Industrial and economic research on portable neutron generators in China

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Abstract. As the application technology of neutron tubes and detectors becomes more mature and diverse, the application of portable neutron generators is also becoming more widespread. The portable neutron generator industry has made significant progress. Starting from four aspects: PEST, industrial operation, upstream and downstream industries, and competitive landscape, an analysis of the current situation of the portable neutron generator industry was conducted. Analyze the development trend of the industry, predict market size and production through gray systematic predicting model GM(1,1), and provide relevant suggestions for sustainable development of the industry by combining technological innovation, product diversification, market expansion, brand building, talent cultivation, and industrial chain collaboration.

Keywords: portable neutron generator, PEST analysis, porter's five forces model, grey prediction

1 Introduction to portable neutron generators

With the development of neutron technology, neutron as a research tool has been widely used in many fields such as chemical industry, exploration, coal analysis, industrial flaw detection, medical treatment, explosives and drug detection, and plays an irreplaceable role. Portable neutron generator has compact structure, small size, convenient storage and transportation; Compared with isotopic neutron sources, the neutron yield is higher and the neutron energy is monochromatic. The ion source can work in continuous or pulse mode, and achieve neutron yield and pulse width control adjustment, and when the power is off, the sealed neutron tube will stop working, which shows the high safety.

The portable neutron generator is composed of a neutron tube and a matching power supply. The structure is shown in Fig.1. The principle is similar to a small fusion reaction, where the heats control the deuterium tritium gas pressure and generate deuterium tritium gas plasma through ion source ionization. Deuterium tritium ions are induced by the negative high pressure applied on the accelerating electrode, and after acceleration, the target plate is bombarded to produce deuterium tritium fusion reaction and emit neutrons [1-3]. According to the different reaction, the neutron tube is divided into D-D neutron tube and D-T neutron tube. D-D neutron tube produces 2.5 MeV neutron energy, D-T neutron tube produces neutron energy 14 MeV .

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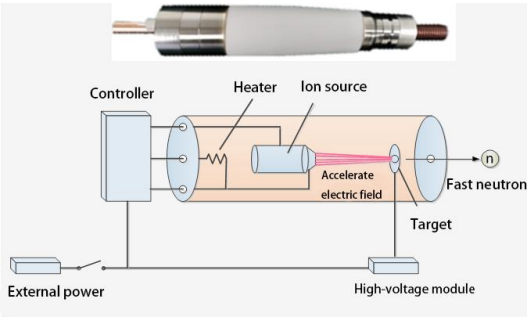

Fig.1 Structural diagram of a Portable Neutron generator

The output of the portable neutron generator is adjustable across 10^8n/s~10^{12}n/s, and its temperature tolerance can reach 150℃, its life can reach 2000-8000h at normal temperature, and which can reach 300-1000h at 150℃.

2 Applications of portable neutron generators

With the application technology of neutron tubes and detectors becoming more mature and diverse, the application range of portable neutron generators is also more extensive. The following is a brief description of the current application status of portable neutron generators:

1) Resource exploration field: The neutron logging technology, using neutron as the probe and the interaction of neutron and formation materials, can not only detect oil or natural gas under the formation, but also detect many energy and mineral resources such as coal, uranium, shale oil and gas[4]. Neutron logging has become one of the most promising logging technologies due to its wide application range, wide measurement parameters and low environmental impact.

2) Public safety: dangerous goods such as explosives and drugs are closely related to public safety[5-6]. As the elements of these dangerous goods are similar to common organic substances, it is difficult to distinguish them by conventional detection methods. Neutron detection technology can react with the nucleus of the substance and produce characteristic gamma rays[7-8].

3) In the industrial field: especially in coal-fired power generation, cement production[9], metal smelting and other industries, the neutron detection technology is also used to accurately identify elements, help factories achieve real-time analysis of industrial materials, and provide accurate basis for the processing and production of materials[10]. This technology can not only improve the utilization rate of materials, reduce pollution emission, and realize "green production"; It can also improve the level of factory automation, reduce production costs for enterprises.

