A Commercial Single Bonner Ball Neutron Energy Spectrometer

TAKUYA KIMURA*1 HIROCHIKA MURASE*1
ICHIRO AWAYA*2 SHUNJI TAKAGI*3
TOMOJI HIRATA*4 KIYOMITSU KAWACHI*4

The neutron Bonner Ball spectrometer, which measures the relatively low-energy neutron spectrum from thermal neutrons to 15 MeV, was installed on Space Shuttle Endeavour in 1998. In 2001, it was Japan's first installed instruments on space station. Mitsubishi Heavy Industries, Ltd. (MHI) is now developing a single-sphere-type spectrometer, which will be smaller than the conventional multi-sphere device. In the future, MHI aims to widen its application range to the aeronautical and nuclear fields.

1. Introduction

On a space station, the natural radiation is at least several hundred times higher than on Earth. Neutron energy spectrometry, which evaluates the effects of secondary neutrons generated in the space station walls on astronauts, has therefore been an important subject in astronautics.

Similar measurements are now believed to be needed in airplanes during high-altitude flights (including commercial airplanes), as well as in the surroundings of nuclear facilities. For example, the Nuclear Safety Technology Center, under the direction of the Ministry of Education, Culture, Sports, Science and Technology-Japan, is researching a portable device to evaluate the neutron dose of the surrounding environment following a neutron-generating accident.

MHI is now developing a single-sphere-type spectrometer, which will be smaller than the conventional multi-sphere type Bonner Ball neutron measuring device. It has achieved this by using only one ball and incorporating a position-sensitive proportional counter (PSPC).

2. Development of the measuring device

2.1 Outline of the neutron spectrometer

Neutron beams have a strong penetrating power and can damage DNA when they hit the human body. Therefore, they have deleterious effect on health in a manner similar to other radioactive materials. Accordingly, neutron monitoring is important for the health of astronauts in the space shuttle and space station. Similarly, on Earth, measuring the neutron environment may be important, depending on the location. Thus, the technology developed in space can likely be used for commercial purposes.

Neutron spectrum measuring devices can be roughly classified into two types: those that use moderators and those that use scintillators. The former are applied for measuring low energy levels [thermal neutrons (0.025 eV) to approximately 15 MeV], and the latter for high energy levels (approximately 10 to 100 MeV).

The Bonner Ball is a typical moderator-type method. It determines the neutron energy distribution using one position-sensitive proportional counter (PSPC) on an axis through the center of the spherical Bonner Ball. It measures the difference in the energy response functions of neutrons that reach different depths in the moderator (**Fig. 1**).

Polyethylene is used for the Bonner Ball, and a mixed gas of ^{3}He and CF_4 is used for the PSPC. To decrease the total size of the device, the Bonner Ball diameter was reduced to 23 cm. This value was chosen by evaluating the linear independence of the response function.

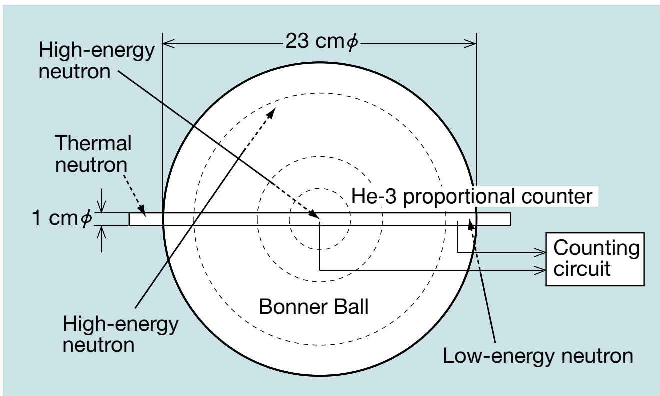

Fig. 1 Measurement principle of a single-sphere-type Bonner Ball detector

*1 Kobe Shipyard & Machinery Works
*2 Nagoya Research & Development Center, Technical Headquarters
*3 Mitsubishi Research Institute, Inc.
*4 Nuclear Safety Technology Center

The charged particles generated in the PSPC generate electrons by ionizing ^{3}He and CF_4. These electrons move to the (anode) core wire and are collected, causing an electron avalanche. In addition, the location where the electrons are collected on the core wire is almost the same as the center of gravity of the electric charge distribution due to ionization. Thus, a charge division method was adopted for the new detector, which determined the location from the charge measured at both ends of the core wire. Because the PSPC could detect the location at which the sensitivity was highest, the conventional multi-sphere (number of spheres: 6) could be replaced by a single sphere (number of spheres: 1), allowing downsizing. The conventional multi-sphere device size was 483 mm × 493 mm × 715 mm, while the new single-sphere device size is expected to be 320 mm × 350 mm × 320 mm.

