DOE/ET/37240--T4 Rev. 1

NUCLEAR ENGINEERING

MASSACHUSETTS INSTITUTE
OF TECHNOLOGY

MASTER

LABORATORY MANUAL FOR SALT-
MIXING TEST IN 37- AND 217-
PIN BUNDLES
BY
YEE-NING CHAN
NEIL E. TODREAS

AUGUST 1980
COO-2245-62TR, Rev. I

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DOE/ET/37240--T4 Rev. 1

COO-2245-62TR
Rev 1

DOE/ET/37240--T4 Rev. 1

DE82 007741

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

LABORATORY MANUAL FOR SALT-
MIXING TEST IN 37- AND 217-
PIN BUNDLES
BY
YEE-NING CHAN
NEIL E. TODREAS

AUGUST 1980
COO-2245-62TR, Rev. I

"This report was prepared as an account of Government-sponsored work. Neither the United States, or the Energy Research and Development Administration nor any person acting on behalf of the Commission

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness or usefulness of the information contained in this report, or that the use of any information, apparatus method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

As used in the above, 'person acting on behalf of the Commission' includes any employee or contractor of the Administration or employee of such contractor, to the extent that such employee or contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Administration or his employment with such contractor."

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
Springfield, Virginia 22151)

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
COO-2245-25	Period June 1, 1975 - August 31, 1975
COO-2245-26	Period September 1, 1975 - November 30, 1975
COO-2245-28	Period December 1, 1975 - February 29, 1976
COO-2245-30	Period March 1, 1976 - May 31, 1976
COO-2245-31	Period June 1, 1976 - August 31, 1976
COO-2245-34	Period September 1, 1976 - November 30, 1976
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
COO-2245-66	Period September 1, 1978 - November 30, 1978

COO-2245-69 Period December 1, 1978 - February 28, 1979
COO-2245-70 Period March 1, 1979 - May 31, 1979
COO-2245-71 Period June 1, 1979 - August 31, 1979
COO-2245-72 Period September 1, 1979 - November 30, 1979
DOE-2245-75 Period December 1, 1979 - February 29, 1980
DOE-2245-76 Period March 1, 1980 - May 31, 1980
DOE-2245-85 Period June 1, 1980 - August 31, 1980
DOE-2245-89 Period September 1, 1980 - November 30, 1980

Reports Issued Under This Contract

- B.1 Original (Available from National Technical
 Topical Reports Information Service, U.S. Depart-
 ment of Commerce, Springfield,
 VA 22151)

E. Khan and N. Todreas, "A Review of Recent Analytical and Experimental Studies Applicable to LMFBR Fuel and Blanket Assembly Design", COO-2245-4TR, MIT, September 1973.

E. Khan, W. Rohsenow, A. Sonin and N. Todreas, "A Simplified Approach for Predicting Temperature Distribution in Wire Wrapped Assemblies", COO-2245-5TR, MIT, September 1973.

T. Eaton and N. Todreas, "Instrumentation Methods for Interchannel Coolant Mixing Studies in Wire-Wrap Spaced Nuclear Fuel Assemblies", COO-2245-9TR, MIT, June 1974.

Y. B. Chen, K. Ip, N. E. Todreas, "Velocity Measurements in Edge Subchannels of Wire Wrapped LMFBR Fuel Assemblies", COO-2245-11TR, MIT, September 1974.

E. Khan, N. Todreas, W. Rohsenow, A. A. Sonin, "Analysis of Mixing Data Relevant to Wire-Wrapped Fuel Assembly Thermal-Hydraulic Design", COO-2245-12TR, MIT, September 1974.

E. Khan, W. Rohsenow, A. Sonin, N. Todreas, "A Porous Body Model for Predicting Temperature Distributions in Wire Wrapped Fuel and Blanket Assemblies of an LMFBR", COO-2245-16TR, MIT, June 1975.

* E. Khan, W. M. Rohsenow, A. Sonin, N. Todreas, "Input Parameters to the ENERGY Code (To be used with the ENERGY Codes Manual), COO-2245-17TR, MIT, May 1975.

* E. Khan, W. Rohsenow, A. Sonin, N. Todreas, "Manual for ENERGY Codes I, II, III", COO-2245-18TR, MIT, May 1975.

P. Carajilescov and N. Todreas, "Experimental and Analytical Study of Axial Turbulent Flows in an Interior Subchannel of a Bare Rod Bundle", COO-2245-19TR, MIT.

* B. Chen and N. Todreas, "Prediction of Coolant Temperature Field in a Breeder Reactor Including Interassembly Heat Transfer", COO-2245-20TR, MIT, May 1975.

* Revised - See Section B.2

B.1 Original Topical Reports (Continued)

F. Carre and N. Todreas, "Development of Input Data to ENERGY Code for Analysis of Reactor Fuel Bundles", COO-2245-21TR, MIT, May 1975.

H. Ninokata and N. E. Todreas, "Turbulent Momentum Exchange Coefficients for Reactor Fuel Bundle Analysis", COO-2245-22TR, MIT, June 1975.

R. Anoba and N. Todreas, "Coolant Mixing in LMFBR Rod Bundles and Outlet Plenum Mixing Transients", COO-2245-24TR, MIT, August 1975.

- * B. Bosy, "Fabrication Details for Wire Wrapped Fuel Assembly Components", COO-2245-27TR, MIT, November 1975.

Ralph G. Bennett and Michael W. Golay, "Interferometric Investigation of Turbulently Fluctuating Temperature in an LMFBR Outlet Plenum Geometry", COO-2245-29TR, MIT, June 1976.

N. E. Todreas, "Thermal Analysis Methods for LMFBR Wire Wrapped Bundles", COO-2245-32TR, MIT, November 1976.

K. L. Basehore and N. E. Todreas, "Development of Stability Criteria and an Interassembly Conduction Model for the Thermal-Hydraulics Code SUPERENERGY", COO-2245-33TR, MIT, December 1976.

