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# Concept Development of Boiling Condensing Small Modular Reactor (BCR)

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## Introduction

- Although current PWR-type SMRs are outstanding in terms of safety, their sizes are still too large to be called 'small' reactors.
- To resolve this issue, the concept of Boiling Condensing Small Modular Reactor (BCR), a hybrid of PWR and BWR, is newly devised in this paper.
- The thermal center difference was calculated under specific geometry and operating conditions.
- Eventually, the height of the reactor pressure vessel (RPV) is estimated to check if it is possible to reduce the reactor size with this concept.

## Characteristics of BCR

1. Natural Circulation, Self-pressurized, Integral Type PWR
   - The BCR maximizes coolant density difference to improve the circulation capacity.
   - No pressurizer inside the RPV. Use boiling and condensing power to self-regulate the system pressure.
   - Steam generators are integrated inside the RPV.
2. Hybrid of PWR and BWR

**PWR Characteristics**

- BCR is basically in the form of PWR in that the coolant system is divided into primary and secondary sides.
- However, the flashing effect in natural circulation based PWRs is not enough to replace coolant pumps, requiring long risers.

**BWR Characteristics**

- BCR allows much more boiling inside the reactor core to maximize buoyancy, with the flow quality at the core exit expected to be 0.2~0.3.
- From the preliminary study on the concept of BCR, the RPV height was expected to be higher than BWR but lower than PWR.

3. Enhanced Heat Transfer in the Steam Generator
   - Heat transfer in the steam generator can be enhanced if helical-shaped tubes are used, but helical coils are difficult to be manufactured, maintained, or analyzed.
   - In the BCR's steam generator, the heat transfer coefficient between two coolant systems is expected to be quite large, as boiling and condensing occur simultaneously on each side.
   - In this case, a straight tube-based shell-and-tube type steam generator is expected to provide enough heat transfer area within a small volume.

## Estimation of Thermal Center Difference

1. Design of BCR
   - Under steady-state in a natural circulation-based reactor, the buoyancy-generated pressure head should be balanced by pressure drop around the primary circuit.

$$\left(\rho_{cold\ leg} - \rho_{hot\ leg}\right) g\Delta H = \Delta p_{core} + \Delta p_{SG} \quad (1)$$

   - The general operating conditions for calculating the pressure drops are summarized in Table. 1.

Table. 1. General operating conditions

| | |
|---|---|
| Electrical output [MWe] | 170 |
| Thermal output [MWt] | 485.7 |
| System pressure [kPa] | 7171 |
| Core inlet/outlet temperature [°C] | 278/287.6 |
| Core exit quality | 0.2 |
| Core mass flow rate [kg/s] | 1274.7 |

2. Core Pressure Drop
   - The core frictional pressure drop was calculated by equation (2). The two-phase multiplier and the friction factors were obtained by homogeneous equilibrium model (HEM) and Cheng & Todreas correlation, respectively.

$$\Delta p_{f,core} = \frac{f_{lo} G_m^2}{2 D_e \rho_l}\left[(z_{OSB} - z_{in}) + \int_{z_{OSB}}^{z_{out}} \phi_{lo}^2 dz\right] \quad (2)$$

   - Core minor head losses at several components such as spacer grids, inlet and outlet were also calculated. The loss coefficient for spacer grids was determined by de Stordeur's model.
3. Steam Generator Pressure Drop
   - The frictional pressure drop at the primary side of the steam generator was obtained by equation (2).
   - The two-phase multiplier profile was deduced from the temperature profile for counterflow. Also, the friction factor along the shell side was derived by using the Cheng and Todreas correlation again.
4. Results
   - The pressure drop calculation results are summarized in Table. 2. Putting these values into equation (1), the thermal center difference is expected be 5.22 m.
   - By roughly assuming that the height of remaining parts of RPV besides thermal center difference is 3.5~4.0 m, the height of the RPV should be 8.72~9.22 m. This implies that it is possible to reduce the reactor size with BCR concept.

