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**INTERIM REPORT ON LABORATORY EXPERIMENTS INVESTIGATING CONSEQUENCES OF FAILURE OF FRONT HYDRAULIC FITTINGS IN "C" OCD GEOMETRY**

D. E. Fitzsimmons and G. M. Hesson

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04/20/1994

# INTERIM REPORT ON LABORATORY EXPERIMENTS INVESTIGATING CONSEQUENCES OF FAILURE OF FRONT HYDRAULIC FITTINGS IN "C" OCD GEOMETRY

## PURPOSE

The purpose of this report is to present the results of the most recent transient heat transfer experiments concerning the possibility of damage to a reactor as a result of high slug temperatures should a front hydraulic connector fail to a tube of "C" operational charge-discharge geometry.

## INTRODUCTION

The failure of a front face hydraulic connector could have serious consequences to a reactor. While such an incident would immediately initiate a scram, the power reduction is dictated by the time required for the insertion of the VSR's and by post-scram delayed fission and fission product decay. Although the post-scram heating is small, the only coolant available is that of hot water forced back through the tube by the low pressures of the rear header. This may provide insufficient cooling, particularly at low rear header pressures.

Reports of two earlier series of experimental tests concerning failure of a front hydraulic fitting have been issued.[1,2] The first of these presented the results of transient tests designed to determine the minimum rear header pressure necessary to provide an adequate coolant flow. The results were somewhat inconclusive and are believed to be highly conservative. The second report presented the results of steady state tests in which reverse direction coolant flow was used under typical reactor rear header pressures and post-scram conditions. While such steady state tests cannot define the consequences of the failure of a front fitting, information from them is of value in explaining the phenomenon of transient tests and in predicting in what areas future transient tests would be most fruitful.

This report presents results of transient tests in which the experimental equipment and procedures incorporated ideas gleaned from the two earlier series. The results should, therefore, be more realistic than those reported previously. The planned program was interrupted before completion by an equipment failure. The information obtained from the completed tests is significant, however, and warrants reporting at this time.

## SUMMARY

Nuclear heating of a train of 32 C I & E slugs was simulated by electrically heating a rod in a C geometry process tube. Failure of a front fitting to such a tube was simulated by simultaneously and rapidly closing a valve in the water supply to the tube and opening a valve in a line which permitted discharge from the inlet of a tube through a front nozzle to atmosphere. Three to four seconds after the valve operation, a power reduction in accord with a 1500 inhour scram was initiated. The reverse flow, rear header pressure and eight rod surface temperatures as well as other less important variables were monitored. A test was continued until conditions of adequate cooling became established. Successive tests were made at successively lowered rear header pressures. All runs reported herein were at 1000 KW initially, and none resulted in excessive rod surface temperatures. The experimental program was terminated by failure of the electrical insulating varnish on the inside of the process tubes.

CONCLUSIONS

In answer to the primary purpose of these tests, the data show that a process tube of "C" operational charge-discharge geometry operating at 1000 KW can suffer the loss of coolant from a front fitting failure if its rear header pressure were 10 psig or higher.

Secondary and supporting conclusions are presented below:

1. The results of these tests are conservative for a variety of reasons.

2. The highest rod surface temperatures occurred near the outlet of the tube, i.e., near the inlet of the reverse flow, and persisted for several minutes after an adequate coolant flow was established. This is ascribed to a stratified flow regime in this region.

3. Apart from the high temperatures due to stratification, establishment of adequate cooling conditions were as estimated from steady state data in HW-60164. On this basis a tube operating initially at 1250 KW could suffer loss of coolant from a front fitting failure if its rear header pressure were at least 12 to 14 psig.

4. These data and conclusions are for "C" reactor operational charge-discharge geometry only. Application to other reactor geometries is not valid and is probably non-conservative.

