RESEARCH AND DEVELOPMENT ACTIVITIES OF A NEUTRON GENERATOR FACILITY

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Abstract

The neutron generator facility at YNRC is used for elemental analysis, nuclear data measurement and education. In nuclear data measurement the focus is on re-evaluating the existing scattered nuclear activation cross-section to obtain systematic data for nuclear reactions such as (n,p), (n,α), and (n,2n). In elemental analysis it is used for analyzing the Nitrogen (N), Phosphor (P) and Potassium (K) contents in chemical and natural fertilizers (compost), protein in rice, soybean, and corn and pollution level in rivers. The neutron generator is also used for education and training of BATAN staff and university students. The facility can also produce neutron generator components.

1. INTRODUCTION

Neutron generator facility at Yogyakarta Nuclear Research Center (YNRC) has three main activities. First activity is R & D in the utilization of the neutron generator for nuclear data measurements, and for elemental analysis using a fast neutron activation analysis technique. Second activity is R&D in technological development and fabrication of neutron generator components. Third activity is a training of BATAN staff and education of students from many universities around Java and Sumatra island. The neutron generator facility has been optimally used since 1990. This manuscript will describe detail activities in the neutron generator facility at YNRC.

The utilization of neutron generators is nowadays common not only in nuclear physics but also in other fields like chemistry, biology, metallurgy, geology, radiotherapy, and in the industry [1,2]. During the last decade, nuclear data measurements using a neutron generator has been carried out for fusion, radiation damage, geophysics and dosimetry applications. In chemistry, neutron generators have been used for analysis of chemical products. The fast neutron activation method has also been used to determine protein content, air and water pollution. In metallurgy, neutron generators have been used to determine oxygen and silicon content in stainless steel [1]. In geology neutron generators has been used to determine the content of minerals such as bauxite, manganese, and copper [1].

Based on the BATAN's program, for the peaceful use of nuclear technology for prosperity, one of the duties of Yogyakarta Nuclear Research Center (YNRC) is to get acquainted with accelerator technology and applications. Research and development of an accelerator at YNRC was started in 1983, in the beginning of Pelita IV (the fourth year of the five year development program), 1983–1988. The construction of two accelerators was started during this Pelita; one was an ion implanter and the other one was a neutron generator. These accelerators were basically ready in the middle of Pelita V (1988–1993). However, they are still in need of improvements in order to use them for Research and Development (R&D) and applications.

During Pelita IV, YNRC got a neutron generator from the Isotope and Radiation Application Research Center, one of the BATAN's institutes. In fact, this neutron generator was a grant from IAEA in 1977. The neutron generator is of the type J 25 made by SAMES/France. The SAMES neutron generator was out of order at that time, and it was transported to YNRC at the end of 1987. After about one year of maintenance and repair of the vacuum and high voltage components, this accelerator became a useful tool in the Research and Development (R&D) related to the utilization of neutron generators.

The R&D by the neutron generator have been carried out in Nuclear Physics group of YNRC. The R&D activities can be divided in two subgroups. The first group is doing R & D in nuclear data measurements and a fast neutron activation analysis based on the utilization of neutron generators. This group usually uses the SAMES neutron generator. The second group works on the technological development and manufacture of neutron generator components. These programs are carried out by 1 PhD, 4 MSc, and 6 BSc in physics as well as by 10 electrical and mechanical technicians. A couple of the team has been trained at Jülich Nuclear Research Center, Bhaba Atomic Research Center, Efremov Accelerator Research Center, Institute of Experimental Physics Kossuth University, etc.

The neutron generator facility was also used for the training of BATAN staff and in the education of students from many universities around the Java and Sumatra islands such as: Gadjah Mada University (UGM), Surabaya Technology Institute (ITS), Diponegoro University (UNDIP), Brawijaya University (UNBRAW), Riau University (UNRI), and North Sumatra, University (USU). More than 20 S-1 (bachelor degree) theses have been written using results obtained at the neutron generator facility.

This paper describes some parts of the research and development activities of the neutron generator facility at YNRC. Firstly, it describes the construction of neutron generator components. Secondly it described the utilization of the neutron generator, thirdly the progress and future R&D on neutron generators, and finally different topics related to the neutron generator facility.

