

CONF-77/20--8

**EDGE BLOCKAGE IN A 19-PIN SODIUM-COOLED BUNDLE\***

**(Submitted for Presentation at the Symposium on the Thermal and Hydraulic Aspects of Nuclear Reactor Safety, 1977 Winter Annual ASME Meeting, November 27, 1977 - December 2, 1977 in Atlanta, Georgia)**

**J. T. Han      M. H. Fontana  
P. A. Gnadt    J. L. Wantland.**

**OAK RIDGE NATIONAL LABORATORY  
Oak Ridge, Tennessee 37830**

**NOTE**  
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, either expressed or implied, or assumes any responsibility for the accuracy, completeness, or usefulness of any information, including any diagrams, drawings, or data, contained hereon, or for the results obtained from the use of the information contained hereon.

**By acceptance of this article, the publisher or recipient acknowledges the U. S. Government's right to retain a non-exclusive, royalty-free license in and to any copyright covering the article.**

**SUMMARY**

To assess the effect of partial flow blockages on the local temperature distributions in LMFBR fuel assemblies, several experiments have been carried out at the Thermal-Hydraulic Out-of-Reactor Safety (THORS) Facility at the Oak Ridge National Laboratory. Two kinds of flow blockages have been investigated: (1) six-channel internal blockage for which the blocked channels are not adjacent to the duct wall, and (2) 14-channel edge blockage for which some of the blocked channels are adjacent to the wall. The larger edge blockage is generally more severe than the internal blockage due to higher temperature rises in the wake behind the blockage. Investigations on the internal blockage have been reported<sup>1-2</sup> earlier, and the experimental results on the edge blockage are analyzed and presented in this report.

\*Research sponsored by the U. S. Energy Research and Development Administration under contract with the Union Carbide Corporation.

In the present study, a 14-channel edge blockage<sup>3</sup> is located in a 19-pin sodium-cooled electrically-heated bundle, which simulates the fuel assemblies of the Clinch River Breeder Reactor (CRBR). The objectives are twofold: (1) to determine experimentally 1. an edge blockage that blocks approximately one-third of the flow area will result in sodium boiling, and (2) to assess quantitatively the effect of a built-in leak, between the blockage plate and the duct wall, upon the temperature rises in the wake behind the blockage. A total of over twenty tests have been performed with the sodium velocity in the range of 1 to 8 m/s and the average power per pin in the range of 10 to 27 kW/m.

Figure 1 shows the instrumentation layout and the blockage profile in the test bundle. Two test bundles were used: THORS Bundle 5A and Bundle 5B. In Bundle 5A, the blockage plate was held flush against the duct wall without a leak. In Bundle 5B, bypass flow was intentionally induced by displacing the blockage plate from the wall at a normal distance of 0.356 mm (0.014 in.) from flat A and consequently at a normal distance of 0.178 mm (0.007 in.) from flats B and F of the duct wall. The large circles shown in Fig. 1 represent the simulated fuel pins with an identification number in the center of each pin. The pins have an outside diameter of 5.84 mm (0.230 in.) and are wrapped by wire-wrap spacers, shown in smaller circles, of 1.42 mm (0.056 in.) diameter with a helical pitch of 305 mm (12 in.). In order to have a more uniform velocity distribution in the bundle, the wire-wrap diameter around the twelve peripheral pins is reduced to 0.71 mm (0.028 in.) for those portions of the wires near the duct wall. The number in each of the smaller circles indicates that a thermocouple junction is physically located at so many "inches" above the start of the heated section of the pins. The pins have a heated length of 457 mm (18 in.) with the blockage plate located between 102 mm (4 in.) and 105 mm (4.125 in.) downstream from the start of the heated section. The black dots inside the pins represent thermal elements to measure the

inner cladding temperature of the pins, and were operational in Bundle 5B only. They are not used in the present study.

