COOLANT MIXING IN LMFBR ROD BUNDLES AND
OUTLET PLENUM MIXING TRANSIENTS

Progress Report

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EXB

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

- A. Quarterly Progress Reports (Available from:
National Technical Information Service
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COO-2245-1	Period June 1, 1972 - November 30, 1972
COO-2245-2	Period December 1, 1972 - February 28, 1973
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COO-2245-6	Period June 1, 1973 - August 31, 1973
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COO-2245-23	Period March 1, 1975 - May 31, 1975
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COO-2245-26	Period September 1, 1975 - November 30, 1975
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COO-2245-30	Period March 1, 1976 - May 31, 1976
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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)

I.A. Assessment of Available Data
(Jim Hawley)

This quarter's work was resumed on a report on the experimental method used in determining the flow split parameters x_1 , x_2 , and x_3 . The scope of this undertaking was expanded to include an explicit list of the steps to be followed in making a flow split measurement under any flow conditions and in any subchannel type in a bundle. Much of the effort here was directed towards eliciting and formally verifying the assumptions which underlie the isokinetic extraction experimental technique. This work should be completed in the next quarter.

Work was also begun on the compilation of bundle average friction factor data for various geometrics (i.e. P/D , H/D) of wire wrapped rods in a hexagonal can. The ultimate goal of this work is to produce a single correlation for bundle average friction factors which accounts for the geometry dependence of this quantity and hence, which is valid for predicting friction factors over the ranges of geometric variables and Reynolds number for which data is currently available.

IB.1 61-Pin Fuel Bundle

(Paul Symolon and Kevin Burns)

At the beginning of this quarter, the 61-pin fuel bundle with 6" lead was assembled, and placed on the testbed. Salt mixing experiments were performed over a range of Reynolds numbers from 550 to 20,000. For each Reynolds number, six sets of mixing data were taken - four with injection into a central subchannel, and two with edge subchannel injection. Although final data reduction requires only one set of mixing data from the two subchannels, additional runs were made in case a particular set is determined to be in error. Reduction of the mixing data was delayed because data reduction code, SUPERENERGY-DRV, was lost sometime during the summer after a large fraction of the project's research assistants graduated. Since no tapes were made, the deck had to be re-typed.

Pressure drop measurements were made for the bundle. A plot of friction factor as a function of Reynolds number (Figures 1 and 2) shows a well-defined power law relationship between the two parameters in the laminar and fully-developed turbulent regions. The plot for the central subchannel friction factors, presented in Figure 1, exhibits a more pronounced transition from the laminar to turbulent region than does the plot for the edge subchannel given in Figure 2. Pressure readings as a function of axial height were also taken.

Presently, flow split measurements are being taken on the 61-pin bundle. This work is expected to continue through December, along with reduction of the mixing data.

Figure 1: Friction Factor vs. Reynolds Number
Central Subchannel

Figure 2: Friction Factor vs. Reynolds Number
Edge Subchannel

IB.5 SHAVED-WIRE 61-PIN BLANKET BUNDLE EXPERIMENT
(Song-Feng Wang)

Coolant mixing for shaved-wire blanket bundle has been studied by the salt injection technique. In the mixing experiment, a tracer substance (salt) which changes the electrical resistance of water is injected at a known location within the test section. Resistance in each subchannel is measured at the exit of the test section by a set of resistance probes. These probes are held in place by a plexiglas plate located on the top of a separator. The separator is installed to prevent subchannel coolant from mixing with its neighbors and to get more reliable results through more uniform salt distribution within each subchannel. The salt concentration patterns at the bundle exit plane will then indicate the coolant mixing behavior due to the presence of wire on each rod and the shaving of the peripheral wires.

Due to the temporary malfunction of the data reduction program SUPERENERGY/DRV, only salt concentration distribution maps were obtained. Typical results are shown in Figures 3-6. In Figures 3 and 4, the salt is injected into the center of the test section at a level of 16 inches from exit. The slight increase in the domain of the salt-present region indicates that the mixing coefficient for turbulent flow is greater than that for laminar flow. Furthermore, the symmetry of the salt distribution with respect to the injection axis reflects that a constant mixing coefficient exists at least in the central region of the test section.

For edge injection, shown in Figures 5 and 6, the salt is injected at a different position, i.e. 12 inches from exit. The coolant mixing coefficient under turbulent flow is apparently also greater than that under laminar flow conditions. From the salt distribution patterns, there exists a fairly strong counter-clockwise swirl flow near the duct wall of the test section. However, the magnitude of this swirl flow is smaller than that in full wire bundle because of the increase in the transverse flow resistance of the shaved wire bundle.

