COO-2245-65

COOLANT MIXING IN LMFBR ROD BUNDLES AND OUTLET PLENUM MIXING TRANSIENTS

Progress Report

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EXB

DISCLAIMER

Reports and Papers Published Under MIT Coolant Mixing in LMFBR Rod Bundles Project

A. Quarterly Progress Reports (Available from:
National Technical Information Service
U.S. Department of Commerce
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COO-2245-1	Period June 1, 1972 - November 30, 1972
COO-2245-2	Period December 1, 1972 - February 28, 1973
COO-2245-3	Period March 1, 1973 - May 31, 1973
COO-2245-6	Period June 1, 1973 - August 31, 1973
COO-2245-7	Period September 1, 1973 - November 30, 1973
COO-2245-8	Period December 1, 1973 - February 28, 1974
COO-2245-10	Period March 1, 1974 - May 31, 1974
COO-2245-13	Period June 1, 1974 - August 31, 1974
COO-2245-14	Period September 1, 1974 - November 30, 1974
COO-2245-15	Period December 1, 1974 - February 28, 1975
COO-2245-23	Period March 1, 1975 - May 31, 1975
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COO-2245-38	Period December 1, 1976 - February 28, 1977
COO-2245-50	Period March 1, 1977 - May 31, 1977
COO-2245-53	Period June 1, 1977 - August 31, 1977
COO-2245-60	Period September 1, 1977 - November 30, 1977
COO-2245-63	Period December 1, 1977 - February 28, 1978
COO-2245-64	Period March 1, 1978 - May 31, 1978
COO-2245-65	Period June 1, 1978 - August 31, 1978

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COOLANT MIXING IN LMFBR ROD BUNDLES AND

OUTLET PLENUM MIXING TRANSIENTS

Contract AT(11-1)-2245

Quarterly Progress Report

The work of this contract has been divided into the following Tasks:

TASK I: BUNDLE GEOMETRY (WRAPPED AND BARE RODS)

- TASK IA: Assessment of Available Data
- TASK IB: Experimental Bundle Water Mixing Investigation
- TASK IC: Experimental Bundle Peripheral Velocity Measurements (Laser Anemometer)
- TASK ID: Analytic Model Development - Bundles

TASK II: SUBCHANNEL GEOMETRY (BARE RODS)

- TASK IIA: Assessment of Available Data
- TASK IIB: Experimental Subchannel Water Mixing Investigation
- TASK IIC: Experimental Subchannel Local Parameter Measurements (Laser Anemometer)
- TASK IID: Analytic Model Development - Subchannels

TASK III: LMFBR OUTLET PLENUM FLOW MIXING

- TASK IIIA: Analytical and Experimental Investigation of Velocity and Temperature Fields

TASK IV: THEORETICAL DETERMINATION OF LOCAL TEMPERATURE FIELDS IN LMFBR FUEL ROD BUNDLES

TASK I: BUNDLE GEOMETRY (WRAPPED AND BARE RODS)

TASK IB.5 SHAVED-WIRE 61-PIN BLANKET BUNDLE EXPERIMENT
(Song-Feng Wang and King-Wo Chiu)

Flow split experiments on shaved-wire 61-pin blanket bundle have been completed. Due to the experimental difficulties and deficiency of equipment at high and low flow rates, flow split measurements in corner subchannels are limited to moderate flow rates. However, this limitation in the measurement range does not affect our general flow split results because the flow in corner subchannels is small (~ 1.6% of total flow). Results of flow split measurement in interior and edge subchannels show that (Figures 1 and 2):

(1) Flow distribution between interior and edge subchannels remains unchanged under turbulent flow condition. The results of measurements in general do not agree with Novendstern's prediction.

(2) Transition starts at bundle average Reynolds number ~ 5000 where flow transits from turbulent to laminar.

(3) No abrupt change in flow distribution was observed in the transition region (Re ~ 5000) whereas, for the full wire blanket bundle, a sudden variation in flow distribution was observed at Re ~ 3000 by C. Chiu.

(4) Compared with full wire blanket bundle results, the coolant flow in the peripheral region (both edge and corner subchannels) is reduced while in the central region it is increased. The percentage of flow gain in the central region is ~ 3% and ~ 15% under turbulent and laminar flow conditions, respectively.

The coolant flow in the corner subchannels is low (~ 1.6% of total flow) and relatively insensitive to the flow condition (Figure 3).

Pressure distributions along axial direction have also been measured both in interior and edge subchannels. For any interior subchannel, 3 wire-wraps from surrounding rods tend to compensate each other and thus eliminate the possible local variation in pressure distribution. Hence, the resulting pressure gradient along axial direction in the central region of the blanket bundle is fairly uniform. On the other hand, due to the lack of symmetry of the wire-wrap in the edge region, all of the wires divert the flow in a preferred direction, giving a tangential component to the upward coolant flow. The resulting swirl flow thus causes local pressure variation when it crosses the wire-wrap on the rod. For the shaved-wire blanket bundle, the transverse resistance (in edge subchannels) for coolant flow is greatly increased, while the axial resistance remains the same. It is expected that this axial-predominant flow will greatly enhance the local variation of the pressure distribution (Figure 4).

Currently, local perturbation in pressure field was observed at low flow rates (Figure 5). More efficient equipment (i.e. inclined manometer) will be used to study the effect of wire-wrap at low flow rates.

