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# A two-dimensional experimental investigation on debris bed formation behavior

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ABSTRACT

Studies on debris bed formation behavior are of crucial importance for the improved evaluation of Core Disruptive Accidents (CDA) that could occur for Sodium-cooled Fast Reactors (SFR). In this work, to clarify the mechanisms underlying this behavior, a series of experiments was performed by discharging solid particles into two-dimensional rectangular water pools. To obtain a comprehensive understanding, various experimental parameters, including particle size (0.256~8 mm), particle density (glass, alumina, zirconia, steel and lead), particle shape (spherical and irregularly-shaped), water depth (0–60 cm), particle release pipe diameter (10–30 mm), particle release height (110–130 cm) as well as the gap thickness of water tank (30–60 mm), were varied. It is found that due to the different interaction mechanisms between solid particles and water pool, four kinds of regimes, termed respectively as the particle-suspension regime, the pool-convection dominant regime, the transitional regime and the particle-inertial dominant regime, are identified. The performed analyses in this work also suggest that under present experimental conditions, the particle size, particle density, particle shape, particle release pipe diameter and water depth are observable to have remarkable impact on the above regimes, while the role of particle release height and gap thickness of water tank seems to be less prominent. Knowledge and data from this work might be utilized for the improved design of core catcher as well as analyses and verifications of SFR severe accident analysis codes in China in the future.

## 1. Introduction

The disaster in March 2011 at the Fukushima Dai-Ichi nuclear power plant in Japan has caused many people to realize that severe accidents, including the Core Disruptive Accidents (CDAs), might occur, even if their probability is extremely lower (Cheng et al., 2014a, 2015). During a postulated CDA in a Sodium-cooled Fast Reactor (SFR), possibly as a consequence of rapid quenching and fragmentation of core materials, a multiphase flow system can form that could be composed of a mixture of liquid sodium, molten fuel, molten structure, refrozen fuel, solid fuel pellets, fission gas, fuel vapor, and other materials (Tentner et al., 2010). A deposition of this system will lead to the formation of debris beds over the core-support structure and/or in the lower inlet plenum of the reactor vessel, as depicted in Fig. 1 (Zhang et al., 2010, 2011).

To prevent the penetration of the reactor vessel by molten fuel, and distribute molten fuel or core debris formed in a CDA into non-critical configurations, in-vessel retention devices (e.g. the core catcher) are used in some SFR designs (Tentner et al., 2010; Waltar and Reynolds, 1981). Although the detailed structure of the core catcher (e.g. single-layer or multi-layer) might be different depending on the reactor-type in different countries (Nakai et al., 2010; Ren, 2015; Vasilyev et al., 2013), it is expected that during a hypothetical CDA, after being quenched and fragmented into fuel debris in the lower plenum region, discharged molten fuel should be accumulated on the layers of the core catcher. To stably remove the decay heat generated from the debris bed on the core catcher, thus, the size, retention capability and structure of the catcher should be carefully designed.

Unfortunately, over the past decades, although extensive studies on debris bed hydrodynamics and heat transfer were performed (Cheng et al., 2010), most of them generally assumed that the upper surface of debris bed is level. Noting the importance of debris-bed geometry (e.g. height) in the heat removal capability, recently by

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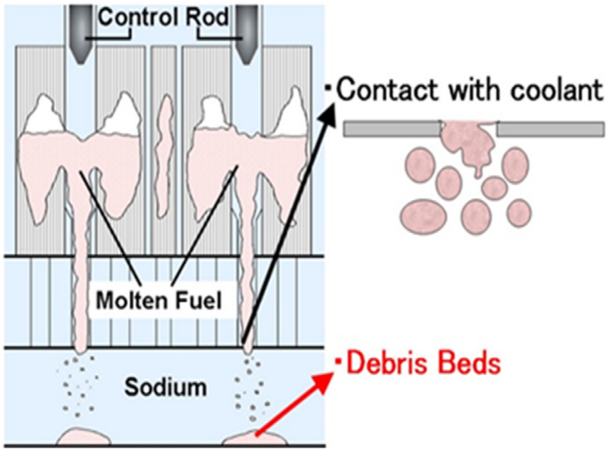

**Fig. 1.** Debris bed profile.

assuming that a conically-shaped debris bed might be initially formed, Cheng et al. (2011a, b; 2013a, b, c; 2014b, c) performed several series of experiments on the so-called debris bed self-leveling behavior (see Fig. 2). Overall, as illustrated in Fig. 3, their experiments can be generally divided into two categories, namely the macroscopic leveling experiments and microscopic flow-regime investigations. Due to the nontransparency of particle beds, the macroscopic leveling experiments were mainly conducted with the purpose to clarify the overall characteristics of leveling (Cheng et al., 2013a, b; 2014b, c), namely the role of experimental parameters (such as particle properties and bubbling rate) on the leveling onset and evolution. As for the microscopic flow-regime series (Cheng et al., 2010, 2011a, 2013a), which also consists of several well-organized tests performed at various bubbling conditions (as shown in Fig. 3), was specifically carried out to ascertain the flow characteristics within particle beds, thus providing convincible visual evidence (esp. bubble-particle interaction) for supporting the overall understandings. It has been confirmed that by combining the knowledge from flow-regime investigations the observed overall leveling characteristics can be understood more effectively (Cheng et al., 2013a).

