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The Improvement of China's Nuclear Safety Supervision Technical Support Ability

Han Wu, Guoxin Yu, Xiangyang Zheng, and Keyan Teng*
The Nuclear and Radiation Safety Center of MEE, No.54 Hongliannancun, Haidian District, Beijing 100082, China

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The International Atomic Energy Agency (IAEA) entails independent decision-making for the safety supervision of civil nuclear facilities. To evaluate and review the safety of nuclear facilities, the national regulatory body usually consults independent institutions or external committees. Technical Support Organizations (TSOs) include national laboratories, research institutions, and consulting organizations. Support from professional organizations in other countries may also be required occasionally. Most of the world's major nuclear power countries adopt an independent nuclear safety supervision model. Accordingly, China has continuously improved upon the construction of such a system by establishing the National Nuclear Safety Administration (NNSA) as the decision-making department for nuclear and radiation safety supervision, six regional safety supervision stations, the Nuclear and Radiation Safety Center (NSC), a nuclear safety expert committee, and the National Nuclear and Radiation Safety Supervision Technology R&D Base, which serves as the test, verification, and R&D platform for providing consultation and technical support. An R&D system, however, remains to be formed. Future endeavors must focus on improving the technical support capacity of these systems. As an enhancement from institutional independence to capability independence is necessary for ensuring the independence of China's nuclear safety regulatory institution, its regulatory capacity must be improved in the future.

Keywords: Nuclear facilities, Supervision, Technical support, Test bench, Safety analysis

*Corresponding Author.
Keyan Teng, The Nuclear and Radiation Safety Center of MEE, E-mail: napolaen@qq.com, Tel: +86-10-8220-5740

ORCID

Han Wu	http://orcid.org/0000-0003-1193-7520	Guoxin Yu	http://orcid.org/0000-0003-4110-5389
Xiangyang Zheng	http://orcid.org/0000-0002-1378-6757	Keyan Teng	http://orcid.org/0000-0002-0025-6482

1. Introduction

China has always attached importance to nuclear and radiation safety. It has repeatedly proposed to strengthen nuclear and radiation safety supervision and adhere to the requirement of safety first. Over the past 30 years, China has established a relatively complete nuclear and radiation safety supervision system, and the nuclear and radiation safety situation is stable. However, with the rapid development of nuclear energy and nuclear technology utilization, nuclear and radiation safety supervision is facing many new challenges. The research analyzes the nuclear and radiation safety supervision mode of major countries in the world and the current situation of nuclear and radiation safety supervision in China, puts forward some detailed conclusions on the construction of technical support system, so as to provide a guarantee for improving China's nuclear and radiation safety supervision ability. This is of great significance for the safe use of nuclear energy.

2. Nuclear Safety Supervision of Major Nuclear Power Countries

In the history of nuclear power development, there have been serious nuclear accidents, such as Three Mile Island in the United States, Chernobyl in the former Soviet Union and Fukushima in Japan. Government have summed up experiences and lessons, paid attention to the improvement of nuclear safety level, developed a variety of advanced reactors, and strengthened supervision. Most of the world's major nuclear power countries adopt an independent nuclear safety supervision, which refers to the safety supervision directly under State Council and the regulator body has no relationship with nuclear power enterprises [3].

The U.S. Nuclear Regulatory Commission (NRC) is the nuclear safety regulatory agency in America. NRC is composed of headquarters and four regional supervision stations. It is responsible for independent nuclear safety supervision and management of civil nuclear facilities in the United States. France has independent nuclear and radiation safety regulation by the General Administration of nuclear safety and radiation protection (DGSNR), the Institute of radiation protection and nuclear safety (IRSN) and the permanent expert group (members are French and foreign experts in various scientific and technological fields) are the main technical support organizations of DGSNR. Japan's nuclear safety regulatory department is the atomic power safety and security agency, its technical support organizations include Japan Atomic Energy Research Institute, nuclear fuel cycle development agency, atomic energy power generation technology agency, power generation equipment technology inspection association, etc. The nuclear safety supervision department entrusts these organization to do specific review and inspection work [1-3].

