FEASIBILITY STUDY ON SINO-UK COOPERATION IN NUCLEAR FACILITY DECOMMISSIONING, WASTE MANAGEMENT AND TRANSPORTATION

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INTRODUCTION

In order to implement the national strategic goal of carbon peaking and carbon neutrality, ensure energy security and the energy restructure of "clean, low-carbon and green development", China has deepened its energy transformation, actively and orderly promoted the construction of nuclear power, and actively explore the multi-purpose and comprehensive utilization of nuclear energy. As of 31 December 2021, there are 71 nuclear power units under construction and operation in the Chinese mainland, including 53 units connected with the grid, with the total installed capacity of 54646.95 MWe (rated). For the nuclear power distribution in the Chinese mainland, please see Figure 1.

With the mass construction and operation of NPPs, the safe treatment and disposal of radioactive waste and the transportation of spent fuel have become the focus of domestic attention. China has been developing nuclear power for more than 30 years, and the decommissioning of NPPs has been mentioned on the national agenda, and preliminary technical and policy preparations have already started.

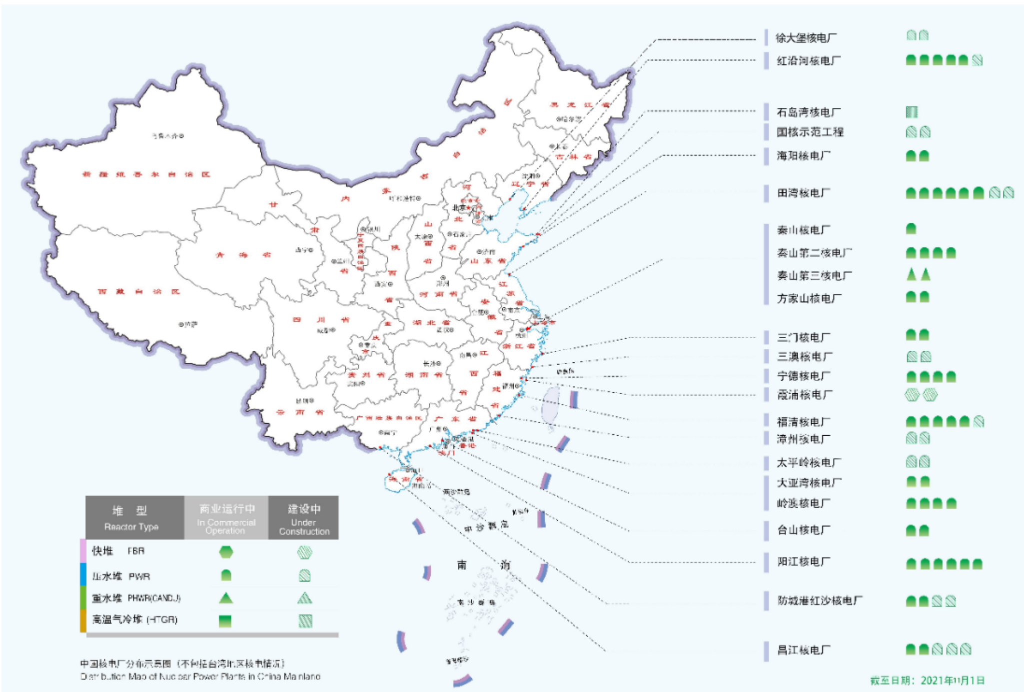

Figure 1. Distribution of NPPs in the Chinese mainland

1. Management Requirements and Responsibilities

1.1 Laws and Regulations

Chinese laws and regulations consist of laws promulgated by the National People's Congress, regulations promulgated by the State Council, administrative regulations promulgated by ministries or local governments, and national standards and technical guidelines. They are listed from high correlation to low degree:

1.1.1 General Laws and Regulations

- 《The Law of the People's Republic of China on the Prevention and Control of Radioactive Pollution》, 2003;
- 《Nuclear Safety Law of the People's Republic of China》, 2017;
- 《Emergency Response Law of the People's Republic of China》, Chairman Order No. 69;
- 《Environmental Protection Law of the People's Republic of China》, 2015;
- 《Production Safety Law of the People's Republic of China》, 2014;
- 《Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste》;
- 《Regulations of the People's Republic of China on Safety Supervision and Administration of Civilian Nuclear Facilities》, HAF001, 1986;
- 《Regulations on the Safety and Protection of Radioisotopes and Radiation Devices》, 2005;
- 《Regulations on the Safety Management of Hazardous Chemicals》, 2011;
- 《Basic Standard for Ionizing Radiation Protection and Radiation Source Safety》, GB 18871-2002;
- 《Radionuclide Activity Concentration in Materials Exempt from Radiation Protection Regulation》, GB 27742-2011;
- 《NPPs, Research Reactors, Nuclear Fuel Cycle Facilities Safety Licensing Procedures Regulations》, 2019.

1.1.2 Regulations on Decommissioning

- 《Technical Regulations for Environmental Management of Reactor Decommissioning》, GB 14588-2009;
- 《Safety Requirements for Decommissioning of Nuclear Facilities》, GB/T 19597-2004;
- 《Regulations on the Management of Decommissioning of Nuclear Facilities and Radioactive Waste Treatment》, CAEA, 2010;
- 《Interim Measures for Collection, Use and Management of NPP Spent Fuel Treatment and Disposal Funds》, 2010;

- 《Measures for the Management of NPP Spent Fuel Treatment and Disposal Fund Projects》, CAEA, 2014;
- 《Technical Criteria for Decontamination of Production Reactor Decommissioning》, EJ/T 941-1995;
- 《Standard format and content for the decommissioning environmental impact report of uranium processing and fuel fabrication facilities》, EJ/T 1037-1996;
- 《Interim Regulations for Acceptable Levels of Residual Radionuclides in Soil of Site Considered for Release (Provisional)》, HJ 53-2000;
- 《Technical Regulations for the Environmental Management of Decommissioning of Uranium Mining and Milling Facilities》, GB 14586-1993.

1.1.3 Regulations on Radioactive Waste

- 《Regulations on the Safety Management of Radioactive Waste》, Order No. 612 of the State Council;
- 《Basic Standard for Protection against Ionizing Radiation and for the Safety of Radiation Source》, GB 18871-2002;
- 《Regulations for Radioactive Waste Management》, GB 14500-2002;
- 《Categorization of radioactive waste》, 2017;
- 《Regulations on the Safety Supervision and Administration of Radioactive Waste》, HAF401-1997;
- 《Minimization of Radioactive Waste in Nuclear Facilities》, HAD401/08-2016;
- 《Radioactive Waste Geological Disposal Facility》, HAD 401/10-2020;
- 《Monitoring and Inspection of Radioactive Waste Disposal Facilities》, HAD 401/09-2019.

1.1.4 Regulations on Spent Fuel Transportation

- 《Railway Law of the People's Republic of China》, Chairman Order No. 32;
- 《Maritime Traffic Safety Law of the People's Republic of China》, Chairman Order No. 7;
- 《Port Law of the People's Republic of China》, Chairman Order No. 5;
- 《Regulations on the Safety Management of the Transport of Radioactive Materials》, Order No. 562 of the State Council;
- 《Regulations on the Control of Nuclear Materials of the People's Republic of China》, issued by the State Council on June 15, 1987;
- 《Road Transport Regulations of the People's Republic of China》, Order No. 406 of the State Council;

- 《Railway Safety Management Regulations》, Order No. 639 of the State Council;
- 《Regulations on the Administration of Domestic Waterway Transportation》, Order No. 625 of the State Council;
- 《Regulations on Highway Safety Protection》, Order No. 666 of the State Council.

1.2 Management Responsibilities

1.2.1 Main Responsibilities of the China Atomic Energy Authority (CAEA)

(1) Responsible for researching and formulating policies and regulations for China's peaceful use of atomic energy.

(2) Responsible for researching and formulating development plans, plans and industry standards for China's peaceful use of atomic energy.

(3) Responsible for the organization, demonstration, project approval and approval of major scientific research projects on the peaceful use of nuclear energy in China, and responsible for supervising and coordinating the implementation of scientific research projects.

(4) Responsible for the control of nuclear materials and the physical protection of nuclear facilities.

(5) Responsible for nuclear export review and management.

(6) To be responsible for the exchanges and cooperation between governments and international organizations in the nuclear field, and to represent China in IAEA and its activities.

(7) Take the lead in taking charge of the national nuclear accident emergency management.

(8) Responsible for the decommissioning of nuclear facilities and radioactive waste management.

1.2.2 Main Responsibilities of the National Energy Administration (NEA)

(1) Responsible for nuclear power management, and take the lead in formulating laws, regulations and rules for the nuclear power industry.

(2) Formulate nuclear power development plans, access conditions, and technical standards and organize their implementation.

(3) Propose nuclear power layout and review opinions on major projects.

(4) Organizing, coordinating and guiding nuclear power scientific research.

(5) Inter-governmental cooperation and exchanges in the field of nuclear power, responsible for the external negotiation and signing of the inter-governmental agreement on the peaceful use of nuclear energy.

1.2.3 Main Responsibilities of the National Nuclear Safety Administration (NNSA)

(1) Responsible for the supervision and management of nuclear safety and radiation safety. Formulate policies, plans, laws, administrative regulations, departmental rules, systems, standards and norms related to nuclear safety, radiation safety, electromagnetic radiation, radiation environmental protection, and emergency response to nuclear and radiation accidents, and organize their implementation.

(2) Responsible for the unified supervision and management of nuclear safety, radiation safety and radiation environmental protection of nuclear facilities.

(3) Responsible for the supervision and management of the licensing, design, manufacture, installation and non-destructive inspection activities of nuclear safety equipment, and responsible for the safety inspection of imported nuclear safety equipment.

(4) Responsible for the supervision and management of nuclear material control and physical protection.

(5) To be responsible for the supervision and management of the radiation safety and radiation environmental protection of nuclear technology utilization projects, uranium (thorium) mines and associated radioactive mines. Responsible for radiation protection.

(6) To be responsible for the supervision and management of the safety of radioactive waste treatment and disposal and radiation environmental protection, and to be responsible for the supervision and inspection of the prevention and control of radioactive pollution.

(7) Responsible for the supervision and management of the transport safety of radioactive materials.

(8) Participate in the emergency handling of nuclear accidents, and be responsible for the emergency handling of radiation environmental accidents.

(9) Responsible for the qualification management of reactor operators, special technical personnel of nuclear equipment and other personnel.

(10) To organize and carry out radiation environmental monitoring and supervisory monitoring of nuclear facilities and key radiation sources.

(11) Responsible for the domestic implementation of international conventions related to nuclear and radiation safety.

(12) To guide the relevant business work of the Nuclear and Radiation Safety Supervision Station.