4) In the field of agriculture and animal husbandry: use neutron radiation to induce biological genetic mutations, artificial cultivation of new seeds[11]. The neutron radiation breeding method has the advantages of simple operation, low cost and good mutation effect. It can not only obtain a large number of seeds of different varieties at one time, but also shorten the breeding cycle effectively, which is on par with the traditional cross breeding.

5) In the field of nondestructive testing: compared with traditional X-ray testing technology, nondestructive testing technology based on neutron photographic system has stronger penetration and can be used for the detection of thicker objects and metal materials, and has a wider range of application[12]. More importantly, the use of different mass elements to absorb neutron differences, neutron detection technology can not only effectively distinguish isotopes, but also for non-destructive testing of radioactive items, this technology has become an effective nuclear material research and identification method, mature application in many countries. Now most neutron sources are reactor neutron sources, but reactors are costly and immobile, which limits the promotion of neutron photography technology. It is necessary to develop a system with low cost and easy movement, and can still meet the requirements of neutron imaging applications after miniaturization[13-14].

3 Industry status of portable neutron generators

The portable neutron generator industry is a technology-intensive industry that involves a lot of high-tech technology and expertise. Production enterprises' main orientation is "order drive" and the degree of product customization is high, so different customers can purchase different specifications and models of products or technical services from enterprises to meet their own production needs.

At present, the domestic portable neutron generator industry is still in the period of technological deepening, the application field is constantly expanding, and the industry does not have obvious periodicity. The downstream application field of the product is wide, the customers are also all over the various countries and regions, and the timing of different customers to choose to buy the product is also very different, so the industry has no obvious seasonality. Based on the current status of the industry, the following analysis is carried out:

3.1 Industrial PEST analysis of portable neutron generators

(1) Analysis of political and legal environment

Portable neutron generators are products that involve nuclear technology so they are subject to strict regulations and regulatory requirements. The production enterprises need a license issued by the Ministry of Ecological and Environmental Protection, and follows the existing industry standard "Technical Conditions for portable neutron generators and neutron tubes for Oil logging"(SY/T 5419-2007). For oil logging, it can learn from the American API Q1 system "Quality Management System Specification for Production Enterprises in the oil and gas Industry"(ninth edition) and the corresponding technical specifications of 66 kinds of products.

(2) Industry economic environment analysis

According to the government work report of the First session of the 14th National People's Congress in 2023, China's GDP will grow by around 5%. Promote stability and quality of imports and exports, and basically balance the balance of international payments; Energy consumption per unit of GDP and the discharge of major pollutants continued to decrease, with a focus on curbing fossil energy consumption, and the quality of the ecological environment steadily improved. There are still many unstable and uncertain factors in the economic operation, but there are still many favorable conditions for China's economic development, and the

fundamentals of the long-term economic development have not changed.

(3) Industry social environment analysis

China's civilian neutron tube research and development began in the 1970s, due to the unique superiority of the neutron, after years of development, many enterprises have mastered the neutron tube research and development technology and can mass production. Neutron tube products have basically formed a large-scale and serialized, the main manufacturers and products are NT series neutron tubes of Northeast Normal University, MZ and MZT series neutron tubes of Xi 'an Petroleum Instrument Factory, and 1042 series neutron tubes developed by the Institute of Electronic Engineering of China Academy of Engineering Physics. At present, the neutron tube developed by Northeast Normal University is mainly used in the field of scientific research and industrial irradiation, and the products of Xi 'an Petroleum Instrument Factory and Electronic Engineering Research Institute are mainly used in bulk in the field of domestic oil exploration and development, and a small amount of them are also used in the field of scientific research and industrial irradiation. In the early days, the development of China's portable neutron generator industry was mainly focused on military applications. With the development of the national economy and the progress of technology, the application of portable neutron generators in the civil field has gradually expanded[15-16].

(4) Industry technical environment analysis

Due to the late start of domestic research, the relevant development technology is tightly blocked by foreign countries, and the development of technology is slow. According to statistics, the number of patent applications related to China's portable neutron generator industry reached 577 in 2013-2022. The main distribution is shown in Table 1.

