Safety Research on Spent Fuel Sea Transport

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Abstract. With the thriving of Chinese nuclear power industry and spent fuel transport, the current transport mainly depending on road network can't meet its demand. To solve the problem, China starts to establish a multimodal transportation using road-sea-railway. Based on safety principle, this paper studies various stages of sea transportation, proposes a transportation scheme for spent fuel, which covers port construction, ship selection, route selection and demonstration, and puts forward the corresponding transport organization system, safety technology supporting system for sea transport.

1. Introduction

In recent years, China's nuclear power has developed rapidly. As of July 2019, there are 45 nuclear power units put into commercial operation, with an installed capacity of 45.9 million kilowatts. There are 11 nuclear power units under construction, with an installed capacity of 12.18 million kilowatts. There are 15 nuclear power units in preparation, with an installed capacity of 16.6 million kilowatts. A total of 45 nuclear power generating sets have been put into operation nationwide. Fuel reprocessing technology plays an important role in ensuring the safe and reliable operation of nuclear power plants by recovering uranium and plutonium from spent fuel [1]. Compared with the rapid development of nuclear power industry, the transportation of spent fuel in China is obviously insufficient.

At present, the transportation of spent fuel is mainly by road, but due to the long distance of road transportation and dense population in the route area, the safety risk and security pressure are large; in the process of transportation, it is necessary to take measures to restrict the traffic along the road, which has a great impact on the normal driving of social vehicles and people's life. At present, there is only 50t road transportation capacity per year, which can't meet the demand of large-scale spent fuel transportation, which restricts the long-term development of nuclear energy in China [2-3]. The sea transport with its outstanding advantages of large transportation volume and small impact on the surrounding environment can be used as an important means of spent fuel transportation.

2. Transport of The UK and French Spent Fuel

As major nuclear power countries, Britain and France have mature spent fuel transportation systems, and their experience in spent fuel transportation is also at the forefront of the world

2.1. Ports

The UK and France spent fuel transportation system adopts the mode of road-sea-railway transport, serving the domestic and international transportation of spent fuel reprocessing, among which sea transportation mainly undertakes the spent fuel from Japan, Australia and other countries to the transfer terminal (Barrow port in the UK, Thurburg port in France) [1-3].
Ramsden terminal for sea rail transit in the UK is located in Barrow port, which belongs to the associated British port (ABP) group. Ramsden terminal is a public terminal, and PNTL obtains the right of use through a long-term contract with ABP. At present, it only serves for sea-railway reloading of radioactive material transportation. ABP is responsible for the regular dredging of the wharf channel [4].

France is a big nuclear power country, with nuclear power accounting for more than 75% of the national power share.

The spent fuel of nuclear power plants from Japan and Australia is transported by sea to the port of Thurburg, France, and then to the Argo reprocessing plant by short-distance highway barge (about 20km). Areva TN, a wholly-owned subsidiary of Areva group, is responsible for the transportation of spent fuel in France.

The special wharf for road-sea reloading is located in the port of Cherbourg, which is a public port. Areva TN company obtains the right to use the berth by signing a contract with the port. The loading equipment of the spent fuel cargo package on the berth is owned by Areva TN company.

2.2. Ships
PNTL is responsible for the transportation of spent fuel in the UK. As a holding subsidiary of INS, PNTL owns three special vessels for the transportation of spent fuel, and INS owns one special vessel for the transportation of spent fuel. Serco is entrusted with the operation and management of the vessel [5].

British and French ships dedicated to the transport of spent fuel meet the technical requirements of INF III, the highest level in the Maritime Code for irradiated fuel, plutonium and high-level radioactive waste promulgated by the international maritime organization. On the basis of meeting the requirements of INF III, the ship adopts higher safety design requirements in terms of structure, cargo tank layout, ship stability, marine equipment, electrical equipment, cargo package fastening, etc [6].

2.3. Transportation Route
According to the international transportation needs of Japan, Australia and other countries, the British and French spent fuel sea transportation enterprises (PNTL) make regular transportation plans and use special ships for transportation [7]. From Japan to the British port of Barrow and the French port of Thurburg, three routes have been planned respectively through the Panama Canal, around the Cape of good hope or cape horn. In terms of route selection, first, consider the security conditions of the channel, especially anti-piracy; second, the backup requirements of the channel.