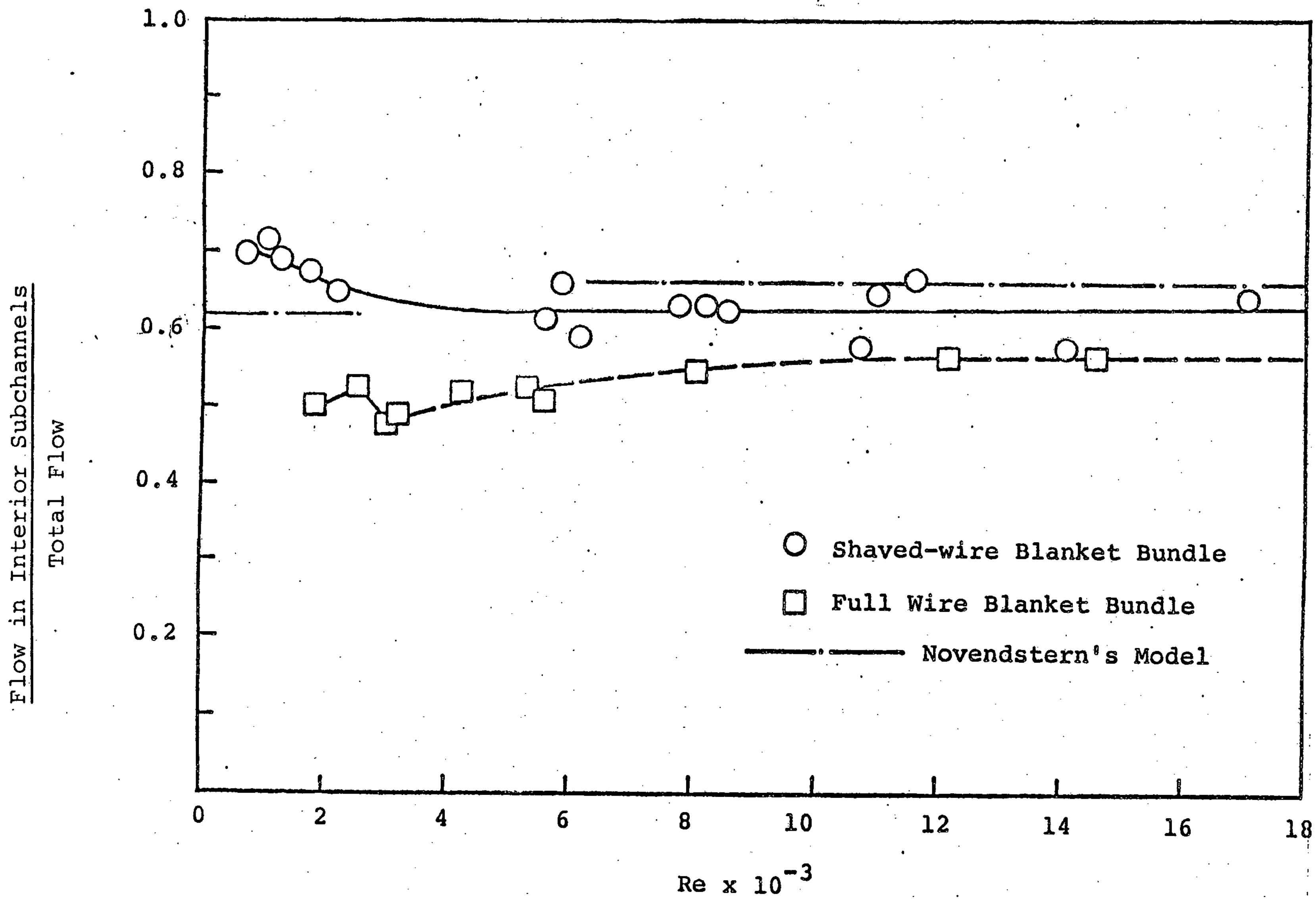

Flow in Interior Subchannels / Total Flow
1.0
0.8
0.6
0.4
0.2
0
2
4
6
8
10
12
14
16
18
Re x 10^{-3}
Shaved-wire Blanket Bundle
Full Wire Blanket Bundle
Novendstern's Model

Figure 1

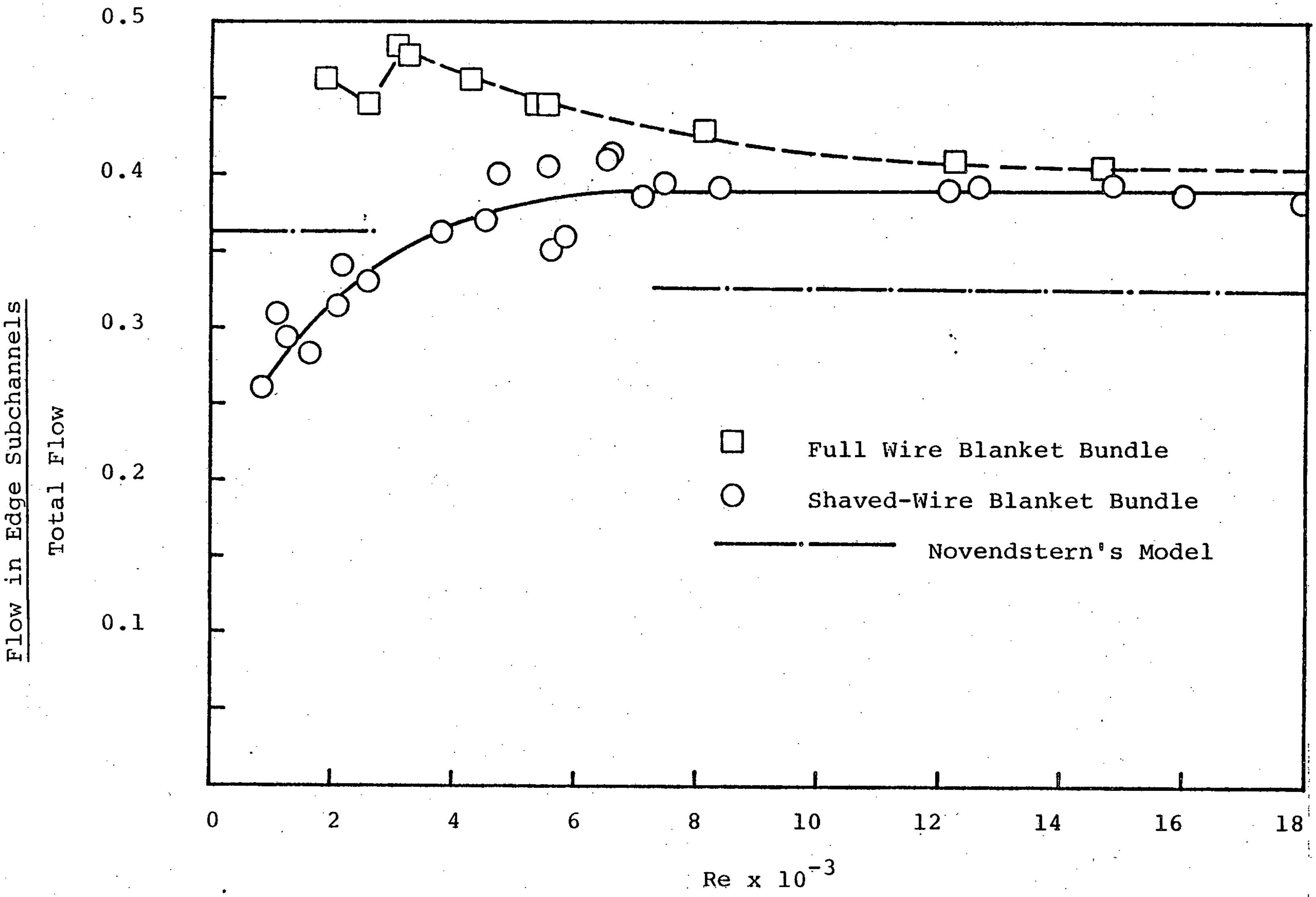

0.5
0.4
0.3
0.2
0.1
Flow in Edge Subchannels
Total Flow
0
2
4
6
8
10
12
14
16
18
Re x 10^{-3}
Full Wire Blanket Bundle
Shaved-Wire Blanket Bundle
Novendstern's Model