Table 1 Distribution of Patent Applications for Small Neutron Generator Industry in China

Unit Name	Number of patents
China Academy of Engineering Physics	45
China Institute of Atomic Energy	44
Lanzhou University	28
China Petroleum Logging Co., Ltd	22
Tsinghua University	14
Beijing Junhe Xinda Technology Co., Ltd	13
PetroChina Company Limited	13

The yield of domestic portable neutron generators can basically cover the range of 10^7n/s-10^{10}n/s, but there is still a gap in yield, stability and life compared with advanced countries such as the United States, Russia and France in the world. At present, all enterprises have increased the research and development of portable neutron generators and their application technology, and portable neutron generators are gradually developing in the direction of miniaturization and long life. With the development of portable neutron generator technology, especially the solution of restricting the life of portable neutron generator technology, portable neutron generator will have a wider application in scientific research, national defense, industry and agriculture and other field.

3.2 Analysis of industrial management

In recent years, China's portable neutron generator industry has made remarkable progress, not only in the technical level continues to improve, but also in the product type, quality and application range has also been greatly improved. In addition, China has also participated in international cooperation actively, and conducted technical exchanges and cooperative research and development with international advanced enterprises, which has promoted the rapid development of China's portable neutron generator industry.

As shown in Fig.2，in 2022, the scale of the global portable neutron generator industry is 215.47 million US dollars, and the scale of China's portable neutron generator industry is 31.222 million US dollars. The scale of China's portable neutron generator industry accounts for about 14.49% of the global proportion. The domestic portable neutron generator industry has experienced a process from scratch, from small to large, from weak to strong, and has developed into one of the internationally competitive industries.

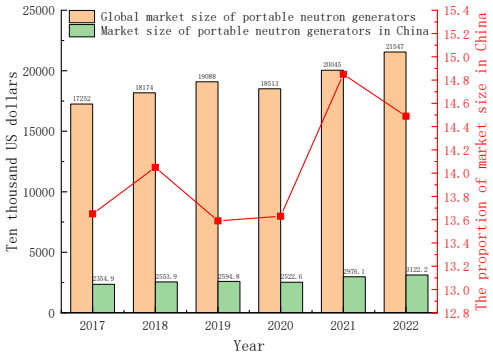

Fig.2 Scale and Global Proportion of China's Portable Neutron Generator Industry from 2017 to 2022

In terms of production capacity, China's portable neutron generator output of 140 units in 2017, by 2022, the production of portable neutron generators reached 208 units. In recent years, the production capacity of China's portable neutron generator industry is shown in fig.3:

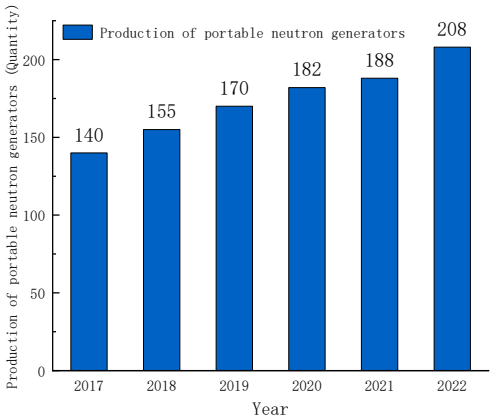

Fig.3 Production Capacity of Portable Neutron Generator Industry from 2017 to 2022 in China

As shown in Fig.4， in terms of demand areas, the total demand for portable neutron generators in China in 2022 is 256 units, of which 5 units are needed in scientific research and laboratory fields; 245 units for industrial applications; Other areas demand for 6 units.

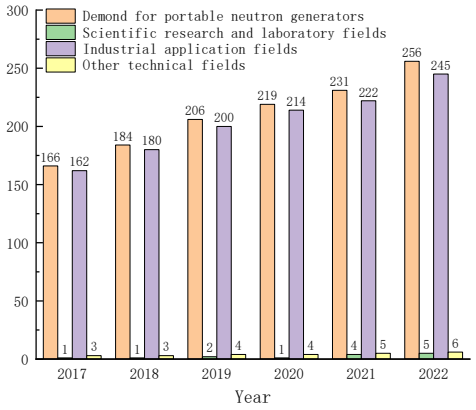

Fig.4 Statistical Chart of Demand for Portable Neutron Generators in China from 2017 to 2022

As shown in Fig.5， in terms of demand region, in 2022, the demand for portable neutron generators in North China is 39 units, the demand for Northeast China is 13 units, the demand for East China is 91 units, and the demand for central and South China is 74 units.

