Development Strategy for Nuclear Fuel Cycle Technology

The nuclear fuel cycle (NFC) is the "main artery" of the nuclear power system. To ensure the safety and sustainable development of China's nuclear power industry, it is necessary to build an independent, complete and advanced research and industrial system appropriate for national circumstances.

A consultative team of the CAS Academic Divisions conducted research into a wide range of topics in the field in 2013, including overall strategy for NFC technological development in China; international development trends of advanced back-end NFC technology; technological analysis of spent nuclear fuel (SNF) reprocessing in fast and thermal reactors; the internal cycle of a fast breeder reactor; production technologies for metal oxides and metal fuels; preliminary techno-economic analysis of a fast reactor and its fuel cycle technology; high-level radioactive waste treatment and its future prospects; the status, challenges and countermeasures for the Th-U fuel cycle; and new methods, materials and technologies for the NFC. The studies resulted in a report, which endeavors to assess the development of today's international NFC technology in a scientific way, draw a roadmap for the development of NFC back-end technology in China, and put forward recommendations for the sustainable development of China's nuclear industry. The following is a brief summary of this report.

To ensure steady and rapid economic development and controlled greenhouse gas emissions, China has adopted a guideline for the safe and efficient development of its nuclear power. According to the Medium and Long-term Plan for Nuclear Power Development (2005–2020), issued by the State Council, China's installed nuclear power capacity will reach at least 70 GW by 2020. After 2020, even larger scale nuclear power development is expected to meet power demand, optimize China's power structure, develop its low-carbon economy, and safeguard its sustainable development.

SNF reprocessing is one of the most complex and challenging chemical treatment processes known today. However, the unbalanced development of the front and back ends of NFC predominantly concerns the international nuclear power community. SNF reprocessing and nuclear waste disposal are very difficult, so advanced technology is needed. SNF reprocessing should be a high priority as long as China is to further advance its nuclear power industry. The importance of establishing a safe NFC system has been fully demonstrated by the Fukushima accident and, in particular, damage to its nuclear fuel elements and the leak of its radioactive spent fuel pool.

China is a latecomer in nuclear power development with generally backward NFC technology. Its research into the back end of NFC, the weakest link of China's nuclear power system, lags behind advanced levels and lacks industrial production capacity. China is at least 25 years behind India in key areas such as mixed-uranium-plutonium oxide nuclear fuel element manufacturing and SNF reprocessing. Therefore, China should speed up research and development of NFC and, in particular, its back-end technology. It is important to note that Chinese governments at various levels give much more importance to nuclear power plants than to NFC research and development, which will undermine the sustainability of China's nuclear power industry and nuclear power safety.

Following the development strategy of nuclear fission power from pressurized water reactor (PWR) to quick reactor, China has selected the technology approach of the closed fuel cycle. Accordingly, it is necessary to set up an independent, advanced closed NFC system. In China, the back end of the NFC includes such steps as PWR SNF reprocessing; production of fast reactor fuel (metal oxides or metal compounds); fast reactor SNF reprocessing; and treatment and disposal of highly radioactive wastes. An advanced NFC system, which could maximize nuclear resources utilization and minimize radioactive waste, is the key link for China to implement the development strategy from PWR to fast reactors, and to ensure the safety and sustainability of nuclear fission energy. Compared with the front end of NFC, unified leadership and planning have long been missing in the back end, leading to insufficient investment, scattered research forces, inadequate support for basic research, and backward engineering technology. No industrial production capacity has been formed in this regard so far, which constitutes the weakest link in China's NFC.

According the study, the major challenges facing China's NFC technology development are the following:

A Decentralized NFC Management System

Departmentalization makes it difficult to coordinate different government agencies and institutions, leading to huge resources waste and the absence of a national policy on NFC.

A Lack of Qualified R&D Professionals with Even Fewer Young Talents

Insufficient NFC researchers are scattered in different organizations like the China National Nuclear Corporation, CAS, universities and defense departments. Worse still, there is a lack of efficient cooperation between them, leading to the divorce of basic research and industrial application.

Weak Basic Research into the NFC Back End

In comparison with front-end NFC and nuclear station development, investment in back-end basic research is far too little, and the pay rates of NFC researchers are much lower than employees of commercial stations. These will have a great negative impact on China's nuclear industry.

