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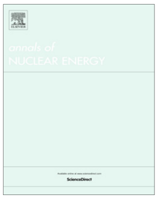

Preliminary study on the fuel-coolant interaction triggered by thermal effect

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ABSTRACT

The phenomenon of thermal interaction plays a key role in fuel and coolant interaction (FCI) during NPP's severe accidents, which determines the ratio of heat transferred to mechanical energy. However, the phenomenon is still not well understood due to its transient process and various involved likely mechanisms. In the present study, a new facility for intermediate-scaled FCI experiments has been set up, named ISFCI, mainly concentrating on the influencing factors and thermal interaction mechanism of high melting substances within the confined space. In the first series of tests, 304SS and Fe-Mo have been chosen for the melt materials with superheating temperature ranging from 150 °C to 300 °C. The initial mass of each material has been controlled by 1 kg or 2 kg. By grouping and characterizing the debris, the effect of initial mass, melt properties and melt superheating temperature on thermal interaction has been qualitatively analyzed. In addition, the pressure data recorded from these tests have been used to quantify the influencing analysis. Based on the morphology analyzing method and quantification, two relatively worse conditions that could cause larger and/or longer pressure increase have been identified.

1. Introduction

In severe accident scenarios, the core-melt accident may occur because of lack of sufficient cooling. Without enough coolant supply, the nuclear core starts to degrade from a relatively high position. As the core is partially damaged, core melt may go through downwards into the lower plenum, and even relocate in the lower head of the vessel. If there is a little water remaining in the lower head, maybe a sort of in-vessel vapor explosion can be induced. While if the lower head has already been dried out, the residual melt may continue to melt through the structure, and finally be scattered around the reactor cavity. Once the high temperature melt contacts with the volatile coolant, the fuel-coolant interaction (FCI) can occur, which may result in vapor explosion and seriously damage the reactor cavity or the containment structure. Due to its likely radioactive threats and many uncertain negative effects involved, researchers have drawn much attention to this issue of FCI.

In regards to interpreting the phenomenon of fuel and coolant interaction, a large set of experiments were launched, one of which was large scale tests of corium or stimulant materials. In this group, ALPHA (Yamano et al., 1995; Yamano et al., 1999) researched on the vapor explosion characters, including dynamic pressure history and debris distribution, and pointed out that such involved FCI mechanisms should be figured out. KROTOS (Huhtiniemi and Magallon, 2001; Hohmann et al., 1995; Huhtiniemi et al., 1999) focused on vapor explosion and energy conversion process based on spontaneous trigger or external trigger condition, and firstly presented that the interaction between hot alumina and cold water is much more violent, thus generating a very strong and sharp pressure increase. However, due to lack of FCI mechanism analysis, such new findings could not completely be adopted in mechanistic code for FCI. KAERI carried out the TROI (Song et al., 2002, 2003; Kim et al., 2008) tests, analyzing the specific effect of melt material on vapor explosion, and concluded that ZrO_2 can trigger an even higher vapor explosion. While, if iron was added to the melt, it seemed that the spontaneous vapor explosion was suppressed, but this result still needs to be examined. The other group of experiments was to research on interaction mechanism by small scale tests. For example, SIGMA (Luo et al., 1999) observed the micro-interaction process by high speed camera, and described the mixing region. MISTEE (Park et al., 2009) was highly instrumented by two high speed cameras and an X-ray detector, depicting the premixing and fragmentation process exactly. Besides, SJTU (Lin et al., 2009) systematically analyzed various impact factors on thermal fragmentation mechanisms by SSFT

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facility and a typical thermal fragmentation partition map was drawn.

Recently, based on the contribution of OECD (OECD/NEA, 2007), it was recognized that the level of loads would not challenge the integrity of the reactor vessel. However, the problem is that the ex-vessel FCI would probably cause the damage of reactor cavity, affecting the integrity of the containment building. In addition, plenty of FCI codes have been adopted in order to obtain better estimations. People still can't select the best result from those predictions obtained from the codes so far, which makes the potential damage unpredictable. Therefore, further research on the thermal interaction of coolant and melt must be carried out aiming at getting better interpretations of this issue.

SJTU has set up an intermediate-scaled experimental facility named 'ISFCI' to carry out the thermal interaction analysis using stimulant materials. The objective of the ISFCI is to study the mechanisms behind the thermal interaction and develops a new mechanistic model for this process, based on the new experimental findings. In this paper, the first series of test results are presented, in which the debris characteristics under different initial conditions will be firstly described, followed by FCI mechanisms behind. Finally, the corresponding pressures generated from each trial will be qualified and quantified so as to support the analysis of the impact factors.

