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WCAP-2993

FINAL REPORT

FEASIBILITY OF A CHEMICAL POISON LOOP SYSTEM

by

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prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CONTRACT NAS 3 5215

WESTINGHOUSE ELECTRIC CORPORATION
ATOMIC POWER DIVISIONS

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September 1966

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TECHNICAL MANAGEMENT
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Final Report

Feasibility of a Chemical Poison Loop System

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ABSTRACT

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The final experiments performed with the Laboratory Version of the Chemical Poison Loop System (CPLS) are described and the results are analyzed. An overall discussion of the feasibility of using a CPLS to control the reactivity of a rocket reactor is contained, wherein it is concluded that the system should be hydraulically and thermally feasible. However, certain chemical instability problems which were not resolved in the work performed make overall feasibility marginal.

AUTHOR

SUMMARY

In order to establish the feasibility of utilizing a Chemical Poison Loop System (CPLS) for the reactivity control of a Tungsten-Water Moderated Rocket Reactor (TWMR), an analytical and experimental program of several phases was undertaken by the Westinghouse Atomic Power Division (WAPD) for the NASA Lewis Research Center. Previous reports have discussed the Reference Flight System, test program plans, the results of the manifold-poison tube array design and testing, and the results of the test programs on poison solutions and materials compatibility.

The final phase of the program involved the construction of a Laboratory Version of the CPLS Flight System, with appropriate hydraulic simulations in the case of certain components. A series of dynamic tests was performed to simulate the required startups and shutdowns of the reactor, with analytical data taken to evaluate system performance. Satisfactory performance was achieved in all instances.

As to overall system feasibility, it is concluded that the design system requirements are generally satisfactorily met. Because of problems with thermal stability of the poison solution, the performance under normal operation conditions must be considered marginal.

I. INTRODUCTION

A. Statement of Purpose

Contract NAS3-5215 between Lewis Research Center, NASA, and Westinghouse Electric Corporation, Atomic Power Division, covers the investigation of the feasibility of a Chemical Poison Loop System (CPLS) to control the reactivity of a tungsten, water moderated reactor for rocket application. This contract was subdivided into five tasks (I-V) covering certain specific objectives. The Summary Report on Task I (NASA-CR-54291) presented the design of the Reference System. The Summary Report on Task II (NASA-CR-54420) presented the design of the laboratory tests planned as a means of establishing feasibility. There were two Summary Reports issued covering the Task III work. Report NASA-CR-54994, presented the work done on the testing of the manifold-poison tube assembly and report NASA-CR-54995 presented the evaluation of the materials compatibility and acceptability with particular emphasis on the poison solution stability.

This report constitutes the final report on the program. It presents the design and testing of the CPLS Simulation Laboratory Version, Task IV, completes the discussion of the ion exchange evaluation, which was partially covered in NASA-CR-54420 and provides a discussion of the overall feasibility of the CPLS, Task V.

B. Requirements for Feasibility

In order to introduce properly the discussions in this report, it is appropriate to review in brief the overall description of the CPLS and the more important design bases.

The Chemical Poison Loop System is a closed fluid system containing a neutron absorbing material (poison) dissolved in water and circulated through appropriately arrayed tubes in a tungsten-water moderated rocket reactor core. Variation of the concentration of the poison solution is made in order to control the reactivity of the reactor between shutdown and full power conditions.

The Chemical Poison Loop System is designed to maintain the desired steady-state concentration of poison in solution and to effect changes in concentration from one steady state concentration to another, as indicated in the following table:

Steady State Condition	Poison Concentration, mg Cd/cc, 90% Cd^{113}
At Shutdown	2.97
At Hot Critical	1.65
At Xenon Override	0.126
Change Rates	mg/cc-sec
From Shutdown to Hot Critical or Xenon Override	0.0119 max
From Xenon Override or Hot Critical to Shutdown - Fast	0.0236
- Slow	0.0059

The CPLS is required to change concentration as indicated for five reactor startups from shutdown (one of these involving over-riding xenon) and five reactor shutdowns. Operation at hot critical will be for a total of 10 hours.

The maximum delay between demand signal and entrance of modified poison concentration into the poison tubes is

Ion Exchange Effluent	0.3 sec.
Normal Poison Insertion	0.2 sec.
Fast Poison Insertion	0.2 sec.

