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Severe Accident Mitigation by using Core Catcher applicable for Korea standard nuclear power plant

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1. Introduction

Nuclear power plants have been designed and operated in order to prevent severe accident because of their risk that contains tremendous radioactive materials that are potentially hazardous. Moreover, the government requested the nuclear industry to implement a severe accident management strategy for existing reactors to mitigate the risk of potential severe accidents. However, Korea standard nuclear power plant(APR-1400 and OPR-1000) are much more vulnerable for severe accident management than that of developed countries. Due to the design feature of reactor cavity in Korea standard nuclear power plant, inequable and serious Molten Core-Concrete Interaction(MCCI) may cause considerable safety problem to the reactor containment liner. At worst, it brings the release of radioactive materials to the environment. This accident applies to the fourth level of defense in depth(IAEA 1996), 'severe accident'. This study proposes and designs the 'slope' to secure reactor containment liner integrity when the corium spreads out from the destroyed reactor vessel to the reactor cavity due to the core melting accident. For this, make the initial corium distribution evenly exploit the 'slope' on the basis of the study of Ex-vessel corium behavior to prevent inequable and serious MCCI, in order to mitigate severe accident.

2. Methods and Results

Analyze the vulnerable point of severe accident in the Korea nuclear power plant, and survey physical properties of the Ex-vessel corium through literature search of abroad studies dealing with MCCI and core catcher. Based on this, the final design of the 'slope' is performed to approximate time-dependent physical properties of the ex-vessel corium and applies fluid formula in respect of the fluid that spreads along the slope.

2.1 Physical properties of ex-vessel corium

The following figure gained approximate time-dependent viscosity and temperature, from based on the 'VULCANO' experiment by using materials similar to corium(VE-07, VE-U1).

Table.1 Composition of VE-07

Material	HfO_2	ZrO_2	SiO_2	Others
Fraction	34.3%	25.5%	24.9%	15.3%

Table.2 Composition of VE-U1

Material	UO_2	ZrO_2	SiO_2	Others
Fraction	45%	19.3%	16.6%	19.1%

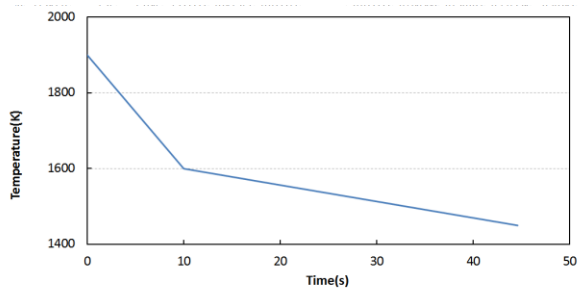

Fig.1. Simplification figure by combining two linear expression time-temperature graph of VE-U1 that measured in experiment of 'VULCANO' (Journeau, Sudreau, Magne&Cognet 2001)

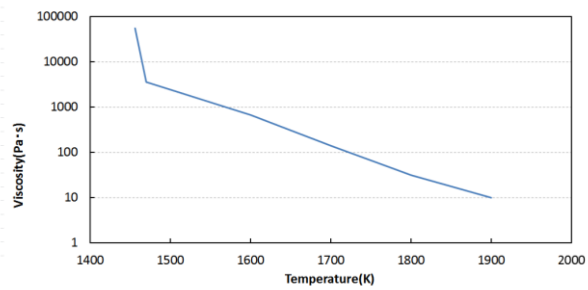

Fig.2. Simplification figure by combining two linear expression temperature-viscosity graph of VE-07 that measured in experiment of 'VULCANO' (Journeau, Sudreau, Magne&Cognet 2001)

2.2 Assumptions

1) Whole corium releases in 20minutes
2) Constant flow-rate during release
3) No MCCI during corium release(negligible)
4) Corium releases only at middle of the reactor vessel bottom
5) Density of corium is 6,500kg/m^3 constantly

2.3 Calculation method

Consider an incompressible Newtonian fluid of viscosity ν. It is driven by gravity on a rigid slope of angle θ to the horizontal. Effects by inertia of the fluid, any motion in the ambient fluid, surface tension at the free interface and dynamics near the contact line at the front of the current are all neglected. If the characteristic flux at the source Q and the time scale of the flow T, then the extent of the current can by scaled by X, where

$$X = T\left(\frac{Q^2 g sin\theta}{3\nu}\right)^{1/3} \quad (1)$$

2.4 Results

Time-distance graph between 1~5 degree of angle θ to the horizontal is as below. At the region that viscosity soars the vicinity of 40 seconds, the velocity decreases sharply. Consequentially, the corium solidifies practically at 40 seconds and more.

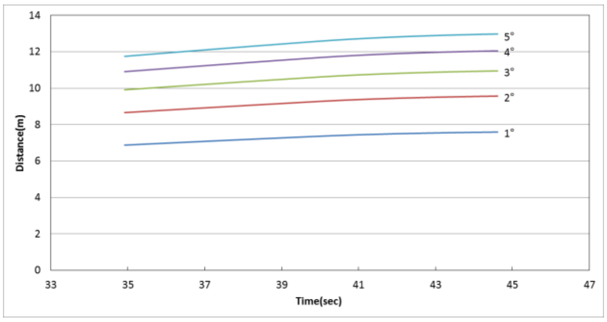

Fig.3. Time-distance graph of corium calculate by the equation (1)

Based on the result, the slope was designed. By trigonometric function, the base line and the slope(angle) are 10.7m and 3 degree respectively, where the inclined plane(slope) is

$$10.7\text{m} \div \cos\theta = 10.7146841\text{m}\ (\theta = 3^{\circ}) \quad (2)$$

And, the height is

$$10.7m \times \tan\theta = 0.561m(\theta = 3^{\circ}) \quad (3)$$

The corium driven by gravity on a rigid slope and it directly flows downward(horizontality independent). Accordingly, the width of the slope is negligible value(same as reactor cavity: 5m).

3. Conclusions

The viscosity has a dominant position in the calculation. As shown in Fig.2, the temperature of the corium 1900K to below, it has a considerable difference in viscosity at in-vessel(above 1900K) and ex-vessel(below 1900K) state. In short, the exposed(ex-vessel) corium viscosity gives outstanding variety for velocity of the flow. According to the result, the spread out distance on the slope is 10.7146841m, considering the rough surface of the concrete(slope) and margin of reactor cavity end(under 11m). Easy to design, production and economic feasibility are the advantage of the designed slope in this study. However, the slope design may unsuitable when the sequences of the accidents did not satisfy the assumptions as mentioned. Despite of those disadvantages, the slope will show a great performance to mitigate the severe accident. As mentioned in assumption, the corium releasing time property was conservatively calculated(fastest). So, applying the slope on the reactor cavity can mitigate the accident any more than not, even accident development unsuspected sequences(flow, releasing time, vessel failure position).

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