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AEC Research and
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UC-81, Reactors - Power
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SINGLE ELEMENT FLOW TESTS FOR TYPE 3 (SM-2) FUEL ELEMENTS IN SM-1, SM-1A, AND PM-2A CORES

ALCO

ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPARTMENT
P. O. BOX 414, SCHENECTADY 1, N. Y.

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APAE Memo - 297

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SINGLE ELEMENT FLOW TESTS FOR TYPE 3 (SM-2) FUEL ELEMENTS IN SM-1, SM-1A, AND PM-2A CORES

By
P. S. Krause

Approved By:
M. H. Dixon, Project Engineer

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New York Operations Office

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ABSTRACT

Channel-to-channel flow distribution within Type 3 (SM-2) stationary and control rod fuel elements modified for use in the SM-1, SM-1A and PM-2A core support structures and control rod tubes was measured in single element flow testing. The experimentally determined flow maldistribution would be applied in thermal analysis of Type 3 elements. Plots of channel-to-channel flow distribution and element pressure drop at various element flow rates are given. Flow distribution for the top-orificed SM-1A and PM-2A stationary elements was within the ± 12% deviation from element average utilized in previous thermal analyses of these cores. Testing of the bottom-orificed SM-1 stationary element and the SM-1, SM-1A and PM-2A control rod assemblies showed flow distribution exceeded ±12% deviation from average. Simple modifications to the SM-1 stationary element indicated the possibility of improving flow distribution in that element.

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1.0 SUMMARY

Channel-to-channel flow distribution studies were conducted on the stationary fuel element and control rod assembly of the SM-1, SM-1A and PM-2A, utilizing Type 3 (SM-2) fuel elements in both cases. These studies were carried out as part of Task 3.0 - Replacement Core Development, of the AEC-Army PWR Support and Development Program.(1) The test objective was to determine flow maldistribution to be used in calculating a maldistribution factor (deviation from average channel velocity) for use in thermal analysis of the Type 3 replacement cores for the SM-1, SM-1A and PM-2A. This thermal analysis will be presented in APAE No. 105.(2) Previous thermal analyses were conducted using a ± 12% maldistribution factor for both the stationary and control rod elements.

Test results indicate that:

1. Flow distribution in the SM-1 stationary fuel element with minimum orifice ranges from +44% to -55% of average channel velocity at design flow rate; flow distribution in the maximum orificed element ranges from +6.8% to -8.8% of average channel velocity at design flow rate.
2. Flow distribution in the SM-1A stationary fuel element with minimum orifice ranges from +6.1% to -6.7% average channel velocity at design flow rate.
3. Flow distribution in the PM-2A stationary fuel element with minimum orifice ranges from +6.2% to -11% of average channel velocity at design flow rate.
4. Flow distribution in the SM-1 control rod assembly ranges from +23.5% to -27.8% of average channel velocity at design flow rate.
5. Flow distribution on the SM-1A control rod assembly ranges from +14% to -23% (both extrapolated) of average channel velocity at design flow rate.
6. Flow distribution in the PM-2A control rod assembly ranges from +13.2% to -22.8% of average channel velocity at design flow rate.

Some modification to the minimum orificed SM-1 stationary element should be made if flow maldistribution in these elements is a problem. Testing has shown that improvements in flow distribution can be made with simple modifications to the element.

2.0 INTRODUCTION

2.1 BACKGROUND

As part of Task 3.0, Replacement Core Development, of the AEC-Army PWR Support and Development Program,(1) a single element flow test program was performed in the Alco General Engineering Laboratory to investigate channel-to-channel flow distribution within Type 3 stationary and control rod fuel elements modified for use in the SM-1, SM-1A and PM-2A cores. Data obtained from this program will provide information for calculation of a maldistribution factor to be used in calculating hot channel factors and burnout ratios as well as providing important information on the present cores now in SM-1, SM-1A and PM-2A.

The Type 3 fuel element differs from Types 1 and 2 fuel elements used in the original cores of SM-1, SM-1A and PM-2A in that the Type 3 fuel plates are 40-mils thick compared to 30 mils in the original cores, resulting in a 10-mil reduction in channel width from 133 to 123 mils. The increased plate thickness as well as the increased fuel concentration in the plate matrix results in a significant increase in total fuel inventory, thereby increasing the prospective core life.

2.2 DESCRIPTION OF REACTORS

The SM-1, SM-1A and PM-2A are pressurized water reactors having APPR type cores with design power outputs of 10, 20 and 10 tMW respectively. Operating conditions for the SM-1 are 1200 psi and 427°F reactor inlet temperature; for the SM-1A, 1200 psi and 423°F inlet temperature; and for the PM-2A, 1750 psi and 500°F reactor inlet temperature. The core array for each reactor is a basic 7 x 7 array with the four corner elements removed in both the SM-1 and SM-1A, and three elements removed from each corner of the PM-2A.

The SM-1 is a bottom orificed core with 38 stationary fuel elements and 7 control rod fuel elements. The SM-1A and PM-2A are both top orificed cores with the SM-1A having 38 stationary and 7 control rod fuel elements and the PM-2A having 32 stationary and 5 control rod fuel elements.

2.3 APPROACH

Stationary element testing utilized a single fuel element with removable end boxes, and various orifice plates for each different core. In each case the minimum orificed element of each core was selected for testing because this orifice has the greatest adverse effect upon flow distribution. Thus, the results of this report present the most adverse conditions of flow distribution within each core. Control rod testing utilized a Type 3 control rod fuel element within the SM-1, SM-1A and PM-2A control rod tubes.

The test loop used for both stationary and control rod testing was capable of delivering flow in excess of design for each respective test. In all cases, the test fluid was water, maintained within a temperature range of 70-80°F.

Similar single element flow studies performed on ETR(3), the MTR(4), and the SM-2(5) show results comparable to those achieved in this test program.

3.0 CALIBRATION TESTING OF CONTROL ROD AND STATIONARY FUEL ELEMENTS

3.1 PURPOSE OF TEST

Since the measured velocity readings taken at the centerline of the fuel element channels are peak or maximum velocity values and average velocity readings are required for analysis, it was necessary to establish an average-to-maximum velocity ratio. The purpose of this test was to experimentally determine this ratio for each channel and obtain an overall ratio for the entire element which could be applied to data received from full fuel element flow testing.

3.2 DESCRIPTION OF TEST RIG AND INSTRUMENTATION

The test rig utilized in calibration testing consisted of two large plenum chambers, a tube which held the fuel element, a surge tank to minimize flow surges, and a standard meter tube. The meter tube consisted of a standard orifice installation. City water entered the surge tank and from there passed through the standard meter tube which was connected to a special channel adapter which channeled all flow (leakage kept to minimum) through an individual channel. Flow control was provided by a valve located before the calibrated flow tube. The test rig is shown in Fig. 3-1.

For this test the instrumentation consisted of both static and total probes located in each channel of the element. Probes were fabricated from 0.065 in. stainless steel tubing and located at channel center by an instrument rake. Each pair of static and total probes measured a maximum channel velocity. An average channel flow rate was measured by a calibrated standard meter tube. All measurements were recorded on U-tube manometers using Meriam blue fluid (sp. gr. 1.75) as the indicating fluid.

3.3 TEST PROCEDURE

During early attempts to calibrate each individual channel, readings were inconsistent, which indicated that instrument lines were not bled properly. A pressurized system was devised which allowed fast and positive bleeding of the instrument lines.

For each individual channel calibration, the following procedure was followed. The loop was filled and pressurized to approximately 30 psi. The loop pressure was maintained by a valve controlling flow from the outlet plenum chamber. Upon filling the loop, the manometers and lines were bled of all air and zeroed.

At various flow rates, as recorded by the meter tube, maximum channel velocity readings were recorded. Average readout time (time for readout instrument to stabilize) was from 12 to 15 minutes per flow setting. The range of channel flow

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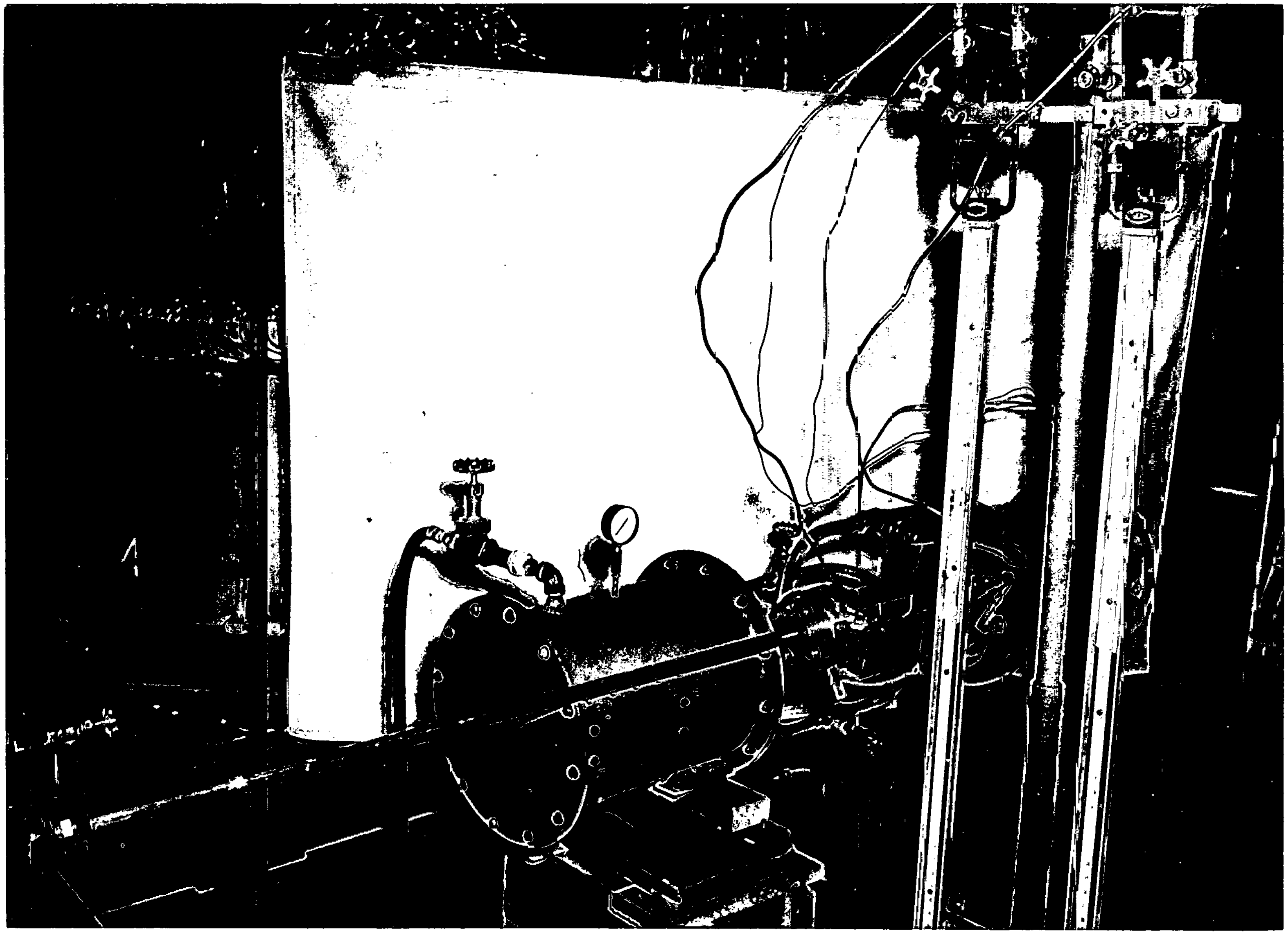

Fig. 3-1 - Calibration Test Rig

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was between 2 and 10 gpm, with readings being taken at three different flow rates going up in flow and essentially the same flow rates going down in flow. This was done to insure the repeatability of the instrumentation. All measurements were recorded on 24-in. manometers and were read within ± 0.1 inches of Meriam blue fluid (sp. gr. 1.75).

3.4 TEST RESULTS

A complete set of channel dimensions were taken prior to testing. Channel measurements, taken at the point of velocity measurement, enabled calculations of average channel velocity to be made from the established relationship of $Q = AV$, where:

Q = flow rate (ft^3/sec) as measured by the calibrated flow tube
A = calculated flow cross-section area (ft^2)
V = is average channel velocity (fps).

At the point of measurement, three channel measurements were made; one at the top of the channel (bordering side plate), one at the center, and one at the bottom of the channel (bordering side plate). These three measurements together with a measurement made across the side plates enabled an accurate calculation of channel area to be made by a trapezoidal approximation. The complete set of measurements taken on the stationary and control rod fuel elements is tabulated in Tables 3-1 and 3-2 respectively. Calculated channel areas are presented in Table 3-3 and Table 3-4.

For each individual channel of the fuel element, a plot of Δh across the standard meter tube vs. Δh channel velocity head was made from data recorded during the test. A typical plot of the best straight line fit of recorded data is shown in Fig. 3-2. Conversion of Δh-vel. head inches blue fluid into velocity (fps) was facilitated by the graph shown in Fig. 3-3. This is a plot of $V = \sqrt{2gh}$, with a factor for conversion of Δh from inches of blue fluid (sp. gr. 1.75) under water to feet of water. Another plot, shown in Fig. 3-4, enabled the conversion of Δh-inches blue fluid across the meter tube, into inches of water which was then converted into flow rate by referring to a plot of flow rate (gpm) vs. differential (in. water) for the standard orifice installation. The data mentioned above was utilized in obtaining a correlation between average and maximum velocity for both the stationary and control rod fuel elements.

3.4.1 Stationary Fuel Element Test Calibration

Results of testing at three flow rates are tabulated in Table 3-3. These results apply to all three stationary element assemblies (SM-1, SM-1A and PM-2A). From this data a plot of average channel velocity vs. maximum channel velocity was made. This plot shown in Fig. 3-5, represents the best straight line fit of data obtained from the calibration of the 17 individual channels and is utilized in obtaining average channel velocity from the measured maximum channel velocity recorded during the flow testing of the entire element (Section 4.0).

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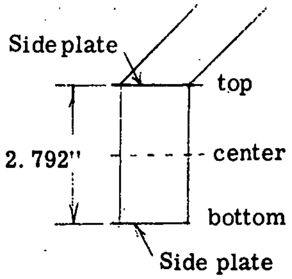
TABLE 3-1
CHANNEL MEASUREMENTS FOR STATIONARY FUEL ELEMENT

Typical Channel



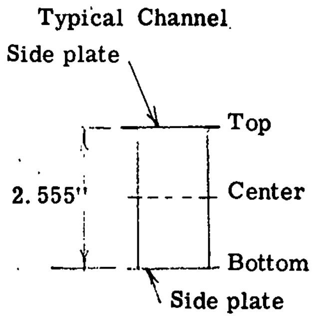
Channel Letter

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1)	121	119	114	125	118	124	129	124	121	116	129	123	114	120	121	119	130
2)	122	116	116	125	119	124	130	123	121	116	128	123	115	120	120	119	130
3)*	122	122	119	124	122	125	124	124	122	123	124	123	124	122	122	121	122
	123	118	114	125	118	124	129	123	120	116	129	123	114	121	118	120	129
	122	121	123	122	124	124	123	125	124	125	122	125	121	122	119	121	124
4)	123	116	115	125	118	123	129	122	121	115	129	123	115	121	119	120	129
5)	123	117	116	124	119	124	129	122	122	115	129	123	115	121	119	120	129
6)*	123	121	120	124	123	125	124	124	122	123	124	123	124	122	122	120	122
	122	117	116	124	119	125	130	121	122	116	129	123	115	121	119	121	128
	122	121	124	122	123	125	123	124	124	125	122	125	121	122	119	121	124
7)	121	117	115	125	118	125	129	123	122	115	129	123	116	120	120	119	130
8)	122	118	115	125	118	124	130	123	121	116	129	123	115	121	119	120	129
9)	122	118	115	125	119	124	130	123	121	116	129	123	115	121	119	119	129
10)*	123	122	122	123	124	125	124	124	123	123	124	124	123	123	123	122	125
	122	118	115	125	118	123	131	122	121	116	130	122	115	121	120	118	130
	124	122	123	122	123	124	124	125	123	123	124	123	123	122	122	119	125
11)	122	117	115	125	118	124	131	122	122	115	131	122	115	121	120	119	130
12)	122	118	115	124	118	124	131	123	122	115	131	122	114	121	119	120	128
13)	122	118	115	124	118	124	131	123	122	114	131	122	115	120	119	121	128
14)*	124	123	122	123	123	125	123	125	123	123	123	124	123	123	123	122	125
	123	118	115	124	118	124	131	123	122	114	131	122	115	121	119	120	129
	126	124	124	122	122	124	123	125	124	123	124	123	123	122	122	118	125
15)	123	118	114	124	119	123	130	123	122	115	130	122	115	121	119	120	128
16)	122	119	114	125	118	123	130	123	122	115	130	122	115	120	120	118	129
17)	122	118	115	125	118	123	130	124	122	115	130	121	115	121	119	118	129
18)*	122	122	119	124	122	125	124	124	123	122	124	122	124	122	122	120	122
	122	118	114	125	117	123	129	124	121	115	130	122	115	121	119	118	129
	123	121	122	121	123	124	123	124	124	123	123	124	121	122	120	120	124
19)	121	117	114	124	118	123	129	124	122	114	130	122	115	120	119	117	131
20)	122	118	113	125	117	124	129	124	122	114	130	122	115	120	119	117	131
21)	121	119	113	125	117	123	130	125	121	115	131	122	114	120	120	117	130
22)*	124	121	122	123	124	125	124	125	123	124	125	124	123	123	121	124	123
	120	118	115	125	117	124	128	125	122	116	131	122	115	122	120	120	129
	124	121	124	122	122	125	124	126	124	123	124	124	123	121	122	121	126

NOTE: 1st measurement 1-1/4" from inlet end of fuel plate. All others at 1" increments; measurement given in mils.

* All three positions - Top, center and bottom; all other measurements made at center.

TABLE 3-2
CHANNEL MEASUREMENTS FOR CONTROL ROD FUEL ELEMENT



Channel Letter

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1)*	123 121 123	122 122 124	122 125 121	122 118 122	123 126 122	122 119 122	123 124 123	122 125 123	125 120 123	123 125 123	122 123 123	121 124 125	123 122 125	124 124 133	122 127 124
2)	118	122	124	117	126	118	123	124	120	125	122	121	117	122	124
3)	121	119	126	117	125	119	123	124	120	125	122	122	116	122	124
4)	121	118	126	117	125	119	123	122	120	126	121	121	116	121	124
5)*	122 121 120	121 118 120	122 126 120	120 116 120	122 125 122	121 119 119	121 123 122	120 122 122	122 120 120	122 126 123	120 121 120	121 121 121	120 117 122	121 122 120	120 124 121
6)	120	119	125	118	124	119	124	122	120	125	121	122	117	121	124
7)	121	118	126	118	124	120	123	122	121	125	121	121	117	123	124
8)	121	119	126	118	125	119	123	123	120	125	121	121	117	123	124
9)*	122 121 119	119 119 119	122 127 120	119 117 119	120 125 123	121 119 120	122 123 124	120 123 121	122 121 122	121 125 123	121 121 119	119 121 120	119 117 123	120 123 119	117 124 121
10)	122	118	127	118	125	119	123	124	119	125	121	121	117	123	124
11)	122	119	125	118	125	119	123	125	120	125	121	121	117	123	124
12)	121	119	125	119	125	119	124	124	120	125	122	120	118	122	125
13)*	120 122 121	120 119 121	121 125 120	121 119 120	121 124 122	121 120 120	121 124 123	121 124 122	121 120 121	122 125 122	120 121 121	120 120 121	119 118 121	122 123 121	119 124 121
14)	122	119	125	118	124	121	123	124	120	125	121	121	118	123	124
15)	122	119	125	119	124	120	124	124	121	124	121	120	119	121	125
16)	122	119	125	118	125	121	123	123	121	125	121	120	119	121	125
17)*	122 122 121	121 119 121	120 125 120	121 119 120	121 124 122	121 120 120	121 124 123	120 123 122	122 121 122	122 125 122	120 121 121	121 120 121	120 119 121	122 122 121	120 124 121
18)	122	120	125	119	124	120	125	124	121	125	121	121	119	121	125
19)	122	120	125	118	124	119	124	123	121	125	122	120	119	121	124
20)*	122 122 121	121 120 120	121 126 120	121 119 120	121 124 122	121 119 120	121 125 123	121 123 122	122 121 122	123 125 122	120 121 122	120 121 121	120 117 121	122 122 121	120 125 121
21)	122	119	126	118	124	119	125	123	121	124	122	119	120	122	125
22)	121	120	125	118	125	119	124	124	121	126	122	119	119	121	127
23)	120	123	125	121	125	121	124	124	121	126	123	121	120	122	125

NOTE: 1st measurement 1/2" from inlet end of fuel plate, remainder at 1" increments from 1st measurement, all measurements in mils.

* Three positions; top, center and bottom, all other measurements made at center of channel.