The optimum injection height for different flow conditions has been studied by repeating salt injection experiments with different injection positions. The result is shown in Table I, and will be compared to those from the fuel bundle test to determine the optimum injection position for different flow conditions and different subchannels.

Reynolds Number	Mass balance = $\frac{\text{Total salt measured}}{\text{Total salt injected}}$			
	12" from exit 3 wire pitches	14" 3½	16" 4	20" 5
848	1.277	1.033	1.059	1.031
1251		.916		.685
1655		.932		.955
2058	.778			.829
2462	.912	.791	.864	.778
4036	1.022	.871	.881	.928
5650	.849		.749	.791
7265			.901	
8879	.883		.865	.860
10493	.918		.877	
12108			.866	
13722	.941		.909	.869

TABLE I

SALT CONCENTRATION DISTRIBUTION MAP:

DIMENSIONLESS RATIOS OF SALT CONCENTRATION*0.01

MIX08.01

BUNDLE R.E. : 2452

AXIAL LEVEL (IN.) : 16.00

INJ. SUBCHANNEL : 1

FLOW SPLITS :

X1= 0.9670 X2= 1.0765 X3= 0.9144

PASSBALANCE RATIO : 1.184

Figure 3

SALT CONCENTRATION DISTRIBUTION MAP:

DIMENSIONLESS RATIOS OF SALT CONCENTRATION*0.01

PIX15.01

BUNDLE R.E. : 13722

AXIAL LEVEL (IN.) : 16.00

INJ. SUBCHANNEL : 1

FLOW SPLITS :

X1= 0.8797 X2= 1.2529 X3= 1.0000

MASSBALANCE RATIO : 1.039

Figure 4

SALT CONCENTRATION DISTRIBUTION MAP:

DIMENSIONLESS RATIOS OF SALT CONCENTRATION*0.01

RX25.01

BUNDLE R.E. : 2462

AXIAL LEVEL (IN.) : 12.00

INJ. SUBCHANNEL : 79

FLOW SPLITS :

X1= 0.9670 X2= 1.0765 X3= 0.0144

MASSBALANCE RATIO : 0.884

Figure 5

SALT CONCENTRATION DISTRIBUTION MAP:

DIMENSIONLESS RATIOS OF SALT CONCENTRATION*0.01

RX49.01

BUNDLE R.E. : 13722

AXIAL LEVEL (IN.) : 12.00

INJ. SUBCHANNEL : 79

FLOW SPLITS :

X1= 0.8797 X2= 1.2629 X3= 1.0000

MASSBALANCE RATIO : 0.941

Figure 6

IB.6 37-PIN BLANKET BUNDLE
(Tom Chiu)

Work is being done on fabrication of a 37-pin blanket bundle with geometric characteristics of $P/D = 1.15$ and $H/D = 20.88$. These numbers are chosen to fill a gap in published experimental data which are also those characteristic of Phenix geometry.

Fabrication work can be divided into two stages: flow housing and wire-wrapped rod fabrication and actual set up of the bundle. Rod fabrication is completed and flow housing fabrication will be completed within this week. Therefore, the bundle set up is anticipated to be done before Christmas.

The experiments which are planned to be done on this bundle in sequence are mixing experiment, flow split which includes the "history effect" test, and pressure drop.

In doing the mixing experiment, a flow separator is usually needed. But in this bundle, the actual area of the subchannel area is large enough so that the sensitivity probe can penetrate into the subchannel without blocking the flow (interior 32%, edge 6%, and corner is 52%). Instead, probe support plates are used and they are designed and being fabricated.

Usually, the flow split experiment is done first so that the flow split parameters are determined to be used for mixing experiment. However, due to data acquisition availability, the mixing experiment will be run first and the necessary parameters will be derived from Chong Chiu's flow split correlations.

Also, a flow history effect experiment on flow split in an edge and interior subchannel will be done to try and observe the hysteresis effect observed in French experiments. The last experiment to be done will be on pressure drop.

In all this experiment, effort will be put on pushing the Reynolds number as low as the instruments allow, to extend the range of existing data.