It is assumed in the present study, similar to the model used in an internal blockage study,<sup>1</sup> that for turbulent flow in the bundle the heat generated by the fuel pins in the wake behind the blockage is transferred to the surrounding free stream primarily through the mass exchange,  $\dot{m}$ , between the wake and the free stream with molecular heat conduction being neglected. The average wake temperature,  $T_{wk}$ , is calculated from the temperature measurements at various locations behind the blockage (as shown in Fig. 1), and the average temperature of the surrounding free stream,  $T_{\infty}$ , is taken to be approximately the bulk mean coolant temperature at the midplane of the wake. The axial wake length,  $L$ , has been measured in the THORS Water Mockup<sup>3</sup> using air bubble injection. Since wake formation is fundamentally a hydrodynamic effect of the blockage, the wake length in the sodium flow is taken to be approximately the same as that in the water at the same Reynolds number and blockage size. The volume of the coolant in the wake and its mass,  $M$ , can then be determined. Making the energy balance for the wake as a control volume yields,  $Q = \dot{m} C_p (T_{wk} - T_{\infty})$  with  $Q$  being the total energy generation rate of the fuel pins in the wake and  $C_p$  being the coolant specific heat. From this equation, the mass exchange rate  $\dot{m}$  is obtained. The residence time,  $\tau$ , is calculated from its definition of  $\tau = M/\dot{m}$ .

The mass exchange rate,  $\dot{m}$ , between the coolant in the wake and its surrounding free stream is shown in Fig. 2 as a function of the coolant velocity  $u_m$ . With increasing velocity, there is an increase in the turbulent mixing and thus an increase in the mass exchange rate as expected. The blockage in Bundle 5A was held flush against the duct wall, and therefore its mass exchange rate is smaller than that of Bundle 5B in which a small bypass flow was intentionally located between the duct wall and the blockage. Note that the difference in  $\dot{m}$  between these two bundles also

increases with the velocity. The coolant residence time in the wake,  $\tau$ , is shown in Fig. 3 versus the mean coolant velocity. It decreases as the velocity increases.

Introducing  $a$ , the characteristic length for the edge blockage, being the square root of the product of the longest lengths of the blockage in the  $x$  and  $y$  directions, perpendicular to the direction of flow, the dimensionless residence time is defined as  $\tau u_m/a$ . Its values are shown in Fig. 4 for Bundles 5A and 5B, and the sodium results of Kirsch and Schleisiek<sup>4</sup> for the flow in a blocked annulus. There is a good agreement between the results of Kirsch<sup>4</sup> and Bundle 5A. The dimensionless residence time is less in Bundle 5B than that of Bundle 5A due to the bypass flow in Bundle 5B. Two straight lines are used to correlate these results. This gives:  $\tau u_m/a = 13$  for edge blockage without a leak (Bundle 5A), and  $\tau u_m/a = 8.6$  for edge blockage with bypass flow (Bundle 5B) at  $7.35 \times 10^4 \leq Re_B = u_m a/v \leq 7.35 \times 10^5$ . The corresponding flow Reynolds number,  $Re = u_m \times D_h/v$ , is in the range of  $10^4$  to  $10^5$ , and this insures that the flow is turbulent in the bundle ( $D_h$  is the hydraulic diameter and  $v$  is the coolant kinematic viscosity). The average temperature rise in the wake,  $T_{wk} - T_\infty$ , is equal to  $13 aQ/(NC_p u_m)$  for Bundle 5A, and equal to  $8.6 aQ/(NC_p u_m)$  for Bundle 5B. The interesting point is that the latter is only 66% of the former. This indicates that the bypass flow between the blockage plate and the duct wall in Bundle 5B has reduced the wake temperature rise by 34%.

In conclusion, no sodium boiling occurred behind the edge blockage (for either Bundle 5A or Bundle 5B) that blocks approximately one-third of the flow area in a 19-pin sodium-cooled bundle with the sodium velocity in the range of 1 to 8 m/s and the average power per pin varying from 10 to 27 kW/m. Furthermore, although the edge blockage is more critical than the internal blockage in the fuel assemblies in general, a slight bypass flow between the edge blockage and the duct wall will substantially reduce the temperature rises in the wake behind the blockage.

