Transactions of the Korean Nuclear Society Autumn Meeting
Jeju, Korea, October 21-22, 2010

Conservative Estimation of In-Vessel Retention for High Power Reactors

Sang Ho Kim*, Soon Heung Chang
Korea Advanced Institute Science and Technology, Department of Nuclear and Quantum Engineering,
335 Gwahak-ro, Yuseong-gu, Daejeon 305-701
**Corresponding author:proton@kaist.ac.kr*

1. Introduction

In-vessel retention (IVR) of molten core is a key severe accident management strategy proposed for lots of advanced light water reactors. For example, the enhanced safety of the Westinghouse Advanced 600MWe PWR (AP600), which relied upon External Reactor Vessel Cooling (ERVC) for IVR, resulted in the U.S. Nuclear Regulatory Commission (US NRC) approving the design without requiring certain conventional features common to existing LWRs[1]. With the concept of IVR safety, many countries will need to construct more nuclear power plants and be dependent on nuclear power as a future energy. Accordingly, there are many reasons for the necessity of higher power reactors than 1400MWe. High power reactor is suitable for Korea territory conditions. Also, under the assumption that the safety will be ensured, higher power reactor will be more economical. Finally, many researches about PWR have done well. Therefore, we will be able to utilize current technologies effectively. In this paper, APR1400, APR+ and future PWR2000 whose power is 2000MWe are considered to calculate the distribution of heat flux and estimate the feasibility for high power reactor IVR in severe accidents [2].

2. IVR Design for APR1400

The schematic layout of external reactor vessel cooling system for in-vessel retention and gravity driven cavity flooding system for ex-vessel cooling is shown in Figure 1.

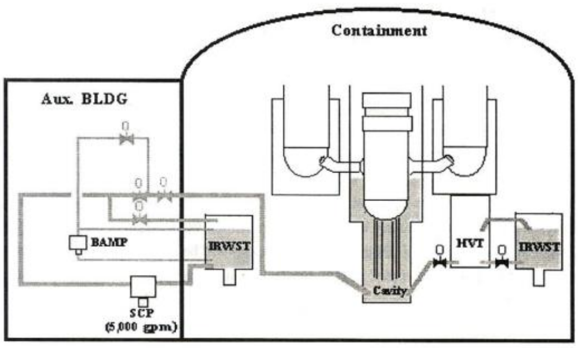

Fig. 1. Schematic diagram of APR1400 IVR-ERVC

External reactor vessel cooling system for in-vessel retention would be operated by shutdown cooling pump with nominal flow rate of 22730 liter per minute. It takes 22.8 minutes to submerge the bottom of the reactor vessel and 37.5 minutes to submerge the bottom of cold legs. The bottom of cold legs is the key water level of IVR. After filling the cavity, it is planned that natural circulation is to be formed. The value of mass flux is dependent on water level and is about zero to 300 kg per m^2·sec.

3. Heat Flux Distribution Calculation

In order to estimate the conservative feasibility of IVR for each high power reactor, many assumptions are set below. There are two dominant debris configurations about corium stratification phenomenon shown in Fig.2. The calculation is done under that molten corium is stratified for two layers which are metallic layer and molten ceramic pool shown in Fig. 2(a). Therefore, there is the significant problem of focusing effect which maximum heat flux is produced on the surface of metallic layer. Also, I used the basic parameters of VESTA code from INEEL and LILAC-LP code from KAERI. According to Rayleigh number range, Kelkar`s heat transfer correlation of internal heated natural convection correlation is applied in accordance with the hemisphere geometry.

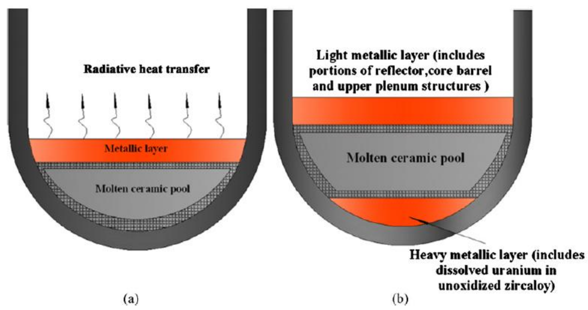

Fig. 2. Alternate debris configurations [3]

The calculation is based on many factors for severe accident. I made the two variables changeable and the other inputs fixed for conservative estimation. The first thing is surely accident scenarios of eight cases. The second variable is the mass of stainless steel. It has many uncertainties for estimation. Therefore, I set the two cases which there would be 56,000 and 100,000 kg of molten stainless steel.

Before the calculation, methodology verification is needed for reasonability. I compared the code results and the results from my calculation. As a result of methodology verification, I could conclude that my calculation is proven within 10% of error. It is a little high, but it is acceptable.