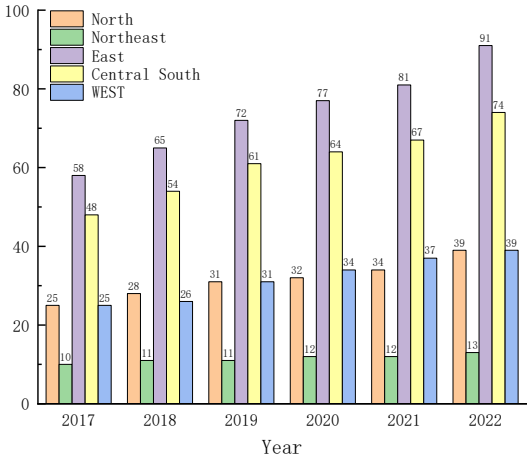

Fig.5 Statistics of demand for Portable Neutron generators in various regions of China from 2017 to 2022

As shown in Fig.6,in terms of price, the average market price of Portable Neutron generators in China in 2022 is 0.82 million yuan/unit, and the average market price in scientific research and experimental fields is 4.4 million yuan/unit; The average market price in the industrial application field is 0.65 million yuan/unit; The average market price in other fields is 4.8 million yuan perunit.

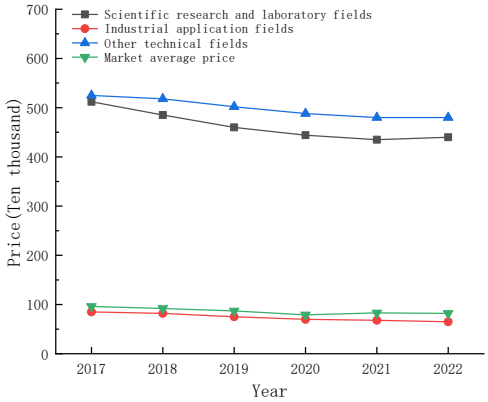

Fig.6 Price Trend of Portable Neutron Generator Market in China from 2017 to 2022

3.3 Impact analysis of upstream and downstream industries

(1) Influence of upstream industry

Portable neutron generators require semiconductor technology to manufacture electronic components and circuits, so the progress of semiconductor technology can promote the progress of portable neutron generator technology and product upgrades. At the same time, the development of the semiconductor industry has also promoted the expansion of the application of portable neutron generators, such as in the field of semiconductor material detection and semiconductor equipment maintenance, portable neutron generators can play a unique role. High-voltage power supply is one of the important upstream industries of portable neutron generators, portable neutron generators need to use high-voltage power supply to generate ion sources, and need to accurately control the pulse width and frequency of ion sources and other parameters. Therefore, the progress of high-voltage power supply technology can promote the promotion of portable neutron generator technology and product improvement. Meanwhile, the development of the high-voltage power supply industry also provides more diversified and higher-performance power supply products, thus providing more options and possibilities for the application expansion of portable neutron generators.

The development of upstream industries such as semiconductors and high-voltage power supplies has an important impact on the portable neutron generator industry, and their progress can promote the progress of portable neutron generator technology and product upgrades, and provide more opportunities and options for the application of portable neutron generators.

(2) Downstream industry impact

Downstream oil and gas exploration and development industry and medical industry has a greater traction and driving role in the development of the industry, and its demand changes directly determine the future development of the industry.

In the medical field, portable neutron generators can be used for the diagnosis and treatment of diseases such as cancer treatment. Through technologies such as neutron photography and neutron activation analysis, doctors can determine the location, size and shape of tumors more accurately, allowing for more effective treatment. With the continuous development of medical

technology, the demand for portable neutron generators is also increasing. Especially in the field of cancer treatment, the application prospect of portable neutron generator is very broad. Therefore, the medical industry has played an important role in promoting the development of the portable neutron generator industry, and with the progress of medical technology and the increase of people's attention to health, the demand for portable neutron generators will increase.

