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Original Article

Assessment of supervision monitoring for radiation environment around the typical research reactors in China

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ABSTRACT

The supervision mode, monitoring basis and monitoring scheme of radiation environment monitoring concerning typical research reactors in China were investigated in this study. Summary and analysis were concluded of the present situation of supervised monitoring of radiation environment, such as monitoring objects, points, frequency and so on, based on the relevant data of monitoring points of four typical research reactors in China. Some experiences and existing problems were analyzed concerning the supervised monitoring of China's research reactors. Tips on topics related to strengthen the monitoring of radiation environment around the research reactors has noted.

1. Introduction

Nuclear safety is closely related to radioactive pollution prevention, public health, environment safe and social stability [1–7]. In recent decades, the safety of China's nuclear power has reached the international advanced level, and the safe operation of research reactors and nuclear fuel cycle facilities has maintained a good record. The Law of the People's Republic of China on the prevention and control of Radioactive Pollution clearly stipulates that the administrative department of environmental protection under the State Council shall be responsible for the supervision and monitoring of important nuclear facilities such as nuclear power plants. The National Nuclear Safety Administration (NNSA) as an independent national regulator formulated the national radiation environment monitoring program, which clarifies the content of supervised monitoring of the radiation environment around the research reactor. The supervisory monitoring for radiation environment around the typical research reactors is an important means of preventing unplanned emissions. Many studies reported on the monitoring of radiation environment in nuclear power plants in the literatures, but there's little coverage of the supervised monitoring of radiation environment in the research reactor. The monitoring data can provide early warning signal of environmental pollution on possible accidents, provide reliable data about the impact on the surrounding environment of nuclear facilities, and assess the risk of environmental whether were polluted by nuclear installations [8–12].

2. Supervisory monitoring regulatory system

2.1. Division of regulatory functions

The Nuclear safety Law of the people's Republic of China stipulate the relevant departments of the State Council to launch radiation environmental monitoring of nuclear installations. The “double track monitoring” system for nuclear and radiation facilities is implemented in China, that is, requiring owners to carry out environmental monitoring, and requiring audit and management departments progressing supervisory monitoring independent of owners [13–16]. The NNSA has three nuclear safety supervision departments performing the functions of supervising the radioactive monitoring of nuclear facilities in China. The monitoring and supervision of the related nuclear installations is mainly the responsibility of Nuclear installations Safety Regulatory Division, and its functions as follow: to be responsible for the formulation of radioactive monitoring policies and regulations for nuclear installations in China; enacting plans of the preparation and implementation for the construction of the national nuclear installations monitoring system; to organize, implement and assess the radioactive monitoring of nuclear installations throughout the country; the examination of annual radioactive monitoring reports on effluents throughout the country, and the disclosure of information.

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In order to effectively supervise the activities of key nuclear facilities in China, the radiation environment monitoring institutions in provinces are entrusted by NNSA to undertake the supervisory monitoring of the nuclear installations in their respective jurisdictions [17–20].

2.2. Monitoring guidelines

To further standardize the monitoring of radiation environment and effectively supervise the radiation environment around the significant nuclear installations in China, the national radiation environment monitoring program (2019 Edition) regulates the monitoring contents of radiation environment around the key nuclear installations, including monitoring objects, monitoring frequency, point setting principles and so on. The Program is authority file compiled according to the national and industry standards, such as, the technical criteria for radiation environmental monitoring (HJ/T 61–2001) and the basic standards for protection against ionizing radiation and for the safety of radiation sources (GB 18871–2002). The monitoring contents of radiation environment around the integrated nuclear base mainly refer to the monitoring scheme of radiation environment around the research reactor (Table 1)

