Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

A Proposal to Use Common Control Rods for the Reactor Protection System and Reactivity Control System in the AHR

Soo-Youl Oh, Chul Gyo Seo, and Byung-Chul Lee
Korea Atomic Energy Research Institute
syoh@kaeri.re.kr

1. Introduction

High neutron flux is one of the most important design requirements for a research reactor, and it is best achieved by making the core as compact as possible. However, the space reserved for control rods in the core limits the compactness of the core. Also the space for the control rod drive mechanisms outside the core, which are bulky in general, results in a narrower work space for the experiments and reactor maintenance. Thus a fewer number of control rods is preferred with respect to the performance of a research reactor.

We propose a concept of using control rods in common for both the Reactor Protection System (RPS) and the Reactivity Control System (RCS) in the Advanced HANARO Reactor (AHR), a 20 MW research reactor intended for export. The AHR design adopts the HANARO concept in principle but with variations that are under investigation. We present herein the AHR core design in general, investigate the amount of reactivity to be controlled to determine the minimum number of control rods, and then discuss the compatibility of the common control rods concept with the General Design Criteria. How the concept improves the neutronics performance of the reactor will be presented in detail elsewhere.

2. Design Feature and Neutronics Characteristics of the AHR Core

In its reference design[1], the AHR core consists of 18 fuel assemblies (FA's) and one central irradiation thimble.

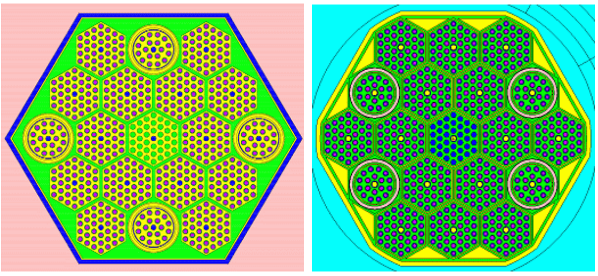
(a) (b)

Fig. 1. Reference AHR Core Configurations: FA's are loaded in one-piece Al block (a), or in flow tubes one by one (b). A dummy assembly is modeled in the central thimble. The outside of the core is the reflector tank filled with heavy water.

The AHR uses two kinds of FA's; 18-elements FA in which 18 fuel rods are arranged in two concentric circular rings and 36-elements FA with three rings in a hexagonal shape. 18-elements FA's are loaded where the control rods are located and 36-elements FA's at the other positions. A control rod, hollow cylinder made of Hf, is inserted, or dropped at the reactor trip signal, into the core embracing an 18-elements FA. The geometry and dimensions of the FA's are the same to those for HANARO. Concerning the fuel material, the AHR is supposed to utilize a rather high density U_3Si_2 fuel (4.0 gU/cc), which is under an irradiation test in HANARO, instead of 3.15 gU/cc U_3Si fuel being used in HANARO.

The thermal neutron flux per unit power is $\geq 2\times10^{13}$ n/cm^{2}s/MW (4×10^{14} n/cm^{2}s) in the reflector region, which is comparable with or higher than the level achieved in the up-to-date research reactors using low enriched uranium like OPAL in Australia.

Table 1 shows the sources and amounts of negative reactivity to be controlled by the RCS during a normal operation, and Table 2 shows those of positive reactivity to be suppressed by the RPS for a reactor trip.

Table 1. Amount of Reactivity to be Controlled during Normal Operation

Source	Amount (mk)
Fuel depletion	35 ~ 40
Power defect	5 ~ 10
Xe build-up at BOC (Equilibrium Xe worth)	30 ~ 40
Reactivity loss due to experiments	15 ~ 25
Xe worth to be overridden for re-start without dead time	10 ~ 15
Sum	110 ~ 120

Table 2. Amount of Reactivity to be Reserved for Trip

Source	Amount (mk)
Shutdown margin	10
Power defect	5 ~ 10
Equilibrium Xe worth (to prevent re-criticality after shutdown)	30 ~ 40
Reactivity inserted by withdrawal of irradiation target*	~ 12
Uncertainty in calculation	5
Sum	~ 75

* The reactivity inserted by the control rod withdrawal accident was assumed as about 7 mk, smaller than the reactivity due to an experiment object withdrawal.