The oil and gas exploration and development industry is directly affected by factors such as exploration and production expenditures of oil companies, and the oil price indirectly affects the industry through its impact on exploration and production expenditures of oil companies. The demand for the industry's products and services is largely dependent on capital investment in oil and gas exploration and development, which has a very strong positive correlation with oil prices. Due to the harsh operating environment of petroleum logging equipment, such as high temperature, high pressure and high vibration, the related quality requirements of products are high. Affected by the global economic environment and geopolitics, there is the possibility of cyclical fluctuations in oil prices, and there is also the risk of rapid decline in a short period of time, which has an impact on the performance of oil and gas exploration and development and oilfield engineering and technical services, and then on the equipment manufacturers of oilfield engineering and technical services.

The operation process of oil and gas exploration and development industry includes physical exploration, drilling, open hole logging, well completion and oilfield production. Directly affected by the downward oil price is the physical exploration, drilling and completion, well logging, oil and gas exploitation, oilfield construction all links, if the oil price is lower than the oil field development cost price, the development of exploration and development will be greatly reduced, drilling, logging business will also be greatly affected, especially the number of new Wells will be significantly reduced, thus affecting the demand for portable neutron generators.

3.4 Analysis of industry competition pattern

As shown in Fig.7,in terms of market concentration, in China's portable neutron generator market segment in 2022, the scale of scientific research and laboratory field is 22 million yuan, accounting for 10.48%; The scale of industrial application is 159 million yuan, accounting for 75.71%.

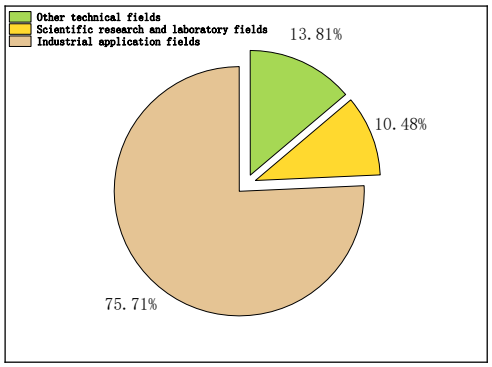

Fig.7 Concentration of Portable Neutron Generator Segmentation Market in China in 2022

As shown in Fig.8,in terms of regional concentration, the largest domestic demand market in 2022 will be East China, and the market size of portable neutron generators will account for 36.58% of the country.

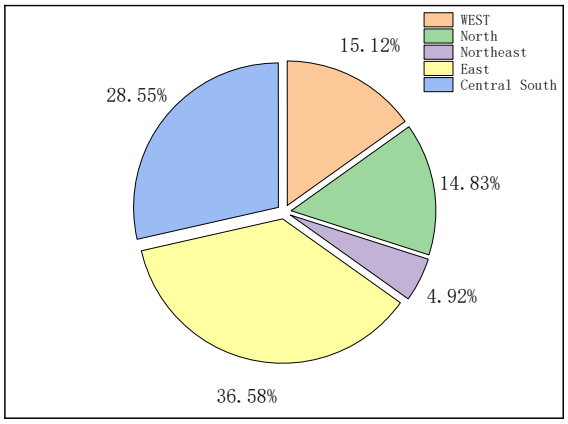

Fig.8 Regional Market Concentration of Portable Neutron Generators in China in 2022

In view of the domestic portable neutron generator industry competition situation, this paper adopts Porter's five forces model for analysis:

(1) Competition among existing enterprises

There are few competitors in the portable neutron generator industry, and the market is mainly monopolized by a few large enterprises. These companies have advanced technologies and patents, and have a high market share and brand awareness. As a result, the degree of competition from competitors is relatively low.

(2) Analysis of potential entrants

The portable neutron generator industry has a high market entry threshold and requires a lot of capital and technical support. In addition, the application of nuclear technology is also subject to strict regulatory and safety requirements. As a result, it is more difficult for new players to enter the market and the threat of new entrants is relatively low.

