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An Overview of Experiments using the Ultrasonic Doppler Method at the Power Reactor and Nuclear Fuel Development Corporation (PNC).

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Extended Abstract

The Power Reactor and Nuclear Fuel Development Corporation is engaged in research and development of the Japanese Liquid Metal Fast Breeder Reactor. Within the scope of this program, the Reactor Engineering Section is undertaking various thermal-hydraulic experiments investigating the adequate cooling of the reactor core under normal and transient conditions. One of the major measurement techniques used to study the various convective phenomena is ultrasound Doppler velocimetry. In this extended abstract, we present a brief overview of the experiments in which Metflow's UVP is used as a velocity measurement tool.

1. Investigation of penetrating flow under mixed convection conditions. (COPIES)

The penetration flow of cold coolant into the vertical sub-assembly channels under mixed convection conditions in the conventional design of the LMFBR has been investigated. A simplified schematic is shown in Figure 1. The phenomenom occurs under operating conditions when the natural convection-driven cold flow is such that it penetrates a vertical channel in which there is upward forced-flow of warmer coolant. This situation is subsequently of significance to the natural convection head that determines flow through the reactor core. In the present experiment, we measured the penetration flow into a simulated vertical channel and compared this with temperature measurements taken at several locations. First, since the temperature and velocity signals were qualitatively very similar, temperature measurements were deemed sufficient in order to identify penetration flow. An experimental correlation describing the penetration depth based dimensionless numbers characterizing the operating conditions was derived. Secondly, we are presently investigating the nature of the penetrating flow itself which appears to be determined by a local balance of inertial and buoyant (turbulent) flows. Figure 1 shows the schematic and one typical result.

2. Investigation of jetting flow of one cold jet surrounded by two hot jets. (THERMAL STRIPING)

Thermal striping refers to the phenomenom of thermal stresses induced on reactor components and structures as a result of contact with random streams of poorly mixed cold and hot coolant. One example is the above-core structure from flow of hot/cold streams coming out of the core in a LMFBR. Since the thermal fatigue of such components and their locations are generally known, understanding the thermal mixing (or non-mixing) of buoyant and forced-flow jets is important to the safe design of the reactor. An experiment in water consisting of UVP measurement of a cold planar jet surrounded by two hotter jets is being conducted. An analysis of preliminary data has been done with a traversing thermocouple array and the UVP. Additional 2D and 3D measurements with an ultrasound probe array are underway. One sample result from preliminary measurements and a schematic of the experiment are shown in *Figure 2.*

3. US-transducer testing in pipe flow in sodium; measurement of transient.

A high-temperature, ultrasound transducer development program for use in sodium is being undertaken at PNC. A simple vertical pipe flow within a sodium loop facility is used as the testbed for various transducer designs. Velocity measurements are being taken with the UVP and indicate that with a sufficient concentration of *tracer* impurities flowing with the sodium, velocity profiles can so far be measured at 300°C. Additional tests at higher temperatures will be performed. Furthermore, we have demonstrated that the UVP can adequately follow a pump-coastdown in our experimental loop. A schematic and one sample result is given in *Figure 3.*

4. Study of vortex dynamics in water.

In a FBR, the entrainment of cover gas situated above the free surface, into the circulation loop is of concern, since the ingested gas may cause operational transients inside the reactor core's flow channels. One recognized entrainment mechanism is by vortices generated in the vicinity of protruding structual components (out of the free surface); that is, sufficiently *energetic* vortices may ingest cover gas and transport this into the circulating flow loop. In an basic experiment investigating the liquid velocity field associated with a vortex generated by stirring or draining a given volume of fluid, the UVP is used as the measurement tool. *Figure 4* shows the experimental apparatus and a sample preliminary result.

