of environmental gamma radiation (KRS): The system is composed of multiple fixed monitoring stations, which are the on-site stations and the off-site stations. The system continuously monitors the gamma radiation in the atmospheric environment within 10km around the nuclear power plant. Some on-site stations will be equipped with aerosol and iodine sampling devices. The monitoring vehicle subsystem is composed of several monitoring vehicles and monitoring network system. It is mainly used for radiation surveys in the surrounding environment of nuclear power plant, so as to timely determine the downwind radiation plume diffusion and dose rate distribution. The monitoring vehicle is mainly equipped with gamma radiation dose rate meter, aerosol and iodine sampling device, portable gamma spectrometer, GPS, wireless communication equipment, power supply equipment, etc.

c) Marine radiation monitoring system (MRMS): The system is mainly composed of water temperature buoy subsystem, shipboard subsystem, radiation monitoring buoy subsystem and the central station system. It can monitor radiation and meteorological elements in real time, including gamma dose rate of water or air, water temperature, wind speed, wind direction, air temperature, air pressure, rainfall, etc.

d) Online monitoring system of hydrology and water quality (HWQMS): The system is capable of online monitoring and real-time warning of various elements such as tides, water temperature, salinity, ocean waves, ocean currents, chlorophyll, and blue-green algae in the sea area near the nuclear power plant.

2.3. Risk Identification
Through the screening, identification and classification of various risk sources, the main environmental risks of nuclear power plant are divided into six categories, Figure 1 shows the main environmental risk categories.
a) Nuclear Accident: Nuclear accidents include design basis accident and severe accident. The former refers to operating conditions that are designed in accordance with established design criteria and targeted measures are taken into account in the design. The latter refers to accidents whose severity exceeds the design basis accidents and causes significant deterioration of the core. The main radiation impact of nuclear accident on the environment comes from the radioisotopes in the source term released, including noble gases, caesium, iodine, particles, etc. According to the different ways of releasing radioactive materials, accidents are divided into gaseous discharge and liquid discharge.

b) Radiation Accident: Various types of radioactive sources, such as Co-60, stored in the radioactive source library of nuclear power plants, may cause radiation accidents if they are lost or stolen.

c) Toxic and Hazardous Chemical Accident: Some toxic and harmful chemicals stored in nuclear power plant, such as chlorine, will cause harm to the environment and humans in the event of a leakage accident.

d) Explosion: Some compressed gases, liquefied gases, flammable liquids, flammable solids, oxidants, etc. used or produced during the operation of nuclear power plant may cause explosion accidents, such as hydrogen.

e) Fire: Some petrochemical products in nuclear power plant, such as diesel, gasoline, etc., may cause fire accident due to improper use.

![Figure 1. Main Environmental Risk Categories of Nuclear Power Plant](image_url)

3. Standardized Framework of Environmental Risk Monitoring and Assessment Technology

3.1. Data Exchange
The core of data exchange (collection, transmission, etc.) is a unified data bus. It provides data transmission and control logic for various systems, devices, components, etc. in a common way. Taking into account the network characteristics of various environmental online monitoring systems and monitoring devices of nuclear power plant, the data bus should support TCP, UDP and other major protocols at the network transmission layer. Furthermore, in order to be compatible with the data of various systems and devices, the data bus should also support mainstream exchange protocols such as FTP, Web Service, Rest API, and Modbus at the application layer. In addition, the input interface of offline data is also included in the realization of the data bus. Multi-source heterogeneous data from different systems and devices and other sources, should also go through the process of data processing and fusion after the unified exchange of the data bus. And then they will become homogeneous data, which can be used for subsequent standardized parameter monitoring and risk assessment.

3.2. Monitoring Parameters
The selection of monitoring parameters is the basis for the construction of monitoring technology. Monitoring parameters mainly refer to a series of items that can sensitively and clearly reflect the basic characteristics of major environmental risk sources and surrounding environmental sensitive receptors and the trend of environmental risk changes. According to the dynamic values of the monitored
indicators, the risk level of the source is determined, the early warning interval is determined, the early warning signal is issued, and the early warning of the risk source status is provided, so as to achieve the purpose of preventing accidents. According to the conclusions of the classification of environmental risk sources of nuclear power plant, monitoring parameters can be divided into source state parameters, environmental parameters, risk characteristic parameters, and so on.

a) Source state parameters: the most basic security monitoring parameters such as temperature, location, flow rate, audio and video, etc.

b) Environmental parameters: mainly include wind direction, wind speed, rainfall, atmospheric stability, temperature, air pressure, humidity and other parameters, which are closely related to the spread and diffusion of risk sources.

c) Risk characteristic parameters: mainly refers to the leakage of risk sources such as containers, devices or discharge ports, generally including activity, concentration, equivalent, etc.