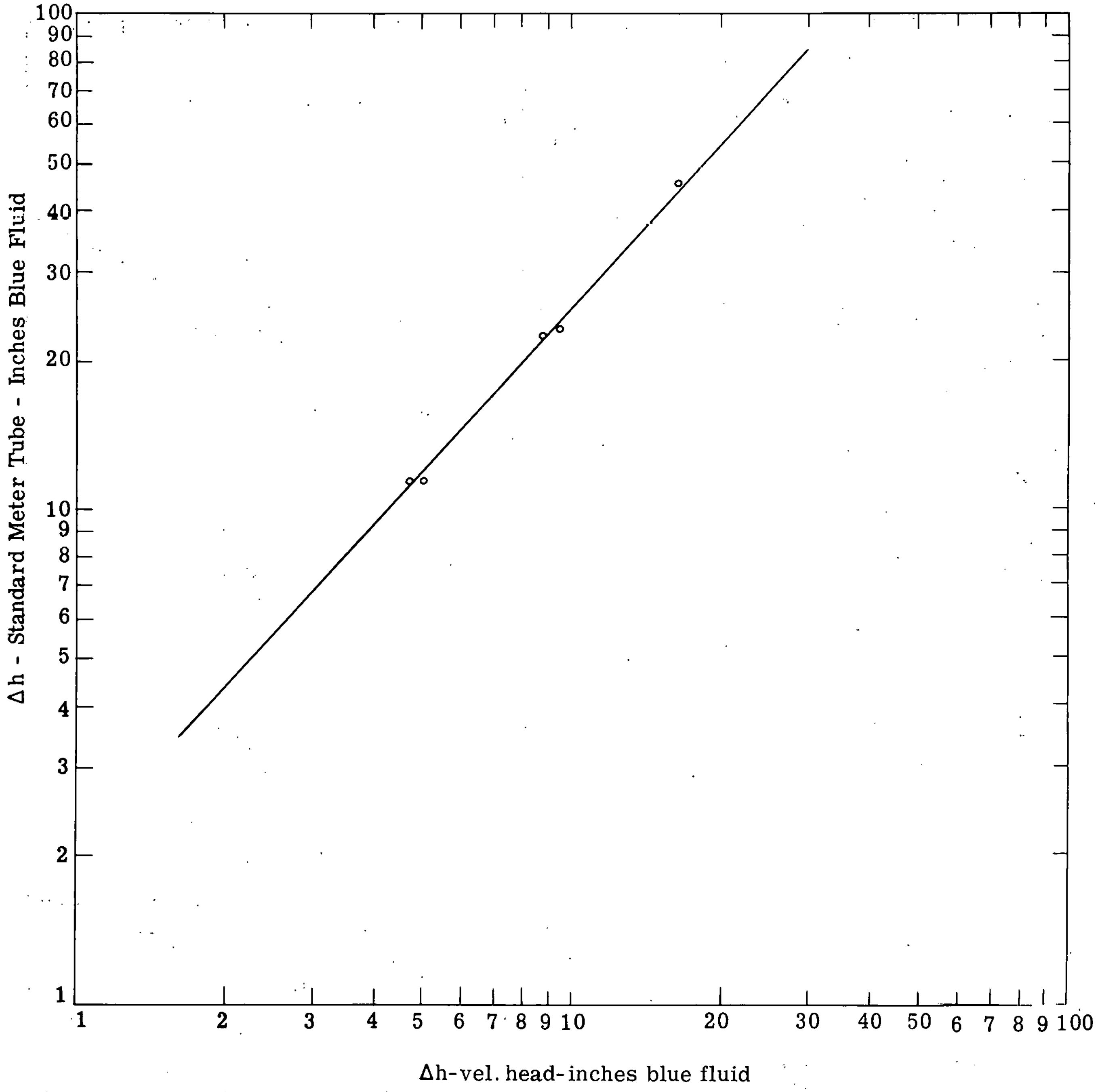


Fig. 3-2 - Channel K Calibration Δh Standard Meter Tube Vs Δh Vel. Head

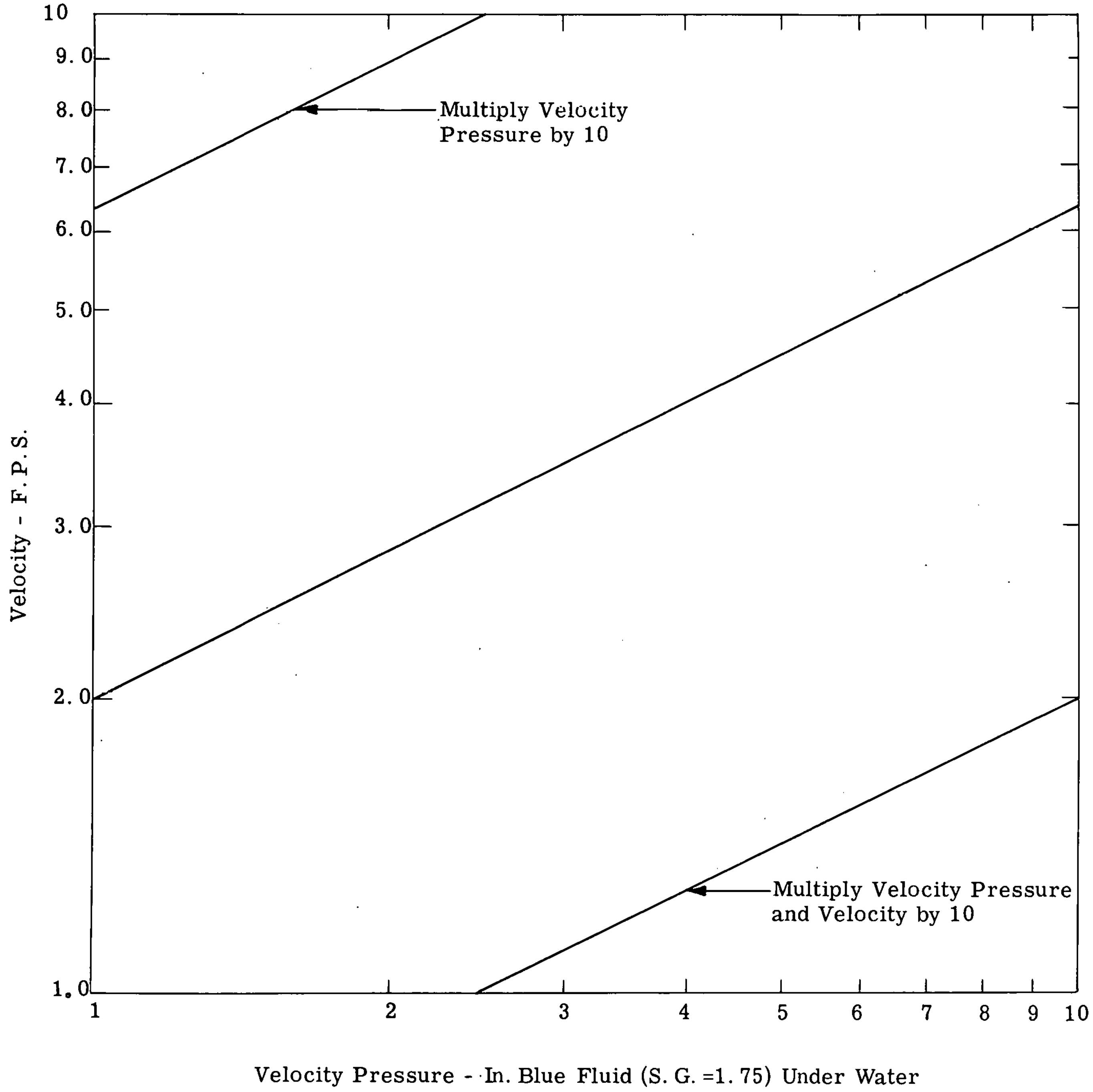


Fig. 3-3 - Velocity Vs. Velocity Head Measured Fluid - Water 80°F

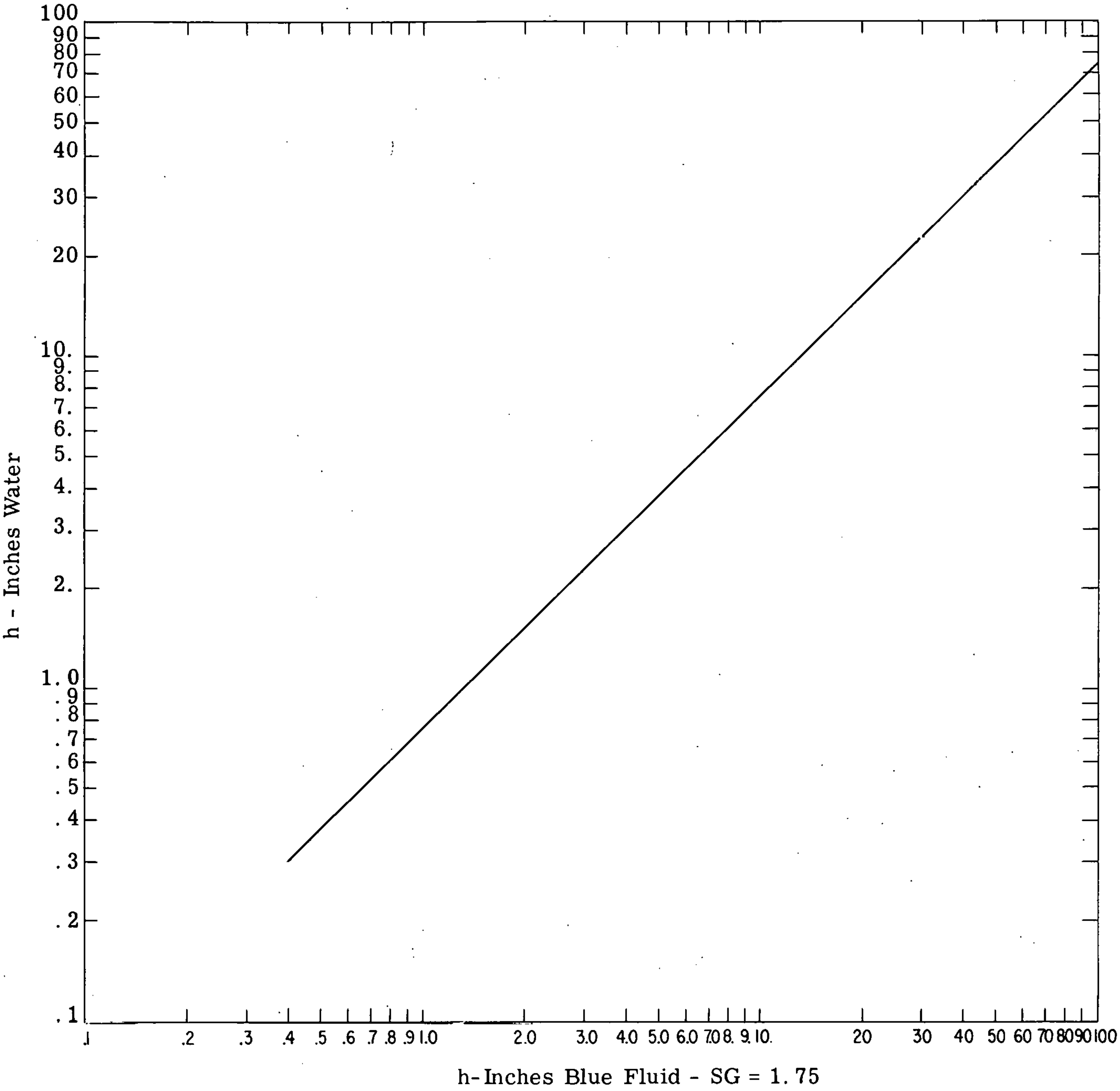


Fig. 3-4 - h-Inches of Water Vs h-Inches of Blue Fluid

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TABLE 3-3
RESULTS OF STATIONARY FUEL ELEMENT CALIBRATION TEST

	Area (Calculated)	Q = 3 gpm			Q = 5.5 gpm			Q = 8 gpm		
Channel	$Ft^2 \times 10^{-3}$	$\overline{V}$	V_{max}	$\overline{V}/V_{max}$	$\overline{V}$	V_{max}	$\overline{V}/V_{max}$	$\overline{V}$	V_{max}	$\overline{V}/V_{max}$
A	2.366	2.83	3.60	.786	5.18	6.18	.838	7.53	8.70	.866
B	2.317	2.88	3.56	.809	5.29	6.08	.870	7.69	8.60	.894
C	2.307	2.90	3.64	.797	5.31	6.28	.846	7.73	8.90	.869
D	2.399	2.79	3.48	.802	5.11	6.12	.835	7.43	8.75	.849
E	2.327	2.87	3.75	.765	5.27	6.45	.817	7.66	9.10	.842
F	2.414	2.77	3.60	.769	5.08	6.31	.805	7.38	9.00	.820
G	2.443	2.74	3.61	.759	5.02	6.25	.803	7.30	8.80	.830
H	2.428	2.75	3.48	.790	5.05	6.12	.825	7.34	8.79	.835
I	2.380	2.81	3.52	.798	5.15	6.22	.828	7.49	8.98	.834
J	2.322	2.88	3.49	.825	5.28	6.15	.859	7.68	8.70	.882
K	2.477	2.70	3.27	.826	4.95	5.68	.871	7.20	8.09	.890
L	2.385	2.80	3.42	.819	5.14	6.05	.850	7.47	8.62	.867
M	2.307	2.90	3.52	.824	5.31	6.21	.855	7.73	8.90	.869
N	2.365	2.83	3.50	.809	5.18	6.00	.863	7.54	8.40	.898
O	2.341	2.86	3.27	.875	5.23	5.60	.934	7.61	7.75	.982
P	2.351	2.84	3.45	.823	5.21	5.88	.886	7.58	8.22	.922
Q	2.457	2.72	3.29	.827	4.99	5.65	.883	7.25	8.00	.906
Total Flow Area	40.386									
Avg. Flow Area	2.376	2.82	3.50	.806	5.16	6.07	.851	7.51	8.61	.873

NOTE: All velocities in fps.

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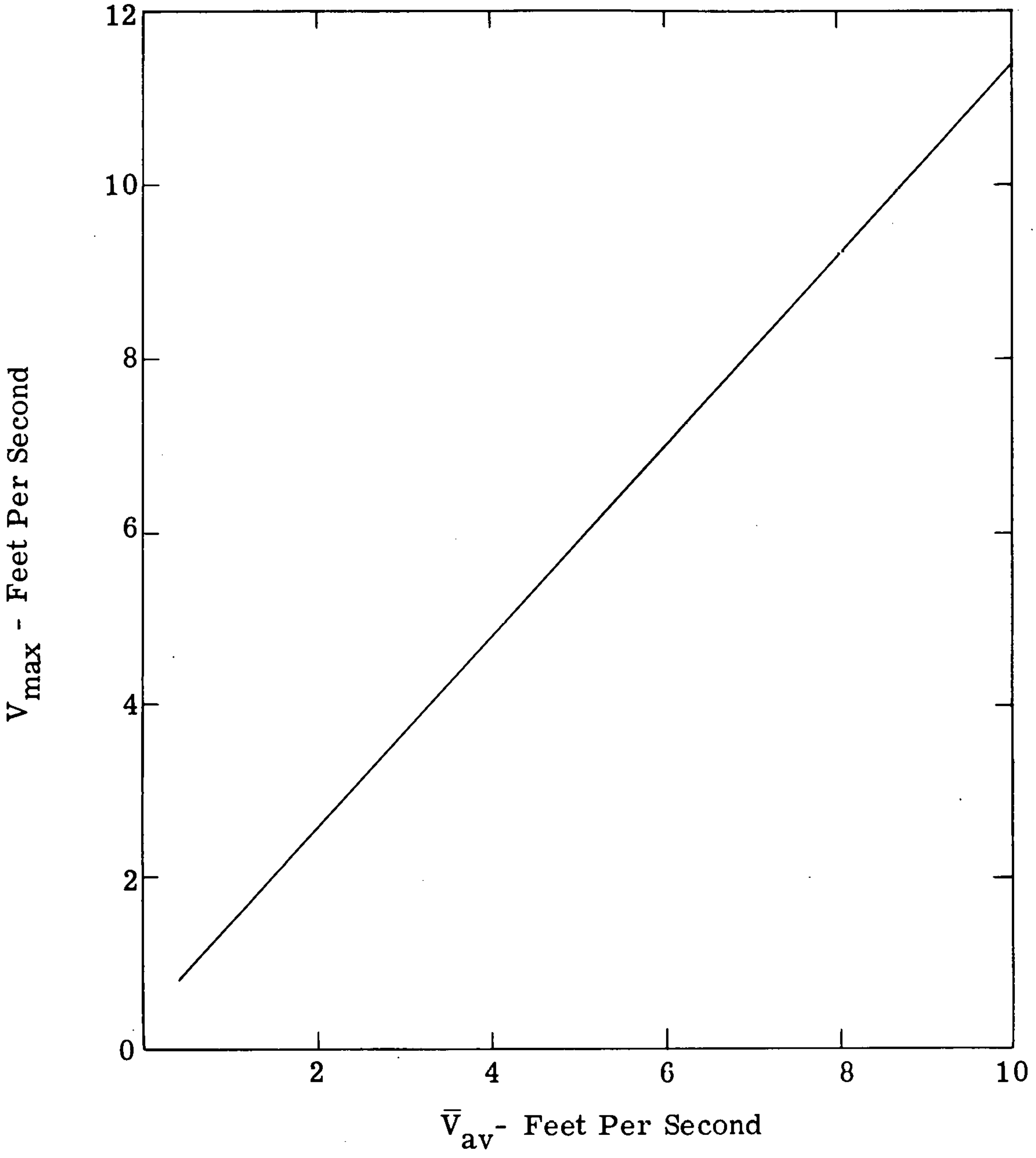

Fig. 3-5 - V_{max} Vs V_{ave} Results of Stationary Element Calibration

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3.4.2 Control Rod Fuel Element Calibration

A tabulation of results from calibration of the instrumented control rod fuel element is given in Table 3-4. A plot of average velocity vs. maximum velocity, representing the average of a family of curves is shown in Fig. 3-6. This curve was used to obtain average channel velocity in the flow test of the control rod assembly. The lattice passages, i. e., ; those formed by the outer fuel plate and control rod tube, were not calibrated but the average channel velocity for these channels was arrived at by using the above mentioned curve (Fig. 3-6).

3.4.3 Effect of Reynolds Number on $\overline{V}/V_{max}$

From data obtained in the two preceding sections an interesting correlation between $\overline{V}/V_{max}$ and Reynolds number was developed. For each channel of the stationary element, the ratio of $\overline{V}$ (average velocity) to V_{max} was obtained at different channel flow rates. The same ratio was developed from control rod data. At the different flow rates, Reynolds number was computed by using average channel velocity and average channel dimensions. A plot showing the relationship between V_{avg}/V_{max} vs. Reynolds number is given in Fig. 3-7.

TABLE 3-4
RESULTS OF CONTROL ROD CALIBRATION TEST

	Calculated Area	Q = 3. 25 gpm			Q = 5. 35 gpm			Q = 8. 74 gpm		
Channel	Ft^2 x 10^{-3}	$\overline{V}$-FPS	V_{max}-FPS	$\overline{V}/V_{max}$	$\overline{V}$-FPS	V_{max}-FPS	$\overline{V}/V_{max}$	$\overline{V}$-FPS	V_{max}-FPS	$\overline{V}/V_{max}$
B	2. 160	3. 35	4. 05	. 827	5. 52	6. 56	. 841	9. 02	10. 40	. 867
C	2. 173	3. 33	4. 10	. 812	5. 49	6. 53	. 841	8. 96	10. 20	. 878
D	2. 187	3. 31	4. 02	. 823	5. 45	6. 50	. 838	8. 90	10. 25	. 868
E	2. 130	3. 40	4. 12	. 825	5. 60	6. 60	. 848	9. 14	10. 35	. 883
F	2. 206	3. 28	3. 93	. 835	5. 40	6. 36	. 849	8. 83	10. 10	. 874
G	2. 142	3. 38	4. 07	. 830	5. 56	6. 53	. 851	9. 09	10. 22	. 889
H	2. 196	3. 30	4. 09	. 807	5. 43	6. 50	. 835	8. 87	10. 12	. 876
I	2. 201	3. 29	3. 95	. 833	5. 42	6. 40	. 847	8. 85	10. 15	. 872
J	2. 169	3. 34	4. 18	. 799	5. 50	6. 65	. 827	8. 98	10. 35	. 868
K	2. 201	3. 29	3. 92	. 839	5. 42	6. 31	. 859	8. 85	9. 91	. 893
L	2. 177	3. 33	4. 05	. 822	5. 48	6. 40	. 856	8. 94	9. 95	. 898
M	2. 189	3. 31	4. 05	. 817	5. 45	6. 50	. 838	8. 90	10. 18	. 874
N	2. 179	3. 32	4. 05	. 820	5. 47	6. 56	. 834	8. 94	10. 40	. 860
O	2. 192	3. 30	4. 06	. 813	5. 44	6. 50	. 837	8. 88	10. 15	. 875
P	2. 212	3. 27	4. 07	. 803	5. 39	6. 53	. 825	8. 80	10. 20	. 863
Total	32. 714									
Avg.	2. 181	3. 32	4. 05	. 820	5. 47	6. 50	. 842	8. 93	10. 20	. 876

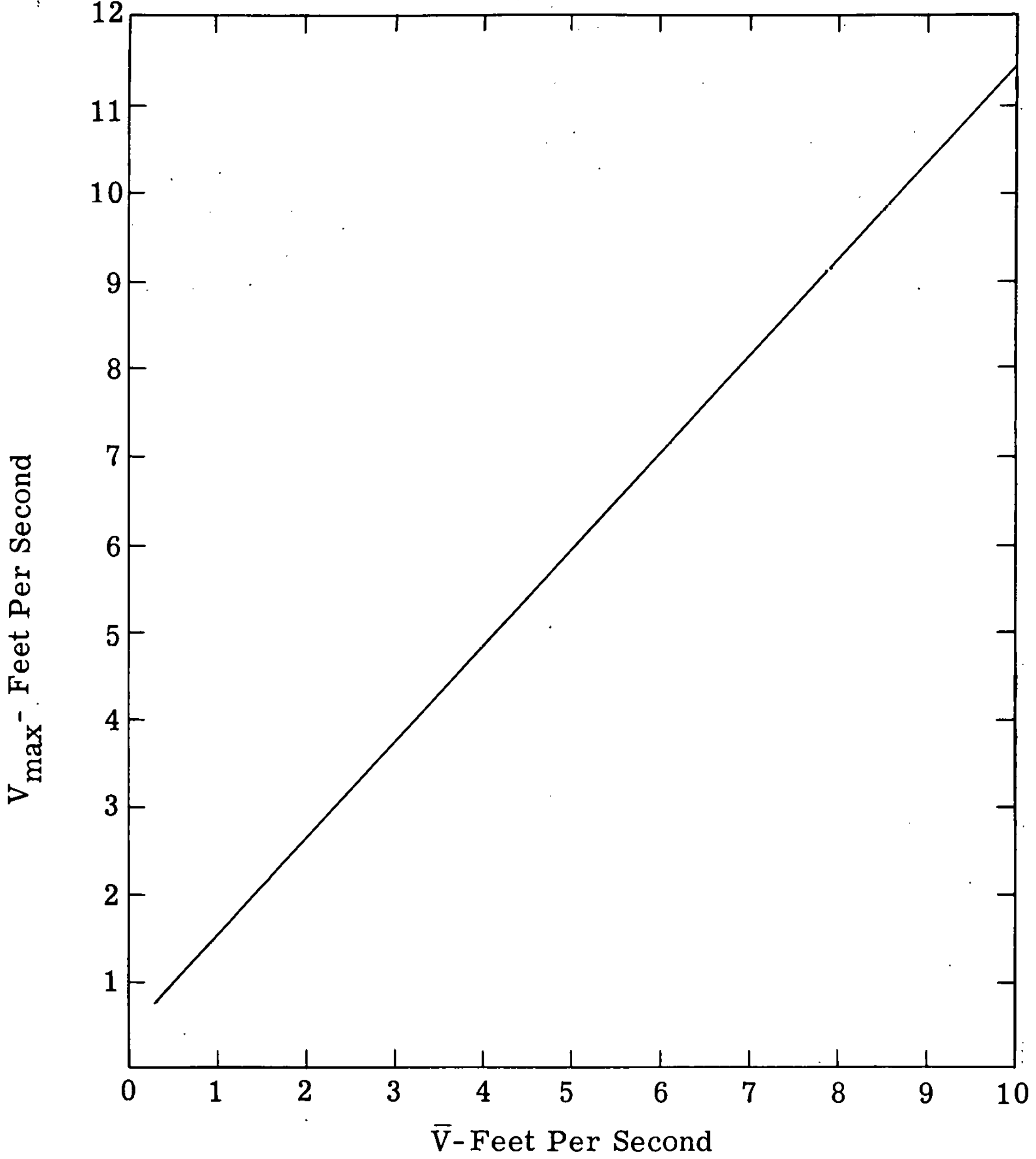


Fig. 3-6 - V_{max} Vs V_{ave} Results of Control Rod Fuel Element Calibration

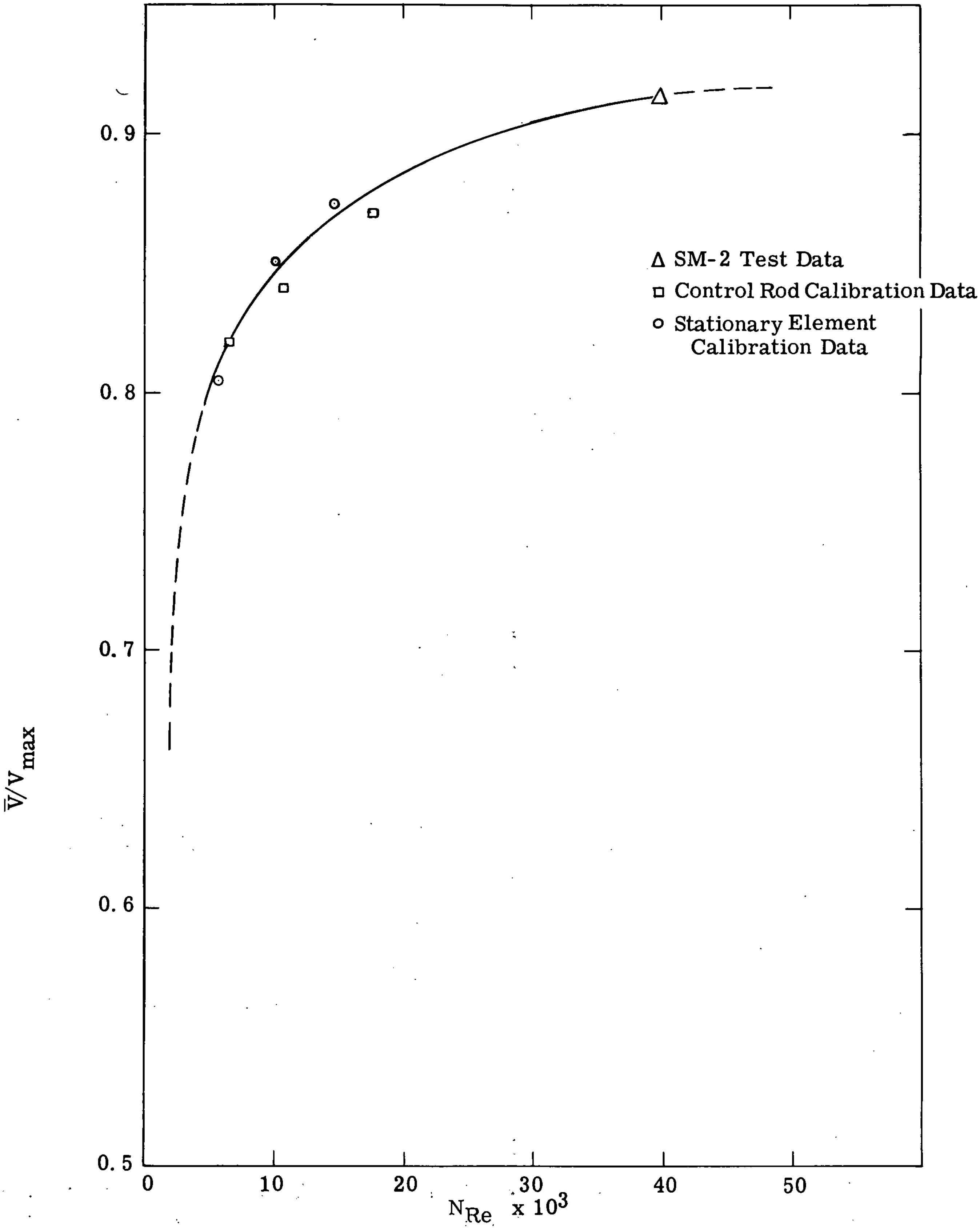


Fig. 3-7 - $\overline{V}/V_{max}$ Vs N_{Re}

4.0 STATIONARY FUEL ELEMENT FLOW TESTING

4.1 PURPOSE OF TEST

The purpose of these tests was to measure channel-to-channel flow distribution within a Type 3 (SM-2) stationary fuel element modified to fit SM-1, SM-1A and PM-2A cores. Overall pressure drop across the stationary element was also required.

4.2 DESCRIPTION OF TEST RIG AND INSTRUMENTATION

This rig consists of an entrance and exit plenum chamber, two flanged 5-in. tube sections, element supports and a flow adjuster assembly. The test section, shown in Fig. 4-1, was inserted into a flow loop which has a pump with capacity of 1500 gpm against a hydrostatic head of 196 ft. The assembled loop is shown in Fig. 4-2. An exploded view of the test element and various internals of the test section are shown in Fig. 4-3. The angles and bands around the element were used to prevent any outer plate buckling due to a pressure differential caused by flow in the outer channels of the element. These were not an integral part of the element. An assembled view of the same components is shown in Fig. 4-4.

The loop also has a heat exchanger capable of maintaining an almost constant loop temperature within a range of 70-80^{o}F. Loop pressure was maintained at approximately 20 psi for all phases of testing.

4.2.1 Instrumentation

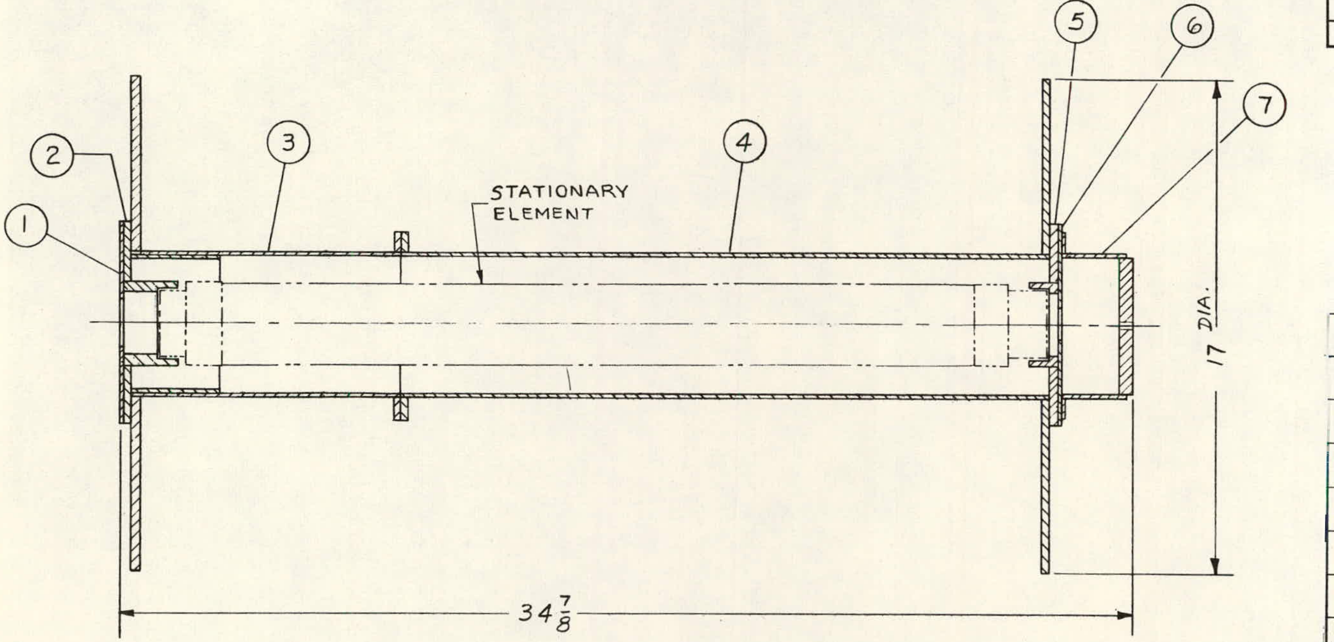
To measure velocity head in each of the 17 channels, a bank of U-tube manometers was assembled. (See Fig. 4-5). The bank consisted of 18 manometers with Meriam blue fluid (sp. gr. 1.75) used as the indicating fluid. Velocity signals (P_{total}-P_{static}) were transmitted from 0.065 in OD static and total probes located at channel exit through a penetrated ring (See Fig. 4-6), and over to the manometers by 1/8 in. OD copper tubing. Each tube of the manometer had a shutoff valve and air bleed valve.

Loop flow was measured by a standard orifice installation, with the signal from the orifice being transmitted to a mercury manometer for accurate measurement.

4.3 DESCRIPTION OF TEST SPECIMEN

The test element for this program was a standard Type 3 (SM-2) fully welded element fabricated by the Alco Welding Laboratory. The same basic element was utilized in testing of the SM-1, SM-1A and PM-2A; the only difference in the three

DATE	LET.	REVISION RECORD	AUTH.	DR.	CHK.



NOTE: "SK" NUMBERS REFER TO MECH. LAB. DRAWING NOS.

Pc No	QUAN.	DWG NO. OR MATERIAL	DESCRIPTION
7	1	C9-50-1086	FLOW ADJUSTER
6	1	SK-1272	ORIFICE PLATE
5	1	SK-1269	ELEMENT SUPP'T-INLET
4	1	SK-1262	TUBE SECTION ASS'Y
3	1	SK-1070	PLENUM CHAMBER-CENTER
2	1	SK-1266	ELEMENT SUPP'T-OUTLET
1	1	SK-1271	ORIFICE PLATE

PART NO. B9-50-1282

BREAK SHARP EDGES
REMOVE ALL BURRS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOLERANCES ON FINISHED FRACTIONAL DIMENSIONS TO BE ± ______

√ FINISH AS INDICATED IN MICROINCHES.
f_1 MACHINE FINISH - ROUGH
f_{10} FLAME CUT OR SAW

ALCO

ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPT.
SCHENECTADY, N. Y., U. S. A.

SCALE 1/4 = 1"
REF.
MATERIAL SPEC.