2. CONSTRUCTION OF NEUTRON GENERATOR COMPONENTS

This program started in 1983 in the beginning of Pelita IV. The aim of this program was to establish the manufacturing technology of neutron generator components. This group works on the development and construction of neutron generator components. After two Pelita, the construction of a homemade neutron ,generator was finished. We called it a homemade neutron generator as most of its components are home made except the vacuum pump and the tritium target. This machine consists of a radio frequency deuteron ion source, a high voltage Cockroft-Walton terminal, an accelerator tube, an electrostatic quadrupole lens, a tritium target, and a vacuum system. The scheme of this machine is shown in Fig. 1.

2.1 Ion source

An RF ion source has been developed and constructed. This ion source [3, 4] is basically similar to the Oak Ridge design. This radio frequency ion source consists of a bottle of Pyrex glass 215 mm long and 30 mm in diameter, with a 1.5 mm in diameter and 6 mm long extraction channel.

The ion source can produce a relatively high deuteron ion beam current. At an optimum condition, the radio frequency ion source yields deuteron ion beam current of 2.5 mA. This was achieved at the operating conditions of: 10^{-2} mm of Hg gas working pressure in the Pyrex tube, 50 MHz working frequency, 740 gauss magnetic field, 7 kV extractor voltage and 70 watt total RF energy of oscillator power. The function of deuteron ion beam current vs. the extractor voltage, the input energy of oscillator and the magnetic field are shown in the Figures 2, 3 and 4.

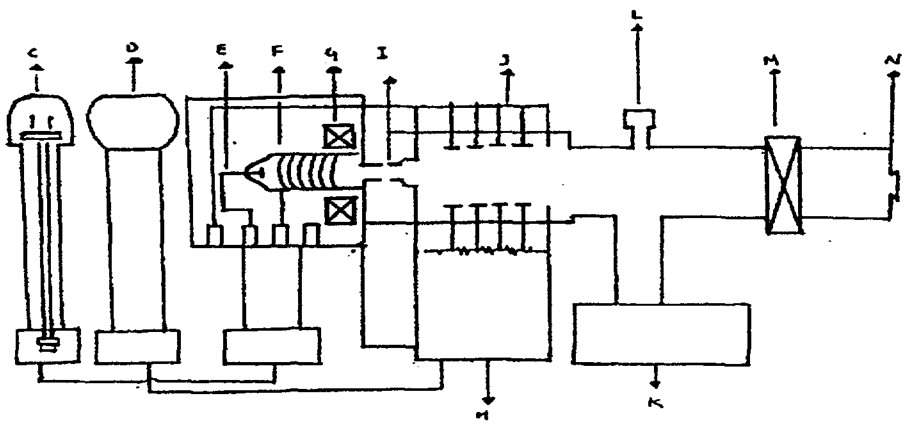

Figure 1. The scheme of the homemade neutron generator Notes: C = insulated power supply, D = HV Cockroft Walton, E = Extraction Voltage, F = RF source, G = Magnet, H = Resistors, I = Beam focusing, J = Accelerator, K = Vacuum pump, L = Vacuum meter, M = Electric Quadrupole Lens, N = TiT target.

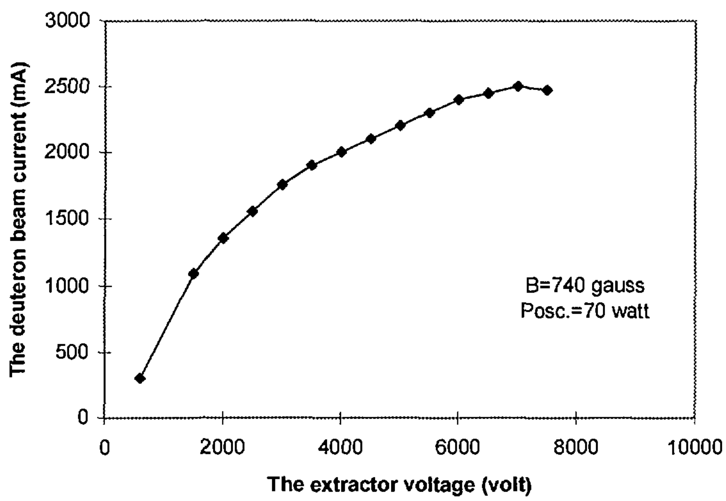

Figure 2. The function of RF ion source output vs. extractor voltage.