3.3. Environmental Risk Assessment Model

3.3.1. Model for Nuclear Accident. According to the different ways of releasing radioactive materials, the assessment models of nuclear accident are divided into gas dispersion and liquid dispersion [12].

a) Gas dispersion model

The model can predict the temporal and spatial changes of plume dispersion around nuclear power plants, estimate and predict the transmission and diffusion of plume in the EPZ (Emergency Plan Zone) during the accident, and give the concentration of radioactive substances in the air and ground at each grid point. On the basis of the above concentration field, the dose of public by external and internal exposure can also be calculated. Furthermore, the model can also give recommendations for protective actions based on criteria such as general intervention levels. The core of the model is the atmospheric dispersion model and the dose estimation model. The most typical atmospheric dispersion model is the Gaussian puff model, which uses multiple puffs to simulate the release, transport and diffusion process of radioactive materials. Equation 1 gives the main calculation method and parameters of the Gaussian puff model.

\[
C(x, y, z) = \frac{2Q}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} \exp \left[-\frac{(x-x_0)^2}{2\sigma_x^2}\right] \exp \left[-\frac{2\sigma^2}{y_0^2}\right] \exp \left(-\frac{(z-z_0)^2}{2\sigma_z^2}\right) \tag{1}
\]

C(x,y,z): air concentration of nuclides of location (x,y,z), Bq·m⁻³.

x₀, y₀, z₀: the coordinates of center point of puff, m.

σₓ, σᵧ, σz: diffusion parameters in x, y, z direction, m.

Q: the amount of radioactive material released, Bq.

b) Liquid dispersion model

In view of the discharge of radioactive waste liquid into the nearshore water in a nuclear accident, the Joseph model is generally used to simulate the dispersion of the nearshore water to provide the concentration distribution of the liquid radioactive material. Equation 2 gives the main calculation method and parameters of Joseph model.

\[
C(r, t) = \frac{1\times10^{-3}Q}{2\pi hp^2t^2} \exp \left(-\frac{r^2}{pt}\right) \tag{2}
\]

C(r,t): the pollution concentration of seawater at distance r at time t after release, Bq/L.

Q: total amount of radioactive material released, Bq.

h: thickness of water layer with uniform concentration, m.

p: horizontal diffusion rate, m/s.

t: time after release, s.

r: radial distance, m.
3.3.2. Model for Radiation Accident. For accidents of loss or theft of radioactive sources, the model of consequence calculation of point source recommended by IAEA is generally used [13]. Equation 3 gives the main calculation method and parameters of the point source model.

$$D = \frac{A \cdot CF_T \cdot (0.5)^{d/2}}{X^2}$$  \hspace{1cm} (3)

\[ \begin{align*} 
 D: & \text{ dose rate, mGy/h.} \\
 CF_T: & \text{ dose conversion factor.} \\
 A: & \text{ activity of point source, kBq.} \\
 X: & \text{ distance to the point source, m.} \\
 d_{1/2}: & \text{ thickness of half value, cm.} \\
 d: & \text{ shielding thickness, cm.}
\end{align*} \]

3.3.3. Model for Toxic and Hazardous Chemical Accident. For accidents involving heavy gas emissions under flat terrain, SLAB model is generally used. For accidents involving the emission of neutral gas and light gas and the diffusion of vaporized gas in the liquid pool under flat terrain, AFTOX model is usually used [14].

3.3.4. Model for Explosion Accident. For explosion accidents, the TNT model given by Equation 4 is generally used.

$$W_{TNT} = \frac{E}{Q_{TNT}} = \frac{1.8A \cdot W_f \cdot Q_f}{Q_{TNT}}$$  \hspace{1cm} (4)

\[ \begin{align*} 
 E: & \text{ total energy of explosion, kJ.} \\
 Q_{TNT}: & \text{ explosion heat of TNT, MJ/kg.} \\
 A: & \text{ TNT equivalent coefficient of vapor cloud.} \\
 W_f: & \text{ the total mass of fuel in the vapor cloud, kg.} \\
 Q_f: & \text{ heat output of fuel, cm.}
\end{align*} \]

3.3.5. Model for Fire Accident. For fire accidents, the fireball model given by Equation 5 is generally used.

$$I = \frac{Q \cdot T_c}{4\pi \cdot x^2}$$  \hspace{1cm} (5)

\[ \begin{align*} 
 I: & \text{ the amount of incident heat radiation received by the target, w/m}^2. \\
 T_c: & \text{ coefficient of conductivity.} \\
 x: & \text{ the horizontal distance of the target from the center of the fireball, m.}
\end{align*} \]

3.4. Environmental Risk Monitoring and Assessment Process

A key step in the standardization of environmental risk monitoring and assessment technology is to connect and integrate related models and technologies in a specific process.