DR.	B. PARKER	9-29-61
TR.		
CHK.	Dockes	9-29-61
APPR.	P.Krause	9-29-61
APPR.		
MET.		[illegible]

NAME STATIONARY ELEMENT TEST SECTION ASSEMBLY

PART NO. **B** 9-50-1282

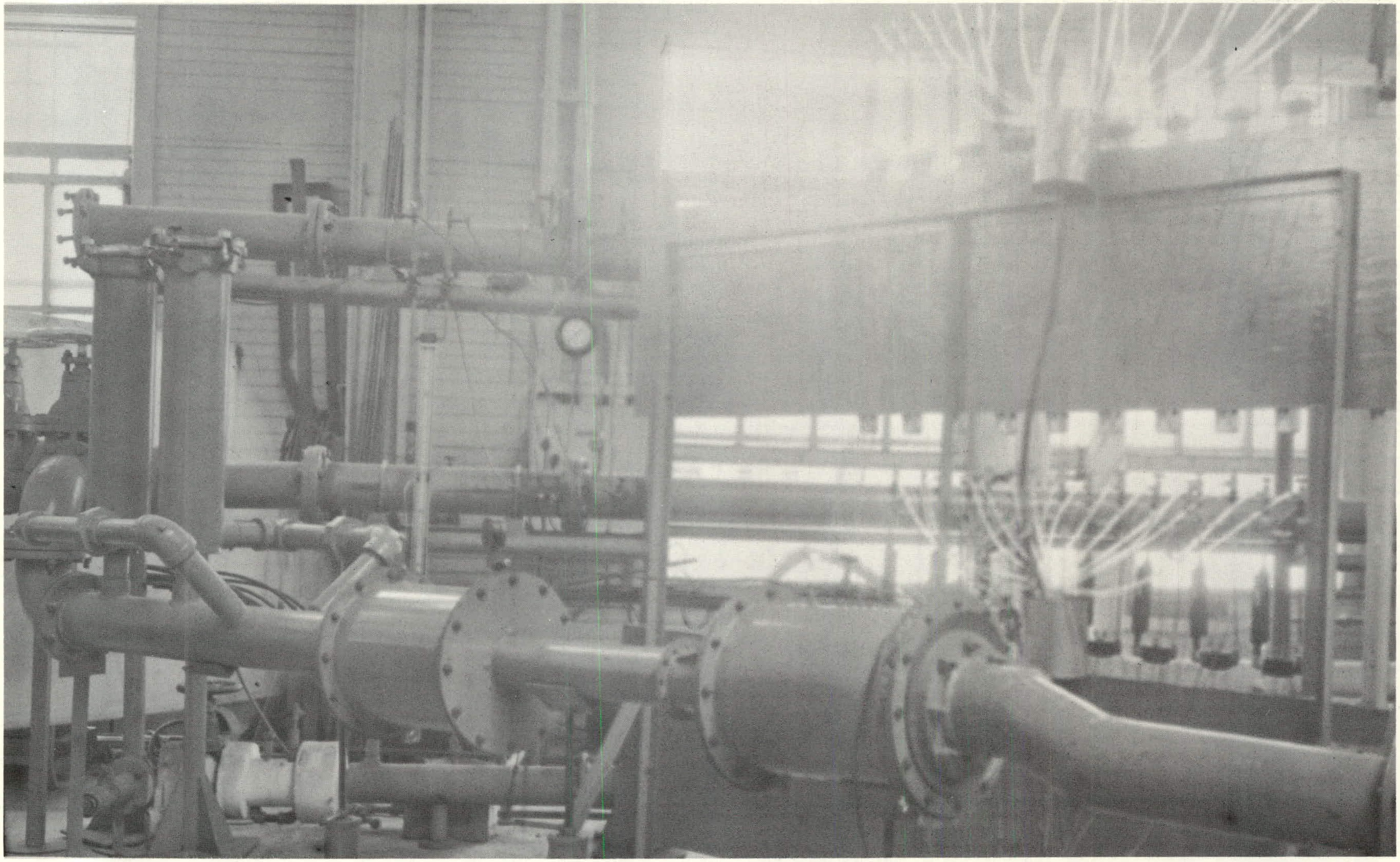


Fig. 4-2 - Stationary Fuel Element Test Section

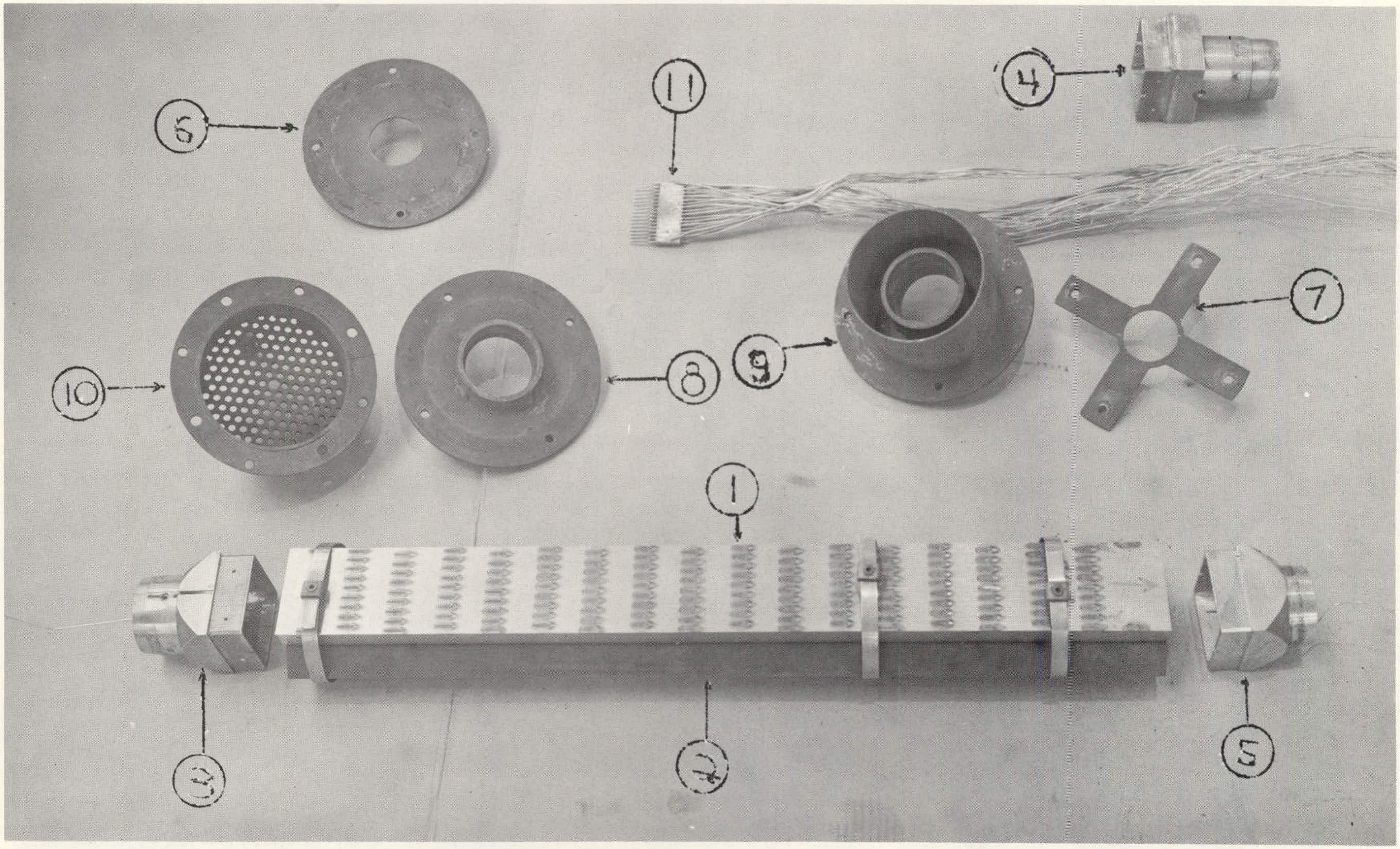


Fig. 4-3 - Exploded View of Statationary Element and Internals of Test Section 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11

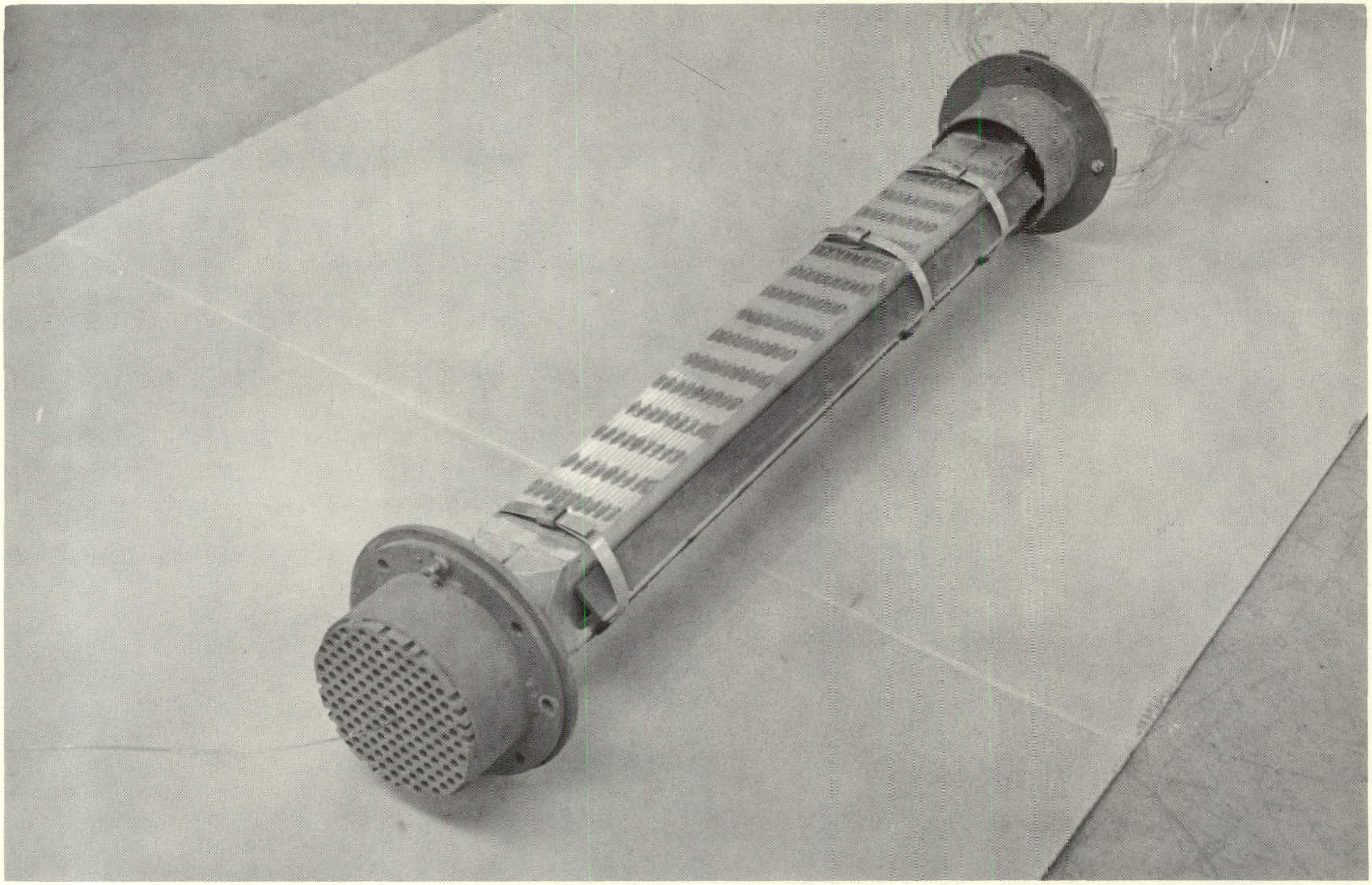


Fig. 4-4 - Assembled View of Stationary Fuel Element with Element Holder and Orifice Plate

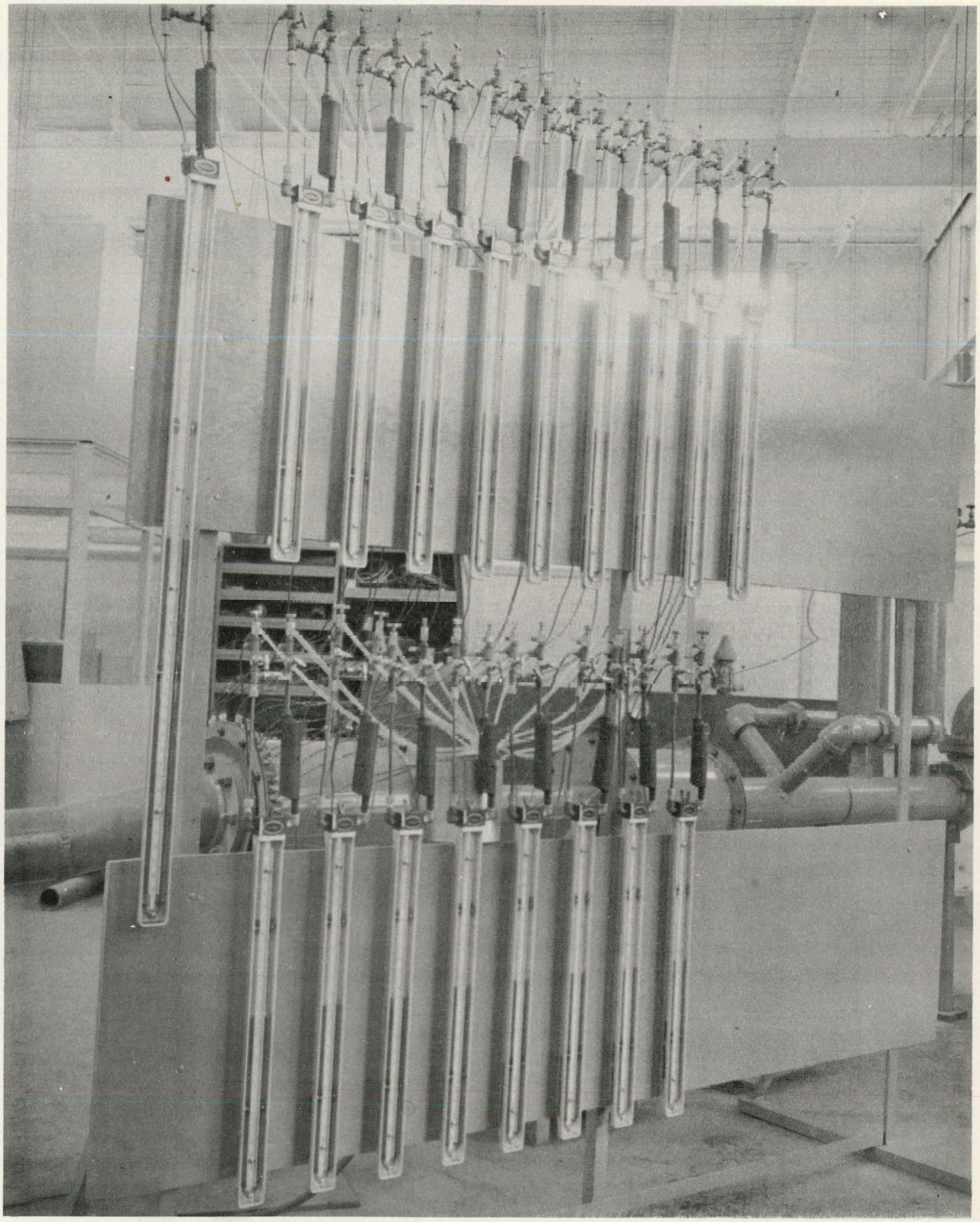


Fig. 4-5 - Single Element Flow Test - Manometer Board

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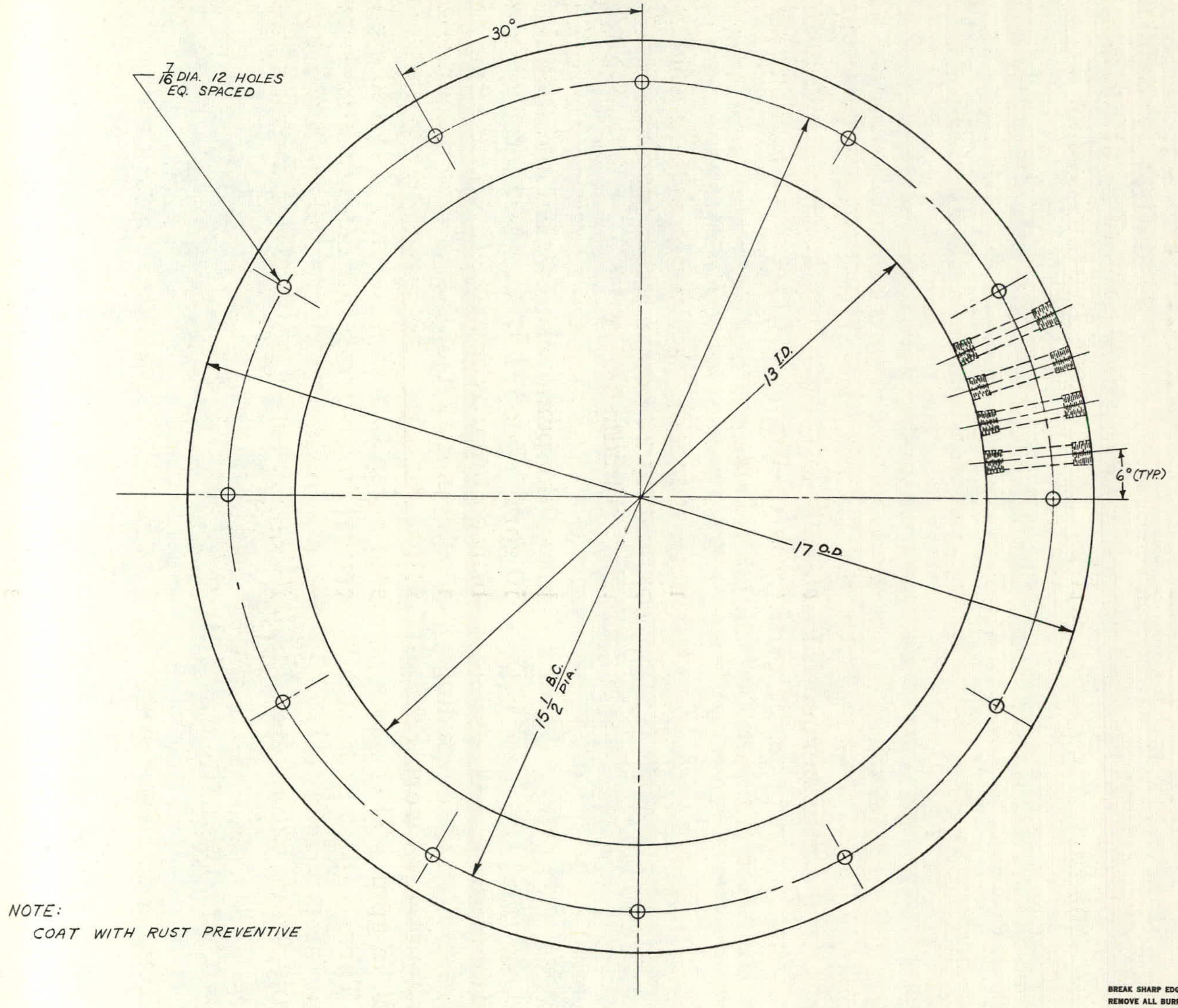
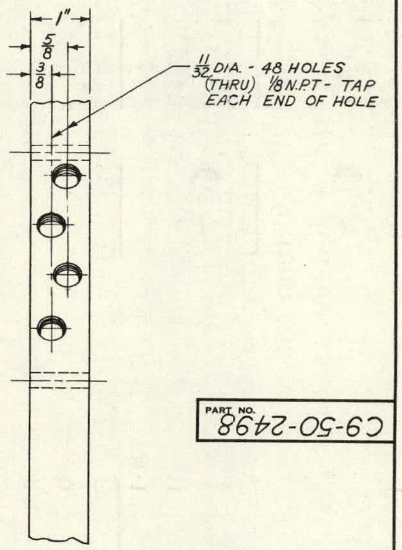




PART NO.
C9-50-2498

NOTE:
COAT WITH RUST PREVENTIVE

BREAK SHARP EDGES
REMOVE ALL BURRS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOLERANCES ON FINISHED
FRACTIONAL DIMENSIONS
TO BE ± 1/32

√ FINISH AS INDICATED IN MICROINCHES.
(ƒ1) MACHINE FINISH - ROUGH
(ƒ10) FLAME CUT OR SAW

ALCO
ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPT.
SCHENECTADY, N. Y., U. S. A.

SCALE 3/4"=1"	REF. C9-50-2360	DR.	A. Petta	3-28-61
MATERIAL SPEC.		TR.		
CARBON STEEL ASTM A-283-B (ALCO SPEC 54140 OR 54170) OR SIMILAR		CHK.	Decker	4-4-61
		APPR.	P. Krause	4-4-61
		APPR.	[illegible]	[illegible]
		MET.	[illegible] Shaw	4/4/61

NAME
PENETRATION RING

PART NO.
C9-50-2498

elements being the outlet end box, which was mechanically fastened for test purposes only. The element assembly is shown in Fig. 4-7. The element was fabricated to Type 3 specifications with all but three channels falling within the required channel width of 0.123 in. ± 0.005 in. Complete channel measurements are given in Table 3-1. The test element drawing exactly duplicated the production drawings made for Task 3.3 of the PWR Support Program. The instrument rake was not permanently fastened to the element; it was held in place by the exit end box which was mechanically fastened to the element. The end boxes used were production units previously utilized in testing of the SM-1, SM-1A, and PM-2A cores. They were mechanically fastened to the element so the same fuel element bundle could be utilized in SM-1, SM-1A and PM-2A stationary fuel element flow testing.

Since reactor lattice passage dimensions could not be accurately simulated in this test, no attempt was made to mock-up the lattices and to measure lattice velocity. All loop flow was passed through the element (bypass leakage if any, was negligible).

4.4 TEST PROCEDURE

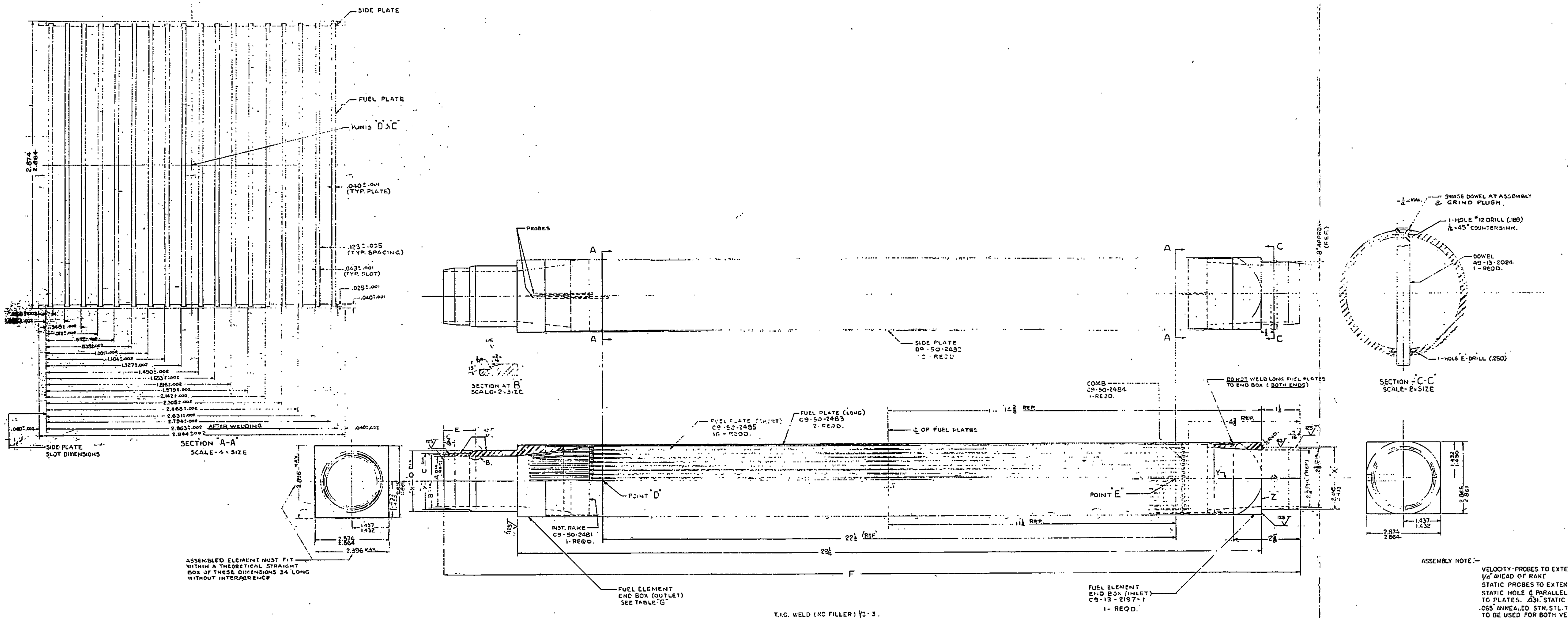
Before each test was begun, all manometers were checked to see that all air was removed from the instrument lines. This was done by checking each manometer to see that it zeroed out properly at the no-flow condition. Any manometer which did not zero-out properly was re-bled. All bleeding was done at low system pressure which facilitated the operation.

After all manometers were balanced (zeroed), the loop pressure was increased to the operating level of approximately 20 psi; no-flow readings were again recorded to make certain each manometer remained zero.

Upon recording the no-flow readings, the pump was started and loop flow throttled to the first test flow rate of 50 gpm. Loop flow was indicated on a manometer. After all manometers had stabilized (approximately 12-15 minutes), velocity readings were taken by recording each column height of the U-tube manometer. After all manometers were read, loop flow was again increased to the next nominal flow rate of 75 gpm. This same procedure was followed in testing at 100 gpm and 125 gpm. These target flow rates were met in testing of all configurations with the exception of the minimum orificed SM-1 stationary element, and the SM-1 control rod assembly which had channel velocities exceeding the range of the manometers.

At each flow rate, the following data was recorded:

1. Total loop flow - gpm
2. Water temperature - °F
3. Velocity pressure - in. blue fluid (sp. gr. 1.75)
4. Overall element pressure drop - in. hg



DRG. NO.	A	B	C	D	E	F	G	REACTOR	NO. REQD
R9-50-1268-1	2	2 1/8	2.250 2.246	2 7/16	1 1/4	33 5/8	C9-50-2486	SM-1, SM-1A	1
R9-50-1268-2	2 1/4	2 3/8	2.495 2.455	OMIT	OMIT	31 5/8	C9-50-2487	PM-2A	1

T.I.G. WELD (NO FILLER) 1/2 - 3.
ODD NUMBER PLATES START 1/8 FROM INLET END.
EVEN NUMBER PLATES START 1 5/8 FROM INLET END.
ON OPPOSITE SIDE OF FUEL ELEMENT,
ODD NUMBER PLATES START 1 5/8 FROM INLET END.
EVEN NUMBER PLATES START 1/8 FROM INLET END.
END WELDS ON OUTSIDE PLATE 1/4 FROM
END OF PLATE 1/2 LONG.

NOTE:
AXIS "Y" MUST PASS THRU POINTS "D" & "E"
DIAMETERS MARKED "X" CONCENTRIC WITH AXIS "Y" WITHIN .002 T.I.R.
SURFACE "Z" SQUARE WITH AXIS "Y" WITHIN .002 T.I.R.

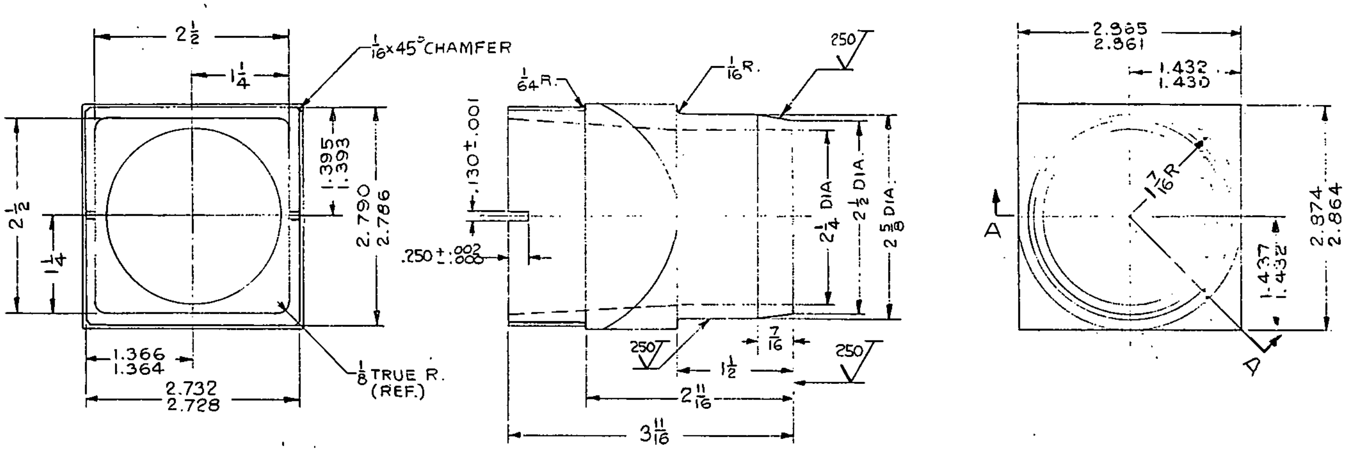
ASSEMBLY NOTE:-
VELOCITY PROBES TO EXTEND 1/4" AHEAD OF RAKE
STATIC PROBES TO EXTEND 1".
STATIC HOLE ℄ PARALLEL TO PLATES. .031" STATIC I.D.
.065" ANNEALED STN. STL. TUBING TO BE USED FOR BOTH VELOCITY AND STATIC PROBES.
PROBES TO BE ASSEMBLED TO RAKE BEFORE MAIN ASSEMBLY.