As is listed in the table above, the supervised monitoring of the radiation environment of the research reactor includes the gamma radiation, the total radioactivity and the measurement of characteristic nuclides in different medium, the medium of measuring including atmospheric environment, terrestrial environment, water, radionuclide measurements of plants and animals in soil and food chains. Usually, the scope of monitoring of environmental gamma radiation is 20 km, and eight azimuth intervals of 2 km, 5 km, 10 km around the factory boundary are intersected. Continuous and cumulative sampling of aerosol should be carried out simultaneously. The points of continuous and cumulative should be the same for data comparison Monitoring frequency can be adjusted according to the actual situation. For example, Beijing has a typical warm temperate semi-humid continental monsoon climate, which has rainfall of year's concentrated in summer. The measurement frequency is required once a season. The sampling will be insufficient in the season of less precipitation. Therefore, it is recommended that the sample collection should be delayed, and the frequency of measurement should adjusted to appropriately. According to the characteristics of the reactor which operating as the plan list, during the period of operation with less liquid effluent discharge, for better warning of accidents and conditions, the gaseous effluent can be monitored. Referring to the air, the total radioactivity, ^{3}H, ^{14}C and iodine are required to monitor with the frequency of 1 time per month.

2.3. Sampling and processing

In accordance with the requirements of the technical specification for radiation environmental monitoring (HJ/T61-2001), we can get the instructions of sampling operations for radiation environmental monitoring, including sampling methods, sample preservation and sampling quantities, sampling quality assurance measures, etc. The monitoring organization ordinarily adopts the uniform filter membrane of the whole country to collect aerosol samples, and strictly implement the technical specifications for the collection and treatment of the monitoring samples issued by the state control network.

2.4. Quality assurance

The measures to assurance quality include internal and external quality control.

The internal quality control has many methods including numerical anomaly verification, drawing instrument quality control chart and comparison of instruments. For radiation analysis, long-term reliability and Poisson distribution test should be carried out regularly to large instruments. Sample analysis should include blank sample, parallel sample, standard recovery rate determination, and specific frequency according to relevant technical specifications. External quality control can take the way of quality assessment, participation in international and domestic authority organization capacity verification and comparison activities, sample inspection and so on [21,22].

3. Monitoring status of typical research reactor in China

3.1. Background

Research reactors mainly used as neutron sources for experimental study play an important role in the development of nuclear science and technology. To analysis the influence of research reactors on environmental radiation, National Nuclear Safety Administration (NNSA) is obliged to supervise the activities of nuclear facilities include research reactor, uranium mining and metallurgical facilities and nuclear electrical power plant etc. After the construction in 1958, the first research heavy water experimental nuclear reactor plays an important role in the development of nuclear energy science and technology for more than 60 years. At present, there are 22 research reactors in China, including the heavy water reactors, the light water reactors, the high temperature reactors, the fast reactors and the critical devices. Difference from the high throughput engineering reactor power of 125 MW, the power of other research reactors were below 60 MW. The research reactors are widely used, including basic nuclear physicochemical experimental research, isotope production, neutron activation analysis, nuclear material irradiation experimental research, advanced material research and development, transmutation chemistry research and so on.

The monitoring data in this paper come from four typical research reactors, which are distributed by Atomic energy institute, Tsinghua nuclear research institute, nuclear power institute and Shenzhen micro-reactor. The atomic energy institute located in Fangshan District in Beijing, which was founded in 1950, is the birthplace of nuclear science and technology in China. It is also a comprehensive nuclear base for national defense scientific research and nuclear energy development and utilization. There are three experimental reactors in Tsinghua Institute of Nuclear Research, and they located in Changping district of Beijing. Both the atomic energy institute and the Tsinghua Nuclear Research Institute are approximately 40 km from downtown. The nuclear power institute is a comprehensive nuclear power research with development base designed, development and production located in Sichuan Province. Shenzhen micro reactor, located in Shenzhen University in Guangdong Province, has been operating safely for 28 years.

3.2. Oversight of monitoring

Around the radius of nuclear installations within 20 km, the location arrangement is based on the principle of 16 azimuth angles, near dense and far sparse, and meet the principles of representativeness, science, maneuverability, stability and so on.