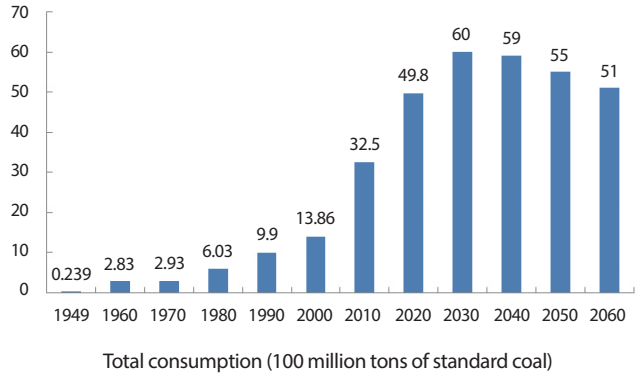

Fig. 1. Total energy consumption since the founding of the people's Republic of China.

3. The Situation of China's Nuclear Safety Supervision

Since 1949, China's total energy consumption has continued to grow. In response to climate change, China proposes to strive to achieve the strategic goal of "carbon peaking" by 2030 and "carbon neutralization" by 2060, which requires efforts to increase the proportion of

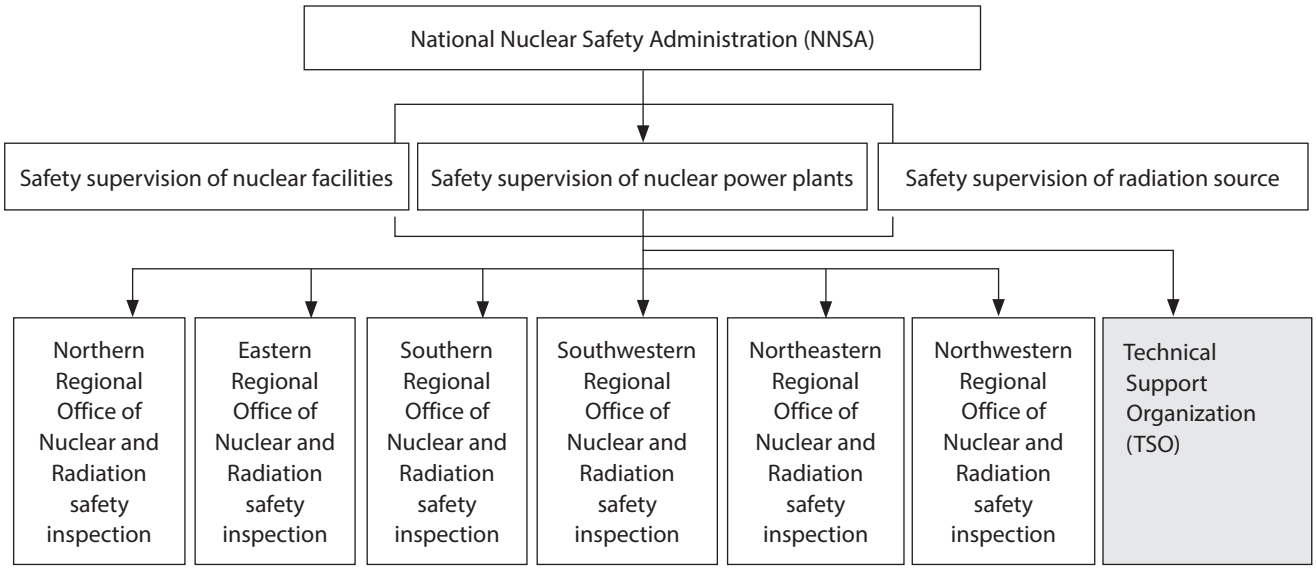

Fig. 2. Chart of China's nuclear and radiation safety regulators.

non-petrochemical energy [4-7]. China must develop nuclear power actively, which puts forward higher requirements for nuclear and radiation safety supervision.

China's government has always attached great importance to nuclear and radiation safety. "Strengthening nuclear and radiation safety supervision" has been incorporated into the guiding ideology of China's economic and social development during the 14th Five Year Plan period. It provides direction guidance for strengthening nuclear and radiation safety in the new era.