2. Decommissioning

China’s nuclear facilities decommissioning emphasizes the whole-process management, clarifies the concept of “facilitating decommissioning”, and the decommissioning activities should be considered from the engineering design stage. The decommissioning strategy of China's nuclear facilities has also been adjusted based on IAEA’s strategy, the initial three decommissioning strategies of immediate dismantling, delayed dismantling and in-situ burial has been changed into immediate dismantling and delayed dismantling.

2.1 Potential Cooperation between China and UK

2.1.1 The status of decommissioning governance technology capability in China

Since the late 1980s, China has carried out comprehensive decommissioning work for most of the old nuclear facilities. For over 30 years, China has successfully implemented a number of decommissioning projects including uranium mining and milling facilities, production reactor facilities, reprocessing facilities, radiochemical laboratories, research reactors, etc., accumulated rich experience in implementation, and mastered various source item investigation techniques, decontamination techniques, and dismantling techniques, radiation protection and radiation monitoring techniques; established treatment and conditioning facilities for different wastes, and mastered treatment technology for different types of waste; established extremely low-level waste landfill, medium and low-level radioactive waste near-surface disposal sites, and formed a complete radioactive waste treatment and disposal capacity. At the same time, China attaches great importance to scientific and technological innovation, organizes scientific research on difficult technologies for decommissioning, actively explores new technologies for decommissioning, and develops scientific research infrastructure. It has basically established a scientific research capability system that meets the actual needs of China's nuclear facilities decommissioning.

2.1.2 Potential cooperation projects between China and UK

(1) The UK could participate in the Chinese projects

1) Decommissioning of NPPs

At present, China has not yet started the decommissioning of NPPs, and is preparing the decommissioning of NPPs. China and UK could cooperate in the following areas:

i. Research on decommissioning strategies and plans

Including the NPPs' decommissioning standard system, decommissioning strategies, the overall decommissioning scheme, and technical schemes for dismantling key equipment.

ii. Source term estimation

Including the estimation method of radioactive inventory in NPPs, mainly for the estimation of the radioactive inventory of items that are difficult for personnel to access, such as the reactor core.

iii. Decommissioning Digital Simulation

Including the construction of a digital platform for NPP decommissioning, focusing on 3D simulation models, and timely estimation of personnel dose in the decommissioning plan, plan optimization, waste flow management, decommissioning design assistance, etc.

iv. Decommissioning cost estimates

Including decommissioning quotas, cost estimation methods and related software development.

2) Special technology and equipment

Although China already has the technical capabilities for the decommissioning of nuclear facilities, plans to upgrade and optimize the existing technology to fill the insufficiency. China and UK ccould have exchanges and cooperation in the following technologies:

i. Source item investigation

Including remote radioactivity measurement methods and technologies in narrow and small spaces; real-time dynamic radiation monitoring technology in fields with higher dose level; monitoring technology for key materials and nuclides; large-scale radioactive waste rapid classification and detection technology, etc.

ii. Decontamination technology

Including large-scale equipment, high-efficiency decontamination technology for large-area walls, research on new high-efficiency decontamination technology, and development of special decontamination equipment.

iii. Cutting and dismantling technology

Including cutting and dismantling technology for high-radiation and large-thickness structures such as reactor pressure vessels and internal components; high-radiation field remote dismantling and control technology; efficient demolition technology for shielding structures, steel cladding structures, large tanks and other facilities; development of long distance and remote demolition tools.

iv. Waste treatment technology

Special wastes generated during decommissioning include: alpha waste, organic waste, waste graphite, radioactive sludge and other waste treatment and conditioning technologies.

(2) China could provide supports for UK projects

After more than 30 years of decommissioning remediation engineering practice and scientific research, China has established a complete and systematic decommissioning professional system, and has cultivated a group of professional talents for decommissioning treatment technology R&D, design and engineering implementation. In response to the UK's technical needs for decommissioning treatment, China could give full play to its own advantages, participate in engineering and scientific research projects in the field of decommissioning treatment in UK in various forms such as engineering design, project implementation, equipment supply, technology output, and joint R&D.

(3) Cooperative development of third-party decommissioning projects

China and UK could also give full play to their own advantages and join forces to jointly find potential opportunities for decommissioning and treatment of nuclear facilities in the world, and form a consortium to jointly bid for decommissioning and treatment projects in other countries.

2.2 Recommendations

2.2.1 Potential projects that could be tendered by foreign companies

At present, some scientific research projects on the decommissioning and treatment of nuclear facilities are being carried out in the Chinese mainland. Some key equipment will be subject to commercial bidding and procurement, and relevant information will be released on the CNNC electronic procurement platform.

2.2.2 Subcontractors looking for international partners

All public bidding projects in China by the principles of openness, justice and fairness, and treat suppliers/subcontractors equally; and comprehensively evaluate partners from technical capabilities, financial strength and service levels.

2.2.3 Recommend third-party agencies

CNEI, a subsidiary of CNNC, has been undertaking business and agent responsibilities for the introduction of foreign-related projects, and UK companies could consult with it. At the same time, there are some French, German and other national technology and equipment agents.

2.3 Certification

According to the "Nuclear Safety Law", the decommissioning organization of nuclear facilities shall apply to the Nuclear Safety Supervision and Administration Department of the State Council for a license. Before decommissioning a nuclear facility, the nuclear facility operator shall submit an application for decommissioning and the following materials:

(1) Application for decommissioning of nuclear facilities;
(2) Safety analysis report;
(3) Environmental impact assessment documents;
(4) quality assurance documents;
(5) Other materials prescribed by laws and administrative regulations.

When a nuclear facility is decommissioned, the operating organization of the nuclear facility shall handle and dispose of the radioactive substances at the site of the nuclear facility in accordance with the principles of being reasonable, feasible and as low as possible, so as to reduce the radioactivity level of structures, systems and equipment to meet the requirements of the standard.

2.4 Status of NPPs and Research Reactors

As of 31 December 2021, there are 53 nuclear power units in operation in the Chinese mainland, please see Table 1 for details.

According to the design life, it is estimated that 7 units will be decommissioned or start decommissioning preparation about 2050, including Qinshan NPP unit 1, Daya Bay NPP, Lingao NPP Phases I&II. In September 2021, in accordance with the relevant requirements of the "Nuclear Safety Law of the People's Republic of China" and the "Regulations of the People's Republic of China on the Safety Supervision and Administration of Civilian Nuclear Facilities", after strict technical transformation and review, the National Nuclear Safety Administration approved to extend the operation of Qinshan NPP unit 1 till 30 July 2041. While the technological upgrades, the other 6 units maybe apply for extension permission. At present, Qinshan NPP unit 1 and Daya Bay NPP have proposed the decommissioning strategy, and are preparing the program.

Table 1. The operating units in the Chinese mainland

NPP	Unit	Capacity (MWe)	Design life (year)	Start time	Remarks
Qinshan		330	30	1994.4	extended to 2041.7
Daya Bay	1#	984	40	1994.2	
	2#	984	40	1994.5	
Qinshan Phase II	1#	650	40	2002.4	
	2#	650	40	2004.5	
	3#	660	40	2010.1	
	4#	660	40	2011.12	
Ling'ao	1#	990	40	2002.5	
	2#	990	40	2003.1	
	3#	1086	40	2010.9	
	4#	1086	40	2011.8	
Qinshan Phase III	1#	728	40	2002.12	
	2#	728	40	2003.7	
Tianwan	1#	1060	40	2007.5	
	2#	1060	40	2007.8	
	3#	1126	40	2017.12	
	4#	1126	40	2018.10	
	5#	1118	40	2020.9	
	6#	1118	40	2021.5	
Hongyanhe	1#	1119	40	2013.6	
	2#	1119	40	2014.5	
	3#	1119	40	2015.8	
	4#	1119	40	2016.6	
	5#	1150	60	2021.6	
Ningde	1#	1089	40	2013.4	
	2#	1089	40	2014.5	
	3#	1089	40	2015.6	
	4#	1089	40	2016.7	
Fuqing	1#	1089	40	2014.11	
	2#	1089	40	2015.10	
	3#	1089	40	2016.10	
	4#	1089	40	2017.9	
	5#	1161	60	2021.1	
	6#	1161	60	2021.12	
Yangjiang	1#	1086	40	2014.3	
	2#	1086	40	2015.6	
	3#	1086	40	2016.1	
	4#	1086	40	2017.3	
	5#	1086	40	2018.7	
	6#	1086	40	2019.7	
Fangjiashan	1#	1089	40	2014.11	
	2#	1089	40	2015.1	
Sanmen	1#	1250	60	2018.6	
	2#	1250	60	2018.12	

NPP	Unit	Capacity (MWe)	Design life (year)	Start time	Remarks
Haiyang	1#	1250	60	2018.8	
	2#	1250	60	2018.10	
Taishan	1#	1750	60	2018.12	
	2#	1750	60	2019.9	
Changjiang	1#	650	40	2015.12	
	2#	650	40	2016.8	
Fangchenggang	1#	1086	40	2016.1	
	2#	1086	40	2016.10	
Shidao Bay	1#	211	40	2021.12	

Table 2. The main research reactors in the Chinese mainland As of 31 December 2021

No.	Name	Type	Thermal power (kW)	Status	start time	decommission time
1	Morning star-1	Subcritical device	0.00	Operating	2005.7	
2	China Advanced Research Reactor	Pool	60000.00	Operating	2010.5	2040.5
3	China Experimental Fast Reactor	Fast reactor	65000.00	Operating	2011.7	2041.7
4	Medical Micro reactor	Micro reactor	30.00	Operating		
5	swimming pool reactor	Pool	3500.00	Operating	1964.12	2032
6	Micro reactor	Micro reactor	27.00	Operating	1984.3	2036.2
7	zero power critical reactor	Fast reactor	0.050	Extended	2000.6	
8	heavy water research reactor	heavy water reactor	15000.00	decommis sioning	1958.6	2007.12
9	high flux engineering reactor	Pool-type	125000.00	Operating	1981.12	2030
10	pulse reactor	Pool type, uranium hydrogen zirconium nuclear fuel	1000.00	Operating	1990.7	2035
11	Zero Power High Flux Reactor	Standard assembly	0.00	Operating	1982.10	2050
12	Reactor in Minjiang	Pool-type	5000.00	Operating	1992.12	2050
13	Zero Power Reactor in NPIC	Standard assembly	0.00	Permanent close	1966.1	1984
14	Research Reactor in Mianyang	Pool-type	20000.00	Operating		
15	Micro reactor in Shenzhen	Micro reactor	30.00	to be decommis sioned	1988.11	
16	10 MW HTGR	HTGR	10000.00	Operating	2003.1	
17	5 MW low temperature reactor	Thermal protection	5000.00	Operating	1989.11	
18	ESR-901	Pool dual core	1000.00	Closed		

Note: some data are not available.

2.5 Key Enterprises Engaged in Decommissioning Governance

China's current decommissioning governance activities are mainly aimed at aged nuclear facilities, radiochemical laboratories and research reactors. There is still not the nuclear power engineering decommissiong practices now. The enterprises that carry out decommissioning governance mainly include China National Nuclear Corporation (CNNC) and China General Nuclear Power Corporation (CGN).

