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SUMMARY

Periodic Large-Amplitude Thermal Oscillations Ocurring in a Buoyant Plume*

by

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Reactor events such as N-1 loop operation in conjunction with a leaky check valve in the down loop can cause flow to be convected back into the reactor outlet nozzle/piping region and to be back-flushed into the reactor outlet plenum. The preceding results in a temperature difference between pipe inflow and plenum. This temperature difference causes buoyancy forces which if large enough can cause:

i) a pipe backflow recirculation loop, and

ii) a thermal plume in the plenum.

Both phenomena are being studied because they can produce undesirable pipe, nozzle and plenum wall thermal distributions, and hence undesirable thermal stresses. The backflow recirculation loop was discussed in Ref. [1]. This paper discusses some features of the plume.

The Buoyancy Effects Tank (BET) was constructed as part of the ANL Mixing Components Test Facility (MCTF) to investigate this flow phenomenon. The initial test-section, shown in Fig. 1, is a clear-acrylic, horizontal, 4.64 m long, 0.102 m ID pipe connected to a 900 gal plenum. The existing MCTF data-acquisition system is used in the BET operation. Fast response thermocouples (~ 10 ms) measure the temperature distributions throughout the pipe and the downstream reservoir. Transparent dye which fluoresces in laser light was used to visualize thin planes of the flow field.

Vortex shedding was observed in the plume as the hot (~ 51°C) water exited the horizontal pipe into the plenum filled with cold (~ 15°C) water. Large, low frequency (~ 0.5-0.8 Hz.) eddies were formed along the lower edge of the plume, similar to Kelvin Helmholtz instability generated vortices [2], and smaller, higher-frequency eddies were formed at the upper corner of the pipe/plenum interface. The vortices generated along the bottom edge of the plume break up upon penetration of the thermocline formed in the plenum.

Later, when the thermocline is below the eddy-formation zone, the behavior of the vortices returns to its original pattern. Figure 2 is a photograph of this vortex flow pattern. The hot water is indicated by the light, fluorescent dye; the cold water is the dark, undyed region. A 4-mil, fast-response (~ 10-ms), copper constantan thermocouple was positioned in the large eddy pattern to measure the temperature response caused by the observed flow pattern. Large, quasi-periodic temperature fluctuations of the order of 76% of the available temperature difference at that elevation occurred for test BETC4 with Re = 7400 and Ri = 4.3. A power spectral analysis is shown in Fig. 3. The frequency of 0.63 Hz determined from the thermocouple response compares favorably with the preliminary frequency estimate of 0.5 - 0.8 Hz from the observed flow patterns.

In summary, thermal plume large scale vortex patterns have been shown to cause large-amplitude thermal oscillations at low frequencies. These periodic, large-scale vortices are generated in the plume and can also cause large-scale plume instabilities (i.e., a periodic deflection of the plume), which are also sources of large-amplitude thermal oscillations. The preceding flow disturbances can cause thermal striping problems since surfaces such as plenum walls, nozzle liners etc. experience temperature oscillations which give rise to thermal stresses. Cracks and component failure can result if the magnitude and frequency of the thermal oscillations are sufficiently large.

References:

[1] K. E. Kasza and P. A. Howard, "Piping-Flow/Thermal-Plume Stratification Interaction Induced by a Pipe-to-Reservoir Temperature Difference," Trans. Am. Nucl. Soc., 43, 781 (1982).

