Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

Feasibility of Accelerator-Driven System

Tae-Yeon Lee* and Hee Seok Lee
Pohang Accelerator Laboratory, San 31, Hyoja-dong, Pohang, Kyungbuk 790-784
**Corresponding author:lee@postech.ac.kr*

1. Introduction

Currently, there are two challenges or threats to the Nuclear Power community. One is the anti-nuclear mood after the East-Japan earthquake one year ago and the subsequent nuclear disaster. We are not sure at this moment when this mood will be eased. The other threat is the recent shale gas boom (or may be called even a revolution) that began in UA and will be spread to all over the world soon. This second threat is just as serious as the first one. Nuclear power will not receive the attention it used to a few years ago. Economically, it may be ok, however, it will be a disaster to the future of mankind, because shale gas will never solve the problem of global warming. Until now, nuclear power is the only alternative to the fossil energy to save the world.

That is why the nuclear power community needs a breakthrough and it is obvious what kind of breakthrough is needed. World needs a safer and cleaner nuclear power plant. A nuclear power plant that will not cause a disaster and that will produce radiotoxic nuclear waste as small as possible. At the moment, the closest system is the accelerator driven system (ADS) [1]. First of all, it is safer in a disaster such as an earthquake, because the deriving accelerator stops immediately by the earthquake. It also minimizes the nuclear waste problem by reducing the amount of the toxic waste and shortening their half lifetime to only a few hundred years. Finally, it solves the Uranium reserve problem because it can use Thorium as its fuel. The Thorium reserve is much larger than that of Uranium.

Although the idea of ADS was proposed long time ago, it has not been utilized yet first by technical difficulty of accelerator. The accelerator-based system needs 1 GeV, 10 MW power proton beam, which is an unprecedentedly high power. The most powerful 1 GeV proton linear accelerator is the Spallation Neutron Source, USA, which operates now at the power of 1.5 MW with the length of 350 m. A conventional linear accelerator would need several hundred m length, which is highly costly particularly in Korea because of the high land cost. A recent fixed-field alternating gradient (FFAG) accelerator that is expected to achieve 10 MW proton accelerator with a modest size is still under research and development.

However, this presentation shows that it is possible to realize ADS with currently available technology by building an accelerator complex with less power accelerators. The target is a cyclotron. Cyclotron is the oldest accelerator type in history and has been used mostly for low beam energy, low power application. However, at the same time, it has got through a series of constant evolutions. There exist a 1 GeV proton cyclotron and also 1.3 MW proton accelerator. It is absolutely possible to construct a 1 GeV, 2.5 MW proton accelerator with current technology. The idea of this research is to build an accelerator complex of 4 such cyclotrons to achieve 1 GeV, 10 MW proton beam for realization of ADS. Details and background of this idea is given below.

2. Accelerator-Driven System

The conventional nuclear reactors operate at critical condition. The criticality of a nuclear assembly is determined by the effective neutron multiplication coefficient k_{eff} which is defined as

$$k_{eff} = \frac{\text{Numbner of fissions in any one generation}}{\text{Numbner of fissions in immediately preceding generation}} \qquad (1)$$

When k_{eff} =1, number of fissions in each succeeding generation is a constant and the chain fission reaction initiated in the system will continue at a constant rate. Such a system is said to be at a critical conditions. If k_{eff} > 1 the number of fission in the system increases with each succeeding generation and the chain reaction diverges; the corresponding condition is referred to as supercritical. On the other hand, if k_{eff} < 1 the chain reaction will eventually die out and the system is called subcritical. Since number fissions is proportional to the number of neutrons absorbed in the system, in relation 1 the number of fissions can be replaced by the number of the absorbed neutrons.

The conventional nuclear reactors operate in a very narrow range of the neutron multiplication coefficient ($0.994 < k_{eff} < 1.006$). Outside of this range either the reactor fades out or becomes supercritical and overheats.

In a subcritical reactor, the number of neutrons originating from fission is not sufficient to overcome the neutron losses (due to leaks and absorption of neutrons by materials within the reactor). Therefore, under no circumstances a chain reaction can be self-sustaining. In order for the fission reaction to proceed, the system must be fed continuously with neutrons from an external source.