2.5.1 China National Nuclear Corporation (CNNC)

The main technical capability for decommissioning in China's is concentrated in CNNC. As the main enterprise for aged nuclear facilities decommissioning, CNNC has undertaken the most tasks. CNNC has successfully implemented a number of major decommissioning projects, covering the entire industrial chain of uranium geological exploration, uranium mining and metallurgy, nuclear fuel cycle facilities, reactors, reprocessing facilities, and waste treatment and disposal, etc. CNNC has formed the completed capabilities in technology R&D and engineering practice It has cultivated a group of professional talents consisted of researcher, designer and engineer. The companes under CNNC in this fields are China Nuclear Power Engineering Co., Ltd. (CNPE), China Nuclear Environmental Protection Co., Ltd. (CNEP), China National Nuclear Industry Corporation 404 (CNNC 404 Co., Ltd.), China Institute of Atomic Energy (CIAE), Nuclear Power Institute of China (NPIC), etc.

CNPE is the general design and contracting unit for decommissioning project, also the research and development unit of decommissioning engineering technology. CNPE has successively completed the decommissioning engineering design of aged nuclear facilities in China, the decommissioning design of radiochemical laboratories, the general contracting work for the decommissioning of Shanghai micro research reactor, and the engineering design and general contracting of several waste treatment conditioning facilities.

CNEP is a professional decommissioning company, officially unveiled on 26 December 2017. Its members include CNNC Sichuan Environmental Protection Engineering Co., Ltd., China Institute of Radiation Protection (CIRP), CNNC EVERCLEAN Co., Ltd., etc. Among them, CNNC Sichuan Environmental Protection Engineering Co., Ltd. is the main operating and implementing unit for facilities to be decommissioned and radioactive waste treatment and disposal facilities. CNNC EVERCLEAN Co., Ltd. is the operator of radioactive waste disposal facilities. China Institute of Radiation Protection has certain research and design capabilities.

CNNC 404 Co., Ltd. is the main operator of facilities to be decommissioned and radioactive waste treatment facilities, as well as the implementation unit of decommissioning treatment projects. It has successively completed the decommissioning of several nuclear facilities, radiochemical laboratories, and research reactors.

CIAE is the operating unit of nuclear facilities, and undertakes the decommissioning treatment of some facilities, and the research and development of basic technologies for decommissioning treatment.

NPIC is the operating unit of nuclear facilities as well as the design and implementation unit of decommissioning treatment projects. It undertakes the governance of the decommissioning of some facilities.

2.5.2 China General Nuclear Power Corporation (CGN)

China General Nuclear Power Corporation's decommissioning governance is undertaked by its subordinate CGN Engineering Co., Ltd. and CGN Uranium Development Co., Ltd.

CGN Engineering Co., Ltd. is the responsible entity of the CGN's decommissioning business and capacity development. It is responsible for the organization and implementation of decommissioning projects, and for the research and development of core technologies and products.

CGN Uranium Development Co., Ltd., as the general unit of CGN's back-end business, actively participates in the road, sea and rail combined transportation system, and has the qualification for railway commercial transportation of radioactive substances (category 7).

(1) "Research on the Deep Geological Environment of Underground Laboratory Sites"
(2) "Study on Hydrogeological Characteristics of Underground Laboratory Sites"
(3) "Study on the Mechanical Properties and Long-term Stability of Deep Surrounding Rock in Underground Laboratory"
(4) "Long-term Monitoring and Impact Study of Underground Laboratory Site Environment"
(5) Research on Key Technologies for Deep Rock Mass Excavation in Underground Laboratory
(6) (6) "Research on Mechanical Excavation Equipment for Disposal Pits"
(7) (7) "Research on the Structural Layout and Disposal Concept of The Underground Laboratory Demonstration Disposal Roadway"
(8) "Research on in-situ test and installation technology of buffer materials

3. Radioactive Waste

In order to meet the management requirements of minimizing radioactive waste, the radioactive waste treatment of NPPs, China has carried out a lot of engineering practice and research in terms of reducing waste source items, introducing advanced technologies and centralized treatment models, and has achieved fruitful results. At the same time, China is also making some progress in promoting the construction of a centralized disposal site for low- and medium-level radioactive waste of NPPs.

China also has some urgent problems in the radioactive waste treatment, and the development of GENIII NPPs has put forward stricter requirements for waste minimization. As UK has advanced technology and management experience in the treatment and disposal of radioactive waste in NPPs, China and UK could explore cooperation on the premise of meeting the requirements of China's laws and policies.

As of 31 December 2019, 16 NPPs operating companies in the Chinese mainland have built a total of 69 radioactive waste treatment and storage facilities; 3 research reactor operating companies have built a total of 11 radioactive waste treatment and storage facilities; a total of 14 radioactive waste treatment and storage facilities have been built by 4 nuclear fuel cycle facility operating companies; one special radioactive waste storage facility has been built.

In addition, a total of 31 nuclear technology-utilized radioactive waste repositories and 1 national centralized repository of disused radioactive sources have been built and operated in the Chinese mainland.

Three low- and intermediate-level solid waste disposal sites have been put into operation in the Chinese mainland. The Beishan underground laboratory project for geological disposal of high-level radioactive waste has started construction in 2021. The total investment of the project is 2.723 billion yuan and is expected to be completed in 7 years. Two near-surface radioactive waste disposal sites are under construction in Yangjiang in Guangdong Province and Jinta in Gansu Province. A near-surface disposal site is also planned for the Xudapu NPP in Liaoning Province. The Jinta Disposal Site in Gansu Province is expected to be put into operation in July 2022.

3.1 Potential Cooperation between China and UK

With the carbon peak and carbon neutrality goals, China's nuclear power is facing a good development opportunities. At present, there are more proposed nuclear power projects, and there will be more bidding projects for radioactive waste treatment devices, it will create potential opportunities for UK enterprises. In terms of spent fuel cycle treatment, China is also actively promoting commercial reprocessing plant project. Higher requirements are put forward for the detection, classification, treatment, decontamination and control of radioactive waste, intelligent level, etc., and some technologies (such as waste gas removal C-14 technology, waste liquid tritium removal technology, steam cracking, etc.) have not mature engineering applications. This provides a historical opportunity for the UK suppliers and joint R&D.

At present, there is still some room for improvement in the comprehensive treatment strategy of waste minimization and the analysis of costs and benefits in China's NPPs, and UK enterprises could provide corresponding technical services by the practices experience and professional software.

3.1.1 Potential cooperation projects

At present, units 3 and 4 of the Xudapu NPP are undergoing international public bidding for radioactive solid waste treatment equipment, its technical route is waste resin conical dryer drying, concentrated liquid drum drying, waste filter core cement fixing and miscellaneous dry waste sorting and compaction.

In the future, there will be a number of nuclear power projects such as Zhejiang Jinqimen, Lianyungang Nuclear Energy Heating Project, Huaneng Xiapu, which are planned to use public bidding (domestic or international) for equipment procurement, also the nuclear power technical upgrade projects should be paid attentions in the future.

At present, the underground laboratory of high-level radioactive waste disposal in China will carry out the following scientific research projects, UK partners have the opportunity to join:

(1) "Research on the Deep Geological Environment of Underground Laboratory Sites"
(2) "Study on Hydrogeological Characteristics of Underground Laboratory Sites"
(3) "Study on the Mechanical Properties and Long-term Stability of Deep Surrounding Rock in Underground Laboratory"
(4) "Long-term Monitoring and Impact Study of Underground Laboratory Site Environment"

(5) Research on Key Technologies for Deep Rock Mass Excavation in Underground Laboratory
(6) "Research on Mechanical Excavation Equipment for Disposal Pits"
(7) "Research on the Structural Layout and Disposal Concept of The Underground Laboratory Demonstration Disposal Roadway"
(8) "Research on in-situ test and installation technology of buffer materials under underground laboratory conditions"
(9) "Study on the Release and Migration Behavior of Nuclides under Deep Surrounding Rock Conditions"

All open tender projects in China adhere to the principles of openness, justice and fairness, and treat suppliers/subcontractors equally; partners will be evaluated comprehensively in terms of technical capabilities, financial strength and service levels.

3.1.2 Chinese partners

CNNC China Nuclear Energy Industry Co., Ltd. (CNEIC) has always been responsible for business and agency responsibilities for the introduction of foreign projects, and UK companies could consult with then. In addition, CNNC EVERCLEAN Co., Ltd., China Nuclear Power Engineering Co., Ltd., CNNC Environmental Protection Co., Ltd., and CGN Environmental Protection Industry Co., Ltd., SPIC State Nuclear Power Uranium Resources Development Co. Ltd.,

3.2 Radioactive Waste Management Policy

(1) The main body of management responsibility. The enterprises that generate radioactive waste assume overall safety responsibility for radioactive waste management. Nuclear facility operating enterprises and radioactive waste treatment and disposal enterprises shall reduce and harmlessly treat and dispose of radioactive waste to ensure its permanent safety; high-level radioactive waste shall be disposed of in a centralized and deep geological manner, and shall be exclusively operated by enterprises designated by the State Council.
(2) The classification of radioactive waste. The low-level radioactive solid waste is disposed of near the surface in the region, the medium-level radioactive solid waste is disposed of in a centralized, medium-depth geological manner, the high-level radioactive solid waste is disposed of in a centralized deep geological manner, and the uranium (thorium) mining and metallurgical solid waste is disposed of relatively centralized landfill on-site.

(3) The principle of environmental friendliness. Through the rational selection and utilization of raw materials, the use of advanced production technology and equipment, and the implementation of material reuse and recycling, the amounts of radioactive waste generated and emissions to the environment could reach the lowest level that is reasonably feasible.

(4) The principle of simultaneous. The radioactive waste management facility shall be designed, constructed and put into use simultaneously with the main facility;

(5) Centralized management principle. The radioactive wastes produced by the utilization of nuclear technology shall be collected and stored in a centralized manner according to the provinces, autonomous regions and municipalities directly under the Central Government. The radioactive waste gas and waste liquid discharged to the environment must meet the national radioactive pollution discharge standards.

(6) Prohibited behavior. It is prohibited to dispose of radioactive solid waste in inland waters or the ocean. It is prohibited to import radioactive wastes and radioactively contaminated articles into the territory of the People's Republic of China or to transfer them through the territory of the People's Republic of China.

(7) The principles of radioactive waste minimization management. In the process of design, construction, operation and decommissioning of nuclear facilities, through measures such as source control, recycling and reuse of waste, cleaning and de-control, optimization of waste treatment and enhanced management, and through cost-benefit analysis, the final amount of radioactive solid waste (volume and activity) could be reasonably as low as possible.

3.3 Radioactive Waste Management System

(1) China implements a licensing system for radioactive waste activities, and prohibits the operation of spent fuel and radioactive waste management facilities without a license.