[2] D. J. Tritton, Physical Fluid Dynamics, Van Nostrand Reinhold Company, New York, p. 211, (1977)

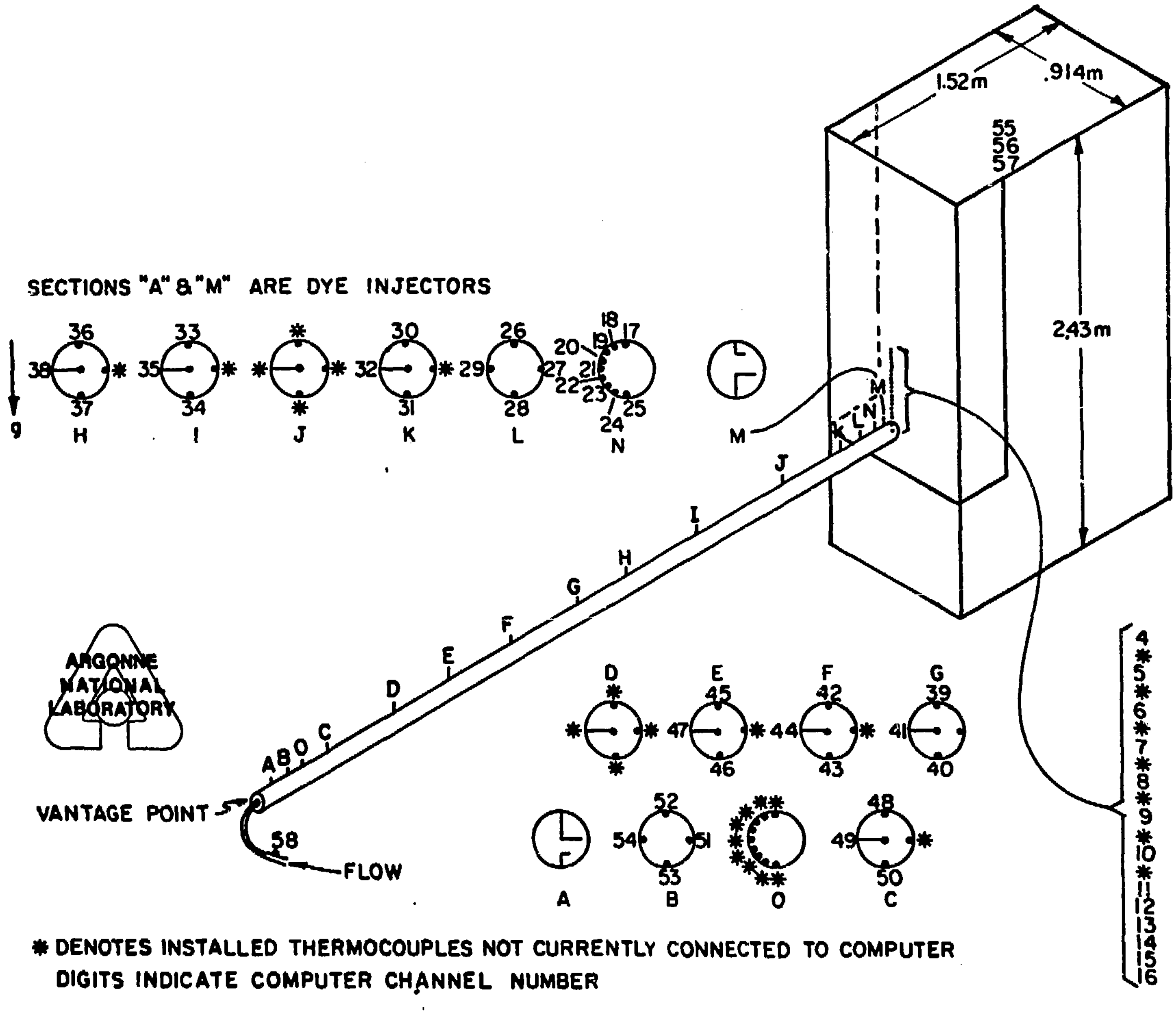
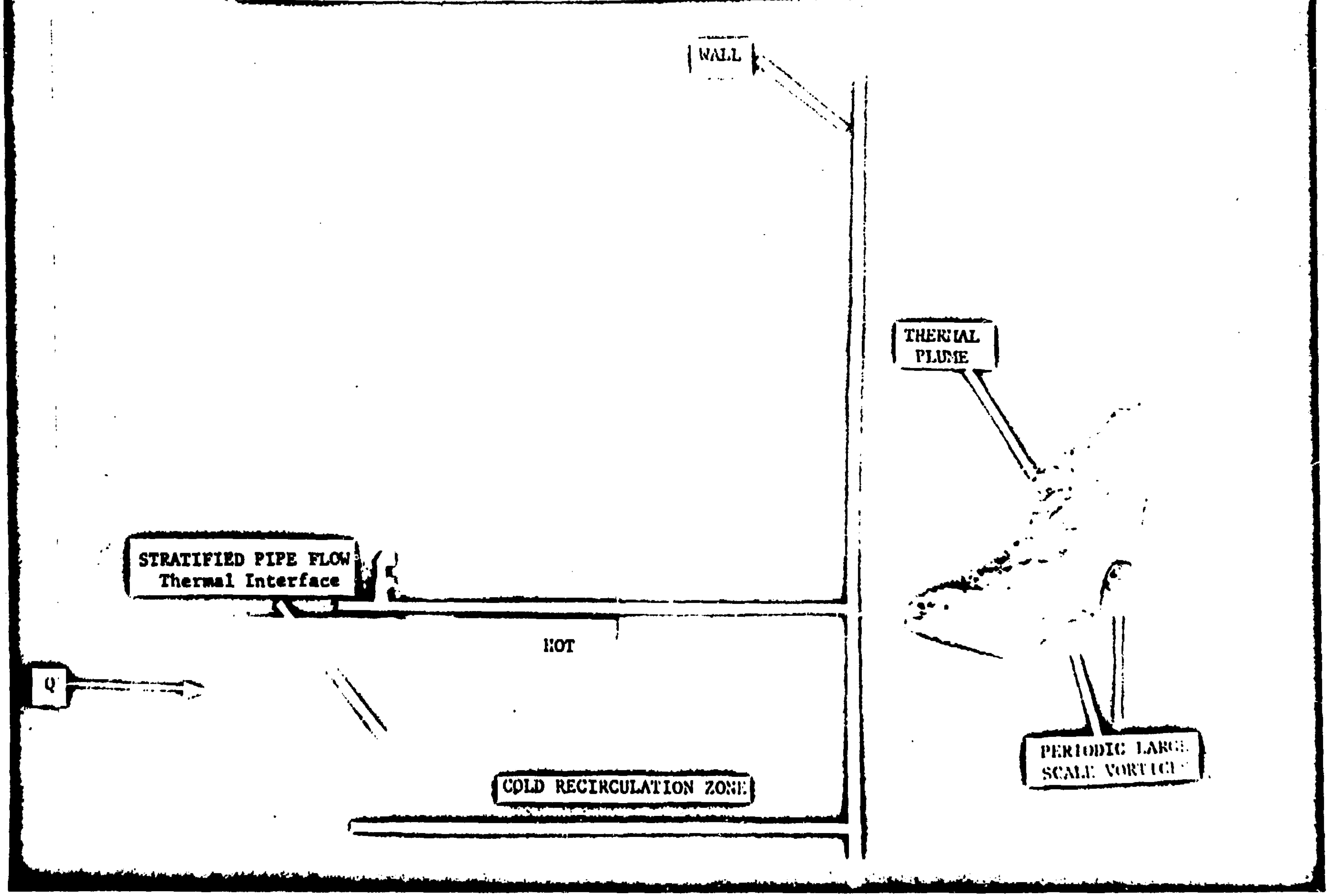