ALCO PRODUCTS

SINGLE ELEMENT FLOW TEST TASK 3,4
INSTRUMENTED DUMMY
STATIONARY FUEL ELEMENT

R9-50-1268

DATE	LET.	REVISION RECORD	AUTH.	DR.	CHK.

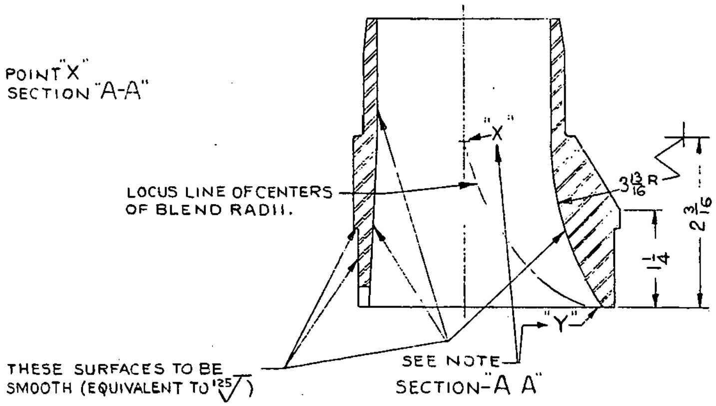


PART NO. C9-50-2487

125 ALL OVER EXCEPT AS NOTED.

NOTES:-

. BLEND UNIFORMLY FROM 1⅛ RADIUS AT POINT "X" TO ⅛ RADIUS AT POINT "Y" AS SHOWN IN SECTION "A-A"



SM 2 FUEL ELEMENT
END BOX
FOR PM 2A REACTOR.

BREAK SHARP EDGES
REMOVE ALL BURRS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOLERANCES ON FINISHED
FRACTIONAL DIMENSIONS
TO BE ± 1/64

√ FINISH AS INDICATED IN MICROINCHES.
(/1) MACHINE FINISH - ROUGH
(/10) FLAME CUT OR SAW

ALCO
ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPT.
SCHENECTADY, N. Y., U. S. A.

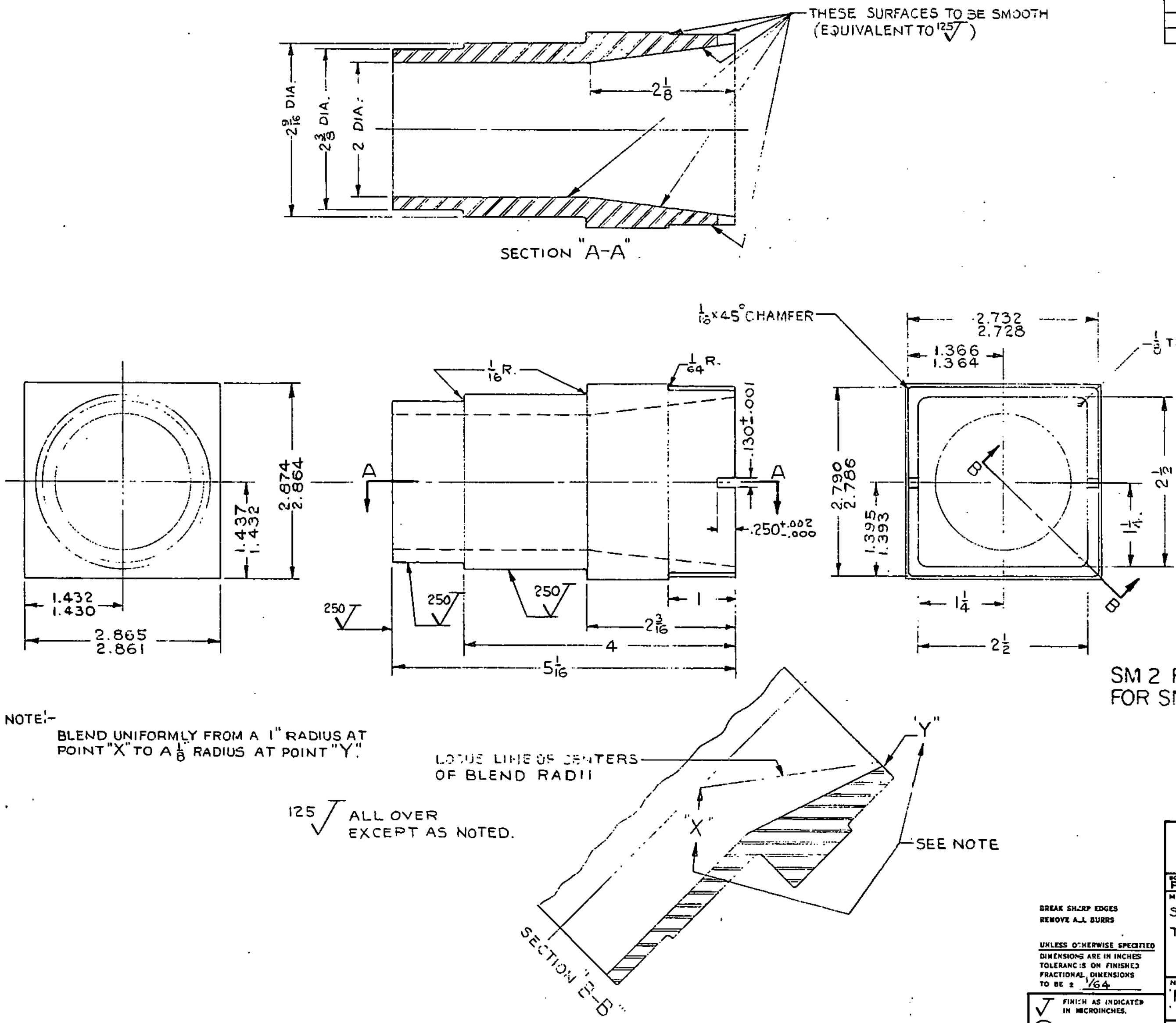
SCALE FULL	REF. R9-50-1263-2	DR.	J. L. Bond 2/13/61
MATERIAL SPEC. STN. STL. CASTING. TYPE 304 OR 316		TR.	
		CHK.	Decker 2-27-61
		APPR.	P. Krause 2-28-61
		APPR.	R. L. Gordon 4-10-61
		MET.	C. S. Wible 2/25/61

NAME SINGLE ELEMENT FLOW TEST TANK-3A
FUEL ELEMENT END BOX
(OUTLET) AE-90-1PE

PART NO.
C9-50-2487

SIM. TO C9-13-2197

DATE	LET.	REVISION RECORD	AUTH.	DR.	CHK.



PART NO. C9-50-2486

SM 2 FUEL ELEMENT END BOX
FOR SM 1 & SM 1A REACTORS

NOTE:-
BLEND UNIFORMLY FROM A 1" RADIUS AT POINT "X" TO A 1/8" RADIUS AT POINT "Y".

125√ ALL OVER
EXCEPT AS NOTED.

BREAK SHARP EDGES
REMOVE ALL BURRS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON FINISHED
FRACTIONAL DIMENSIONS
TO BE ± 1/64

√	FINISH AS INDICATED IN MICROINCHES.
(∫1)	MACHINE FINISH - ROUGH
(∫10)	FLAME CUT OR SAW

ALCO

ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPT.
SCHENECTADY, N. Y., U. S. A.

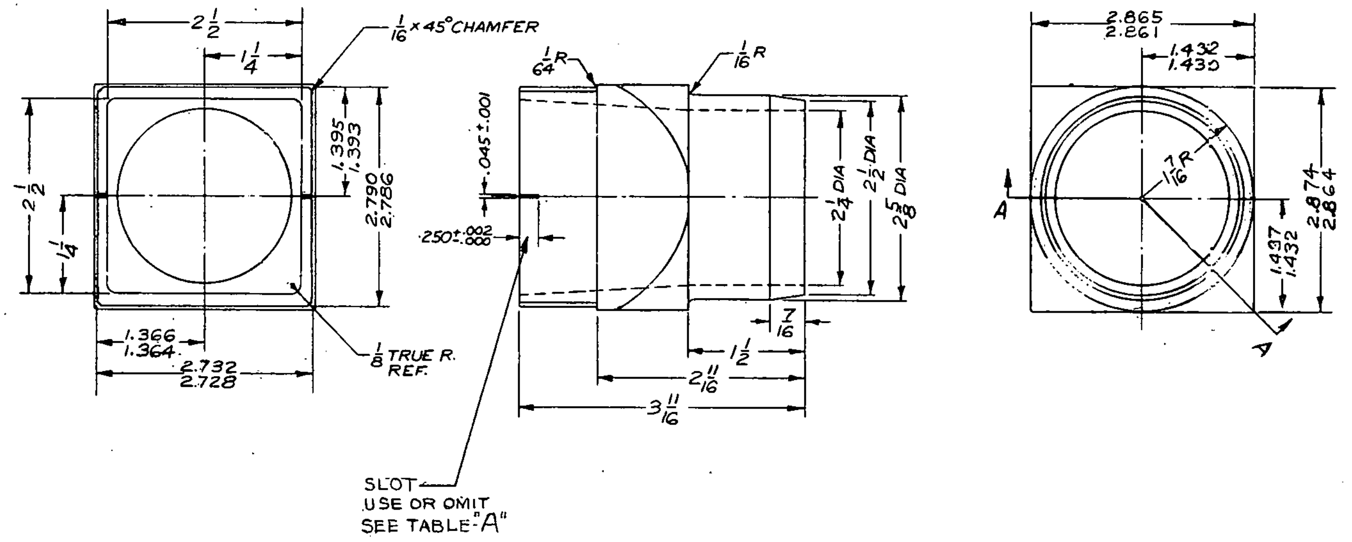
SCALE FULL.	REF. R9-50-1268-1	DR.	J.L. Boyd	2/10/61
MATERIAL SPEC. STN.STL. CASTING TYPE-304 OR 316		TR.		
		CHK.	Decker	2-27-61
		APPR.	P. Crause	2-28-61
		APPR.	S.L. Jordan	4-10-61
		MET.	A Switzler	2/28/61

NAME SINGLE ELEMENT FLOW TEST TASK 3.4
FUEL ELEMENT END BOX
(OUTLET) AE-90-1PE

PART NO.
C9-50-2486

DRG NO.	A
C9-13-2197-1	USE
C9-13-2197-2	OMIT

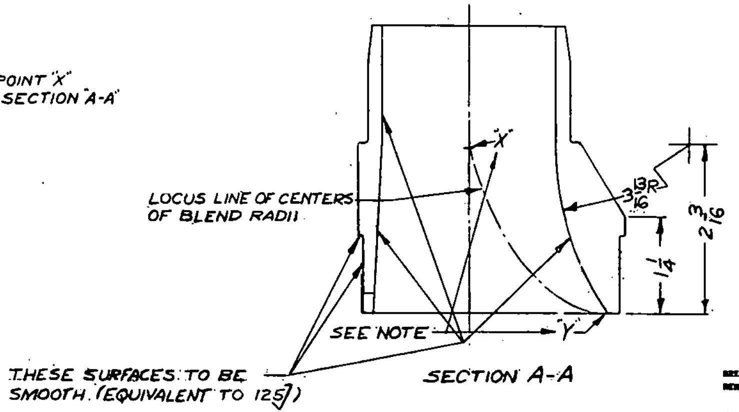
DATE	LET.	REVISION RECORD	AUTH.	DR.	CHK.



PART NO. C9-13-2197

NOTES:

BLEND UNIFORMLY FROM 1 1/8 RADIUS AT POINT "X" TO 1/8 RADIUS AT POINT "Y" AS SHOWN IN SECTION "A-A"



SECTION A-A

SM-2 FUEL ELEMENT END BOX
FOR SM-1 & SM-1A REACTORS

BREAK SHARP EDGES
REMOVE ALL BURRS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOLERANCE ON FINISHED FRACTIONAL DIMENSIONS TO BE ± 1/64

√ FINISH AS INDICATED IN MICROINCHES.
(/1) MACHINE FINISH, ROUGH
(/10) FLAME CUT OR SAW

ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPT.
SCHENECTADY, N. Y., U. S. A.

SCALE FULL	REF. R9-13-1048 R9-13-1049	DR.		1-17-61
MATERIAL SPEC. STAINLESS STL. CASTING LOW IMPURITY STN. STL. TYPE 347.		TR.		
		CHK.	Becker	1-23-61
		APPR.		2-2-61
		APPR.		2-2-61
		MET.		

NAME FUEL ELEMENT END BOX (INLET)

PART NO. C9-13-2197

At least two comparable runs were made at each different flow rate to insure reliable results.

4.5 DATA REDUCTION

Test data, consisting of readings of two column heights for each manometer, was reduced by calculating the velocity pressure differential represented by these columns and then converting this differential into velocity (maximum) in feet per second. This conversion was facilitated by using the graph shown in Fig. 3-3 which is a plot of $V = \sqrt{2\ gh}$. Once maximum velocity was obtained, average channel velocity was determined by going to a plot of V_{avg} vs. V_{max} shown in Fig. 3-6. This plot represents the best straight line fit of data obtained from calibration of the stationary fuel element.

4.6 SOURCES OF ERROR

Although all precautions were taken to minimize error in obtaining data, some possible sources of error that were present are listed:

1. Velocity probe misalignment - Alignment was checked prior to installation and after testing; no change was noted.
2. Leakage in instrument leads - a constant check was made to insure a tight, leak-free instrument system. No external leakage was noted and possible internal leakage could not be checked.
3. Air in instrument lines - the source of error was easily detected since it resulted in very erratic readings. Frequent checks were made to guard against this possible source.

These same sources of error apply to control rod testing.

4.7 TEST RESULTS

With the exception of the SM-1 element with minimum orifice, test results showed flow distribution to be within the ± 12% of element average used in previous analyses. A complete description of each test is presented in the following sections.

4.7.1 SM-1 Stationary Fuel Element Flow Tests

The Type 3 stationary element for SM-1 was tested with two different orifice selections. The first selection was the maximum orifice : 2.02 in. diam (element #54), the second selection being the minimum orifice : 1.19 in. diam (element #12, #21, #27, #61, #67). The tolerance on these orifice diameters was ± 1/64". The orifice location for both these tests was at the element inlet. The core location of the different selections tested is shown in Fig. 4-11.

4.7.1.1 SM-1 Test with Maximum Orifice

Average channel velocity distribution for the maximum orifice (2.02 in.) selection is shown in Fig. 4-12. The graph shows the flow distribution obtained at nominal flow rates of 50, 76, 100, and 125 gpm. The actual flow rate prescribed for this element in the SM-1 core is 106.13 gpm. At the prescribed flow rate maximum deviations of +6.8% and -8.8% were noted in channels D and J respectively. A complete tabulation of this data is given in Table 4-1.

4.7.1.2 SM-1 Test with Minimum Orifice

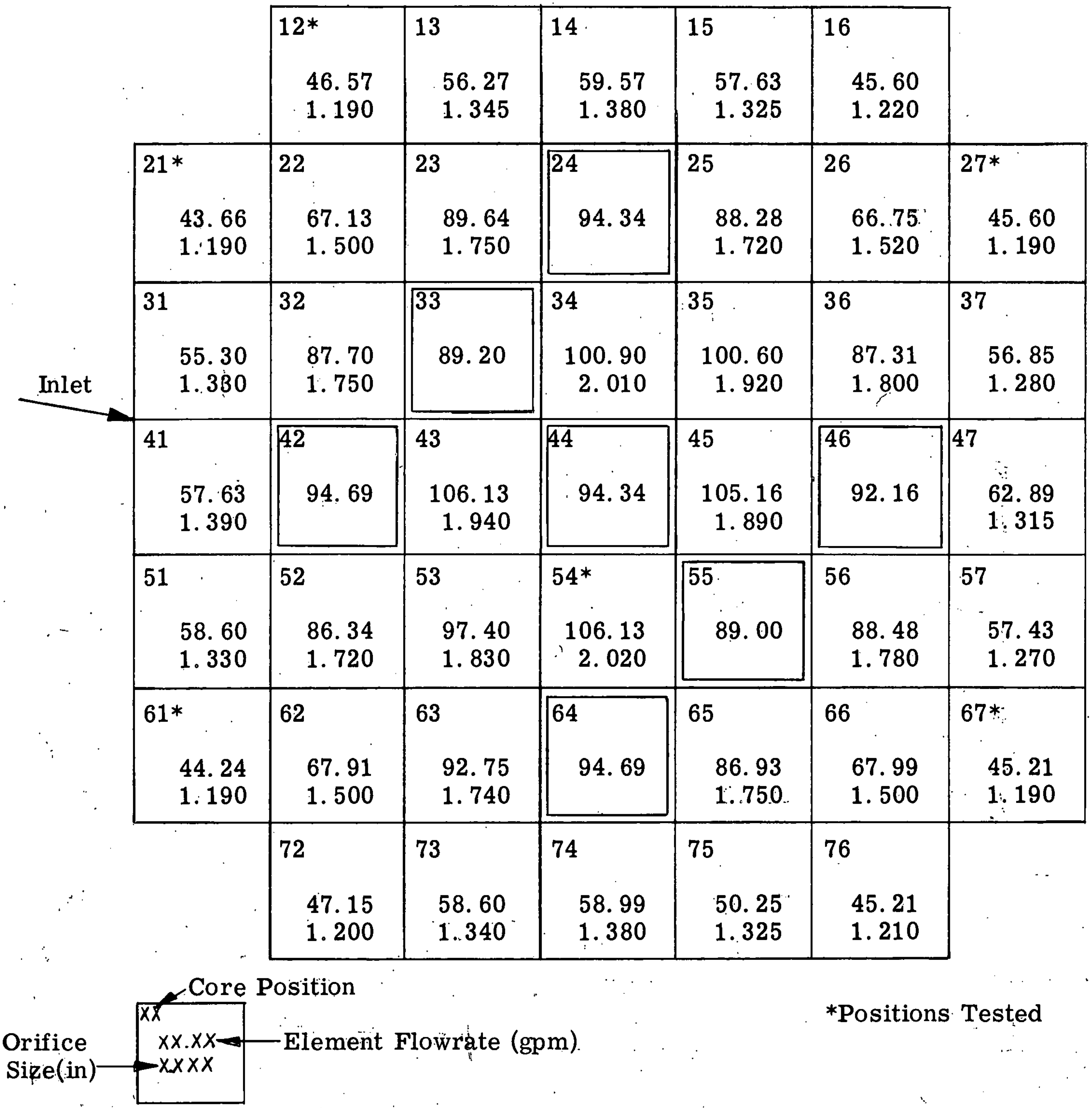
The results of this test are plotted in Fig. 4-13. Flow distribution was obtained at nominal flow rates of 52, 75 and 87 gpm. Higher flow rates could not be obtained because velocity readings in the center channels exceeded the range of the manometer. The prescribed flow rate for this element in the core ranges between 43.66 and 45.60 gpm. At the nominal test flow rate of 52 gpm, maximum deviations of +44% and -55% of average were recorded in channels G and A respectively. A complete tabulation of the data is given in Table 4-2.

A marked difference can be seen when comparing flow distribution results of the maximum and minimum orifice selections. A completely different flow profile was obtained. This difference in profile can probably be traced to the downstream movement of the vena contracta resulting from the increase in flow velocity past the smaller orifice. The inlet end box of the element did not allow sufficient distance for the flow pattern to recover from the vena contracta before entering the channels; thus flow was starved in the outer channels and overabundant in the center.

When flow was increased from a nominal flow rate of 52 gpm to a nominal rate of 75 gpm the flow profiles were very nearly identical; but, as element flow was increased further, a transition occurred and the profile changed. It was quite apparent that this increase in flow velocity caused the vena contracta to move farther downstream, thus causing the flow profile to become more peaked in the center channels and more starved in the outer channels.

4.7.1.3 SM-1 Test with Minimum Orifice and Conical Diffuser - "Proof of Principle"

Because of the poor flow distribution obtained in the SM-1 test with minimum orifice, investigation was made to determine the effects upon flow distribution of a flow device capable of being installed in the element entrance. The first attempt, a conical diffuser, 2 inches long with 1/2 in. top diam and 1 in. bottom diam, was fabricated and located as shown in Fig. 4-14. For test purposes only, the diffuser was attached to the orifice plate (attachment could have been made to end box) with the leading edge of the diffuser even with the leading edge of the orifice plate.



	12* 46.57 1.190	13 56.27 1.345	14 59.57 1.380	15 57.63 1.325	16 45.60 1.220	
21* 43.66 1.190	22 67.13 1.500	23 89.64 1.750	24 94.34	25 88.28 1.720	26 66.75 1.520	27* 45.60 1.190
31 55.30 1.330	32 87.70 1.750	33 89.20	34 100.90 2.010	35 100.60 1.920	36 87.31 1.800	37 56.85 1.280
41 57.63 1.390	42 94.69	43 106.13 1.940	44 94.34	45 105.16 1.890	46 92.16	47 62.89 1.315
51 58.60 1.330	52 86.34 1.720	53 97.40 1.830	54* 106.13 2.020	55 89.00	56 88.48 1.780	57 57.43 1.270
61* 44.24 1.190	62 67.91 1.500	63 92.75 1.740	64 94.69	65 86.93 1.750	66 67.99 1.500	67* 45.21 1.190
	72 47.15 1.200	73 58.60 1.340	74 58.99 1.380	75 50.25 1.325	76 45.21 1.210	

Fig. 4-11 - SM-1 Core Flow Distribution and Orifice Size

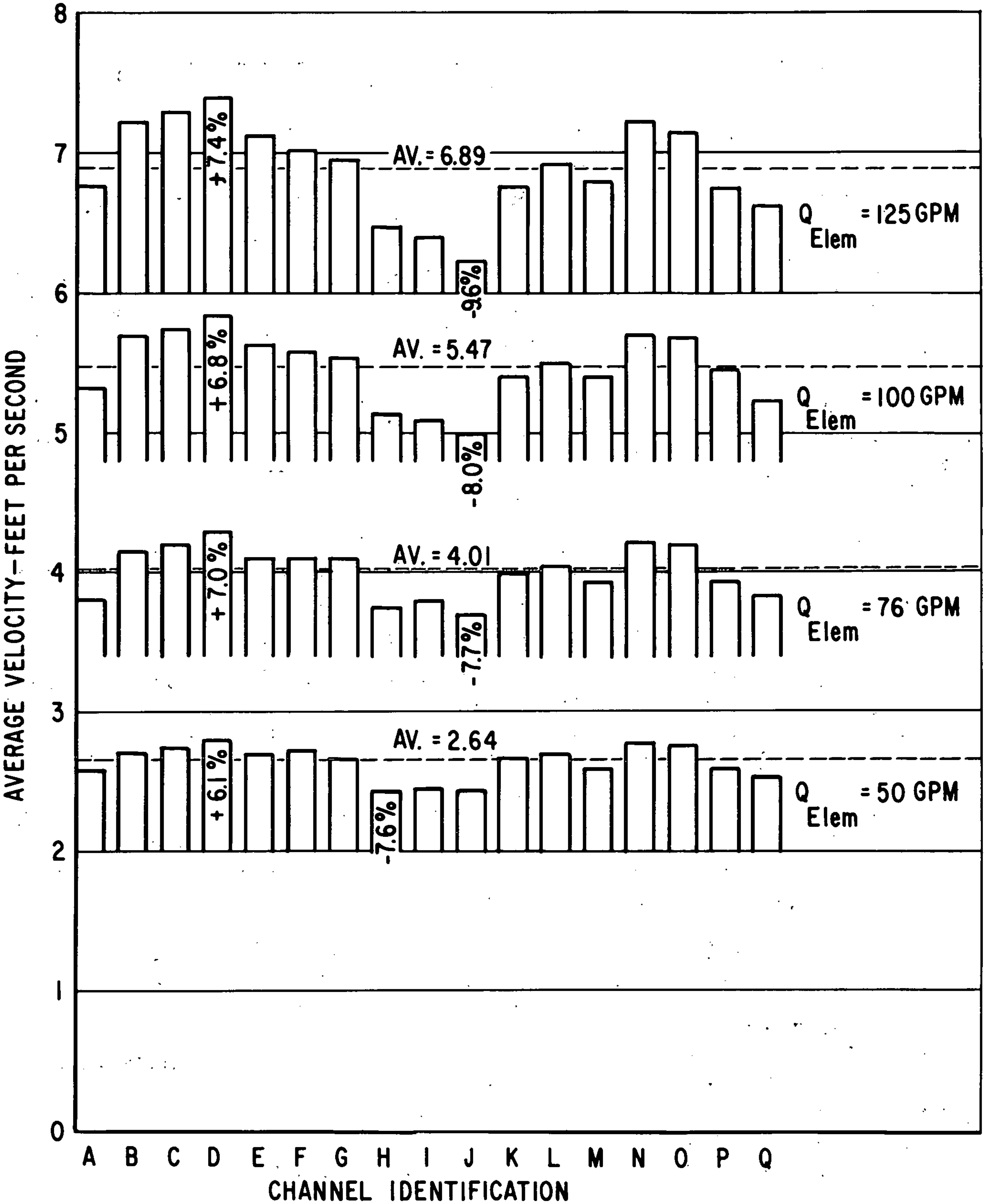


Fig. 4-12 - SM-1 Stationary Element Flow Distribution - 2.02" Orifice Located at Inlet

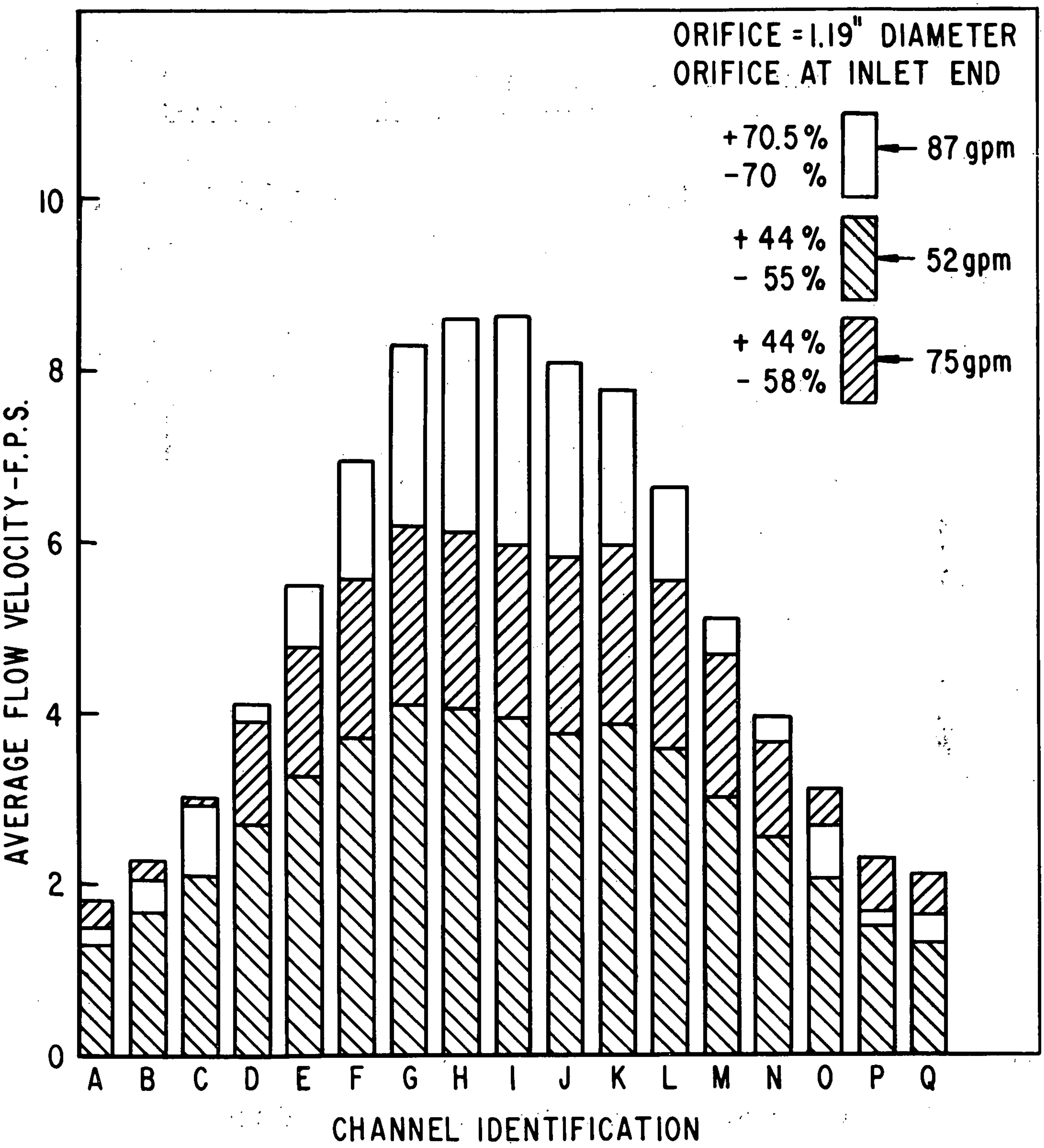


Fig. 4-13 - SM-1 Stationary Element Flow Distribution - 1.19" Orifice Located at Inlet