The RCS should provide more than 120 mk to meet all the control requests. As the reactivity worth of one control rod is estimated as in the range of 40 ~ 60 mk, three control rods can implement the role of the RCS. Concerning the RPS, including one additional control rod assumed as in the stuck-out condition, three control rods can reserve the amount of reactivity required for the reactor trip.

If the RCS and RPS utilize control rods dedicated to any one system exclusively from the other, total number of six control rods is required; three for the RCS and the other three for RPS. However, in the case the RCS and RPS share common control rods, calculations of the criticality at a cold zero power condition suggests that only four control rods are enough for the RPS/RCS with the due assumptions on accident conditions.

3. Compatibility with the GDC

We investigated the compatibility of the common control rods concept with the General Design Criteria (GDC) of the USA.[2] The GDC considers power plants. Nevertheless, it is regarded as the basis of a regulation even for a research reactor. Ten criteria, from Criterion 20 to 29, are given with respect to the protection and reactivity control systems. The point of investigation is whether the GDC requests components exclusively belonging to any one system, RCS or RPS, so we focused on criteria 24 and 25. Other criteria shall be met in general irrespective of the common rods concept.

Criterion 24 states that ‘the protection system shall be separated from control systems to the extent that’ the protection system remains intact even in the case of unavailable common, if any, components. This seems to mean in other words that both systems may not be separated if the RPS can work properly. In addition, ‘interconnection of the protection and control systems shall be limited,’ but such an interconnection is not completely ruled out.

Criterion 25 states that the RPS shall be designed to work properly for any single malfunction of the RCS such as accidental withdrawal of the control rods. In the case of AHR with common control rods, a rod withdrawal accident would progress as the following scenario. As a control rod is being withdrawn accidentally, the reactor power increases. When the power reaches the set point of the RPS, a trip signal is initiated, and then the Control Rod Drive Mechanism is de-energized to drop three intact control rods into the core. If the shutdown using the control rods is not enough, the secondary shutdown system, a heavy water dump system in the AHR, will be initiated. The point here is to give a priority to the trip signal over a control signal.

Even in the common control rods concept of the AHR, the RPS and RCS are separated from each other in terms of instrumentation and control. Signal acquisition and processors for the RCS are independent from those for the RPS physically and electrically. Two systems share only the control rods as one of the system components, and a failure of that component (e.g., stuck-out) is fully taken into account in the accident analyses. Moreover, any single failure or malfunction of the RCS does not cause a failure of the RPS. Remember that a control rod is a kind of fail-safe, passive component to be dropped into the core by gravity.

4. Conclusion

For the AHR that is under design development, the neutronics calculations showed that the RCS and RPS need only four control rods if both systems use the rods in common. In the case that each system utilizes the control rods exclusively as in a usual reactor design like HANARO, six control rods are estimated to be needed; three for the RCS and the other three for the RPS.

The common control rods concept introduced herein does not impair the design philosophy on the safety that is reflected in the GDC.

Designs adopting a similar concept are also found in recent large scale research reactors. However, we are not considering any other extra components such as additional shutdown rods in the reflector region to strengthen the functions of the control or protection systems.

Acknowledgement

We carried out this work under the auspicious of the Ministry of Science and Technology.

REFERENCES

[1] Cheol Park, *et al.*, “Design of a New Research Reactor: Preliminary Conceptual Design (3^{rd} Year),” KAERI/RR-2635/ 2005, Korea Atomic Energy Research Institute, Jan. 2006.

[2] “General Design Criteria for Nuclear Power Plants,” Title10, Code of Federal Regulations, Part 50, Appendix A, U.S.A. (www.nrc.gov/reading-rm/doc-collections/cfr/part050)