Robert Masterson and Neil E. Todreas, "Analysis of the Feasibility of Implementing an Implicit Temporal Differencing Scheme in the SUPERENERGY Code", COO-2245-35TR, MIT, February 1977.

S. Glazer, C. Chiu and N. Todreas, "Collection and Evaluation of Salt Mixing Data with the Real Time Data Acquisition System", COO-2245-36TR, MIT, April 1977.

B. Mikic, E. U. Khan and N. E. Todreas, "An Approximate Method for Predicting Temperature Distribution in Wire Wrapped Fuel Assemblies of an LMFBR", COO-2245-37TR, MIT, April 1977.

J. T. Hawley, C. Chiu and N. Todreas, "Development of a Technique for Subchannel Flow Rate Measurements in LMFBR Wire Wrapped Assemblies", to be issued as COO-2245-39TR 6/80. Never issued. Replaced by DOE/ET/37240-80TR.

- * Revised - See Section B.2

B.1 Original Topical Reports (Continued)

- * C. Chiu and N. Todreas, "WARD Blanket Assembly Pre-Test Predictions by SUPERENERGY", COO-2245-40TR, MIT, May 1977.
- C. Chiu, N. Todreas, W. M. Rohsenow, "Flow Split Measurements in LMFBR Blanket Assemblies", COO-2245-41TR, MIT, April 1978.
- C. Chiu, J. Hawley, W. M. Rohsenow and N. Todreas, "Pressure Drop Measurements in Wire Wrapped Blanket Assemblies", COO-2245-42TR, July 1977.
- C. Chiu, W. M. Rohsenow and N. Todreas, "Mixing Experiments in LMFBR Wire Wrapped Blanket Assemblies", COO-2245-43TR, April 1978.
- Yi Ben Chen and Michael W. Golay, "Coolant Mixing in the LMFBR Outlet Plenum", COO-2245-44TR, June 1977.
- J. Kelly and N. Todreas, "Turbulent Interchange in Triangular Array Bare Rod Bundles", COO-2245-45TR, July 1977.
- K. L. Basehore and N. E. Todreas, "Assessment of the Need to Incorporate a Variable Swirl Flow Model into the ENERGY Code", COO-2245-46TR, July 1977.
- K. L. Basehore and N. Todreas, "Analysis of the Thermal-Hydraulic Behavior in the CRBR Secondary Control Assembly, Including Interassembly Heat Transfer Effects", COO-2245-47TR, July 1977.
- J. G. Bartzis and N. E. Todreas, "Hydrodynamic Behavior of a Bare Rod Bundle", COO-2245-48TR, MIT, June 1977.
- M. R. Fakori-Monazah and N. E. Todreas, "Measurement and Analysis of Flow Wall Shear Stress in an Interior Subchannel of Triangular Array Rods", COO-2245-49TR, MIT, August 1977.
- * A. S. Hanson and N. E. Todreas, "Fluid Mixing Studies in an Hexagonal 61-Pin, Wire-Wrapped Rod Bundle", COO-2245-51TR, MIT, August 1977.
- S. Glaser, N. Todreas, W. Rohsenow, and A. Sonin, "TRANSENERGY S,M - Computer Codes for Coolant Temperature Prediction in LMFBR Cores During Transient Events", COO-2245-52TR, MIT, February 1981.
- C. Chiu, W. M. Rohsenow, and N. E. Todreas, "Mixing Experiments in an Alternating Wire Wrapped Assembly", COO-2245-54TR, MIT, December 1977.

* Revised - See Section B.2

B.1 Original Topical Reports (Continued)

- * C. Chiu, W. M. Rohsenow and N. E. Todreas, "Turbulent Sweeping Flow Mixing Model for Wire Wrapped LMFBF Assemblies", COO-2245-55TR, MIT, April 1978.
- * C. Chiu, W. M. Rohsenow and N. E. Todreas, "Flow Split Model for LMFBF Wire Wrapped Assemblies", COO-2245-56TR, MIT, April 1978.
- K. Basehore and N. E. Todreas, "SUPERENERGY: Multiassembly Thermal-Hydraulic LMFBF Code", to be issued as Topical Report COO-2245-57TR, MIT, NED
- C-N. Wong and L. Wolf, "A 3-D Slug Flow Heat Transfer Analysis of Coupled Coolant Cells in Finite LMFBF Bundles", COO-2245-58TR, MIT, February 1978.
- Roohollah Karimi and L. Wolf, "Two Dimensional Structural Analysis of Reactor Fuel Element Claddings Due to Local Effects", COO-2245-59TR, MIT, April 1978.
- Vincent Manno and Michael Golay, "Measurement of Heat and Momentum Eddy Diffusivities in Recirculating LMFBF Outlet Plenum Flows", COO-2245-61TR, MIT, June 1978.
- * Hafeez Khan, Chong Chiu and Neil Todreas, "Laboratory Manual for Salt Mixing Test in Rod Bundles", COO-2245-62TR, MIT, October 1978.
- J. Y. Kim and L. Wolf, "Fully-Developed Mixed Convection Heat Transfer and Pressure Drop in Characteristic Coolant Cells of Finite Hexagonal Bare Bundles", COO-2245-67TR, MIT, Dec. 1978.
- M. K. Yeung and L. Wolf, "A Multicell Slug Flow Heat Transfer Analysis of Finite LMFBF Bundles", COO-2245-68TR, MIT, December 1978.
- S. F. Wang, W. M. Rohsenow, N. E. Todreas, "Steady, Laminar, Fully-Developed Mixed Convection in Finite Rod Arrays", COO-2245-73TR, MIT, Feb. 1981.
- P. D. Symolon, N. E. Todreas, "A Manual for Use with the Computer Code Superenergy-Data Reduction Version", COO-2245-74TR, MIT, February 1980.
- K. J. Burns, N. E. Todreas, "Laboratory Manual for Static Pressure Drop Experiments in LMFBF Wire Wrapped Rod Bundles," DOE/ET/37240-77TR, July 1980.
- K. J. Burns, N. E. Todreas, "A Comparison Between the SIMPLE and ENERGY Code Mixing Models," DOE/ET/37240-78TR, July 1980.
- * Revised - See Section B.2

B.1 Original Topical Reports (Continued)

J. T. Hawley, C. Chiu, W. M. Rohsenow, N. E. Todreas, "Correlations for Subchannel and Bundle Friction Factors and Flowsplit Parameters for Laminar, Transition, and Turbulent Longitudinal Flows in Wire Wrap Spaced Hexagonal Arrays", DOE/ET/37240-79TR, Dec. 1980.