2.2 Composition of the neutron spectrum measuring device

The device consists of the detector and the circuit, which are designed to conform to the following standards:
JIS D 1601 (Vibration testing methods for automobile parts), equivalent to Type 3B [stage of 45, static acceleration of 70 (m/s^2)].
JIS Z0302-1995 (Waterproof packaging), equivalent to Type 2B (water spray test for 5 minutes).

The signals detected from the right and left sides of the detector are amplified in the circuit, and the location at which the sensitivity is strongest is detected as a voltage ratio (**Fig. 2**). The device is contained in two enclosures and transported to the site ("outdoor site" is assumed) in a car. Then, the device is distributed and used for measurement.

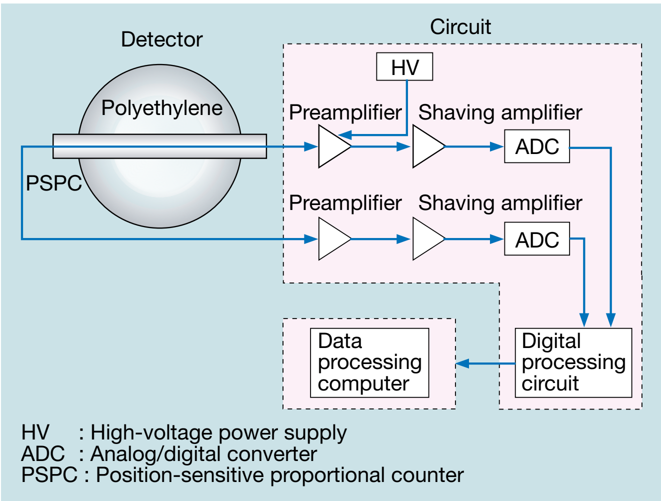

Fig. 2 Composition blocks

2.3 Features of the respective parts

(1) Detector

The detector (**Fig. 3**) consists of the PSPC and polyethylene moderator sphere. The PSPC is of a SUS304 cylindrical shape (**Fig. 4**), with a diameter of 10 mm, sensitive portion of 276 mm, and thickness of 0.5 mm. The core wire is Nichrome, with a diameter of 15 μm and a high electric resistance to enhance the location detection accuracy. A vibration resistance specification was adopted by consideration of the linear

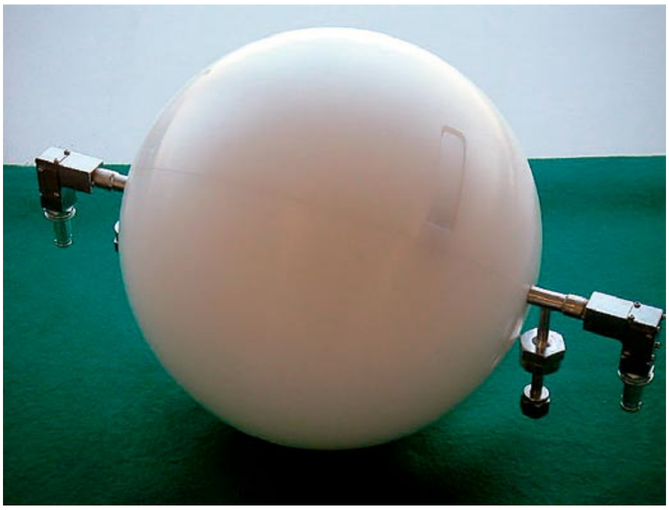

Fig. 3 Detector

Fig. 4 PSPC

The analysis model uses axial symmetry.
Modeling was performed in the vicinity of the field tube.