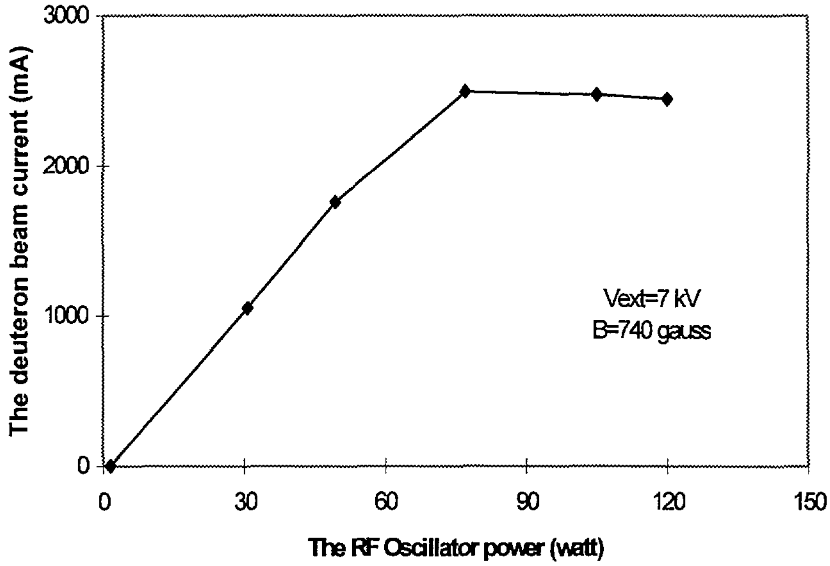

Figure 3. The RF ion source output vs. the RF power.

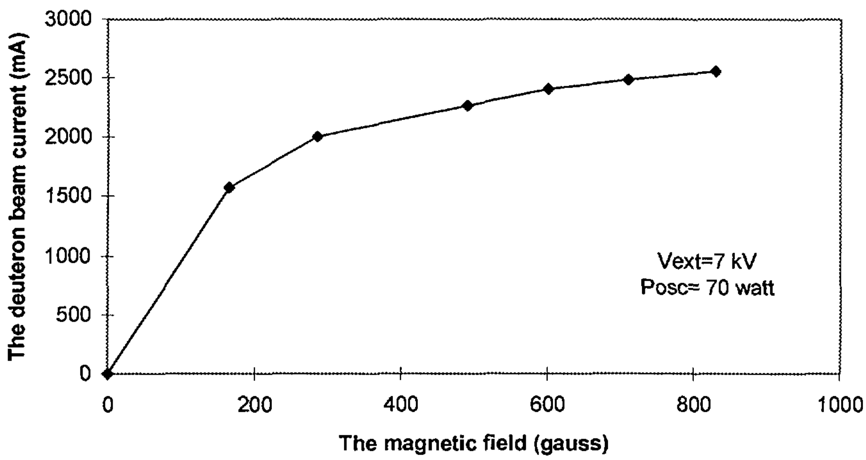

Figure 4. The RF ion source output vs. the magnetic field.

2.2 High voltage Cockroft Walton generator

A 7-stage high voltage Cockroft Walton generator [5, 6, 7] was constructed for the neutron generator using 20 kV/1A high voltage diodes, 0.28 μF/30 kV high voltage capacitors and stainless steel ring electrodes of 82 cm diameter. The dimension of this generator is 70 cm x 80 cm x 190 cm (LWH). The homemade high voltage Cockroft Walton generator supplies the acceleration tube up to 150 kV at a load current of 5 mA. However, the high voltage power supply can not operate at maximum output voltage due to some problems related to the accelerator tube. This generator operates at 125 kV and 3 mA. Recently, the HV power supply has been stabilized by completing the Cockroft Walton generator circuit with a closed loop feedback control system. The main components used for voltage stabilization are a resistor divider as an output sensor; an integrated circuit comparator and a brush motor to control the output of the power supply source. Now, high voltage power supply has a good stability in the load current range of 0 to 5 mA around an output voltage of 130 kV as shown in the Figure 5.