J. T. Hawley, C. Chiu, N. E. Todreas, "M.I.T. Extraction Method for Measuring Average Subchannel Axial Velocities in Reactor Assemblies", DOE/ET/37240-80TR, July 1980.

K. J. Burns, W. M. Rohsenow, N. E. Todreas, "Laminar/Transition Sweeping Flow Mixing Model for Wire Wrapped LMFBR Assemblies", DOE/ET/37240-81TR, July 1980.

T.E. Greene, N. E. Todreas, "Criteria for Onset of Mixed Convection in Wire Wrap Spaced Hexagonal Arrays", Report DOE/ET/37240-82TR, to be issued.

D. R. Boyle and M. W. Golay, "Transient Effects in Turbulence Modelling", DOE/ET/37240-83TR, Feb. 1980.

P. D. Symolon and N. E. Todreas, "Fluid Mixing Studies in a Hexagonal 217 Pin Wire Wrapped Rod Bundle," DOE/ET/37240-84TR, Feb. 1981.

S. F. Wang, W. M. Rohsenow, and N. E. Todreas, "Flow Split, Pressure Drop, and Mixing Experiments in a 61 Pin Shaved-Wire Blanket Assembly, DOE/ET/37240-86TR, Feb. 1981.

S. F. Wang, N. E. Todreas, "Computer Model for M.I.T. Correlations for Friction Factors, Flow Split, and Mixing Parameters in LMFBR Wire-Wrapped Rod Assemblies, DOE/ET/37240-87TR, Feb. 1981.

S. F. Wang and N. E. Todreas, "Experimental Investigations of Laminar Mixed Convection in a Square Array of Bare Rods," Report No. DOE/ET/37240-88TR, Feb. 1981.

Reports Issued Under This Contract

- B.2 Revised (Available from National Technical
Topical Reports Information Service, U.S. Depart-
 ment of Commerce, Springfield,
 VA 22151)

S. F. Wang and N. E. Todreas, "Input Parameters to Codes Which Analyze LMFBR Wire-Wrapped Bundles," COO-2245-17TR, (Revision I), MIT, May, 1979.

- ** E. Khan, W. Rohsenow, A. Sonin, N. Todreas, "Manual for ENERGY Codes I, II, III Computer Programs", COO-2245-18TR, Revision I, MIT, July 1976.

- ** B. C. Chen and N. E. Todreas, "Prediction of Coolant Temperature Field in a Breeder Reactor Including Inter-assembly Heat Transfer," COO-2245-20TR, (Revision I), MIT, December, 1976.

H. Khan, "Fabrication Details for Wire-Wrapped Fuel Assembly Components," COO-2245-27TR, (Revision I), MIT, September, 1978.

- ** K. W. Chiu, "Fabrication Details for Wire-Wrapped Fuel Assembly Components," COO-2245-27TR, (Revision II), MIT, September, 1979.

C. Chiu, W. M. Rohsenow and N. E. Todreas, "Turbulent Sweeping Flow Mixing Model for Wire Wrapped LMFBR Assemblies", COO-2245-55TR, Rev. 1, MIT 1978.

- ** J. T. Hawley, Y. N. Chan and N. E. Todreas, "Input Parameters to Codes which Analyze LMFBR Wire Wrapped Bundles," COO-2245-17TR, (Revision II), December 1980.

- ** P. D. Symolon and N. E. Todreas, "Fluid Mixing Studies in a Hexagonal 61 Pin Wire Wrapped Rod Bundle," COO-2245-51TR, (Revision I), February 1981.

- ** Y. N. Chan and N. E. Todreas, "Turbulent Sweeping Flow Mixing Model for Wire Wrapped LMFBR Assemblies," COO-2245-55TR, (Revision II), December 1980.

- ** Y. N. Chan and N. E. Todreas, "Turbulent Flow Split Model and Supporting Experiments for Wire Wrapped Core Assemblies," COO-2245-56TR, (Revision I), December 1980.

- ** Y. N. Chan and N. E. Todreas, "Laboratory Manual for Salt Mixing Test in 37- and 217-Pin Bundles," COO-2245-62TR, (Revision I), August 1980.

- ** Latest Revision

Reports Issued Under This Contract

B.2 Revised (Available from National Technical
Topical Reports Information Service, U. S. Depart-
(Continued) ment of Commerce, Springfield,
VA 22151)

** T. E. Greene and N. E. Todreas, "WARD Blanket Assembly
Pre-Test Predictions by SUPERENERGY," COO-2245-40TR,
Revision I, April 1981.

** Latest Revision

Reports Issued Under This ContractC. Papers and Summaries

Y. B. Chen, K. L. Ip, and N. E. Todreas, "Velocity Measurements in Edge Channels of Wire-Wrapped LMFBR Fuel Assemblies," American Nuclear Society Transactions, Vol. 19, 1974, pp. 323-324.

