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Control Carbon to Prevent corium Stratification In-Vessel Retention

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1. Introduction

APR1400 and OPR1000, Korea Hydro & Nuclear power plant core meltdown accident has been evaluated a high level in severe accident. When the reactor core is melted down, it is stratified into the metal layer and the ceramic layer. As the heat conductivity of metal layer is higher than that of the ceramic layer, heat concentration occurs in the upper part of the bottom hemisphere which comes into contact with the metal layer. As a result, the thermal margin decreases, and the nuclear reactor vessel may be destroyed. To control Carbons, which is the major cause of stratification, Ruthenium and Hafnium are inserted inside the lower reactor head which initiates a chemical reaction with Carbon. SPARTAN program is used to confirm a reaction probability which is measured in bond energy and strength etc. To analyze the possibility of bonding with Carbon, the initial property of Ruthenium and Carbon are measured during the calculated absorbing process. After following that theory, the Spartan program is able to determine if it can insert the metal. After verifying the combination of Ruthenium and Carbon, the Spartan program analyzes the impact of the Carbon to prevent the corium stratification. It determines the possibility of the success with the introduction of the IVR concept.

2. Methods and Results

As an alternative to prevent core melt stratification, we determine the composition of the core melt. Then using Ruthenium, Hafnium, find out about the bonding energy.

2.1 Decision Metal

Important requirements when determining the metal are as follows.

1) Set the specific gravity from 8 to 13 kg To be similar to UO2 property
2) No radioisotope should be included.
3) It must be possible to explain the principle of combination with Carbon.
4) Economically
5) To secure integrity during normal operation
6) Melting point > 2300 Boiling point > 2800

Table Ⅰ.Properties of the elements and certain molecules

	Corium	Corium	Hafnium	Rhenium
Symbol	Ceramic	Metal	Hf	Re
Atomic Number	-	-	72	75
Atomic or Molecular Number	-	-	13.29	186.207 g/mol
Melting Point	1600℃	1600℃	2230℃	3186℃
Density	6~7 g/㎤	8~12 g/㎤	13.29 g/㎤	12.45 g/㎤
Radioacitve			Stable	Stable
Price	-	-	562$/kg	5641$/kg

2.2 Corium and Metal

2.2.1 Status of Corium according to time

Within the first 200s, the thin vertical steel rods/structures are surrounded by debris and have completely melted, adding to the mass to of the liquid while plates remain mostly intact. At about 800s, debris field begins to lose its mostly homogenous liquid/solid mixture composition and divides into two distinct regions. The liquid metal/oxide stratification can be seen at 1400s. By 1800s, the debris temperature has reached the melting temperature of UO2 and the region occupied by debris shrinks starting from 2600s on until 4000s, at which point nothing is essentially left. From 4000s on, the configuration consists of a metal/oxide stratified liquid field.

2.2.2 Effect of Carbon in corium

1) In all experiments conducted to study the behavior of the oxidic-ceramic melt pool, composed of U-Zr-O, slightly oxidized and having a Carbon content of 0.3~0.4 wt.%, two unmixed layers were formed and stratification occurred.
2) In the behavior experiments for oxidic-ceramic melt pool with a Carbon content of 0.01 wt.% or less, no stratification occurred.

2.2.3 Carbon affinity dependent on temperature

It is difficult to break Carbon bond because Carbon affinity of Ruthenium is lower than Carbon affinity of boron. However the average temperature of corium is determined 2800℃, binding energy goes down and corium is in a molecular state. Despite the high temperature, binding energy of Carbon with boron is still strong. Therefore Ruthenium and Hafnium are difficult to estimate the binding affinity of Carbon. To estimate the binding energy of Carbon with Ruthenium at high temperature, temperature dependent affinity of Carbon with boron must be analyzed. After finding the data of affinity of Carbon and corium property, the Ruthenium alloy is used to increase binding energy of Carbon and make a similar corium density. When a severe accident occurs, Ruthenium alloy reacts first with Carbon, a component of the reactor corium, and prevents stratification.

2.2.4 Analysis of Carbon and Ruthenium by using Spartan

By using SPARTAN program which is a molecular modeling and computational chemistry application, we calculate the binding energy between Carbon and Ruthenium. An example that is shown below is the calculation method of bond energy between NH3 and BH3. When meltdown occurs, possibility of combination between Carbon and Ruthenium can be determined by using this method.

Table Ⅱ. Result of bonding energy by Spartan program

	Bond Energy (kJ/mol)
NH3	-12.83
BH3	142.83
NH3BH3	-38.08

NH_3BH_3 *Bond Energy*

$$Bondenergy = (E_{acid} + E_{base}) - E_{adduct} =$$
$$(-12.83 + 142.83) - (-38.08) = 168.08\ kj/mol$$

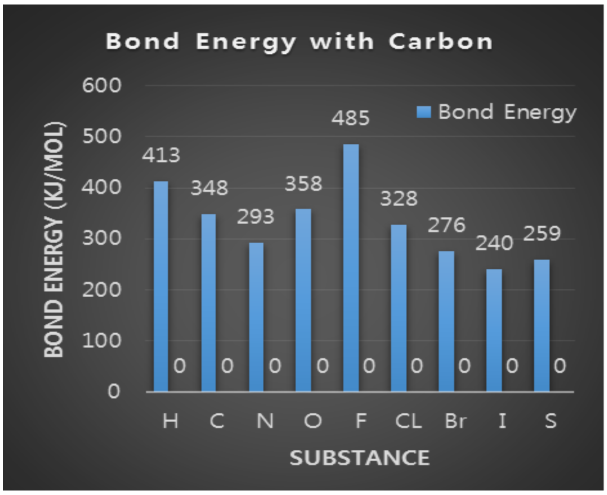

Fig Ⅰ. Bond energy with carbon

3. Conclusions

Ruthenium is suitable to Carbon bonding process to decrease affect to corium behavior which do not form stratification. The metal which can combine with Carbon should be satisfied with temperature as high as 2800℃. Therefore, the further research works are determined by using the Spartan program to calculate the Carbon and Ruthenium bonding energy, and to check other bonding results as follows.
After check the results, review this theory to insert the Ruthenium in reactor vessel.

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