- China implements a nuclear facility safety licensing system, and the National Nuclear Safety Administration (NNSA) is responsible for the approval and issuance of nuclear facility safety licenses. The licenses include the nuclear facility site selection review opinion, the construction license, the nuclear facility operation license, and the nuclear facility decommissioning approvals. Nuclear facilities include NPPs, research reactors, nuclear fuel cycle facilities, and civilian nuclear facilities such as radioactive waste treatment and disposal facilities. The operating organizations of the above-mentioned nuclear facilities must apply for and obtain corresponding licenses before carrying out activities such as site selection, construction, operation, and decommissioning of nuclear facilities. Only after a facility operating organization has obtained the relevant license or approval documents, it could carry out the corresponding construction, loading, operation, decommissioning and other activities.

- Enterprises specializing in the storage and disposal of radioactive solid waste shall obtain a license for storage and disposal of radioactive solid waste. The license for storage and disposal of radioactive solid waste shall be approved and issued by the Ministry of Environmental Protection (NNSA).

(2) Regulatory inspection, documentation and reporting systems.

- China implements the following regulatory systems: radioactive pollution monitoring system, radioactive gaseous and liquid effluent discharge permit system, effluent and environmental monitoring system, and nuclear accident emergency response system, etc.
- The National Nuclear Safety Administration and its dispatched agencies conduct routine inspections of nuclear facilities. The competent environmental protection department of the people's government at or above the county level and other relevant departments shall supervise and inspect the safety of activities such as radioactive waste treatment, storage and disposal in accordance with the 《Law of the People's Republic of China on the Prevention and Control of Radioactive Pollution》 and the 《Regulations on the Safety Management of Radioactive Waste》.
- For the spent fuel and radioactive waste management facilities, the nuclear facility operating organization shall implement documented management for test procedures, operation procedures, quality assurance records, test results and data, operation and maintenance records, and records of defects and abnormal events. The radioactive solid waste storage and disposal organization shall establish a record file for the storage and disposal of radioactive solid waste, and truthfully record the matters related to the storage and disposal activities.

- The radioactive solid waste storage organization shall, in accordance with the regulations of the Ministry of Environmental Protection (NNSA), regularly and truthfully report the radioactive waste generation, discharge, treatment, storage, clearance, and delivery for disposal. The radioactive solid waste disposal organization shall truthfully report the reception and disposal of the radioactive solid waste, and facility operation in the previous year to the relevant departments before March 31 each year.
- In the event of a nuclear and radiation accident emergency, the operating organization of a nuclear facility must immediately report to the relevant department. The radioactive solid waste storage organizations and disposal organizations shall report the discovered latent dangers or radiation accidents to the corresponding competent authorities.

(3) provisions in the Regulations and license related to spent fuel and radioactive waste management are enforced in China. For licensees who violate regulations and license provisions , the NNSA has the right to take mandatory measures when necessary, order the licensees to take safety measures or stop activities that endanger safety. The NNSA may, according to the seriousness of the circumstances, impose punishments such as warning, improvement within a time limit, suspension of work or business for rectification, and revocation of licenses; for non-compliance with the penalty decision, and failure to prosecute within the time limit, the NNSA shall apply to the people's court for compulsory execution.

3.4 Certification Requirements

3.4.1 Application conditions

Applications are open to foreign institutions. An entity applying for the storage and treatment of radioactive waste shall meet the following conditions:

(1) It possess the status of a legalperson;

(2) There is an organizational structure that could ensure the safe operation of the facility, including departments responsible for facility operation, safety protection (including radiation monitoring), and quality assurance;

(3) There are more than three professional technicians in radioactive waste management, radiation protection and environmental monitoring, including at least one registered nuclear safety engineer;

(4) It has radioactive detection, radiation protection and environmental monitoring equipment in line with the relevant national standards for the

prevention and control of radioactive pollution, and the provisions of the State Council's ecological environment department;

(5) (5) It has a sound management system and a quality assurance system that meets the requirements of nuclear safety supervision and management, including operation procedures, quality assurance programs, operation monitoring plans, radiation monitoring plans, emergency plans,

3.4.2 **Application for a storage permit**

An enterprise applying for a storage license shall, before the radioactive waste storage facility is put into operation, apply to the nuclear safety supervision and administration department of the State Council and submit the following documents:

(1) Application form for radioactive waste storage license;
(2) Final safety analysis report (including site selection safety analysis report);
(3) Approval documents for environmental impact assessment documents;
(4) The original and duplicate (photocopy) of the business license of the enterprise legal person, or the original and duplicate (photocopy) of the public institution legal person certificate, and the photocopy of the ID card of the legal representative;
(5) Personnel engaged in radioactive waste storage management and operation must provide training and examination certificates, and a copy of the certificate of registered nuclear safety engineer;
(6) The list of radioactive detection, radiation protection and environmental monitoring equipment;
(7) Documents certifying the radioactive waste storage management system, including operating procedures, quality assurance program and the list of procedural documents, radiation monitoring plans, storage facility operation monitoring plans, emergency plans, records and archives management documents, etc.;
(8) Other documents stipulated by laws and administrative regulations. The nuclear safety supervision and management department of the State Council will conduct a technical review of the above documents according to law, and the review time is usually not more than 3 months.

3.4.3 **Applying for a radioactive waste disposal license**

An enterprise applying for a storage license shall, before the radioactive waste storage facility is put into operation, apply to the nuclear safety supervision and administration department of the State Council and submit the following documents:

3.4.3.1 *Information submitted before the construction of radioactive waste treatment facilities*

An enterprise applying for a disposal license shall, before the construction of a radioactive waste disposal facility starts, submit a construction application to the nuclear safety administration department of the State Council and submit the following documents:

(1) Preliminary safety analysis report (including sitting safety analysis report);

(2) Approval documents for environmental impact assessment documents;

(3) Quality assurance program (construction stage);

(4) The original and the duplicate (photocopy) of the business license of the enterprise legal person, or the original and duplicate (photocopy) of the legal person certificate of the public institution, and the photocopy of the ID card of the legal representative; the nuclear safety supervision and administration department of the State Council will conduct a technical review of the above-mentioned documents in accordance with the law, and the review time usually does not exceed 3 months.

3.4.3.2 *Information submitted before operation of radioactive waste treatment facility*

An enterprise applying for a disposal license shall apply to the nuclear safety administration department of the State Council and submit the following documents before the radioactive waste disposal facility is put into operation:

(1) Application form for radioactive waste disposal license;

(2) Final safety analysis report;

(3) Approval documents for environmental impact assessment documents;

(4) The original and the duplicate (photocopy) of the business license of the enterprise legal person, or the original and duplicate (photocopy) of the legal person certificate of the public institution, and the photocopy of the ID card of the legal representative;

(5) The training and assessment certificate of the personnel engaged in the management and operation of radioactive waste, and the photocopy of the certificate of the registered nuclear safety engineer;

(6) The list of radioactive detection, radiation protection and environmental monitoring equipment;

(7) Documents certifying the radioactive waste treatment management system, including operating procedures, quality

assurance program (operation stage) and the list of procedural documents, radiation monitoring plans, storage facility operation monitoring plans, emergency plans, and records and archives management documents, etc.;

(8) Other documents stipulated by laws and administrative regulations. The nuclear safety administration department of the State Council shall conduct a technical review of the above-mentioned documents in accordance with the law, and the review time usually does not exceed 3 months.

3.4.4 Application for engaging in near-surface disposal of radioactive solid waste

An enterprise applying for the near-surface disposal of radioactive solid waste shall meet the following conditions:

(1) It has the status of a state-owned or state-controlled enterprise legal person, and has a registered capital of not less than ¥ 30 million;

(2) There are organizations that could ensure the safe operation of near-surface disposal facilities, including departments responsible for disposal facility operation, safety protection (including radiation monitoring), and quality assurance;

(3) There are more than ten professional technicians in radioactive waste management, radiation protection and environmental monitoring, among which there are no less than three registered nuclear safety engineers;

(4) There are radioactive detection, radiation protection and environmental monitoring equipment in compliance with the relevant national standards for the prevention and control of radioactive pollution and the provisions of the State Council's ecological environment department, as well as necessary radiation protection equipment;

(5) There is a financial guarantee to ensure that its disposal activities will continue until the expiration of the safe custody period.

3.4.5 Application for medium-depth disposal and deep geological disposal activities of radioactive solid waste

3.4.5.1 Application conditions

Enterprises applying for medium-depth disposal and deep geological disposal activities of radioactive solid waste shall meet the following conditions in addition to the conditions specified in Items (2), (4) and (5) of this Section 3.3.4 :

(1) It has the status of a state-owned or state-controlled enterprise legal person, and has a registered capital of not less than ¥ 100 million;

(2) There are more than 20 professional technicians in radioactive waste management, radiation protection and environmental monitoring, among which there are no less than five registered nuclear safety engineers.

3.4.5.2 *Site selection stage*

An enterprise applying for a disposal license shall submit a disposal facility siting safety analysis report to the nuclear safety supervision and administration department of the State Council during the disposal facility siting stage.

3.4.5.3 *Before construction*

Before the construction of a disposal facility, the enterprise applying for the disposal license shall submit a construction application to the nuclear safety administration department of the State Council and submit the following documents:

(1) Preliminary safety analysis report;
(2) Approval documents for environmental impact assessment documents;
(3) Quality assurance program (construction stage);
(4) The original and the duplicate (photocopy) of the business license of the enterprise legal person, or the original and duplicate (photocopy) of the legal person certificate of the public institution, and the photocopy of the ID card of the legal representative.
The nuclear safety supervision and management department of the State Council will conduct a technical review of the above-mentioned documents in accordance with the law, and the review time usually does not exceed 12 months.

3.4.5.4 *Before operation*

Before a disposal facility accepts radioactive solid waste, the enterprise applying for a disposal license shall apply to the nuclear safety supervision and administration department of the State Council and submit the following documents:

(1) Application form for radioactive waste disposal license;
(2) Final safety analysis report;
(3) Approval documents for environmental impact assessment documents;
(4) The original and the duplicate (photocopy) of the business license of the enterprise legal person, or the original and duplicate (photocopy) of the legal person certificate of the public institution,

and the photocopy of the ID card of the legal representative;

(5) Proof of training and assessment of personnel engaged in the management and operation of radioactive solid waste disposal, and a photocopy of the certificate of registered nuclear safety engineer;

(6) The list of equipment for radioactive detection, radiation protection and environmental monitoring;

(7) (7) Financial guarantee certificate;

(8) (8) Documents certifying the radioactive solid waste disposal management system, including disposal operation procedures, quality assurance program (operation stage) and list of procedural documents, disposal facility operation monitoring plan, radiation monitoring plan, emergency plan, record file management documents, and information management system supporting documents, etc.;

(9) (9) Other documents stipulated by laws and administrative regulations. The nuclear safety supervision and management department of the State Council shall conduct a technical review of the above-mentioned documents in accordance with the law, and the review time usually does not exceed 12 months.