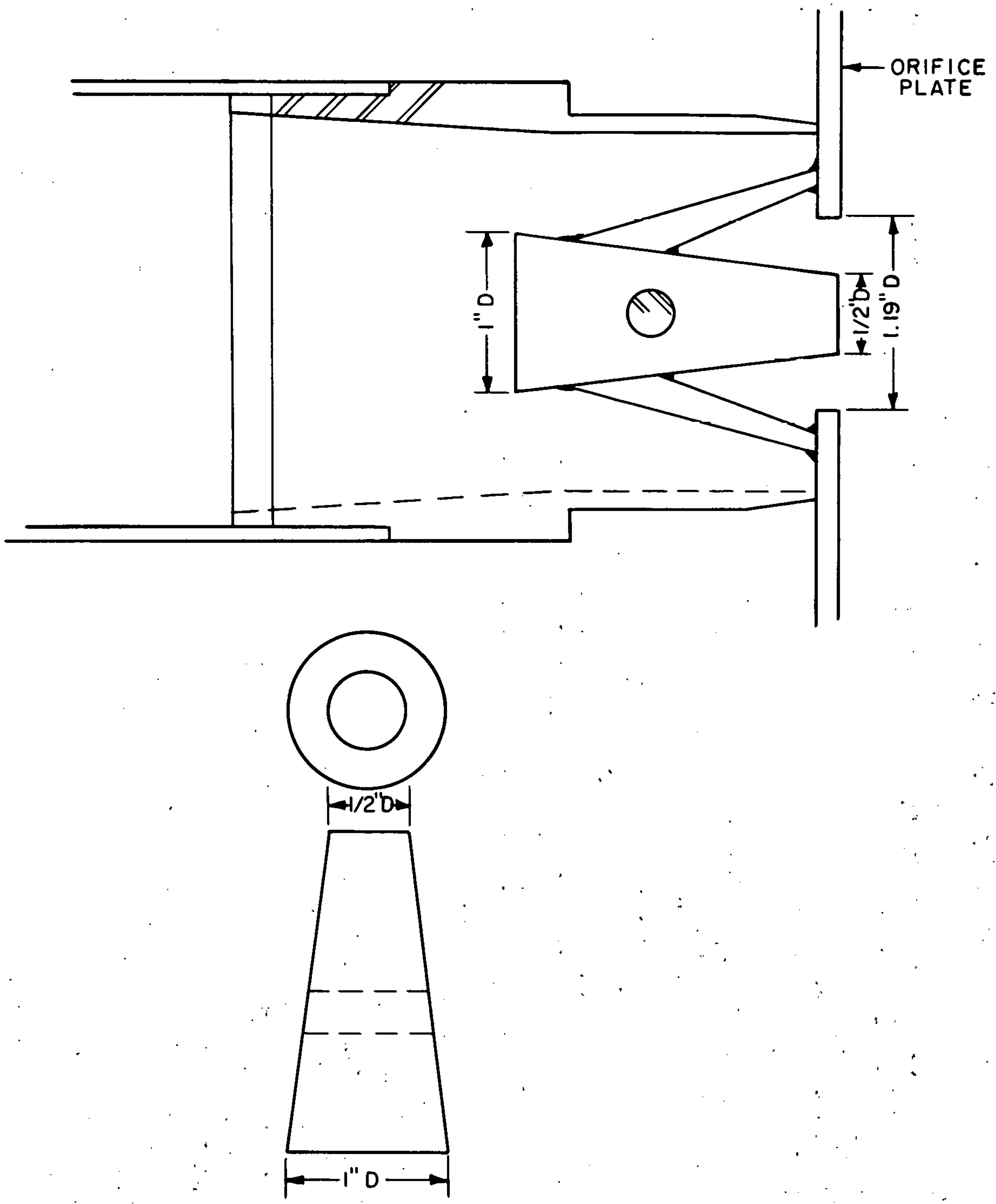


Fig. 4-14 - Location of Conical Diffuser within Inlet End Box

TABLE 4-1

SM-1 STATIONARY ELEMENT FLOW DISTRIBUTION - 2.02 In. Orifice at Inlet

Channel Letter	Q = 50 gpm		Q = 76 gpm		Q = 100 gpm		Q = 125 gpm	
	$V_{max-meas}$ fps	$\overline{V}_{correct}$ fps	$V_{max-meas}$ fps	$\overline{V}_{correct}$ fps	$V_{max-meas}$ fps	$\overline{V}_{correct}$ fps	$V_{max-meas}$ fps	$\overline{V}_{correct}$ fps
A	3.20	2.58	4.66	3.82	6.21	5.32	7.80	6.77
B	3.35	2.72	4.95	4.15	6.62	5.70	8.30	7.22
C	3.37	2.73	5.01	4.20	6.68	5.75	8.38	7.30
D	3.45	2.80*	5.11	4.29*	6.80	5.84*	8.50	7.40*
E	3.32	2.70	4.91	4.11	6.55	5.63	8.20	7.13
F	3.36	2.72	4.91	4.11	6.50	5.58	8.07	7.01
G	3.29	2.67	4.90	4.10	6.45	5.54	8.00	6.95
H	3.07	2.44 ⊛	4.55	3.76	6.03	5.14	7.49	6.49
I	3.10	2.45	4.58	3.80	5.98	5.09	7.40	6.40
J	3.10	2.45	4.49 ⊛	3.70 ⊛	5.85	4.99 ⊛	7.22	6.23 ⊛
K	3.29	2.67	4.81	4.00	6.32	5.41	7.80	6.77
L	3.32	2.70	4.85	4.05	6.42	5.50	7.98	6.92
M	3.21	2.59	4.73	3.93	6.30	5.40	7.82	6.80
N	3.42	2.78	5.02	4.21	6.65	5.70	8.30	7.22
O	3.40	2.76	5.00	4.20	6.62	5.69	8.25	7.15
P	3.22	2.60	4.75	3.95	6.37	5.46	7.78	6.75
Q	3.17	2.54	4.64	3.85	6.14	5.24	7.65	6.62
Average		2.64		4.01		5.47		6.89
* +% of Avg.		6.1		7.0		6.8		7.4
⊛ -% of Avg.		7.6		7.7		8.8		9.6

TABLE 4-2
SM-1 STATIONARY ELEMENT FLOW DISTRIBUTION
1.19 In. Orifice at Inlet

Channel	Q = 52 gpm		Q = 75 gpm		Q = 87 gpm	
	V_{max}	$\bar{\bar{V}}$	V_{max}	$\bar{\bar{V}}$	V_{max}	$\bar{\bar{V}}$
	fps	fps	fps	fps	fps	fps
A	1.84	1.28 ⊛	2.41	1.80 ⊛	2.10	1.52 ⊛
B	2.28	1.68	2.94	2.29	2.65	2.01
C	2.76	2.10	3.70	3.00	3.62	2.91
D	3.38	2.70	4.71	3.91	4.91	4.10
E	3.97	3.25	5.65	4.79	6.40	5.49
F	4.49	3.71	6.48	5.55	8.00	6.95
G	4.91	4.10*	7.18	6.19*	9.47	8.30
H	4.83	4.04	7.09	6.10	9.80	8.60
I	4.75	3.95	6.95	5.97	9.82	8.61*
J	4.55	3.77	6.78	5.82	9.18	8.04
K	4.64	3.85	6.94	5.97	8.90	7.78
L	4.35	3.59	6.48	5.55	7.65	6.62
M	3.70	3.00	5.54	4.69	6.01	5.12
N	3.23	2.55	4.75	3.95	4.62	3.82
O	2.69	2.05	3.81	3.10	3.35	2.67
P	2.10	1.52	2.97	2.30	2.28	1.68
Q	1.89	1.31	2.73	2.10	2.24	1.65
Average		2.85		4.30		5.05
* +% of Avg	44		44		70.5	
⊛ -% of Avg	55		58		70	

Flow distribution was obtained at nominal flow rates of 51, 75, 100 and 125 gpm. At the flow rate closest to the prescribed element flow rate (43.66-45.60 gpm), maximum deviations were +34% and -23.1% of average in channels A and J respectively. The results are plotted in Fig. 4-15. A complete tabulation is presented in Table 4-3. By comparing Fig. 4-13 and Fig. 4-15 one can observe the effect of the conical diffuser; a complete reversal in profile in which the flow in channel A went from -55% to +34% of element average, and the flow in channel J went from +32.6% to -23.1% of the element average. The low depression of channel flow in the center channels could possibly be improved by redesign of the element locating pin which goes completely across the end box, and is known to have an effect upon center channel velocity distribution.

Comparison of overall pressure drop (including ΔP across orifice) before and after addition of the diffuser cone has shown that pressure drop actually decreases with the addition of the conical diffuser. These results are given in Section 4.7.1.5.

4.7.1.4 SM-1 Test With Minimum Orifice and Perforated Plate - "Proof of Principle"

A second attempt to improve upon the poor SM-1 flow distribution resulted in selection of a perforated plate - 1/8-in. thick with a series of holes 1/8 in. diam and 3/16 in. diam arranged so the outer channels would receive a greater proportion of flow than the center channels. The perforated plate is shown in Fig. 4-16. The plate was fitted into the inlet end box just before the comb of the fuel element. The effect of this modification on flow distribution can be seen in Fig. 4-17. A complete tabulation of this data at nominal element flow rates of 50, 75, 100 and 125 gpm is given in Table 4-4. The results of this test were encouraging, since the modification does exactly what it was intended to do; re-distribute flow from the center channels into the outer channels. At the prescribed element flow rate of 50 gpm (an approximate value), the flow distribution was +21% and -29.4% of element average in channels H and P respectively. As flow rate increases, the flow profile shifts slightly. This is probably due to the shifting of the vena contracta as the flow is increased.

4.7.1.5 Pressure Drop Test of SM-1 Stationary Element

To accurately determine the overall stationary element pressure drop (across element assembly only), a test was run with the velocity instrumentation and orifice plate removed. Results of this test are tabulated in column #1, Table 4-5. A plot of this data is shown in Fig. 4-18.

To determine the effect of the conical diffuser on pressure drop, a test was conducted with and without the conical diffuser. Since the conical diffuser was attached to the orifice plate for test purposes, the pressure drop comparison also included the pressure drop across the orifice. This data is also tabulated in Table 4-5 and plotted in Fig. 4-18. Comparison of this data (column 2 and 3, Table 4-5) shows that the conical diffuser actually reduces the total pressure drop across the element and orifice plate, probably because it breaks up the vena contracta and redistributes the flow.

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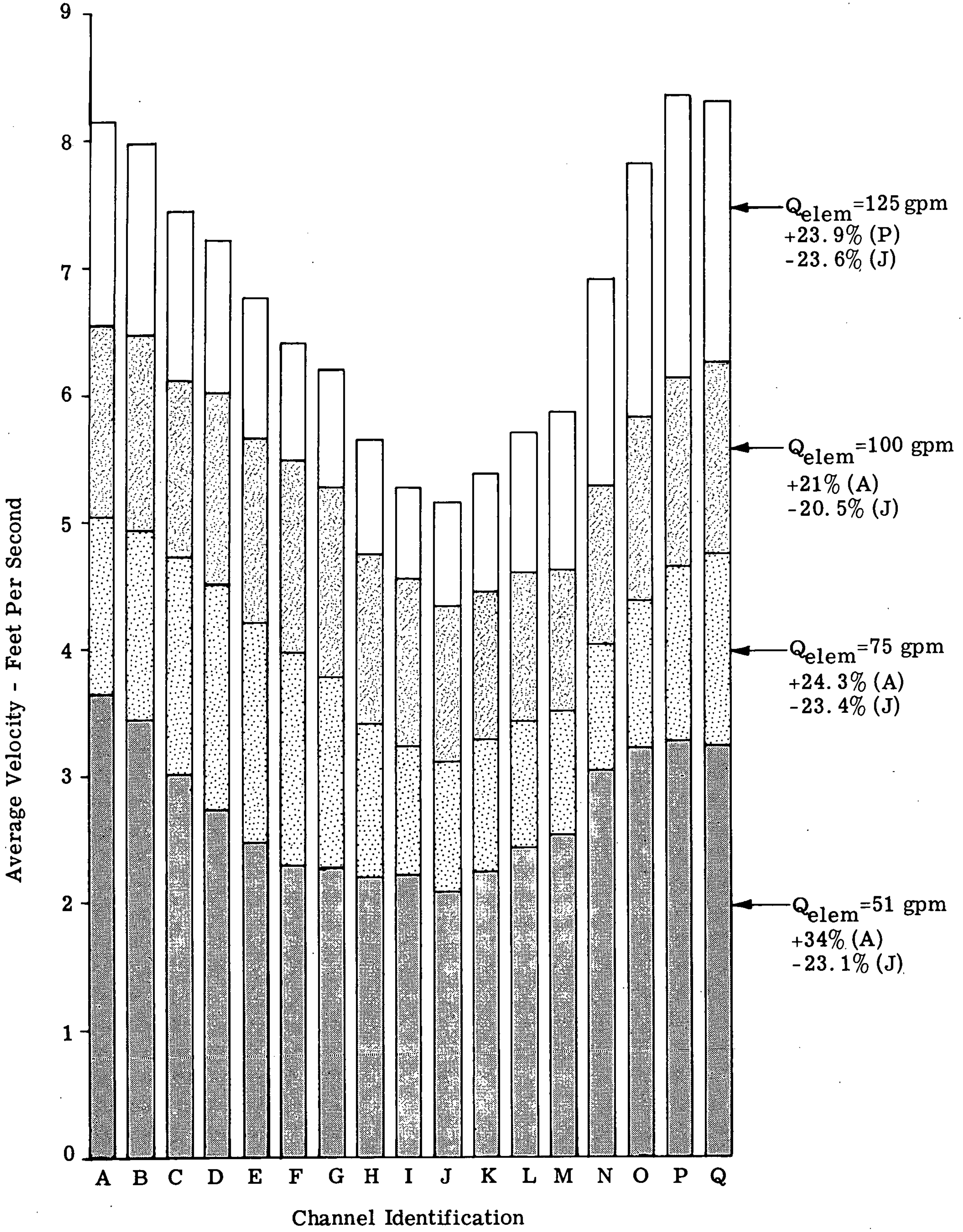

Fig. 4-15 - SM-1 Stationary Fuel Element Flow Distribution 1.19" Orifice with Diffuser Cone Located at Element Inlet

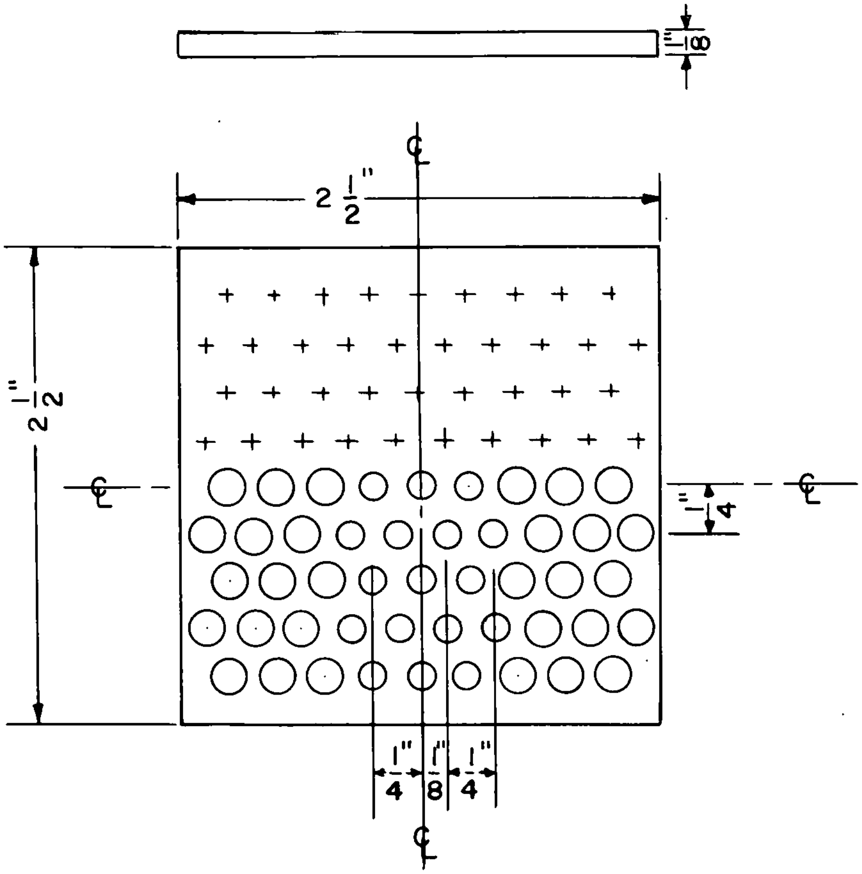

Fig. 4-16 - Perforated Plate for SM-1 Element

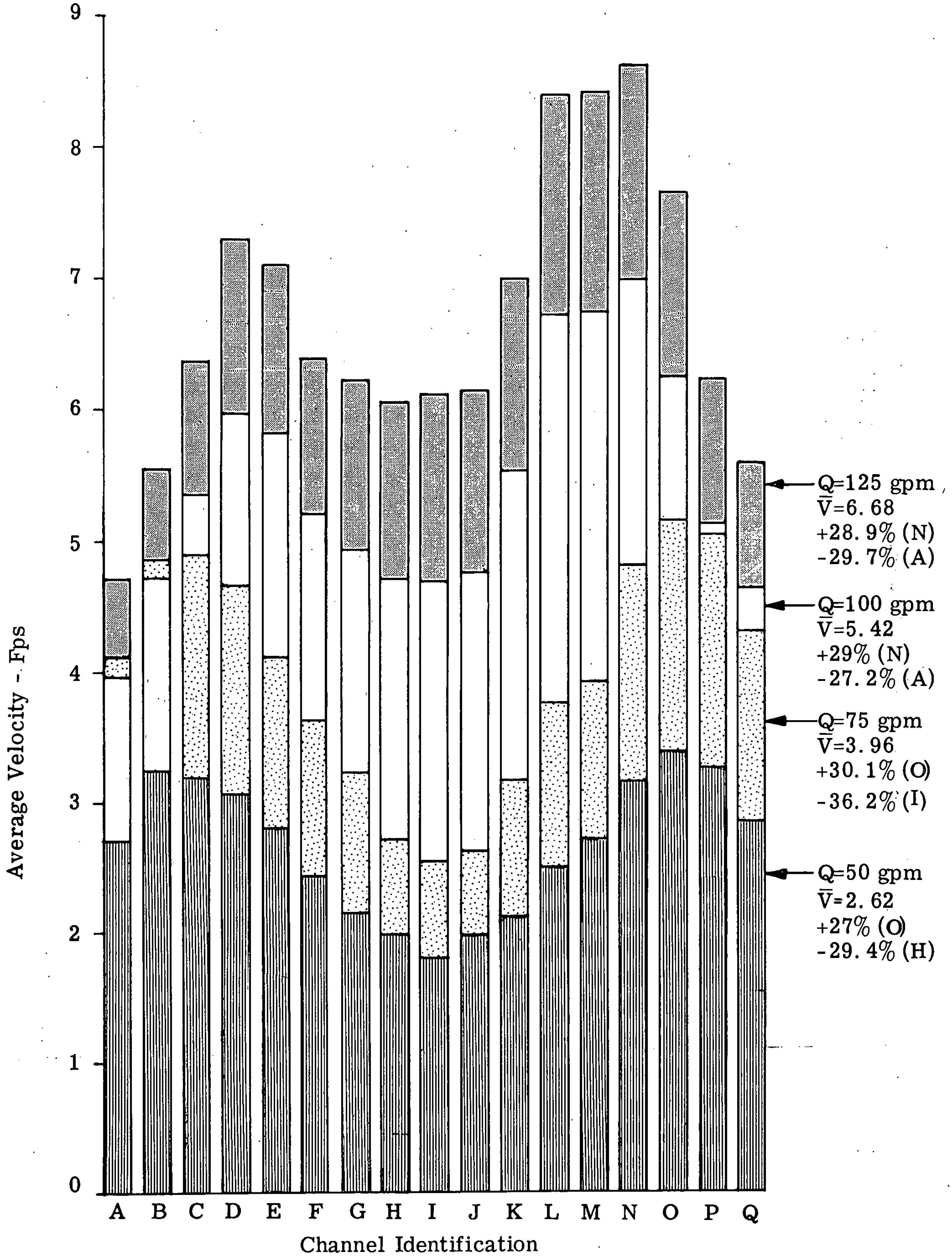

Fig. 4-17 - SM-1 Stationary Element Flow Distribution - 1.19" Orifice and Perforated Plate Located at Element Inlet

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TABLE 4-3
SM-1 STATIONARY FUEL ELEMENT FLOW DISTRIBUTION WITH DIFFUSER CONE LOCATED IN EXTRANCE END BOX - 1.19" ORIFICE

Channel	Qelem = 51 gpm		Qelem = 75 gpm		Qelem = 100 gpm		Qelem = 125 gpm	
	V_{max}-FPS	$\bar{V}$-FPS	V_{max}-FPS	$\bar{V}$-FPS	V_{max}-FPS	$\bar{V}$-FPS	V_{max}-FPS	$\bar{V}$-FPS
A	4.43	*3.66	5.94	*5.05	7.58	*6.56	9.30	*8.15
B	4.20	3.46	5.82	4.95	7.49	6.48	9.10	7.98
C	3.73	3.02	5.49	4.73	7.12	6.12	8.51	7.46
D	3.44	2.74	5.36	4.52	7.00	6.02	8.30	7.22
E	3.16	2.49	5.02	4.21	6.60	5.66	7.80	6.78
F	2.96	2.30	4.77	3.98	6.40	5.49	7.42	6.41
G	2.94	2.29	4.54	3.78	6.18	5.28	7.18	6.20
H	2.83	2.20	4.15	3.41	5.60	4.74	6.48	5.56
I	2.86	2.22	3.96	3.22	5.40	4.56	6.18	5.28
J	2.72	⊛2.10	3.83	⊛3.11	5.15	⊛4.32	6.05	⊛5.15
K	2.90	2.26	4.01	3.29	5.29	4.45	6.28	5.38
L	3.10	2.44	4.19	3.43	5.43	4.60	6.63	5.70
M	3.20	2.53	4.28	3.51	5.45	4.61	6.82	5.87
N	3.73	3.02	4.83	4.04	6.18	5.28	7.95	6.90
O	3.94	3.22	5.20	4.38	6.76	5.81	8.97	7.82
P	3.99	3.26	5.49	4.64	7.10	6.12	9.52	8.35
Q	3.94	3.22	5.60	4.75	7.24	6.25	9.45	8.29
Avg.		2.73		4.05		5.43		6.74
* +% of Avg.		34		24.3		21		23.9
⊛ -% of Avg.		23.1		23.4		20.5		23.6

TABLE 4-4
SM-1 STATIONARY FUEL ELEMENT FLOW DISTRIBUTION
1.19" ORIFICE AT INLET
PERFORATED BAFFLE PLATE LOCATED IN ENTRANCE END BOX

Channel	Qnom. = 50 gpm		Qnom. = 75 gpm		Qnom. = 100 gpm		Qnom. = 125 GPM	
	V_{max}-FPS	$\bar{V}$-FPS	V_{max}-FPS	$\bar{V}$-FPS	V_{max}-FPS	$\bar{V}$-FPS	V_{max}-FPS	$\bar{V}$-FPS
A	3.35	2.67	4.90	4.10	4.74	⊛3.95	5.53	⊛4.70
B	3.88	3.16	5.72	4.86	5.56	4.71	6.46	5.54
C	3.88	3.16	5.75	4.89	6.28	5.37	7.36	6.37
D	3.76	3.05	5.51	4.66	6.95	5.99	8.35	7.27
E	3.38	2.70	4.90	4.10	6.78	5.82	8.16	7.09
F	3.04	2.39	4.36	3.61	6.10	5.20	7.36	6.37
G	2.79	2.16	3.94	3.21	5.78	4.92	7.20	6.21
H	2.45	⊛1.85	3.38	2.70	5.54	4.70	7.01	6.04
I	2.49	1.88	3.20	⊛2.53	5.53	4.69	7.10	6.11
J	2.37	1.77	3.29	2.61	5.60	4.75	7.12	6.12
K	2.68	2.04	3.89	3.17	6.45	5.53	8.02	6.98
L	3.47	2.78	9.52	3.75	7.75	6.72	9.56	8.39
M	3.17	2.51	4.70	3.91	7.77	6.75	9.57	8.40
N	3.84	3.13	5.66	4.80	8.02	*6.99	9.80	*8.61
O	4.06	*3.33	6.03	*5.15	7.24	6.26	8.74	7.62
P	3.89	3.17	5.92	5.04	6.01	5.12	7.20	6.21
Q	3.47	2.78	5.11	4.30	5.47	4.62	6.49	5.56
Avg.		2.62		3.96		5.42		6.68
* +% Avg.		21		30.1		29		28.9
⊛ -% Avg.		29.4		36.2		27.2		29.7

The results of testing with the perforated plate are also tabulated below and plotted in Fig. 4-19. A reading of pressure drop was not obtained at 125 gpm because the signal was greater than the range of the instrument. A comparison of the results from this test with the results obtained from testing with the 1.19 in. orifice shows that this plate adds slightly to the total drop across the orifice and element. However, at the low flow rate prescribed for this element, no significant increase in pressure drop is noted. Only at higher flow rates was the increase noted.

TABLE 4-5
SM-1 STATIONARY ELEMENT PRESSURE DROP

	1	2	3	4
Element Flow Rate, gpm	Element Pressure Drop - Ft H_2O No Orifice	Element ΔP with 1.19" Orifice Incl. Ft H_2O	Element ΔP with 1.19" Orifice & Diffuser Cone Incl. Ft H_2O	Element ΔP with 1.19" Orifice & Perforated Plate Incl. Ft H_2O
50	1.14	8.18	6.18	8.13
75	2.31	17.95	13.29	18.81
100	3.91	31.76	23.35	33.30
125	5.95	48.64	37.64	*53.30

* Extrapolated from Curve.

4.7.2 SM-1A Stationary Fuel Element Flow Tests

The Type 3 stationary element for SM-1A was tested with one orifice selection: the minimum orifice - 1.68 in. diam (element position #22). The orifice location for this test was at the element outlet (corresponding to the top of the core support structure). The minimum orifice was chosen since it has the greatest adverse effect on flow distribution. The position of this element in the core is shown in Fig. 4-20.

4.7.2.1 Test with Minimum Orifice

Results of this test at nominal element flow rates of 50, 75, 100 and 125 gpm are plotted in Fig. 4-21. At the prescribed flow rate of 127 gpm (see Fig. 4-20) the maximum deviation from average channel velocity was +6.1% and -6.7% in channels D and A respectively. A complete tabulation of this data is given in Table 4-6.

