Proposal of Compact Accelerator-based Neutron Source (CANS) by using ^{7}Li-d nuclear interactions

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1. Introduction

High flux neutrons are demanded to research the fusion material, medical fields and other applications [1]. With the neutron beam, irradiation tests of fusion reactor materials or the study of transmutation of long-lived radioactive nuclear waste or non-destructive testing are possible [2]. The efforts to increase the neutron flux are reached to utilize the accelerator-based system [3-7]. The most used in this system is proton-based accelerator [8]. As an alternative to generate the high flux neutrons, a lithium ion colliding to deuterium target which is the inverse kinematic reaction is suggested in this paper. Utilizing the existing ion irradiation facility in KAERI, the neutrons of 14 MeV could be generated in forward direction.

KAHIF (Korea Atomic Energy Research Institute Heavy Ion Irradiation Facility) is providing He and Ar ion beams for research fusion material since it is transferred from KEK [9-10]. This ion irradiation facility could transport the lithium ion up to 1.09 MeV/u with split-coaxial radio frequency quadrupole (SC-RFQ) and interdigital H-mode drift tube linac (IH-DTL). In order to generate forward directed neutron beam, additional Li ion source, deuterium target, and extra shielding around the target area will be required.

2. Neutron Source

Common reactions to generate the neutron source are of irradiating proton or deuterium beam to deuterium or tritium or Li target. The representative reactions producing neutrons are listed in Table I [11]. Considering an accelerator-driven neutron source, the total neutron yield from the ^{7}Li(d,n)^{8}Be reaction by 2.0 MeV deuterium beam is about 10^{9} n/s/uA. Assuming 5 % utilization of the beam, the expected neutron yield is about 10^{10} n/s [11]. The deuterium beam with 2.0 MeV is possible to irradiate to the Li target, using KAHIF facility. However, during the accelerating deuterium beams, the linac components will be contaminated by neutron and tritium.

Table I: Representative Neutron Generation Reactions [11]

Reaction	Threshold Energy [MeV]	Product Energy (n) [MeV]
^{2}H(d,n)^{3}He	-	2.45
^{3}H(d,n)^{4}He	-	14.05
^{7}Li(p,n)^{7}Be	1.880	0.03
^{1}H(^{7}Li,n)^{7}Be	13.094	1.44
^{7}Li(d,n)^{8}Be	-	13.35

The most well-known reactions used in accelerator-driven neutron source are ^{7}Li(p,n)^{7}Be and ^{9}Be(p,n)^{9}B. However, the mass of the proton is much lighter than of the target nucleus, the generated neutrons are emitted in all directions. To solve limitation of the conventional accelerator-driven neutron sources, an inverse kinematic reaction has been proposed [12-14]. As the heavier mass of deuterium target, lithium ion could focus the generated neutrons forward to irradiated direction. This forward focused neutron beam includes the more higher flux neutron than isotopic neutron source.

To overcome the contamination of the linac and the focused neutron source, we suggest a Li ion beam to collide deuterium target for producing neutrons. Based on the simulation results by Gean4 Code, a 7 MeV energy Li ion beam colling to deuterium target could produce 14 MeV neutrons [14]. Due to the heavier mass of Li, the produced neutron flux is focused to forward direction. Also, tritium is not produced during the reaction, the beam line could cleanly operate. The design specifications for generating 14 MeV neutron are summarized in Table II [14].

Table III: Design Requirements for 14 MeV Neutron

Parameter	Value	Unit
Acceleration ion	$^{7}Li^{3+}$	-
Beam energy	7	MeV
Beam current	>1	mA
# of neutron	$>10^{10}$	n/s (average)

3. Plans for CANS

3.1. KAHIF

As an ion irradiation facility, KAHIF is located in KAERI. He^{+} and Ar^{10+} ion beams are available for investigating the properties of the nuclear fusion material. The demonstration material test for the displacement per atom (DPA) due to neutron is performed using this ion irradiation facility recently. The ion implantation or ion beam analysis are also possible with the stable operation.