The output high voltage vs. input mains voltage (home electricity) and load currents are shown in Figures 5 and 6.

2.3 Power supplies

To supply the RF oscillator, the beam extracting and focusing systems as well as other equipment located on the high voltage terminal, an insulated motor generator is used [6, 7]. The generator is operating with 1500 rpm, 220 Volt giving 3 kW output power. It is supported by a 30 cm diameter and 1.5 m high PVC tube, and connected to the motor by a PVC rod of 10 cm diameter. The input signal to the Cockroft Walton HV generator is 1 kHz generating a 500 watt output square waves. The power supplies located on the high voltage terminal are controlled by PVC rods rotated by electrical motors on ground potential. The same method is used for controlling the gas inflow to the ion source

2.4 Acceleration tube

The homemade multigap accelerator tube is made of Plexiglas and 20 stainless steel electrodes. These electrodes were glued by using special epoxy. The diameter of the accelerator tube is 100 mm. The diameter of the inner electrode is 60 mm and this electrode

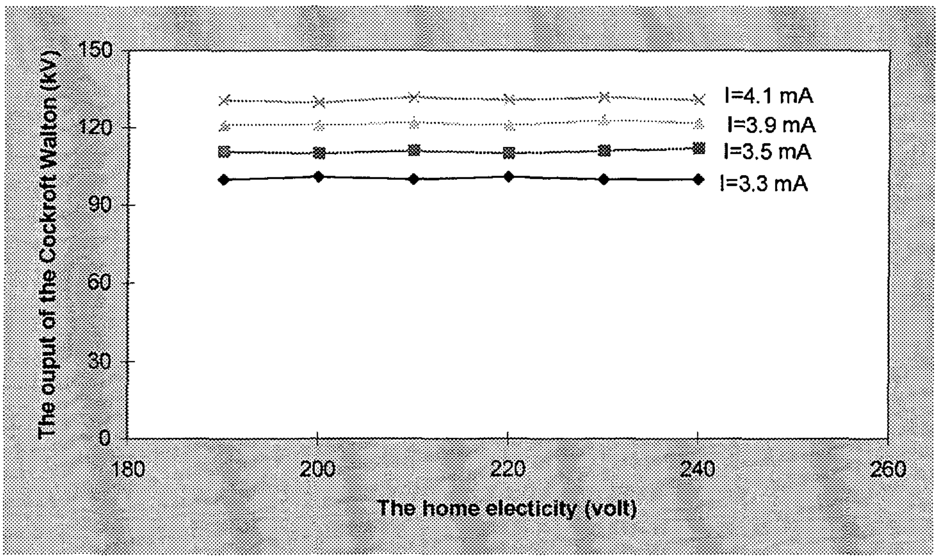

Figure 5. The output of Cockroft Walton HV PS vs. mains voltage.

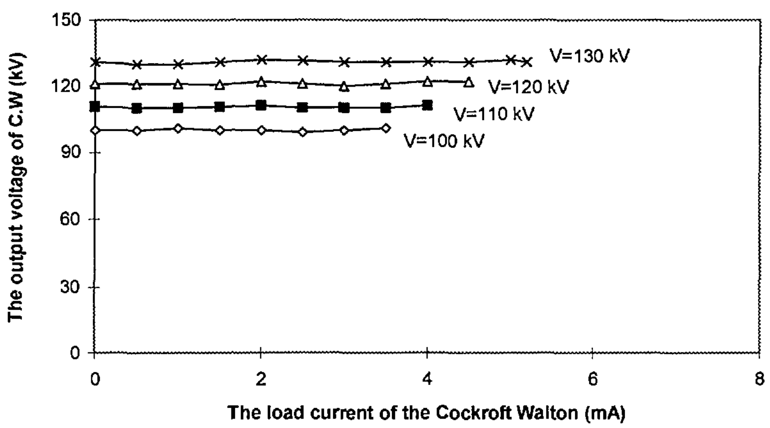

Figure 6. The output voltage of Cockroft Walton HV PS vs. load current.

can yield a high gradient electric field. The gap between the electrodes is 5 cm. The accelerator tube can operate only up to 130 kV and 1.5 mA of deuteron beam current due to the heat produced on the electrodes. This heat can crack the accelerator tube, so during operation, the accelerator tube should be cooled. We have difficulties to get aluminum or ceramic rings to replace the Plexiglas in order to increase the operating voltage of the accelerator tube.

