Benchmark Data for Validation of Computational Simulations of Nuclear System Thermal Fluids Behavior for the Texas A&M Upper Plenum Experimental Facility

ASME V&V 30 Subcommittee

I. INTRODUCTION

Energy demand is currently a major concern for world leaders. Nuclear power plants are one of the technological advancements that can supply this demand. With nuclear reactor technologies still under development, researchers continue to work to develop Generation IV reactors. Generation IV is the future of nuclear reactors, and is safer and more economical than previous generations. One of the important Generation IV reactors is the High Temperature Gas-cooled Reactor (HTGR), shown in Figure 1, with a core outlet temperature of ~1000°C or higher (Technology Roadmap, 2002).

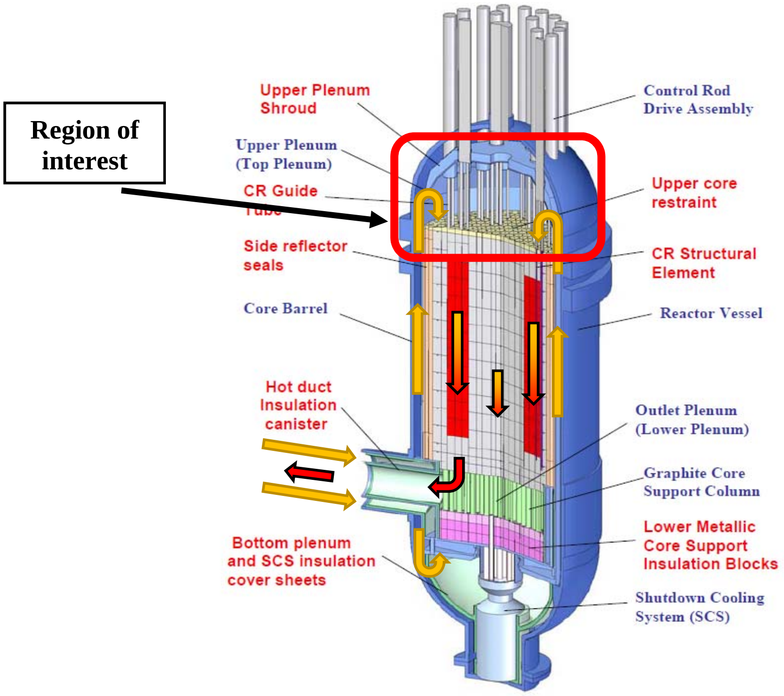

Figure 1: The core of the High Temperature Gas-cooled Reactor (HTGR), the red box shows the upper plenum of it; the region of interest in this study.

Given that the HTGR is cutting edge technology, investigating its safety is a key to ensuring its success. The U.S. Department of Energy (USDOE) and Idaho National Laboratory (INL) are developing a safety code for the reactor to be used under normal operations and accidental scenarios. Two main accident scenarios that occur at the upper plenum of the HTGR include the depressurized conduction cooldown (DCC) and the pressurized conduction cooldown (PCC). In the DCC or the Loss-Of-Coolant Accident (LOCA), the primary coolant undergoes a quick depressurization, thus causing a reactor scram. With the pump failing, a natural circulation occurs between the reactor vessel and the confinement leading to a rejection of the head by natural circulation. Meanwhile, the PCC or Loss of Flow Accident (LOFA) occurs when a force loss happens during a reactor scram due to power loss. During a reactor scram, blowers and pumps cease working, but the primary system remains at full pressure. Here, natural convection will move the heat from the core to the reactor cavity cooling system (RCCS). At the upper plenum of the reactor, the mixing of hot plumes that come from the heated coolant channel (aka the fuel) of the reactor core will occur (Haque et el. 2006).

Researchers at the Texas A&M University have performed flow experiments to study the flow mixing of a single jet and multiple jets in a scaled facility of the HTGR to support the research on advanced nuclear reactors. The general purpose of these experiments is to conduct high spatial and temporal resolution measurements of velocity and temperature fields related to flow mixing and heat transfer in the upper plenum when the jets/plumes emerge from the core. The ultimate goal of the research project is to study the flow and heat transfer characteristics of isothermal and non-isothermal single- and multiple jets mixing in the upper plenum volume and impinging on the top wall. The research activities will provide an experimental database suitable for validating numerical simulations. The experimental facility is a 1/16th scaled down version of the HTGR prototype.

This report includes the geometric information of the test facility and boundary conditions for the isothermal single-jet experiments.