3.1 The Situation of China's Regulatory Agency

China's nuclear and radiation safety regulatory body is composed of the National Nuclear Safety Administration (NNSA), six regional nuclear and radiation safety supervision stations, the nuclear and radiation safety center (NSC) and other technical support organizations. NNSA is the decision-making agency. Six regional nuclear and radiation safety supervision stations conduct regional on-site supervision. NSC and other organizations are technical support units.

Due to the importance of nuclear safety, the laws and regulations in China specify that the State shall take the implementation of nuclear safety supervision. Since 1989, China has established a nuclear and radiation safety supervision system. Especially in 2011, with reference to international practices, China approved 1,016 Supervisors for 37 nuclear power units which are under construction and operation, it is basically met the needs of nuclear safety supervision. But Since 2011, the number of nuclear and radiation safety Supervisor has not been adjusted.

China's nuclear and radiation safety supervision system has been consistent with the world since its establishment. It adopts the national direct supervision mode to supervise the whole process of nuclear facilities [8]. For example, a supervision system has been established to implement 24-hour continuous supervision. At the same time, an independent safety review system has been established to carry out technical review on activities involving nuclear and radiation. NNSA also set the project officer and project manager system to organize and coordinate all activities of supervise.

Fig. 3. Integrated safety system verification and test bench of multipurpose small PWR.

Fig. 4. Mass spectrometer laboratory.

3.2 The Situation of Regulatory Technical Support System

At present, China mainly relies on the national nuclear and radiation safety supervision technology R&D base as the test, verification, and R&D platform to provide consultation and technical support.

For the safety of nuclear power plant, a multi-purpose small PWR test bench has been built, it carries out research on key mechanism and phenomena of low-pressure injection, characteristics of low-pressure safety injection and reliability of natural circulation of low-pressure and low-temperature. The height ratio of the test device is 1:2, the total height of the bench is about 15 m, and the cover area is 102 m^2.

A Laboratory has been built for the radiation environment monitoring. It is equipped with high-resolution mass spectrometer (ICP-MS), ultra-low background and high-purity germanium γ Spectrometer, ultra-low background α/β Radiation measurement equipment, which is used for sample pretreatment and ionization measurement. Through the national radiation environment monitoring data system, NNSA collects the daily monitoring data of 500 automatic stations of the state-controlled automatic monitoring network, and carries out radiation environment background investigation.

For the safety analysis, a key experiment for simulation

Fig. 5. Full range validation simulator Laboratory of CPR1000.

analysis and verification of nuclear safety review laboratory has been built. It mainly carries out basic research, simulation calculation, analysis, and verification of nuclear facility accidents through software, and it is to build a full-scale verification simulator (1:1 with CPR1000 NPP) to carry out verification and analysis.

For the nuclear technology utilization, low background laboratories (iron chamber and lead chamber) have been built. After taking shielding measures, the γ is lower than 14 $ngy \cdot h^{-1}$, which is in the leading level in China.

China has established a national, provincial and municipal radioactive effluent monitoring system, and established

Fig. 6. A laboratory with a background below the natural radioactivity level.

Fig. 7. Radioactive effluent monitoring laboratory.

Table 1. Laboratory completion schedule of national nuclear safety supervision technology R&D

Year	Name of laboratory
2016	CPR1000 full range verification simulator laboratory
2019	Technical support platform of UAV for radiation monitoring
2020	Radiation environment monitoring laboratory, Radiation environment monitoring data laboratory, Accelerator mass spectrometer Laboratory
2021	Small PWR safety system verification test bench, Nuclear safety review simulation analysis and verification laboratory, Low radioactivity background laboratory, Nuclear power plant site and civil engineering laboratory, etc.
2022	Test and verification bench for material characteristics of nuclear power equipment
To be built	HPR1000 simulation verification laboratory, Nuclear safety data and intelligent application laboratory

a national radiation environment quality monitoring system and a supervisory monitoring system for the radioactive effluent from key nuclear facilities.

4. Problems

Although China has built a number of important laboratories in the national nuclear and radiation safety regulatory technology R&D base, it still has not formed R&D system. At the same time, a series of important Laboratories began to be constructed and put into use after 2019, but there was less cooperation between laboratories.

