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Review

Corium behavior and steam explosion risks: A review of experiments

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ABSTRACT

After the Three Mile Island accident, numerous studies on the severe nuclear accident have been conducted. In a degraded core accident, the high-temperature melt corium may drop into the low-temperature coolant, which is called the fuel coolant interaction (FCI). Due to the velocity difference between the melt jet and the coolant as well as the violent film boiling around the melt, the melted corium may fragment into small particles. With the increase of the contact area between the melted corium and the coolant, plenty of coolant steam is produced. The timescale for heat transfer is shorter than that for pressure relief, resulting in the formation of shock waves and/or the production of missiles at a later time during the expansion of coolant steam explosion. During a severe reactor accident scenario, steam explosion is an important risk, even though its probability to occur is pretty low, since it could lead to large releases of radioactive material, and destroy the reactor vessel and surrounding structures. This study provides a comprehensive review of vapor explosion experiments, especially the most recent ones. In this review, small- to intermediate-scale experiments related to premixing, triggering and propagation stages are first reviewed and summarized in tables. Then intermediate- to large-scale experiments using prototypic melt are reviewed and summarized. The recent OECD/SERENA2 project including KROTOS and TROI facilities' work is also discussed. The studies on steam explosion are vital for reactor severe accident management and will lead to improved reactor safety.

Contents

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1. Introduction

Steam explosion is a violent fuel-coolant interaction (FCI) with a significant amount of steam generated and exploded and is of vital importance in nuclear reactor severe accident management. Violent interactions are observed when the high-temperature liquid comes into contact with the cold volatile liquid in a steam explosion (Zhou et al., 2014). The timescale for heat transfer is much shorter than that for pressure relief, resulting in the formation of shock waves and/or the production of missiles at a later time during the expansion of coolant steam explosion. The steam explosion may endanger the reactor vessel and surrounding structures. Then there is a possible release of radioactive materials into the environment from a nuclear reactor. So, steam explosions have been widely studied to achieve a better reactor severe accident management (Berthoud, 2000).

The fuel-coolant interaction can generally be divided into four stages: coarse premixing, triggering, propagation, and expansion (Abe et al., 2006), as shown in Fig. 1. At the coarse premixing stage, the melt jet under high temperature drops into the coolant. Then the molten jet is dispersed into droplets. Due to rapid heat transfer and phase transition between the high-temperature melt and low-temperature coolant, vapor films will be generated surrounding the melt droplets. At the triggering stage, the effect of instability or external pressure pulse could lead to a collapse of the films. Then the melt corium contacts with the coolant directly, which will lead to violent evaporation and steam generation.

This paper provides a comprehensive review of the experiments on fuel-coolant interaction (FCI) and steam explosion. Section 1 briefly introduces the definitions, different stages, and importance of fuel-coolant interaction and steam explosion. Then in Section 2, various FCI scenarios are introduced, including both in-vessel and ex-vessel poured/stratified FCIs. Section 3 reviews the small to intermediate experiments related to the premixing, triggering and propagation stages, while Section 4 summarizes the large-scale experiments conducted in different facilities. Section 5 provides some observations and discussions on the experimental results and the material effects. We conclude the paper in Section 6. The premixing and the explosion are the most critical stages in a steam explosion. The small-scale experiments are used for the mechanism understanding and model validation since the premixing process cannot be measured precisely from large-scale experiments, while the large-scale experiments provide a steam explosion experimental data aggregation from different large-scale facilities.

2. Various FCI scenarios

As shown in Fig. 2, four situations in LWR are identified in which a steam explosion could occur. An in-vessel poured FCI

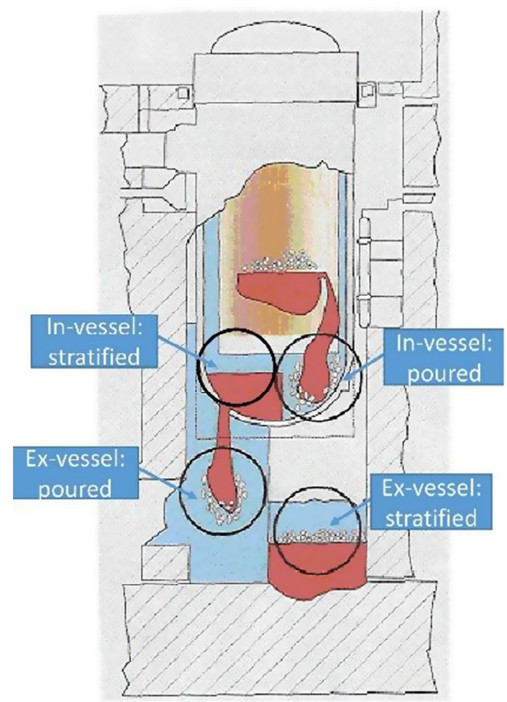

Fig. 2. Various FCI scenarios in LWR reactors (Seghl et al., 2008).

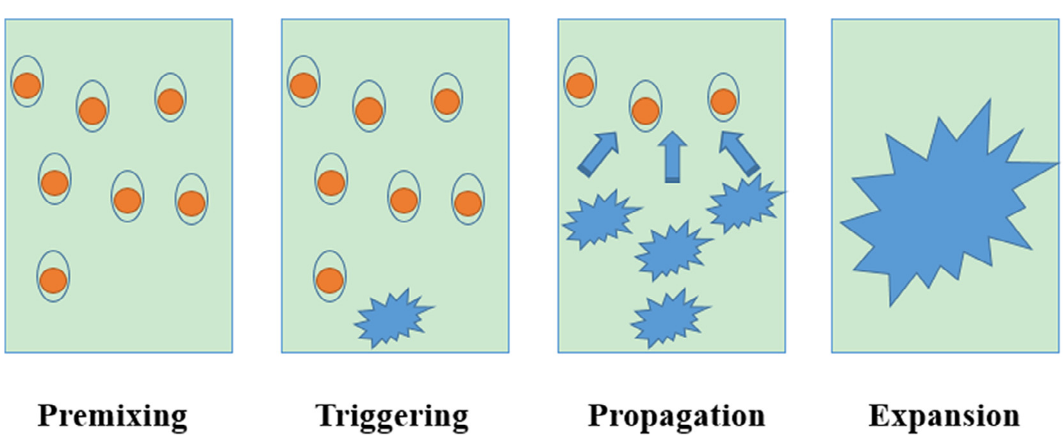

Fig. 1. Four stages of steam explosion (Abe et al., 2006).