P. Carajilescov and N. Todreas, "Experimental and Analytical Study of Axial Turbulent Flows in an Interior Subchannel of a Bare Rod Bundle," J. of Heat Transfer, Vol. 98, No. 2, May 1976, pp. 262-268, (Included as Appendix to Quarterly Progress Report, COO-2245-15).

E. Khan, W. Rohsenow, A. Sonin, and N. Todreas, "A Porous Body Model for Predicting Temperature Distribution in Wire-Wrapped Fuel Rod Assemblies," Nuclear Engineering and Design, 35 (1975), pp. 1-12.

E. Khan, W. Rohsenow, A. Sonin, and N. Todreas, "A Porous Body Model for Predicting Temperature Distribution in Wire-Wrapped Rod Assemblies Operating in Combined Forced and Free Convection," Nuclear Engineering and Design, 35 (1975), pp. 199-211.

R. G. Bennett and M. W. Golay, "Development of An Optical Method for Measurement of Temperature Fluctuation in Turbulent Flows," American Nuclear Society Transactions, Vol. 22, 1975, p. 581.

B. Chen and N. Todreas, "Prediction of the Coolant Temperature Field in a Breeder Reactor Including Interassembly Heat Transfer," Nuclear Engineering and Design, 35, (1975), pp. 423-440, (Included as Appendix to Quarterly Progress Report, COO-2245-23).

R. Bennett and M. W. Golay, "Interferometric Investigation of Turbulently Fluctuating Temperature in an LMFBR Outlet Plenum Geometry," Presented at the ASME Annual Winter Meeting, December, 1976, (Included as Appendix in Quarterly Progress Report, COO-2245-30).

B. B. Mikic, E. U. Khan, and N. E. Todreas, "An Approximate Method for Predicting Temperature Distribution in Wire-Wrapped Fuel Assemblies of a Liquid Metal Fast Breeder Reactor," Mech. Res. Comm., Vol. 3, (1976), pp. 353-360.

L. Wolf, R. Karimi, J. Y. Kim, C. N. Wong, and M. K. Yeung, "2-D Thermoelastic Analysis of LMFBR Fuel Rod Claddings," Paper C4/d, 4th International Conf. Structural Mechanics in Reactor Technology, San Francisco, August 1977.

Reports Issued Under This ContractC. Papers and Summaries (Continued)

M. Yeung, and L. Wolf, "Effective Conduction Mixing Lengths for Subchannel Analysis of Finite Hexagonal LMFBR Bundles," Transactions of the American Nuclear Society, June 1977, Vol. 26, pp 463-464.

C. Chiu and N. Todreas, "Flow Split Measurements in an LMFBR Radial Blanket Assembly," Transactions of the American Nuclear Society, June 1977, Vol. 26, pp 455-456.

J. Y. Kim and L. Wolf, "Laminar Mixed Convection Heat Transfer in Finite Hexagonal Bundles," Transactions of the American Nuclear Society, (1977), Vol. 27, pp 384-385.

J. Kelly and N. Todreas, "Turbulent Interchange in Triangular Array Bare Rod Bundles," Paper NR-3, Presented at Sixth International Heat Transfer Conference, Toronto, August 1978.

C. Chiu, N. E. Todreas, and W. M. Rohsenow, "Turbulent Flow Split Experiment and Model for Wire-Wrapped Assemblies," Transactions of the American Nuclear Society, June, 1978, Vol. 28, TANSO 28, (1978), pp 536-537, ISSN: 0003-018X.

C. Chiu, N. E. Todreas, and W. M. Rohsenow, "Pressure Drop Measurements in LMFBR Wire-Wrapped Blanket Bundles," Transactions of the American Nuclear Society, Vol. 30, pp 541-543, (1978).

C. Chiu, N. E. Todreas, and W. M. Rohsenow, "Turbulent Mixing Experiment and Model for Wire-Wrapped Assemblies," Trans. of the American Nuclear Society, Vol. 30, pp 547-548 (1978).

M. Fakory and N. Todreas, "Experimental Investigation of Flow Resistance and Wall Shear Stress in the Interior Subchannel of a Triangular Array of Parallel Rods," J1. Fluids Eng., Vol. 101, pp 429-435 (Dec. 1979).

J. G. Bartzis and N. E. Todreas, "Turbulence Modeling of Axial Flow in a Bare Rod Bundle," J1. Ht. Trans., Vol. 101, No. 4, pp 628-634 (Nov. 1979).

Reports Issued Under This ContractC. Papers and Summaries (Continued)

C. Chiu, W. M. Rohsenow, and N. E. Todreas, "Prediction of Temperature Distribution in Wire-Wrapped Nuclear Fuel Rod Assemblies," Proceedings NATO Mtg, Vol. 1, pp 175-184, published by Hemisphere Pub. Co., Washington, DC (1978).

S. Glazer, T. Greene, N. Todreas, and L. Wolf, "Transient Thermal-Hydraulic Analysis in the Forced-Convection Regime (TRANSENERGY)," TANSOA, Vol. 32, Atlanta, 1979.

C. Chiu, W. M. Rohsenow, and N. E. Todreas, "Turbulent Flow Split Model and Supporting Experiments for Wire-Wrapped Core Assemblies," Nuclear Technology, Vol. 50, pp 40-52, August 1980.

Chiu, C., Hawley, J. T., Rohsenow, W. M., and Todreas, N. E., "Parameters for Laminar, Transition and Turbulent Longitudinal Flows in Wire Wrap Spaced Hexagonal Arrays," Accepted for presentation at the Topical Meeting on Nuclear Reactor Thermal Hydraulics, Saratoga, NY, October 5-8, 1980.

Rohsenow, W. M., Todreas, N. E., Wang, S. F., "Buoyancy Effects on Subchannel Friction Factors in Bare Rod Bundles," Submitted for consideration at Specialists' Meeting on Decay Heat Removal and Natural Convection in FBRs, February 28-29, 1980, Upton, New York.