2. Design of the ISFCI facility

In order to investigate the thermal interaction of coolant and melt, a new facility for intermediate-scaled experiments has been built, which can be schematically shown in Fig. 1. The ISFCI facility consists of a furnace in the upper part, a gate valve, a fast valve in the middle part, a graphite drill at the end of one pipe and a pressure vessel which contains a debris collector in the lower head. All the components are closely connected with each other, in case of pressure loss.

2.1. Furnace and melt release equipment

An induction furnace, which is placed on the second floor of the platform, is designed to heat the experimental material to overheating state in a graphite crucible and the design temperature is around 2000 °C. With the help of the infrared thermometer installed in the center of the furnace lid and the PLC module, the heating temperature could be controlled, stored and presented along the way as well. The graphite crucible is a hollow cylinder, about 300 mm in height, 70 mm in inner diameter and 5 mm in thickness, which can contain 3–4 kg simulant melt at most. Besides, some auxiliary systems must be included, such as prevacuum system, which contains a vacuum pump, some valves and pipes. In order to remove the oxygen from the furnace, the vacuum pump should be used twice prior to the experiment. Considering the request for melt release, the furnace must be maintained in a positive pressure. Therefore, when the oxygen content is relatively low, the protective gas (N_2) is supplied from the protective gas inlet and covers the whole heating zone. When the melt reaches a certain temperature, the graphite crucible drops out of the furnace after pneumatically rotating the platform beneath the heating zone, and the crucible will go through the gate valve. The platform is also controlled by the PLC module and the air supply is from an air compressor (0.9 m^3/min, 1.3 MPa).

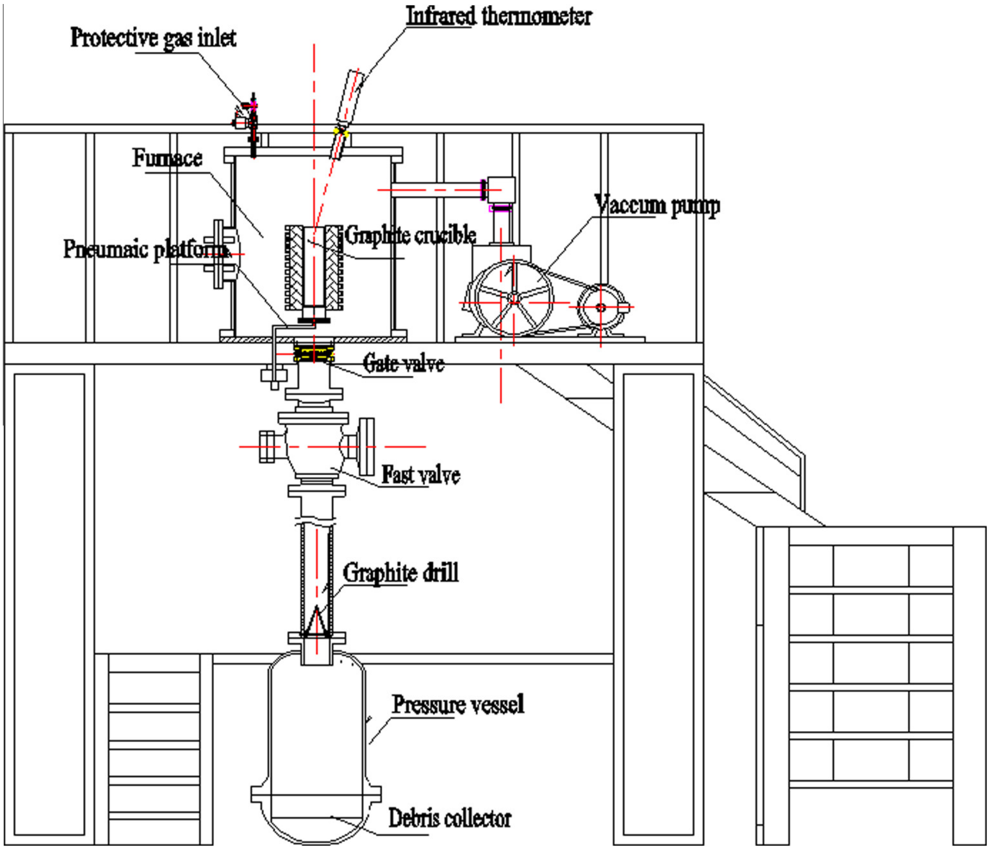

Fig. 1. Schematic diagram of the experimental facility.