II. TEST GEOMETRY DESCRIPTION

1. Facility overview

This section describes the experimental facility of jets/plumes mixing in the upper plenum, which is a 1/16th scaled down version of the reference Generation IV MHTGR. The scaling analysis of the test facility has been discussed in McCreery and Condie (2006). A brief review of the experimental facility is provided herein. Figure 2 shows an overview of the experimental facility, including the facility design with primary components, a flow chart, a sketch of the flow measurement area, and a core layout. The facility is a closed loop. The primary components of the facility were the lower and upper plena, and the core connecting the two plena. As the current core design of the HTGR contains 1020 fuel blocks arranged in a hexagonal shape, the core of the scaled facility contains 25 blocks that are built from 25 pipes (diameter $D_j = 19.05$ mm) to simulate the coolant channels. The coolant channels of the scaled facility were also arranged in the hexagonal shape and into five groups, whose locations were the top (T), bottom (B), right (R), left (L), and center (C), as shown in Figure 2.

For the isothermal single-jet experiments, the water is firstly filled into the water tank and a centrifugal pump is used to circulate the flow. The pump flow rate is regulated using a variable frequency converter, and measured by a flowmeter. Steady state is achieved when the flow maintains a stable flow rate. In the current study, the flow characteristics of a single, central jet (C) discharging and mixing of the fluid at the upper plenum for various Reynolds numbers were experimentally investigated. The Reynolds number is defined by $Re = V_{avg} D_j/\nu$, where ν is the kinematic viscosity of water at the average inlet temperature (see table 1), and V_{avg} is the mean bulk flow velocity at the inlet of the upper plenum. The current upper plenum is fabricated as a single body of clear cast acrylic, which provides more optical clearance to the interior volume of the fluid. To mitigate the optical distortions caused in the hemisphere curvature, a square correction box, containing the operation fluid, was installed around the hemisphere.

