Conceptual Design of a Neutron TOF Facility at KoRIA

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1. Introduction

Korea Rare Isotope Accelerator (KoRIA) is a heavy-ion accelerator which is being developed mainly for producing RI beams to study nuclear physics and astrophysics. One of the important application areas of KoRIA is the nuclear data. Various types of stable beams can be used for measurements related to the reactions induced by charged particles. In addition, proton and deuteron beams among charged particles can be used to produce neutrons by irradiating appropriate target materials. Those neutrons are used to measure the cross sections and other nuclear data related to neutron-induced reactions. In this paper, we introduce the conceptual design of a neutron TOF facility which can produce fast neutrons for neutron cross section measurements.

2. Methods and Results

2.1 Research Topics

Three research topics are suggested for the measurements of nuclear data using KoRIA. Topic 1 is the measurement of fast neutron related nuclear data. The cyclotron of KoRIA can provide 70 MeV proton and 35 MeV deuteron beams. When a proton or deuteron beam bombards a light nuclei target such as Li, Be, or C, fast neutrons are produced. Those fast neutrons have energies approaching those of cyclotron beams. Therefore, the measurements of fast neutron related data are possible in KoRIA. Topic 2 is the measurements of nuclear data using spallation neutrons. The linac of KoRIA provides 600 MeV protons, which can produce spallation neutrons when protons irradiate a heavy nuclei target such as W, Ta, Pb, or U. The spallation source consists of a wide energy range of neutrons. Topic 3 is measurements using charged particles. The linac of KoRIA provides a variety of stable particles from a proton to uranium with the energy of 200 MeV/u (U). Heavy ion beams can be accelerated to the proton or deuteron target to study nuclear reaction models based on the inverse kinematics. Proton, deuteron, and He beams can be used to measure cross sections of some samples using surrogate reactions.

2.2 Nuclear Data Measurements Using Fast Neutrons

In KoRIA, 70 MeV, 1 mA proton beams and 35 MeV deuteron beams from a 70 MHz cyclotron can be used for fast neutron production. Although the current of deuteron beam is expected to be about 0.2 mA for now, the final current of deuteron beam will be decided in the technical design phase. When thick targets are used, fast neutrons produced by the beam have broad energy spectrums up to proton or deuteron beam energies. Since not much neutron-induced reaction data is available above 14 MeV, fast neutrons produced in KoRIA can be used to generate nuclear data for neutrons with energy greater than 14 MeV. Fission, (n,xn), (n,p), and (n,α) reaction cross sections are unknown for many nuclides with neutron energy on an order greater than ~ 1 MeV. Through experiments involving fast neutron reactions, it is also possible to study the pre-equilibrium model, such as the transition between evaporation and intra-nuclear cascade [1].

2.3 Fast Neutron TOF Facility

Fig. 1 shows the layout of the fast neutron experimental hall and beam lines inside the hall.

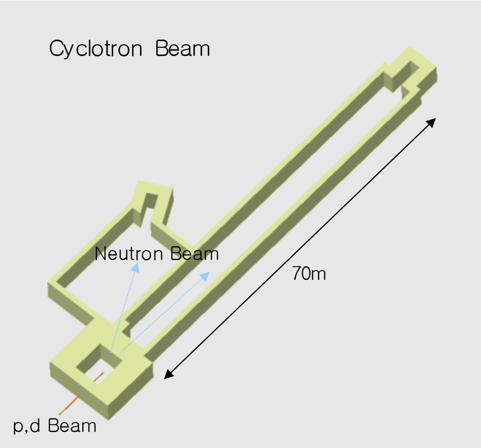

Fig. 1. Fast neutron experimental hall and beam lines

The beam line for the fast neutron facility consists of an accelerated p and d beam lines and a neutron beam line. Protons or deuterons accelerated by the cyclotron are delivered to the neutron production target to produce neutrons. A thick targets such as Li, Be, or C is used to produce neutrons. In the case of a thick target, the beam is stopped in the target. Neutrons produced by a thick target go through collimators and react with experimental samples. There are two neutron beam lines at 0° and 30°. Neutrons passing through the experimental samples can be scattered from the wall of the experimental hall. A neutron beam dump needs to be installed to absorb neutrons to prevent background.

