AN ACCELERATOR-ASSISTED NUCLEAR FUEL ASSEMBLY FOR A FUTURE PROJECT AT KURRI

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Abstract

A nuclear fuel assembly assisted by a linear accelerator has been proposed as a future neutron source of the Research Reactor Institute, Kyoto University (KURRI). The injector linac provides 300 MeV, 0.3mA protons to produce neutrons by a spallation reaction. Final goal of this project is to multiply neutrons by a subcritical nuclear fuel assembly. This system is expected to bring new opportunities as a second generation neutron source at KURRI and also to play an important role in the basic studies of the future hybrid reactor.

1 INTRODUCTION

The Kyoto University Reactor(KUR) has been providing low energy steady neutrons since 1964 for various research fields such as reactor physics, nuclear physics, nuclear chemistry, biology and medicine. Strong requirements for high energy and pulsed neutrons have been arising up recently according to the advancement in each field. To meet the requirements, a "new neutron source" has been discussed in the working group of the future plan committee of KURRI. A combination of a proton accelerator and a nuclear fuel assembly is proposed as one of possible candidates.

2 INJECTOR LINAC

The primary particles to produce neutrons efficiently are high energy proton and deuteron which can be accelerated advantageously by a linear accelerator(LINAC) at high beam intensity[1]. In order to obtain intense neutrons, it is desirable that the reactor technology is effectively applied to produce neutrons in combination with a moderate size linac.

The project " Neutron Factory" is proposed. It is composed of a hybrid system of particle accelerators and a subcritical assembly. The outline of the system is shown in Fig. 1.