Chiu, C., Morris, R., and N. Todreas, "Experimental Techniques for Liquid Metal Cooled Fast Breeder Reactor Fuel Assembly Thermal/Hydraulic Tests," Invited Paper for Special Issue of Nuclear Engineering and Design, Vol. 62, No. 1-3, 253-270, Dec. 1980.

Bishop, A. and N. Todreas, "Hydraulic Characteristics of Wire-Wrapped Rod Bundles," Invited Paper for Special Issue of Nuclear Engineering and Design, Vol. 62, No. 1-3, 271-293, Dec. 1980.

ACKNOWLEDGEMENTS

We are indebted to Mr. Paul Symolon for his helpful guidance and discussion in and out of the laboratory and also for his proofreading of the report; to the Undergraduate Research Opportunities Program of M.I.T. for contributing part of the financial support.

ABSTRACT

This laboratory manual deals with the procedure employed during salt tracer experiments used in evaluating the hydraulic characteristics of a rod bundle. A description of the standard equipment used is given together with the details of manufacture of probes used for detecting the salt concentration. Details of the bundle construction have been excluded as they are available in the reference cited. An attempt has been made to point out potential trouble areas and procedures.

REVISION RECORD

The original Laboratory Manual for Salt Mixing Test in 61-pin Bundles," Hafeez-ur-Rehman Khan, Chong Chiu and N. E. Todreas, was essentially written for 61-pin bundles. Since we are running only 37- and 217-pin bundles, a revised manual is necessary. This new manual is modeled after the original version. All modifications and additions to the different procedures for the mixing test on 37- and 217-pin bundles have been incorporated. The figures have been redrawn; a more accurate calibration curve for Rotometer R4 has also been included.

TABLE OF CONTENTS

	Page
1. Introduction	1
2. General Equipment Description	3
2.1 Fuel Assembly	3
2.2 Injector	3
2.3 Main Flow Loop	4
2.4 Salt Injection System	6
2.5 Salt Detection System	6
3. Salt Tracer Experiment	8
3.1 Setting Up	8
3.2 Calibration of Probes	9
3.3 Experimental Procedures	11
Appendix	14
I Construction of the Probes	14
II Mounting of Probes	18
Figures	20-30
References	31

LIST OF FIGURES

	<u>Page No.</u>
Fig. 1 Fuel Rod Test Section Fully Assembled	21
Fig. 2a Injection Rod	22
2b Injector	22
Fig. 3 Flow Diagram of the Main Water Circulation Loop	23
Fig. 4 Calibration Curve for Rotometer R2 Fischer & Porter meter 7303 A3749 A1	24
Fig. 5 Salt Injection System	25
Fig. 6 Calibration Curve of Rotometer R4 Fischer & Porter meter using tube FP-1/8-12-G-5/81	26
Fig. 7 Calibration Curve of Rotometer R5 Fischer & Porter meter using tube FP-1/4-20-G-5/81	27
Fig. 8 Salt Detection System	28
Fig. 9 The Construction of Probes	29
Fig. 10 Subchannel Numbering Scheme for 217-pin Bundle	30

INTRODUCTION

The analysis of energy transfer within the subchannels of a reactor rod bundle requires a correlation for determining the coolant mixing within the bundle. Such correlations are based on the data obtained from, among other methods, Salt Tracer Experiments (also referred to as Mixing Test). The salt is injected by means of an injector inserted in a fuel rod with holes into the different sub-channel types: central, edge and corner. The injection of the salt solution is done in such a manner that the main flow is not disturbed, i.e., the vertical component of the injection velocity equals the axial flow velocity in the sub-channel where injection is taking place.

The spread of the salt is detected by probes at the exit plane on the top of the bundle. The conductivity of the water is proportional to the salt concentration and this property is exploited by the probes.

The old version of this report (Reference 3) was essentially written for 61-pin fuel and blanket LMFBR bundles. This report was written because the procedures for the Mixing Test on 37- and 217- pin bundles are, in many respects, different from those for the 61-pin bundles. The figures have also been redrawn; a more accurate calibration curve for Rotometer R4 has been included.

As of this writing, the 37-pin bundle has been found to have a non-uniform housing. Since it is too expensive to build a new housing, it is planned to put together a new 37-pin assembly

to fit the extruded, hexagonal housing originally used by a 217-pin assembly. The parameters of the new 37-pin bundle have not been included in this report because the procurement of the new stainless steel rods and matching wires have not been finalized. However, the new bundle will be located in the test stand where the 217-pin bundle was located and the pertinent sections of the report should be interpreted accordingly.

GENERAL EQUIPMENT DESCRIPTION

The hexagonal test section of a 217-pin liquid metal fast breeder reactor (LMFBR) bundle is made up of wire-wrapped rods arranged in a triangular lattice.

2.1 Fuel Assembly (Fig. 1)

Diameter of rods	= 0.231"
Diameter of wires	= 0.057"
Length of rods	=58.125"
Wire lead length	=12.000"

Note: All rods are made from hollow tubes with the bottom ends specially designed to be held down by a hexagonal rod support. The injection rods (Fig. 2a) have holes drilled along the length of the tubes at an angle of 30° to the vertical axis to minimize the jet effect of fluid injection into the main bundle flow.

2.2 Injector (Fig. 2b)

It is made up of a hollow cylinder, closed at one end. The other end is connected to a long tube which helps in placing it at the desired depth in the bundle. It has four grooves, two on each side of the central injection hole, where O-rings are fitted. These O-rings provide a tight fit in the injection rod and thereby ensure that the flow of the salt solution is in the desired direction and depth.

2.3 Main Flow Loop

Fig. 3 shows the flow loop for both bundles, i.e., 37-pin and 217-pin. Water is drawn from the canal by pump 1 into the tank. A filter is employed in the line so that debris from the canal does not pass into the tank. Large pieces of debris are liable to accumulate in the bundle and restrict the flow passages. Pump 2 draws water from the tank and circulates it through the bundles.