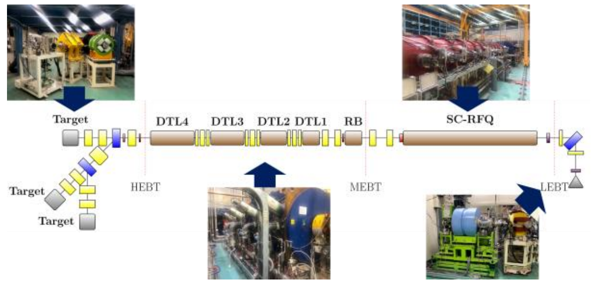

Fig 1. Schematic layout of KAHIF

Fig 1 shows the configuration of KAHIF beam line. The low energy beam transport section of the beam line includes 18 GHz ECR-IS, 90° bending magnet, Einzel lens, the quadrupole magnets and SC-RFQ. Once the ions are extracted from ECR-IS, the ions are accelerated up to 2.07 keV per nucleon before SC-RFQ. SC-RFQ which has 25.96 MHz resonance frequency is bunching, focusing and accelerating the ion beams up to 178 keV per nucleon. Through the 51.92 MHz rebuncher (RB), the ion beams are entered to IH-DTL which has the same resonance frequency as the rebuncher caviy. The ion beams are accelerated by four IH-DTL up to 1.09 MeV/nucleon. With the full operation of KAHIF, the stable non-radioactive ion beams could be irradiated with 1.09 MeV/nucleon for various applications. $^{7}Li^{3+}$ ion beam could achieve up to 7.63 MeV in KAHIF.

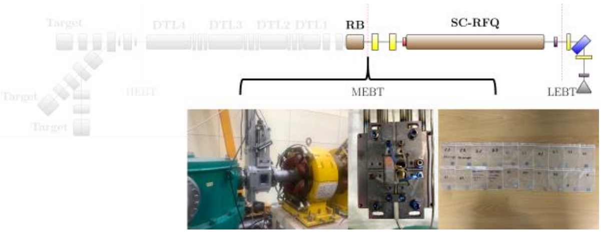

Fig 2. Current service beam line section in KAHIF. The target chamber, the sample holder and the samples for irradiation of He ion beams are shown. The samples could be heated up to 550 ℃ at the holder. Usually, the sample is mounted by 10 mm x 10 mm x 1 mm size. The beam could be irradiated to four samples of this size by one time.

The operation of KAHIF is currently available before the rebuncher cavity. Fig 2 shows the recent operation section, the target chamber, the sample holder and the samples. For research the neutron damage on the metal sample, He^{+} ion beam with 22.0 uA (average) and Ar^{10+} ion beam with 15.0 uA (average) are irradiated.

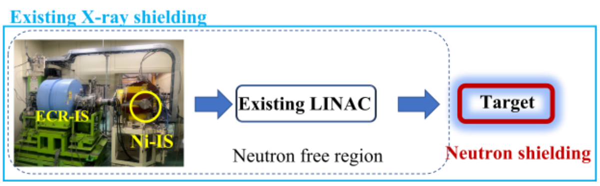

Fig 3. Modifying the beam line for Li ion source and deuterium target. Additional port for Li-IS is shown in the picture. The neutron shielding needs only around the target area. For x-ray shielding, 5 mm thickness of Pb wall is installed around the entire beam line.

3.2. Li Ion Source

In order to generate Li ion beams, the space for the additional Li-IS at the bending magnet is prepared (Fig 3). The problem is what kind of the Li-IS could be suitable to install in current KAHIF beam line [15-17]. The beam reproducibility, beam emittance, beam uniformity, beam current, and possible vacuum condition, the requirements for Li-IS need to be established. Also, the life time of the Li-IS should be considered.

As the Li-IS, the solid surface Li ion source [17] is the one of the possible option. By the thermionic emission from a lithium alumino-silicate surface, the Li+ beam current density, 1 mA/cm^2, could be achieved.

3.3. Deuterium Target

The deuterium-loaded titanium target for D-D neutron source has been developed [18]. The SLIM calculation results of incident 7 MeV ^{7}Li beam shows that the depth of titanium needs 10.1 um [14]. The deuterium target could be made by coating 20 um of titanium at the surface of water-cooling Cu plate. When the beam is switched off, the target could be regenerated by the deuterium gas with heating of the plate.

3.4. Shielding

Concerning the radiation safety license of the facility, the 5 mm thickness of Pb wall has been installed around the beam line (Fig 3). And the 10 mm thickness of Pb wall surrounds the ECR-IS section for x-ray shielding. The advantage of Li ion irradiation is considering only the neutron shield around the target area. This saves lots of the money for shielding entire beam line when using deuterium beam.

The neutron shielding design is required the available space at the target area. The calculation of the shielding material will be conducted by MCNP [19].

4. Conclusions

Utilizing of the operating ion irradiation facility in KAERI, the compact accelerator-based neutron source is proposed to generate 14 MeV neutrons in this paper. The ion irradiation facility could accelerate ion beams from 0.178 MeV/u up to 1.06 MeV/u. A 7 MeV Li beam colliding deuterium target could produce the total neutron yield about 10^9 n/s/uA. Li-IS, deuterium target, and neutron shielding are need to be optimized to requirements of the reaction. The specifications of these considerations will be studied. This research could be extended to the development of portable or movable high neutron source.

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