4.1 Lack of Supervisors

The task of nuclear safety supervision is becoming heavier, and the supervision ability is becoming less and less.

By the end of 2021, 53 nuclear power plants were operating in China's mainland, and the total generating capacity of the nuclear power was 407 (100 million kwh), accounting

Table 2. Main indicators of operating nuclear power units in China from 2013 to 2022

Main indicators	2013	2014	2015	2016	2017	2018	2019	2020	2021
Number of operating nuclear power units	17	22	28	35	37	44	47	49	53
Total power generation of nuclear power plant (100 million kwh)	1,107.1	1,305.80	1,689.93	2,105.19	2,474.69	2,865.11	3,481.31	3,662.43	4,071.41
Proportion in national cumulative power generation	2.11%	2.39%	3.01%	3.56%	3.94%	4.22%	4.88%	4.94%	5.02%
The average number of supervisors per nuclear power unit	30	28	25	23	23	20	18	17	15

for 5.02% of China's mainland's total generating capacity. There was no international event grade 1 (INES) or above. Compared with 2013, the number of nuclear power plants in China's mainland increased from 17 to 53. In 2013, nuclear power units with 110.71 (100 million kwh) were operated, accounting for about 2.11% of China's mainland's total generating capacity [9]. On the contrary, the average number of supervisors per nuclear power unit in China has decreased from about 30 in 2013 to 15 in 2021, which is not only lower than that of major nuclear power countries, but also at the lowest level in China's history.

4.2 Complex Unit Types

In addition to no boiling water reactor, China's nuclear power units almost include all kinds of nuclear power reactor types in the world, including CANDU of Canada, M310 of France, VVER of Russia, EPR of France, AP1000 of the United States, HPR1000, CPR1000 and high temperature gas-cooled reactor independently designed by China. The design, construction, installation, commissioning and operation of these reactors are different, which greatly increases the difficulty of supervision.

4.3 Lack of Regulatory Technology

In 2018, the third generation nuclear power plants (AP1000 and EPR) were put into operation in China, which promoted the transformation of China's nuclear safety supervision from absorbing and learning from international experience to exporting scheme. Compared with the world's major nuclear power countries, China's nuclear safety science and technology support capacity is insufficient. There are still many key research that have not been carried out in the fields of new reactor design, serious accident management, multi reactor site emergency, radiation environment monitoring and evaluation, spent fuel and radioactive waste safety, decommissioning of nuclear facilities and life extension safety. At the same time, the construction of nuclear and radiation safety regulatory information lags behind, and the regulatory data over the years have not been effectively integrated.

4.4 Technology R&D Base

The function of the national nuclear and radiation safety supervision technology R&D base has not been fully

Table 3. Typical reactor types of nuclear power plants in China

Type of reactor	Technical mode	Nuclear power plant	Number of unit
CANDU of Canada	Deuterium oxide is used as coolant and moderator, natural uranium is used as fuel, and refueling is carried out without shutdown.	Qinshan Nuclear Power Plant Phase III	1
M310 of France	Large pressurized water reactor, three loop design.	Daya Bay Nuclear Power Plant	4
EPR of France	European third generation pressurized water reactor nuclear power technology.	Taishan Nuclear Power Plant	2
VVER of Russia	Pressurized water reactor nuclear power technology developed by Russia.	Tianwan Nuclear Power Plant (unit 1−4)	4
AP1000 of the United States	Third generation nuclear power technology designed by the United States.	Sanmen Nuclear Power Plant	4
HPR1000	Third generation nuclear power technology independently developed by China.	Fuqing Nuclear Power Plant (unit 5−6)	2
CPR1000	Improved second generation plus nuclear power technology developed by China on the basis of M310.	Hongyanhe Nuclear Power Plant (unit 1−4)	4
CAP1400	The third generation pressurized water reactor nuclear power technology developed by China on the basis of AP1000.	Shidaowan Nuclear Power Plant (under construction)	4

brought into play.