In this process, online data and offline data related to the environment are first aggregated and merged into a unified database through the data bus. Then, the risk characteristic parameters in the database are under real-time monitoring. When the parameter changes and exceeds the preset threshold, an early warning signal will be sent. Decision-makers of environmental protection select an appropriate assessment model based on the type of risk indicated by the alarm, calculate and give the risk prediction result, and further take corresponding countermeasures, including certain protective measures and intervention actions. Figure 2 describes the details of the process.
4. Environmental Risk Monitoring and Assessment Platform

4.1. Design Principle and System Architecture
Based on a layered design, from bottom to top, the platform is divided into seven layers. Figure 3 gives the system architecture of the platform.

a) Sensor Monitoring Layer: This layer includes various existing online monitoring systems and special sensors. It is the real data source of the entire platform, and provides all kinds of collectable environmental data for the upper layer.

b) Infrastructure Layer: This layer includes facilities of computing, storage, network and safety.

c) Data Exchange Layer: Based on the data bus, this layer provides all the realizations of data acquisition, transmission, processing, and fusion.

d) Data Resource Layer: Based on database, this layer stores various business data, covering environmental data, device data, sensitive receptor data, etc.

e) Application Support Layer: This layer provides common components or middleware for the implementation of application modules, including GIS, BI, data encryption, message, data visualization, assessment model etc.

f) Business Application Layer: This layer implements specific business functions, and its core is "a map plus four modules". Among them, the four functional modules correspond to business in different fields. On the basis of the above four modules, the environmental risk map, as a unified carrier and visualization form of the platform, integrates and fuses various environmental basic data, risk parameters and assessment data.

g) End User Layer: This layer is directly facing end users, generally monitoring personnel and decision-makers of environmental protection of nuclear power plants. Users access the platform and perform related operations through terminal devices such as large screens, computers, and adapted UI.
Figure 3. The System Architecture of Environmental Risk Monitoring and Assessment Platform

4.2. Functional Module
The main functional modules are concentrated in the business application layer, and its core is "a map plus four modules".

Among them, the four functional modules correspond to business in different fields. The data management module is used to manage and maintain various business data in the platform, covering environmental data, device data, sensitive receptor data, etc. The parameter monitoring module automatically monitors parameter changes in real time. When risks may or have occurred, early warning and alarm information will be given in time. In the risk assessment module, users can select the corresponding assessment model according to different risk and accident types, manually input or automatically access the related parameters, and then start the assessment. The module automatically calculates the environmental and health consequence caused by the accident, and combines certain guidelines to give appropriate protective measures and interventions. The system configuration module is an auxiliary module of the platform, it is used for the management, maintenance and configuration of system parameters, users, permissions, etc.

On the basis of the above four modules, the environmental risk map, as a unified carrier and visualization form of the platform, integrates and fuses various environmental basic data, risk parameters and assessment data. Relying on GIS (Geographic Information System), big data, BI (Business Intelligence) and other technologies, the environmental risk map module realizes the unified visualization of multi-source and heterogeneous data. On the basis of high-resolution satellite image data, superimposed with raster maps, heat maps, isoline maps, three-dimensional models and dynamic effects, this module can fully demonstrate the dynamics of environmental risk parameters and the spatiotemporal characteristics of risk assessment results.
4.3. Application of the Platform
In some nuclear power plants in China, based on the actual situation and the environmental risk monitoring and assessment technology described in this paper, an application platform was designed and constructed for the monitoring, assessment, management of environmental risk. Figure 4 shows the main functions and UI of the platform.

The application situation shows that the platform and the technology it relies on can solve existing problems and effectively improve the ability of environmental risk monitoring and assessment of these nuclear power plants.
5. Conclusions
Based on existing research foundation, in order to solve the related problems in the field of environmental risk of nuclear power plant, this paper conducts in-depth research and discussion on the monitoring and assessment of environmental risk. It proposes a set of standardized technical framework. Based on this framework, an application platform is designed and implemented and applied to the environmental risk monitoring, assessment, and management of nuclear power plant. Practice shows that the standardized technical framework and application platform have a certain promotion value. At the same time, the model and method of comprehensive environmental risk management also need further discussion and research.

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