# Research status and development of neutron detector

**Hengchun ZHAO**

China Institute for Radiation Protection

#P-S2-44

## 1. Background

The discovery of neutrons is an important milestone in the development of physics in the 20th century. In 1932, Chadwick discovered neutrons in the experiment of bombarding beryllium with alpha particles. He received the Nobel Prize for Physics in 1935 for the discovery of the neutron. Neutron is electrically neutral so that it is not affected by Coulomb force and has strong penetrability. Neutron is difficult to be directly measured by detectors, neutron detectors rely upon a conversion process where an incident neutron interacts with a nucleus to produce a secondary charged particle. These charged particles are then directly detected and from them the presence of neutrons is deduced. The measurement of neutrons is important for the aerospace industry, nuclear security, industrial production, basic scientific research, and radiation medicine. Commonly used neutron detectors include scintillator detectors, semiconductor detectors, gas ionization detectors, thermoluminescence detectors, and self-sufficient energy detectors. Many countries have conducted in-depth research on these neutron detectors.

## 2 Research Status of Neutron Detectors

### *2.1 scintillator detectors*

Scintillation detectors are mainly composed of different types of scintillators and photomultiplier tubes. Currently scintillation detections are one of the most widely used ionizing radiation detectors. The scintillators used for neutron detection include organic scintillators and inorganic scintillators. Organic scintillators have high neutron detection efficiency and fast time response, while inorganic scintillators have the characteristics of small size and good scintillation performance.

Among the inorganic scintillators, the 6LiF/ZnS(Ag) scintillator has a high luminous efficiency, which is about three times that of anthracene crystals. 6LiF/ZnS(Ag) scintillator has good n-γ discrimination ability, so it can be used under certain gamma background. However, 6LiF/ZnS(Ag) cannot be prepared as a single crystal, and can only be prepared as a mixture using organic binder, so the optical performance of the scintillator is low. LiI(U) scintillator has high light yield, but it has the disadvantage of deliquescence.

Among the organic scintillators, ST451 liquid scintillator uses xylene as the solution and PPO and POPOP as the first and second luminescent substances. It is a general-purpose plastic scintillator with high luminous efficiency, good scintillation decay time and High light transmission performance, but its n-γ discrimination ability is weak.

The current research on scintillator neutron detectors, on the one hand, is to develop new neutron scintillators with higher performance, and on the other hand, to improve the n-γ discrimination ability of scintillators because scintillators are very sensitive to gamma rays. Commonly used n-γ discrimination methods include pulse slope method, charge comparison method and vector projection method. It is also necessary to find new methods to improve the n-γ discrimination performance of scintillators.

### *2.2 semiconductor detector*

The semiconductor detector uses semiconductor material as the detection medium. The detection principle of the semiconductor detector is that charged particles enter the sensitive volume of the semiconductor detector to generate electron-hole pairs, and the electron-hole pairs drift under the action of an external electric field to output signals. Semiconductor detectors have the characteristics of high energy resolution and wide linear range. When a semiconductor detector is used to measure neutrons, the neutrons first enter the thin film layer made of the neutron-reactive material to react to generate charged particles, and the charged particles then enter the semiconductor material to generate a signal.

Traditional semiconductor detectors such as high-purity germanium detectors have high requirements on the working environment, poor radiation resistance, and require low temperature conditions. Therefore, the detectors need to be equipped with liquid nitrogen or other cooling systems, resulting in poor portability of the detectors. The research of new semiconductor detectors needs to solve the problems of poor radiation resistance and low temperature conditions, so it is necessary to find semiconductor materials that are resistant to high temperature and radiation. New semiconductor materials currently under study include diamond semiconductor, silicon carbide semiconductor, gallium nitride semiconductor, etc.

Diamond semiconductor has high carrier mobility, high breakdown electric field, low dielectric constant, high thermal conductivity and high melting point. Due to these excellent properties, diamond is considered the ultimate material in next-generation electronic devices. Over the past decade, diamond growth techniques have improved, and synthetic diamonds have come close to natural diamonds. Doping-controlled p-type, n-type diamond, and intrinsic diamond growth techniques are also maturing. The stable physical and chemical properties and high hardness of diamond make it very difficult to process the diamond microstructure. To improve the performance of diamond semiconductors, further research on the crystal structure is required.

### *2.3 Gas ionization detector*

Gas ionization detectors refer to radiation detection that uses gas as the detection medium. The main principle is that the ray ionizes the working gas in the detector, and then collects the generated electric charge to detect the ray. Gas neutron detectors have the advantages of simple manufacture, strong radiation resistance and high detection efficiency. Gas neutron detectors include $BF_3$ proportional counters, $^3He$ proportional counters and boron-coated proportional counters.

The $BF_3$ proportional counter was the first neutron detector to be used. Its working principle is that the neutrons enter the $BF_3$ proportional counter and undergo a nuclear reaction with $^{10}B$ to generate secondary charged particles. Under the action of the electric field, the charged particles are amplified by the gas and output the pulse signal, so as to obtain the neutron incident information. The fluoride ion in $BF_3$ gas is highly toxic and corrosive, and if there is leakage, it will cause serious harm to the environment and personnel. Therefore, the use and storage of $BF_3$ need to be strictly controlled, so $BF_3$ gas is rarely used in current neutron detectors.

The 3He proportional counter was invented in the 1960s with the discovery of the 3He gas. The proportional counter tube is filled with 3He gas, and the tube body is cylindrical and the centre of the tube is a metal anode wire. The 3He proportional counter is the most widely used neutron detector today. However, there is a shortage of 3He gas resources, resulting in a much smaller supply than demand. The current world supply of 3He comes entirely from the decay of tritium originating in the nuclear weapons programs in the United States and Russia. Neutron detectors have been the major consumers of 3He for the last few decades. There is a great need to build alternatives that address the needs of the neutron scattering science and a variety of 3He alternatives are studied to meet different needs.

In the field of gas detectors, boron-coated neutron detectors have become a hot research topic in various countries. Boron-lined proportional counters are a direct physical replacement for a 3He tube and avoid the hazardous characteristic of BF3. The tubes use an inert atmosphere proportional gas and have good gamma ray rejection capability. Tubes vary in size between a few millimeters (straw tubes) to several centimeters in diameter and may have position sensitivity for neutron scattering science applications.

### *2.4 Thermoluminescence detector*

Thermoluminescence dosimeters use the principle of thermoluminescence to record radiation doses. The thermoluminescence dosimeter is exposed to radiation in the radiation field first, and then the dosimeter is heated, and the intensity of the emitted light is proportional to the irradiated energy. This can then be used to measure neutron dose. Its advantages are small size, good portability and low price. The disadvantage is that the reading cannot be repeated, the lower limit of the dose that can be measured is high and the uncertainty is large.

### *2.5 self-sufficient energy detectors*

Self-sufficient energy detectors are mainly used for the measurement of neutron flux rates in nuclear reactors. They have the advantages of simple structure, strong radiation resistance and long service life. To cope with the environment of high temperature, high pressure and strong radiation field in the core of a nuclear reactor, further research on the radiation resistance, stability and measurement accuracy of self-sufficient energy detectors is required.

### *3.1 conclusions*

At present, neutron detectors are mainly used in low-energy physics, reactor monitoring and neutron source exploration. With the development of science and technology, neutron detectors will face more high-energy physics, strong radiation fields and space environments in the future. . Neutron detectors developed in the future need to meet the needs of detection in the moon, Mars and other environments, and help human space exploration. Future neutron detectors should be portable, economical and able to adapt to the harsh environment of space.