During steady state or transient operation of the system the concentration in the poison tubes in the reactor is the same within $\pm$ 5%.

In performing its functions the CPLS must also be subjected to specified environmental conditions.

A schematic diagram of the CPLS flight system is shown in Figure 1.

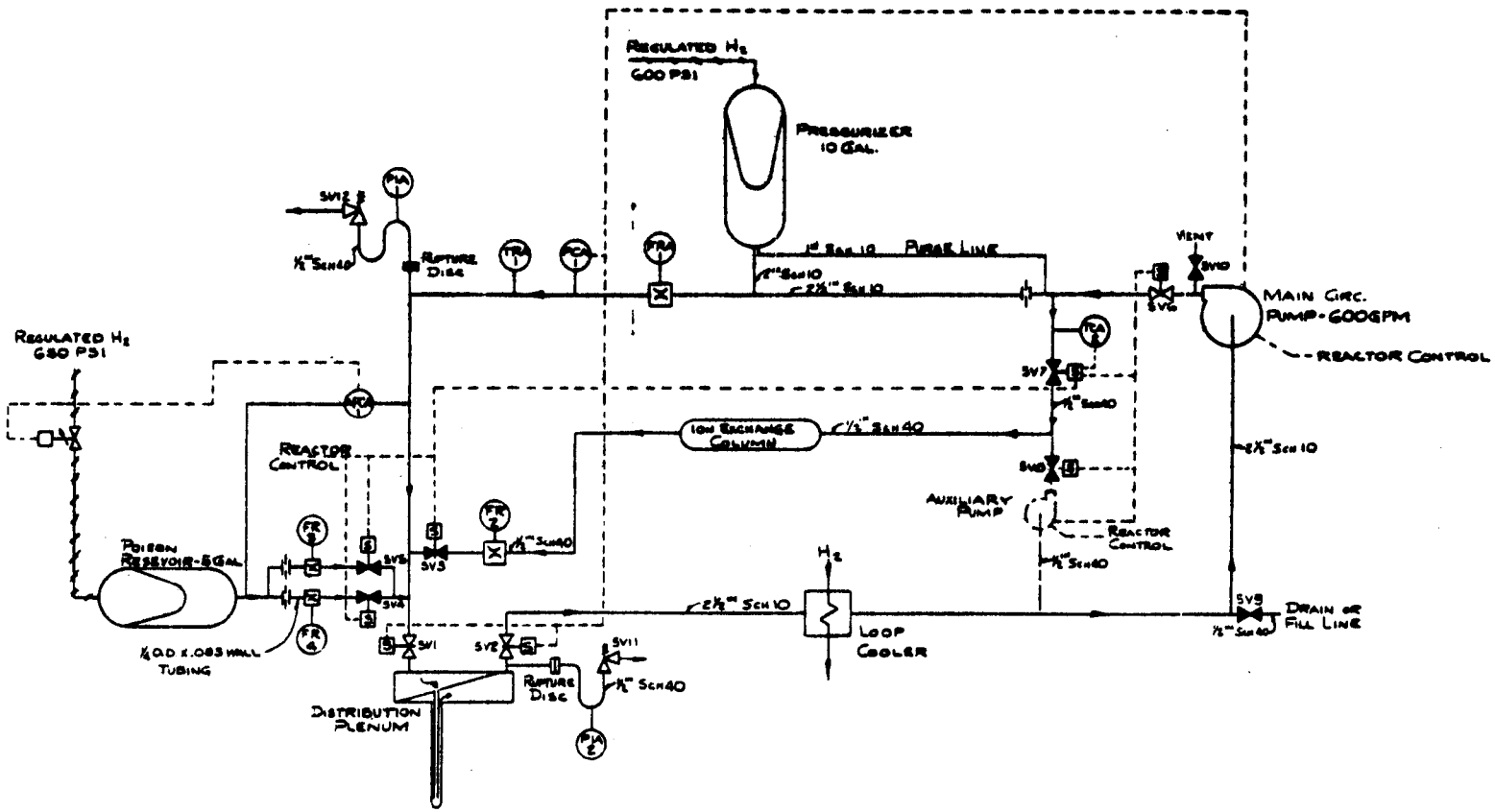


Figure 1

Chemical Poison Loop System
Flow Diagram

II. DESIGN AND FABRICATION OF THE CPLS LABORATORY VERSION

A. General

Having established through the open loop work on the manifold-poison tube model, reported in NASA-CR-54994, that the poison could be introduced into the various poison tubes of the core in a uniform manner within the prescribed times, the CPLS Simulation-Laboratory Version was utilized to obtain closed loop data. The concept was to build and test a closed loop, simulating as well as possible the piping and components of the CPLS flight system and substituting simple fluid devices for the manifold-poison tube assembly and for the heat exchanger. Transient, closed loop data thus obtained, in combination with the previous testing of the manifold-poison tube assembly, would be used in performance evaluation.

B. Design and Fabrication of CPLS Simulation Laboratory Version

1. Mechanical Design

The CPLS Simulation Laboratory Version was designed to simulate as close as possible the piping layout, components and instrumentation of the actual Flight System in order to establish feasibility within the scope of the experimental program. Details for the design basis and experimental program were previously described in Task II Report (NASA-CR-54420, WCAP-2803). However, later modifications were required.

All components in the system are listed in Table 1. Figures 2, 3, and 4 show the location of the major system components.

A piping layout for the Reference CPLS was made using as guide lines NASA layout drawings of the rocket engine assembly. However, for the Laboratory Version it was necessary to make the following modifications in the piping and component layout:

a. About 46 inches of additional 2-1/2 inch pipe were added to the main loop piping in order to allow for the difference in size between the turbo-pump shown in the layout drawings and the motor driven pump and its supporting structure being used in the Laboratory Version.

b. The length of the 1 inch purge line to the pressurizer, and the 2-1/2 inch pipe connecting this component to the loop is 21 inches longer. This was necessitated by the installation of a 3/4 inch gate valve in the purge line, and the 2-1/2 inch gate valve in the return line to the loop. These valves were needed in order to isolate the pressurizer from the loop when sampling its contents.