ID. ANALYTIC MODEL DEVELOPMENT - BUNDLES

EXTENSION OF TRANSENERGY-S TO MULTIASSEMBLY TRANSIENT ANALYSIS (Tom Greene)

The current repertoire of computer codes based on the ENERGY model can be divided into three principle categories.

1. Steady-State, Single Assembly (ENERGY I, II, III)
2. Steady-State, Multiassembly (SUPERENERGY)
3. Transient, Single Assembly (TRANSENERGY-S)

A logical extension of the model would be to develop a transient code for multiassembly analysis. Some simple modifications are being made to the single bundle code, TRANSENERGY-S to determine the general characteristics of a multiassembly version of the code.

Our objective is to make a comparison between the characteristics of a multiassembly TRANSENERGY and several multiassembly transient codes now under development at other laboratories. If the comparison indicates that there is a need which can be met by a multiassembly version of TRANSENERGY-S, then a complete development will be recommended for the LMFBR program.

The following sections briefly describe the modifications made to TRANSENERGY-S and the sample problem to be used to evaluate the code.

1. TRANSENERGY Model Modified for Multiassembly Analysis

The computational model employed in TRANSENERGY-S is a spatially explicit difference formulation of the ENERGY Equation. This model has been extended to the multiassembly version with some modifications in the treatment of the duct wall and the interassembly gap.

A preliminary analysis indicated that, if the interassembly gap were to be modalized, then the code would require excessively large amounts of core storage and long running times.

A resistance model of the duct wall and the interassembly gap was also investigated. It was found that the use of a resistance model can result in a significant reduction in core storage and computation time compared to the nodalized gap model. Two principal drawbacks were encountered with the resistance model. Convective heat transfer in the gap and the heat capacity of the coolant in the gap are neglected. Further analysis has indicated that neglecting these quantities should not have a significant effect on the overall results.

The resistance model developed is a temporally explicit difference equation in which axial and circumferential heat transfer through the duct wall is neglected. These assumptions are justified because of the thinness of the duct wall and the high thermal conductivity of the sodium coolant. A more detailed justification is given by Chen (1). Figure 5 illustrates the thermal connections made through the interassembly gap. Note that, in the corners, all three assemblies are thermally coupled.

2. A Routine has been Developed to Calculate the Minimum Time Step

When working with a transient code, the axial step-size must be fixed over all time steps since the calculation of conditions at a given timestep depends, in part, on the conditions existing at the previous time-step. This means that the time step-size is the only quantity which may be varied in order to satisfy the numerical stability criteria. An additional complication arises when several assemblies are analysed together: the same time step-size must be used in each bundle so that interactions between bundles can be calculated.

A subroutine, DTMIN, has been developed which finds the maximum allowable time step in each bundle and then takes the smallest of these timesteps as the timestep for the next iteration.

3. TRANSENERGY to Analyze 3 19-Pin Bundles

The modification of TRANSENERGY is near completion. After debugging, a sample problem, consisting of three thermally-coupled 19-pin assemblies will be analysed. The results of the sample problem will be used to determine the merits of a multiassembly TRANSENERGY code relative to the other codes now being developed.

FIGURE 5. Interassembly Thermal Resistance Connections

ID. References

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TASK III. LMFBR OUTLET PLENUM MIXING

III.1 Transient Effects in Turbulence Modeling
(D. Boyle)Progress to Date

Activity during this period has centered around four principal components of this effort: (a) the hydraulic flow loop, (b) the Laser Doppler Anemometer (LDA), (c) automated data recording system, and (d) the VARR II computer code. Progress in each area is discussed in turn.

(a) Hydraulic Flow Loop - The special rectangular channel test section that was used to set-up and check out the LDA, associated electronics, and transient measurement techniques has been removed from the loop. The refurbished Outlet Plenum test cell (in FFTF configuration), with inlet modifications as described in the last report, was installed. Hydrodynamic testing of the cell and its modified inlet region has been completed. Flow visualization techniques were used to verify the functioning of the added capability for inlet velocity profile control; these modifications also provide the potential for measurements at higher Reynold's numbers because of the reduction in flow resistance at the inlet region.

A back-flush capability has been added to the flow loop. This additional piping was installed because the fine-mesh screens, placed in the test-cell inlet to inhibit large scale turbulence effects, can be partially clogged by foreign matter in the loop. Mild back-flushing cleans the screens and returns the contaminants to the main storage tank where they can be removed by the installed clean-up loop.

