POHANG NEUTRON FACILITY BASED ON 100-MeV ELECTRON LINAC *

G. N. Kim#, Y. S. Lee, and D. Son
Institute of High Energy Physics, Kyungpook National University, Taegu 702-701, Korea
H. S. Kang, M. H. Cho, I. S. Ko, and W. Namkung
Pohang Accelerator Laboratory, POSTECH, Pohang 790-784, Korea

Abstract

Pohang Neutron Facility (PNF) is a pulsed neutron facility based on the 100-MeV electron linear accelerator. It was constructed for nuclear data production in Korea, and it consists of an electron linear accelerator, a water-cooled Ta target with a water moderator and a time-of-flight path with an 11 m length. The 100-MeV electron linac uses a thermionic RF-gun, an alpha magnet, four quadrupole magnets, two SLAC-type accelerating sections, a quadrupole triplet, and a beam-analyzing magnet. In design of a water-cooled Ta target, we used the Monte Carlo simulation codes, EGS4 and MCNP version 4B. The neutron energy spectrum is measured for different water levels inside the moderator and compared with the calculation results by the Monte Carlo N-Particle (MCNP) transport code system.

1 INTRODUCTION

The nuclear data project as one of the nation-wide nuclear R&D programs was launched by the Korea Atomic Energy Research Institute (KAERI) [1]. Its main goals are to establish a nuclear data system, to construct the infrastructure for the nuclear data productions and evaluations, and to develop a highly reliable nuclear data system. The Pohang Accelerator Laboratory (PAL) proposed a pulsed neutron facility, which consists of a 100-MeV electron linac, a water-cooled Ta target, and at least three different time-of-flight (TOF) paths [2]. The 100-MeV electron linac was designed and constructed based on experiences obtained from construction and operation of the 2-GeV electron linac at PAL [3]. The nominal beam energy of the designed electron linac was 100 MeV with RF power of 80 MW, and the operating frequency was 2,856 MHz. We completed construction of a pulsed neutron facility, the Pohang Neutron Facility (PNF), on December 1999.

The PNF characteristics are described in the next section. The neutron energy spectra are measured for different water levels inside the moderator and compared with the calculation results by the Monte Carlo N-Particle (MCNP) transport code system [4].

*Work supported partly by the SRC program of KOSEF, and by KAERI
Email: gnkim@knu.ac.kr, Joint appointment at PAL, POSTECH.

2 POHANG NEUTRON FACILITY

The Pohang Neutron Facility (PNF) consists of an electron linac, a water-cooled Ta target, and an 11 m long TOF path. The electron linac consists of standard subsystems: a thermionic RF-gun, an alpha magnet, four quadrupole magnets, two SLAC-type accelerating sections, a quadrupole triplet, and a beam-analyzing magnet. A 2-m long drift space is added between the first and the second accelerating section to insert an energy compensation magnet or a beam transport magnet for other research. The overall length of the linac is about 15 m. The RF-gun is one cell cavity with a dispenser cathode of 6 mm diameter. The RF-gun produces electron beams of 1 MeV, 300 mA, and 1.5 μs [5]. The alpha magnet is used to match the longitudinal acceptance from the RF-gun to the first accelerating section. Electrons move along an alpha-shaped trajectory in the alpha magnet with the bend angle of 278.6°. Four quadrupole magnets are used to focus the electron beam in the beam transport line from the thermionic RF-gun to the first accelerating section. The quadrupole triplet installed between the first and the second accelerating sections is used to focus the electron beam during the transport to the experimental beam line at the end of the linac.

After RF-conditioning of the accelerating structures and the wave-guide network, we tested the beam acceleration [6]. The available RF power from a SLAC 5045 klystron was up to 45 MW due to the peak power limitation of the existing pulse modulator. The RF power fed to the RF-gun was 3 MW. The beam energy is 75 MeV, and the measured beam currents at the entrance of the first accelerating structure and at the end of the linac are 100 mA and 40 mA, respectively. The length of electron beam pulses is 1.5 μs, and the pulse repetition rate is 12 Hz. The diameter of electron beam is about 20 mm at the beam profile monitor in front of the target. The measured energy spread is about 1~3 %. The energy spread was reduced by adjustment of the RF phase for the RF-gun and by optimization of the magnetic field for the alpha magnet.