Figure 2

Flow in Corner Subchannels / Total Flow

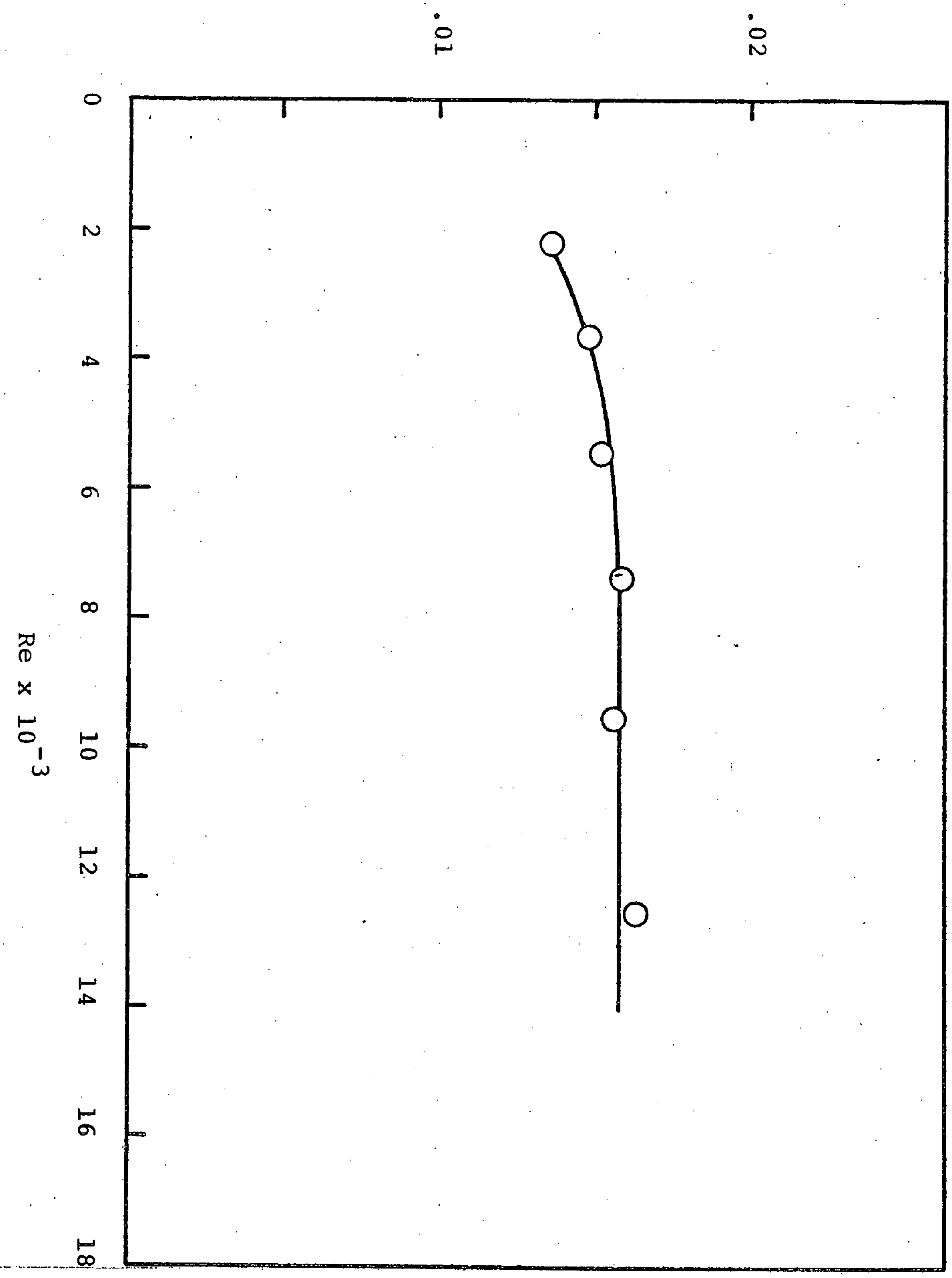
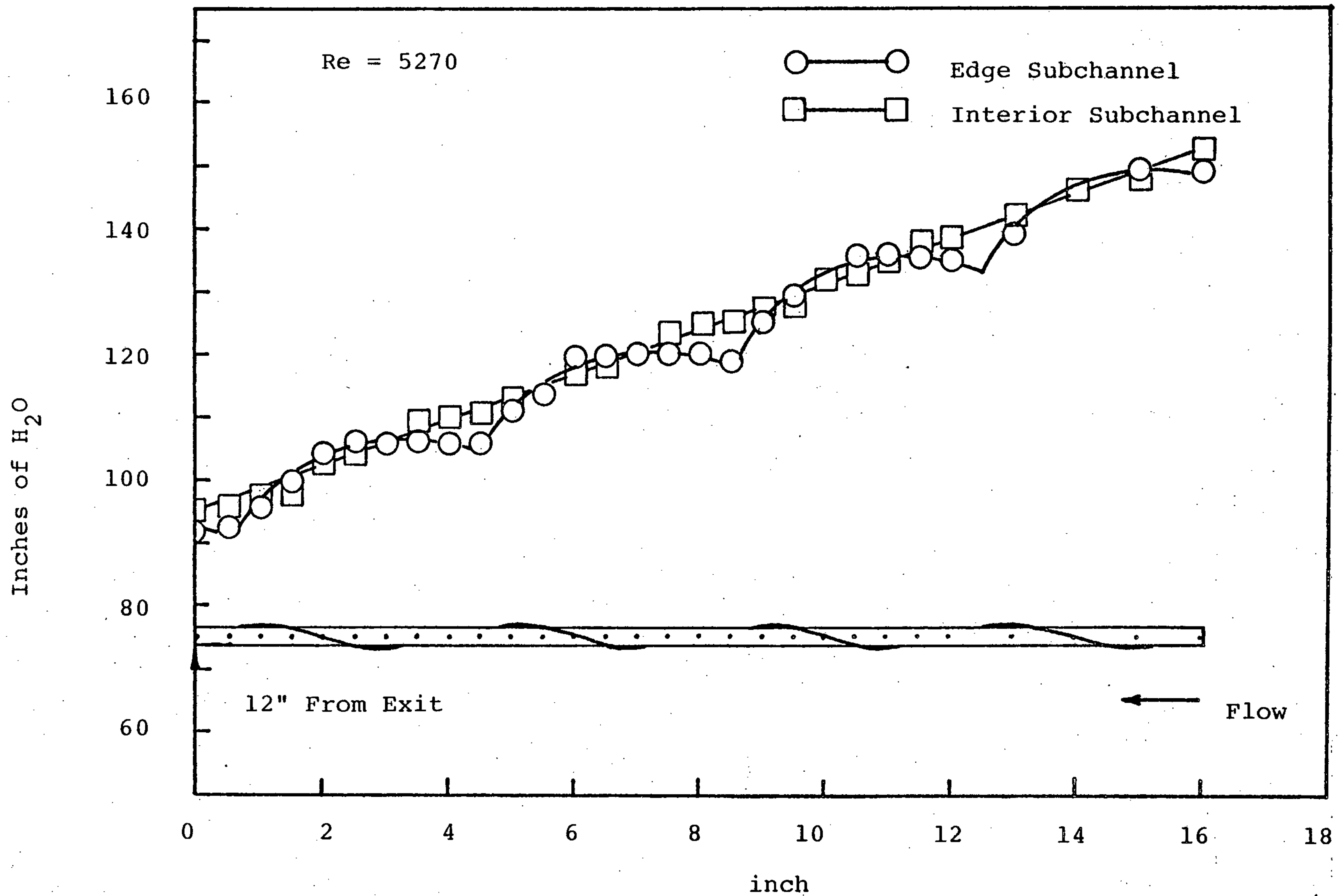