TABLE 1

CPLS Laboratory Version
Mechanical Components

Quantity	Item	Description	Material of Construction	Design Pressure psig	Design Temperature °F	Operating Pressure psig	Operating Temperature °F	Function
	Primary Components							
1	Main Circ. Pump	Worthington Centrifugal Pump Model 3HN-112	18-18 chrome nickel steel	600	850	600	150	To circulate system fluid (Vol. = 3.4 gals.)
1	Pressuriser	Greer Hydro-Pneumatic Transfer Barrier Accumulator - 10 Gallon Capacity Model 30A-10TBWS with Special Port Assembly	Shell: 4130 steel coated with "Lith-coat" vinyl coating Buna-N bladder 304 SS port assy	3000	100	600	150	To maintain system pressure and absorb volume changes (Vol. = 5 gals.)
1	Poison Reservoir	Greer Hydro-Pneumatic Transfer Barrier Accumulator - 5 Gallon Capacity Model 30A-5TBWS	Shell: 4130 steel coated with "Lith-coat" vinyl coating Buna-N bladder 304 SS port assy	3000	180	600	150	Poison injection reservoir - To contain concentrated poison solution to be injected into main loop when required
1	Ion-Exchange Column	10" Sch. 40, 316 SS Pipe with 300 lb. Flanges Dwg. No. 540-F-794	Type 316 SS	800	250	600	150	Contains ion-exchange resins which removes poison from loop fluid
1	Ion-Exchange In-Line Cooler	Double Pipe Counter Current Heat Exchanger	Primary side: 1" sch. 40, 304 SS pipe secondary side: 2" sch. 40 carbon steel pipe	2400	600	600	150	To cool loop fluid passing through IX column down to 120°F or less
1	Distribution Manifold and Poison Tubes Simulator	Sketch No. NASC-104 & 105	Type 316 SS	800	250	600	150	To simulate distribution manifold and poison tubes volume and time constant, and provide cooling (Vol. = 13.9 gals.)
1	Simulated Heat Exchanger.	Sketch No. NASC-106 & 107	Type 316 SS	800	250	600	150	To simulate heat exchanger volume and time constant, and provide cooling (Vol. = 4.5 gals.)
	PIPING							
	Main Loop Piping and Fittings	2-½" Sch. 10 Pipe	Type 316 SS - Seamless	800	250	600	150	Contains main loop poison solution (Vol. = 5.1 gals.)
	Ion-Exchange By-pass Line	½" Sch. 40 Pipe	Type 316 SS - Seamless	800	250	600	150	Circulates poison solution through ion-exchange column
	Pressurizer Purge Line	1" Sch. 10 Pipe	Type 316 SS - Seamless	800	250	600	150	Circulates poison solution through pressurizer to maintain same concentration with main loop fluid
	Injection Lines	¼" O.D. x 0.049" Wall Thickness Tube	Type 316 SS - Seamless	800	250	600	150	Connect poison reservoir and main loop piping
	Sampling & Instrument Lines	¼" O.D. x 0.049" Wall Thickness Tube	Type 316 SS - Seamless	800	250	600	150	Sampling lines and connects pressure monitoring instrumentation
	VALVES							