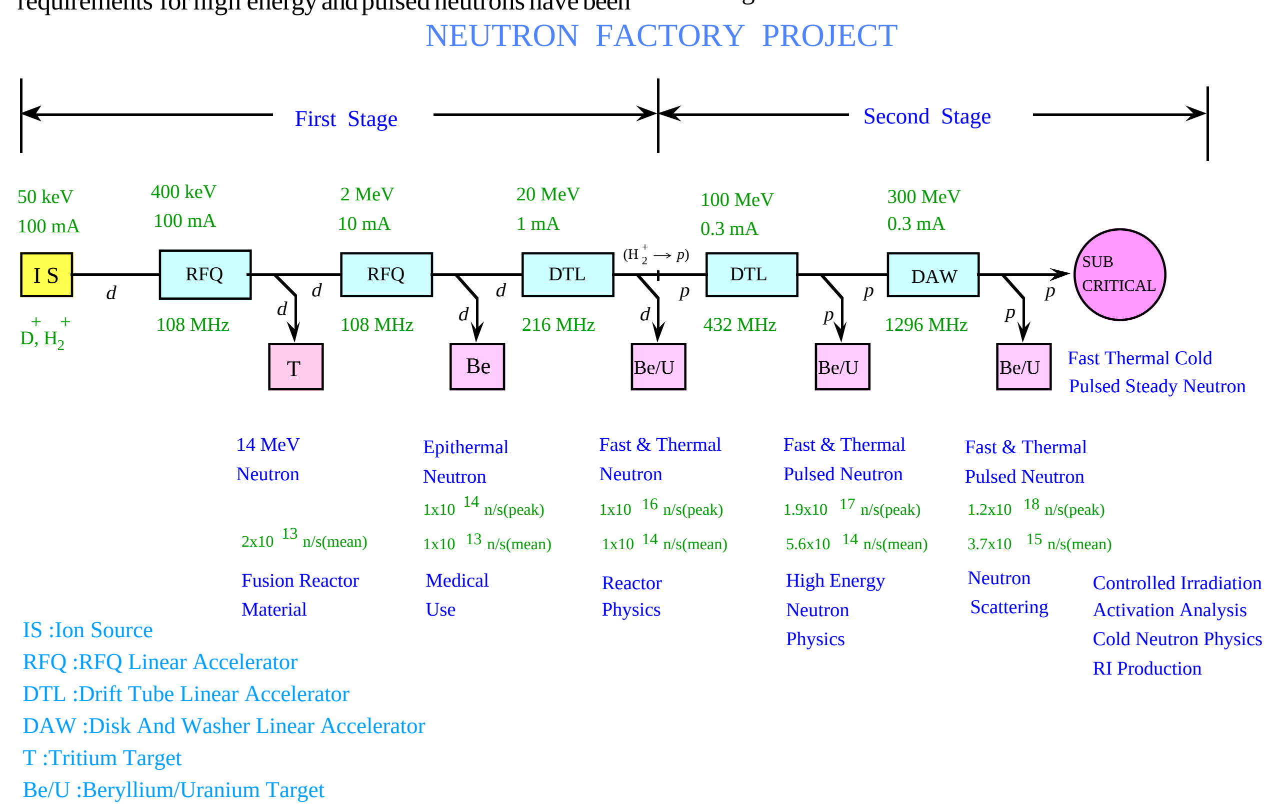

Figure 1: Block diagram of Neutron Factory

The brief report on this system has been given in Ref[2]. Deuterons or hydrogen molecules of 100 mA beam intensity extracted from a high current ion source are accelerated to 400 keV by the first RFQ . The beam energy is raised up to 2 MeV by the second RFQ at the 10% duty pulse operation. The drift tube linac(DTL) at 1% duty is employed to get the beam energy of 20 MeV . For the higher energy than 20 MeV, the proton acceleration is economical. Therefore, the 20 MeV H_2^+ beam which can be accelerated by the deuteron linac is stripped before the second stage DTL. Finally, we expect to obtain a proton beam of 300 MeV and 0.3 mA by a Disk and Washer (DAW) linear accelerator.

In each stage of the particle energy, every variety of neutrons become available as follows.

1) *14 MeV neutrons*

Among the neutron producing reactions, the (D,T) reaction has the largest cross section. It reaches 5 barns at 105 keV deuteron bombarding energy. By using 400 keV deuterons from the first RFQ, intense 14 MeV neutrons can be generated and used for the study on fusion reactor materials. Difficult problems arising from a large amount of tritium targets should be solved. For fusion reactor material irradiations, the ^{9}Be(d,n) reaction is also useful to produce neutrons with energy around 14 MeV by higher energy deuterons as proposed in the IFMIF project at JAERI.

2) *Epithermal neutrons*

The second RFQ generates about 3 MeV neutrons by the deuteron bombardment on the Be target. They can be moderated down to epithermal neutrons which are efficiently used for the BNCT. The fundamental study on the BNCT presently performed with thermal neutrons at KUR can be upgraded by utilizing high quality epithermal neutrons. To produce epithermal neutrons very efficiently, the p(^{7}Li,n) reaction by the 2.5 MeV proton is used at MIT[4]. Therefore, the 2.5 MeV proton beam by a small accelerator may be more favorable for medical use.

3) *High energy pulsed neutrons*

The 20 MeV deuterons obtained by the DTL linac can produce about 10 MeV pulsed neutrons by the ^{9}Be(d,n) stripping reaction. The DTL is operated at 1% duty and high energy neutron experiments such as the T.O.F. spectroscopy in reactor physics become possible.

4) *Intense pulsed neutrons*

The final energy and beam intensity of the primary particles are planned to be 300 MeV and 0.3 mA, respectively, which allow the mass production of high energy neutrons by a spallation reaction. We can expect the neutron intensity of 1.2×10^{18} n/s at peak and 3.7×10^{15} n/s in mean, which enables neutron scattering experiments such as the structure analysis of condensed matters.

5) *Neutrons for material irradiation*

The final goal of the Neutron Factory project is to inject spallation neutrons into a subcritical assembly to multiply them safely and efficiently. Details of the target system are studied preliminary for a simple case[3]. Intense neutrons can make great evolution in research fields such as precisely controlled irradiation of materials and the cold neutron physics which require much more neutrons than presently available at KUR.

An example of design parameters for proposed linacs is summarized in table 1. A conservative design is proposed by a working group as shown in table 1 in which higher energy section uses RF of 216 MHz and 432 MHz. The Disk-And-Washer(DAW) type is considered as an alternative design.

The deuteron beam with energies lower than 20MeV enters the Kyoto University Critical Assembly(KUCA) to be used for test experiments on the subcritical neutron target. At the 300 MeV terminal, a new target system of a subcritical nuclear fuel assembly is constructed to obtain intense neutrons for material irradiation and neutron scattering experiments.

Table 1 The example of design parameters for linacs.