Figure 3



Re = 5270
Edge Subchannel
Interior Subchannel
160
140
120
100
80
60
Inches of H_2O
12" From Exit
Flow
0
2
4
6
8
10
12
14
16
18
inch

Figure 4

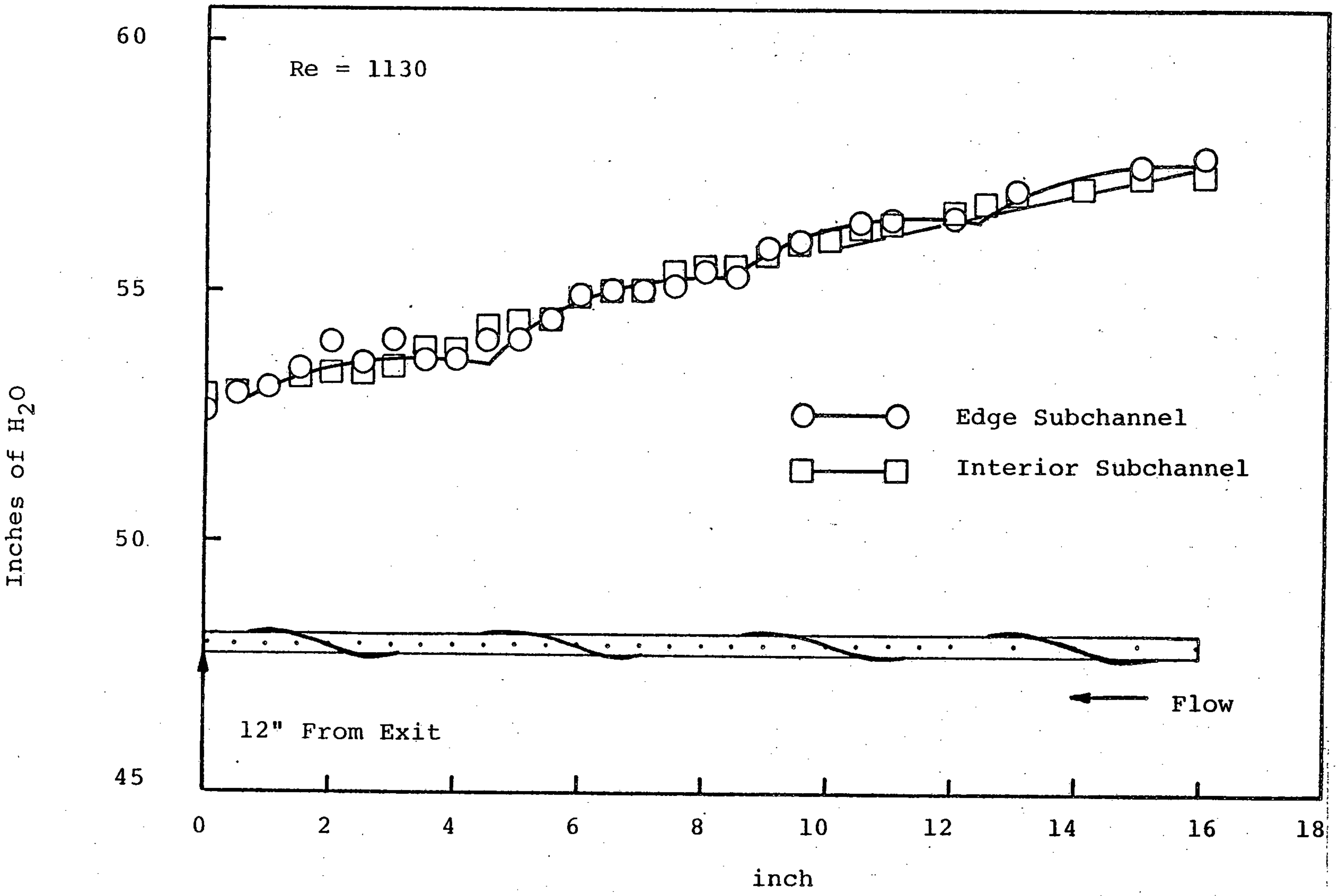

Re = 1130
60
55
50
45
Inches of H2O
Edge Subchannel
Interior Subchannel
Flow
12" From Exit
0
2
4
6
8
10
12
14
16
18
inch

Figure 5

TASK III. LMFBR Outlet Plenum Flow Mixing

TASK III.1: Measurement of Transient LMFBR Outlet Plenum Turbulent Flows
(D. Boyle)

When a turbulence model is used to calculate a flow transient the quantities calculated are actually ensemble-averaged flow properties, which will change in time during the transient. In performing such calculations it is assumed that the same free parameters in the turbulence model used to describe the flow apply throughout the transient. The available literature is largely silent regarding whether this is a good assumption--or indeed regarding whether turbulence models give accurate predictions of fluid flow transients.

In this effort, testing of two-equation turbulence models under transient conditions is being undertaken as a logical extension of prior work testing such models under steady isothermal conditions. In the latter work the strong sensitivity of turbulence model predictions to the specification of boundary conditions, to the values of the turbulence model's free-parameters, and to the degree to which the assumption of turbulence isotropy is satisfied were illustrated; and the range of validity of this class of models was defined.