REFERENCES

1. J. T. Han et al., "Thermal-Hydraulic Correlations of a Six-Channel Blockage in a Sodium-Cooled Simulated LMFBR Fuel Assembly," Proceedings of the International Meeting on Fast Reactor Safety and Related Physics, October 5-8, 1976 at Chicago, Illinois.
2. N. Hanus et al., "Quasi-Steady State Boiling Downstream of a Six-Channel Blockage in a 19-Pin Simulated LMFBR Subassembly, Ibid.
3. M. H. Fontana et al., Thermal-Hydraulic Effects of Partial Blockages in Simulated LMFBR Fuel Assemblies with Applications to the CRBR, ORNL-TM-4779, July 1975.
4. D. Kirsch and K. Schleisiek, "Flow and Temperature Distributions Around Local Coolant Blockages in Sodium-Cooled Fuel Subassemblies," Progress in Heat and Mass Transfer, Edited by O. E. Dwyer, Vol. 7, Pergamon Press, New York (1973).

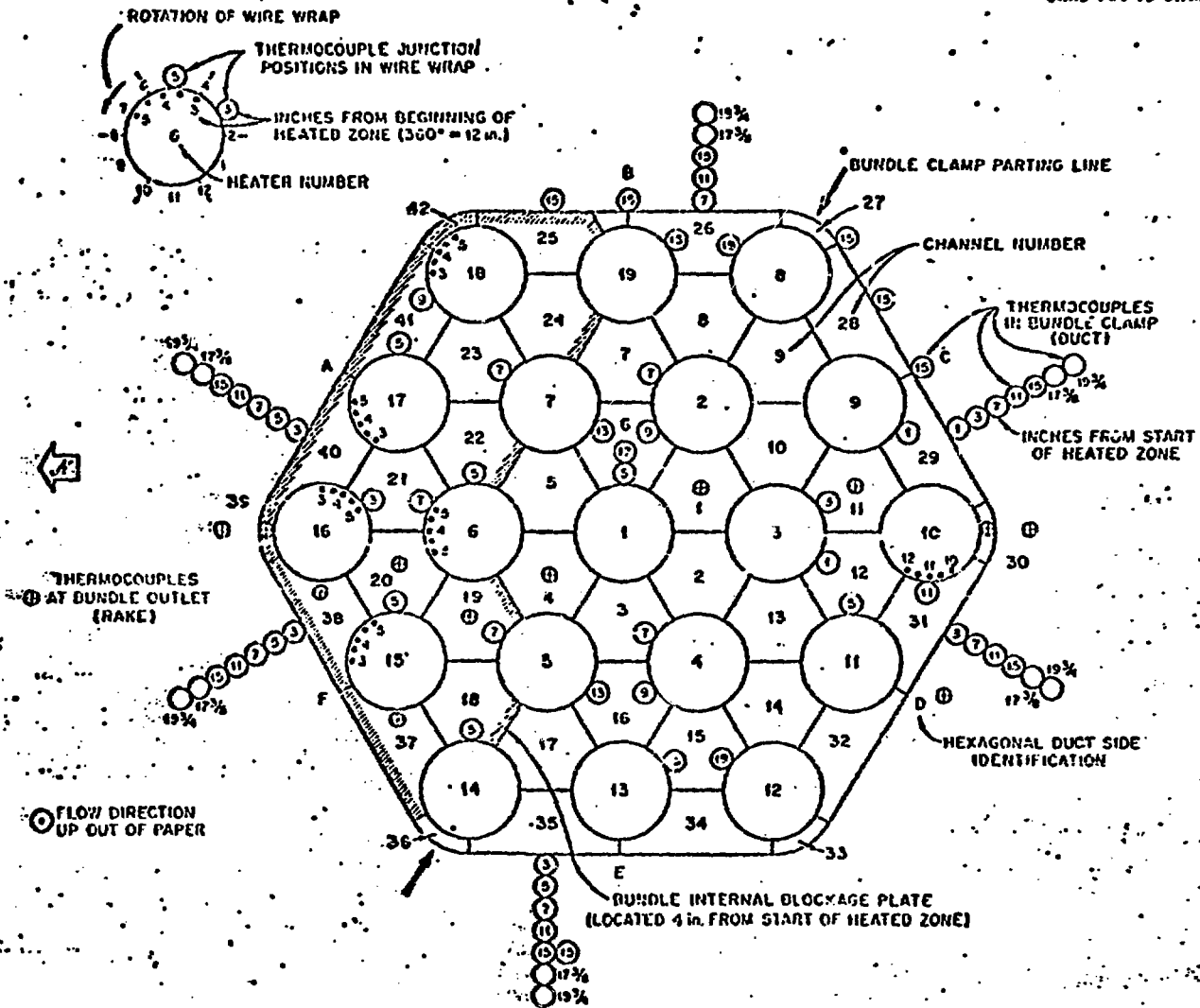


Fig. 1 Cross section of THORS bundles 5A, and 5B showing the outline of the blockage plate in bundles 5A and 5B and all test section temperature instrumentation. The heater-internal thermocouples in rods 6, 10, 15, 16, 17, and 18 were not operable in bundle 5A.