EXPERIMENTAL APPARATUS AND PROCEDURES

A diagram of the experimental apparatus is presented in Figure 2. The apparatus consists of the test section, the water recirculation system and the electrical generating equipment. The test section is a reasonably accurate prototype of a C reactor process tube from the beginning of the active section to the rear header with the exception that the active section is offset from the dummy section to permit the electrical connections to the heater rod. The test section was lagged to minimize heat losses. At the upstream end the hole and annulus connect to 1" pipes which in turn connect into a 2" pipe. The 2" pipe connects to a T, and then through either of two air-operated valves for operation either normally or with a simulated front fitting loss. The air valves operated in conjunction and in opposite directions, i.e., when one opens the other closes. For normal operation, the test section is connected to the pump discharge and water circulates through the test section and the water recirculation system. For front fitting failure simulation, the test section is connected to a C front nozzle, whose inlet port is connected directly to a 3" pipe which in turn discharges at atmospheric pressure to drain. This simulates the case where the front pigtail has stripped loose from the front nozzle.

The heater rod is heated electrically by three DC generators with a nominal output of 1175 KW. For these runs the power was controlled with a Moseley Model 2S Autograf equipped with curve following accessories. With the curve following accessories the unit operates as a function generator and was used to control the power in accord with the first 150 seconds of a 1500 inhour scram. For periods of time greater than 150 seconds power decrease of a scram is very slow and was simulated manually.

The heater rod was of C I & E design, 1.464" OD by 3/8" ID. The outside diameter was reduced 0.010" to correct for the 0.005" thick insulating varnish on the inside of the process tube. The rod was made of sections of brass and copper-nickel alloys welded together. The different electrical resistivities of the brass and the various copper-nickel alloys gave a stepwise form of heat generation which approximated a cosine heat generation. Ten thermocouples were imbedded at the top surface of the rod. These gave temperature readings somewhat higher than, but related to the top of rod surface temperatures. Six hold-down pins were inserted through the top of the process tube at approximately equally spaced intervals along the tube. These were intended to reduce the upward bowing the rod undergoes due to vertical temperature gradients during the severe conditions imposed. Figure 3 shows the heater rod construction, the form of its heat generation and the thermocouple location.

Loss of a front hydraulic connector was simulated in the following manner: Normal flow was established and the tube operated at 1000 KW and 125°C outlet water temperature until steady state conditions were reached. Water was by-passed into the rear header to maintain its temperature at 100 to 105°C. The air-operated valves in the inlet piping were then actuated. This shut off the water supply to the tube and opened the inlet port of the front nozzle to atmosphere. Approximately three seconds after the valve actuation a power reduction was started in simulation of a reactor scram. The rear header pressure, reverse flow, several rod surface temperatures as well as other pressures and water temperatures were monitored on high speed recording instruments. Successive runs were at successively lower rear header pressures. All runs were continued until attainment of adequate cooling conditions were established by back flow from the rear header.

THEORY

The familiar concepts of a boiling or demand curve and a tube supply curve can be used to describe qualitatively the course of events following the failure of a front hydraulic fitting. In this case the supply curve is a flat horizontal line at the appropriate rear header pressure. The boiling or demand curve, whose intersection with the supply curve determine the operating point, is actually a constantly moving one during the course of the transient. Figure 1 graphically explains this:

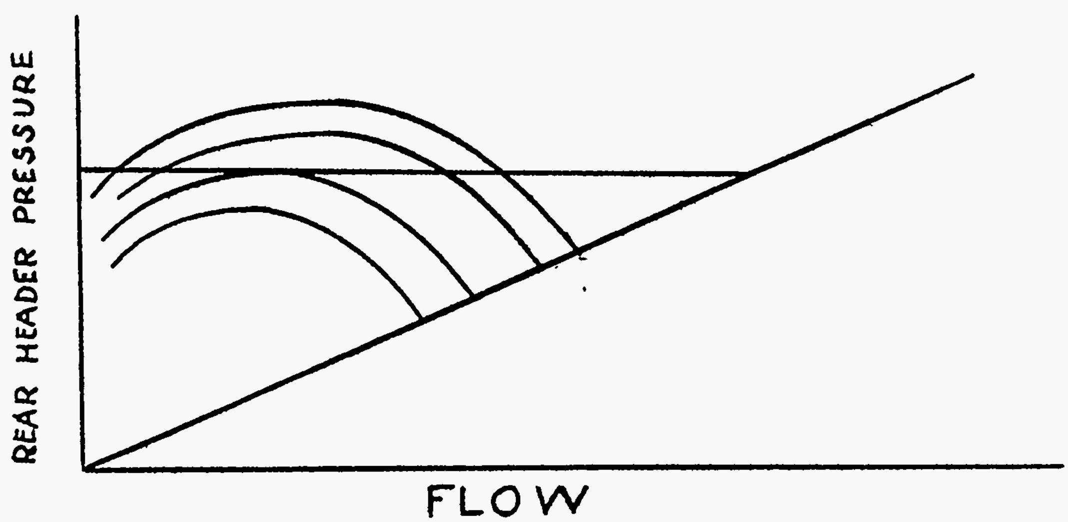


Figure 1



[redacted]

The horizontal line is the supply curve for a given rear header pressure. The lines labeled $\theta_1$, $\theta_2$, $\theta_3$ and $\theta_4$ are the boiling or demand curves for successively later times after the occurrence of the fitting failure. At time $\theta_1$, the operating point is $P_1$. At later times, $\theta_2$ and $\theta_3$, the operating points are $P_2$ and $P_3$. At time $\theta_3$, the supply curve is tangent to the peak of the boiling curve. At any time after this, the boiling curve lies below the supply curve and a condition of excess header pressure exists. When excess header pressure conditions are obtained, the operating point is $P_4$, the intersection of the supply curve and the non-boiling isotherm.

These boiling curves cannot be quantitatively determined. Their form is primarily a function of the heat input to the coolant. The heat input is, in turn, a function of the nuclear heat generation at the time in question and the rate of heat transfer into the water. The rate of heat transfer to the water is dependent upon the heat transfer coefficient, and more important, the transient thermal characteristics of the slugs and the immediate past transient heat accumulation history of the slugs. None of these factors can be determined exactly for a system as complex as a Hanford reactor process tube.

Boiling curves have been determined by steady state experimentation at rear header pressures and water temperaturs and heat generation rates typical to reactor post-scram conditions(3). Such curves are equilibrium curves at the conditions which would be reached if the scram power and water temperature decay could be frozen long enough to establish steady state conditions. The moving transient boiling curves would lie below the steady state curves early in the transient while a large part of the generated heat is used in heating the slugs and would lie above the steady state curves later in the transient when the slugs are cooling and releasing heat to the water in addition to that being generated.

Associated with each of the steady state boiling curves are slug surface temperatures. At very early times the equilibrium temperatures are very high and slug jacket melting would be expected if the equilibrium conditions were reached. At somewhat later times cooling by boiling would be adequate to prevent slug jacket melting, even at equilibrium conditions. Still later the condition of excess header pressure with a large water flow is reached, and slug surface temperatures not much higher than the rear header water temperatures would occur. The transient slug surface temperatures would be less than those indicated by the steady state experiments early in the transient while the slugs are heating and would be greater than those later in the transient while the slugs are cooling.

An examination of Figure 1 will show that the higher the rear header pressure, the sooner adequate cooling conditions will be reached. The problem then is to determine how fast the slug temperatures rise early in the transient, and, more important, what rear header pressure is necessary to cause the operating point to move into adequate cooling regions before slug surface temperatures are reached which would cause jacket melting.

## EXPERIMENTAL RESULTS

Five runs were completed in this series before experimentation was halted by an electrical short caused by degradation and failure of the electrical insulating varnish on the inside of the process tube. The first three runs were at rear header pressures of 15 to 25 psig, and attained adequate cooling within 20 to 40 seconds without exceptionally high rod surface temperatures. No further results from these runs will be included in this report. The experimental results for the last two runs is tabulated in Tables I and II which give the behavior of the pertinent variables with respect to time after the simulated front fitting failure.

The next to last run, Run 53, was made at a rear header pressure which varied between extremes of 6 to 15 psig, but which held between 7 to 9 psig during most of the run. During this run the hottest rod surface temperatures were found to occur near the rear header end of the heater rod on thermocouples which were not being monitored with recording instruments. Temperature data from these thermocouples (Numbers 9 and 10) were obtained by visual observation of steady state indicating instruments, and the times indicated in Table I are only approximate.