3.3. Analysis

3.3.1. Monitoring point meet the specifications

By sorting out the monitoring point data of the monitoring scheme from Tables 2a and b, the map of the number of supervised

Table 1
Monitoring items for the radiation environment on the periphery of four reactors.

object	principle	frequency	item
Land gamma radiation	At the highest concentration of the ground outside the factory, the boundary is intersected according to the azimuth interval of radius 2,5,10,20 km,8, which is close to dense and sparse	1 time/season	gamma air absorption dose rate
	Automatic monitoring stations	Continuous	gamma air absorption dose rate
	The highest concentration on the ground outside the plant; Around the factory boundary according to the radius of 2,5,10,20 km,8 azimuth interval crossing points, near dense, far sparse	1 time/season	gamma radiation cumulative dose
Aerosols	Plant boundaries; The highest concentration on the ground outside the plant; Residential area <10 km from the factory boundary under the dominant wind direction; Reference points	Continuous sampling (select a point for annual continuous sampling analysis If possible) once a month Cumulative sampling 1 time/month, sampling volume about 10,000 m^3	Alpha gross and beta gross、gamma radionuclides
Air	Same as aerosol	1 time/month 1 time/half year	^{3}H、^{14}C ^{131}I、^{133}I
Precipitation (rain, snow, hail)	Same as aerosol	Cumulative sample/season	^{3}H
Dry sediment	Same as aerosol	Cumulative sample/season	^{90}Sr、gamma nuclides,
Wet sediment	Same as aerosol	Cumulative sample/season	alpha gross and beta gross
Surface water	Surface water projected to be affected; Upstream reference points	1 time/half year	^{3}H、gamma nuclides
Ground water	Groundwater sources that may be affected; Reference points	1 time/half year	^{3}H、gamma nuclides
Drinking water	Potentially affected drinking water sources; Reference points	1 time/season	total α、 total β、^{3}H、gamma nuclides
Sea water	Sea area near discharge port; Reference points	1 time/half year	^{3}H、gamma nuclides
Aquatic organisms	The downstream waters or sea areas of the discharge port; Reference points	1 time/year	gamma nuclides
Sedimentation	Same as surface water (sea water)	1 time/year	^{90}Sr、gamma nuclides
Terrestrial plants	Leading downwind direction or drainage downstream irrigation area; Major crops; Reference points	Harvest period	gamma nuclides
Livestock, Poultry	The nearest village under the main wind direction outside the factory	1 time/year	gamma nuclides
Cow (sheep) milk	The nearest dairy outside the main wind direction plant <30 km	1 time/half year	^{131}I
Indicator organisms	The highest concentration on the ground outside the plant; Emissions	1 time/year	Characterized nuclides as indicated by concentration
Soil, shore sediments	Within 16 azimuths (properly encrypted under dominant wind direction) < 10 km; Reference points	1 time/year	^{90}Sr、gamma nuclides
Intertidal zone soil	Intertidal soil near discharge port; Reference points	1 time/year	^{90}Sr、gamma nuclides

Note: monitoring of the gamma radionuclides should focus on the characteristic nuclides emitted by nuclear installations, including:1) gamma nuclides in aerosols and sediment generally include, but are not limited to, radionuclides such as ^{7} Be、^{54}Mn、^{58}Co、^{60}Co、^{4} K、^{95}Zr、^{131}I、^{137}Cs、^{134}Cs、^{144}Ce; 2) radionuclides in biological, soil, shore sediments, intertidal soil, sediment generally include, but are not limited to, radionuclides such as ^{40} K、^{54}Mn、^{58}Co、^{60}Co、^{95}Zr、^{110m}Ag、^{137}Cs、^{134}Cs、^{144}Ce; 3) radionuclides in water generally include, but are not limited to, radionuclides such as ^{54}Mn、^{58}Co、^{60}Co、^{65}Zn、^{95}Zr、^{110m}Ag、^{124}Sb、^{137}Cs、^{134}Cs、^{144}Ce.

monitoring points of radiation environment in China's typical research reactor is obtained as shown in Fig. 1 below.

Fig. 1 shows the specific distribution of the number of supervised monitoring points in the radiation environment of typical research reactors in China. The monitoring objects are gamma dose rate, aerosol, air, precipitation, dry and wet deposition, surface water, drinking water, soil, terrestrial organisms, indicator organisms, sediment, shore sediment and livestock and poultry. Monitoring medium covers air, aqueous and soil. According to the different power and the operation frequency of the reactors, the numbers of the monitoring points for the radiation environment of different nuclear installations are slightly different in China. In order to more effectively supervise the early warning of radiation caused to the surrounding environment during the operation of the reactor, the number and frequency of monitoring points have been strengthened during the operation of the integrated nuclear reactor. According to the characteristics of the research reactor, the monitoring points and numbers were optimized to make the