FIG. 1. INSTRUMENTATION LOCATIONS

FIG. 2. PHOTOGRAPH OF HOT FLOW FROM HORIZONTAL PIPE EMPTYING INTO PLENUM SHOWING BOTH THE COLD (DARK) RECIRCULATION REGION IN THE PIPE AND THE VORTEX PATTERN IN THE THERMAL PLUME IN THE PLENUM. ANL NEG. NO. 113-82-105 #9.



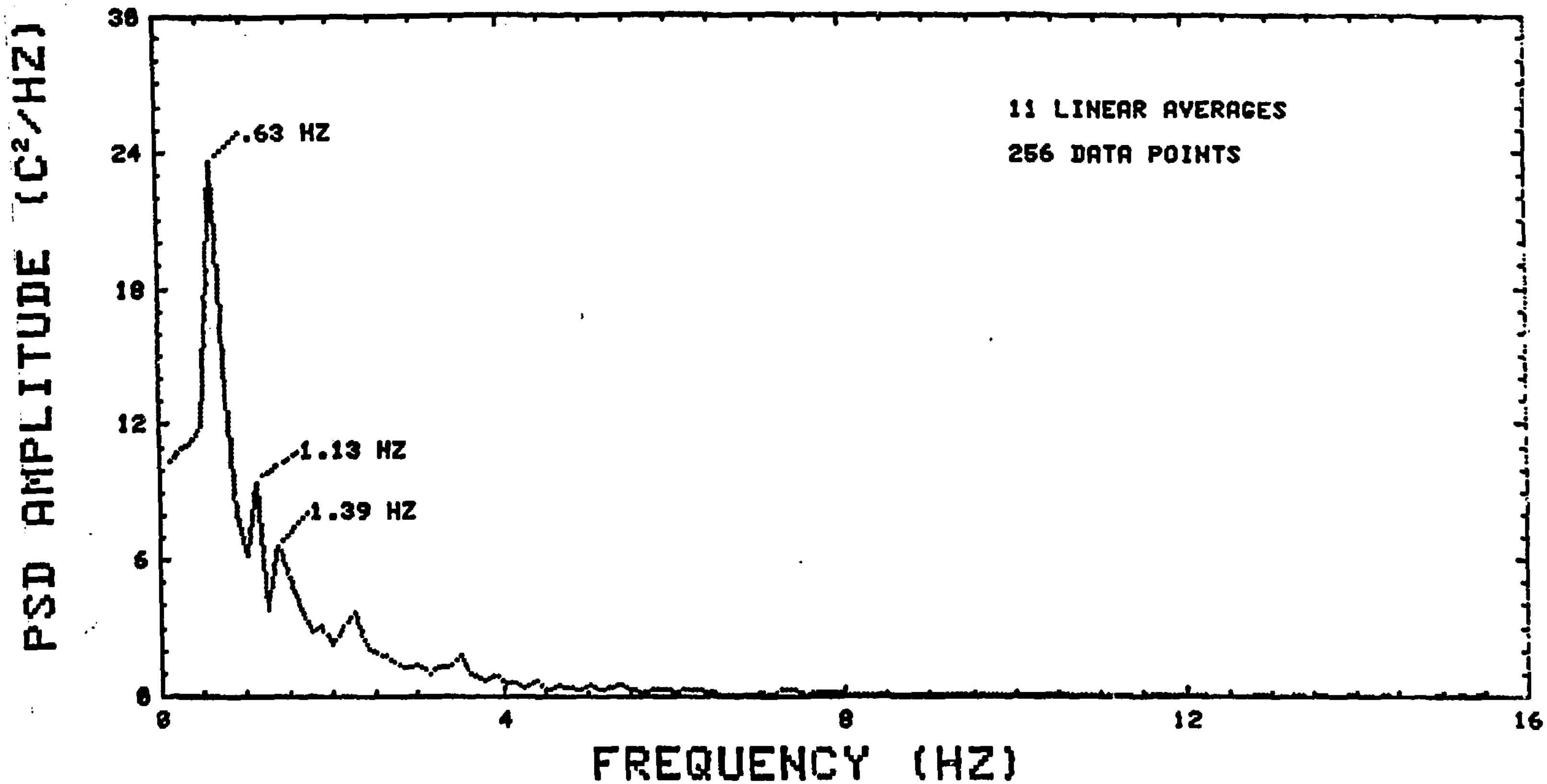


FIG. 3. POWER SPECTRAL ANALYSIS OF RESPONSE OF THERMOCOUPLE POSITIONED IN VORTEX PATTERN OF THERMAL PLUME WITH LINEAR AVERAGING.