CONCEPT OF THE CORE FOR A SMALL-TO-MEDIUM-SIZED BWR THAT DOES NOT USE CONTROL RODS DURING NORMAL OPERATION

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ABSTRACT – A small-to-medium-sized boiling water reactor (BWR) with a natural circulation system is being developed for countries where initial investment funds for construction are limited and electricity transmission networks have not been fully constructed. To lighten operators' work load, a core that does not use control rods during normal operation (control rod-free core) was developed by using a neutronics calculation system coupled with core flow evaluation. The control rod-free core had large core power fluctuation with conventional burnable poison design. The target of core power fluctuation was set to less than 10% and was achieved by optimization of burnable poison arrangement.

1. Introduction

The importance of nuclear power as an energy source is linked to the needs for energy security and lowered greenhouse-gas emissions. Demand for small- and medium-sized distributed power sources is expected to increase [1], because they have merits that their initial investment funds for plant construction are limited and they can be used even if electricity transmission networks have not been fully constructed. However, small- and medium-sized nuclear power reactors have not been commercialized yet because of their scale demerit.

Hitachi-GE Nuclear Energy (Hitachi-GE) is developing a small-to-medium-sized reactor based on the DMS (Double MS: Modular Simplified & Medium Small Reactor) developed under the sponsorship of the Japan Atomic Power Company [2]-[3]. The DMS is an innovative 300-400MWe class BWR aiming to overcome the scale demerit using proven technologies of conventional BWR plants. Hitachi-GE plans to undertake work on two additional items: (1) development of the core that does not use control rods during normal operation in order to lighten operators' work load; and (2) enhancement of the safety characteristics in consideration of the severe accident at the Fukushima Daiichi Nuclear Power Plant, especially for a long-term station blackout (SBO) event. In this paper, the work on item (1) is described.

2. Method for evaluating the natural circulation type BWR core

The natural circulation type BWR which is being developed by Hitachi-GE is illustrated in Figure 1. Steam is generated in the core and rises in the divided chimney as a two-phase flow of saturated water and steam. Water and steam are separated above the divided chimney by gravity force. Steam goes to the main steam line through the steam dryer, and water goes to the downcomer, mixes with feedwater, and goes down to the lower plenum. Natural circulation force comes from the pressure difference of the static head between the inside and outside of the shroud. The divided chimney is adopted to enhance the natural circulation force. Since the void fraction, which is the ratio of steam volume to total volume of steam and water in the core and divided chimney, mainly depends on the core absolute power, the core flow depends on the core power. In this study, the relationship between the core flow and the core power was tabulated by using the TRACG code [4]. Core characteristics were evaluated by using a 3-dimensional core simulator and a power-flow table.

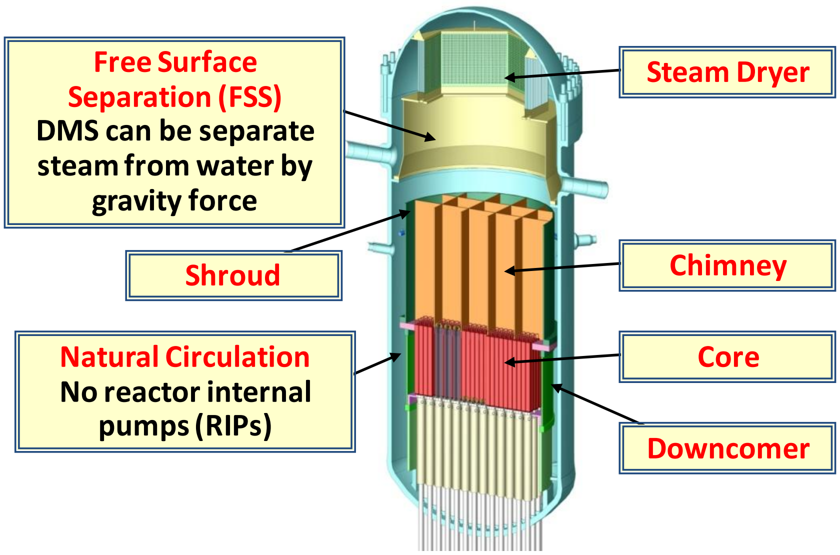

Figure 1 Schematic showing the small-to-medium-sized BWR concept developed by Hitachi-GE

3. Control rod-free core

In the case of conventional BWRs, core power is controlled to the rated value by controlling the amount and arrangement of burnable poison such as gadolinia (Gd) in the fuel assembly, inserting or withdrawing control rods, and changing the core flow rate by using the reactor internal pumps (RIPs). In the case of the natural circulation type core that does not use control rods during normal operation, just designing the amount and the arrangement of Gd in the assembly can be used to control the core power. However, it is difficult to get constant core power just using Gd because the amount and the arrangement of Gd are not controllable during operation. Our target is to reduce the variation width of the core power to less than 10%, which was determined in order to keep thermal efficiency of a steam turbine almost constant.