Table 2a
Monitoring items for radiation environment around typical integrated research reactors.

targets	Atomic energy institute			Tsinghua institute of nuclear research		
	projects	Frequency	Location Name	projects	Frequency	Location Name
Air	gamma radiation dose rate (continuous)	continuous	401 Tongji Hospital; 401 Animal House; 401 Sewage Treatment Works; 401 Fire Brigade; 401 Graduate School	gamma radiation dose rate (continuous)	continuous	Tsinghua No.200 high temperature reactor west; Tsinghua No.200 northeast gate; Tsinghua No.200 high temperature reactor southeast
	environmental surface gamma radiation dose rate	1time/season	Near the gate (E); Beifang Village (SSE); Shawo Village (NNW); Xinzhen (ESE); Dayuan Shang (NNE); Xiaodong Village (SSE); Tuoli (N); 80 mu of land (WNW); Yangtougang (SW); Gucheng Park (NE)	environmental surface gamma radiation dose rate	1time/season	Outside the gate roadside grassland (S); Huyu (N); Taiping Zhuang (E); Old Beijing miniature landscape garden (SE); Huyu garden villa (NW); Nankou Town (SWS); Nankou Village (WSW); eulogy supervisor (ENE); Deshengkou (NNE); Beijing Senfu Company (SE)
	gamma radiation cumulative dose	1time/season	Near the gate (E); Beifang Village (SSE); Shawo Village (NNW); Xinzhen (ESE); Dayuan Shang (NNE); Xiaodong Village (SSE); Tuoli (N); 80 mu of land (WNW); Yangtougang (SW); Gucheng Park (NE)	gamma radiation cumulative dose	1time/season	Outside the gate roadside grassland (S); old Beijing miniature garden (SE); Huyu (N); Taiping Zhuang (E); Huyu Garden Villa (NW); Nankou Town (SWS); Nankou Village (WSW); eulogy supervisor (ENE); Beijing Senfu Company (SE)
	^{3}H、^{14}C	1time/month	Beifang Village, Wan Liu Zhong Road (Reference points 1time/half year)	^{3}H、^{14}C	1time/month	Taiping Zhuang, Wan Liu Zhong Road (Reference points 1time/half year)
	^{131}I、^{133}I	1time/half year	401 Animal House; 401 Graduate School; Wan Liu Zhong Road, Beifang Village (Reference points)	^{131}I、^{133}I	1time/half year	Taiping Zhuang; southeast of Qinghua No.200 High Temperature Reactor; Wanliuzhong Road (Reference points)
Aerosol	Alpha gross and beta gross; gamma radionuclide	1time/month	Beifang Village; 401 Graduate School; 401 Animal Room; Wanliuzhong Road (Reference points)	Alpha gross and beta gross; gamma radionuclide	1time/month	Taiping Zhuang; southeast of high temperature reactor of Tsinghua No.200; northeast gate of Tsinghua No.200; Wanliuzhong Road (Reference points)
Settlement	Alpha gross and beta gross radionuclide Sr-90	Cumulative sample/season	Beifang Village; 401 Graduate School; Wanliuzhong Road (Reference points)	Alpha gross and beta gross; gamma radionuclide Sr-90	Cumulative sample/season	Taiping Zhuang (peasant household); southeast of Tsinghua No.200 high temperature reactor; Wanliuzhong Road (Reference points)
Precipitation	^{3}H	Cumulative sample/season	Beifang Village; 401 Animal House; Wanliuzhong Road (Reference points)	^{3}H	Cumulative sample/season	Taiping Zhuang; southeast of Qinghua No.200 High Temperature Reactor; Wanliuzhong Road (Reference points)
Surface water	gamma radionuclide、^{3}H	1time/half year	Dashihe River; upper reaches of Dashihe River (Reference points)	gamma radionuclide、^{3}H	1time/half year	Xinli zhuang; 19 Yuquan Road, Shijingshan District (Reference points)
Drinking water	Alpha gross and beta gross; gamma nuclide; ^{3}H	1time/season	Bei Fang Village, Sha Wo Village; Water Source No .3(Reference points)	Alpha gross and beta gross; gamma nuclide; ^{3}H	1time/season	Xinli Zhuang; Water Source No.3 Plant (Reference points)
Wastewater	Alpha gross and beta gross, industrial waste water discharge	1time/half year	Industrial wastewater discharge	Alpha gross and beta gross	1time/half year	Evaporation pool
Soil	gamma nuclide;^{90}Sr	1time/half year	Bei Fang Village, Sha Wo Village, Xin Zhen, Xiao Dong Village, Tuo Li, 80 mu of land, Dayuan Shang, Xizhuang Hu Village, Yangtou Gang, Yan Village, Nanpu Village, Tian GE Zhuang Village, oral village, Jiao Zhuang, Qian Zhu GE Zhuang Village; Miyun Reservoir former Hotel (Reference points)	gamma nuclide;^{90}Sr	1time/year	Beijing micro-view garden, Huyu, Huyu Scenic Area, Dongyuan Village, Xinlizhuang, Taiping Zhuang, Nankou Village, Nankou Town, Nankou Park, Longhutai Village, Xishankou Village, Gongling Supervision Village, Deshengkou Village; Miyun Reservoir Hotel (Reference points)
Terrestrial plants (maize)	gamma nuclide	1time/year	Beifang Village; surrounding Miyun Reservoir (Reference points)	gamma nuclide	1time/year	Taiping Zhuang, surrounding Miyun Reservoir (Reference points)
Indicative organisms (pine needles)	^{90}Sr、gamma nuclide	1time/year	North Square Village	gamma nuclide,^{90}Sr	1time/year	Taiping Zhuang
Ground water	gamma nuclide ^{3}H	1time/half year	North Square vegetable irrigation water; Shijingshan District Yuquan Road 19 deep water well (Reference points)			
Sedimentation	^{90}Sr、gamma nuclide	1time/year	Dashihe River, upper reaches of Dashihe River			
Sedimentary sediments	^{90}Sr、gamma nuclide	1time/year	Dashihe River; surrounding Miyun Reservoir (Reference points)			

