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# Preliminary Study on the Concept of Boiling Condensing Reactor for Natural Circulation PWR Type SMR

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## Introduction

✓ Recently, the small modular reactor (SMR) is being actively developed in many countries and there are many types of reactor being developed and some land based water-cooled SMRs are close to the commercialization stage.

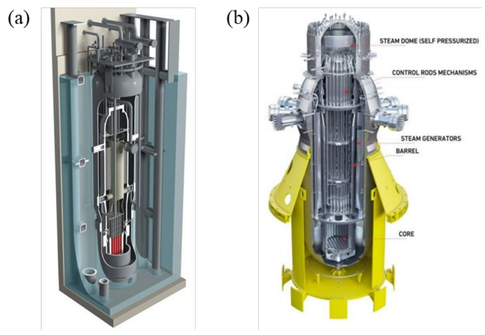
✓ However, the size of the reactor pressure vessel (RPV) becomes considerably larger since it requires a high riser to provide natural circulation driving head.

✓ In this paper, the authors propose the concept of a boiling condensing reactor (BCR) that allows in-core boiling in a PWR type natural circulation reactor. By allowing boiling in the reactor core, it is expected that the height of RPV can be greatly reduced due to the improvement of thermal driving head.

## Concept of Boiling Condensing Reactor

### ➢ Natural Circulation Based Integral PWR

✓ To reduce the thermal center difference, some of PWR type single-phase natural circulation reactors, including CAREM, use flashing which refers to the partial evaporation when a saturated liquid undergoes depressurization while rising to the steam generator.




▲ (a) NuScale (b) CAREM

✓ Although the buoyancy can be increased due to flashing, the size of RPV cannot be effectively reduced since the density difference is not maximized at the thermal center.

| | CAREM (CNEA, Argentina) | NuScale (NuScale Power, USA) | ACP100 (CNNC, China) |
|---|---|---|---|
| Reactor type | Integral PWR | | |
| Thermal power [MWt] | 100 | 160 | 385 |
| Electrical capacity [MWe] | ~30 | 50 | 125 |
| Primary circulation | Natural circulation | Natural circulation | Forced circulation |
| System pressure [MPa] | 12.25 | 12.8 | 15 |
| Core inlet/exit temperatures [°C] | 284/326 | 258/314 | 286.5/319.5 |
| RPV height/diameter [m] | **11/3.2** | **17.8/3.0** | **10/3.35** |

▲ Technical parameters of integral PWR type SMRs

✓ As can be seen from the above table, when natural circulation is adopted, the RPV height becomes very high compared to the reactor capacity.

✓ In order to develop a competitive SMRs in the future, the size of RPV needs to be reduced when considering modular production and transportability.

### ➢ Boiling Condensing Reactor

✓ For the development of a safe and compact PWR type SMR, the concept of BCR is suggested.

✓ The BCR is basically a PWR-based concept that allows boiling in the reactor core.

✓ Although the boiling of coolant occurs at the core, the radioactivity issues of the turbine building are the same as that of the general PWR since it adopts an indirect cycle unlike BWR.

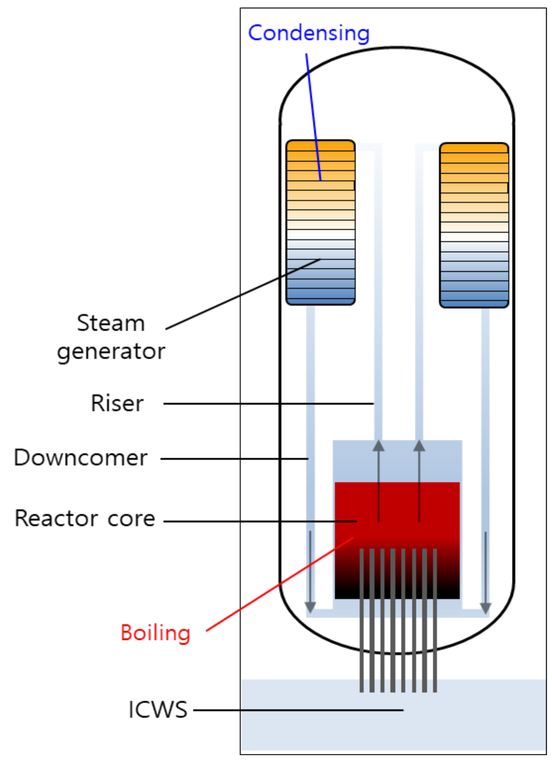
✓ The quality at the upper core is expected to be between 0.0 and 0.2 since there is no need to produce dry saturated steam.