3.4.6 Review of application documents

The nuclear safety administration department of the State Council shall conduct formal examination on the received license application documents. If the application documents are incomplete or do not conform to the statutory form, the applicouldt will be informed of all the contents that need to be supplemented and corrected within five working days; if the application documents are complete and conform to the statutory form, or the applicouldt submits all supplemented and corrected application documents as required, the application documents are accepted; otherwise it will not be accepted. The nuclear safety supervision and administration department of the State Council shall issue a written certificate for acceptance or rejection of a license application; if a technical review is required, it shall also inform the estimated time of the technical review.

3.5 The status of radioactive waste gas treatment

According to the source and characteristics of radioactive waste gas, the radioactive waste gas produced by NPPs is divided into oxygen-containing waste gas and hydrogen-containing waste gas. The hydrogen-containing waste gas is mainly composed of hydrogen, nitrogen, gaseous fission products (Kr, Xe, I, etc.) and gaseous activation products (N-16, C-14), etc., and has a high level of radioactivity. The main components of oxygen-containing waste gas are air, water vapor and a small amount of radioactive gases and aerosols. For hydrogen-containing waste gas, China adopts pressurized storage decay and activated carbon retention decay technology to treat inert gas; for oxygen-containing waste gas, China uses activated carbon adsorption and high-efficiency filtration to remove iodine and aerosols.

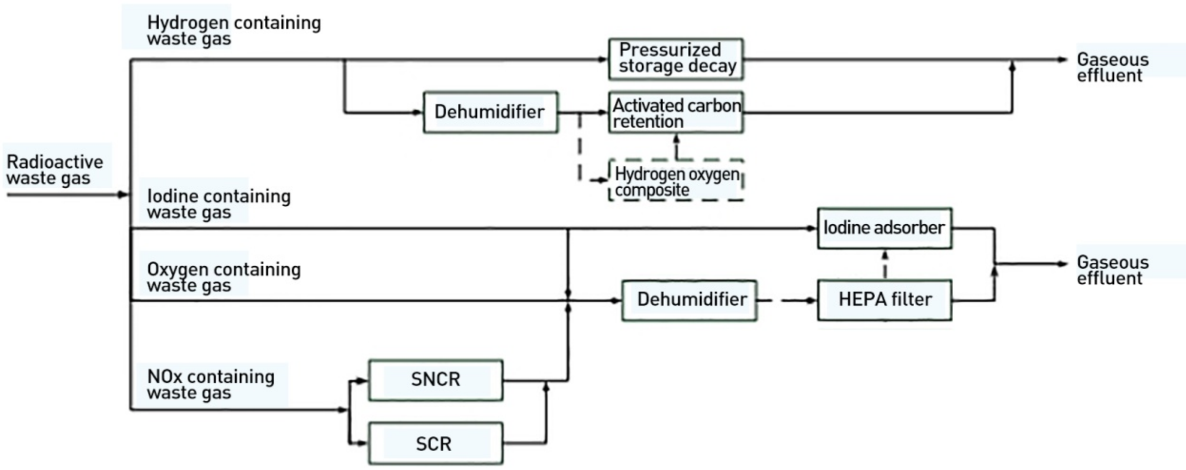

Figure 2. The technical route of radioactive waste gas treatment in China

The inert gas pressurized storage decay technology has been applied in the projects such as M310, second-generation plus, HPR1000 and other types of units in the Chinese mainland. The inert gas retention decay technology has been applied in projects such as AP1000, VVER, EPR, Guohe One, HPR1000 and ACP100 (small modular reactor) in the Chinese mainland. The technique utilizes the principle of dynamic physical adsorption of noble gases by activated carbon to decay short-lived Kr and Xe nuclides. Activated carbon adsorption and iodine removal technology and high-efficiency filtration and aerosol removal technology have been applied in the projects such as M310, second-generation plus, VVER, EPR, CAP1400, HPR1000 and ACP100 in the Chinese mainland.

For the hydrogen-containing exhaust gas of NPPs, in order to reduce the risk of hydrogen explosion and improve the safety of nuclear power units, Hualong No. 1 and subsequent models are carrying out research on the engineering application of hydrogen-oxygen composite technology for hydrogen-containing exhaust gas, which will be realized in subsequent nuclear power projects. Engineering application, CGNPC and China Nuclear Power Engineering Co., Ltd. are conducting research on hydrogen-oxygen composite technology. At the same time, in the process of plasma fusion treatment of radioactive waste, due to the generation of radioactive waste gas containing nitrogen oxides, China is carrying out engineering application research on SCR and SNCR to treat nitrogen oxides.

3.6 The status of radioactive waste liquid treatment

According to the source and characteristics of radioactive waste liquid, radioactive waste liquid of NPP is divided into three categories: process drainage, chemical drainage and ground drainage according to chemical composition and radioactivity. The main chemical component is boric acid, and the main radionuclides are H-3 and C-14. , Co-58, Co-60, Ag-110m, etc. For process drainage, ion exchange technology or flocculation + ion exchange technology is usually used to treat radionuclides; for ground drainage, filtration technology is usually used to remove solid particle impurities; for chemical drainage, natural circulation evaporation, forced circulation evaporation and heat pump evaporation technology are used for concentration treatment. Concentration treatment.

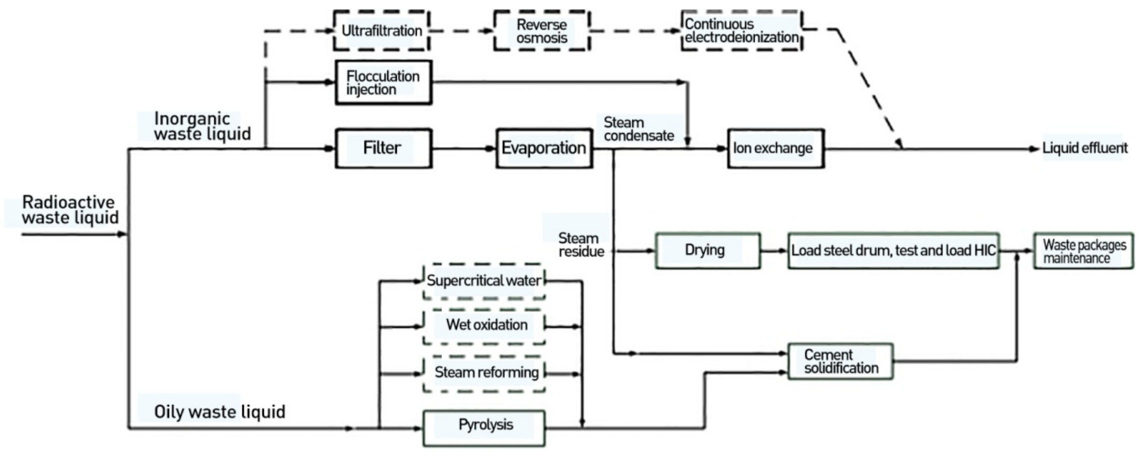

Figure 3. The technical route of radioactive waste liquid treatment in China

Ion exchange technology uses organic resin to remove ionized radionuclides, and has been applied in the projects of M310, AP1000, VVER, CAP1400 and other types of units in the Chinese mainland. For the colloidal nuclides (such as Co-60, Ag-110m) present in the radioactive waste liquid of NPPs, HPR1000 adopts flocculation injection and activated carbon adsorption technology to remove particulate matter and radionuclides in the radioactive waste liquid, to achieve the effect of protecting the ion exchange bed and reducing the amount of waste resin.

Natural circulation evaporation technology uses thermosiphon action to circulate and evaporate feed liquid between heater and evaporator, the technology has been applied in M310, second-generation plus, VVER, HPR1000 and other types of units. Forced circulation uses a circulating pump to circulate the feed liquid during the evaporation process to enhance the heat transfer effect, the technology has been applied in the M310 model unit. Heat pump evaporation technology is an energy-saving technology that uses a steam compressor to compress and heat up the secondary steam generated by evaporation as an evaporation heat source, the technology has been applied in AP1000, EPR, CAP1400 and HPR1000 .

For the deep purification technology of low-level waste liquid, China is carrying out new waste liquid treatment technology to further improve the purification coefficient and waste minimization level, such as ultrafiltration, reverse osmosis and continuous electric desalination and other membrane treatment technologies. Engineering verification research has been carried out in Daya Bay NPPs carry out engineering applications.

Inland plant sites have higher requirements on the discharge concentration of liquid effluent due to the limitation of water body and dilution capacity. The disposal of inland nuclear power radioactive liquid waste will be a new challenge. In recent years, China been actively carrying out research on deep purification technology for waste liquid from inland nuclear plant sites.

3.7 The status of Radioactive Solid Waste Treatment

In terms of radioactive solid waste treatment, the technologies commonly used in the early stages of NPPs in the Chinese mainland include: using cement solidification technology to treat waste resin and residual liquid; using cement fixing technology to treat waste filter cores and non-compactable waste; adopting cone drying technology to treat Waste resin; drying of residual liquid and radioactive waste liquid by using in-tank drying technology and fluidized bed drying technology; waste resin after conditioning and drying using high integrity container (HIC), drying of salt barrel with residual liquid, and incineration Ash drums, as well as dewatered waste resin and waste filter cartridges; miscellaneous dry waste using sorting and super-compaction techniques; combustible solid waste and radioactive waste oil using incineration techniques; degradable protection using degradation and thermal oxidation techniques supplies; dismantling, decontamination and smelting of scrap metal waste.