When just the uniform arrangement of Gd concentration was used in a fuel assembly, the core power change during normal operation without using control rods varied up to 30% (Figure 2 (blue line)). The core power decreased from the beginning of cycle (BOC) to the middle of cycle (MOC). This was because neutron multiplication of the core strongly depended on the Gd exposure of the fresh fuel assemblies. Since the operation cycle length of the Hitachi small reactor is 24 months, the number of fresh fuel assemblies is relatively large. In order to suppress the core power change, use of low concentration Gd fuel was set for the axially lower part of the fuel assembly. The low concentration Gd was burned out by the time of the MOC, so the neutron multiplication factor between BOC and MOC increased.

The core power decreased at the end of cycle (EOC). This was due to depletion of fissile fuel. The low concentration Gd fuel set for the axially lower part of the fuel assembly also contributed to the increased core power at EOC. The position of the axial power peaking shifted to the axially lower part of the assembly during progression from BOC to MOC and the core-averaged void fraction increased. On the other hand, the fissile fuel at the axially lower part was depleted and the position of the axial power peaking shifted to the axially upper part of the assembly at EOC and the core-averaged void fraction decreased. Since the uranium saving effect was enhanced by this spectral shift effect, the core power at EOC increased. Figure 2 (green line) shows the final results. The core power change could be suppressed to less than 10%.

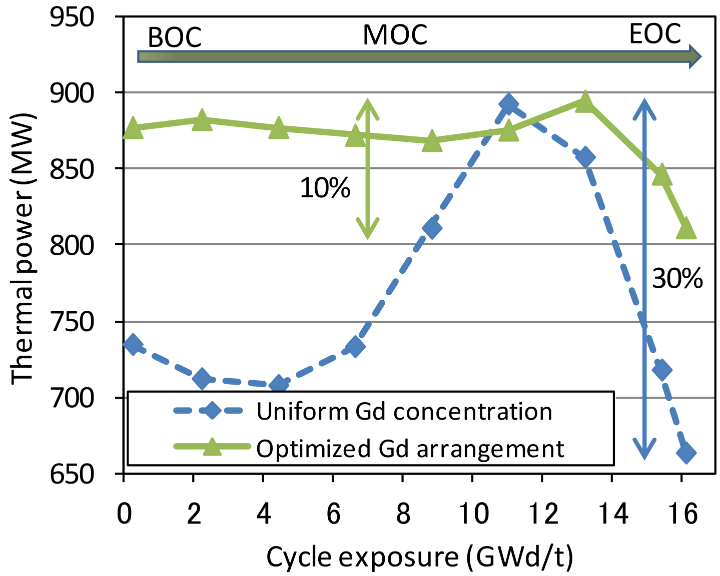

Figure 2 The variation of core power of control rod-free core

7. Conclusion

Development of a control rod-free core was described in which the core power level fluctuation could be controlled to less than 10% by using a low concentration of Gd in the axially lower part of the fuel assembly.

8. References

[1] Nuclear Energy Agency, "Current Status, Technical Feasibility and Economics of Small Nuclear Reactors", Paris, France (2011).

[2] Y. Kawabata, M. Matsuura, S. Hirako, and T. Hoshi, "The Plant Feature and Performance of DMS (Double MS: Modular Simplified & Medium Small Reactor)", ICONE16-48949, Orlando, Florida, USA (2008).

[3] T. Ikegawa, Y. Ishii, M. Matsuura, and T. Hoshi, "Transient Performance of Medium Small LWR "DMS-400" Evaluated Using TRACG Code", ICONE16-48610, Orlando, Florida, USA (2008).

[4] T. Hara, et al., "TRACG Application to Licensing Analysis", Proc. of 7th Int. Conference on Nuclear Engineering, ICONE7-7311, Tokyo, Japan (1999).