Lessons Learned from Development of NuScale NPP for Successful Standard Design Certification of i-SMR

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1. Introduction

The highlight of present SMR market is known as VOYGR by NuScale[1]. The plant is a scalable power plant equipped with a fully passive safety system which can be operated with only two kinds of discharge valves based on the pressure balance between containment vessel(CNV) and reactor pressure vessel(RPV). VOYGR adopting the multi-module operation overcomes the insufficient economics on the small and medium size reactor. In light of safety, innovative ECCS and PRHRS submerging steel vessel into swimming pool can eliminate the various and complicated safety systems[2].

Innovation of NuScale significantly leads to the highest goal of SMR development while leaving a big mark in the SMR market. In case of BWRX-300 of GE recently, it suggested that the economic target value is 2250USD/kWe, which is comparable to the value of conventional large LWR [3].

The beginning of SMR development in Korea is the SMART development of KAERI in 1997[4]. SMART obtained standard design approval in 2012 and now is proceeding the SDCA on SMART100 which equipped the fully passive safety system reflected the response of Fukushima nuclear accident in 2011. In addition, association of University, Research Institute, Industry and Government is propelling to develop the conceptual design of new i-SMR. As a subsequent research plan, the preliminary feasibility assessment on the i-SMR has been conducted with a target to obtain the SDA in 2028. The developing i-SMR is expected to outperform the VOYGR of NuScale so that are being made to secure innovation and economic efficiency.

In the middle of conceptual development, it is meaningful to look at the nuclear reactor development of NuScale. The present study is to briefly describe the conceptual development process of NuScale and to derive lessons of learning for the successful conceptual development of i-SMR.

2. Historical Development of NuScale

NuScale system is begin with NERI project of the MASLWR of association with INL, Oregon state University(OSU) and NEXANT which is a branch company of BECHTEL. NuScale was founded based on the development direction and concept of the early MASLWR. Basic design of NuScale system engineering was launched at the time of participating the Flor engineering company[1].

2.1 Before MASLWR

Prior to the NERI of development of MASLWR reactor, the STAR project in the United States has begun. It is a R&D plan to restore the initiative of the nuclear reactor development in the 21st century and the revival of nuclear industry. As a part of this plan, the development of light-water type small and medium-size reactor was promoted. Two representative concepts were selected in STAR such as IRIS and NILUS. NILUS is similar to many of the concepts adopted by NuScale that is natural circulation operation, partially submerged reactor concept, etc. Basically, the concept of NILUS is introducing the safety system of BWR to PWR type as shown in Figure 1. Based on the literature[5], it is assumed that conceptual development and Top Tier Requirement(TTR) establishment were performed with reference to NILUS in the early stage of MASLWR development.

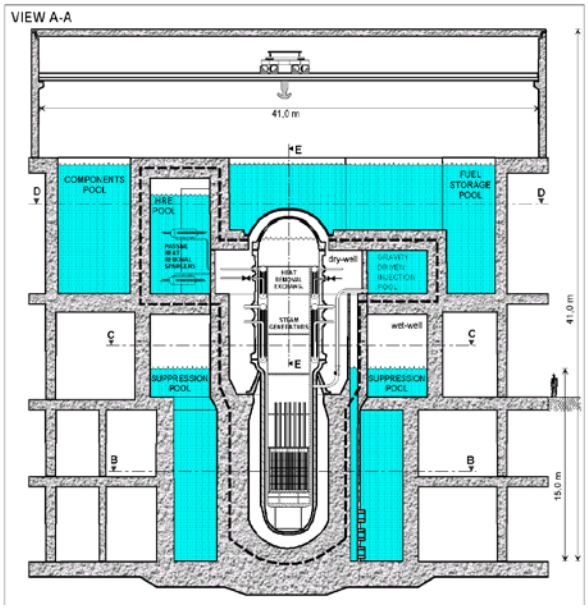

Fig. 1. Layout of the NSSS of NILUS : integrated pressure vessel with connected safety circuit [5]

2.2 MASLWR

MASLWR[6] is a SMR resultant of associated project with OSU , INL and NEXANT. The reactor has the

innovative multi-module operation. The concept of multi-module operation with nearly 30 power modules was adopted to improve the economics of MASLWR. The multi-module of MASLWR requires the minimized volume of CNV and the modularization in CNV unit. The concept of multi-module and modular construction concept require the simplified safety system which should be installed all in one in containment vessel.

For this purpose, Innovative ECCS which is consisted of a submerging containment vessel and safety vent valve for depressurization was developed for satisfying the multi-module requirement. The safety concept was verified by the experiments and analysis of OSU. MASLWR test results were distributed for 3rd party verification as an international research project of the IAEA to ensure the verification and reliability of the test.