5. Convective heat transfer in 4 sub-channel and 37-pin bundle geometries

In convective heat transfer of coolant flow through tube bundles, the existence of flow blockages poses safety questions. Additionally, if the blockage is porous and participates in the heat transfer process, the safety criteria may be different than when the blockage is impermeable. *Figure 5* shows representative schematics of two ongoing convective heat transfer experiments in which there is a flow blockage in the flow path. The 4 sub-channel experiment focuses on the *4 sub-channels* defined by a triangular flow channel (cross-section) with four (partial) pins and a blockage in the central region. The objective here is to measure the *local* convective heat transfer within these 4 sub-channels. In the second experiment, the *global* flow characteristics of a 37-pin bundle, enclosed in a hexagonal vertical channel (the full-scale geometry of the 4 sub-channel counterpart), is being investigate with the blockage located along one face of the hexagon (see shaded area). Each of the 37-pins additionally has a wire-spacer wound along its length in order to promote *swirling* flow. This flow and that around the blockage are being investigated by both a laser Doppler anemometer (LDA) and a UVP velocimetry. One example UVP velocity profile of flow above the blockage is presented.

6. Inter-wrapper flow(IWF) and heat transfer

In the present design of the FBR, the fuel pins of the reactor are placed inside a hexagonal enclosure conveniently called a *wrapper can.* A large number wrapper cans in turn comprise the reactor core. When thermal energy is transported out of the core by the coolant, it exits into an upper volume called an upper- plenum. Here the hot fluid can be cooled by heat exchangers (DHX, liquid-to-liquid) and may flow back to a lower plenum beneath the core. It has been shown that, under certain thermal-hydraulic conditions, the inter-wrapper convective heat transfer contributes a significant amount to the heat removal capability of the reactor's cooling system. This has been attibuted to the inter-wrapper flow (IWF); that is, convective heat transfer amongst the wrapper cans. In order to quantify convective cooling by IWF, a sector model of the relevant geometry is being constructed. A top view and a representative side-view is shown in Figure 6. It is our objective in this experiment to use the UVP for: 1) local measurements, 2) cross correlational measurements and 3) regional, 2D and 3D, UVP measurements.

Figure 1a) Schematic of COPIES test section with TCs and UVP-TDX. Cold liquid flows from colling box to vertical channel which has upward, heated flow. b) Example velocity profile of penetrating flow.

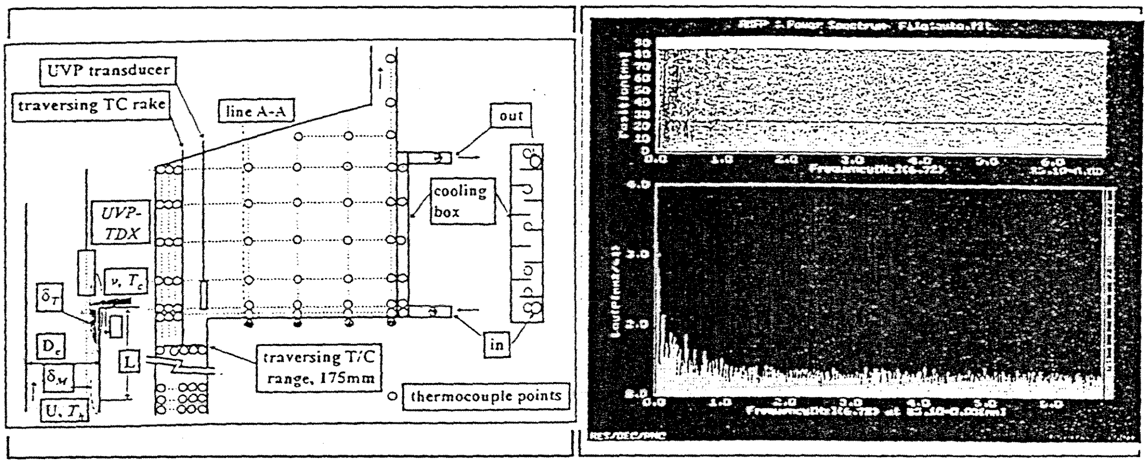

Figure 2a) Schematic of *Thermal Striping* facility. Three jets flow from central exits; Front window is approximately the measurement region. b) Example average velocity profile with standard deviation.