As a photoneutron target, it is necessary to use heavy mass material in order to produce intense neutrons by way of bremsstrahlung under high-power electron beams. We have chosen tantalum as the target material, which has advantage of high density (16.6 g/cm^3), high melting point (3,017°C), and high resistant against the corrosion by cooling water. A water-cooled Ta target was designed by the Electron Gamma Shower simulation code, EGS4 [7]. The Ta target was composed of ten Ta sheets, 49 mm in diameter and 74 mm in total length [8]. There was 1.5 mm water gap between Ta sheets in order to cool the target effectively. The target housing was made of 0.5 mm thick titanium. The calculated conversion ratio from a 100 MeV electron to neutrons was 0.032 obtained by using the EGS4. According to this result, the neutron yield per kW beam power for the electron energy above 40 MeV at the target was 2.0×10^{12} n/sec, which was about 2.5% lower than the calculated value based on the Swanson's formula, 1.21×10^{11} $Z^{0.66}$, where Z is the atomic number of the target material and the electron energy is above 40 MeV [9].

Since we have to utilize space and infrastructure at PAL, an 11 m long TOF path and a detector room were constructed vertically to the electron linac. The TOF tubes were made by stainless steel with two different diameters of 15 and 20 cm.

3 PHOTONEUTRON SPECTRA

3.1 Experimental Arrangement

The experimental setup for the neutron TOF spectrum measurement is shown in Fig. 1. The target is located at a position where the electron beam hits the target center, and the target is aligned vertically with the center of the TOF tube. This target was set at the center of a water moderator made by using an aluminum cylinder with a thickness of 0.5 cm, a diameter of 30 cm and a height of 30 cm. A Pb block, 20 cm × 20 cm in area by 10 cm in thickness, was placed at the entrance of 15 cm diameter TOF tube to reduce the gamma flash generated by the electron burst from the target and scattered high-energy neutrons. In addition, a 0.5 cm thick Pb plate was attached in front of the TOF tube. There is 1.8 m thick concrete between the target room and the detector room. The sample was placed at the midpoint of the TOF path.

As a neutron detector, we used a ^{6}Li-ZnS(Ag) scintillator BC702 with a diameter of 12.5 cm and a thickness of 1.5 cm mounted on an EMI-93090 photomultiplier. It was located at a distance of 10.8 m from the photoneutron target. The neutron detector was shielded by lead bricks and borated polyethylene plates.

In order to monitor the neutron intensity during the experiment, a BF3 proportional counter with a diameter of 1.6 cm and a length of 5.8 cm was placed in the target room at a distance of about 6 m from the target. The BF3 counter was inserted in a polyethylene sphere with a diameter of 30.5 cm and surrounded by borated polyethylene with a thickness of 5 cm and Pb bricks with a thickness of 10 cm to shield thermal neutrons generated from the moderator and walls inside the target room and to protect gamma flash generated by the electron burst from the target.

During the experiment, the electron linac was operated with a repetition rate of 12 Hz, a pulse width of 1.5 μs, a peak current of 30 mA, and electron energy of 60 MeV.

3.2 Data Acquisition System

The block diagram of the data acquisition system is also shown in Fig. 1. The TOF signal from signal from a ^{6}Li-ZnS(Ag) scintillator was connected to an amplifier system (ORTEC-113 pre-amplifier and ORTEC-571 amplifier). The amplifier output was then fed as a discriminator (Disc.) input, whose output was used as a stop signal of a 150 MHz time-digitizer (Turbo MCS). The lower threshold level of the discriminator was set to 30 mV. The Turbo MCS was operated as a 16384-channel time analyzer. The channel width of the time analyzer was set to 0.5 μs. The 12 Hz trigger signal (RF Trigger) for the modulator of the electron linac was connected to an ORTEC-550 single channel analyzer (SCA), the output signal was used as the start signal for the Turbo MCS. The Turbo MCS is connected to a personal computer. The data were collected, stored and analyzed on this computer.

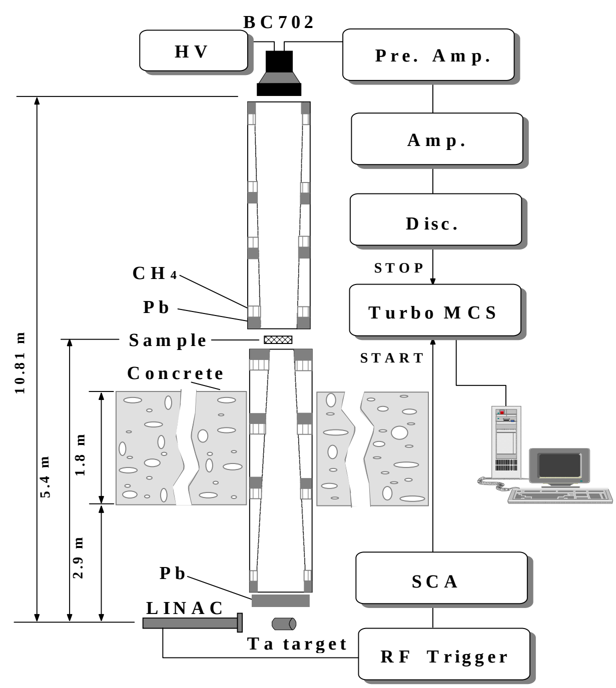

Figure 1: Experimental setup and a block diagram for data acquisition.