In the current work the previous approach is being extended to isothermal transient flows, with the aim of understanding the limitations of, and of making improvements in the capabilities of transient simulations. The importance of this work to the LMFBR base-technology research effort is relatively direct and clear. The current work has the following separate components, which are subsequently discussed in detail:

1. Repetition of parts of the previous steady state work to provide knowledge of the initial state from which the transients commence, and in order to resolve a small number of outstanding questions regarding the previous work,

2. Development of a reliable experimental system for repetition of flow coast-down experiments,

3. Development of a capability for automatic multi-channel time-dependent data acquisition, and

4. Performance of flow coastdown experiments and independent turbulence model calculation of the measured quantities--with analysis to determine the limits of model validity, and to guide model improvements.

Major efforts have involved Tasks 2 and 3, and these are reported in detail in the following sections.

As noted in the preceding Progress Report, two major equipment items essential to the transient experiments were to be procured or constructed during this period: (A) a repeatable flow-transient generator (Task 2), and (B) an electronic data recording device (Task 3). In addition to acquisition of this new equipment, final calibration of the Laser Doppler Anemometer (LDA) and verification of the technique for fluid velocity measurements has been completed.

(A) Repeatable Flow-Transient Generator (RFTG)

The turbulence parameters to be measured in this experiment can only be obtained by constructing ensemble averages of the time varying fluid flow properties measured by the LDA. This necessarily requires a flow transient that can be faithfully repeated a large number of times. Further, the transient to be measured must be initiated automatically so that the data recorder will always collect data from the same time base for each run.

The technique selected is illutrated in Fig. 1. A 2 in. diaphragm control valve has been installed at the outlet of the pump. During the steady-state (full flow) period, air is supplied via a three-way solenoid valve as shown. By regulating pressure of the source of air to the control valve bonnet the steady-state flow rate can be repeatably set at any initial value required. At the start of the transient, the solenoid is energized, and air is permitted to bleed slowly out of the bonnet (and parallel-connected surge tank) through a micrometer-adjusted needle valve. The micrometer setting determines the rate of air pressure decrease in the control valve bonnet and thereby the valve closure speed, and ultimately, the fluid flow rate. This simple system fulfills the automatic requirement, and has been tested for repeatability with excellent results.

A heat exchanger (not shown) is installed in the hydraulic loop to maintain a constant fluid temperature over any number of test runs. In addition, the outlet plenum test-cell has been modified to eliminate the effects of the sharp-edged entrance experienced with the FFTF configuration. The new design also permits external control of the inlet velocity distribution at the top of the chimney region.

(B) Data Recording System

There are five (5) analog voltage signals of interest generated by the LDA during the flow transient($\overline{U}$, $\overline{V}$, $\overline{u'^2}$, $\overline{v'^2}$, $\overline{u',v'}$). All five signals are time-averages of random fluctuations that vary continuously throughout each test run. These five signals must be recorded for a large number of identical test runs, compensated for averaging errors, converted to appropriate units, ensemble averaged, analyzed statistically and plotted for each measurement point in the test cell. A small Tektronix tape recorder has been interfaced to the experiment by a sophisticated Analog to Digital Converter (ADC) produced in-house to perform the data collection task.

The ADC is designed flexibly to allow easy adjustment to varying experimental conditions. Seven bit (plus sign) accuracy is provided for digitizing up to six analog signals simultaneously. The sample rate can be varied and a large header space is provided to record numerous descriptors and experimental constants prior to each run. The Tektronix tape recorder was selected since the tape cassettes from this machine are compatible with a Tektronix mini-computer (currently installed at MIT) which will be used to perform the required computations. The data recording system was 98% complete at the end of the reporting period; an illustrative schematic is shown in Fig. 2.

(C) Laser Doppler Anemometer (LDA)

Set up and test of the LDA in the dual channel reference beam mode has been accomplished. The use of frequency trackers produced by two different manufacturers necessitated minor equipment modifications to insure that both systems (one for each velocity component) are driven by identical Bragg shift frequency sources. The required modifications were made in such a way as to allow rapid conversion back to single channel mode for future experiments.

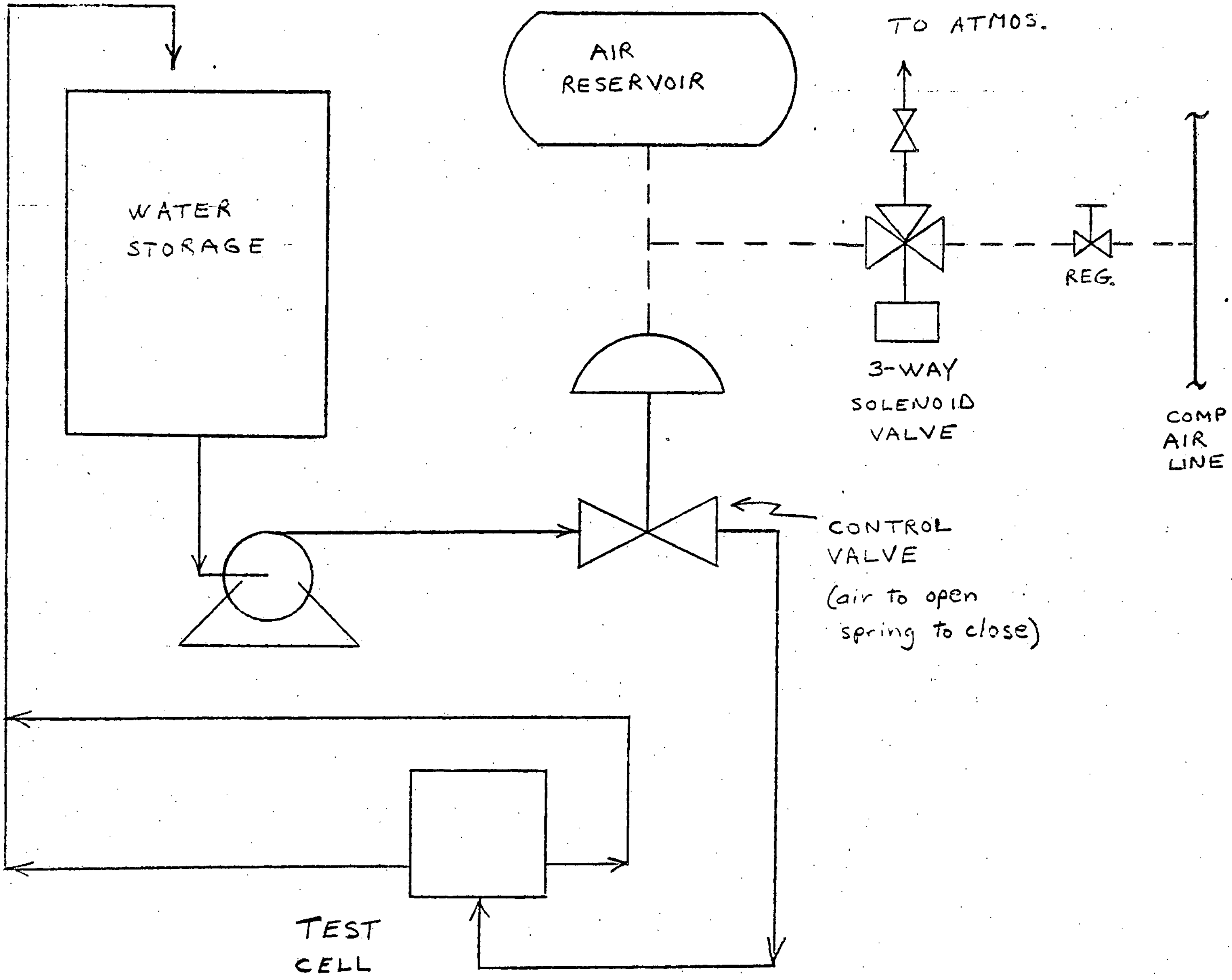
The flow calibration rectangular flow channel, described in the last report, has been utilized to verify the accuracy of the two dimensional LDA measurements. Velocity and turbulence kinetic energy distributions have been measured which compare well with results obtained from hot-wire measurements in similar geometries. Flow rates calculated by integrating the measured velocity distributions are within a few percent of the mechanical flow meter (rotometer) readings. Reynold's stress distributions have been measured across the channel showing the requisite symmetry. In addition, the trackers have demonstrated their ability to follow the doppler frequency as it changes during the flow transient.