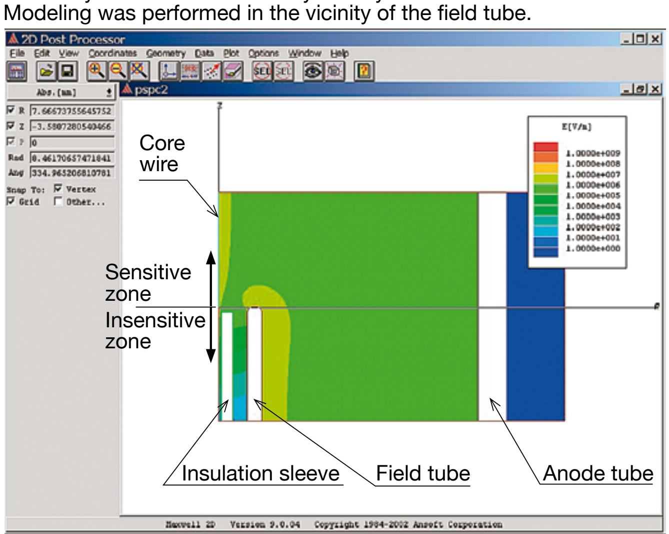

Fig. 5 Analysis of the electric field in the proportional counter (applied voltage of 2 kV)

thermal expansion. Furthermore, a shape to avoid local concentration of the electric field was adopted for the PSPC detector, especially at its ends, in accordance with the electric field analysis by Maxwell-2D (**Fig. 5**). This prevented the electron avalanche from occurring at locations other than the sensitive region. The moderator is a 230-mm-diameter sphere and is covered by a 0.5-mm-thick cadmium cylinder to remove the effect of thermal neutrons.

(2) Circuit

The circuit consists of a preamplifier, high-voltage power supply, input processing circuit, analog/digital (A/D) converter, and digital processing circuit. It has an interface for a personal computer. Further downsizing was achieved by adopting a hybrid integrated circuit (IC) with actual experience of amplifiers and board-mounting high-voltage power supplies, realizing the digital processing circuit in one chip and integrating the whole circuit into one circuit board.

(3) Enclosures

Enclosure 1 (**Fig. 6**) contains the detector, preamplifier, and high-voltage power supply, and enclosure 2 contains the main circuit and battery. The motivation for this distribution into two enclosures is to eliminate the shielding effect by the circuit and battery, and the effect of the scattered radiation. Anti-humidity measures are used for both enclosures to protect the detector and the circuit. The weight of the whole device, including both enclosure 1 and enclosure 2, is approximately 22 kg, which causes no problems during transportation.

Fig. 6 Enclosure 1

2.4 Calibration by a standard field

After manufacturing, this device was subjected to a standard calibration test using the thermal neutron standard field and the monochromatic fast neutron standard field (144 keV, 565 keV, and 5 MeV) of the National Institute of Advanced Industrial Science and Technology, to determine its fundamental sensitivity characteristics. We are currently verifying the neutron field by assuming the surrounding environments of nuclear facilities.

3. Conclusion

We manufactured a new neutron spectrometer using a single-sphere variation on the conventional multi-sphere Bonner Ball device. It is designed for commercial use in aeronautics and the nuclear industry, in addition to applications on the space station and in possible future lunar exploration.

We are grateful for discussions with Dr. Osamu Sato, Chief Researcher and Dr. Satoshi Iwai, Chief Specialist Researcher of Mitsubishi Research Institute, Inc., and Mr. Hideki Harano and Mr. Tetsuro Matsumoto of National Institute of Advanced Industrial Science and Technology, Professor Akira Uritani (Nagoya University) and Emeritus Professor Chizuo Mori (Nagoya University), all of whom gave us guidance.

This research was supported by the "Survey of Total Support System of Countermeasures during Emergency" in FY 2005, which was performed by the Nuclear Safety Technology Center as an entrusted project from the Ministry of Education, Culture, Sports, Science and Technology, based on the former Special Account for Power Sources Development.

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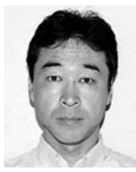
Takuya Kimura

Hirochika Murase



Ichiro Awaya

Shunji Takagi

Tomoji Hirata

Kiyomitsu Kawachi