Since the produced neutrons have white energy spectrum, a TOF system is needed to measure neutron energies. The beam width of a pulsed beam is required to be about 1 ns. The flight length was decided to be 70 m based on the requirement that the energy resolution of 70 MeV neutron is about 0.5 % at the maximum flight length. Since the time resolution related to the target is not available due the incomplete target design, the resolution is estimated by considering the time resolution due to the detector (~ 1 ns) and beam width only. An appropriate pulse repetition rate should be determined to avoid overlap of successive neutron pulses. If the minimum value of a neutron energy range is lowered, the repetition rate should also be lowered. If the neutron measurement energy ranges are the same for two pulsed beams, then lower repetition rate is required for the pulsed beam with a longer flight path. The maximum repetition rate can be estimated by the arrival time of a neutron having the minimum energy in the measurement energy range. If the neutron energy for measurement is greater than 1 MeV, the repetition rate is required to be less than 200 kHz for a flight length of 70 m. If the flight length is 5 m, the maximum repetition rate is 2.8 MHz. In case that the neutron energy for measurement is greater than 1 keV, the maximum repetition rates are 6 kHz and 90 kHz for flight lengths of 70 m and 5 m, respectively. The basic repetition rate of the cyclotron is 70 MHz. If the repetition rate is decreased, the average current may also be decreased. The variation of average current due to the repetition rate will be investigated.

2.4 Fast Neutron Production Target

We carried out intensive computer simulations using the GEANT4 code [2]. Fig. 2 shows the Bragg peaks for light element targets at 35 MeV.

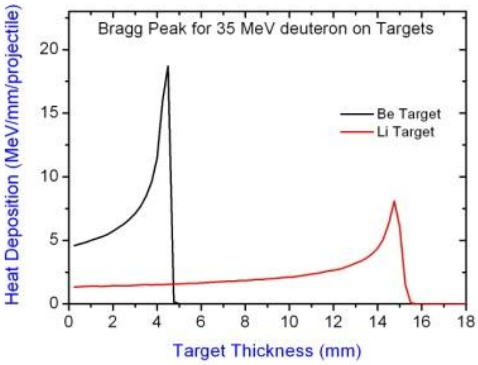

Fig. 2. Bragg peaks for light element targets

The GEANT4 simulations were carried out for the target with a diameter of 30 cm and a Gaussian beam profile of 0.2 cm FWHM by dividing the targets into thin slices and calculating the energy deposition in each of the slices per projectile. The energy spread of the beam is assumed to be Gaussian with an FWHM of 0.5 %. Fig. 3 shows the GEANT4 simulation results of the neutron emission from the surfaces of Li target irradiated with 35 MeV projectiles. Since the main purpose of the neutron target is to provide neutrons to the time of flight system, only neutrons emitted from the central zone of the target surface can pass through the collimator. We assume that the diameter of the central zone is 2 cm.

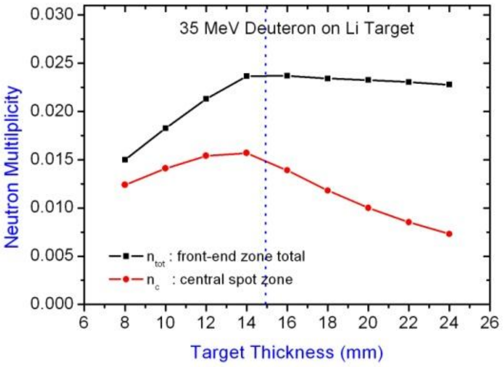

Fig. 3. Neutron emission from the target surface

MCNPX calculation was performed for the 70 MeV proton beam to calculate neutron fluxes. A cylindrical target was adopted with a diameter of 20 cm, and a pencil beam was assumed. The thickness of the target was set to 11.5 cm, 3 cm, and 2.5 cm for Li, Be, and C, respectively. The total production rates were calculated to be 0.130, 0.121 and 0.018 for Li, Be, and C, respectively. The result of MCNPX calculation is 1.9 x 10^{-8} n/cm^2·p (5 m from the C target) for the 70 MeV proton and 0° case.

3. Conclusions

Three research topics are suggested for the measurements of nuclear data using KoRIA. The short-term goal is to produce fast neutrons using cyclotron beams such as 70 MeV proton or 35 MeV deuteron, and use those neutrons for measurements. The long-term goal is to produce spallation neutrons and use those neutrons and charged particles for measurements. The conceptual design of the fast neutron TOF facility was performed. The facility has two neutron beam lines at 0° and 30°. The beam width of a pulsed beam is required to be about 1 ns. The flight length was decided to be 70 m. The technical design work will be continued.

REFERENCES

[1] X. Ledoux et al., "Technical Proposal for the SPIRAL2 Instrumentation: Neutrons for Science (NFS)", GANIL report, 2008

[2] S. Agostinelli et al., (GEANT4 Collaboration) Nucl. Instrum. Meth. A 506, 250 (2003).