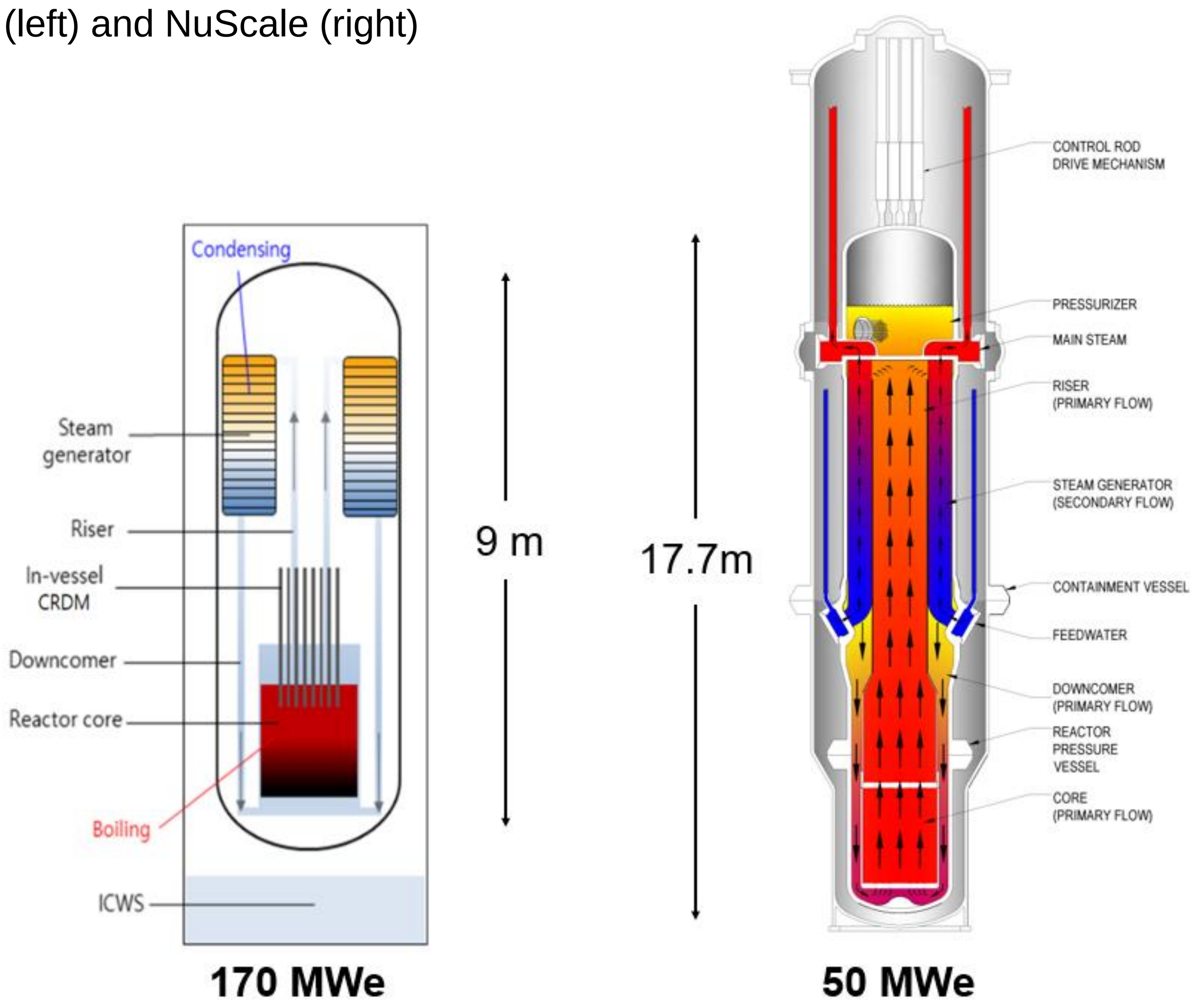
Table. 2. Pressure drop calculation results (Unit: [kPa])

| | | |
|---|---|---|
| Core | Friction | 9.41 |
| | Spacer grids | 1.06 |
| | Inlet & Outlet | 3.96 |
| Heat Exchanger | Friction | 16.30 |
| Total pressure drop | | 30.72 |

## Summary and Further Works

- The height of RPV was estimated to be approximately 9 m.
- Compared to the NuScale whose RPV height is about 17.7 m and the electrical output per power module is 50 MWe, a BCR produces more than 3 times of electrical energy in almost half the size.

Fig. 1. Comparison of RPV height and electrical output between BCR (left) and NuScale (right)




- Based on precise heat transfer analysis and material testing, whether the conventional shell-and-tube type heat exchanger can withstand this condition should be unraveled.