In this paper, motivated by acquiring some evidence to verify whether the initial particle bed formed is conical or not, a series of experiments on the debris bed formation behavior is conducted within a variety of conditions including much difference in particle size (0.256~8 mm), particle density (glass, alumina, zirconia, steel and lead), particle shape (spherical and irregularly-shaped), water depth (0–60 cm), particle release pipe diameter (10–30 mm), particle release height (110–130 cm) and the gap thickness of water tank (30–60 mm). The experimental apparatus and procedures are described in Section 2, while the obtained results and their interpretations are discussed in detail in Section 3. Knowledge and

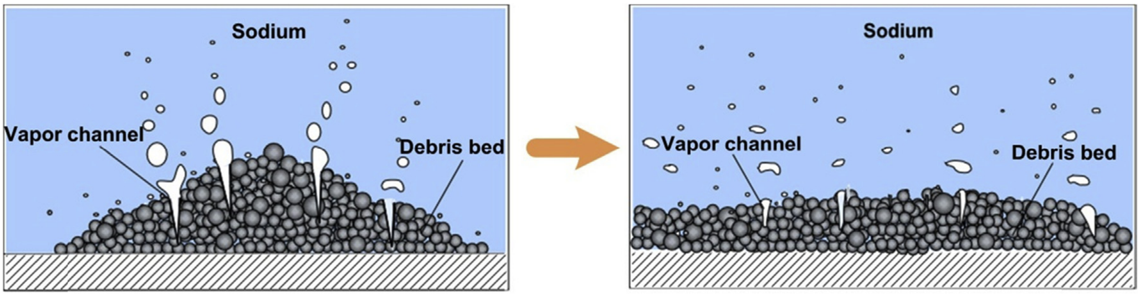

**Fig. 2.** Debris bed self-leveling behavior.

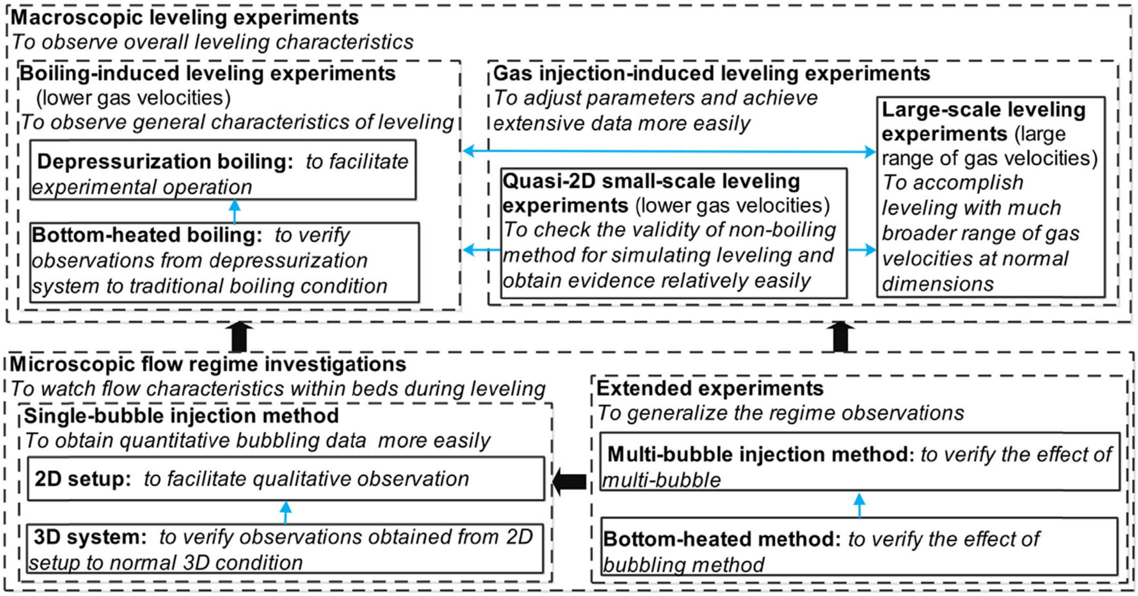

**Fig. 3.** Constitution of leveling-related experiments performed by Cheng et al. (2013a, 2014b). (a) Schematic view of experimental system (b) Detailed view of the main apparatus.