2.5 Electric quadrupole lens

The quadrupole lens [8] consists of four perpendicularly crossed hyperbolical electrodes. Each of the electrode pairs are connected to a positive and a negative voltage regulated between 0 and ±30kV. The size of the quadrupole lens unit is 100 mm in diameter and 170 mm long. The lens electrodes are 45 mm long and 25 mm wide. The lense can focus a deuteron ion beam on a tritium target of 2–3 cm in diameter.

2.6 Ion beam current measurement

A Faraday cup consisting of collectors, feedthrough and current meters measures the ion beam current. The Faraday cup is made of copper with a plate diameter of 4 cm.

2.7 Vacuum system and tritium target

The vacuum system is using a rotary pump and a turbomolecular pump bought from EDWARD VACUUM Company providing vacuum up to 10^{-6} mm of Hg. Tritium targets in the form of TiT are procured from USA.

3. THE UTILIZATION OF THE NEUTRON GENERATOR

The YNRC, neutron generator group also carries out research in the field of nuclear data measurements and neutron activation analysis. This group is using the French neutron generator SAMES J 25 granted by the IAEA. This machine produces a fast 14.7 MeV neutron flux in the order of 10^9 n/cm^{2}sec at optimum conditions. At present, the application of this neutron generator is focused on nuclear data measurement related to the re-evaluation of scattered neutrons, nuclear activation cross-section with the aim to get more systematic data for a certain nuclear reactions such as (n,p), (n,α), and (n,2n). We have also done a lot research related to neutron activation analysis i.e. analyzing Nitrogen (N), Phosphor (P), and Potassium (K) in chemical and natural fertilizers (compost), analyzing protein in rice, soybean and corn as well as analyzing the pollution level in city rivers.

3.1 Analysis of protein content in rice and soybean

The nuclear method [9, 10] was introduced to the users especially to the agriculture researchers as an alternative method. They usually use a chemical procedure, the so-called Keydall method for determination of protein content. The nuclear method has advantages over the chemical method. The nuclear method can be used for destructive as well as nondestructive analysis but the chemical method is always destructive. In this work the ^{14}N(n,2n)^{13}N reaction was used. The activation time was 30 minutes; the cooling time was 3 minutes and the counting time was 30 minutes. Using the gamma peak of 511 keV from (n, 2n) reaction and the relative method, the protein content in rice was found to be 6.51±0.03% of sample weight. The protein content in white, yellow, black, and green soybeans are respectively 28.9%, 29.5%, 24.12%, and 29.5% of sample weight. They are in agreement with the data obtained by the Directorate of Nutrition of the Department of Health.

3.2 Measurement of phosphorus content in TSP and NPK

In this work [11] the $^{31}P(n,\alpha)^{28}Al$ reaction was used. By using the gamma peak of 1778.34 keV from the (n,α) reaction and relative method, the phosphorus content was found to be 20±1% of sample weight in TSP and 6.5±0.6% of sample weight in NPK. These data were in agreement with the data given by the manufacturer, i.e. 20.1% for TSP and 6.5 % for NPK.

3.3 Nuclear data measurements

Our neutron generator has been used for reaction cross-section measurements mostly as preliminary research. We have developed a method for cross-section measurements using a two-detector technique [12]. In this technique, the activated sample is simultaneously measured by two gamma detectors, and the reaction cross-section is derived from gamma ray counts obtained by the two detector system. Experimental results show that the two detector technique provides a better accuracy than a one detector system. Some major elements for fusion reactor materials such as Mg, Si, V, Fe, Cu and In have been tested using the two detector technique. The results were compared with other from the literature and found to be in good agreement, as is shown in Table 1. [12,13].