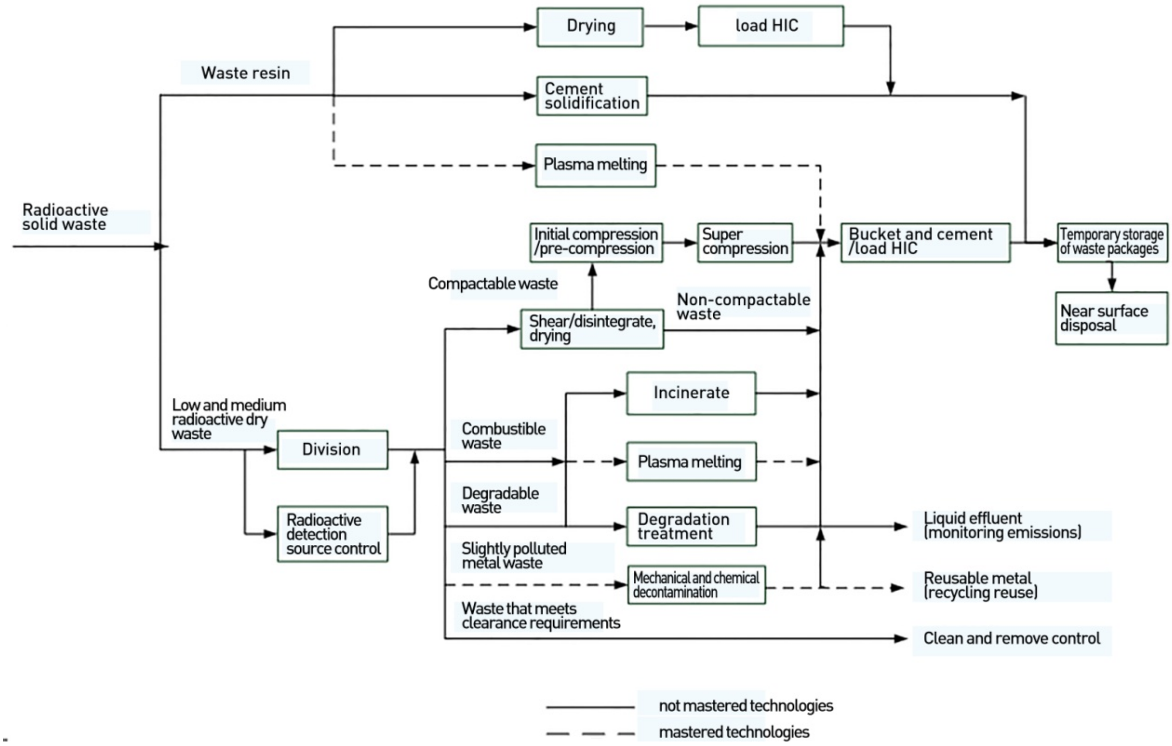

Figure 4. The technical route of radioactive solid waste treatment in China

3.7.1 The used technologies for radioactive solid waste treatment

(1) Including the design of key equipment and the research and development of cement curing formulas with different chemical components, the second-generation plus improved nuclear power units, Hualong nuclear power projects and other projects use 200L and 400L steel drums in-tank and out-of-tank mixing cement curing technology, which is suitable for waste resin and disposal of wet waste such as residual liquid.

In the design of the waste treatment center of Tianwan Nuclear Power Base in cooperation with Germany's NUKEM Company, waste resin and steam residue drying technology are used, and the main equipment is supplied by Germany's NUKEM Company. At present, many nuclear power projects such as Sanmen NPP, Tianwan NPP, Xiapu NPP and Zhangzhou NPP, etc., have adopted waste resin and residual liquid drying technology. The 200L waste barrels with drying waste resin or drying steam residue drying salt are loaded with concrete HIC, which could meet the requirements of near-surface disposal.

(2) Filter cartridge treatment technology: The used water filter cartridges in many nuclear power projects are treated by cement fixing technology

route, which is the most common water filter cartridge treatment technology in China.

Ventilation filter cartridges adopt a storage decay scheme according to the radioactivity level and nuclide type. The metal frame of the waste ventilation filter cartridges could be cleaned and decontaminated after being disassembled and decontaminated; or the solution of three-way compaction into a steel drum, super compaction and cement fixation. Waste ventilation filter cartridges with relatively high levels of radioactivity are subject to volume reduction.

(3) Combustible solid wastes: Since combustible wastes are all compactable wastes, primary compaction, super compaction and cement fixation technology routes are used to treat combustible solid wastes in many nuclear power projects.

In Tianwan NPP and HPR1000 Nuclear Power Project, degradable protective equipment and corresponding degrading devices are used to reduce the amount of combustible solid waste. This method could reduce the generation of waste packages to be disposed of at NPP sites that do not have the conditions for constructing combustible waste incinerators.

(4) Compactable solid waste: At present, there are many engineering examples of using super compactors to treat low-level solid waste in nuclear facilities in China. The dry waste compaction and packaging equipment independently developed in China could realize independent design and independent supply.

(5) Non-compactable solid waste: In many NPPs, cement solidification technology is used to treat non-compactible solid waste. Cement fixation technology is a commonly used solid waste preparation technology. The waste in the container is poured into the cement slurry and fixed in the cement matrix, and the performance of the waste body meets the requirements of near-surface disposal. The radioactive waste filter cartridge, the barrel cake after overpressure reduction and the non-compactible dry waste are cemented, and 200L and 400L steel barrel waste bags are produced after treatment. This technology has been adopted on the M310 improved nuclear power units and the HPR1000 units.

(6) Concrete High Integrity Container (HIC) packaging technology: Put 200L steel drums (such as waste drums containing drying salt, drying resin, etc.) that do not meet the requirements for near-surface disposal into concrete HIC and seal them. After being loaded into the concrete HIC, it could meet the requirements of near-surface disposal. The technology has been adopted in Tianwan Waste Treatment Center and Sanmen Site Waste Treatment Facilities.

(7) Inside the NPP, special vehicles and loading and unloading systems are used to transport radioactive waste resin, concentrate, waste filter elements, and dry waste to centralized treatment facilities for processing. The waste resin, waste liquid and waste filter cartridge transportation systems (including loading and unloading parts) of Sanmen NPP and Tianwan NPP are supplied by Westinghouse's German branch and NUKEM.

(8) Waste temporary storage technology: After various solid wastes are processed, waste barrels, boxes, and containers are formed, which need to be stored in the temporary waste storage in NPPs or nuclear facilities. Storage warehouses generally use digital control cranes and automatic spreaders to remotely transport waste packages, and store them for a certain period of time and transport them to disposal sites for disposal. In the engineering design of many nuclear facilities, different types of radioactive solid waste temporary storage warehouses have been designed, including storage areas transferred by digital control cranes and storage shaft-type waste warehouses. China has completed the engineering design of various types of high-, medium- and low-level radioactive waste repositories in nuclear power projects and nuclear chemical projects. It has rich experience and is capable of independent design and independent supply.

3.8 The status of Radioactive Waste Minimization

With the large-scale construction of third-generation NPPs such as HPR1000, China has actively carried out research on NPP waste minimization strategies to achieve waste minimization goals in terms of source item management, introduction of advanced technologies and new management models. The target value of the annual waste generation of the HPR1000 nuclear power unit currently under construction is ≤50 m3/RY (reactor-year). According to the Chinese User Requirements Document (CUR) of Advanced Pressurized Water Reactor, the annual waste generation of the subsequent new nuclear power units should be ≤30 m3/RY.

China has carried out research on the engineering application of advanced technologies such as new waste liquid membrane treatment, degradable waste treatment, waste resin conical drying, concentrated liquid barrel drying, HIC, combustible waste incineration and plasma melting, and gradually applied in new NPPs. At the same time, it is also carrying out research on new technologies such as waste resin wet oxidation, supercritical water oxidation, steam reforming, and polymer curing.

Newly built NPPs mostly adopt the on-site waste management model of "scattered and centralized", and NPPs that have been in operation for a long time are also seeking optimization of waste management. The newly built nuclear power unit of HPR1000 has achieved centralized waste treatment, and a waste treatment center of the whole plant has been configured to centrally process the whole plant's waste and improve the level of waste treatment.

At present, the Sanmen NPP adopts a "scattered and centralized" radioactive waste management model. The nuclear island waste treatment facility is a single-unit configuration, and the site waste treatment facility (SRTF) is shared by multiple units. The waste management model of the Sanmen NPP is the first to be used in China. Although some problems may be encountered in the early stage of operation, this model provides a streamlined waste treatment process, improves equipment utilization, and is conducive to the use of large-scale. It is a waste treatment equipment with high volume reduction, which not only improves the economy, but also helps to achieve the goal of waste minimization. Subsequently, China's Shandong Haiyang and Jiangsu Tianwan NPPs also completed the engineering application of the centralized treatment mode of the site waste treatment center.

3.9 Radioactive Waste Treatment Research and Development and Concern Technology

3.9.1 Technologies under Development

For waste liquids with high levels of radioactivity under abnormal or accident conditions of NPPs, China is carrying out engineering application research on mobile waste liquid treatment technology, and using highly selective inorganic adsorption media such as activated carbon and zeolite to treat radionuclides.

China Institute of Radiation Protection has developed a wet oxidation technology for waste resin, which could oxidize radioactive waste resin into inorganic waste liquid, and then carry out evaporation and cement solidification treatment, which has been completed in the Qinshan NPP.

For wastewater such as washing and showering, China is carrying out engineering research on treatment technologies such as electric Fenton and ultraviolet light. In addition, for the small amount of oily waste liquid produced by NPPs, China has carried out supercritical water oxidation technology engineering research.

Technologies that China is developing or engineering for nuclear power include: the use of plasma melting technology to treat dry waste, waste resin and insulation materials, the use of boron-containing concentrate to efficiently cure the steam residue, the use of wet oxidation technology to treat waste resin, the use of steam reforming technology to treat waste resin and combustible waste, the use of polymer curing technology to treat waste resin and distillation residue drying salt, these technologies have not yet achieved engineering application.

3.9.2 Technologies of future interest

However, research and cooperation in the removal, application and long-term storage of C-14 and Kr-85 in China have yet to be carried out.

The directions of research technologies for the treatment of radioactive waste liquids that China is currently focusing on include the treatment of oily wastewater, tritium removal from inland NPPs, and "near-zero" discharge of liquid effluents.

China is concerned about the medium-depth disposal of medium-level radioactive waste generated after deep reduction of waste volume (e.g. waste resin plasma incineration). In addition, medium-depth disposal technology is also in the process of research and development, including medium-depth geological disposal and packaging, disposal, evaluation and other technologies of deep geological disposal are paid attentions by China.

China's high-temperature gas-cooled reactors and heavy water reactors will produce more C-14 waste, and fast reactors will produce radioactive waste sodium. The minimization, treatment and disposal technology of these wastes is an important part of the further technology research and development and international cooperation. In terms of "problem" waste treatment, according to the physical and chemical properties of the waste, appropriate methods of detection and classification, dismantling and cutting, wet combustion, water or dry storage, decay treatment and other methods are adopted for treatment. The disposal of these "problem" wastes is also the focus of potential cooperation between China and UK. For C-14 waste, a treatment scheme of inorganicization and then C-14 recovery could be used; for radioactive waste with a short half-life, decay post-treatment or reuse is preferred. The general idea is to solve these "problem" wastes by accurately classifying, downgrading according to principles, reducing the harm of radioactive spreading , and recycling as much as possible.

With the rapid development of 5G communications, industrial automation and other technologies, China is also paying attention to the R&D and application of unmanned transportation, intelligent preparation, treatment and temporary storage of radioactive waste in the field of radioactive waste treatment.