Since the trackers are of different manufacture, and therefore slightly different circuit design, it has been found to be necessary to low-pass filter the output signals of each tracker. The cut-off frequency of the filter is set at a value high enough to pass those velocity fluctations which provide a significant contribution to the turbulence kinetic energy, however, high frequency noise components are eliminated by this procedure. A matched set of adjustable low-pass filters has been designed and built so that the outputs of both trackers are filtered in precisely the same way.

Future Tasks

Measurement of experimental turbulence field parameters (Tasks 1 and 4) in the outlet plenum test cell is scheduled to begin early in the new period. Final debugging and check-out of the data recording system is in-process, and the software for mini-computer data-handling will be written and tested in parallel with the experimental data collection. Initial steady-state data runs (Task 1) will be required to map the steady-state flow field throughout the test cell in order to accurately initialize the VARR II computer code. From this point, transient experimental and computer data (Task 4) runs can begin.

REPEATABLE FLOW TRANSIENT GENERATOR



- REPEATABILITY (SIX SEQUENTIAL 5-MIN. RUNS)
  FLOW RATE $\frac{\sigma}{\mu} < .02$ AT POINT OF WORST AGREEMENT

Figure 1

DATA RECORDING AND REDUCING

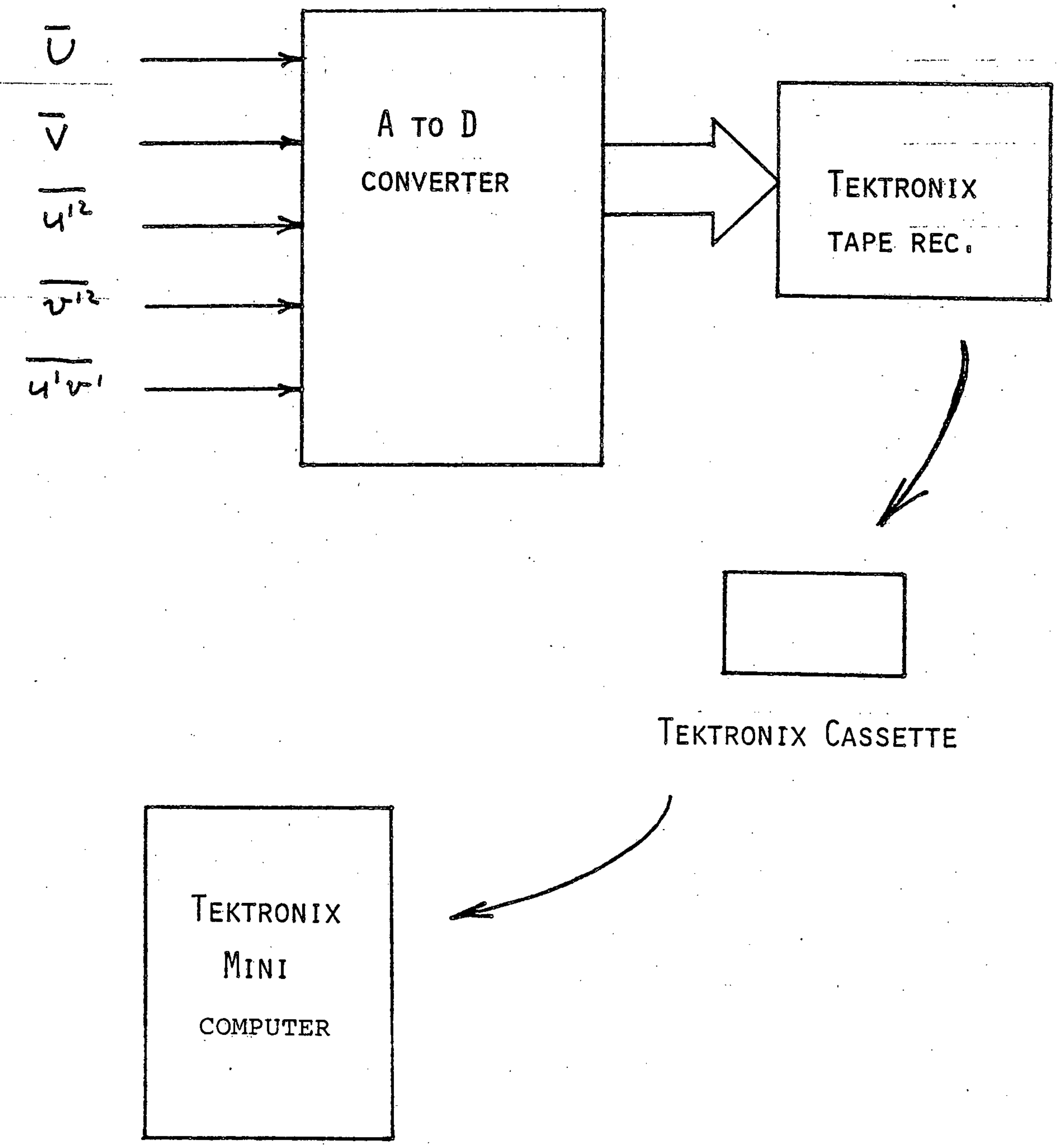


Figure 2

TASK III.2 Combined Temperature and Velocity Measurements (V.P. Manno)

During the past quarter the experimental work of the subtask concerned with investigation of turbulent heat transport phenomena was completed. The completion of the work consisted of obtaining <v'T'> maps in both the FFTF and CRBR geometries and constructing flow maps of the time average parameters such as mean velocity and temperature. These final mappings were used to evaluate the velocity and temperature gradients needed to calculate the eddy diffusivities. Velocity maps were attained using the LDA system while a thermocouple was employed in the temperature gradient measurements.