When operating the 217-pin bundle at flow rates above 50 GPM, valves 2, 4 and 5 are closed. Valve 1 is always opened and valve 3 is partially opened such that with valves 4, 5 and 6 closed, the level of the water in the tank does not drop. During the experiment the flow through the bundle is controlled by valve 6 and is metered by venturimeter V2 and indicated by rotometer R2. At lower flow rates, below 50 GPM, valve 6 is closed and valve 4 is opened. The flow rate is measured by system M3 with an outlet pipe connected to a point after valve 6 (dotted line in Fig. 3) but before the lower plenum.

When operating the 37-pin bundle at flow rates above 50 GPM, valves 6, 7, 8 and 9 are closed. Valve 4 is opened and the flow is regulated by valve 5. The metering and indication of the flow rates is done by system M1. For lower flow rates, below 50 GPM, valve 5 is closed and valve 7 is opened. Valves 8 and 9 are used independently or together to control the flow rates. The outlet of system M3 is now connected to a point at the bottom of

the 37-pin bundle.

The principal components used are described below:

- a) Pumps 1 and 2 - Both these centrifugal pumps are similar and manufactured by the Bell and Gossett Company. Each pump has a maximum capacity of 300 GPM at 180 ft. water head pressure.

Note: It is absolutely essential that the priming water should be opened at all times.

- b) Metering System M1:

Venturimeter V1 - a TEFCO 3" meter No. A-105-2 KKM.

Rotometer R1 - a Fischer & Porter meter No. 7910 A0361 A1 of 350 GPM capacity and using tube FP-1/2-27-G-10/55.

- c) Metering System M2:

Venturimeter V2 - a TEFCO 3" meter No. 300A-105-2 KKM.

Rotometer R2 - a Fischer & Porter meter No. 7303 A3749 A1 of 360 GPM capacity and using tube FP-1/2-27-G-10/55.

Note: Both venturimeters V1 and V2 are factory calibrated but the rotometers have to be calibrated. The calibration curve for rotometer R2 is shown in Fig. 4.

- e) Metering System M3:

Flowmeters R3-1 and R3-2 are of a type which do not require the use of a separate venturimeter for measuring purposes.

Rotometer R3-1 - a Fischer & Porter meter of 37.0 GPM capacity and using tube FP-2-27-G-10/83.

Rotometer R3-2 - a Fischer & Porter meter of 19.1 GPM capacity and using tube FP-1-1/2-G-10/83.

e) Valves:

Valves 1, 2, 3, 4, 5 and 6 are identical 3", solid-wedge gate valves manufactured by the Jenkins Company. They are specified as 125 WSP, 200 OWG. Valve 7 is a 2" solid-wedge gate valve made by the Jenkins Company and is specified as 125 WSP, 150 OWG. Valve 8 and 9 are identical $1\frac{1}{2}$ " solid-wedge gate valves also manufactured by the Jenkins Company and are specified as 125 WSP, 200 OWG.

2.4 Salt Injection System

The salt injection system, illustrated in Fig. 5, consists of a large vessel, pressurizable up to more than 120 psi, connected to the injector via a flowmeter. The calibration curves of rotometers R4 and R5 are shown in Figs. 6 and 7, respectively.

Rotometer R4 is a Fischer & Porter meter using tube FP-1/8-12-G-5/81.

Rotometer R5 is a Fischer & Porter meter using tube FP-1/4-20-G-5/81.

2.5 Salt Detection System (Fig. 8)

The salt concentration at various points of the bundle is detected electronically by an "Interdata Computer System". The probes (see Appendix for the details of construction and location) mounted in the brass flow separator (or, for instance, in a 37-pin

bundle, the probes are mounted on a skeletal plexiglass-neoprene-plexiglass sandwich probe support). Platinum is used for the electrodes because of its chemical inertness and high electrical conductivity. The details of the computer system are obtainable in Reference 2.

Note: The subchannel areas in the flow separator are so small that the tips of the probes tend to touch the sides when mounted and so short-circuit. To overcome this, the inside of the subchannels are painted with Rust-Oleum (Navy-Gray). This paint should be inspected every time the probes are removed from the separator and a new coat of paint is applied if the old coat starts to flake.

SALT TRACER EXPERIMENT

3.1 Setting Up

1. Insert the injector in the injection rod after the flow separator (or, for instance, in a 37-pin bundle, the probes are mounted on a skeletal plexiglass-neoprene-plexiglass sandwich probe support) is mounted.
2. Plug the top of the injection rod not being used. This can be done either by a rubber cork or by using a solid rod of the same diameter as the injector. An unplugged rod will cause appreciable flow deviations.
3. Mount the flow separator assembly (i.e. with probes already mounted on it) in place.

Note: The flow separator assembly has to be bolted to the top plate. The locating holes are provided in the top plate. This operation is facilitated by first removing the upper plenum, align and bolt the separator and then put back the upper plenum. Seal the joints with RTV.

4. Connect the probes to the junction box. Care should be taken to ensure that correspondingly numbered labels are connected together and that the 16-pin plugs are correctly inserted in the sockets. Note that some plugs have been labelled "reverse" and should be inserted accordingly.
5. Check that all outlets of the junction box are correctly plugged into the white box (MPX). The connecting scheme is

shown in Fig. 8.

6. Connect the MPX to the computer by means of the 34-pin connector cable marked "White Box". This cable should be oriented such that the red lining of the cable is on the side of the red dot on the MPX box.
7. Connect the video terminal to the computer.
8. Plug in the MPX, video terminal and the computer.
9. Switch on the system.

Note: The MPX should always be switched off when the cables are being plugged in or the probes are being replaced.