4. Result

The results of maximum heat flux are illustrated in Fig. 3 and 4. The data of Fig. 3 is based on the condition which the mass of molten stainless steel is 56,000kg. The data of Fig. 4 is based on the condition which it is 100,000kg.

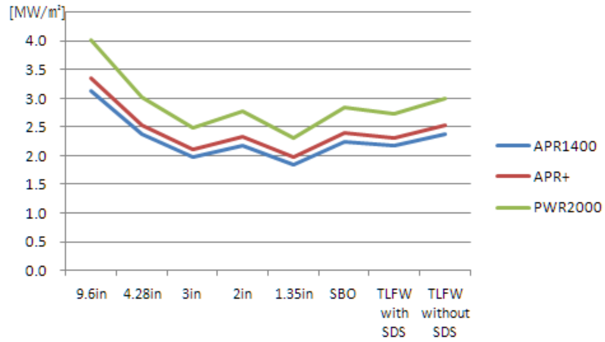

Fig. 3. Maximum heat flux for each reactor in case 1

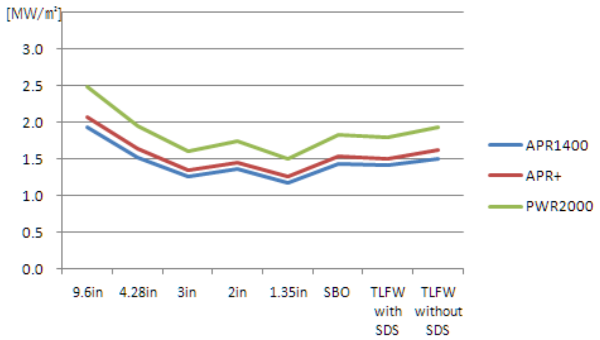

Fig. 4. Maximum heat flux for each reactor in case 2

In previous many researches for APR1400, there will be a thermal margin for seven accidents except LBLOCA and the maximum heat flux on metallic layer is greatly dependent on the mass of molten stainless steel [1]. The calculated results show that thermal margin is also sufficient except LBLOCA for APR+ under the second stainless steel condition. However, in case of PWR2000, it is proven that there will be no thermal margin excluding SBLOCA under the assumption that IVR design is the same as APR1400.

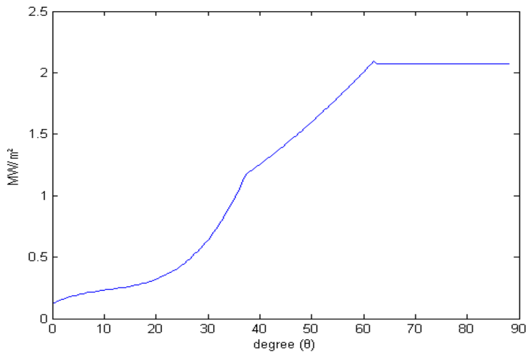

Fig. 5. Heat flux distribution of APR+ LBLOCA

As a result, the heat flux distribution of APR+ LBLOCA under the stainless steel second condition is illustrated in Fig. 5 applied by ACOPO correlation [4]. It is possible to get the heat flux distribution for each reactor, accident scenario and debris assumption. All of the results can be represented using the maximum heat flux and the correlation.

5. Conclusion

The feasibility is estimated focused on heat flux distribution for each high power reactor under the assumption of IVR design which is just changed on the basic design parameters related with power increase. Accordingly, those are so conservative because the conservative calculation and assumptions are used and this process do not apply the coolability enhancement methods such as micro-porous aluminum vessel surface coating and enhanced design insulator, although the basic design parameters are applied.

There are many methods to get heat flux distribution from the bottom of reactor vessel in severe accident. This study provides the upper limit of heat flux distribution which we can expect because the results are calculated under the conservative conditions. As a future work, it is needed to estimate the feasibility from realistic simulation and find the method of coolability enhancements in order to make thermal margin increase related with critical heat flux for the high power reactor conditions.

REFERENCES

[1] J.L. Rempe et al., In-Vessel Retention Strategy for High Power Reactors, Idaho National Engineering and Environmental Laboratory, 2005
[2] Yoon Sun Chung, A Study on the Conceptual Design of a 2000MWe Pressurized Water Reactor, Korea Advanced Institute of Science and Technology, 2002
[3] Y.P. Zhang et al., Analysis of Safety Margin of In-vessel Retention for AP1000, Xi`an Jiaotong University, 2010
[4] Sehgal, B.R., Remaining Issues in Severe Accident Safety Research, RASPLAV-2000 Seminar, Munich, Germany, 2000