(3) Alternative threat analysis

Alternatives to portable neutron generators are mainly other types of ray sources. Although portable neutron generators have unique advantages in certain applications, the continuous development of alternative technologies may pose a threat to their market share.

(4) Bargaining power of suppliers

Suppliers to the portable neutron generator industry are mainly companies that provide nuclear materials, equipment and components. The scale, technical strength and supply capacity of suppliers will affect the procurement cost and product quality of enterprises. However, because the supply of nuclear materials is strictly regulated and controlled, the bargaining power of suppliers is relatively low.

(5) Customer bargaining power

The buyers of portable neutron generators are mainly scientific research institutions and industrial enterprises. The size, market share and purchasing power of the buyer will affect the selling price and sales volume of the enterprise. Because portable neutron generators are high-tech products, the bargaining power of buyers is relatively low.

4 Development prospects of portable neutron generator industry

The development trend of the neutron generator industry mainly includes the following aspects:

(1) Technological innovation promotes development

Neutron generator is a high-tech product, its technical level and research and development ability directly affect the development of the industry. With the continuous progress and innovation of science and technology, the performance and function of neutron generators are also constantly improving, which provides a strong support for the development of the industry. In the future, with the continuous emergence of new technologies, the technological innovation of the neutron generator industry will be more active, and the industry will continue to move forward.

(2) Market demand continues to grow

Neutron generators have a wide range of applications in medical, safety and material analysis, and with the development of these fields, the market demand for neutron generators is also growing. At the same time, with the improvement of people's understanding of neutron rays and application technology, the application field of neutron generators will continue to expand, further promoting the growth of market demand.

(3) International competition intensifies

The neutron generator industry is a high-tech field, and its technology and products have high added value, so it is more attractive. With the improvement of the degree of internationalization, more and more enterprises begin to enter the neutron generator industry, and the market competition will be more intense. In the future, the competition in the neutron generator industry will be more international, and enterprises need to continuously improve their technical level and innovation ability to meet the challenges of market competition.

(4) Increased policy support

Neutron generator industry is a high-tech industry, and its development needs strong support from the government.

In the future, with the country's emphasis on and support for the high-tech industry, the policy environment of the neutron generator industry will be more favorable, providing more opportunities and policy support for the development of enterprises.

(5) Coordinated development of industrial chains

The industrial chain of the neutron generator industry is relatively complete, including material procurement, production and manufacturing, and sales channels. In the future, with the development of the industry and the intensification of market competition, the cooperation between enterprises and the coordinated development of the industrial chain will be more

important. Enterprises need to strengthen cooperation with upstream and downstream enterprises, form a good industrial ecosystem, and jointly promote the development of the industry.

Based on the original data, use the GM(1,1) model for grey prediction[17-18].The production of China's neutron generator industry shows as fig.9, and it is estimated that 415 units will be reached by 2030.

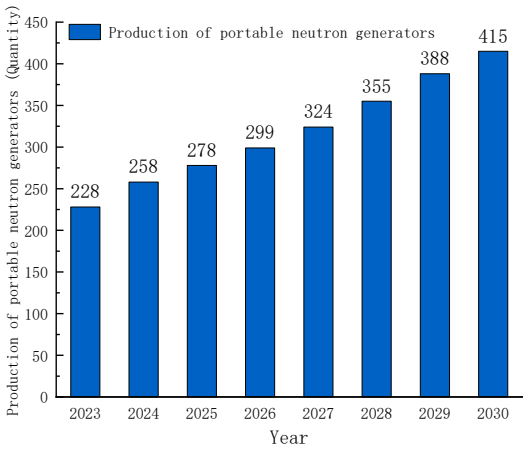

Fig 9 Production Forecast for Portable Neutron Generator Industry from 2023 to 2030

China's neutron generator industry demand will continue to expand, is estimated to reach 442 units by 2030 shows as fig.10.