✓ The thermal driving head can be dramatically increased because the vapor density is 7-9 times smaller than that of liquid at the operating pressure of the PWR.

✓ In addition, since there is no need for a depressurization component at the riser, it is expected that a highly effective natural circulation reactor cooling system can be achieved.

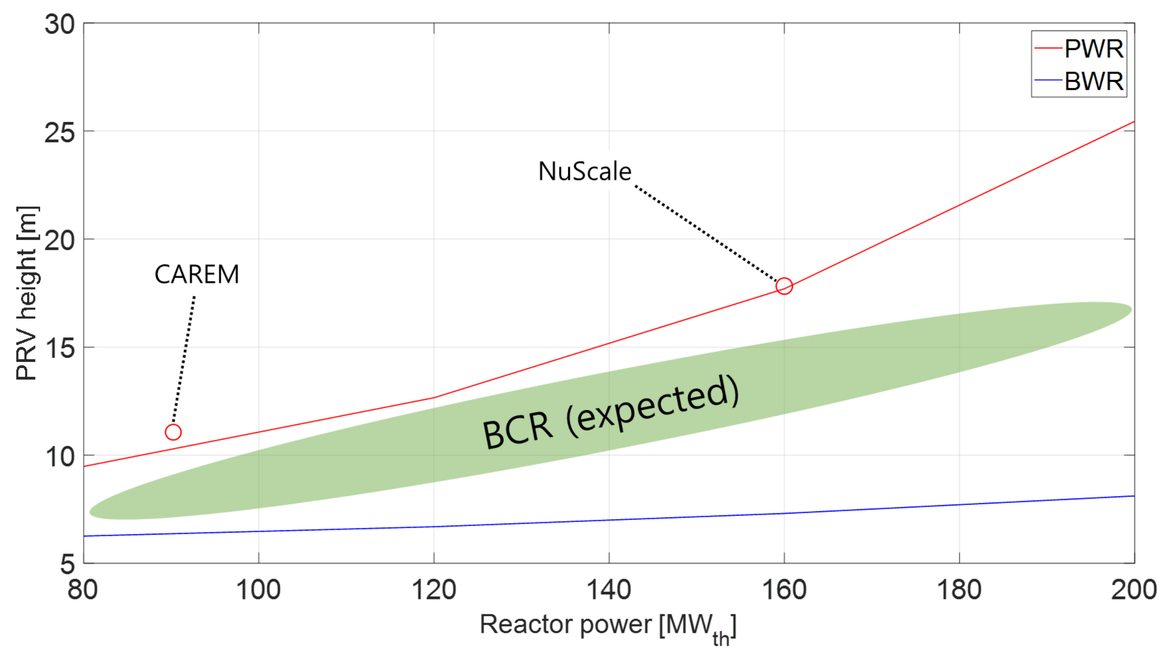
✓ The below graph shows the comparison of RPV height of natural circulation nuclear reactors.

✓ The result of BWR corresponds to the extreme case, and considering the BCR concept that allows a little boiling in PWR, the RPV height of BCR will be between PWR and BWR as shown in the figure.




▲ Conceptual diagram of primary circuit of BCR

✓ Depending on the degree of boiling tolerance, it is expected to be more competitive in the future SMR market where compactness is emphasized.




▲ Comparison of RPV height of natural circulation reactors

✓ In addition to the RPV height, there will be potential advantages in various aspects on the concept of BCR.

✓ Effective two-phase heat transfer occurs on both sides of the steam generator, there is a possibility that the steam generator can become more compact.

✓ It is also possible to achieve self-pressurization and simplify the startup procedure.

✓ However, further research seems to be needed as there may be technical and regulatory issues that can arise from allowing in-core boiling.

## Summary and Further Works

✓ In this paper, the concept of boiling condensing reactor (BCR) is suggested for natural circulation PWR type SMRs.

✓ It is a PWR based concept that allows a little boiling in the reactor core.

✓ By adopting two phase natural circulation based indirect-cycle reactor, it is expected to be more compact and simplified.

✓ In the future, it will be further investigated on the technical aspects of the BCR concept.

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