monitoring work more representative, objectively and feasible. The monitoring points can meet the requirements of the corresponding specifications, such as, section 5.2.1.1 of HJ/T 61–2001 and section 8.7 of GB 18871–2002.

3.3.2. Distribution of monitoring points

The research reactors involved in this paper are distributed in three regions of China. According to Tables 2a and b, the total number of supervisory monitoring points of typical research

Table 2b
Monitoring items for radiation environment around typical integrated research reactors.

targets	Nuclear power research institute			Shenzhen micro-reactor		
	projects	Frequency	Location Name	projects	Frequency	Location Name
Air	Automatic monitoring station gamma radiation air absorption dose rate	continuous	Nanba living area, complex building, wooden city, landfill, boundary card			
	gamma radiation air absorption dose rate	1time/ season	Nanba living area, complex building, wooden city, Xima Township, Huatou Town, Longtuo Township, Jiepai Town, Qianfoyan, Zhongxing Town, Sanbao Town	gamma radiation air absorption dose rate	2time/ season	Inside and outside buildings surrounding reactor (11 points)
	gamma radiation cumulative dose	1time/ season	Nanba living area, complex building, wooden city	gamma cumulative dose	1time/ year	Inside and outside buildings surrounding reactor (6 points)
	^{3}H、^{14}C	1time/ season	Nanba living area, complex building, Mu Cheng, Ya'an Bifeng Gorge (Reference points)			
	^{131}I、^{133}I	1time/half year	Nanba living area, complex building, Mu Cheng, Ya'an Bifeng Gorge (Reference points)	^{125}I、^{131}I	2time/ year	under Gaseous emission chimney, outside the east gate of micro heap, river source (Reference points)
Aerosol	^{7}Be、^{54}Mn、^{58}Co、^{60}Co、^{144}Ce、^{4} K、^{137}Cs、^{134}Cs、^{131}I and so on; Alpha gross and beta gross	11 time/ season	Dam living area, wooden city, boundary sign, Ya'an Bifeng Gorge (Reference points)、Complex (1time/ month)	gamma radionuclide	21 time/ year	under Gaseous emission chimney, outside the east gate of micro heap, river source (Reference points)
Settlement	^{7}Be、^{54}Mn、^{58}Co、^{60}Co、^{144}Ce、^{4} K、^{137}Cs、^{134}Cs、^{131}I and so on; Alpha gross and beta gross;^{90}Sr	1time/ season	Nanba living area, complex building, Mu Cheng, Ya'an Bifeng Gorge (Reference points)			
