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Preliminary Conceptual Designs of Various RV-SGV Assemblies for the Innovative Next Generation SMART Plus

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1. Introduction

In 2019, the Korea Atomic Energy Research Institute (KAERI) and the King Abdullah City for Atomic and Renewable Energy (K.A.CARE) had established the Korea-Saudi Arabia Joint Research and Development Center. Several joint research project has been conducting under the support of the center, among which a project to propose a preliminary conceptual design of the innovative next generation SMART (System-integrated Modular Advanced ReacTor) Plus is actively performing. In the present study, the recent achievements on the preliminary conceptual designs of various reactor vessel – steam generator vessel (RV–SGV) assemblies for SMART Plus will be briefly described.

2. Objectives and Scope

The main goal of this project is to propose a preliminary conceptual design of innovative next generation SMART Plus to enhance its economic efficiency and safety by introducing innovative element technologies. To enhance the competitiveness of SMART [1], several element technologies have been suggested such as printed circuit steam generator (PCSG), in-vessel control element drive mechanism (IV-CEDM), an improved reactor vessel (RV) module, and so on. The most important and promising one of those is to utilize a printed circuit heat exchanger (PCHE) as a steam generator, and to develop an improved RV module adopting the PCSG, which can enhance the economic efficiency of SMART Plus.

Several types of conceptual design candidates of SMART Plus were investigated thoroughly in the present study to find out the most effective reactor configuration for economic enhancement without drastic degradation of safety. There are five conceptual designs for arrangement of an RV and steam generator vessels (SGVs), i.e., integral, 1-SGV modular, 2-SGV modular, 3-SGV modular, and 4-SGV modular arrangement. They are illustrated in Fig.1, where PCSGs and the cores are depicted as blue bars and orange boxes, respectively. Both side-view and top-view of each arrangement are provided for comparison, even though they are drawn not to scale.

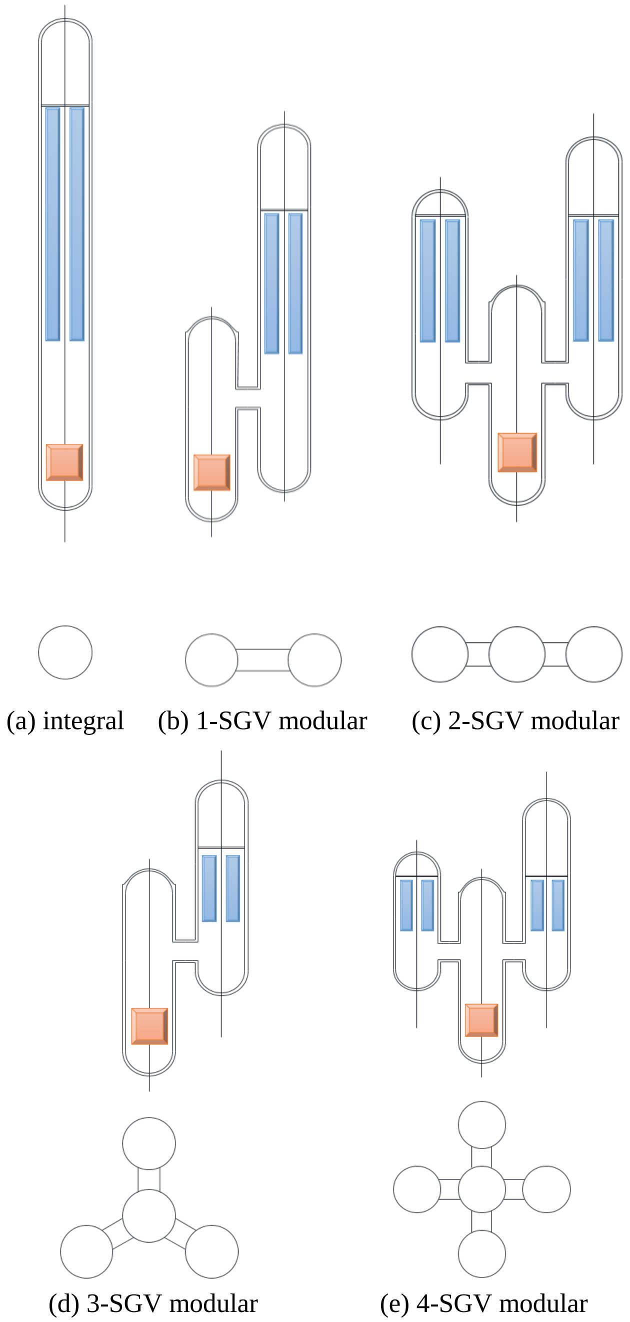

Fig. 1. Conceptual designs of various RV-SGV assemblies (Not to Scale)

In the present study, advantages and disadvantages for each candidate were compared in terms of safety and economic efficiency.

