In pebble bed–type nuclear reactors, the fuel pebbles form a randomly stacked bed with a nonuniform packing density. To investigate flow and heat transfer through these beds and to develop realistic models, we need a good understanding of the nature of randomly stacked beds and validated computational methods that can generate realistic beds. To this end, the average packing fraction (PF) and the radial and axial PF profiles were accurately measured of a bed containing 5400 acrylic pebbles with a diameter of 12.7 mm. In a second experiment, we determined the pebble locations of a bed containing 8900 glass pebbles with diameters of 1.66 to 2.00 mm using three-dimensional X-ray tomography, from which various microscopic stacking properties were evaluated for both the bulk of the bed away from the wall and in the near wall region. Results were compared with the properties of a bed that was generated by using a computational method based on the removal of overlaps to validate that method.

Results for the computed bed are in good agreement with the experiments and with the literature, giving confidence that the method is capable of generating beds with realistic packing structures, although the experimental results for the microscopic stacking properties in the near-wall region are of insufficient quality for a meaningful comparison. Analysis of the various results shows different stacking properties near the wall than in the bulk of the bed, indicating the stacking is anisotropic near a boundary forming semiordered layers parallel to the wall with hexagonal-like stacking properties, which implies flow and heat transfer might also be isotropic near the wall and could need different models near the wall than in the bulk to be accurately described. Finally, the probability distribution of PFs of small clusters of around 45 pebbles showed that the local PF inside a packed bed can vary strongly, both in the bulk and near the wall, which might significantly affect flow rates and could result in hot spots.

I. INTRODUCTION

The pebble bed–type very high temperature reactor (VHTR) is one of the main candidates for the next generation nuclear power plants; see, for example, the South African pebble bed modular reactor1,2 (PBMR) and the Chinese high temperature reactor (HTR) pebble bed modular3 (HTR-PM) reactor designs. Its main benefits include online refueling, high coolant outlet temperature resulting in more efficient electricity production and new applications such as hydrogen production, and passive safety, a particularly desirable property in light of the Fukushima accident. In a pebble bed reactor, the fuel is contained in TRISO particles, which in turn are encapsulated in graphite pebbles. These pebbles form a randomly stacked bed inside a graphite reflector through which the helium coolant is pumped.

In pebble bed calculations, the bed is commonly modeled as a fully homogenized mixture of coolant and pebble materials using a uniform packing fraction (PF). However, it is well known that the packing density of randomly stacked beds is not uniform but exhibits strong...