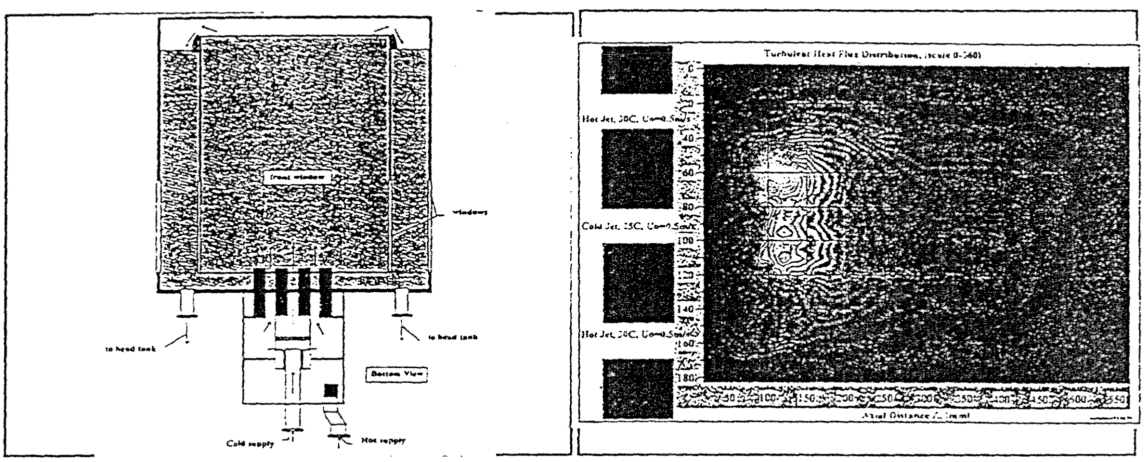

Figure 3a) Schematic of pipe-low in sodium (upward) with high-temperature TDX to be tested. b) Example velocity profiles at three different flowrates and specified sodium and cold-trap temperatures respectively. Solid line is the approximate turbulent 1/7th profile.

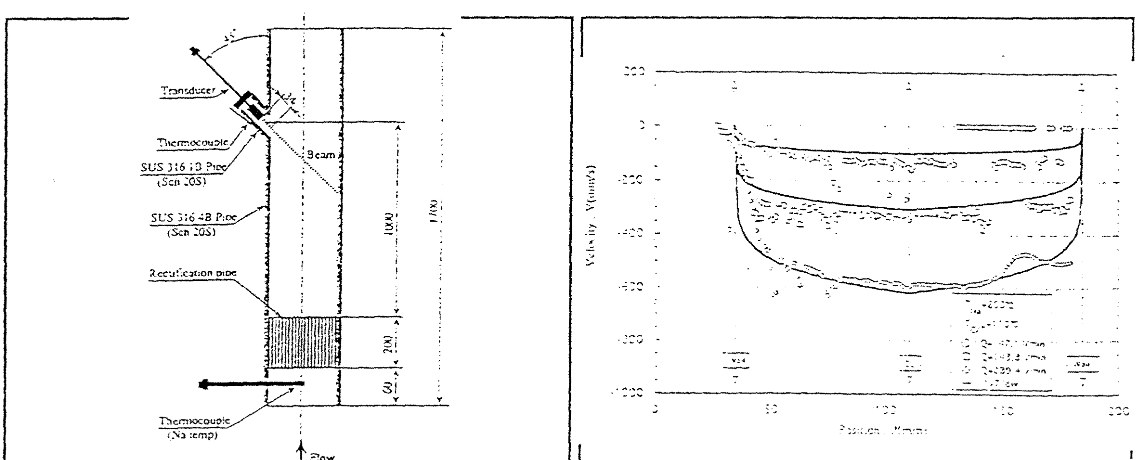

Figure 4a) Schematic of *vortex* apparatus with multi-probe arrangement. b) Example velocity profile.