3. Results and Discussion

3.1 Integral

As depicted in Figure 1 (a), the PCSG is integrated within a single RV, while the PCSG blocks are arranged horizontally and stacked vertically, along with the primary side flow paths. The hot side primary coolant from the core flows vertically upward through the central space among the PCSG blocks, and the cold side primary coolant flows through the circumferential space between the RV inner wall and PCSG blocks, vertically downward. From a fluid system design viewpoint, the height difference between the core and SGs has positive effects on natural circulation flow rate. However, the height of the PCSG module is excessive which could cause severe non-uniformities in the flow rates through each layer of PCSG blocks. Also, the excessive height of the RV yields difficulties in mechanical structural design.

3.2 1-SGV modular

In this configuration, the PCSG module is located in a separated pressure vessel other than the RV as shown in Figure 1 (b). This SGV is connected to the RV via a connection vessel providing primary coolant flow paths for both the hot side through the center and cold side through the circumferential space. The pressurizer is placed at the upper space within the SGV instead of the RV to ensure suppression of bubble generation inside the RCS. The 1-SGV modular arrangement can slightly reduce the total height of the RV-SGV assembly, but the asymmetrical RCS flow path yields design difficulties. Also, the flow velocity inside the cross vessel flow path is excessive, and the cross flow paths are not short enough, causing an increase in cost and RCS pressure loss.

3.3 2-SGV modular

This design concept has the core installed at the bottom of the RV, the IV-CEDM is installed above the core. The PCSGs are adopted in two SGVs. This increased redundancy enhances safety of the reactor. Also, it is advantageous for maintenance of the PCSGs. The pressurizer would be installed in either of the SGVs. The 2-SGV modular arrangement reduces the height of the PCSG modules to half. The cross vessel flow path is shorter than that of the 1-SGV modular arrangement with slower flow velocity, thus it is advantageous both in cost and RCS pressure loss.

3.4 3-SGV modular

In this 3-SGV modular configuration, three independent PCSG modules are used, each connected to the RV via connection vessel. Having three SGVs allows the height of the PCSG modules to be reduced. Non-uniformities of primary and secondary side mass flow in vertical direction are still expected but much less than the previous designs. The pressurizer can be installed in either one of the SGVs or the RV. To ensure suppression of bubble generation inside the RCS and avoid refueling complications, the pressurizer would be installed in the SGV instead of the RV. The RCS flow path is symmetric in 120 degrees from the top view perspective. However, the fuel arrangement inside the core is symmetric in 45 degrees, which might cause some non-uniformities in the flow rates through the core, IV-CEDM, and PCSG blocks.

3.5 4-SGV modular

The arrangement of the core and IV-CEDM in this configuration is the same as the previous design. The main difference is having 4-SGV, which allows the reduction of the height of the PCSG modules. Non-uniformities of primary and secondary side mass flow in vertical direction are still expected but slightly less than the previous designs. The RCS flow path is symmetric in 90 degrees from the top view perspective which shows better symmetry among the previously discussed designs except for the integral design. However, some non-uniformities in the flow rates through the core, IV-CEDM, and PCSG blocks are still expected to occur.

4. Conclusions

It can be concluded that 2-SGV modular configuration has many advantages over others, while the disadvantages by addition of the SGV is sufficiently limited as well. The 3-SGV and 4-SGV can further reduce the height of the RV-SGV assembly, but the degree of height reduction is relatively small against the linear increase of cost. The design concerns discussed in the present study for each design candidate may contribute to design improvements of SMART Plus.

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REFERENCES

[1] KAERI and K.A.CARE. (2019). Preliminary Safety Analysis Report for SMART Units 1&2. Republic of Korea.