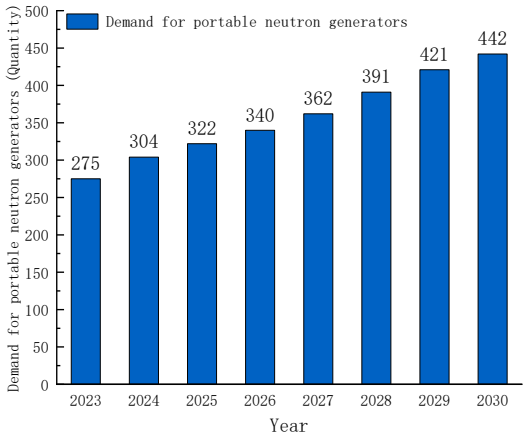

Fig.10 Prediction of demand for neutron generator industry from 2023 to 2030

The market size of China's neutron generator industry will continue to expand, and it is estimated that it will reach 388 million yuan by 2030 shows as fig.11.

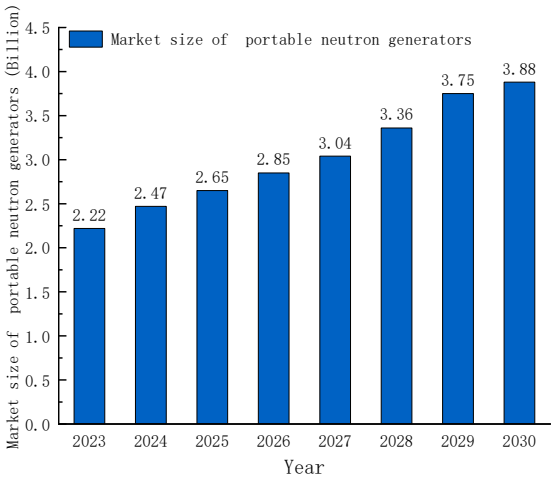

Fig.11 Market Size Forecast for Portable Neutron Generator Industry from 2023 to 2030

The Chinese government attaches great importance to basic research and scientific and technological innovation, and the neutron generator, as one of the national key experimental equipment, is supported and policy-oriented by the government. The Chinese government has given strong support to the neutron generator industry, including policy support, capital investment, personnel training and other aspects. This provides an important guarantee and impetus for the development of the neutron generator industry. As the neutron generator industry continues to thrive, the following needs to be considered:

(1) Technological innovation: The portable neutron generator industry should continue to carry out technological innovation to improve accuracy, stability and reliability. Technological innovation can be achieved by introducing foreign advanced technology, strengthening cooperation with universities and scientific research institutions, and increasing R&D investment.

(2) Product diversification: According to the needs of different industries and fields, the development of diversified portable neutron generator products to meet the market demand. For example, different types of portable, high-precision, high-energy products can be developed for different application needs.

(3) Market expansion: actively explore domestic and foreign markets to improve the competitiveness of neutron generators in the international market. It can expand the market by participating in international exhibitions, strengthening cooperation with foreign customers, and carrying out international trade.

(4) Brand building: Strengthen the brand building of the portable neutron generator industry and improve the visibility of enterprises and products. The brand image can be enhanced by strengthening publicity and promotion, participating in industry evaluation activities, and applying for patents.

(5) Talent training: Strengthen the industry's talent training, to provide talent support for the development of the industry. Professional talents can be cultivated through cooperation with

universities and vocational colleges, vocational training, and the introduction of foreign talents.

(6) Industrial chain coordination: Strengthen the cooperation between upstream and downstream enterprises in the portable neutron generator industry chain to achieve the coordinated development of the industrial chain. Industrial chain coordination can be achieved by signing strategic cooperation agreements, establishing industrial alliances, and sharing resources.

5 Conclusions

Portable Neutron generators have good monochromaticity, high yield, and do not produce γ Radiation, which can emit pulsed neutrons and provide stable and controllable neutron rays, has been widely used in fields such as oil logging, geological exploration, and coal quality analysis. We conducted an analysis of the current status of the Portable Neutron generator industry from four aspects: PEST, business situation, upstream and downstream industries, and competitive landscape. Analyze the development trend of the industry, predict the size and production of the market through gray systematic predicting model GM(1,1), finally provided relevant suggestions for the sustainable development of the industry.

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