10. Initialize the system by the method given in Reference 2.

3.2 Calibration of Probes

For the 217-pin bundle, the calibration is best carried out before mounting the flow separator assembly onto the top plate in the upper plenum.

1. Use a sensitive laboratory balance, for instance, the balance in the Nuclear Reactor Laboratory (bldg. NW 12), to weigh three of 2 grams each and five of 4 grams each of common salt.

Note: The salt is obtained from the Chemistry Stock Room, sub-basement of Building 18.

2. Measure 100 lbs of water in a large barrel.
3. Immerse the flow separator assembly in the barrel.
4. Using the computer, take and store the probe readings at zero salt concentration.

5. Remove the flow separator assembly and dissolve 2 gms of salt in the water. Stir thoroughly.
6. Repeat steps 3 and 4 but note that the salt concentration is 2 gms/100lbs. of water.
7. Repeat step 5, adding an additional 2 gms of salt to make the total salt concentration to be 4 gms/100lbs. of water. Repeat steps 3 and 4.
8. Take calibration data for salt concentrations of 0, 2, 4, 8, 12, 16 and 20 gms. in 100lbs. of water.

Unlike the 217-pin bundle, the probes for the 37-pin bundle are mounted on the exit plane by a skeletal plexiglass-neoprene-plexiglass sandwich probe support. The probes are, as such, not portable on a separator. Consequently, the calibration procedure is done with the probes already mounted inside the upper plenum and not in large barrel.

1. As for the 217-pin bundle but weigh one each of 2, 4, 8, 12, 16 and 20 gms. of salt instead.
2. Flush the bundle with water at 70-100 GPM for a few minutes.
3. Using the computer, take and store the probe readings at zero salt concentration.
4. Drain the water via the drain valve.
5. Close the drain valve.
6. Dissolve 2 gms. of salt in 100 lbs. of water in a large barrel. Stir thoroughly.
7. Using a small pump or a bucket put the solution into the bundle. Ensure that the probe tips are fully covered by

the saline solution.

8. Using the computer, take and store the probe readings onto floppy disc for 2 gms. of salt in 100 lbs. of water.
9. Drain the bundle.
10. Flush the bundle again.
11. With fresh water in the bundle, take another set of data and store it. This will form the background reading.
12. Thoroughly clean the bucket and prepare salt solution of next concentration.
13. Repeat steps 4, 5, 7, 8 (for new concentration), 9, 10, 11 and 12.

For both the 37- and 217-pin bundle, remove the floppy disc, after taking the data, to the Joint Computer Facility (JCF) where the calibration curves can be plotted (see Reference 2).

3.3 Experimental Procedures.

1. Drain the pressurized vessel of the salt injection system and flush it thoroughly with water.
2. Clean the large plastic barrel.
3. Measure 800 grams of salt and dissolve it in 100 lbs. of water. Stir thoroughly.
4. Transfer the salt solution into the pressurized vessel either by a small pump or a bucket and funnel.
5. Close the inlet valve.
6. Pressurize the tank by opening the air valve; 30 psig should be sufficient.

7. Turn on the main pumps and allow water to flow through the bundle.
8. Align the injector with the hole in the injection rod at the required injection depth.

Note: This is done by initially placing the injector at the required depth (found by the difference between the length of the injector and the length above the exit plane of the bundle) and then slowly moving it up and down till a steady stream of water emerges from the connecting tube.

9. Connect the injector to the injection system as illustrated in Fig. 5.
10. Take the background reading.
11. Read the water temperature.
12. Adjust the main valve to get the desired flow rate.
13. Allow some time for the flow to become steady and then set flowmeters R4 or R5 to the desired injection rate of salt solution.
14. Allow some time for the injection flow to become steady and take and store the data.
15. Stop the injection of salt solution.
16. Flush the bundle for a few minutes to wash away all traces of injected salt.
17. Repeat steps 10 to 16 for each desired flow rate.
18. After completing the experiment at one injection site, shut off the main pumps. Remove the injector and place it in

its new position. Be sure to plug the tops of the injector rods not being used. You are now ready to repeat the experiment.

Note: The probes should be re-calibrated (see 3.2) if the experiment is being done after a lapse of a few days.

APPENDIX

I. Construction of the Probes

1. Cut the red/white wire into approximately 3-foot lengths. One length is required for a probe.
2. Strip about $\frac{1}{2}$ " of the insulation at one end.
3. Cut the platinum wire into $\frac{3}{4}$ " segments; two segments are required for each probe.
4. Use the wire wrapping gun to wrap the exposed wire onto about $\frac{1}{4}$ " of the platinum segment.
5. Solder the wire onto the platinum segment.
6. Put a 1" heat shrink tubing over the joint and seal it in place using a heat gun.
7. Cut the stainless steel tubing (0.128" O.D. and 0.095" I.D.) into 4" lengths.
8. Mount the tubing into a lathe collet and face off both ends. Next, apply a center-drill to taper the inside edge of one of the ends. This prevents damage of the red/white wire or heat shrink tubing during assembly of the probe.
9. Pull the wire through the tapered end of the s.s. tube so that only the platinum leads are sticking out. Be careful not to tear the wire insulation or heat shrink tubing (see Fig. 9).
10. Use a voltmeter to check for short-circuit of either wire to case or to each other.
11. Mount all probes upright in a wooden holder.

12. Mix a small amount of structural cement as directed on the box. Drop a small amount over the end of the tube and allow to dry overnight. Reverse the probes in the holder and similarly seal the other end of the tube. This will hold the platinum leads and wire in place.
13. Strip away excess cement carefully with a sharp knife. Any excess cement at the end with the platinum leads will introduce problems during assembly in the flow separator.
14. Check for short-circuit again.