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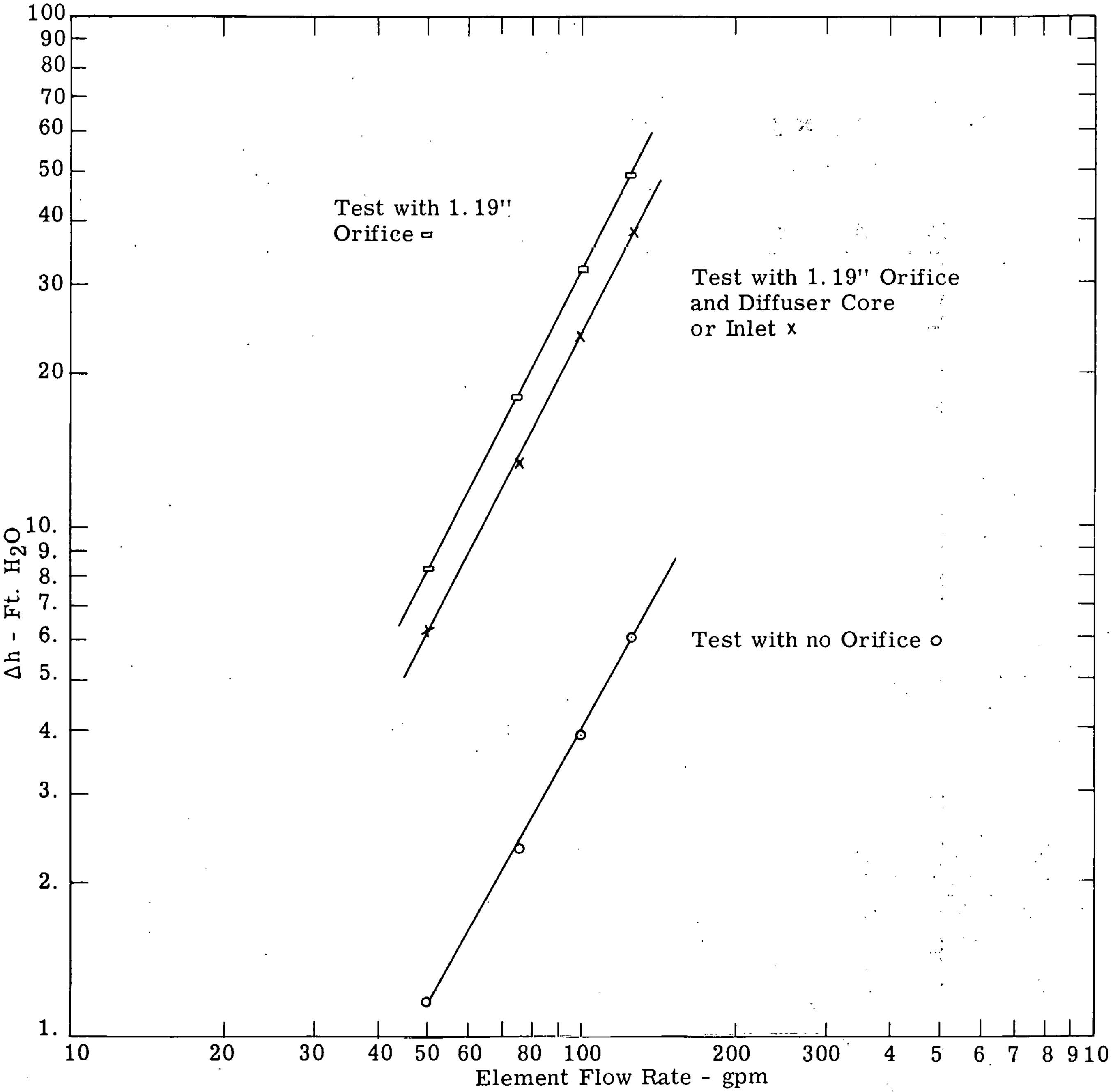


Fig. 4-18 - SM-1 Stationary Fuel Element Pressure Drop - Ft H_2O Vs Element Flow Rate - gpm

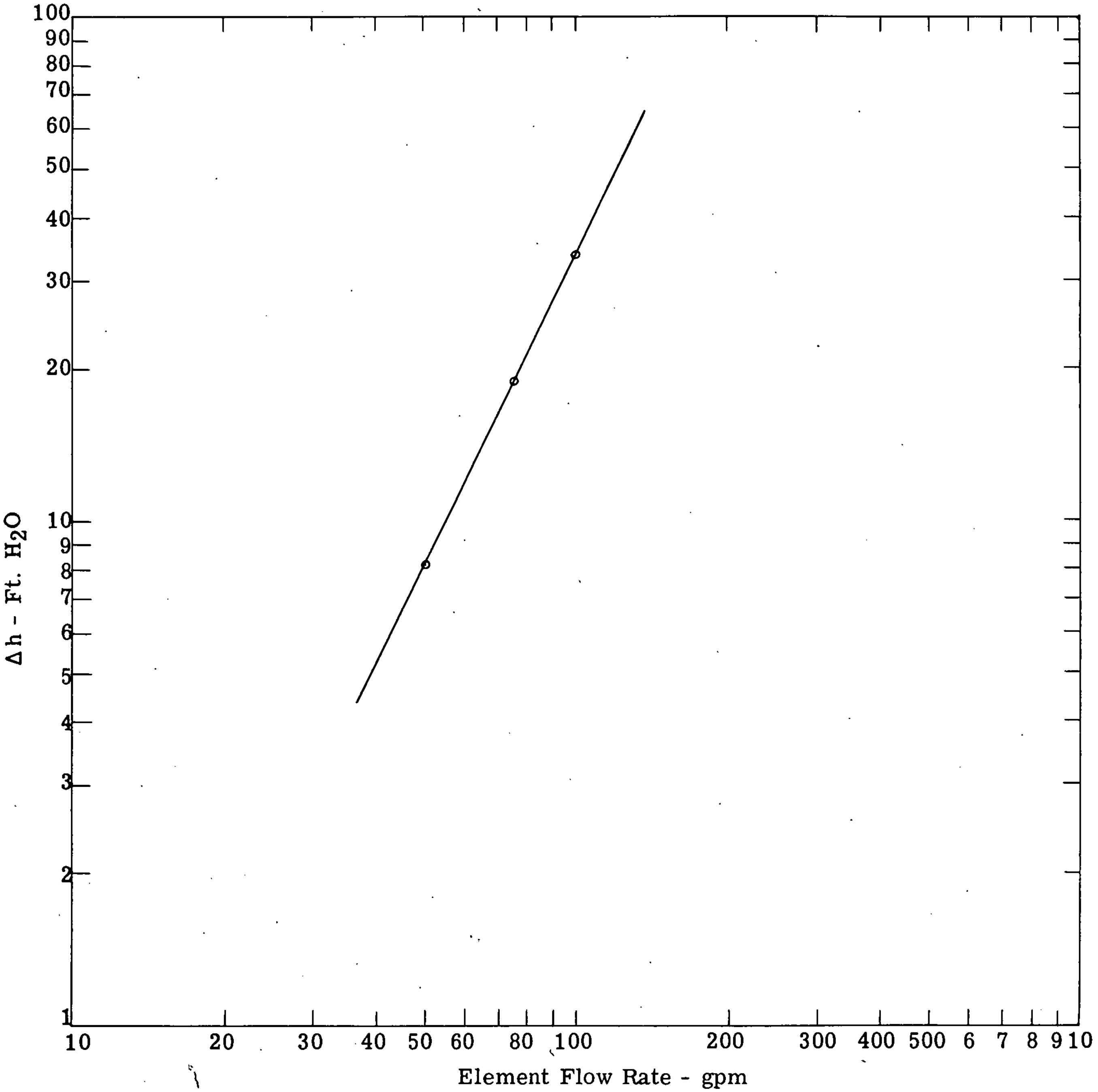
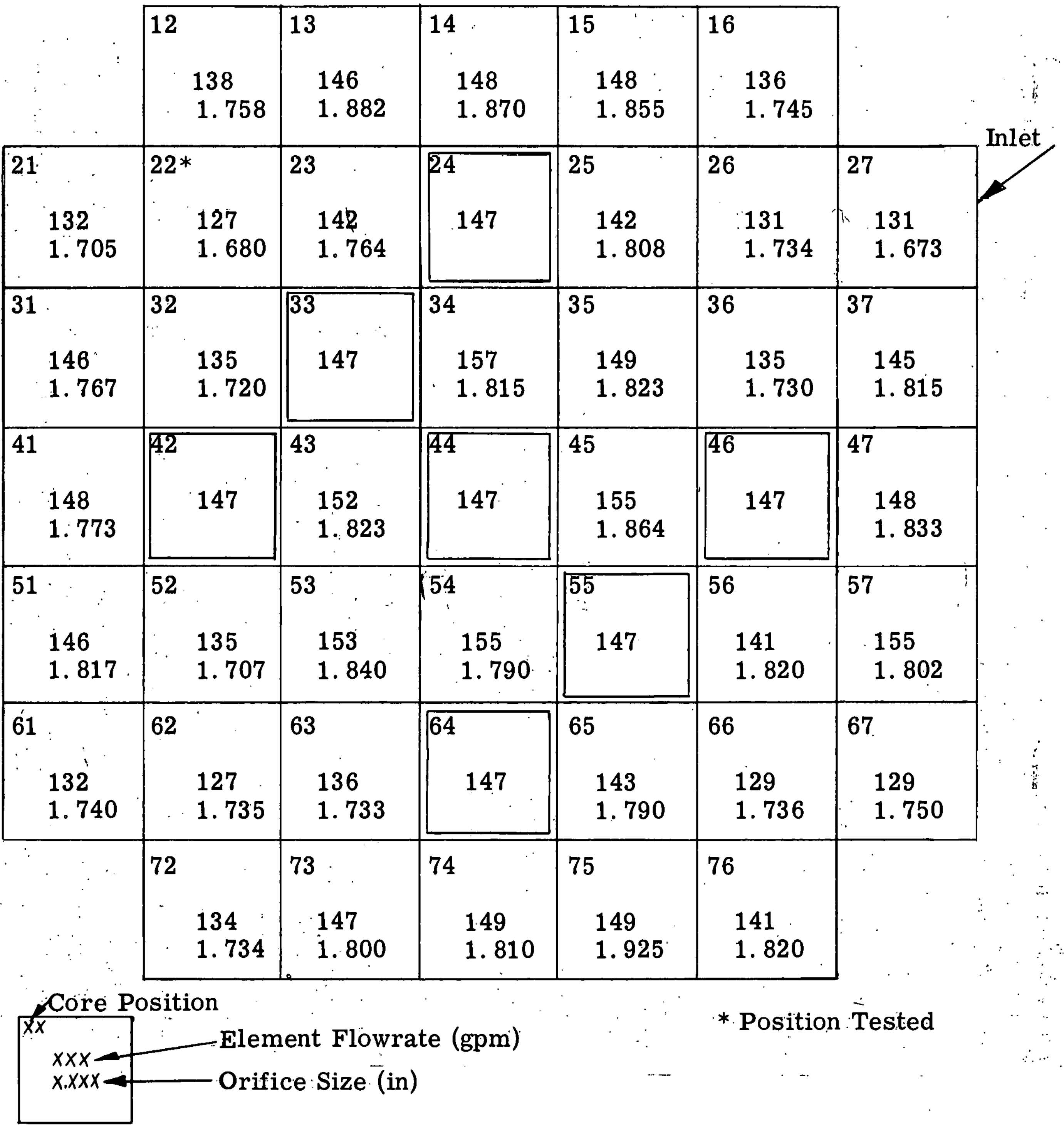


Fig. 4-19 - SM-1 Stationary Fuel Element (with Orifice and Perforated Plate at Inlet) Pressure Drop - Ft H_2O Vs Element Flow Rate-gpm



	12 138 1.758	13 146 1.882	14 148 1.870	15 148 1.855	16 136 1.745	
21 132 1.705	22* 127 1.680	23 142 1.764	24 147	25 142 1.808	26 131 1.734	27 131 1.673
31 146 1.767	32 135 1.720	33 147	34 157 1.815	35 149 1.823	36 135 1.730	37 145 1.815
41 148 1.773	42 147	43 152 1.823	44 147	45 155 1.864	46 147	47 148 1.833
51 146 1.817	52 135 1.707	53 153 1.840	54 155 1.790	55 147	56 141 1.820	57 155 1.802
61 132 1.740	62 127 1.735	63 136 1.733	64 147	65 143 1.790	66 129 1.736	67 129 1.750
	72 134 1.734	73 147 1.800	74 149 1.810	75 149 1.925	76 141 1.820	

* Position Tested

Fig. 4-20 - SM-1A Core Flow Distribution and Orifice Size

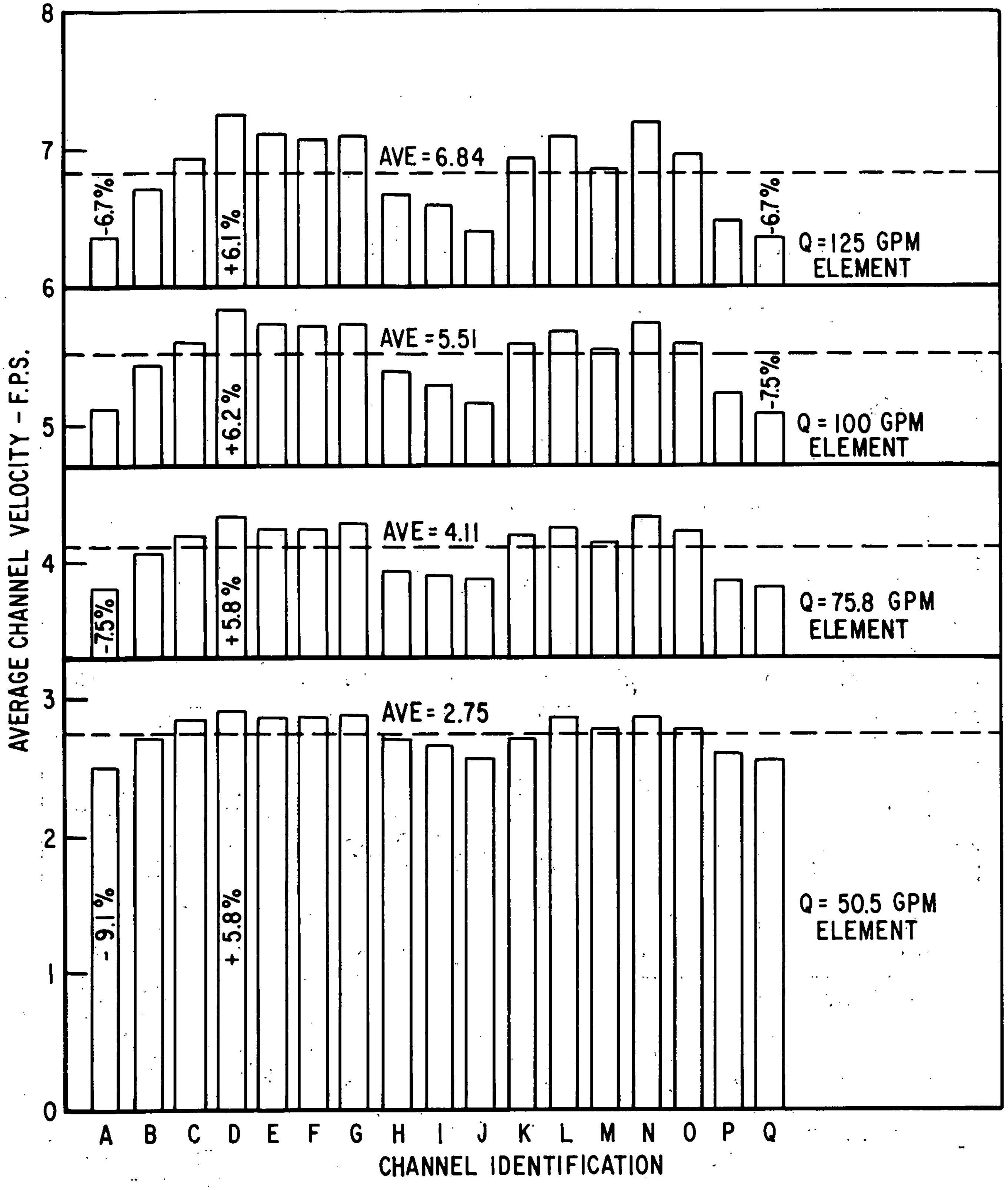


Fig. 4-21 - SM-1A Stationary Element Flow Distribution - 1.68" Orifice Located at Exit

TABLE 4-6
SM-1A STATIONARY ELEMENT FLOW DISTRIBUTION
1.68 In. Orifice at Exit

Channel	Q_{nom} 50.5 gpm		Q_{nom} 75.8 gpm		Q_{nom} 100 gpm		Q_{nom} 125	
	V_{max}-FPS	$\overline{V}$-FPS	V_{max}-FPS	$\overline{V}$-FPS	V_{max}-FPS	$\overline{V}$-FPS	V_{max}-FPS	$\overline{V}$-FPS
A	3.17	2.50⊛	4.58	3.80⊛	6.00	5.12	7.39	6.38⊛
B	3.41	2.72	4.88	4.08	6.36	5.45	7.75	6.72
C	3.53	2.85	5.00	4.20	6.60	5.66	8.00	6.95
D	3.61	2.91*	5.19	4.35*	6.80	5.85*	8.35	7.26*
E	3.56	2.88	5.09	4.27	6.69	5.74	8.20	7.12
F	3.56	2.88	5.09	4.27	6.68	5.73	8.15	7.08
G	3.59	2.89	5.11	4.30	6.69	5.74	8.18	7.10
H	3.41	2.72	4.83	3.94	6.30	5.40	7.70	6.68
I	3.35	2.67	4.81	3.91	6.20	5.30	7.63	6.60
J	3.23	2.57	4.67	3.89	6.07	5.17	7.40	6.40
K	3.41	2.72	5.01	4.21	6.51	5.60	8.00	6.95
L	3.56	2.88	5.09	4.27	6.64	5.70	8.16	7.09
M	3.47	2.79	4.96	4.15	6.48	5.56	7.91	6.87
N	3.56	2.88	5.15	4.34	6.70	5.75	8.28	7.20
O	3.47	2.79	5.05	4.25	6.51	5.60	8.02	6.98
P	3.29	2.61	4.77	3.88	6.15	5.25	7.51	6.50
Q	3.23	2.57	4.62	3.84	5.99	5.10⊛	7.37	6.38⊛
Avg $\overline{V}$		2.75		4.11		5.51		6.84
* +% of Avg	5.8		5.8		6.2		6.1	
⊛ -% of Avg	9.1		7.5		7.5		6.7	

4.7.2.2 Test With Minimum Orifice with Element Locating Pin Removed

When testing both the SM-1 with maximum (2.02 in. diam) orifice, and the SM-1A with minimum orifice, a definite dip in flow through the center channels was noted. A profile such as this was entirely unexpected since results of MTR(3) and ETR(4) testing with similar end boxes show a profile peaking at element center. Since the only object obstructing flow was the 1/4 in. diam locating pin located approximately 3-1/2 in. from the fuel plates, this pin was removed. The effect of the removal of this pin can be seen by comparing Fig. 4-21 and Fig. 4-22. The center channels are now above average while flow in the outer channels has dropped off considerably. In fact, flow maldistribution has increased to +12% and -13.7% in channels G and A respectively at the prescribed element flow rate of 127 gpm. Some irregularity was still noted in the center channels. A tabulation of this data is presented in Table 4-7.

4.7.2.3 Pressure Drop Test of SM-1A Stationary Element

Overall stationary element pressure drop (no Δh across orifice) at flow rates of 50, 75, 100 and 125 gpm is tabulated below. These pressure drops are identical to those obtained in testing of the SM-1 stationary element since the two elements are identical and no orifice pressure drop was included.

4.7.3 PM-2A Stationary Fuel Element Flow Test

The PM-2A stationary fuel element differed from the SM-1 and SM-1A fuel element in one respect; it had a different exit end box which reduced the overall element length by 2 in. The orifice plate for this element is located at the element exit (corresponding to top of core support structure).

Once again, the smallest orifice -1.83 in. diam - was selected for test purposes since this orifice has the greatest adverse effect on flow distribution. The position of this element (element #22) within the core, together with the required element flow rate, is shown in Fig. 4-23.

Flow distribution results at nominal element flow rates of 50, 75, 100 and 125 gpm are plotted in Fig. 4-24. At the test flow rate nearest the required element flow rate of 113 gpm, flow maldistribution is +6.2% and -11.1% of average channel velocity in channels D and Q respectively. The data is tabulated in Table 4-9.

4.7.3.1 Pressure Drop Test of PM-2A Stationary Element

Overall stationary element pressure drop (across element assembly only) was obtained with the instrument rake and orifice plate removed. Data was obtained at flow rate of 50, 75, 100 and 125 gpm. This data is tabulated in Fig. 4-10 and plotted in Fig. 4-25.

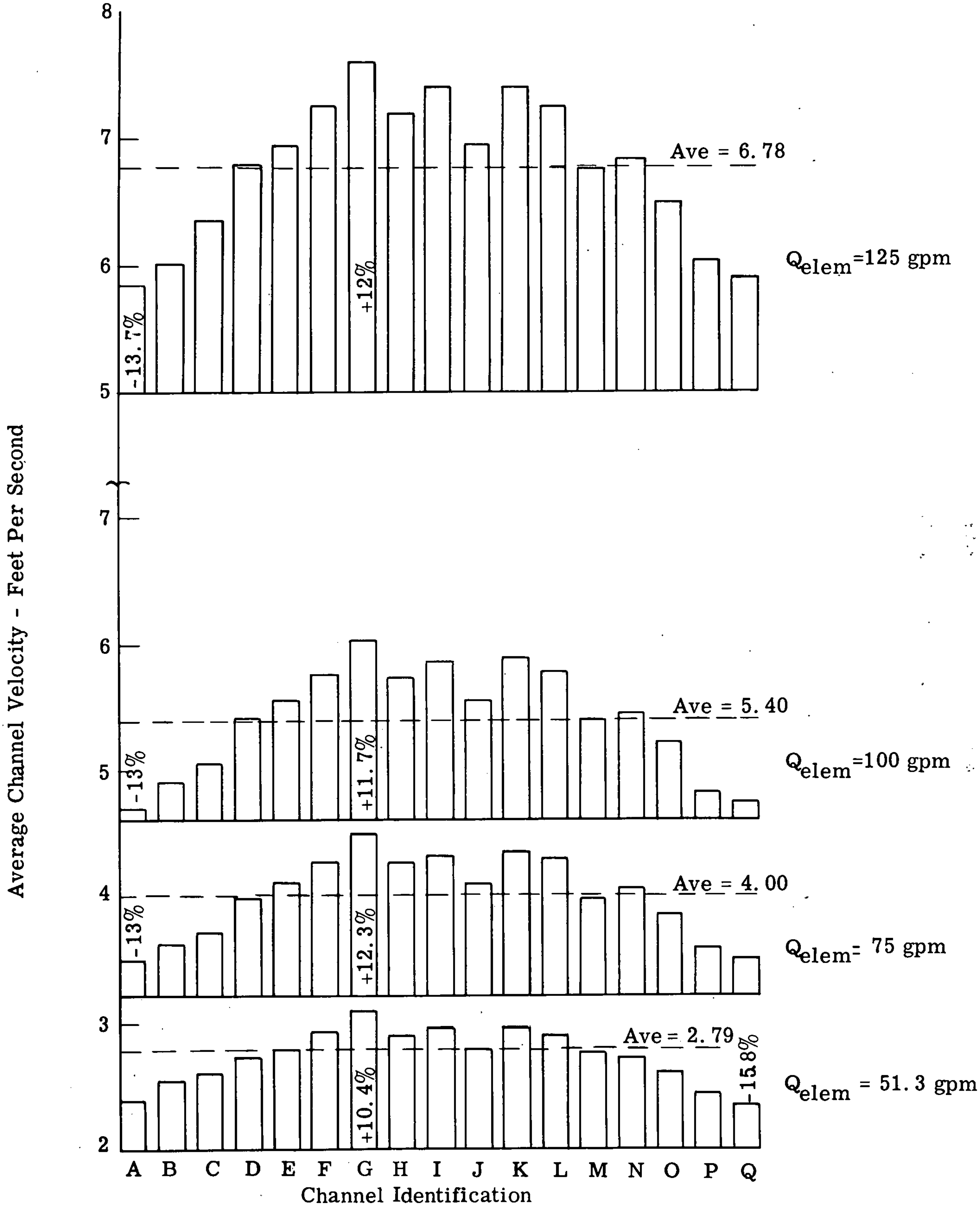


Fig. 4-22 - SM-1A Stationary Element Flow Distribution 1.68" Orifice Located at Exit - Locating Pin Removed

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TABLE 4-7
SM-1A STATIONARY ELEMENT FLOW DISTRIBUTION
1.68 In. Orifice at Exit
No Locating Pin in Inlet End Box

Channel	Q_{elem} = 51.3 gpm		Q_{elem} = 75.0 gpm		Q_{elem} = 100 gpm		Q_{elem} = 125 gpm	
	V_{max}-FPS	$\overline{V}$-FPS	V_{max}-FPS	$\overline{V}$-FPS	V_{max}-FPS	$\overline{V}$-FPS	V_{max}-FPS	$\overline{V}$-FPS
A	3.04	2.39	4.21	3.48 ⊛	5.55	4.70 ⊛	6.80	5.85 ⊛
B	3.20	2.53	4.38	3.62	5.75	4.89	7.10	6.11
C	3.26	2.58	4.49	3.71	5.94	5.06	7.34	6.35
D	3.41	2.72	4.79	3.99	6.32	5.42	7.84	6.80
E	3.47	2.78	4.90	4.10	6.47	5.55	8.00	6.95
F	3.62	2.92	5.08	4.27	6.71	5.77	8.35	7.27
G	3.78	3.08*	5.31	4.49*	7.00	6.03*	8.70	7.60*
H	3.59	2.89	5.04	4.24	6.67	5.73	8.28	7.20
I	3.65	2.95	5.14	4.32	6.81	5.86	8.49	7.40
J	3.47	2.78	4.90	4.10	6.48	5.56	8.01	6.96
K	3.65	2.95	5.15	4.34	6.84	5.89	8.50	7.42
L	3.59	2.89	5.10	4.29	6.72	5.78	8.34	7.26
M	3.45	2.77	4.77	3.98	6.30	5.40	7.79	6.76
N	3.41	2.72	4.85	4.06	6.35	5.45	7.89	6.84
O	3.29	2.61	4.65	3.86	6.12	5.22	7.51	6.50
P	3.10	2.44	4.33	3.59	5.69	4.82	7.00	6.03
Q	3.00	2.35 ⊛	4.26	3.51	5.59	4.73	6.88	5.91
Avg.	3.41	2.79	4.79	4.00	6.31	5.40	7.80	6.78
* +% of Avg	10.4		12.3		11.7		12.0	
⊛ -% of Avg	15.8		13.0		13.0		13.7	

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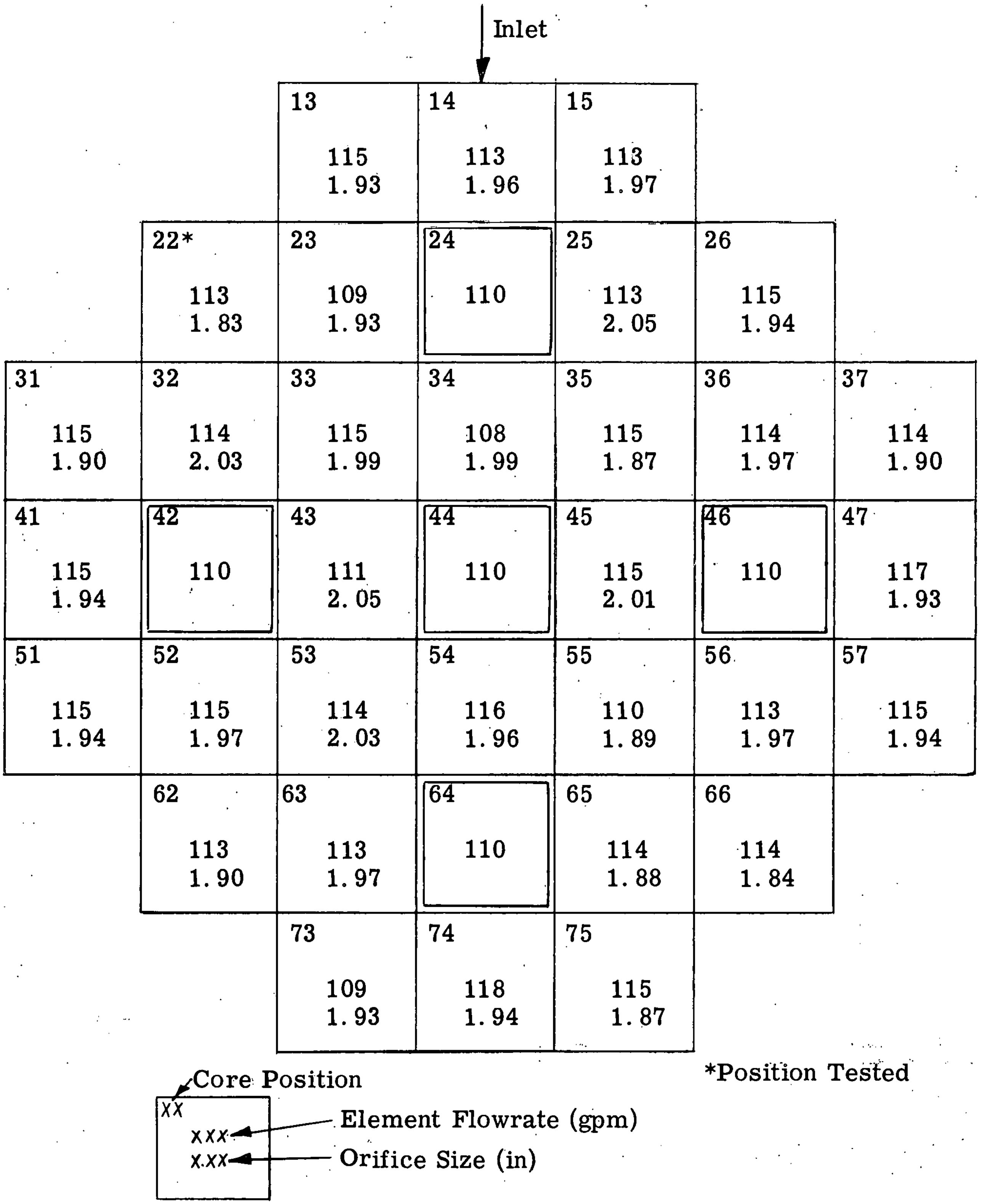