3.10 Sino-Foreign Cooperation Experience in the Treatment and Disposal of Radioactive Waste

At present, the Chinese enterprises focus on technical research that is more conducive to radioactive waste gas and waste liquid purification, waste volume reduction, decontamination and clearance, waste package safety performance and equipment automation level. These studies aim to improve the level of radioactive waste disposal and management. The Chineseenterprises have mastered the filtration, ion exchange, flocculation, activated carbon adsorption, natural circulation evaporation, forced circulation evaporation, heat pump evaporation, cement solidification /fixation, waste resin and concentrate drying, HIC preparation, waste compaction and volume reduction, low-level waste incineration and other technologies; are currently undergoing membrane treatment (UF, RO, CEDI), inorganic adsorption, plasma incineration treatment of multi-type waste and other technologies of engineering applications, with strong R&D, design and operation capabilities. In the field of radioactive waste treatment, China also welcomes the participation of foreign enterprises to achieve a strong alliance.

At present, the Chinese enterprises have carried out large-scale cooperation with foreign suppliers such as Westinghouse, Framatome, NUKEM and other foreign suppliers in the field of radioactive waste treatment of nuclear power and nuclear chemical industry, and have built corresponding engineering facilities. Foreign enterprises may consider participating in China's engineering and scientific research projects in the field of radioactive waste treatment in various forms such as facility design, equipment supply, technology export, and joint research and development.

In nuclear power projects such as Fuqing, Fangjiashan and Hainan, China has cooperated with Westinghouse (Germany) to design and supply cement solidification facilities and dry waste sorting and super compaction equipment. In the Sanmen nuclear power project, we cooperated with Westinghouse to design and supply the waste treatment system for nuclear island and the waste treatment facility for site. In the Tianwan project, the design and supply of the radioactive waste treatment center was carried out in cooperation with the German company NUKEM. In the Haiyang Nuclear Power Project in Shandong Province, in cooperation with the Americould Es Corporation, the design and supply of waste treatment facilities on site was carried out. In the Taishan nuclear power project, in cooperation with AREVA, the design and supply of the waste treatment system was carried out.

Taking the VPC glass curing project of Sino-German cooperation as an example, China conducted public bidding in the form of international bidding. In the end, the German consortium (EVONIC, WAK, KAH, KIT) won the bid. The division of labor between China and Germany is as follows: The German side completes the conceptual design (CD), China and Germany jointly complete the basic design (BD), China completes the detailed design (DD), the German side examines and confirms, the German side supplies the core equipment, the German side provides on-site technical services, and the German side ensures the performance of the facility, in short, the German side provides design and core equipment supply.

In addition, in the field of nuclear facility decommissioning and radioactive decontamination, China Institute of Radiation Protection and French COGEMA Company have carried out technical research cooperation and purchased 5 patents. In the field of glass solidification of high-level liquid waste, CNNC 821 plant cooperates with German Kah company in process and furnace technology, with German steag company in mechanical, electrical and ventilation, and with German wak company in general technical responsibility and operation. In the field of NPP waste disposal, Qinshan, Tian Wan, Fuqing and other NPPs have cooperated with Germany's NUKEM in the supply of low-level waste liquid cement curing process and equipment, and Tianwan Nuclear Power has cooperated with Americould Eastern Technologies in the supply of degradable PVA protective clothing and its degradation process technology and equipment. To carry out cooperation, China's AP1000 project cooperates with ES Corporation of the United States in radioactive waste treatment process and main equipment.

4. Spent Fuel Transportation

Since the 1980s, China has established the policy of closed-loop nuclear fuel cycle. The transportation of spent fuel between NPPs and reprocessing plants is an important part of the closed-loop nuclear fuel cycle system. At the same time, with the gradual filling of the spent fuel pools of some NPPs, the need to transport spent fuel out of the reactor for off-site storage or further reprocessing has become increasingly prominent.

According to the construction and operation of China's NPPs and the service life of NPPs, in the foreseeable future, the demand for spent fuel transportation in the China will continue to increase on a large scale.

4.1 Potential Cooperation between China and UK

4.1.1 Physical protection of spent fuel transport by the road, sea and rail

In order to ensure the safety of spent fuel combined transportation and reloading, it is necessary to refer to the requirements of the regulations on the transportation of spent fuel and the physical protection of nuclear facilities, determine the design scheme of the security system, and design and build the security system for the combined transport. The security system must organically combine human and technical defense measures, human defense is organized and implemented by the spent fuel transport unit, technical defense according to the distribution of spent fuel transport vehicles, transport package and important equipment, reasonable setting of physical barriers, entrance and exit control systems, security lighting, video surveillance systems and communications and other technical measures, the spent fuel transport environment around the control of personnel and vehicles, possible hostile elements or hostile gangs of intrusive behavior, could make a timely, rapid and accurate response.

Since China implemented road transport of spent fuel in 2003, it has established a complete physical protection scheme applicable to road transport of spent fuel. With the initial operation of China's spent fuel by the combined transport system, the physical protection scheme of sea-way transport, rail-way transport and reloading stations needs to be further optimized by absorbing international transport experience.

4.1.2 Emergency plans and responses for spent fuel combined transportation

Since 2003, relying on the project of road transport of spent fuel, China has gradually established a set of emergency plans and response measures that could meet the emergency response to spent fuel road transport accidents, filling the gap in the field of emergency response to radioactive material transport accidents.

With the gradual establishment and operation of the combined transportation system, it is necessary to study the corresponding emergency plans and response measures for the accident scenarios of sea and railway transportation.

4.1.3 Development of spent fuel rail transport vehicles

The current D15B concave bottom flat car for spent fuel rail transportation is based on the original D15 car, using a new technology, its speed has been increased to 120km/h, and could carry 100 tons of spent fuel package. In the future, the development of spent fuel rail transport vehicles could be optimized, such as the study of closed carriages or isolation covers to load spent fuel package, so as to be more conducive to safety and security during transportation.

4.1.4 Research and development of dual-use containers for storage and transportation of spent fuel

China is currently conducting research and construction of a centralized dry storage facility for spent fuel to meet the rapidly growing demand for off-reactor storage of spent fuel. The development and configuration of spent fuel storage and transportation dual-purpose containers will improve the efficiency of concentrated dry storage and transportation of spent fuel, and facilitate further reprocessing of spent fuel. In the future, China and UK could seek opportunities for relevant cooperation in the field of storage and transportation dual-purpose container research and development.

4.1.5 Research and development of high level radioactive waste liquid transport package

With the decommissioning of nuclear facilities, the demand for transportation of high level radioactive waste liquids has gradually emerged. There are technical difficulties in the transportation of high level radioactive waste liquid, such as high level of radioactivity, transportation of liquid goods, gas decomposition and release, etc., it is necessary to learn from international mature experience to develop and configure special high-radioactive waste liquid transportation containers.

4.2 Recommendations

4.2.1 Recommend potential projects that could be openly tendered

In the future, the potential projects open to foreign parties for bidding in China's spent fuel transportation sector are:

(1) International transportation of radioactive materials such as spent fuel;
(2) Imports of package for the transport of radioactive materials such as spent fuel;
(3) Research on physical protection schemes for combined transportation of spent fuel;
(4) Research on the emergency plan for combined transportation of spent fuel;
(5) Development of spent fuel railway transport vehicles;
(6) Transport container maintenance process and equipment research.

4.2.2 Subcontractors who are looking for international partners

CNNC EVERCLEAN is the first enterprise in China to engage in spent fuel transportation, and finished the first transportation in 2003. Through years of practice, it has accumulated rich experiences, cultivated a group of outstanding talents, has a high-quality professional team, and has a variety of transportation containers, tools and other special equipment. In recent years, it has actively promoted the establishment of the combined transportation system, and gradually put it into operation.

CNNC EVERCLEAN has cooperated with multinational enterprises such as the UK, the United States and Russia to carry out the design and manufacture of spent fuel transport containers, research transportation program, and implement international transportation of spent fuel, and has been actively seeking international partners in this field.

4.2.3 Third Party Agencies

As the most experienced spent fuel transportation enterprise in China, CNNC EVERCLEAN adheres to a positive and open attitude and has the ability and willingness to cooperate with UK enterprises.

4.3 Licensing of Spent Fuel Transport Container

According to the "Regulations on the Safety Management of Radioactive Materials Transportation" and other regulations, the design of the spent fuel transportation container should be reported to the nuclear safety regulatory authority for review and approval before it is used for the first time in manufacturing. The design enterprise shall submit a written application to the nuclear safety regulatory department of the State Council and submit the following documents:

(1) General design drawing and design specification;
(2) Design safety evaluation report;
(3) Quality assurance program.

Enterprises that engaged in the manufacture of spent fuel transportation containers shall apply for a manufacturing license for Class I radioactive material transport containers. The manufacturing license is valid for 5 years.

If a spent fuel transport container manufactured by an overseas enterprise is used, the user shall report to the nuclear safety regulatory authority for review and approval before the first use. Enterprises applying for the use of spent fuel transport containers manufactured by overseas enterprises shall submit a written application to the nuclear safety regulatory department of the State Council and submit the following documents:

(1) A copy of the design approval document issued by the nuclear safety regulatory authority of the country where the design enterprise is located;
(2) Design safety evaluation report;
(3) Evidence of the relevant performance of the manufacturing enterprise;
(4) Quality certificate;
(5) An explanatory document that complies with the laws and administrative regulations of the People's Republic of China, as well as the radioactive material transportation safety standards or standards recognized by the nuclear safety regulatory department of the State Council.
Enterprises using spent fuel transport containers shall evaluate the safety performance of their spent fuel transport containers every two years, and report the evaluation results to the nuclear safety regulatory department of the State Council for the record.

4.4 Licensing of Spent Fuel Transportation Activities

According to the Regulations on the Safety Management of Radioactive Material Transportation and other regulations, shippers carrying out spent fuel transportation activities shall prepare special reports such as nuclear and radiation safety analysis reports, transportation accident emergency plans, and report them to the competent national authorities for review and approval. Before the transportation of spent fuel, the carrier shall apply to the competent national authority for approval of road access, transfer and departure, and file with the competent environmental protection authority at the place of departure.

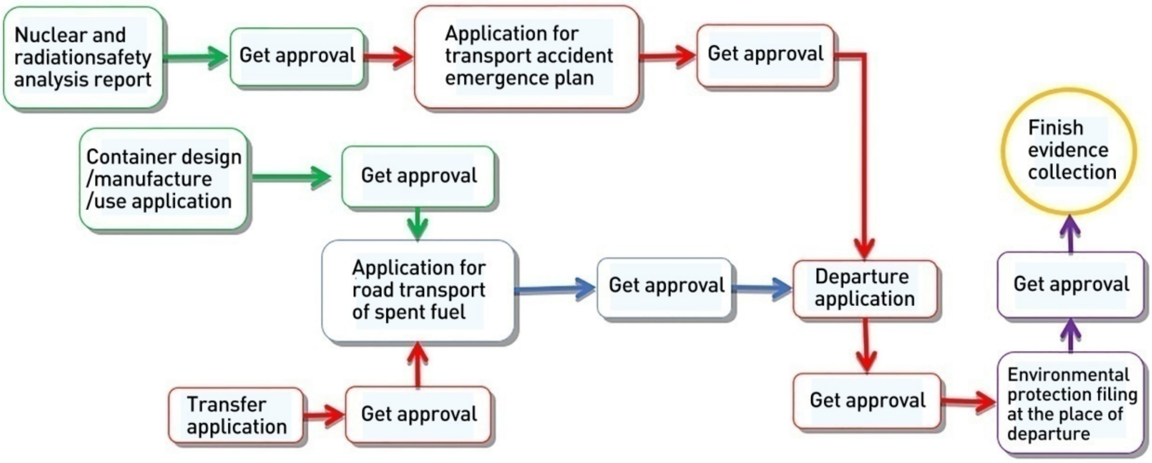

Figure 5. The detailed licensing flow for spent fuel transportation activities

4.5 Status of Spent Fuel Transportation

China has always supported and actively promoted international cooperation on the peaceful use of nuclear energy by member states of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) on the premise of strictly fulfilling their treaty obligations.