(b) Laser Doppler Anemometer (LDA) - During this period a Spectra-Physics Model 589 Air Spaced Etalon was installed in the cavity of the Argon Laser system. The purpose of the etalon is to inhibit longitudinal oscillations in all but one laser frequency. Operation in the single mode permitted by the etalon results in a much improved coherence-length for the laser. A long coherence-length is required for LDA operations, especially when split-beam path lengths are not exactly equal, which is the case for the dual channel measurements being performed in this experiment. The increased coherence length should yield an improvement in the signal-to-noise ratio at the tracker input and thereby reduce signal broadening due to noise. The benefits of this modification

include more efficient signal tracking (higher slew-rate) and reduced tracker output noise (more accurate turbulence intensity measurements).

(c) Automated Data Recording System - Unexpectedly late delivery of some necessary electronic components has held up the final stage of construction and testing for the device. The system micro-processor has been programmed and tested to the extent possible. All components have been mounted in the final cabinet configuration, and preliminary tests have been completed. Current projections place this equipment in operation by mid-January.

(d) VARR II Computer Code - This code will be used to predict the turbulence field parameters measured in the experimental portion of the effort. The code has been recently exercised on a new outlet plenum sample problem devised at ANL. In the process, a coding mistake was discovered in the MIT VARR II source-deck and corrected. The corrected code has been verified on both the original and new sample problems. Work has begun on a technique for printer/plotter display of the code output depicting the relevant turbulence parameters during the flow transient to be modelled.

III.2 Modelling of Buoyant Turbulent Flows (C. Chaing)

During the past quarter work has begun concerned with detailed measurements of turbulent buoyant flows. This is a natural extension of past work--concerned first with steady isothermal flows (in order to study steady momentum transport) and later with unsteady isothermal flows (Item III.1) (in order to study the ability of turbulence models to predict transient flow ensemble averages). In this effort the base of information provided by previous work would be extended to include buoyant flow phenomena.

It is planned that this work would be carried out in a two-dimensional LMFBR outlet plenum flow geometry--as with the previous work. Primary concern is directed currently toward identification of the proper instrumentation to use in this work. Because of non-uniformities of the index of refraction of light in buoyant mixing liquids it appears that the Laser Doppler Anemometer (LDA)--used in other parts of this project--will not be applicable to this problem. The limitations of the LDA system and the merits of competing systems are currently being examined in order to identify the best approach to the measurement. As with previous work, the measurements would be compared to turbulence model predictions of the flow--with the goal of identifying and correcting model deficiencies.

III.3 Three-Dimensional Steady Isothermal Flows (R. Sawdye)

During this quarter work has begun on measurements and calculations concerning general three dimensional flows. Anticipating the publication of a three-dimensional code from BNWL attention is focussed upon adapting current experimental capabilities to three-dimensional flow measurements. In this work three-dimensional turbulence effects would be examined by mapping in three-dimensions, both the mean-flow and statistical turbulence quantities which commonly appear in current-generation turbulence models. From the comparison of measured and calculated results, needed model improvements and inherent limitations would be identified.

Current work is concerned with design of the experiment, and when the BNWL model becomes available work to utilize it will be started.

IV. Wire-Wrapped Rod Bundle Heat Transfer Analysis (Chung-Nin Wong)

The development of the computer code to study the wire-wrapped rod bundle heat transfer problem has been underway. The structure of this code is basically composed of two main parts: the fluid flow part and the heat transfer part. The fluid flow part involves solving the Navier-Stokes Equation by applying the pressure solution technique which was discussed in the last report. The principal objective is to obtain the velocity field and the pressure potential in the coolant. Having the first part solved, the velocity field will feed into the energy equation which belongs to the second part of the problem. By solving the energy equation, the temperature distribution in the coolant, the clad, the fuel, and the wire will be obtained.

In the meantime, our concentration is on solving the momentum equation in order to obtain the velocity field and the pressure potential in the coolant. This process involves two-step iterations. First, a Newton-Raphson method is used to obtain the velocity field of the coolant with the specified pressure gradient. Then, this pressure gradient will be adjusted and the velocities will be re-iterated until finally they all satisfy the continuity condition and also the boundary conditions. Obviously, the overall process takes a substantial amount of iterating time and needs a large storage space. To handle these problems properly, an external storage space and an efficient calculational scheme are required.

Possibly, within the next quarter of the year, the fluid flow part will be completed. Then, testing of the program will begin. Several problems will be solved and analyzed. The result of these testings will be discussed in the next progress report.