		13 115 1.93	14 113 1.96	15 113 1.97		
	22* 113 1.83	23 109 1.93	24 110	25 113 2.05	26 115 1.94	
31 115 1.90	32 114 2.03	33 115 1.99	34 108 1.99	35 115 1.87	36 114 1.97	37 114 1.90
41 115 1.94	42 110	43 111 2.05	44 110	45 115 2.01	46 110	47 117 1.93
51 115 1.94	52 115 1.97	53 114 2.03	54 116 1.96	55 110 1.89	56 113 1.97	57 115 1.94
	62 113 1.90	63 113 1.97	64 110	65 114 1.88	66 114 1.84	
		73 109 1.93	74 118 1.94	75 115 1.87		

Fig. 4-23 - PM-2A Core Flow Distribution and Orifice Size

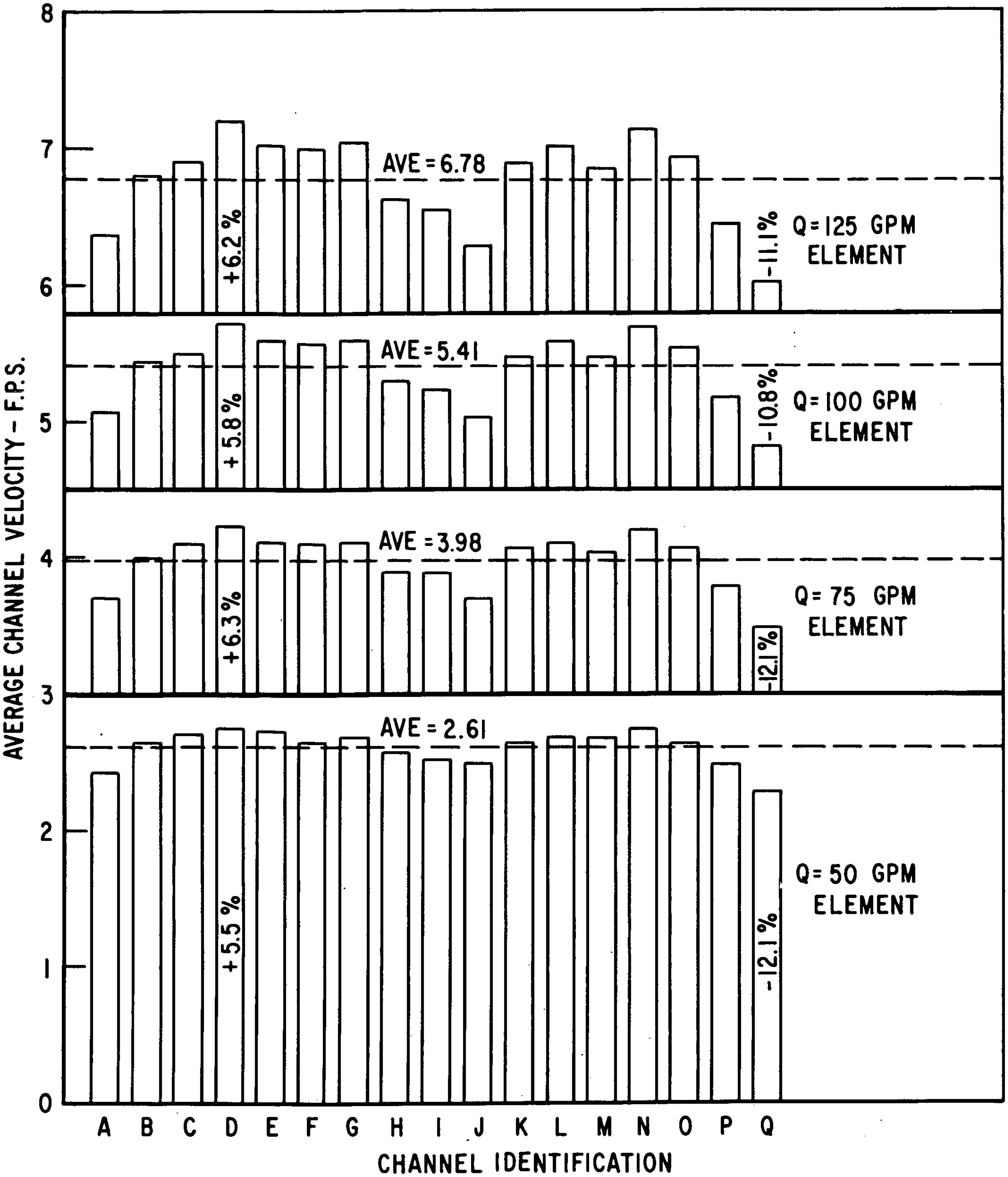

Fig. 4-24 - PM-2A Stationary Element Flow Distribution - 1. 83" Orifice Located at Exit

TABLE 4-8
SM-1A STATIONARY ELEMENT PRESSURE DROP

Flow Rate gpm	Overall Pressure Drop Ft H_2O
50	1.14
75	2.31
100	3.91
125	5.95

4.8 CHECKS OF MEASUREMENTS

The following is a sample calculation of those made at each flow rate to obtain a check on velocity measurements given in Section 4.7. Since all loop flow passed through the stationary element, loop flow equals element flow. Any difference would be due to leakage past the element or to slight measurement error.

SM-1A Stationary Element (1.68 In. Orifice) - at 125 gpm loop flow

Average channel velocity = 6.84 fps

Flow Area = 40.386×10^{-3} ft^2

$$\text{Flow} = 6.84 \times 40.386 \times 10^{-3} = 276.24 \times 10^{-3} \text{ cfs}$$

$$= \frac{276.24 \times 10^{-3}}{2.228 \times 10^{-3}} = 123.98 = 124 \text{ gpm}$$

This calculation indicates that at 125 gpm element flow, only 1 gpm is lost due to leakage or possible instrument error and that data would be consistent. Thus it can be assumed that the velocities reported are valid.

TABLE 4-9
PM-2A STATIONARY FUEL ELEMENT FLOW DISTRIBUTION
1. 83 In. Orifice at Exit

Channel	Q = 50 gpm		Q = 75 gpm		Q = 100 gpm		Q = 125 gpm	
	V_{max}-FPS	$\bar{V}$-FPS	V_{max}-FPS	$\bar{V}$-FPS	V_{max}-FPS	$\bar{V}$-FPS	V_{max}-FPS	$\bar{V}$-FPS
A	3. 07	2. 42	4. 49	3. 71	5. 96	5. 07	7. 38	6. 38
B	3. 32	2. 64	4. 79	3. 99	6. 33	5. 44	7. 84	6. 80
C	3. 38	2. 70	4. 90	4. 10	6. 42	5. 50	7. 97	6. 91
D	3. 44	2. 75 *	5. 03	4. 23*	6. 67	5. 72*	8. 29	7. 20*
E	3. 41	2. 72	4. 91	4. 11	6. 52	5. 60	8. 09	7. 02
F	3. 32	2. 64	4. 90	4. 10	6. 50	5. 58	8. 05	7. 00
G	3. 36	2. 68	4. 91	4. 11	6. 52	5. 60	8. 10	7. 04
H	3. 23	2. 57	4. 69	3. 90	6. 20	5. 30	7. 65	6. 63
I	3. 20	2. 52	4. 67	3. 89	6. 14	5. 24	7. 58	6. 56
J	3. 13	2. 49	4. 49	3. 71	5. 92	5. 03	7. 30	6. 30
K	3. 32	2. 64	4. 88	4. 08	6. 40	5. 49	7. 96	6. 90
L	3. 36	2. 68	4. 91	4. 11	6. 52	5. 60	8. 09	7. 02
M	3. 36	2. 68	4. 83	4. 04	6. 39	5. 48	7. 92	6. 87
N	3. 44	2. 75*	5. 02	4. 21	6. 64	5. 70	8. 24	7. 15
O	3. 32	2. 64	4. 88	4. 08	6. 48	5. 55	8. 00	6. 95
P	3. 13	2. 49	4. 58	3. 80	6. 09	5. 19	7. 48	6. 47
Q	2. 94	2. 29 ⊛	4. 24	3. 50 ⊛	5. 67	4. 82 ⊛	7. 01	6. 03 ⊛
Avg.		2. 61		3. 98		5. 41		6. 78
* +% of Avg	5. 5		6. 3		5. 8		6. 2	
⊛ -% of Avg	12. 1		12. 1		10. 8		11. 1	

TABLE 4-10
PM-2A STATIONARY ELEMENT PRESSURE DROP

Flow Rate gpm	Overall Element Pressure Drop Ft H_2O
50	0.929
75	1.990
100	3.435
125	5.210

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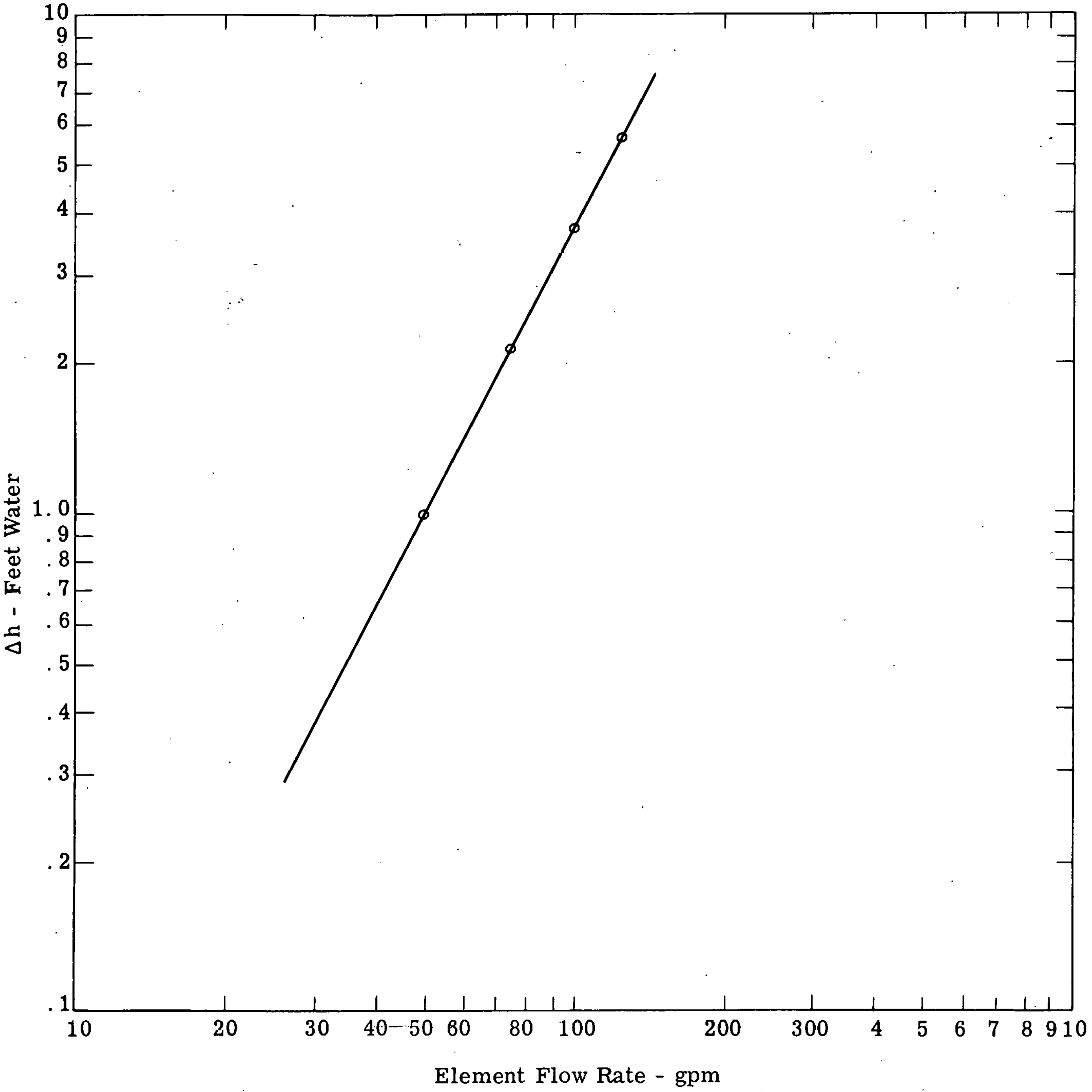

Fig. 4-25 - PM-2A Stationary Fuel Element Pressure Drop (Ft. H_2O) Vs Element Flow Rate (gpm)

5.0 CONTROL ROD ASSEMBLY TEST

5.1 PURPOSE OF TESTS

The purpose of this test was to determine channel-to-channel flow distribution within a Type 3 (SM-2) control rod fuel element installed in SM-1, SM-1A and PM-2A control rod assemblies.

5.2 DESCRIPTION OF TEST RIG AND INSTRUMENTATION

The test rig used for control rod testing was identical to the rig used in stationary element testing with the exception of an extension piece added to house the additional length of the control rod assembly. The test rig is shown in Fig. 5-1 and 5-2.

The control rod fuel element was instrumented in the same manner as the stationary fuel element (Sec. 4.2.1). Instrument lines were connected to a penetrated ring and out to manometers. Loop flow was again measured by a standard orifice installation connected to a mercury monometer for accurate measurement. Since all loop flow passed through the control rod, loop flow is equivalent to element flow.

5.3 DESCRIPTION OF TEST SPECIMEN

The control rod fuel element was a standard Type 3 (fully welded) element fabricated by the Alco Welding Laboratory. The instrumented element control rod fuel element is shown in Fig. 5-3. Complete channel measurements are presented in Table 3-2. This element was fabricated to Type 3 Specifications in accordance with production drawings made for Task 3.3 of the PWR Support and Development Program.

The control rod assembly consisted of the following components: absorber, fuel element, and tube and piston section. Absorbers and tubes were production units previously utilized in testing of SM-1 and SM-1A and PM-2A cores. No control rod cap was used since this item was not available to the program and proved to be too expensive to fabricate. Besides, the chief objective of the test was to determine channel-to-channel flow distribution, which would not be affected by the cap assembly located so far downstream. An exploded view showing the SM-1A control rod components and test section is shown in Fig. 5-4. An assembled view of the same components is shown in Fig. 5-5. This same test specimen was used in PM-2A testing since the only difference between the SM-1A and PM-2A control rod assemblies is the overall length, which would not affect flow distribution in the fuel element located so far downstream of the exit of the assembly.

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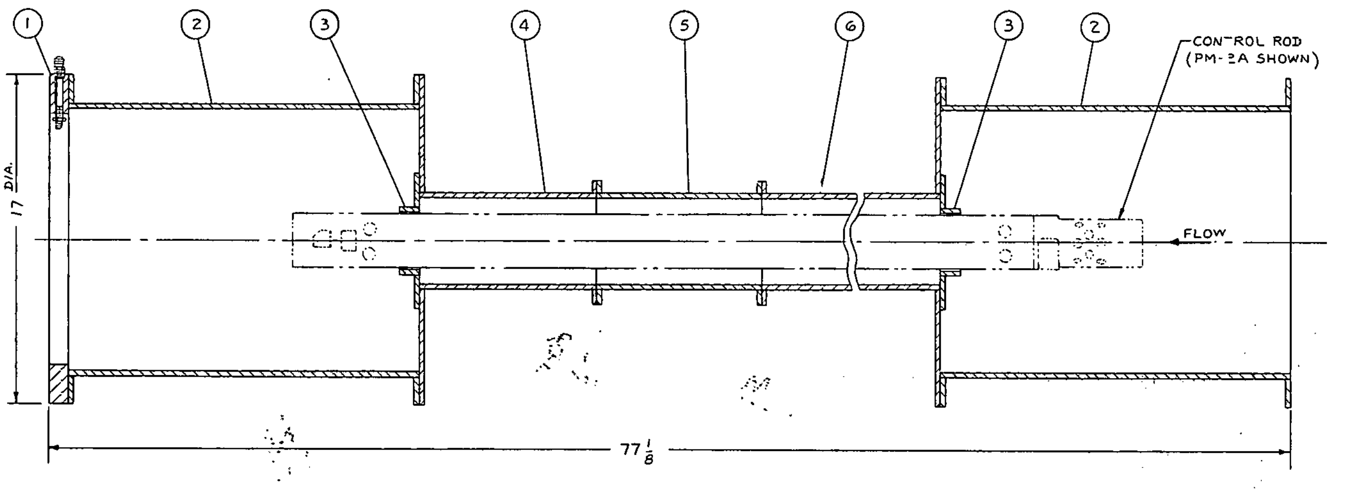

PART NO. C9-50-1279

6	1	SK-1262	TUBE SECT. ASS'Y
5	1	SK-1275	ASS'Y- EXTENSION TUBE SECT.
4	1	SK-1070	PLENUM CHAMBER-CENTER
3	2	SK-1078	SUPPORT FLANGE
2	2	SK-1072	PLENUM CHAMBER
1	1	C9-50-2498	PENETRATION RING
Pc No	QUAN	DWG NO OR MATERIAL	DESCRIPTION

NOTE: "SK" NUMBERS REFER TO MECH. LAB. DRAWING NOS.

BREAK SHARP EDGES
REMOVE ALL BURRS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOLERANCES ON FINISHED
FRACTIONAL DIMENSIONS
TO BE ± ______

√ FINISH AS INDICATED IN MICROINCHES.
(/1) MACHINE FINISH - ROUGH
(/10) FLAME - CUT OR SAW

ALCO

ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPT.
SCHENECTADY, N. Y., U. S. A.

SCALE 1/4 = 1"
REF.
MATERIAL SPEC.

DR.	B. PARKER	9-29-61
TR.		
CHK.		9-29-61
APPR.		9-29-61
APPR.		
MET.		9/29/61

NAME CONTROL ROD TEST SECTION ASSEMBLY

PART NO. **C**9-50-1279

5-3

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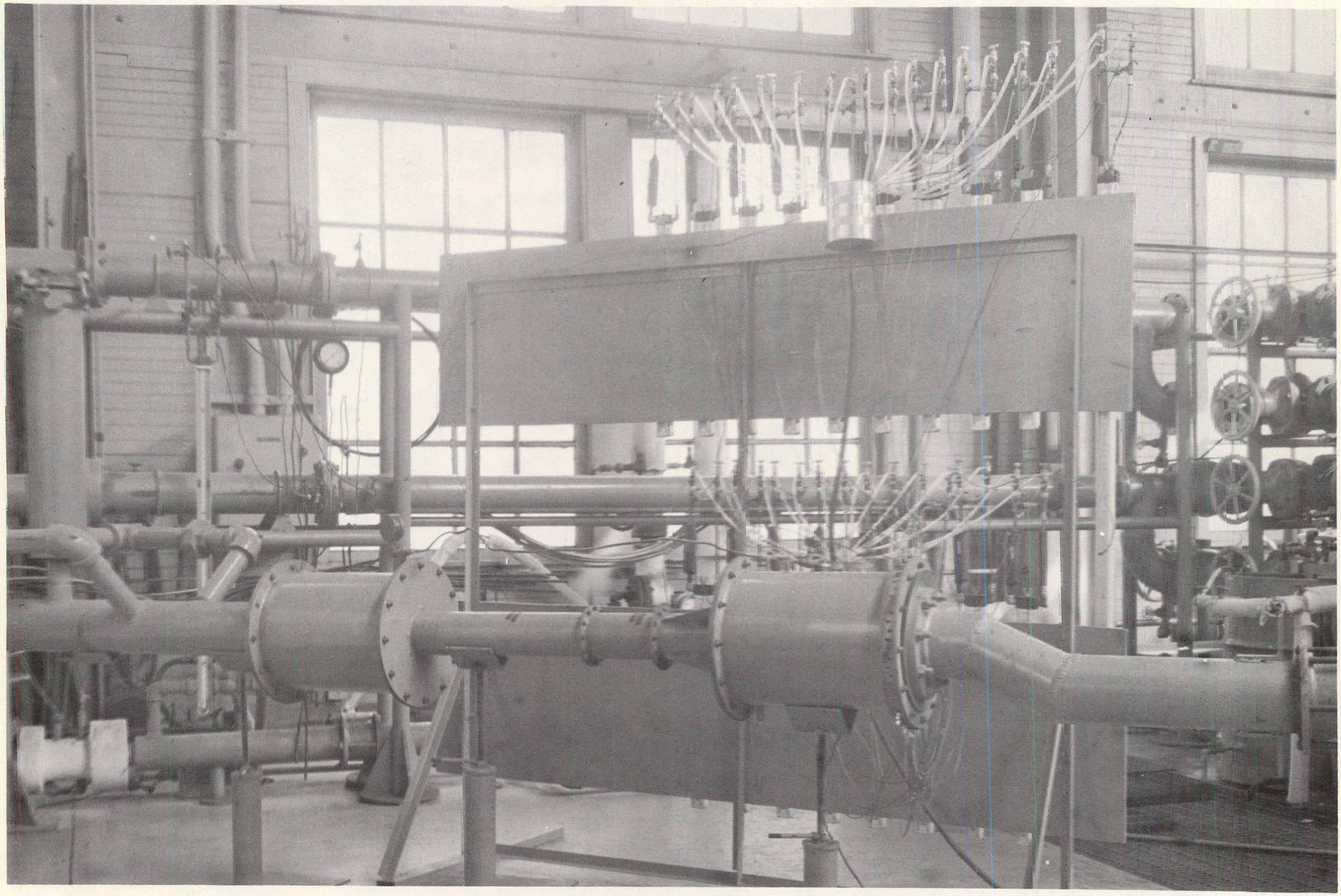

Fig. 5-2 - Control Rod Assembly Test Loop

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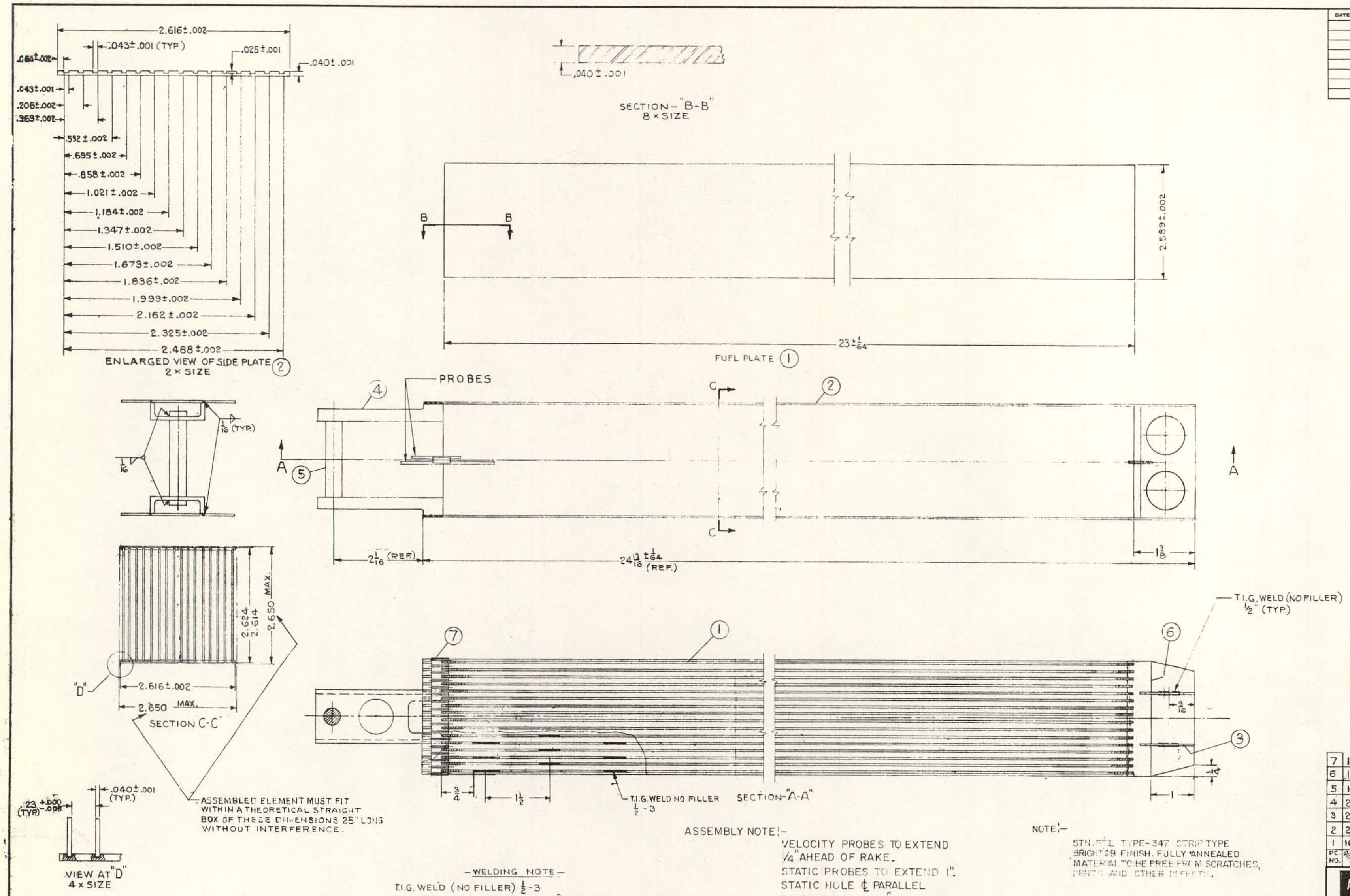

ASSEMBLED ELEMENT MUST FIT WITHIN A THEORETICAL STRAIGHT BOX OF THESE DIMENSIONS 25" LONG WITHOUT INTERFERENCE.

ASSEMBLY NOTE:-

VELOCITY PROBES TO EXTEND 1/4" AHEAD OF RAKE.
STATIC PROBES TO EXTEND 1".
STATIC HOLE ℄ PARALLEL TO PLATES. .031" STATIC I.D.
.065" ANNEALED STN. STL. TUBING TO BE USED FOR BOTH VELOCITY AND STATIC PROBES.
PROBES TO BE ASSEMBLED TO RAKE BEFORE MAIN ASSEMBLY.

-WELDING NOTE-

T.I.G. WELD (NO FILLER) 1/2 -3
ODD NUMBER PLATES — START 3/4 FROM HANDLE END.
EVEN NUMBER PLATES — START 2 1/4 FROM HANDLE END.

-OTHER SIDE OF ELEMENT-

EVEN NUMBER PLATES — START 3/4 FROM HANDLE END
ODD NUMBER PLATES — START 2 1/4 FROM HANDLE END

NOTE:-

STN. STL. TYPE-347 STRIP TYPE BRIGHT 2B FINISH. FULLY ANNEALED MATERIAL TO BE FREE FROM SCRATCHES, DENTS AND OTHER DEFECTS.

PART NO. D9-50-1269

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON FINISHED FRACTIONAL DIMENSIONS TO BE ± 1/64

√ FINISH AS INDICATED IN MICROINCHES.
(/1) MACHINE FINISH - ROUGH
(/10) FLAME CUT OR SAW

PC. NO.	QUAN.	DRG. NO. OR MATERIAL	DESCRIPTION
7	1	C9-50-2492	INSTRUMENT RAKE
6	1	B9-50-2488	COMB.
5	1	A9-50-2489	PIN - HANDLE
4	2	A9-50-2490	HANDLE
3	2	B9-50-2491	PLATE EXTENSION
2	2		SIDE PLATE
1	16		FUEL PLATE

ALCO
ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPT.
SCHENECTADY, N.Y., U.S.A.