Precipitation	^{3}H	1time/ season	Nanba living area, complex building, Mu Cheng, Ya'an Bifeng Gorge (Reference points)			
Surface water	^{65}Zn、^{54}Mn、^{58}Co、^{60}Co、^{144}Ce、^{95}Zr、^{137}Cs、^{134}Cs、^{110m}Ag、^{124}Sb and so on,^{3}H	1time/half year	1000 m downstream of outlet of large rock trough; 200 m upstream of Qianfoyan dam (Reference points)	gamma radionuclide	1time/ year	Nanfang Lake
Drinking water	^{65}Zn、^{54}Mn、^{58}Co、^{60}Co、^{144}Ce、^{95}Zr、^{137}Cs、^{134}Cs、^{110m}Ag、^{124}Sb and so on,^{3}H、Alpha gross and beta gross	1time/ season	Well Water/Drinking Water in Nanba Living Area; Longtuo Township Well Water/Drinking Water (Reference points)			
Wastewater				gamma nuclide	1time/ year	Shenzhen University Building Hall
Soil	^{4} K、^{54}Mn、^{58}Co、^{60}Co、^{144}Ce、^{95}Zr、^{137}Cs、^{134}Cs、^{110m}Ag and so on,^{90}Sr	1time/year	Nanba living area, complex building, wooden city, Xima Township, Longtuo Township, Qianfoyan	gamma nuclide	1time/ year	Weidui East Grassland, Weidui South Grassland, Weidui North Grassland, Heyuan (Reference points)
Terrestrial plants (maize)	^{4} K、^{54}Mn、^{58}Co、^{60}Co、^{144}Ce、^{95}Zr、^{137}Cs、^{134}Cs、^{110m}Ag and so on	1time/year	Nanba Living Area, Ya'an Bifeng Gorge (Reference points)			
Indicative organisms (pine needles)	^{60}Co、^{137}Cs 、^{90}Sr	1time/year	South Dam			
Sedimentary sediments	^{4} K、^{54}Mn、^{58}Co、^{60}Co、^{144}Ce、^{95}Zr、^{137}Cs、^{134}Cs、^{110m}Ag and so on,^{90}Sr	1time/year	Shore 1000 m downstream of outlet of big rock trough,			

Table 2b (*continued*)

targets	Nuclear power research institute			Shenzhen micro-reactor		
	projects	Frequency	Location Name	projects	Frequency	Location Name
			200 m upstream of Qianfoyan dam (Reference points)			

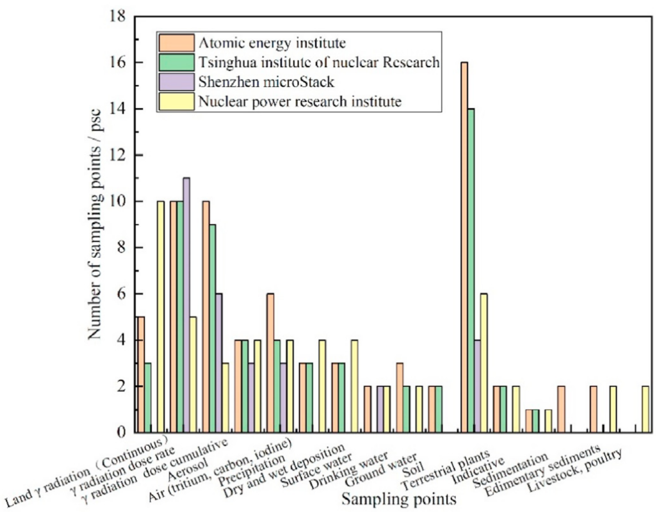

Fig. 1. Number of supervised monitoring points for radiation environment of typical research reactors in four nuclear facility.

reactors in China is 208, including 128 supervisory monitoring points in Beijing comprehensive nuclear research base, 51 supervisory monitoring points in Sichuan province, and 29 supervisory monitoring points in Guangdong research experimental micro-stack. As is shown in Fig. 2, the proportion of monitoring points is 61% in Beijing, 25% in Sichuan and 14% in Guangdong. The regional distribution accords with the number of research reactor, the complexity of reactor type in each region and the reactor power.