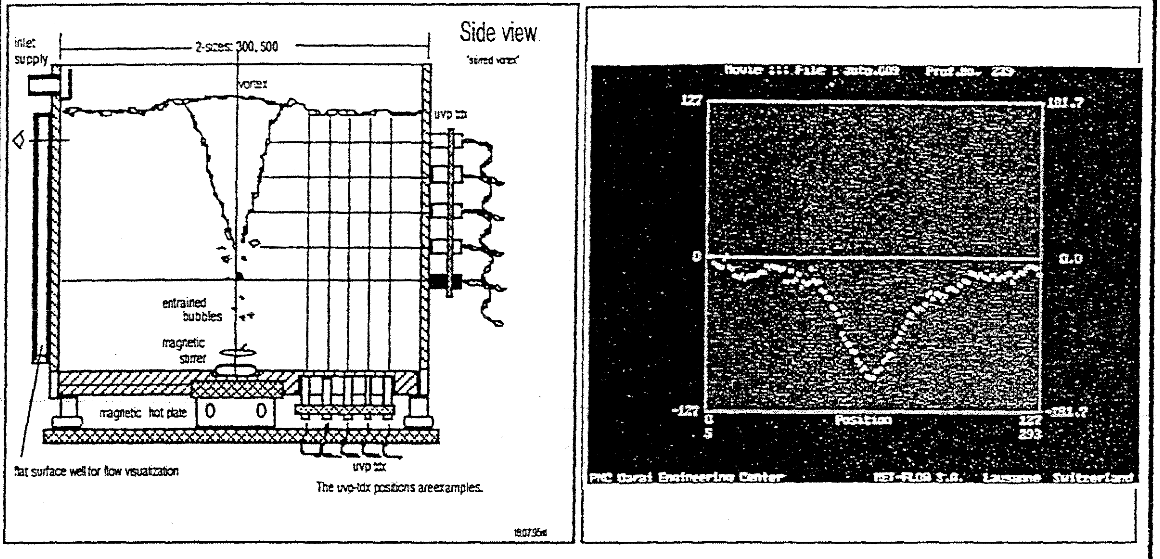

Figure 5a) Isometric view of both the 4-subchannel and a segment of the pin-bundle with wire-spacers, as well as a cross-sectional view of the 37-pins with a blockage. b) Example velocity profile of the wake region above the blockage.

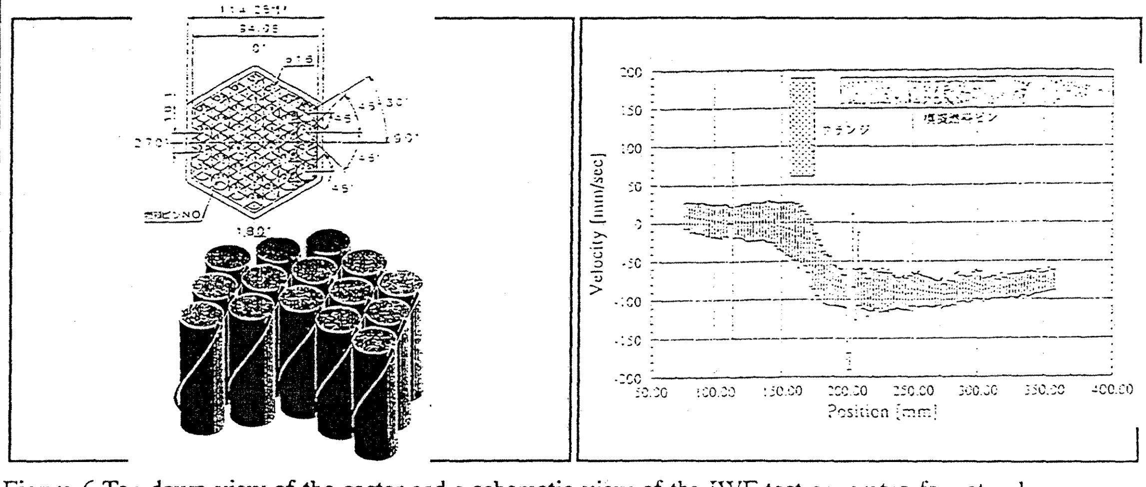

Figure 6 Top-down view of the sector and a schematic view of the IWF test apparatus for natural circulation tests. There is another arrangement for forced circulation. The UVP will be used in various regions