2.4. Laws and Regulations
A sound system of regulations and standards for the transportation of spent fuel is the basis for reliable spent fuel transportation. The regulations for the safe transportation of spent fuel are divided into four levels. First it is the regulations on the safe transportation of radioactive substances (IAEA SSR6) formulated by the International Atomic Energy Agency; the second is the TDG formulated by the United Nations Expert Committee on the transportation of dangerous goods. The contents of the TDG related to radioactivity are based on IAEA SSR6 is the basis; the third is the regulations of different modes of transportation formulated by IMO, ICAO and EU, among which the radioactive part is based on TDG; the fourth is the national regulations formulated by each member country according to its actual situation and the regulations of each mode of transportation. In road-sea-railway transportation, the relevant agreements on the transport of dangerous goods such as ADR, adn, rid, IMDG and ICAO of the European Union shall be observed respectively. Please see the following figure 1.
3. China's Current Spent Fuel Transport

China's current spent fuel transport mainly depends on road, which is not sufficient enough. In the aspect of spent fuel transportation, China's nuclear materials have been managed by military transportation for a long time, and the large-amount transfer of nuclear materials adopts military transportation mode. After the reform and opening up, the nuclear power plant began commercial operation, and the mode of commercial transportation of nuclear materials was opened. However, the civilian transportation lacked management rules for radioactive materials transport by road-sea-railway. In 2003, Daya Bay nuclear power plant started its first long-distance road commercial transfer of spent fuel. Four ministries and commissions (National defence Science and engineering Commission, Ministry of public security, Ministry of transport and Ministry of Health) jointly issued the Interim Provisions on road transport management of spent fuel for nuclear reactors. National ministries and commissions began to gradually improve the management system for transport of radioactive materials, and the lack of management system is gradually being made up, but the lack is still exists. The rules from different authorities are not coordinated with the others, which brings great difficulties to the actual operation.

4. China's Spent Fuel Sea Transport

4.1. Ports Selection

The port is a node for spent fuel sea transport, which can implement sea-rail or sea-road reloading, and also has the function of regional spent fuel concentration.

Conditions required for the spent fuel ports:

- It is better to be 3000-5000 tons. The breakwater, channel and turning area shall meet the requirements of 3000-5000 tons ships entering and leaving the port;
- It should have the capacity of loading and unloading heavy equipment or package;
- It should have a temporary storage of spent fuel packages (containers) to ensure the safe and overall transfer of spent fuel packages (containers);
- The traffic conditions around the port are easily accessible, especially for heavy package;
- It should be qualified for spent fuel handling.
4.2. Ship Requirement

According to the regulations of the International Maritime Organization and the requirements for the safety of the transport of radioactive substances, spent fuel ships must meet the following requirements:

- The hull structure shall have dual functions of anti-collision and anti-radiation: in order to improve the impact protection capacity of the ship, the double bottom and double shell reinforced hull structure is adopted, and the watertight transverse bulkhead is set, which can not only enhance the impact resistance, but also improve the sinking resistance of the ship; in order to improve the radiation protection capacity of the ship, the anti-radiation hatch cover structure and the radiation isolation water tank can be set.
- Set up the cargo package (container) binding device: the cargo package must be reliably connected with the hull in the cabin to resist the impact of relative motion and inertia force between the cargo package and the hull caused by various external forces of the ship under adverse sea conditions. The standardization of the package provides convenient conditions for setting the package binding device.
- Installation of cargo tank cooling device: the surface temperature of the cargo package can reach 85 ℃. In order to ensure the transportation safety and improve the working environment, the cooling device shall be installed in each independent cargo tank.
- The ship should have good navigation performance: it mainly refers to the small stall and good sea keeping when sailing in the wind; the performance of rudder and heading stability should be coordinated. Generally, the propulsion control device with two engines, two oars and two rudders can effectively improve the propulsion and control performance of the ship.
- Equipped with advanced communication and navigation facilities: in order to ensure the navigation safety of the ship at sea, reliable communication and navigation facilities must be established. Among them, a complete communication system shall be established for the communication equipment to ensure the realization of effective smart navigation facilities between the posts inside the ship and the ship shore. Ship global positioning system and tracking system shall be established.
- Establish effective monitoring system and reliable emergency plan: in order to avoid accidents, the ship shall be equipped with necessary and reliable radiation dose monitoring equipment, alarm equipment, fire-fighting equipment and emergency treatment, emergency rescue facilities, etc.