For the last run, Thermocouple 9 and 10 were connected to the recording instruments. The rear header pressure during this run varied largely from 11 to 14 psig with extremes of 9 to 15 psig.

The electrical shorts which halted this series occurred at the ribs at the front face end of the test section and near the top of the tube at the rear face end of the test section. This indicates that in spite of the six hold-down pins used in this assembly, the rod tended to bow upwards severely enough to touch the top of the process tube at the rear face end.

## DISCUSSION

Reiterating, the purpose of these tests was to determine the possibility of damages to a reactor due to high slug temperatures arising from the failure of a front hydraulic connector on a "C" OCD tube. More specifically, the tests were intended to define the rear header pressure necessary to cause sufficient reverse flow through the tube to achieve adequate cooling conditions soon enough to prevent excessive slug temperatures. The data in Tables I and II provide an answer to this question. The data indicate that a "C" OCD tube operating at 1000 KW can suffer the loss of a front hydraulic fitting if the rear header pressure is 10 psig or greater. This answer is not as clear cut as would be desirable because the rear header pressure varied throughout the runs. However, during Run 53, the worst case, the pressure remained between 7 and 9 psig during most of the run.

As outlined on page 5, the expected behavior was an initial large jump in rod surface temperatures between the simulation of the front fitting failure and the initiation of the scram. After the scram the rod surface temperature would be expected to increase at a slow and gradually decreasing rate until adequate cooling conditions were reached, following which the temperatures would decrease. Coincident with this would be a gradually increasing reverse flow through the tube. Reverse flow boiling curves constructed from steady state data permitted an estimate of how long after the incident adequate cooling conditions would be reached.

With one important exception, the results of these runs were in accord with the expected behavior. The initial jump in rod surface temperature was from 100°C to 150°C above the initial temperature. In most cases, the rod surface reached maximum temperatures at times in agreement, actually somewhat earlier, with those predicted from the steady state data. In the worst case, the maximum temperature reached by these couples was less than 300°C. Once adequate cooling was reached, the temperature dropped to within a few degrees of the coolant temperature.

In one very significant respect, the results of these tests did differ from the above outlined expected behavior. The thermocouples giving the highest temperatures were the two nearest the rear of the test section, i.e., nearest the inlet of the reverse flow. Furthermore, these high temperatures persisted for several minutes after adequate cooling conditions were established as evidenced by the fact that all the other thermocouple locations had cooled and reverse flow rates of 1 to 6 gpm had been reached. The high temperature points were in the region of coolest coolant and were outside the high heat flux region and would,therefore, be expected to be the coolest points and to be the first to recover. Some evidence was found in the steady state tests that high temperatures might occur near the inlet of the reverse flow. It occurred in only a few cases, too few to characterize under what conditions it might be expected.

The reason for this apparently anomalous high temperature location is postulated to arise from the very low liquid velocities near the coolant inlet. It is believed that at the low reverse flow rates associated with a front fitting failure, the liquid does not fill the tube near the inlet end. This leaves part of the rod in a stagnant steam atmosphere above the liquid and cooling is very poor. Farther downstream past the point where steam formation starts, the high specific volume of the steam results in high velocities and relatively good heat transfer. The low velocity and probable stratified flow are, therefore, deemed responsible for high temperatures up to the point of steam formation.

The conclusions drawn from these tests are conservative in their application to a reactor for two reasons. First, the test section heater rod was made to generate all the heat going into the tube. In a reactor up to 20 per cent[3] of the heat would be generated in the graphite. The experimental heat flux and consequently the rod to coolant temperature difference was, therefore, up to 25 per cent too high. Furthermore, in a reactor a portion of the heat generated in the graphite would be dissipated into the cooler tubes around the affected one.

Secondly, the experimental heater rod bows upward in the process tube. In these tests, six pins were inserted through the top of the tube at three to four foot intervals to restrain the bowing. The pins were not entirely effective. In the region of the highest temperature, the pins were found to have indented into the heater rod as much as 1/32". Furthermore, there is undoubtedly some bowing between pins. Such lifting of the heater in the tube would aggravate any stratification effects.