Since the first implementation of road transportation of NPP spent fuel in 2003, China has established a spent fuel transportation system based on road transportation, including NPP spent fuel transportation container system, road transportation equipment system, radiation protection system, emergency response system and safety and quality assurance system. This system has been in operation for many years and has a good record of safe transportation without incident.

Figure 6. The road transportation of spent fuel from NPPs

With the growing demand for spent fuel transportation, China has constructed the combined transportation system. New transport equipment such as spent fuel transport package, railway transport vehicles and transport ships has been newly configured, and the transport route has been demonstrated and determined. By the end of 2021, the combined transportation system of spent fuel was put into operation.

4.6 The Combined Transportation and Transportation Equipment

According to the Regulations on the Safety Management of Radioactive Material Transportation and other regulations, shippers carrying out spent fuel transportation activities shall prepare special reports such as nuclear and radiation safety analysis reports, transportation accident emergency plans, and report them to the competent national authorities for review and approval. Before the transportation of spent fuel, the carrier shall apply to the competent national authority for approval of road access, transfer and departure, and file

4.6.1 Combined transportation

China's NPPs in operation and under construction are mainly distributed in coastal areas, while off-reactor wet storage pools and spent fuel reprocessing plants are located inland. Achieving the storage and reprocessing of spent fuel from the reactor requires thousands of kilometers distance transportation. Faced with the rapidly growing demand for spent fuel transportation, it will not be sustainable to rely solely on road transportation for off-reactor storage and reprocessing.

The spent fuel is transported by short-distance road transportation + sea transportation, and transported to the spent fuel receiving facility through a fixed transit port and a fixed land channel (road + railway, combined with short-distance road according to the actual situation).

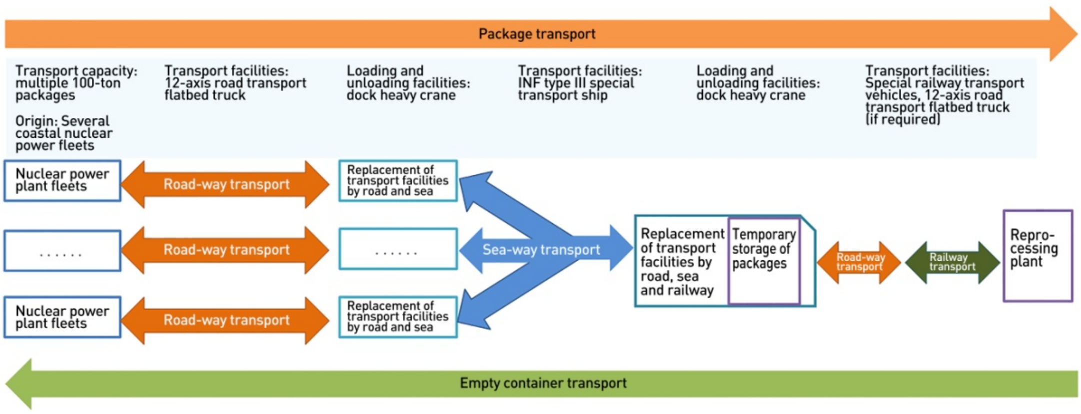

Figure 7. The process flow of the combined transportation

4.6.2 Spent fuel transport package

Since the first transportation of NPP spent fuel in 2003, China has successively deployed various types of 100-ton package such as NAC-STC, TUK-153, HI-STAR 60, HI-STAR 100MB, and CNSC. These transport package could be used for the transportation of spent fuel assemblies from NPPs such as PWR, VVER-1000, etc.

Figure 8. NAC-STC spent fuel transport package

4.7 Transport Means

4.7.1 Spent fuel carrier

According to the International Maritime Organization, ships transporting radioactive material must meet the requirements of the "International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes on Board Ships" (INF Code). China has independently designed and built the "Xin'an Auspicious" ship for spent fuel transport, which obtained the certificate in 2021.

Figure 9. "Xin'an Auspicious" ship

The “Xin’an Auspicious" ship is classified as INF III, suitable for carrying items such as irradiated nuclear fuel or high-level radioactive waste that does not limit the total radioactive activity. The cargo hold of the ship could carry multiple 100-ton spent fuel packages. The ship completed its first sea shipment of spent fuel by the end of 2021.

4.7.2 Spent fuel railway transport vehicle

The State Railway Administration and other relevant departments have organized and demonstrated that it is determined that the D15B concave-bottomed flat car is used as the railway transportation vehicle for spent fuel cargo in China (see Fig.10). The model is independently designed and built by China and is dedicated to the transportation of spent fuel by rail. Its technical conditions meet the requirements.

Figure 10. D15B type concave bottom flat car

4.8 Typical Cases of International Cooperation

4.8.1 International transportation of spent fuel for Ghana and Nigeria

In order to strengthen the nuclear security of the international community and prevent nuclear proliferation, China with the International Atomic Energy Agency, the United States, Russia and other relevant countries and international organizations have successively carried out low-enrichment transformation of Ghana and Nigeria HEU micro-reactors since 2014. International shipments of spent HEU fuel back to China are an important part of the LEU reconstruction project

The Russian Sosny Company and the Czech Skoda Company are responsible for the design and configuration of the spent fuel transport container. The air transportation of spent fuel from Ghana and Nigeria airports to Chinese airports is carried out by the Russian company Sosny. The road transportation from the Chinese airport to the spent fuel receiving facility is carried out by CNNC EVERCLEAN. China has actively cooperated and successfully completed the international transportation of spent fuel from Ghana and Nigeria in 2017 and 2018.

Figure 11. Ghana micro-reactor HEU spent fuel transportation

4.8.2 Transportation of bathroom accessories with excessive radioactivity

In 2012, a batch of copper fittings for bathroom elbows exported by Kohler Company exceeded the standard radioactivity and needed to be transported back to the original place through international transportation. CNNC EVERCLEAN and French Areva TN jointly implemented the road transportation from Ningbo Port to Jiangxi, eventually all 25,914 sanitary parts with radioactive excesses were successfully returned.

Figure 12. Transportation of bathroom accessories with excessive radioactivity

4.8.3 Configuration of NPP spent fuel transport container

Daya Bay NPP Units 1 and 2 were officially put into commercial operation in 1993. In order to ensure the continuous and safe operation of nuclear power, it is necessary to transport the unloaded spent fuel for off-reactor storage. In 2003, China imported the NAC-STC spent fuel transport container and auxiliary equipment from NAC International Corporation of the United States through international bidding, and successfully completed the first spent fuel transport from Daya Bay NPP in the same year, and established the spent fuel transport audit management system and operating system.

Tianwan NPP units 1 and 2 have been officially put into commercial operation since 2007. With the continuous operation of NPPs, there is also a demand for spent fuel transportation. In 2016, China imported the TUK-153 spent fuel transport container and auxiliary equipment from Russia's Energotex, and put into several uses since 2017.

Figure 13. Transportation of spent fuel from Tianwan NPP

In addition, in 2007 and 2018, China had successively imported HI-STAR 60 and HI-STAR 100MB spent fuel transport containers from Holtec International of the United States through international bidding; in 2019, the NCS 45 spent fuel rod transport container were imported from Orano, Germany NCS Corporation.

4.9 Exchanges between China and UK

China and UK have decades of exchanges and cooperation in all aspects of spent fuel transportation.

During the period from 1996 to 1998, CNNC EVERCLEAN and UK BNFL

Corporation cooperated to carry out the "China Nuclear Transportation System Design Research". In the study, a short-term/long-term plan for the transportation of spent fuel from China's NPPs was proposed, and it is suggested that the transportation of spent fuel in China should be carried out by road in the near future, and combined transportation by road-way, sea-way and rail-way in the long-term.

In 2014, CAEA, CNNC, the UK Department of Energy and Climate Change, and the International Nuclear Services Corporation (INS) jointly signed the "Memorandum of Understanding on Strengthening Cooperation in the Civilian Nuclear Industry Fuel Cycle Industry Chain" in London, UK, and a consensus was reached on cooperation between CNNC and INS in the fields of nuclear fuel cycle and transportation. In the following two years, China and UK jointly formulated the "Joint Work Plan" and held several meetings to continue and in-depth exchanges on the construction of the transportation system. The two sides conducted a field investigation of the UK's road-way, sea-way and rail-way transport system, and discussed various aspects, such as maritime transport, railway transport, terminal operation, terminal reloading, ships, railway vehicles, and related auditing and management.

Figure 14. The Chinese delegation in Sellafield Complex

In 2017, the Ministry of Transport, China Railway Corporation, CNNC and others and NDA, INS, DRS, PNTL and other UK enterprises have conducted extensive exchanges and discussions on the construction of the spent fuel road-way, sea-way and rail-way combined transportation system, and after a field visit to the UK facilities, such as Sellafield Reprocessing Plant, Barrow Port Special

Terminal for Spent Fuel Transportation, PNTL Company's Spent Fuel Special Ship, etc.

Figure 15. China delegation visiting the Port Barrow

CONCLUSION

UK is one of the first countries in the world to use nuclear energy for civil purposes, with good technical reserves and rich experience in the field of nuclear facility decommissioning, waste treatment and disposal, and transportation; China is the country with the fastest development of civil nuclear energy at present, with the world's largest nuclear power construction market, and has a wide range of needs in the field of nuclear facility decommissioning, waste treatment and disposal, and transportation. It is hoped that the nuclear energy communities of the two countries will, under the guidance of the Sino-UK Joint Statement on Civil Nuclear Energy Cooperation, be frank, open and closely cooperate to continuously create a win-win cooperation.

Abbreviations:

CAEA: China Atomic Energy Authority

NEA: National Energy Administration

NNSA: National Nuclear Safety Administration

CNEIC: China Nuclear Energy Industry Co., Ltd.

CNPE: China Nuclear Power Engineering Co., Ltd.

CNEP: China Nuclear Environmental Protection Co., Ltd.

CIAE: China Institute of Atomic Energy

NPIC: Nuclear Power Institute of China

CIRP: China Institute of Radiation Protection

CGN: China General Nuclear Power Corporation