In addition to finishing the experimental portion of the endeavor, the data was analyzed and a final report was written. This report which is presently being printed is titled "Measurement of Heat and Momentum Eddy Diffusivities in Recirculating LMFBR Outlet Plenum Flows" and its D.O.E. Report number is COO-2245-61TR. In the final report a complete listing and analysis of the data is presented in conjunction with a comprehensive description of the overall experimental technique. Also the eddy diffusivities of heat and momentum are evaluated at the 11 measurement stations described in previous progress reports.

Since the results are presented in their entirety in the final report which will soon be available, discussion of particular results will not be presented in this report. However a review of the final conclusions is presented. First, the optical system developed has been proven to be a useful tool for the measurement of eddy diffusivities in transparent media. Second, the parallel spectral analyses which were performed on the analog signals were shown to be helpful in monitoring the qualitative nature of a turbulent flow field. In the realm of the measurements themselves, significant directional anisotropy was found at all measurement stations except for position D of the CRBR geometry which is the only location in either configuration free of hydrodynamic or thermal entrance length effects. The general conclusion drawn from these results is that the turbulence is quite anisotropic and the use of isotropic turbulence modelling to describe transport phenomena in these geometries is not a valid approach. Finally, basic differences in the flow patterns of the two geometries were observed and the chief cause of the distinction is found to be the taller chimney structure of the CRBR configuration coupled with its narrower expanse.

TASK IV: Theoretical Determination of the Local Temperature Fields in LMFBR Fuel Rod Bundles

Topic: Wire-Wrapped Rod Bundle Heat Transfer Analysis
(Chung-Nin Wong)

I. Introduction

Since the beginning of this quarter of the year, the emphasis of the work in this task has shifted to study the effect of the helical wire on the heat transfer capability of the fuel pin. Helical wire wraps are commonly used as the spacer in the LMFBR Fuel Assembly Design. The helical wire induces coolant mixing between the subchannels. However, at the same time, the contact of the wire with the neighboring fuel pin may also possibly increase the hot spot temperature in the cladding. The complexity of the wire creates a lot of interesting heat transfer problems.

II. Intention of This Work

The basic goal is to obtain the three-dimensional velocity and temperature distribution within the coolant cell as well as the temperature profile of the clad, the fuel and the wire. Thus, throughout this analysis, the thermal entrance effect will also be included in the consideration. No assumption on the coolant pressure drop will be made. The intention is to calculate the pressure potential field so that the validity of the widely-used Novendstern pressure drop correlation will be checked.

III. Report of the Work

The governing equations such as the continuity equation, the momentum equations and the energy equation have been formulated in a normalized form. Since the natural convection regime has been neglected throughout this analysis, the momentum equations and the energy equation can be decoupled. For the estimation of the pressure drop in the coolant region, the pressure-solution technique has been suggested such that an additional governing equation for the pressure field which is in the form of Possion's Equation has been formulated. The advantage of formulating the pressure equation is the elimination of the continuity equation; leaving four governing equations which are Navier-Stokes Equations in three different directions, plus the pressure potential equation, with four unknowns: V_r, V_θ, V_z, and P.

The next major concern in this analysis is looking for the best way to handle the boundary conditions. For the sake of simplicity, each individual cell will first be considered as an isolated cell, as shown in Figure 1. Then, the result obtained from a subchannel analysis will be fed into this analysis as the new boundary condition. With this newly-imposed boundary condition, the calculation will be performed again.

For the numerical analysis part, a new upwind derivative finite differencing scheme [1] will be used for the convection term.

That is:

$$\phi_{i+\frac{1}{2},j,k} = \phi_{i,j,k} + \left(\frac{\partial \phi}{\partial x}\right)_{i,j,k} \frac{\Delta x}{2} + O\left(\frac{\Delta x^2}{4}\right)$$

This numerical scheme, as shown, has a better convergent rate and a more accurate solution than either the normal upwind derivative scheme or the central differencing scheme.

Finally, the commonly used successive Over-relaxation Iteration will be applied. The outline of the calculational scheme is shown in Figure 2.

IV. Recommendation and Future Work

After the computer code has been furnished, the program will be tested upon the following subjects:

(a) Flow in a Simple Concentric Tube

(b) Fully-Developed Flow in a Tube containing a Twisted-Tape [2]

(c) Swirl Flow in an Internal Cell with Wire Wrap

V. References

[1] J. G. Bartzis and N. E. Todreas, "Hydrodynamic Behavior of a Bare Rod Bundle", COO-2245-48TR, June, 1977.

[2] A. W. Date, "Prediction of Fully-Developed Flow in a Tube Containing a Twisted-Tape", Int. J. Heat Mass Transfer, Vol. 17, pp. 845-859.