The individual probes are now ready. They have to be connected in groups of eight to the ribbon cable and platinized before assembly in the flow separator. The following procedure is used:

1. Strip the insulation off the ends of the individual wires in the 16-wire Ribbon cable.
2. Slip on heat shrink tubing pieces onto the free ends of the probe wires.
3. Connect the probes to the ribbon cable after ensuring that the two wires of a probe are connected to adjacent wires on the cable.
4. Solder the joints and seal the heat shrink tubing in place over the joint, after allowing for overlap on both sides. A good joint is formed by twisting the wire together before soldering.
5. Check each probe with a voltmeter.

6. Label the probes (1 to 8) to correspond to the number on the 16-pin connector of the ribbon cable. Wrong numbering will lead to unknown connections with the interfacing computer. The labelling can be easily done by visual inspections. Alternatively, the computer system can be used by plugging in the ribbon into one of the connecting joints in the white box after ensuring that the first pin of the connector fits into the first socket and so on. Switch on the system. Place the probes in water and label accordingly by taking one probe at a time out of water. The reading is different in water and in air.
7. Using masking tape or any substitute, tie the red/white wires of the probes together leaving about 8" to facilitate mounting them in the flow separator.
8. The next step is to platinize the probes and it is done as follows:
 - a. Prepare a cleaning solution of 100 ml isopropyl alcohol, 100 ml ethyl ether, 50 ml concentrated HCl and 50 ml distilled water in a beaker. Soak the probes, eight at a time, in the solution for about 2-3 minutes. Rinse with running water. It is recommended that gloves and apron be worn and work in a well ventilated area.
 - b.. Place the platinizing solution in the small 50 ml beaker and attach it to the clip on the side of the platinizing kit (# 3139).
 - c. Place the probes in the solution and attach the ribbon

cable to the kit.

- d. Switch on the current to 50 mA. Platinize for 3-4 minutes while changing the polarity of the current every 30 seconds or so with the help of the switch on the kit. The probes should be shaken periodically (say, with every change of polarity) to prevent the formation of bare spots due to the rising bubbles. The results of platinizing is a uniform black coating of platinum on the platinum segments (Fig. 9) of the probes.
- e. Rinse the probes in running water for about 5 minutes.
- f. The platinized probes should be stored in water prior to use.

The following items are available from:

1. Red/White wire: 30 gage, 7/38 strand, type B TWPR
C.E. Scrymgeour Co.
13 Grant Ave., Burlington, MA 01803
2. Heat shrink tubing: colorless
C.E. Scrymgeour Co.
: black
Restart Electronics
820 Port Washington Blvd.,
Port Washington, N.Y. 11050
Tel: (516) 883-3500.
3. 16-wire Ribbon Cable: 5-foot lengths with connecting plugs
7P 16-3T60-1.

Augat Inc.

33 Perry Ave., Attleboro, MA 02703

4. Platinum Wire: E.E. stock-room or Erglehart Industries,
New Jersey.
5. Structural Cement: Scotch-weld structural adhesive # 2216.
3M Company
John G. Shelly Company
16 Mia Lane, Wellesley Hills, MA
6. Platinizing Kit: # 3139
Yellow Spring Instrument Company
Yellow Springs, Ohio.
7. Platinizing Solution: (order well in advance).
Platinum Chloride 3% dissolved in 0.025%
lead acetate solution. Recorder # 3140
Yellow Spring Instrument Company
Yellow Springs, Ohio.

II. Mounting of Probes.

1. Screw the separator/locating pins into the flow separator housing (exit plane of the 37-pin bundle).
2. Place the locating plexiglass plate in position and a piece of pre-drilled neoprene sheet on top (an additional plexiglass plate is used for the 37-pin bundle) and tighten them in place.
3. Label the ribbon cables 1 to 16.
4. Mount the probes according to Fig. 10. Start by placing probe # 1 of ribbon cable # 1 in subchannel # 1 and continue by

mounting probe # 2 of cable # 1 into subchannel # 2 and so on. After fixing the eight probes of cable # 1, move on to cable # 2 and so on until all the probes are mounted. The probes should be mounted such that only the tips of the platinum segments are inside the flow separator (subchannel for the 37-pin bundle) to avoid excessive blockage of flow. The neoprene sandwich will hold the probes in place and there is no need to mess around with RTV.

5. Carry out the mounting with the separator immersed in a bucket of water so that the tips of the probes are soaked too. As for the 37-pin bundle, the whole bundle has to be flooded by closing the valve as the lower plenum.
6. Connect the connecting plugs of the ribbon cables to the corresponding positions in the junction box. Some plugs are labelled "reverse" and should be done accordingly. The computer system can now be used for checking short-circuits. Replace bad probes.

FIGURES

Fig. 1 Fuel Rod Test Section Fully Assembled

Fig. 2a
Injection Rod

Fig. 2b Injector

Fig. 3 Flow Diagram of the Main Water Circulation Loop

Fig. 4 Calibration Curve for Rotometer R 2

Fischer and Porter meter 7303 A 3749A1

Fig. 5 Salt Injection System

Fig. 6 Calibration Curve of Rotometer R4

Fischer and Porter meter using tube

FP-1/8-12-G-5/81

Fig. 7 Calibration Curve of Rotometer R5

Fischer and Porter meter using tube

FP-1/4-20-G-5/81

Fig. 8 Salt Detection System

Fig. 9 The Construction of Probes

Fig. 10 Subchannel Numbering Scheme
for 217-pin bundle

REFERENCES

1. "Fabrication Details for Wire Wrapping Fuel Assembly Components", Brian J. Bosy, Report C00-2245-27TR, (Revision 1 by Hafeez Khan).
2. "Collection and Evaluation of Salt Mixing Data with the Real Time Data Acquisition System", S.Glazer, C.Chiu and N.E.Todreas, Report C00-2245-36TR.
3. "Laboratory Manual for Salt Mixing Test in 61-pin Bundles", Hafeez-ur-Rehman Khan, Chong Chiu and N.E.Todreas, Report C00-2245-62TR.