3.3 Data Taking and Analysis

In order to determine the flight path distance for our facility, we used neutron TOF spectra for Sm, Ta, W, and Ag sample runs. A Cd filter of 0.5 mm in thickness was used to suppress thermal neutrons. The samples were placed at the midpoint of the flight path.

The resonance energy *E* and the channel number *I* are used to find the flight path length *L* in the following equation by the method of least squares fitting.

$$I = \frac{72.3 \times L}{\Delta t \times \sqrt{E}} + \frac{\tau}{\Delta t}$$

In the above equation, Δt is the channel width of the time digitizer and was set to 0.5 μs. The delay time τ is the time difference between the start signal from the RF trigger and the real zero time. The flight path length L is determined from the fitting. As shown in Fig. 2, the results of the fit are: L=10.81±0.02 m and τ =0.87 μs.

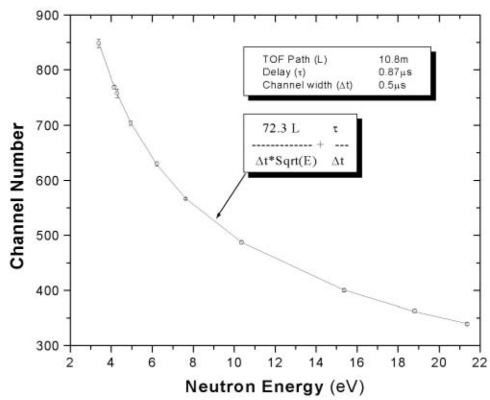

Figure 2: A fit of the flight path length to resonance energies

In order to investigate the neutron energy spectra for the different water levels inside the moderator, we used three water levels: G2 corresponds to 0 cm water level above the target in which water is around the target but no water above the target. G3 is the geometry with a water level of 5 cm above the target surface. Geometry G4 is a full of water in the moderator, which corresponds to 11 cm water level from the target surface.

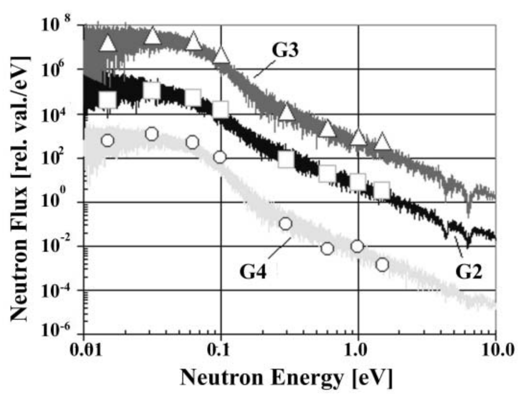

Figure 3: Measured and calculated neutron spectra for three geometries

The measured neutron spectra for three geometries were shown in Fig. 3 compared with those of the MCNP calculations. In this figure, the neutron flux for G3 (G4) geometry was multiplied with a factor 10 (0.1) for better visualization. The points (quadrates, triangles, and circles are for G2, G3, and G4 geometry, respectively) represent the result of the MCNP calculation. The experimental and calculated data were well agreed within the experimental uncertainty.

4. SUMMARY

In order to construct infrastructure for nuclear data production, the Pohang Neutron Facility based on an electron linac was constructed in December 1999. From March 2000, the electron linac was operated with a repetition rate of 12 Hz, a pulse width of 1.5 μs, a peak current of 30 mA, and an electron energy of 60 MeV in order to test a target system, a data acquisition system, and to measure the neutron energy spectrum. The neutron energy spectra produced by the photoneutron target with a water moderator were measured with a ^{6}Li-ZnS(Ag) glass scintillator as a neutron detector with the neutron TOF method at 11 m flight. As a neutron monitor, a BF_3 proportional counter was used. The neutron TOF spectra were normalized with the total counts in the neutron monitor. We measured the neutron TOF spectra for different water levels inside the moderator and compared experimental results with the MCNP calculations in order to maximize the thermal neutron flux. The measured neutron energy spectra for different water levels in the moderator were verified by the MCNP calculations.

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