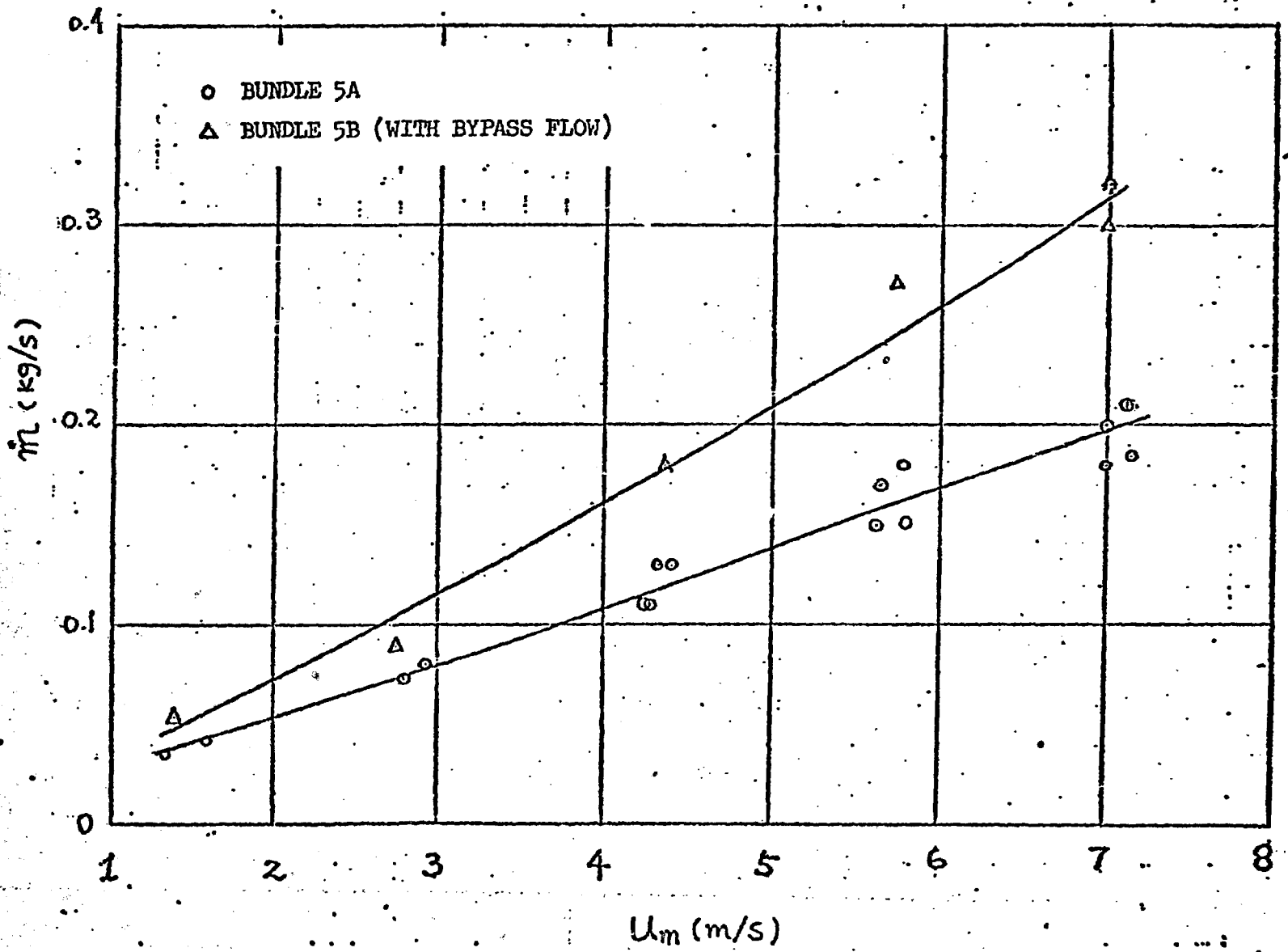


Fig. 2. Mass exchange rate for the wake behind a 14-channel edge blockage.

