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Effect of application SiC fuel cladding for mitigating focusing effect in situation of IVR

Sub Lee Song*, Soon Heung Chang
Dept, Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology
373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea
**Corresponding author: bluesaturn@kaist.ac.kr*

1. Introduction

Nuclear power has been charged in an important role for electricity supply from 20th century. Through 1980s-TMI and Chernobyl accidents, safety of nuclear power plant was always the center of public attention for its reliability.

Severe accident is a type of accident that may challenge safety systems at a level much higher than expected, usually stands for core melt accident. There were some strategies for preventing, handling or mitigating severe accident because release of radioactive materials into environment outside must be prevented.

2. IVR-ERVC strategy

One of the strategy is IVR-ERVC(In Vessel Retention-External Vessel Cooling). It is a method for cooling reactor vessel by submerging the reactor vessel exterior. The purpose of IVR concept is to maintain core melt in reactor vessel not to release outside. So prevention of failure of reactor vessel is the most significant problem for success of IVR strategy, preventing release of radioactive materials outside vessel.

After core is molten, there will be decay heat generation depends on thermal power of reactor. This decay heat will be transferred to reactor vessel wall, so wall should be cooled appropriately for preventing vessel failure.

When core is melted, the molten core will be relocated at the bottom of the reactor vessel. At that time the molten core will be composed by two parts, oxidic pool, and metallic layer.

2.1 core melt compositions and focusing effect (RASPLAV, MASCA experiments)

There are some studies about this core melt compositions. The important problem in core melt composition is positioning of these two parts because it influences the wall heat flux. Oxidic pool is composed of UO_2, ZrO_2, and other oxides, and metallic layer is composed of Fe, Zr, mainly. This two parts separation was discovered from RASPLAV experiment and it said separation was triggered by Carbon which is contained in control rod(B_4C), because the two layer stratification was not triggered when weight fraction of Carbon is less 0.01w/o.

Furthermore, in MASCA experiment, the three layer formation was observed. The heavy material, such as U, combined with light metals, Zr, and Fe, and its density became larger than other oxides, so combination of U and light metals was sunk down under oxide pool.

This phenomenon is called three layer formation, and three layers are light metal layer(top layer), oxidic pool, and heavy metal layer(bottom layer), each. The problem of this phenomenon is thining of top metal layer.

When decay heat is produced from oxidic pool, the heat transfer will be occurred upside to metal layer mainly because the heat transfer rate of metal layer is much better than oxidic pool. If we assume there will be no coolant(water) inside vessel at the time of core melt relocation, more conservatively, the heat transfer from top metal layer to atmosphere in vessel will be only dependent on radiative heat transfer. Of course, the radiative heat transfer rate is very low, so almost heat from oxidic pool will be transfer to vessel wall which is contacted with top metal layer. At that part of the vessel, heat flux will be increased dramatically. This phenomenon is called focusing effect. So for preventing vessel failure at that point, in IVR-ERVC condition, the heat flux should be less than CHF at that point.

There are still many uncertainties in this field, but many studies has been conducted for preventing CHF, enhancing CHF, or mitigating heat flux from core melt.

In this sense this study has been conducted for restraining three layer formation, so preventing focusing effect at vessel wall, enhancing success probability IVR-ERVC strategy.

3. SiC fuel cladding and Material effects in IVR

Silicon carbide(SiC) is a compound of silicon and carbon with chemical formula SiC. Due to its resistance to the high-temperature and high-radiation environment, there are movements that applying SiC as a cladding material for LWR. SiC also gave possibility for HTGR(High Temperature Gas-cooled Reactor) fuel cladding.

J.M. Seiler et al calculated the evolution of the density of oxidic and metallic phases in thermodynamic equilibrium as a function of the mass of steel. Their result tells when oxidation fraction of zirconium decreases, the mass of metal that stratifies below the oxidic pool increases. The oxidiation fraction of zirconium decrease means the number of remaining metal Zr . In a word the larger number of metal Zr intensifying metal layer sunk, three layer formation.

From this result, the idea has been rised that applying SiC cladding instead of Zr cladding can help prevent three layer formation which means reduction of focusing effect.

4. Methods and Results

The metal layer heat flux at the vessel wall in core melt accident was calculated in case of SiC cladding and compared with normal Zr cladding conditions.

Several assumptions has been conducted. No radiation heat transfer to upper atmosphere, and convection heat transfer in metal layer is not considered for conservative calculation. The heat transferred to metal layer from oxidic pool is assumed to half of the total residual power in conservative manner.

The reactor details for calculation such as thermal power, mass and volume of metal inside core was adopted 600MWe reactor(AP600).

The value for calculation is shown Table 1.

Reactor thermal power	1800 MWth
Total decay heat	15 MW (0.8% of thermal power
Vessel radius	2 m
Steel mass in core	155.5 ton
Steel volume in core	18.97 m^3
Zr mass	15.8 ton
Zr volume	2.58 m^3

Table 1. Reactor specification for calculation

And the evolution of the density of oxidic and metallic phases which depends on Zr oxidation fraction(J.M. Seiler et al) was referred.

	%	h_lim [cm]	M(top) [ton]	M(bot) [ton]	M(tot) [ton]
Zr cladding (Oxidation fraction)	25	0.39	34	32	66
	30			25	59
	40			14	48
Sic cladding	X			X	34

Table 2. Amount of metal layer for preventing CHF

Table2 shows the evolution of minimum metal layer height and corresponding mass that needs for preventing CHF at vessel wall(Referred CHF value at vessel wall(vertical plate) was referred from SULTAN exp- about 1.5MW/m^2)

From PRA results AP600(Theofanous et al) the 70 ton of metal layer formation is the most probable case. So calculation has been conducted for this case.

If we take the heat flux in case of oxidation fraction 25% as a denominator for heat flux ratio, the evolution of heat flux is shown Table 3.

	Oxi. Fraction 25	Oxi. Fraction 30	Oxi. Fraction 40	Sic Cladding (No Zr)
Height of layer	0.43	0.51	0.63	0.80
Heat flux ratio	1	0.84	0.68	0.54

Table 3. Heat flux comparison

5. Conclusion

Amount of molten metal is main factor of determining wall heat flux. SiC reduces the effect of Zr which leads molten pool stratification, three layer formation. Thermal margin for CHF at vessel wall is enlarged in case of SiC using rather than Zr using. Performance of SiC cladding in case of normal operation should be evaluated more. It has relatively worse thermal conductivity than the usual material, Zr.

REFERENCES

[1] J.M. Seiler et al, Consequences of Material Effects on In-vessel Retention, Nuclear Engineering and Design 237 (2007), pp.1752-1758

[2] T.G. Theofanous et al, In-vessel Coolability and Retention of a core melt, Nuclear Engineering and Design 169 (1997), pp.1-48

[3] R.L. Webb, Principles of Enhanced Heat Transfer, John-Wiley & Sons, New York (1994)

[4] J.R. Thome, Enhanced Boiling Heat Transfer, Hemisphere Publishing Corporation, Washington, DC (1990).

[5] D.M. Carpenter, Assessment of Innovative Fuel Designs for High Performance Light Water Reactors, Master Thesis(MIT) 2006

[6] D. Feng, Innovative Fuel Designs for High Power Density Pressurized Water Reactor, Ph.D Thesis(MIT), 2005

[7] Z. Alkan et al, Silicon Carbide Encapsulated Fuel Pellets for Light Water Reactors, Progress in Nuclear Energy 38 (2001), pp.411-414