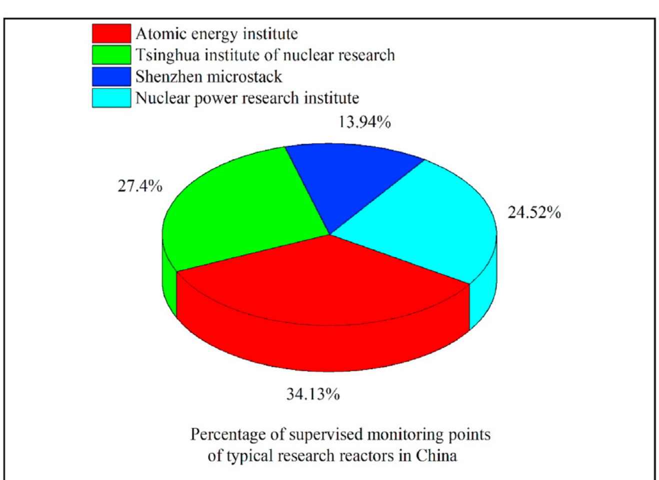

Fig. 2. Percentage of supervised monitoring points of typical research reactors in China.

3.3.2. *Monitoring projects*

The air absorption dose rate can representative the radiation level of environmental directly, which is an important component of environmental radiation monitoring. The data of air absorption dose rate not only be used to monitor the condition of sources of nuclear facilities and other radiation devices, but to be the alarm for abnormal or accidental release, even can provide data for estimating the dose of gamma radiation from the environment to the public. Therefore, there are relatively more points of dose rate are arranged. The numbers of monitoring points in four units are shown in Fig. 3 below. From the diagram, the percentage of soil is 19.23%, the gamma dose rate is 17.31%, and the cumulative dose monitoring points is 13.46% close to gamma dose rate monitoring points. Therefore, gamma instantaneous dose rate and cumulative dose can be more representatively. The monitoring points of aerosol, tritium, carbon, iodine and radiation environmental quality in air is 7.21%, 8.17%, and 8.65% respectively (all around 8%). Above notes the proportion for monitoring purposes is well-distributed. The number of water samples, plant samples and animal samples are sufficient. It can be used as the improvement of supervisory monitoring data.

4. Results and discussion

From the current supervisory monitoring work of the four typical research reactors above, the supervised monitoring of the radiation environment of the research reactor can basically reflect the radioactivity level around the nuclear installations, and the setting of the points meets the requirements of the relevant specifications. However, there are still some problems in the monitoring of radiation environment in China.

4.1. *Research reactor radiation environment monitoring system is not perfect*

At present, the radiation environment monitoring system for nuclear power plants in China has constructed. In the construction of new nuclear power plants, the supervision monitoring system of nuclear power plants is generally composed of two parts: radiation environment monitoring system and effluent monitoring system. However, the research reactors in China are short of the radiation environment monitoring system. The monitoring system of the peripheral radiation environment around the research reactors has not yet formed, and the monitoring system of the radioactive effluent is overall deficiency, including the lack of effluent on-line monitoring system and effluent radioactive laboratory. Sample measurements of a small amount of effluent are generally carried out in the radiation environment laboratory. It is suggested that the national monitoring institutions should constantly improve the system of supervised monitoring of radiation environment in China. The pace of construction of supervised monitoring radiation environment laboratory, effluent radioactive laboratory and on-line monitoring system of radioactive effluent need to accelerate.

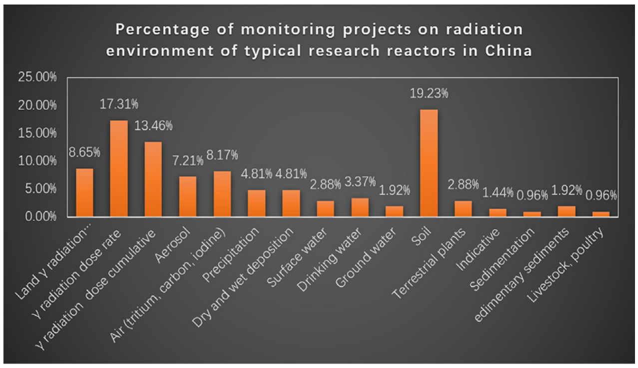

Fig. 3. Percentage of monitoring projects on radiation environment of typical research reactors in China.