4.3. Transportation Route Selection

There are two kinds of domestic routes along the coast of China: near shore route, short but complex; there are many obstacles such as shoals and reefs, many fishing grounds and fishing boats, many frequent ships, and the tide changes are complex; far shore route, although it can overcome some of the above adverse effects, has a long navigation time and a long windward anchorage, which is not conducive to the rescue and disposal of maritime accidents. By comprehensive comparison, in order to ensure the safety of the marine transportation of spent fuel, the ship route selects the inner route and offshore area, and the basic principle of route selection should meet the following requirements:

- The route shall be designed along the sheltered sea area, and the offshore side shall be relatively close, so as to facilitate the timely disposal of emergency accidents;
- The route design shall be clear about the planning of the wind shelter anchorage, so as to facilitate the access to the nearest anchorage in time when the marine climate changes;
- The route design should avoid the obstacle area and no navigation area, and avoid crossing the central fishing ground in the fishing season;
- The water depth of the route shall be controlled within - 200m to ensure the safety of the cargo package after sinking and facilitate the salvage;
- Avoid sensitive areas (ecological protection areas, breeding areas, etc.).
In addition, in order to facilitate emergency rescue, emergency berthing ports and anchorage area should be selected and determined in different areas of the route of the spent fuel transport.

4.4. Transport Plan
In the process of transportation of spent fuel, the government, the company and the people play an important role respectively.

4.4.1. Government. The government is responsible for formulating strict laws, regulations, standards and specifications in line with the whole process of spent fuel transportation, putting forward high standard requirements for the manufacturing or construction of equipment and facilities of spent fuel transportation containers, ships, vehicles, ports and transfer stations, and restricting the behaviors and management of spent fuel transportation.

4.4.2. Enterprise. Shipper, carrier, shipping company, port company, security and emergency disposal technical support company are the main body of transportation. High standard construction and manufacturing of spent fuel transportation containers, ships, vehicles, ports and transfer stations are needed to improve the reliability of equipment and facilities, attach importance to scientific research and development, devote to research on improving safety level, strengthen research on nuclear safety technology of spent fuel packages, and further improve the reliability of transportation.

Spent fuel facilities shall establish a highly monitored security system to strengthen the protection of specific risks (chemical, fire, radioactive, etc.), site and material (PMS) services and emergency capacity building.

Strengthening the training of personnel is the guarantee for the implementation of various laws and regulations and the realization of safe transportation. Train professional operation and management personnel, select professional and experienced carriers, strengthen safety culture and review of organizational and human factors (FOH), deploy preventive measures and regular training to reduce the possibility of accidents, improve the safety of personnel, and prepare staff for emergency situations through accident drills.

4.4.3. People. Looking back on the development of nuclear power in the world, the Chernobyl nuclear accident and Fukushima nuclear accident have greatly affected the development of nuclear power in the world, but at the same time, they have also become a favourable opportunity for better understanding. Extensive and in-depth public publicity activities of nuclear power have promoted the popularization of nuclear power knowledge in the public and improved the public's nuclear science literacy.

5. Conclusion
Based on the future domestic demand for spent fuel transportation and the current situation of sea transportation, this paper studies the various stages of sea transportation, and puts forward a plan for sea transportation of spent fuel that is suitable for China's national conditions, including port selection, ship selection and configuration requirements, route selection and demonstration; based on the plan for sea transportation of spent fuel, it establishes regulations, standards, ship operation, organization management and safety guarantee system of the sea transportation of spent fuel.

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References

[1] Yang Y H, Liu J Q, Xu P P and Zhao B Y 2020 Analysis on the domestic development of china’s nuclear power industry Science Technology and Industry 20 (5) 113-118

[2] Ming Z, Wang S and Duan J 2016 Review of nuclear power development in China: environment analysis, historical stages, development status, problems and countermeasures Renewable & Sustainable Energy Reviews 59 1369-1383

[3] Feng W D, An H X and Ye D Y 2018 History and prospect analysis of spent fuel and radioactive waste across boundary movement and multi-nations Environmental Engineering 36 (supplement) 995-1002

[4] Frank R 2008 Radioactive Waste Management for U.S.EPR (Phoenix: WM Conference)

[5] Wang H, Tong M Y, Sun S and Yang W H 2015 Research progress of spent fuel transport container Mechanical Engineer 5 65-69

[6] IAEA 2007 Operation and Maintenance of Spent Fuel Storage and Transportation Casks/Containers Vienna (Austria: International Atomic Energy Agency)

[7] Jia M L, Liu M and Li P 2019 Spent fuel safety management in japan and its enlightenments Nuclear Safety 18 (4) 33-40