In conclusion, it must be pointed out again that these results are applicable to a tube of I & E slugs of C reactor operation charge-discharge geometry operating initially at 1000 KW. Steady state data indicate that such a tube operating at 1250 KW would require a rear header pressure 2 to 4 psig greater than for the 1000 KW case. While the flow mode for the steady state case was different from that of these transient tests, the 2 to 4 psig extrapolation is probably reasonable. Extension of these results to other reactor geometries is not warranted.

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## REFERENCES

(1) HW-57740 - Results of Preliminary Tests Simulating Rupture of a Front Pigtail on C Reactor - D. E. Fitzsimmons, G. M. Hesson, October 10, 1958.

(2) HW-60164 - Results of Reverse Flow Experimental Tests For C Operational Charge-Discharge Tube at Low Tube Powers - D. E. Fitzsimmons, G. M. Hesson, April 30, 1959.

(3) HW-38870 - Heat Generation and Total Heat Output From the Pile After Shutdown - S. S. Jones, November 23, 1954.

## TABLE I

## EXPERIMENTAL RESULTS FROM RUN 53

| Time, Sec. | Rear Header Pressure, Psig. | Reverse Flow, Gpm | Rod Surface Temperatures, °C — Thermocouple No. 3 | 4 | 5 | 7 | 9(1) | 10(1) |
|---|---|---|---|---|---|---|---|---|
| 0 | 16 | 0 | 110 | 80 | 108 | 140 | | |
| 10 | 15 | <0.2 | 220 | 210 | 250 | 130 | | |
| 20 | 12 | <0.2 | 230 | 228 | 262 | 202 | | |
| 30 | 10 | 1.8 | 250 | 240 | 278 | 222 | | |
| 40 | 10 | 1.2 | 258 | 250 | 285 | 245 | | |
| 60 | 9 | 1.2 | 260 | 252 | 288 | 248 | | |
| 80 | 9 | 1.1 | 250 | 245 | 280 | 240 | | |
| 120 | 9 | 0.7 | 230 | 220 | 265 | 212 | | |
| 450 | 8 | 1.0 | 110 | 115 | 120 | 95 | | |
| 620 | 7 | 1.3 | ↓ | ↓ | ↓ | ↓ | | |
| 820 | 6 | 1.5 | ↓ | ↓ | ↓ | ↓ | 500 | |
| 860 | 6 | 2.0 | ↓ | ↓ | ↓ | ↓ | | 560 |
| 900 | 7 | 4.5 | ↓ | ↓ | ↓ | ↓ | | |
| 950 | 9 | 4.5 | ↓ | ↓ | ↓ | ↓ | 300 | 450 |

**Notes**

(1) The rod surface thermocouples 9 and 10 were read from steady state indicating instruments during this run. The times are approximate.

TABLE II

EXPERIMENTAL RESULTS FROM RUN 54

| Time, Sec. | Rear Header Pressure, Psig | Reverse Flow, Gpm | Rod Surface Temperatures, °C Thermocouple No. 3 | 4 | 5 | 7 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|
| 0 | 17 | 0 | 95 | 90 | 160 | 204 | 180 | 90 |
| 10 | 15 | 0 | 230 | 230 | 270 | | 350 | 312 |
| 20 | 11 | .7 | 240 | 240 | 270 | 232 | 325 | 332 |
| 30 | 11 | .9 | 250 | 245 | 280 | 250 | 460 | 358 |
| 40 | 11 | 1.7 | 250 | 240 | 280 | 245 | 520 | 372 |
| 50 | 11 | 2.0 | 240 | 202 | 280 | 240 | 520 | 388 |
| 60 | 11 | 2.0 | 200 | 175 | 275 | 230 | 500 | 395 |
| 90 | 12 | 1.8 | 105 | 115 | 140 | 115 | 480 | 420 |
| 120 | | 1.8 | 100 | 90 | 105 | 115 | 470 | 422 |
| 150 | 13 | 1.7 | | | | | 460 | 430 |
| 180 | 14 | 1.5 | | | | | 450 | 432 |
| 210 | 14 | 1.5 | | | | | 440 | 430 |
| 240 | 13 | 1.5 | | | | | 440 | 425 |
| 300 | 13 | 1.5 | | | | | 440 | 410 |
| 330 | 13 | 1.6 | | | | | 425 | 65 |
| 360 | 11 | 1.7 | | | | | 420 | |
| 420 | 11 | 2.1 | | | | | 430 | |
| 480 | 15 | ~4 | | | | | 400 | |
| 510 | 12 | 4 1/2 | | | | | 160 | |
| 550 | 9 | ~6 | | | | | 60 | |