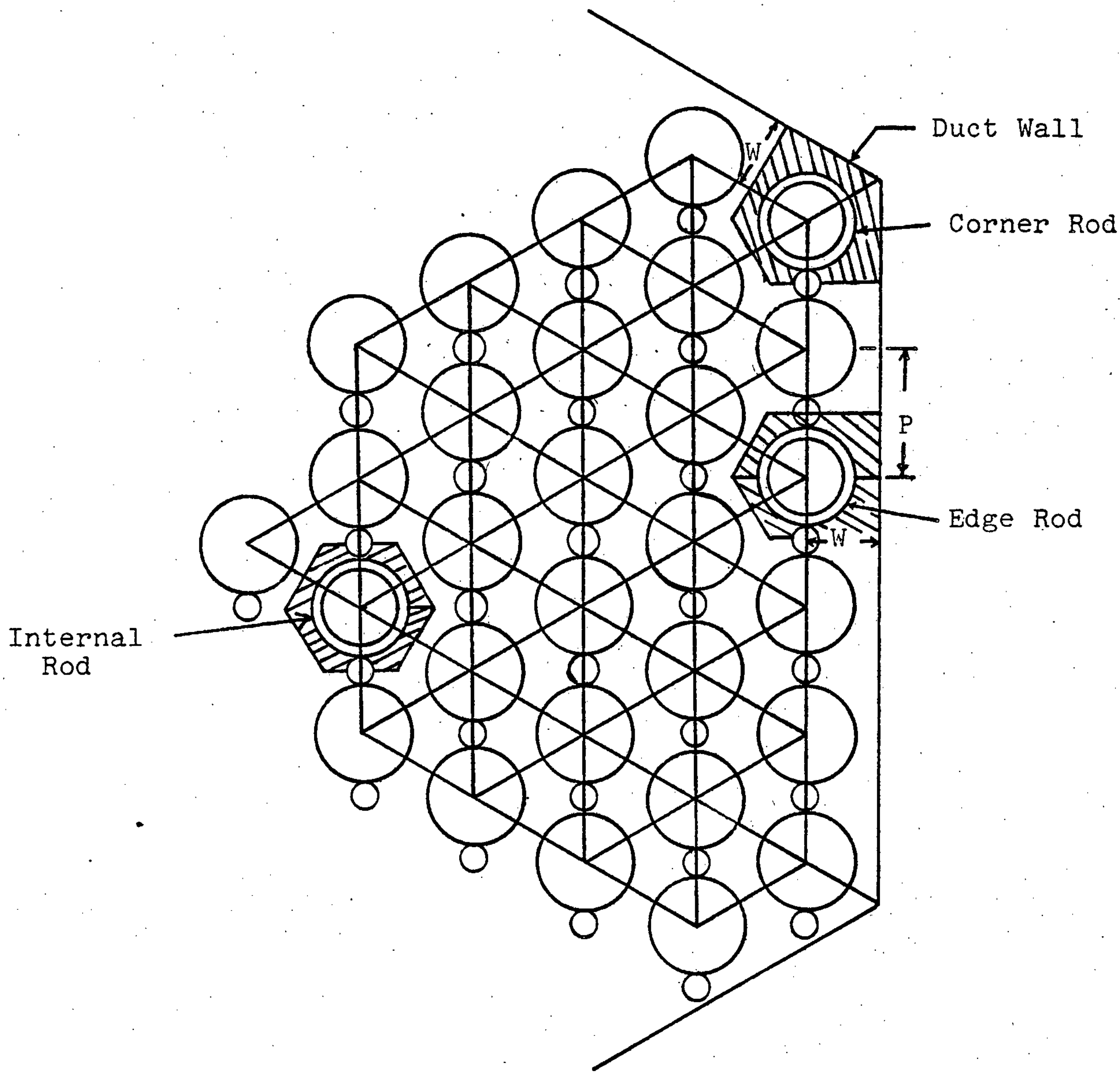


Fig. 1   Schematic Diagram for Fuel Assemblies

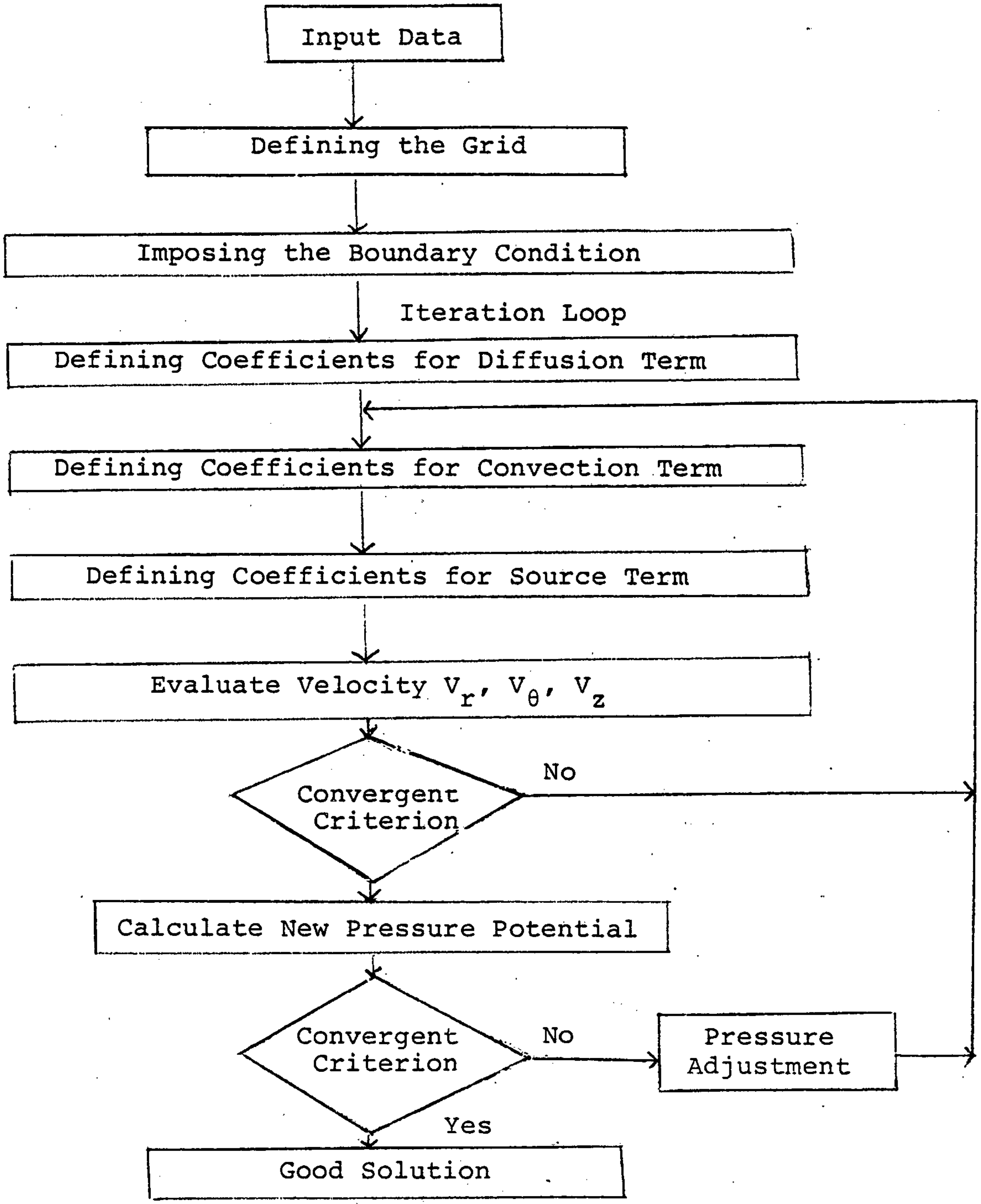


Figure 2. Outline of the Calculational Scheme