In irradiation of a heavy metallic target (such as lead) with relativistic ions (such as proton, deuteron, helium, carbon ...) neutrons are produced by spallation of the target nuclei. Figure 1 shows the neutron yield as a function of the incident proton energy. It shows that 1 GeV proton is adequate to achieve maximum number of neutrons.

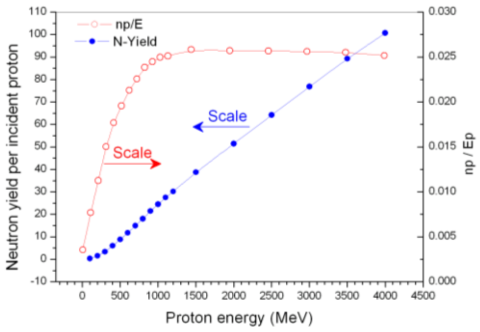

Fig. 1. Variations of the neutron multiplicity *np*, and neutron yield per unit energy of the incident proton (np/E_p) as a function of incident proton energy. The energy gain of an accelerator-based reactor is directly proportional to np/E_p.

3. Accelerators

So far, in the ADS considerations, mostly a linear accelerator has been considered as a candidate for the accelerator, mainly because it has a straightforward way of increasing energy and power at least in principle. The beam energy is increased by putting more accelerating columns, which increases its length though, and the beam power is increased by increasing its current (for example, by increasing the repetition rate). By contrast, a synchrotron has limitation to increase its repetition rate and thus its current. However, the problem with a linear accelerator is that it costs huge to construct it because it is very long. 1 GeV proton accelerator SNS is 350 m long.

Another problem of linear accelerator is its operation stability. For successful operation of ADS, the accelerator should be operated quite stably as shown in Fig. 2. But, linear accelerator tends to fail more frequently than other types.

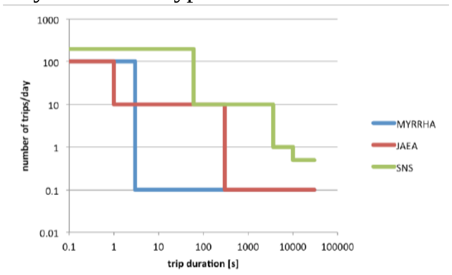

Fig. 2. Beam trip frequencies: recorded in SNS, allowed by JAEA, accepted for MYRRHA.

Another potential candidate for the ADS-accelerator is FFAG that is capable of delivering high energy and high current proton beam, however, it is still under R&D and will take years to be ready.

That is why this paper focuses on a cyclotron, particularly isochronous cyclotron. Currently it gives one of the most powerful accelerator by achieving 1.3 MW proton with 0.59 MeV, at PSI, Switzerland [2]. At the same time, there is a higher than1.0 GeV cyclotron at Riken, Japan [3]. Combining these two technologies, it is possible to construct 1 GeV, 2-2.5 MW cyclotrons. It may not be possible to construct 1 GeV, 10 MW single cyclotron in the near future, however, 1 GeV, 10 MW proton beam is realizable by a complex of 4-5 cyclotrons. The nuclear core side may need an adaptation for several proton beams, but it is not a technical difficulty. The circumference of the PSI cyclotron is less than 30 m. The cyclotron complex will still be a modest size.

Fig. 3. The PSI cyclotron.

3. Summary

Accelerator-Driven system can be realized by use of a complex of 4-5 cyclotrons, which can be constructed with the current technology. And, the land scale necessary for the complex will still be modest. In this short summary, the conceptual ideas of ADS using a cyclotron complex have been proposed.

REFERENCES

[1] K. D. Tolstov, Some aspects of accelerator breeding, Preprint 18 - 89 - 778, Joint Institute for Nuclear Research, Dubna, Russia, 1989.

[2] http://abe.web.psi.ch/.

[3] AIP Conference Proceedings 1218, pp. 1410-1417 (2010).