	RFQ1	RFQ2	DTL1	DTL2	DTL3*
Particle	H_2^+,D^+	H_2^+,D^+	H_2^+,D^+	H^+	H^+
Energy(MeV)	0.4	2	20	100	300
Mean current(mA)	100	10	1	0.3	0.3
Duty(%)	CW	10	1	1	1
Frequency(MHz)	108	108	216	216	432
Cell number	90	67	78	138	329
Length(m)	1.182	3.065	10.316	62.73	134.81
RF power(MW)	0.3	0.8	3	12	48

*) Disk-And-Washer(DAW) type is considered as an alternative design.

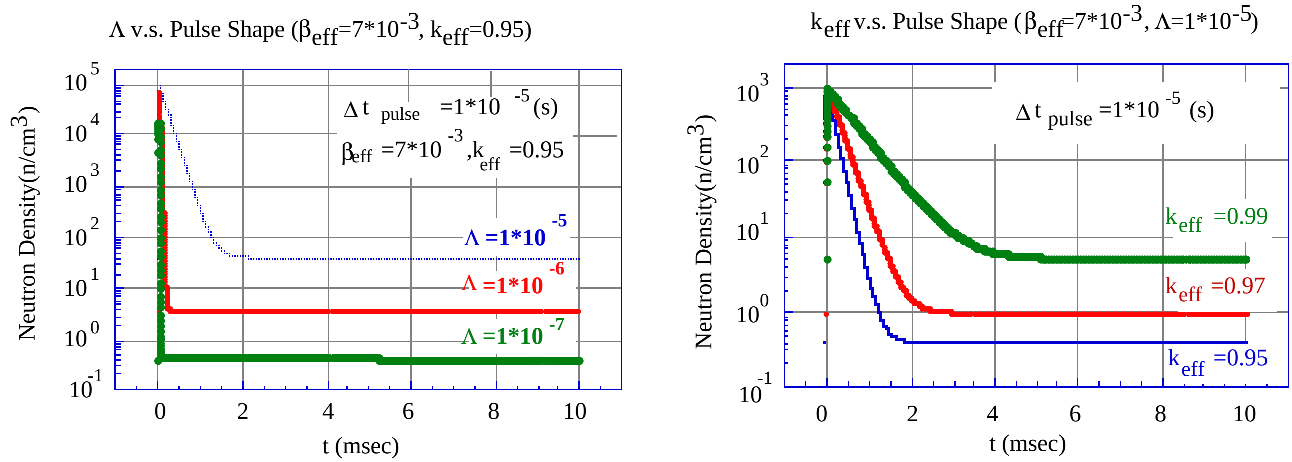

Figure 2: Dependence of the neutron pulse shape on k_{eff} and L at the equilibrium state.

3 NEUTRON PULSE SHAPE IN HYBRID REACTOR

Neutronics design calculations were carried out to obtain information on a hybrid system[3]. We report here some results of preliminary studies on the neutron pulse shape in the "hybrid" reactor calculated by the one-point reactor kinetics with an external source. It is well known that the neutron pulse shape strongly depends on values of k_{eff}, the effective delayed neutron fraction β_{eff} and the neutron generation time Λ.

Figure 2 shows the dependence of the neutron pulse shape on k_{eff} and Λ at an equilibrium state, when 100 neutron pulses with a density of 10^{10} cm^{-3} s^{-1} and a width of 10^{-5} s are introduced into the system per second. From this figure, it was found that the signal-to-noise (S/N) ratio of the neutron pulse, which is defined as a ratio between the peak and the background levels, becomes larger with reduced values of Λ and k_{eff}, whereas the peak level is maintained approximately at the same level. The decay of a neutron pulse becomes faster with reduced values of Λ and k_{eff}. The effect of β_{eff} on the decay of a neutron pulse was also investigated and was found to be remarkable when k_{eff} approaches to unity. For the neutronics design of the "hybrid" system, one should be careful that Λ and β_{eff} depends on k_{eff} on the basis of the reactor physics theory.

More detailed studies are required for the design of planned subcritical assembly. This can be performed in the first stage of the “Neutron Factory “ project by using the pulsed neutrons generated by the 20MeV linac.

4 SUMMARY

In order to offer opportunities to utilize high energy pulsed neutrons as well as low energy steady neutrons, the KURRI has started toward the realization of a multipurpose neutron source assisted by particle accelerators. The nuclear hybrid system itself is very interesting and worthwhile because it involves many technical subjects in both accelerator technology and nuclear engineering. We hope that this proposal will be discussed and polished up by those who are interested in neutrons, accelerators and nuclear systems.

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