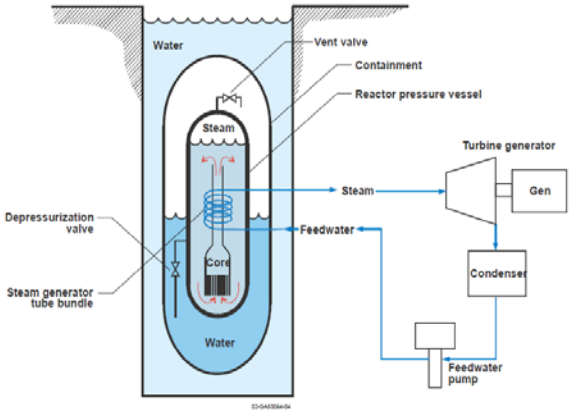

Fig. 2. MASLWR Baseline Design Concept [6]

2.3 NuScale

Based on the MASLWR design, NuScale's power module with increased thermal power is designed to secure economic feasibility. Flor company participated as the E&C responsible partner and carried out the design work.

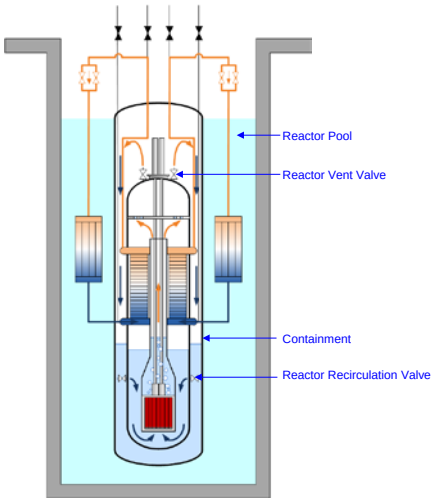

Fig. 3. Simplified NSSS Protection design in NuScale[2]

The operation of the multi-module was verified through the simulator for simultaneous operation of 12 NPM under control of single main control room. The simulator was carried out in parallel with the design work in the form of updating the NuScale design progress based on the MASLWR system[2].

NuScale increased capacity compared to MASLWR and reduced the number of modules. Figure 3 shows the design of NuScale and the concept of ECCS submitted to DC licensing [2].

2.4 VOYGR

NuScale recently announced the name of the reactor as VOYGR, increasing its electric power to 77 MWe from 50 MWe per module. Currently, VOYGR is in the process for a new DC [1].

Table 1 shows the history of power upgrade of NuScale. This increase in power is possible because the ratio of power to flow rate of the initially designed core has more margin in comparison with that of existing reactor.

Table I: Problem Description

	MASLWR	NuScale	VOYGR
FAs	24 ass 1m height	37-ass 2m height	37-ass 2m height
Electric power	35 MWe	50 MWe	77 MWe
Refueling	5 yr	24 month	24 month
No of modules	30	12	12

2.5 Lessons learned of i-SMR conceptual development

The concept design stage is the period in which the accumulation of technology and design consideration, and innovative idea are the most contributed. In the case of NUWARD, which was recently announced in France, the conceptual design period is shown in nearly twice that of the standard design period [7].

System engineering shows the importance of conceptual design stage. In the initial and conceptual design stages, design changes influenced favorably in project progression, but changes at the end of design are pointed out as the main reason for project failure. In the case of large commercial reactor project, unplanned expenditure of indirect expenses is the risk factor in the reactor construction[8]. The extra expenditure resulted in the design change at the last stage.

NuScale worked closely with regulation body to overcome the regulation challenges. For example, the operation of the multi-module with single main control room was not permitted in the GDC and SRP requirement. However, NuScale shows the verification through simulator on the all of requests from NRC and

resolves the regulation issues at now. In this process, the conceptual design of MASLWR is a key element that enables the development of the simulator in parallel with the design.

Currently, i-SMR is conducting conceptual design under the control of KHNP. Innovative technologies will be applied in the design of i-SMR. In this application with multi-module concept, the simulator will play an important role for these technologies to obtain a design approval. Additionally, the simplified safety system of i-SMR like NuScale should be applied to accommodate the multi-module design.

3. Conclusions

Through the NuScale reactor design and development process, considerations in the conceptual design of i-SMR were reviewed. The conceptual design of MASLWR became the important basis of the NuScale Power module. The safety system concept and multi-module were certified in NRC regulation within the planned licensing period based on the MASLWR test and the conceptual design. The conceptual design of i-SMR is also expected to be the important basis for obtaining licenses in 2028 like MASLWR.

ACKNOWLEGEMENTS

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