TABLE 1: COMPARISON BETWEEN NEUTRON CROSS SECTIONS MEASURED BY ONE AND TWO DETECTORS (HPGE AND NAI[TL]) METHOD AND THE REFERENCE VALUES.

Reaction	Cross Section (millibarn)					
	Measured values *			Reference values **		
	HPGe	NaI (Tl)	HPGe & NaI(Tl)	1	2	3
Mg-26(n,α)Ne-23	93.33±3.49	88.78±9.90	91.06±5.25	89.0	84.0±10	77.0±8
Mg-25(n,p)Na-25	56.60±3.17	51.85±8.67	54.23±4.61	44.9	49.0±20	44.0±5
Si-29(n,p)Al-29	105.60±4.40	103.74±3.66	104.67±2.86	100.0	120.0±20	120.0±20
Si-28(n,p)Al-28	240.53±9.76	240.80±6.61	240.66±5.89	235.0	250.0±30	230.0±30
V-51(n,p)Ti-51	27.71±1.18	27.45±1.12	27.58±0.81	27.0	35.0±5	35.5±5
V-51(n,α)Sc-48	17.65±0.74	17.65±0.63	17.65±0.48	-	15.0±2	17.0±3
Fe-54(n,2n)Fe-53g	17.08±0.54	15.18±0.63	16.13±0.42	15	10.5±1	15.5±1
Fe-56(n,p)Mn-56	109.17±3.47	113.44±4.61	111.31±2.89	103.0	112.0±6	103.0±6
Cu-65(n,2n)Cu-64	1057.37±29.26	1057.11±24.90	1057.24±19.21	1100.0	913.0±50	956.0±50
Zr-90(n,α)Sr-87	196.22±17.47	193.82±6.93	195.02±9.40	194.0	112 ±0.3	120±40
Zr-90(n,2n)Zr-89	778.19±47.15	787.15±22.29	782.67±26.08	770.0	740.0±3	714±50

*) Abdurrouf [13]

**) 1. S.S Nargolwalla, et al [2]

2. M. Bormann, et al, "Table and Cross Section for (n,p), (n,α), (n, 2n) Reaction in the Energy Region of 1 – 37 MeV", Handbook of Nuclear Cross Section, IAEA Report-156, Vienna, p.87–272, 1974.

3. G. Erdtman, "Neutron Activation Table", Weinheim Verlag Chemie, New York, 1976

4. PROGRESS AND FUTURE R&D ON THE NEUTRON GENERATOR

Recently we finished the set up of the fast neutron spectrometer by using the pulse shape discrimination (PSD) method. In this method the neutron field was measured by using liquid scintillator NE-213, the neutron (corresponding to the proton) and the gamma (corresponding to the electron) pulses were discriminated by using a pulse shape analyzer (PSA). The neutron flux was obtained by unfolding of the proton spectrum.