Unbalanced Growth of Major Links in the NFC System

For instance, the development of major plants for back-end reprocessing lags behind that of commercial demonstrative units of fast reactors. The purchase of a Russian-made BN-800 fast reactor and its fuels could result in a situation where China's demonstrative fast reactors are "making bricks without straw". In addition, the ADS sub-critical demonstrative reactor in conception is unduly ahead of China's second nuclear reprocessing plant. These problems have had a serious impact on the implementation of China's policy of efficient development of nuclear power under the precondition of ensuring safety

Therefore, the consultative team made the following policy recommendations:

National Top-down Planning for the NFC Back-end Technology Development by Overall and Rational Arrangement

NFC is the "artery" of the nuclear fission energy system and the mainstay of the sustainable development of nuclear power. Without exception, the research and development of spent fuel reprocessing technology is a government responsibility, and should be planned by government departments on behalf of the state. Sticking to the principle of decision-making, guidance and monitoring by the government, we should endeavor to conduct top-down and systematic planning at the national level. The planning should be implemented by government departments step by step in a balanced way.

The top-down design should include overall planning in three different research levels (basic, applied and process research) and three different technology levels (mainline, cultivating, and exploratory technologies). A forward-looking, nationwide, authoritative and operational roadmap for NFC development should be drawn up in line with the national nuclear power development goals, with full consideration of the current national technological conditions and development potential, and by drawing on the experience of foreign plans in this regard. We should follow the principle of integrating basic research (focusing on scientific issues), applied research (focusing on technological issues) and industrialized application (focusing engineering issues). It is advisable to set up as soon as possible a consultative committee for NSC technology development mainly comprising scientists. It should make decisions and assessments in terms of the NFC development roadmap at the national level, the launch of major NFC projects, and talent training in light of national major needs. Efforts should be made to do away with the practices of "trade monopoly, trap-and-block segmentation, and multiple leaderships," which have hindered China's SFC development and wasted resources. It is advisable that the committee be made up of experts with academic achievements and integrity and management experts with strategic vision, who will be selected by the Academic Divisions of both the Chinese Academy of Sciences and the Chinese Academy of Engineering on behalf of the State Council. They should come from different organizations including CAS, universities, China National Nuclear Corporation, and defense departments, and will lay a solid institutional foundation for developing an advanced NFC system by cooperation and division of labor.

Accelerate Nuclear Power Legislation

It is advisable to speed up the legislation regarding nuclear power. A levy on the price of nuclear power should be taken to fund the R&D of SNF reprocessing. At the same time, the pay levels of NFC R&D workers should be raised to the level of those in commercial nuclear power plants. Studies should be made in how to set up an NFC system fitting China's conditions. Work should be done to both clarify the leading and supervisory roles of the government and to bring into full play the initiative of enterprise and private capital.

Launch Basic Research Program on NFC

It is advisable that the Ministry of Science and Technology adopt proactive policies to support basic and applied research of NFC. A series of research projects should be started during the 12th Five-year Plan Period on topics such as nuclear power plant development, spent fuel reprocessing and high level radioactive waste disposal.

Set up NFC Research and Training Centers

NFC professional training in China, a weak link, is failing to satisfy national demand. It is advisable that the Ministry of Education increase investment in NFC programs in universities with a good grounding. While more than 60 US universities are involved in research into the back end of NFC reprocessing, the number in China is very small. Drawing on the experience of postgraduate programs in advanced countries, China should invest at least 10 million yuan each year to train graduates from NFC programs and raise the level of their scholarships.

International Cooperation on the Basis of Self-reliance

It is recommended that China pursue international cooperation on the basis of self-reliance with regard to NFC reprocessing research and development and NFC reprocessing plant building. It is advisable to hold a scientific debate at the national level on the extremely costly purchase of reprocessing facilities from foreign firms, which is under negotiation, so the wisdom of the wholesale introduction of the technology must be thoroughly considered. In addition, proactive arrangements should be made for studies of the basic science, techniques and facilities of nuclear fuel reprocessing to lay a solid foundation in this regard and enable China to have a favorable position in international negotiations. Efforts should be made to bring into full play the role of the CAS and universities.

Give Full Scope to Major Science Facilities and Open NFC Research Platforms

At present, several major research platforms in this regard are under construction, including experimental facilities for spent fuel reprocessing, and laboratories for fast reactor fuel R&D and for high-level radioactive waste disposal and treatment. All of them should be open to domestic institutions as national platforms for back-end research and development of the NFC. It is advisable to set up a key laboratory for NFC, and a high-level radioactive beamline in Beijing or Shanghai synchrotron radiation facilities for the study of physiochemical characterization of the actinides, such as uranium and plutonium. High-performance super computers should also be given a full role in NFC studies.

The consultative team also made technical recommendations for the development strategy of China's NFC, such as a roadmap of proliferation first and transmutation second, optimum utilization of fuel resources, separated plutonium, and aqueous reprocessing of heating reactor spent fuel.