In 2019, China established a national R&D base for nuclear and radiation safety supervision technology. The total construction area of the technology R&D base is about 95,000 square meters. It is planned to cover nuclear facilities, nuclear safety equipment, nuclear technology utilization projects, radioactive mines associated with uranium (thorium) mines, radioactive waste, transportation of radioactive materials, electromagnetic radiation devices, and environmental supervision of electromagnetic radiation. It covers all aspects such as site selection, design, construction, commissioning, operation, and decommissioning. However, the funds approved in the early stage are mainly used for land and construction. Due to the lack of capacity-building funds, it is impossible to form a regulatory technology R&D system and a complete technical support capacity for nuclear and radiation safety supervision.

5. Conclusion and Suggestion

5.1 Conclusion

The independence of China's nuclear safety regulator has been achieved. Relying on the national R&D base of nuclear and radiation safety supervision technology, China has formed a test, verification and R&D system, which can provide consultation and technical support and meet the requirements of the safety development of civil nuclear facilities. The nuclear and radiation safety situation is generally stable.

5.2 Suggestion

1) The most important thing for China is to improve its regulatory capacity, which is based on sufficient scientific

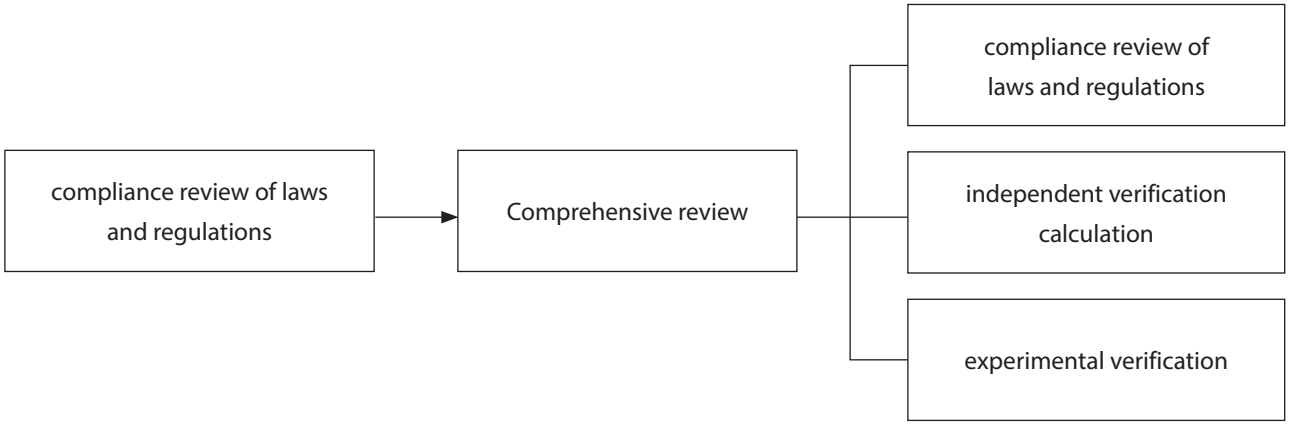

Fig. 8. Transformation of nuclear safety review mode.

basis by establishing a perfect technology R&D system. It is necessary to continuously improve the National Key Laboratory for simulation analysis and verification of nuclear safety review. Gradually shift the nuclear power safety review from the compliance review of laws and regulations to the comprehensive review of independent verification calculation and experimental verification.

2) It is necessary to establish an independent verification method for nuclear safety equipment, continuously improve the verification system for in-service inspection of nuclear power plants, and enhance the technical ability of supervision and law enforcement.
3) It is necessary to accelerate the development and construction of nuclear and radiation safety supervision data platform, strengthen the ability of data and information collection, integration and analysis, enhance the state control ability of key nuclear facilities, enhance the ability of daily work scheduling, and promote the optimization of safety supervision.
4) It needs to build an international cooperation center for nuclear and radiation safety on, the basis of the national research and development base, deepen international cooperation, build domestic and foreign cooperation and exchange platforms, provide comprehensive international services for nuclear power going out, and help countries in need to improve the level of nuclear and radiation safety supervision. The nuclear and radiation safety is a global issue related to human security, it requires joint efforts of many parties, take in-depth international cooperation for response to climate change.

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