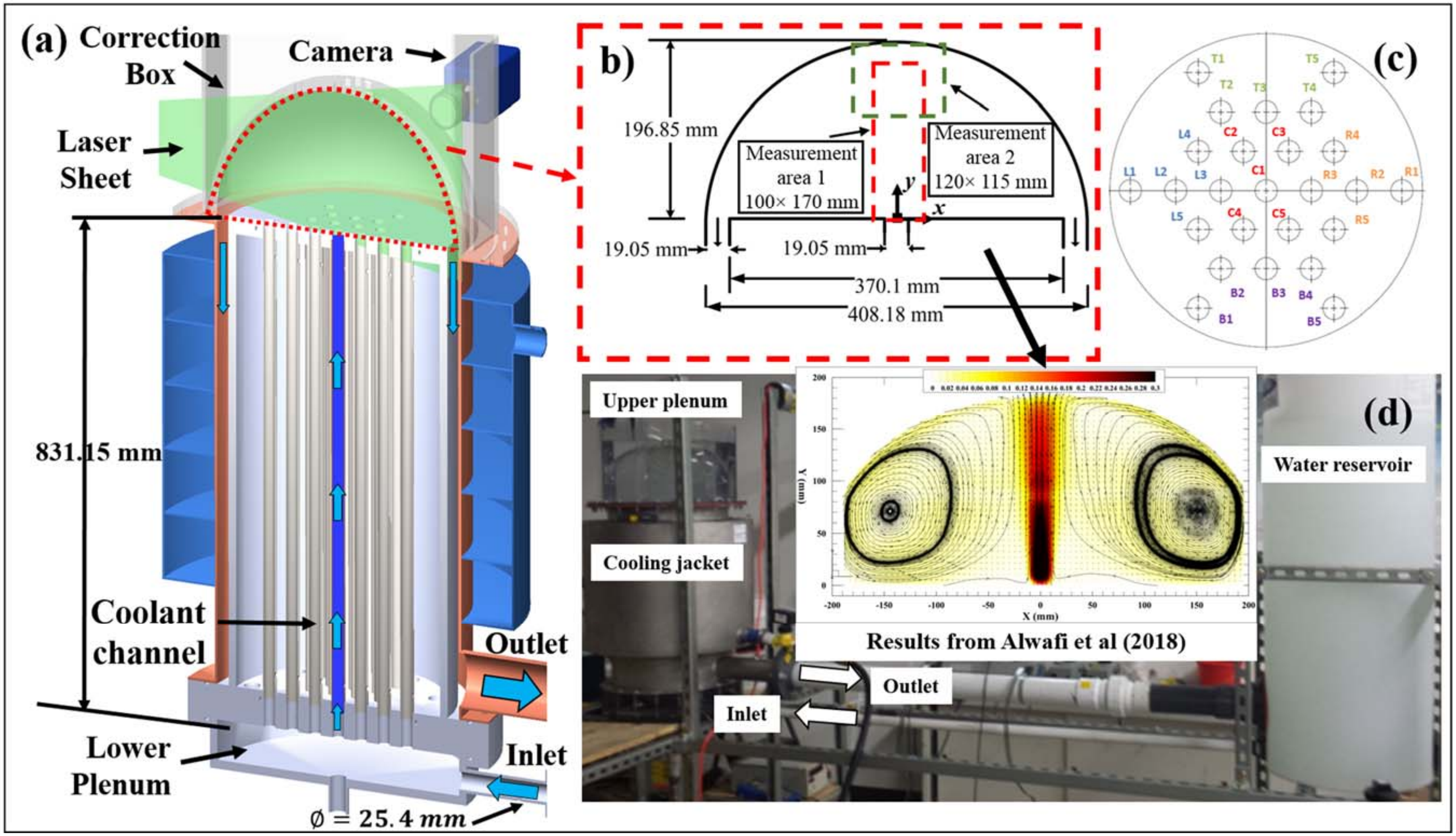

Figure 2: An overview of the experimental facility of 1/16th scaled of MHTGR, a) cross section of the core, upper and lower plena and particle image velocimetry (PIV) experimental setup for a single jet, b) upper plenum dimensions and the TR-PIV test areas, c) the core layout, *C*1 is the single opened channel in this study, and (d) a photo of the experiment facility. A close-up view shows the velocity streamlines in the upper plenum from full-field measurements of Alwafi et al. (2018).

2. Test section dimension:

Velocity measurements in the upper plenum were acquired using particle image velocimetry (PIV) technique in two measurement areas. The first measurement area is close to the jet inlet, i.e., measurement area 1, and the other is close to the upper plenum top wall, i.e., measurement area 2. They encompassed as 100 × 170 mm^2 and 120 × 115 mm^2 (width × height), i.e., approximately $5.25D_j \times 9D_j$ and $6.3D_j \times 6D_j$, for measurement areas 1 and 2, respectively. The origin of the coordinate system was at the center of the jet outlet, where the x and y coordinates represent the horizontal (transverse) and vertical (axial) directions, respectively, in the PIV measurement plane. In the current study, the flow characteristics of an isothermal single jet mixing in the upper plenum corresponding to five Reynolds numbers ranging from Re_1 = 3,413 to Re_5 = 12,819 were characterized by the PIV measurements.

Figure *3* shows the dimensions of the upper plenum from two perspective views.

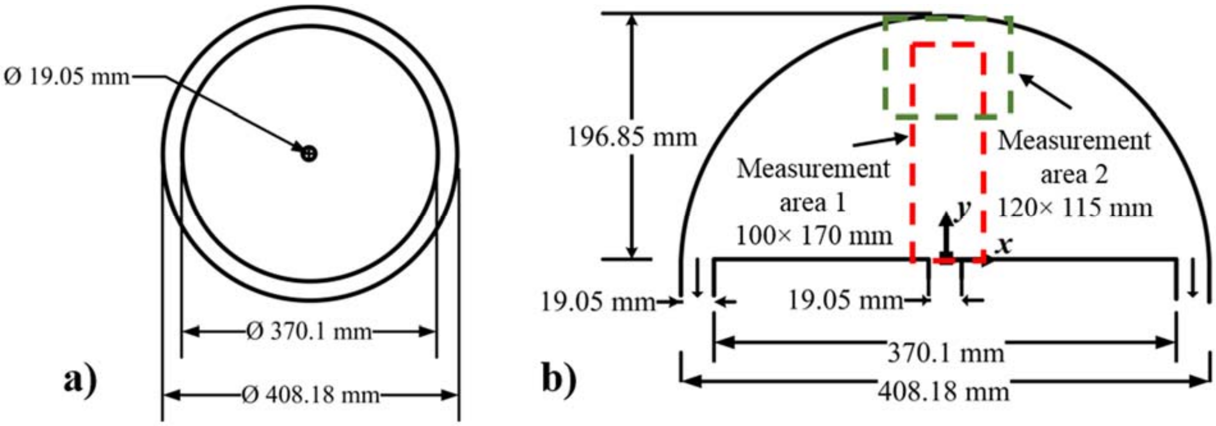

Figure 3: The dimensions of the upper plenum, a) top view and b) cross-section view.

III. BOUNDARY CONDITIONS OF THE ISOTHERMAL SINGLE JET EXPERIMENTS

This section provides boundary conditions of the isothermal single jet experiments corresponding to five different Reynolds numbers. Table 1 shows the mass flow rate at the jet inlet, the Reynolds numbers, and averaged inlet temperature.

Table 1: Mass flow rate at the jet inlet, Reynolds numbers, and the averaged inlet temperature for different experimental sets.

Set	Mass flow rate at the jet inlet [kg/s]	Reynolds number	Averaged inlet temperature [^{o}C]
1	0.05	3,413	19.74
2	0.089	5,963	
3	0.118	7,912	
4	0.158	10,622	
5	0.19	12,819	

References

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