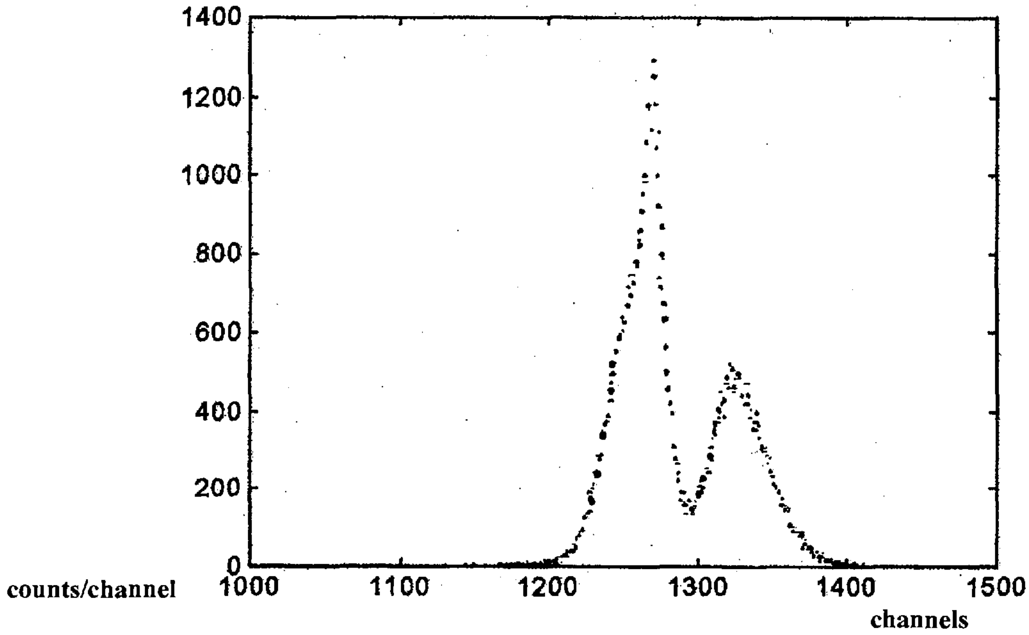

Figure 7 The neutron gamma PSD spectrum from the PHR neutron spectrometer.

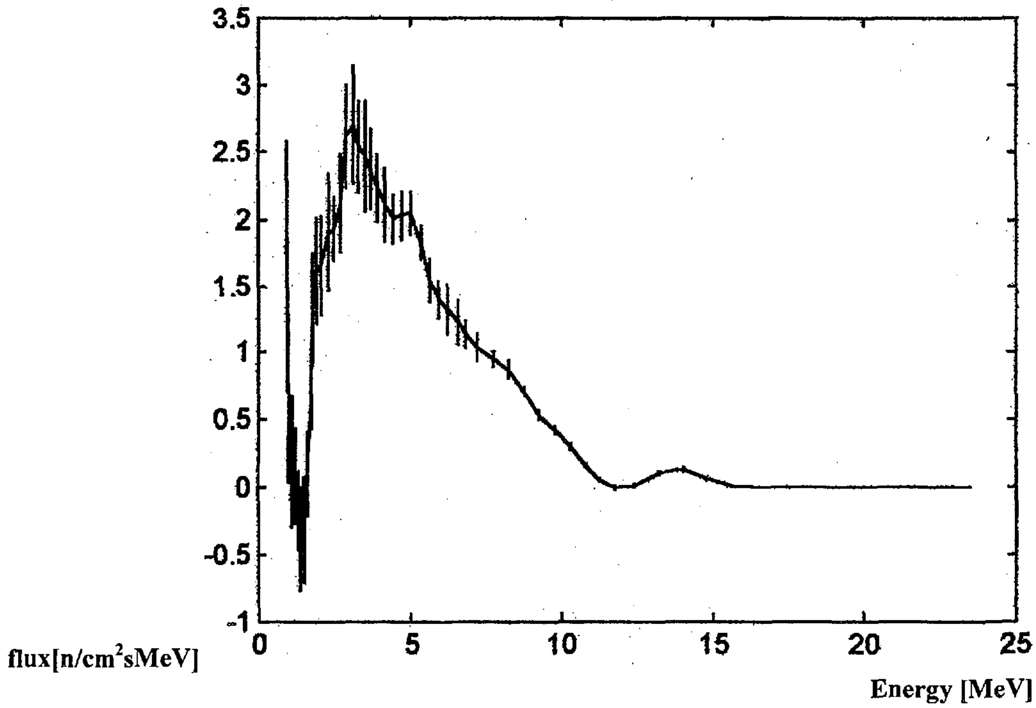

Figure 8. The neutron spectrum of AmBe measured by PSD method.

This setup was tested using an AmBe neutron source with the activity of 10^3 n/s. The output pulse height distribution of the neutron spectrometer is shown in Figures 7 and 8 [14]. This measurement was carried out in normal condition (not in a neutron scattering free) laboratory. The systematic data of the (n,α) reactions were evaluated [15]. The data were determined using the neutron activation method and our results are shown in Figure 9. Combined fast and thermal neutron activation analysis has been applied to identify Fe, Mg, and N elements in downy mildew corn leaves (Sterospora maydis R. Butler) [16]