4.2. *Insufficient monitoring capacity of research reactors*

The provincial monitoring agencies are entrusted by the NNSA to undertake the supervisory monitoring for the radiation environment of the research reactors in their provinces. At present, there are about 10 staffs engaged in monitoring work in each province, and they are also responsible for sample collection, measurement analysis and data collation. Especially in the radioactive effluent monitoring projects, skilled technicians who are with excellent monitoring technology and familiar with the monitoring equipment and process treatment for radioactive liquids are inadequate. It is suggested that the provincial monitoring institutions should intensive cultivate the technical personnel for radiation environment monitoring, increase the input on monitoring equipment, strengthen the training for technical personnel, and continuously improve the supervisory monitoring ability of our country.

4.3. *State support for monitoring funds needs to be strengthened*

Provincial monitoring institutions are facing many difficulties in carrying out supervisory monitoring of radiation environment within their jurisdiction. Through the on-site investigation and research work carried out in the review work, the provincial monitoring agencies indicated that the financial support of the state investment is far from supporting the development of the supervisory monitoring work of the nuclear facilities in the jurisdiction. With the support of limited funds, each provincial monitoring institution still needs to require much human effort in terms of sampling, data analysis and writing monitoring data reports. According to the requirements of the monitoring scheme, the workload of sampling, analysis, measurement and report preparation is relatively large, and the monitoring competencies construction cannot be separated from the support of policies and funds. In our country, the investment for radiation environment supervisory monitoring of research reactors needs to be strengthened.

5. Conclusion

The supervisory monitoring items of four typical research reactors in China set up reasonably and acceptability. The number and frequency of monitoring points meets the requirements of relevant specifications according to the principles of science and rationality. Individual monitoring items and frequency are optimized according to the actual situation.

I. Based on monitoring experience feedback, in general, nuclear power plant gas emissions have little impact on the terrestrial environment. Under normal operating conditions, the quantity of radioactive effluents produced in liquid and gaseous state is very less. Thus, the number and frequency of monitoring points required by the supervisory monitoring projects of the research reactors can be reduced accordingly.

II. There are obvious regional climate differences in China, it is wet in the South, while the North is dry. Such as humid climate in the south country, high air humidity, little amount of dust and gray in the air. The climate in the north is dry especially in the northwest, the radionuclides are great differences in the types and contents in the north and south. Therefore, the radiation environment monitoring items such as aerosols can be adjusted according to the actual situation.

III. According to the control value of environmental radiation protection of NPP (GB6249), the control values of tritium, carbon - 14 and other nuclides are 7.5×10^{13} Bq, 1.5×10^{11} Bq/year, 5.0×10^{10} Bq/year; tritium, carbon - 14 and the remaining nuclides are 3.5×10^{14} Bq/year, 2×10^{11} Bq/year, 2×10^{11} Bq/year. For reactors with a thermal power greater than or less than 3, 000 MW, the mission limits can appropriate adjust to own situation. Each nuclear facility has designated emission limits of years authorized by NNSA. The radioactive release reported by supervisory monitoring system of research reactors are showed on the annual report of the radiation environment around state controlled major nuclear and radiation facilities. We can conclude that the radioactive release of the four typical reactors is at the bottom level in accordance with the annual report of 2020.

Supervision monitoring of radiation environment is an important work to ensure the environment safety of operating nuclear installations. For the considerations of long-term security, the monitoring systems for the radiation environment around the research reactors should be established and improved. Potential risks and early warning of accidents be from research reactors can be timely detected by supervised monitoring. It is not only need to improve the reliability of the operation of the research reactors, but also to ensure the safety of the surrounding radiation environment. Safety monitoring data will help to ease the nuclear panic of public. The supervision level of safety for nuclear reactors in China will be increase with the enhancement of the radiation monitoring ability of provincial environmental protection departments.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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