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Accelerator-Driven System with Current Technology

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1. Introduction

Currently, there are several challenges or threats to the Nuclear Power community. One of the recent one is the anti-nuclear mood spread after the East-Japan earthquake and the subsequent nuclear disaster. We are not sure at this moment when this mood will be eased. However, it will be a disaster to the future of mankind to dump nuclear power because the problem of global warming continues and 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) making use of the Thorium fuel [1]. First of all, it is safer in a disaster such as an earthquake, because the deriving accelerator stops immediately by the earthquake. And, there won't be a Fukushima-like accident, because this Thorium ADS reactor uses air cooling. 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. 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 0.6-1 GeV and at least a few 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. Another difficulty is reliability of accelerator operation. To be used as a power plant facility, accelerator should obviously operate such that the power plant may continuously generate electricity at least for months with no interruption. However, the reality is that a high power proton accelerator is hardly operated even a few hours without interruption, although very short interruptions are tolerable. Anyway, it will take a time to develop an accelerator sufficiently reliable to be used for power generation.

Now the question is if it is possible to realize ADS with the current level of accelerator technology. This paper seeks the possibility.

2. Urgency of Accelerator-Driven System in Korea

Korea has operated nuclear power plants for more than 30 years and is now operating 24 nuclear power plants. The number of nuclear power plants will be 29 in a few years. However, spent fuel is going to fill the storage in nuclear plants in a few years. This problem should be solved in the near future. An obvious choice is nuclear transmutation by ADS. Considering that Korea has a relatively small land compared to its population, it is very difficult to construct a permanent storage for spent fuel. Also, considering that the conventional fast reactor is not available as a safe facility, nuclear transmutation based on ADS seems to be the most reasonable and urgent solution. This is one of the reasons why progress of ADS so urgent in Korea.

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.

The issue of the accelerator power and expense may be resolved by building an accelerator complex with smaller accelerators, such as a cyclotron. 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 we focus on a cyclotron, particularly isochronous 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. Currently it gives one of the most powerful accelerator by achieving 1.3 MW proton with 0.59 MeV, at PSI, Switzerland [2], and this cyclotron is going to be upgraded to 2.4 MW soon. At the same time, there is a higher than 1.0 GeV cyclotron at Riken, Japan [3]. Hence, it is possible to construct a 0.6-1 GeV, 2-2.5 MW cyclotrons with current technology. Furthermore, a 1 GeV, 10 MW cyclotron was already designed with only 5.7 m ring radius [4], although it is not clear when this machine will be realized.

Fig. 1. PSI cyclotron. As can be seen, there are 4 RF sections

However, 1 GeV, 10 MW proton beam is realizable by a complex of 4-5 PSI cyclotrons, right now. The circumference of the PSI cyclotron is less than 30 m. The cyclotron complex will still be a modest size. [5] Hence, it is clear that cyclotron is a serious candidate for the accelerator of ADS.

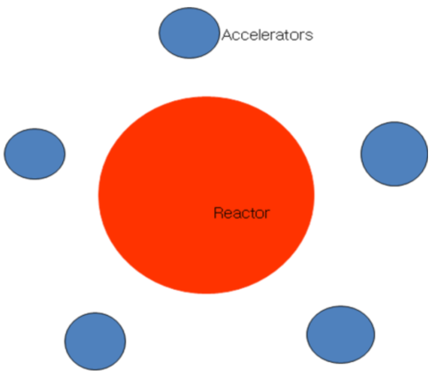

Fig. 2. Conceptual figure of an accelerator complex

3. Operation Stability

Another problem of linear accelerator is its operation stability. For successful operation of ADS, the accelerator should be operated quite stably.

This problem may be greatly improved by using the above accelerator complex and distributing the probability of accelerator fault to a few accelerators. This way, the operation stability can be improved greatly. Suppose an accelerator complex of 5 cyclotrons of 2.5 MW. Note that 4 cyclotrons can supply 10 MW required for power generation, and 1 cyclotron can be ready as a backup accelerator. Suppose also that $p<1$ is the probability of fault of a cyclotron. Then, the probability that all cyclotrons are down simultaneously will be p^5, which is usually a very small number. Hence, mostly, there will be a few cyclotrons operational and nuclear reaction will continue.

This may also be solved if we limit our concern to transmutation, not paying attention to power generation. In other words, the current level of accelerator stability may not be responsible for power generation, but it may be enough for transmutation. Transmutation exclusive facility does not need be always operational.

It may be possible to realize ADS in terms of small accelerators such as cyclotron by constructing an accelerator complex, or a transmutation exclusive facility in terms of a single cyclotron. This is possible with current technology.

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