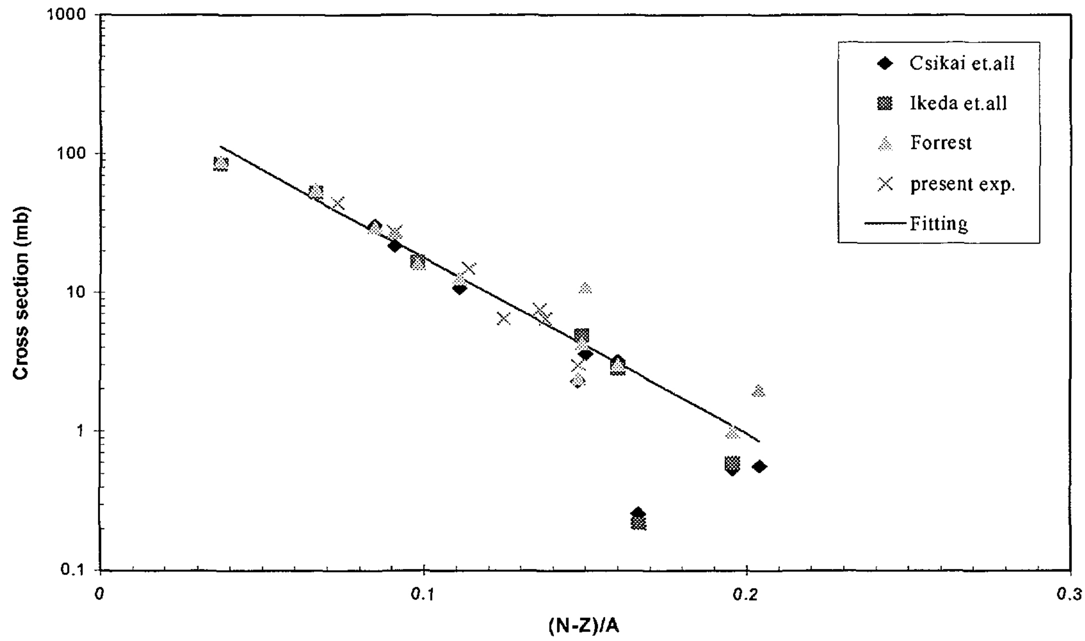

Figure 9: Dependence of (n,a) cross sections on (N-Z)/A asymetry parameter

Fast neutron activation analysis was used to determine the nitrogen content, and thermal neutron activation analysis was used to determine the Fe and Mg contents. Normal corn leaves and downy mildew corn leave were irradiated and analyzed. The experimental results show that the downy mildew corn leaves contain 161.51 to 192.07 ppm of Fe, 170.75 to 272.36 ppm of Mg, and 2541.23 to 2682.61 ppm of N. The normal corn leaves contain 291.48 to 352.66 ppm of Fe, 637.37 to 705.82 ppm of Mg, and 36773.15 to 3745.66 ppm of N. The downy mildew corn leaves has a lower content of Fe, Mg, N than normal corn leaves. Thus the sterospora maydis cause the decreasing of the Fe, Mg, and N content in corn leaves.

In the future, we are going to install the prompt gamma analysis system for bulk assays using the neutron generator as the neutron source. Some instruments for this purpose are ready. However we have not yet decided, whether we are going to use the pulsed neutron source or the continuous neutron source. The pulsed neutron source is better in point of the background, however we do not have a pulsing system for the neutron generator. Another work; we are going to carry out is integral data measurement on some shielding using local components. This measurement will be carried out by using the fast neutron pulse height response spectrometer and the foil activation method. The fast neutron activation analysis will routinely be used by agriculture, biology, and geology researchers.

Besides the above described topics we are also involved in nuclear physics teaching of students from many universities around our institute; supervising them in nuclear physics research related to our neutron generator.

5. MISCELLANEOUS

The neutron generator facility is also used in the training of BATAN staff and in the education of students from many universities around Java and Sumatra island such as: Gadjah Mada University (UGM), Surabaya Technology Institute (ITS), Diponegoro University (UNDIP), Brawijaya University (UNBRAW), Riau University (UNRI), and North Sumatra, University (USU). More than twenty S-1 (bachelor honors) thesis have been written in which the experiments were carried out at this neutron generator facility.

In recent years, we have difficulties in getting tritium targets (TiT) for neutron generators. The SAMES company is not delivering it. We have tried to buy it from a company in the USA but the company wants to sell more than 5 pieces of TiT.

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