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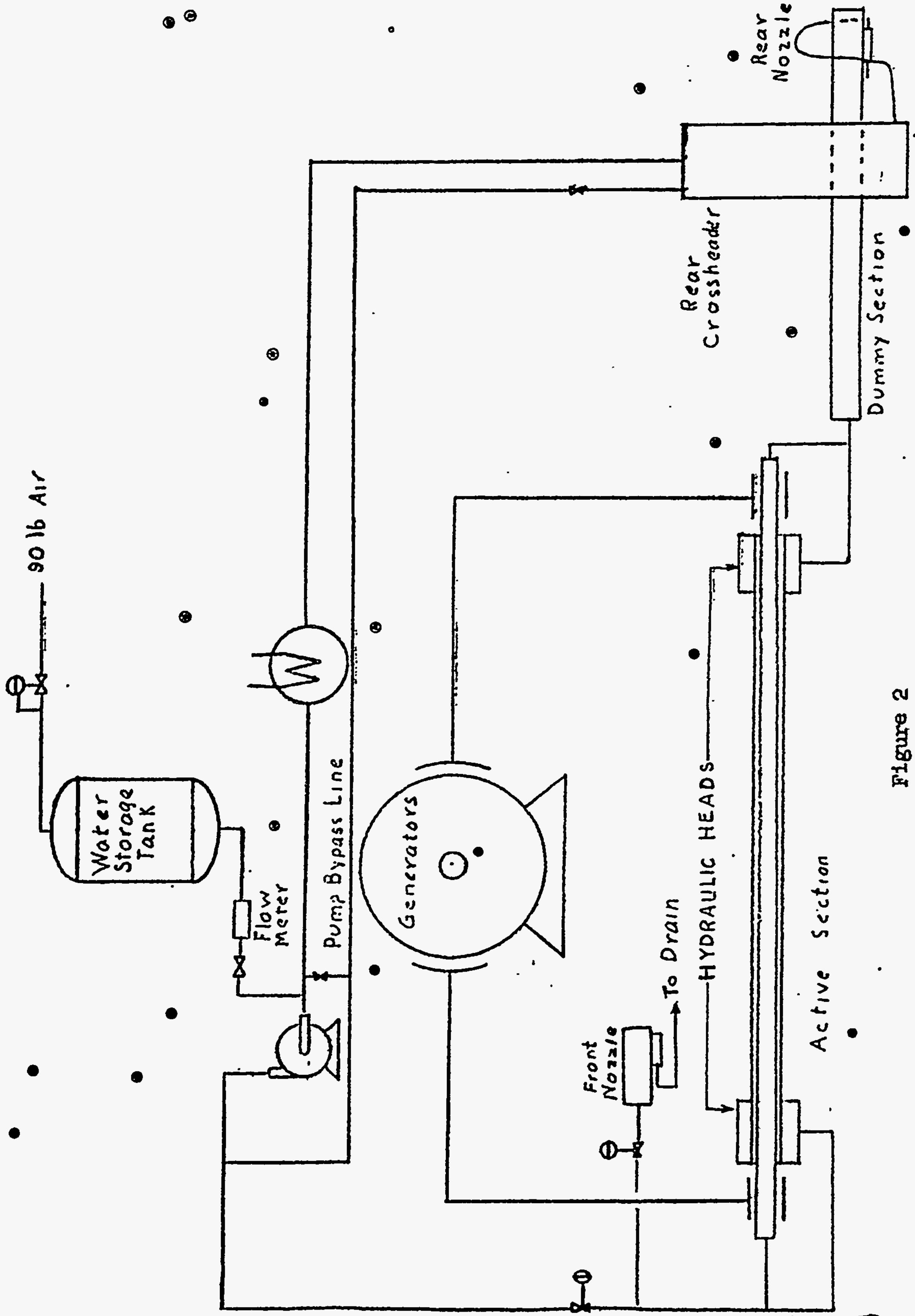