SCALE FULL	REF.	DR.	J.L. Boyd	2/15/61
MATERIAL SPEC.		TR.		
SEE NOTE.		CHK.	Decker	2-27-61
		APPR.	P. Krause	2-28-61
		APPR.	J.L. Snider	6-10-61
		MET.	G. Swidler	2/28/61

NAME SINGLE ELEMENT FLOW TEST TASK 3.4
INSTRUMENTED DUMMY
CONT. ROD FUEL ELEMENT Au 901PE

PART NO. D9-50-1269

5-7

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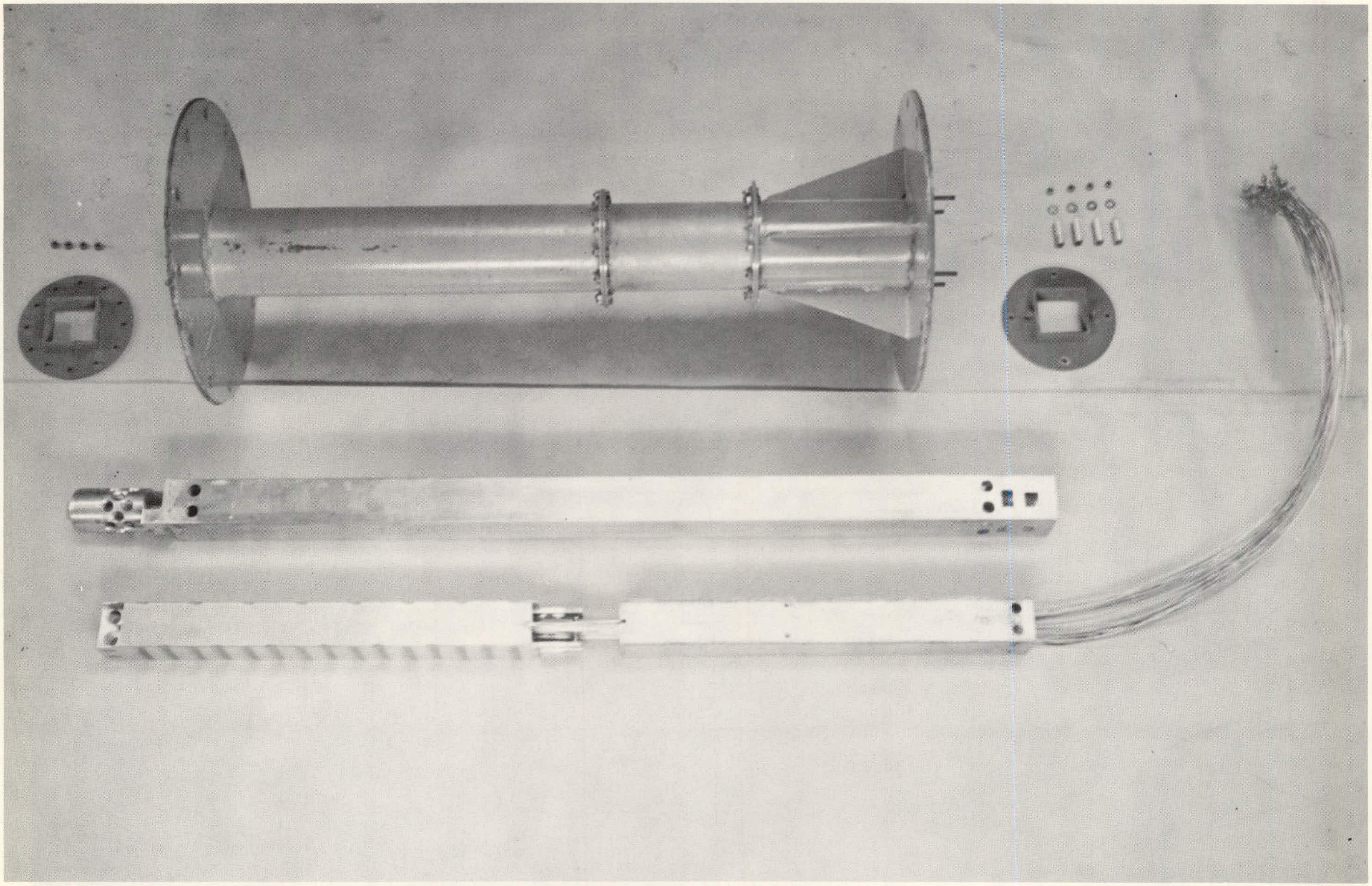

Fig. 5-4 - Control Rod Assembly and Test Section - Exploded View

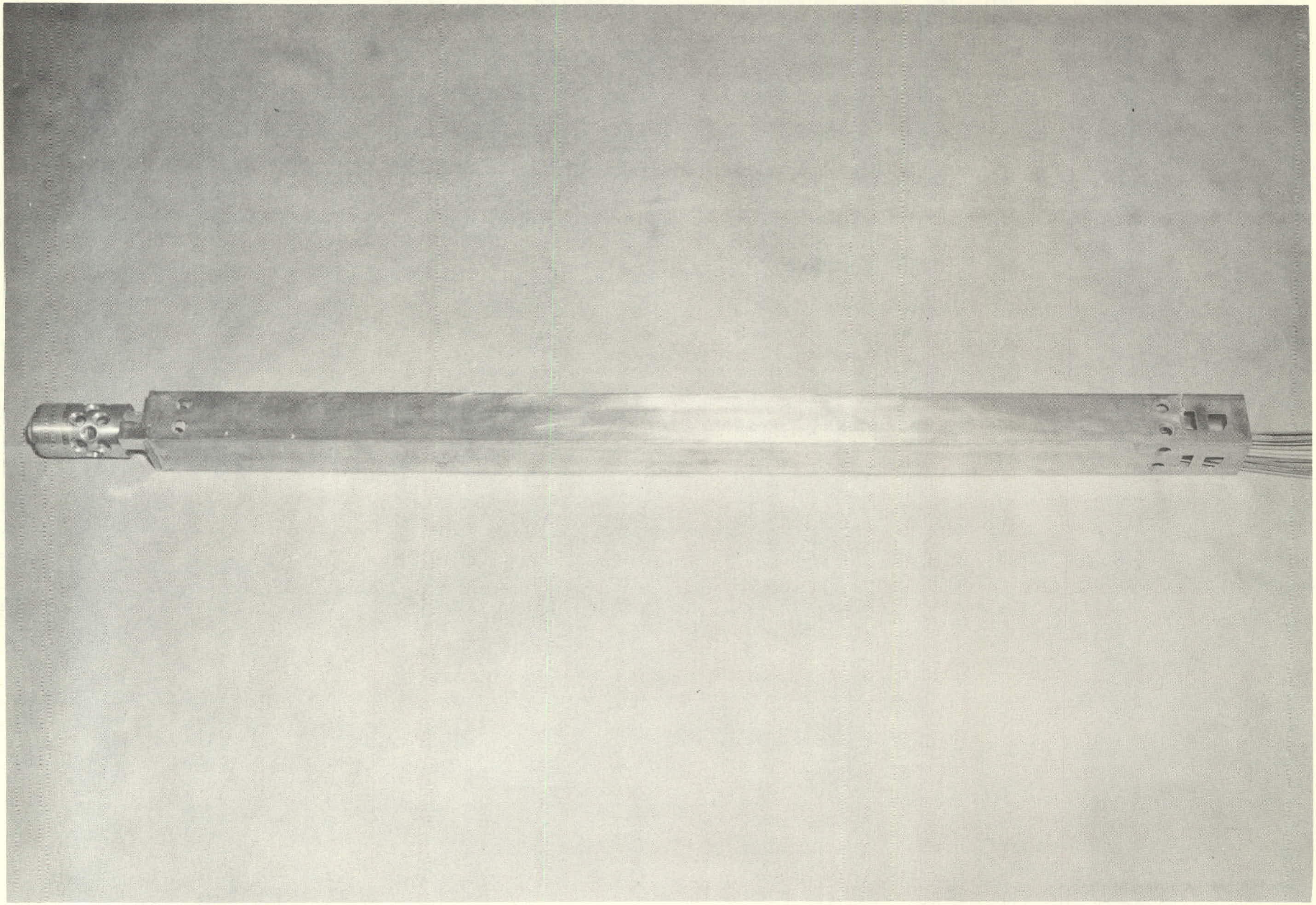

Fig. 5-5 - SM-1A Control Rod Assembly Assembled View

The SM-1 test specimen differed slightly from the SM-1A type in that no flow holes were present at the bottom of the tube, thereby presenting a different entrance flow condition than experienced in the SM-1A, PM-2A test. The fuel element and absorber were inserted and positioned in the tube as centrally as possible. No special attempt was made to control the lattice passages formed by the outer fuel plates and the tube.

5.4 TEST PROCEDURE

Control rod assembly test procedures were identical to those utilized in testing of the stationary element (See Section 4.4). However, no overall assembly pressure drop was obtained because the cap assemblies were not available for these tests. The following data was recorded at each flow rate:

(1) Total loop flow - gpm

(2) Water temperature - ^{o}F

(3) Velocity pressures - in. Blue Fluid (Sp.gr.1.75)

At least two comparable runs were made at each different flow rate to insure reliable results.

5.5 DATA REDUCTION

The method of data reduction used in control rod testing was identical to that discussed in Section 4.5 except that average channel velocity was determined from Fig. 3-7 which is a plot V_{avg} vs. $V_{max.}$ obtained from calibration of the control rod fuel element.

5.6 TEST RESULTS

Test results obtained from the two different control rod assemblies are presented in the following sections.

5.6.1 SM-1 Control Rod Assembly Test

Flow distribution within the Type 3 control rod fuel element for SM-1 at flow rates of 50, 76, 99, and 114 gpm is shown in Fig. 5-6. A complete tabulation of this data is presented in Table 5-1.

Required control rod flow rates are shown in Fig. 4-11. These range from 89.00 to 94.69 gpm. The test flow rate most comparable to the required control rod flow rate is 99 gpm. At this flow rate, average channel velocity-(lattices

TABLE 5-1
SM-1 CONTROL ROD ASSEMBLY FLOW DISTRIBUTION

Channel	Q = 50 gpm		Q = 76 gpm		Q = 99 gpm		Q = 114 gpm	
	V_{max}-FPS	$\bar{V}$-FPS	V_{max}-FPS	$\bar{V}$-FPS	V_{max}-FPS	$\bar{V}$-FPS	V_{max}-FPS	$\bar{V}$-FPS
A (Lattice)	3.10	2.50	4.28	3.51	5.49	4.56	6.24	5.23
B	3.07	2.47	4.17	3.44**	5.34	4.42**	6.08	5.09**
C	3.32	2.69	4.75	3.91	6.16	5.16	7.05	5.95
D	3.53	2.87	5.28	4.39	6.86	5.78	7.86	6.67
E	3.44	2.79	4.98	4.12	6.39	5.36	7.30	6.18
F	4.09	3.34	6.10	5.10	7.93	6.75	9.07	7.82
G	4.30	3.52	6.40	5.37	8.30	7.09	9.50	8.23
H	4.35	3.57	6.59	5.54	8.58	7.36	9.80	8.52
I	4.46	3.66*	6.70	5.64*	8.80	7.56*	10.10	8.82*
J	4.38	3.60	6.59	5.54	8.64	7.40	9.90	8.62
K	4.26	3.50	6.40	5.37	8.39	7.17	9.60	8.32
L	4.11	3.36	6.15	5.15	8.03	6.84	9.20	7.94
M	3.59	2.91	5.18	4.30	6.72	5.66	7.65	6.49
N	3.61	2.93	5.25	4.35	6.80	5.72	7.79	6.61
O	3.44	2.79	4.69	3.86	5.85	4.89	6.63	5.57
P	3.04	2.45**	4.31	3.54	5.53	4.61	6.28	5.26
Q (Lattice)	2.68	2.13 ⊛	3.94	3.22 ⊛	5.19	4.31 ⊛	5.92	4.94 ⊛
Avg. (Inc. Lattice)		3.00		4.49		5.92		6.84
* +% of Avg.		22		25.6		27.7		28.9
⊛ -% of Avg.		29 Latt.		28.3		27.2		27.8
Avg. (No. Lattice)		3.10		4.64		6.12		7.07
* +% of Avg.		18		21.6		23.5		24.8
** -% of Avg.		21		25.9		27.8		28

TABLE 5-2
SM-1A AND PM-2A CONTROL ROD ASSEMBLY FLOW DISTRIBUTION

Channel	Q = 50 gpm		Q = 75 gpm		Q = 100 gpm		Q = 120 gpm	
	V_{max}-FPS	V-FPS	V_{max}-FPS	V-FPS	V_{max}-FPS	V-FPS	V_{max}-FPS	V-FPS
A (Lattice)	3.20	2.59	4.45	3.65	5.74	4.79	6.82	**5.73
B	3.23	⊛2.63	4.55	⊛3.75	5.88	⊛4.91	6.97	⊛5.87
C	3.38	2.74	4.91	4.06	6.48	5.44	7.73	6.56
D	3.84	3.14	5.53	4.60	7.25	6.14	8.69	7.45
E	3.86	3.15	5.56	4.64	7.30	6.18	8.76	7.51
F	4.01	3.29	5.90	4.92	7.74	6.57	9.31	8.04
G	4.12	3.37	5.97	4.98	7.85	6.67	9.49	8.21
H	4.17	3.41	6.05	5.05	8.00	6.81	9.65	8.37
I	4.26	*3.50	6.18	*5.17	8.18	*6.98	9.88	*8.60
J	4.20	3.44	6.15	5.15	8.10	6.91	9.80	8.52
K	4.12	3.37	6.08	5.09	8.00	6.81	9.62	8.35
L	4.12	3.37	6.01	5.02	7.89	6.70	9.50	8.23
M	3.89	3.17	5.69	4.74	7.43	6.29	8.94	7.69
N	3.77	3.07	5.44	4.52	7.14	6.01	8.59	7.36
O	3.59	2.91	5.19	4.30	6.80	5.72	8.10	6.91
P	3.35	2.71	4.83	4.00	6.27	5.25	7.52	6.37
Q (Lattice)	3.10	**2.50	4.43	**3.64	5.74	**4.79	6.90	5.81
Avg.(inc. Lattice)		3.08		4.55		6.06		7.39
* + % of Ave.		13.6		13.6		15.2		16.4
** - % of Ave.		18.8		20.0		21.0		22.5
Avg. (no Lattice)		3.15		4.67		6.23		7.60
* + % of Ave.		11.1		10.7		12.0		13.2
⊛ - % of Ave.		16.5		19.7		21.2		22.8

excluded) was 6.12 fps, with channel I being 23.5% above average and channel B 27.8% below average. If lattices are included, the maximum deviations from average channel velocity (5.92 fps) now appear in lattice Q and channel I with lattice Q being 27.2% below average and channel I 27.7% above average.

Although no particular effort was made to centrally position the fuel element within the tube, the lattices show very good flow symmetry. Because of the limited scope of the program no effort was made to determine the effect of non-central positioning on flow distribution.

5.6.2 SM-1A and PM-2A Control Rod Assembly Test

Channel-to-channel flow distribution for this test is shown in Fig. 5-7 with a complete tabulation of data presented in Table 5-2.

Referring to Fig. 4-20, the required control rod flow rate for the SM-1A is 147 gpm. The test flow rate nearest the required flow rate is 120 gpm. A higher flow rate was not used since channel velocity measurements went beyond the manometer range. At this flow rate, average channel velocity, lattices excluded, was 7.60 fps with channel I being 13.2% above average and channel B 22.8% below average. Maximum deviations from average become ≠16.4% and -22.5% of average channel velocity (7.39 fps) in channels I and Q respectively when lattices are included. The same analysis pertains to the PM-2A since the required control rod flow rate is 114 gpm as shown in Fig. 4-23.

From the data obtained at different flow rates one can see that flow maldistribution increases slightly as flow rate increases. To obtain a maldistribution factor at 147 gpm, a slightly higher factor than reported here would have to be used.

By comparing Fig. 5-7 and 5-8, one can observe the effect of the bottom flow holes present on the SM-1A and PM-2A type assembly. At each flow rate a definite improvement in maldistribution is noted. Velocity peaking in the channels adjacent to the center channel was reduced while flow in the outer channels and lattices increased slightly.

5.7 CHECK OF MEASUREMENTS

The following sample calculation was made at each flow rate to obtain a check on velocity measurements given in the preceding Section 5.6. The sum of the flow through the control rod fuel element and the active lattices (formed by the outer fuel plates and control rod tube) should approximately equal the total loop flow.

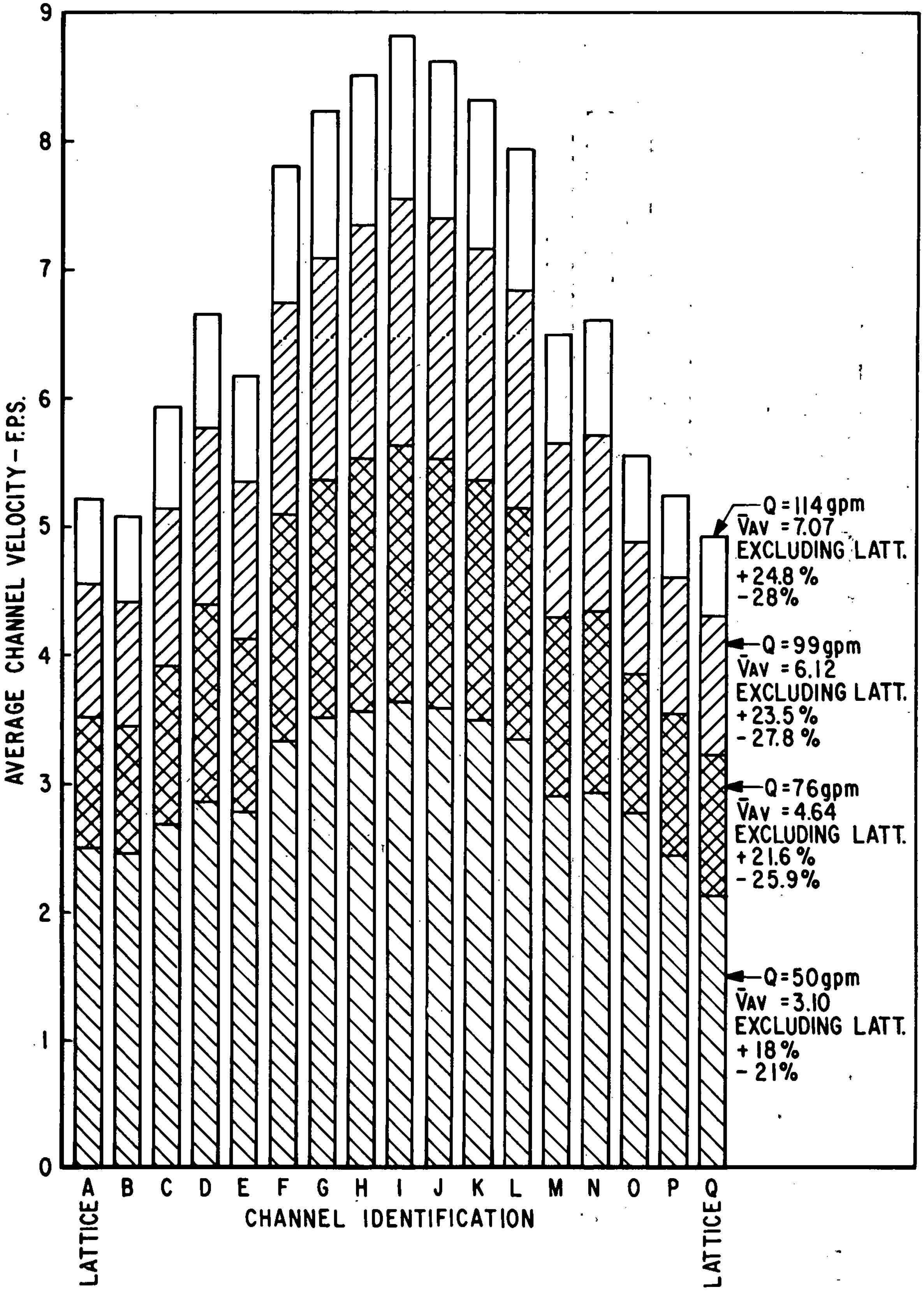

Fig. 5-6 - SM-1 Control Rod Assembly Flow Distribution

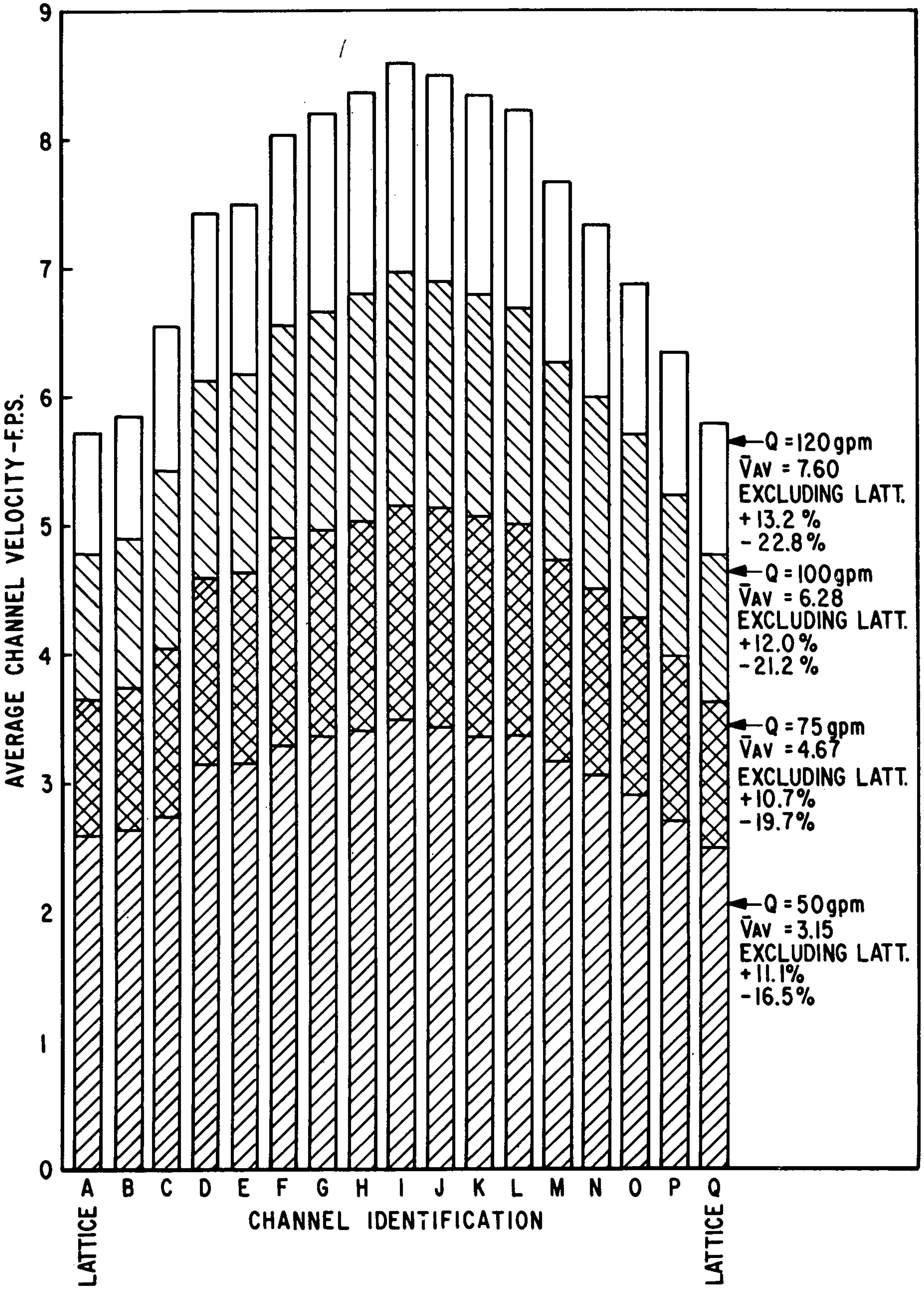

Fig. 5-7 - SM-1A and PM-2A Control Rod Assembly Flow Distribution

Any difference would be due to bypass leakage past the control rod tube, or to measurement error.

SM-1 Control Rod Assembly at 50 gpm.

Average channel velocity (lattices excluded) = 3.10 fps

Average lattice velocity = 2.32 fps

Element flow area = 32.714×10^{-3} ft^{2}

Lattice (active) flow area = 3.391×10^{-3} ft^{2}

Element flow = $(32.714 \times 10^{-3})\ (3.10) = 101.41 \times 10^{-3}$ cfs

= $(101.41 \times 10^{-3})\ (4.488 \times 10^{2}) = 45.51$ gpm

Lattice flow = $(3.391 \times 10^{-3})\ (2.32) = 7.867 \times 10^{-3}$ cfs

= $(7.867 \times 10^{-3})\ (4.488 \times 10^{2}) = 3.53$ gpm

Summation of the flows 45.51 + 3.53 = 49.04 gpm

This calculation, with a total loop flow of 50 gpm, indicated an uncertainty of 1 gpm due to buildup of possible instrument errors or bypass leakage.

6.0 CONCLUSIONS

6.1 STATIONARY FUEL ELEMENT FLOW DISTRIBUTION

6.1.1 SM-1 Stationary Element (Bottom Orificed)

Testing of the Type 3 stationary element modified for SM-1, with the maximum orifice (2.02 in. diam) showed channel-to-channel flow distribution ranged from + 6.8% to -8.8% of average channel velocity at the design flow rate. This is well within the +12% maldistribution factor used in previous thermal analyses. Testing with the minimum orifice (1.19 in. diam) indicated flow distribution within the element ranged from + 44% to -55% of average channel velocity (far above the + 12% target value). Because of the limited scope of the program, no intermediate orifices were tested to determine at which point the target values were exceeded.

Preliminary investigations were made to determine the effects of two element flow fixes upon flow distribution. One was a conical diffuser, the other a perforated plate; both were capable of becoming an integral part of the element. The investigation showed that definite improvement can be made in the flow distribution within this minimum orificed element.

6.1.2 SM-1A Stationary Element (Top orificed)

Testing of the Type 3 stationary element modified for SM-1A, with the minimum orifice (1.68 in. diam) showed channel-to-channel flow distribution ranged from + 6.1% to - 6.7% of average channel at the design flowrate. This is well within the assumed target value of + 12% used in previous thermal analyses. Since the minimum orifice represents the condition having the most adverse effect upon flow distribution, presumably flow distribution within the elements with larger orifices is also within the acceptable limits of + 12%.

6.1.3 PM-2A Stationary Element (top orificed)

Flow distribution ranged from + 6.2% to -11.1% of average channel velocity in testing the PM-2A stationary element with minimum orifice (1.83 in. diam). Since flow distribution in the element with minimum orifice was within the acceptable limits, it can be concluded that flow distribution in all other elements of the core is also within the acceptable limits.

6.2 CONTROL ROD ASSEMBLY FLOW DISTRIBUTION

6.2.1 SM-1 Control Rod Assembly

Flow distribution within the fuel element ranged from + 23.5% to -27.8% of average channel velocity at the design flow rate. This is much greater than the assumed + 12% target value, indicating that some modification should be made to the inlet end design.

6.2.2 SM-1A and PM-2A Control Rod Assembly

Flow distribution ranged from + 14% to -23.4% (both extrapolated) in the SM-1A and from + 13.2% to -22.8% in the PM-2A. The slight improvement in flow distribution over the SM-1 can be traced to the presence of additional flow holes at the bottom (inlet end) of the control rod tube. Additional modifications should be made to the inlet end of the control rod tube to improve the above maldistribution, since it is still not within the acceptable limits.

7.0 RECOMMENDATIONS

1. An investigation should be made to determine methods of improving the poor flow distribution within the SM-1 stationary elements with small orifices, and determine the feasibility of using such a flow improvement device in all future elements of the SM-1 type.

2. A design study and test program should be initiated to determine a method for improving the flow distribution within the control rod assemblies of the SM-1, SM-1A and PM-2A.

3. An investigation should be made to measure local flow velocities and velocity profile within a single SM or PM- channel to provide fundamental information for use in thermal analysis.

4. A test program should be initiated to determine the effect on flow distribution of non-central positioning of the control rod fuel element within the control rod tube.

5. In future design of reactor cores, bottom orificing should be used only if a flow test program is performed to establish flow distribution patterns within each element.

8.0 BIBILIOGRAPHY

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