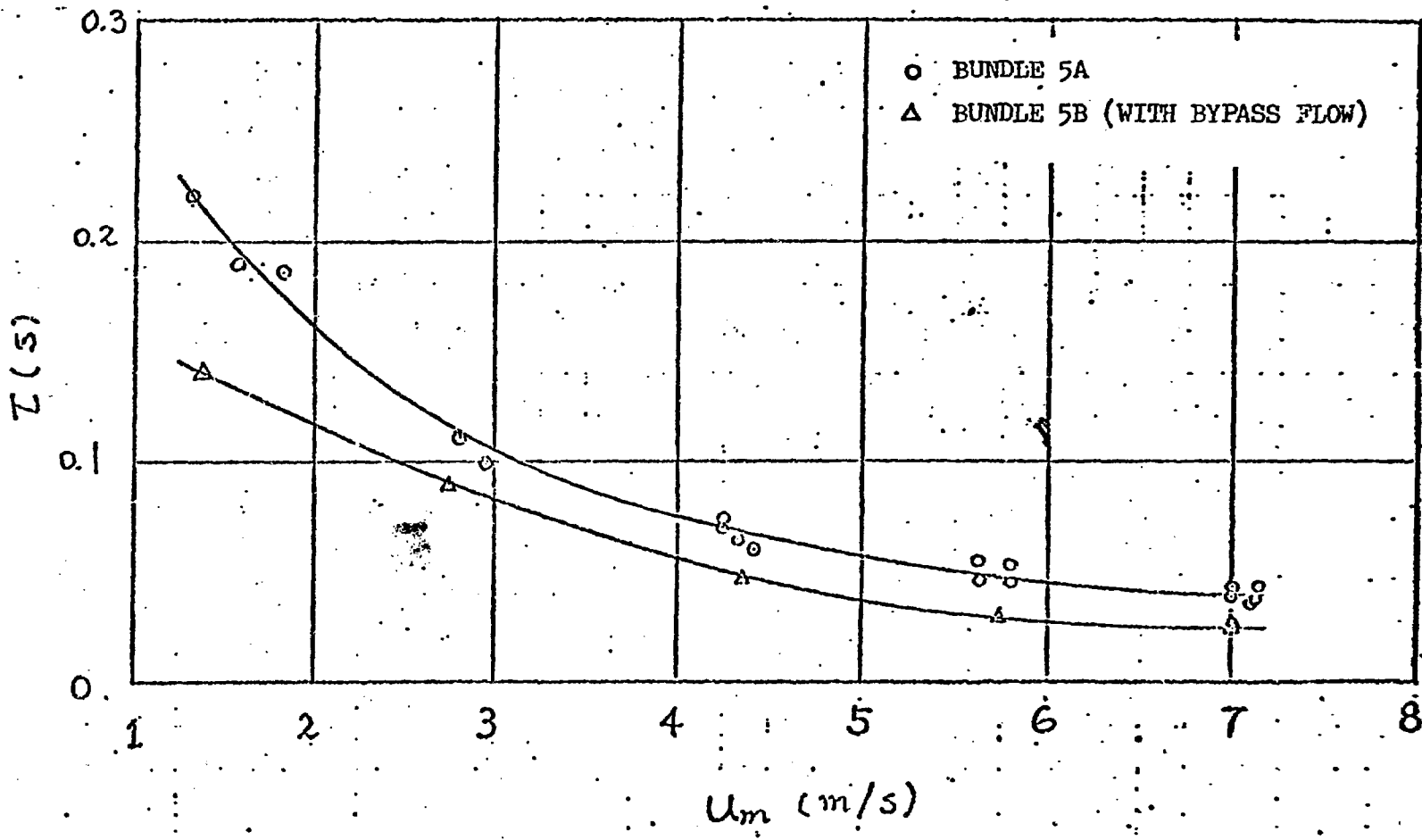


Fig. 3. Residence time for the wake behind a 14-channel edge blockage.

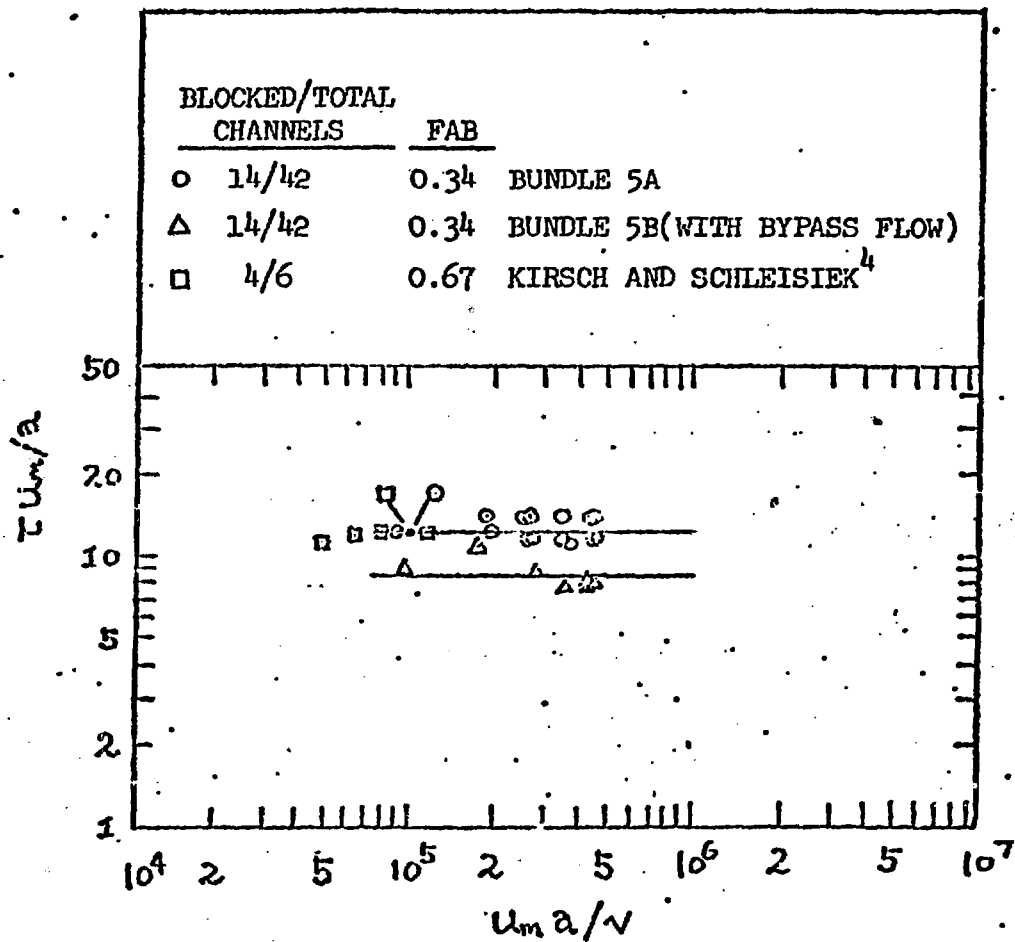


Fig. 4 Dimensionless residence time for the wake behind edge blockages in sodium-cooled pin bundles( FAB = blocked fraction of total flow area).