Figure 2

Schematic Diagram of Test Section

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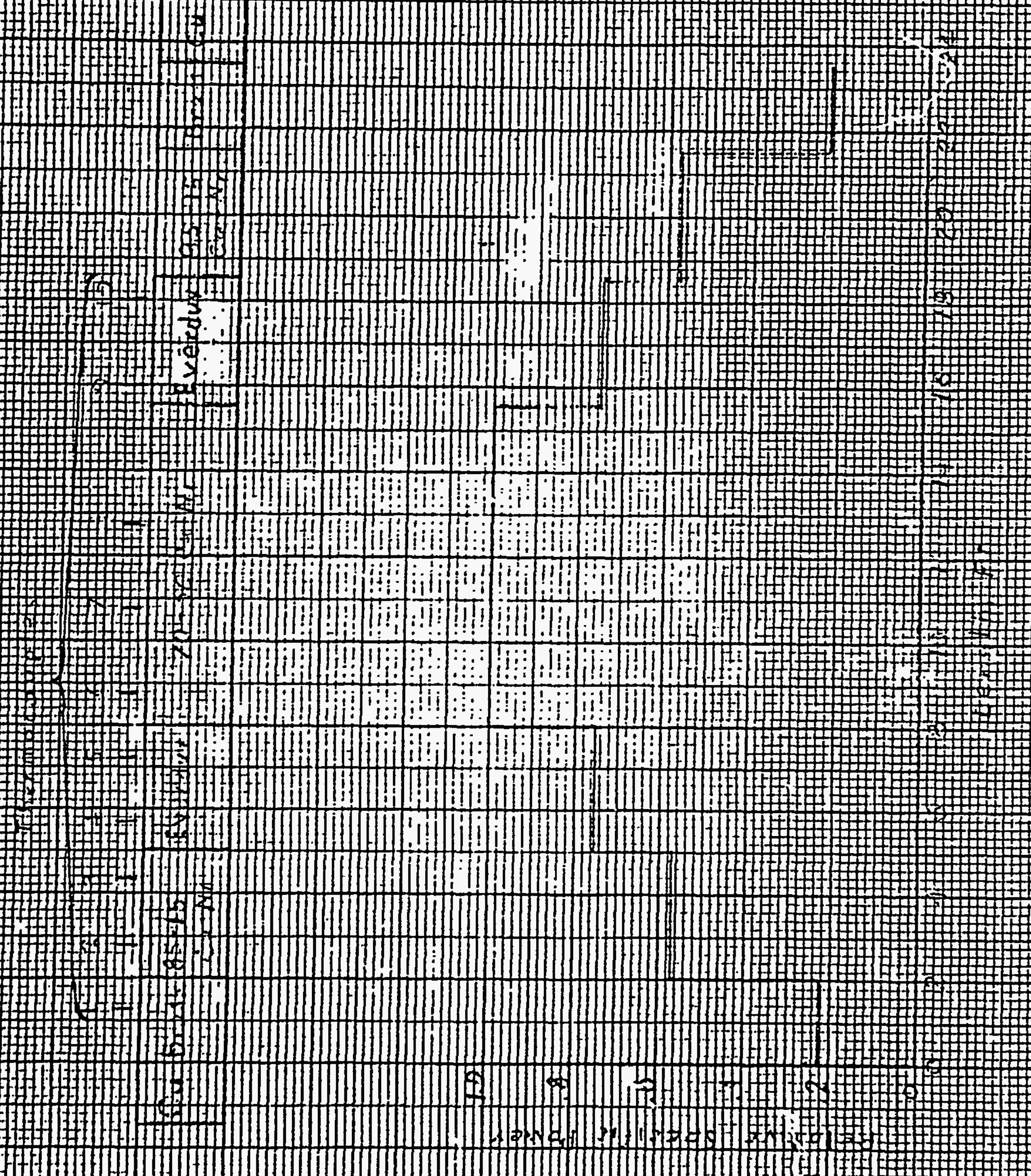

FIGURE 3 FEATHER ROD DESIGN

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