2	No. 5V1 & 5V2 Main Loop Inlet & Outlet Block Valve	Aloyco 2-½" 300# Gate Valve with Miller Pneumatic Actuator	Type 316 SS body and gate carbon steel and brass cylinder and spring	800	250	600	150	To isolate in-core components in case of rupture in out-of-core piping (Vol. = .2 gal ea.)
2	No. 5V3 & 5V7 Ion-Exchanger By-pass Line	Atkomatic ½" Pilot Piston, Solenoid Operated Valve	Type 316 SS body. Teflon seat. Type 416 SS armature	3000	500°F	600	150	Normally closed valve. On and off flow control with fluid temperature override to close at high temperature conditions
2	No. 5V4 & 5V5 Fast & Slow Poison Injection Line	Atkomatic 1/8" Direct Lift Solenoid Operated Valve Normally Closed	Type 316 SS body Teflon seat. Type 416 SS armature	3000	500°F	600	150	Normally close valve. On and off flow control for fast and slow poison injection rates
1	No. 5V6 & Main Loop Line	Aloyco 2-½" 300# Gate Valve	Type 316 SS body & gate	800	250	600	150	Manually operated valve to control loop's main flow (Vol. = .2 gal.)
1	No. 5V8 Pressuriser Block Valve	Aloyco 2-½" 300# Gate Valve	Type 316 SS body & gate	800	250	600	150	Manually operating valve use to isolate pressuriser from main loop
1	No. 5V9 Main Line Drain Valve	Aloyco ½" 300# Gate Valve	Type 316 SS body & gate	800	250	600	150	Manually operated valve main loop drained valve

TABLE 1 (Continued)

CPLS Laboratory Version
Mechanical Components

Quantity	Primary Components Item	Description	Material of Construction	Design Pressure psig	Design Temperature °F	Operating Pressure psig	Operating Temperature °F	Function
1	No. 5V10 Main Loop Vent Valve	Whitey ¼" Needle Valve with Swagloc Connections	Type 316 SS	3000	70	600	150	To vent air from system during filling operation
2	No. 5V11 & 5V12	Republic Safety Relief Valve	Type 316 SS	1500	70	1000	150	To protect in-core and out-core components from rupture due to extreme high pressures
1	No. 5V13	1" Gate Valve	Brass	250	70	100	70	To control cooling water flow through simulated heat exchanger. Manually operated
1	No. 5V14	3/4" Gate Valve	Type 316 SS	2500	70	600	150	To control pressurizer purge line flow. Manually operated
1	No. 5V16 Filling Line Valve	Whitey ¼" Globe Type Valve with Swageloc Connections	Type 316SS	3000	70	600	150	Shutoff filling line
2	No. 5V17 & 5V18 Fast & Slow Poison Injection Valves	Whitey ¼" Needle Valve with Micro-regulating Stem	Type 316 SS	3000	70	700	70	To manually adjust fast and slow injection flow rates
1	No. 5V19 Rupture Disc Block Valve	Aloyco 2-½" 300# Gate Valve	Type 316 SS	800	250	600	150	To isolate rupture disc assembly from main loop during normal operation. Manually operated
1	No. 5V20 - 5V23 Sampling Line Valves	Whitey ¼ Needle Valve with Swageloc Connections	Type 316 SS	3000	70	600	150	Sampling lines shutoff valves

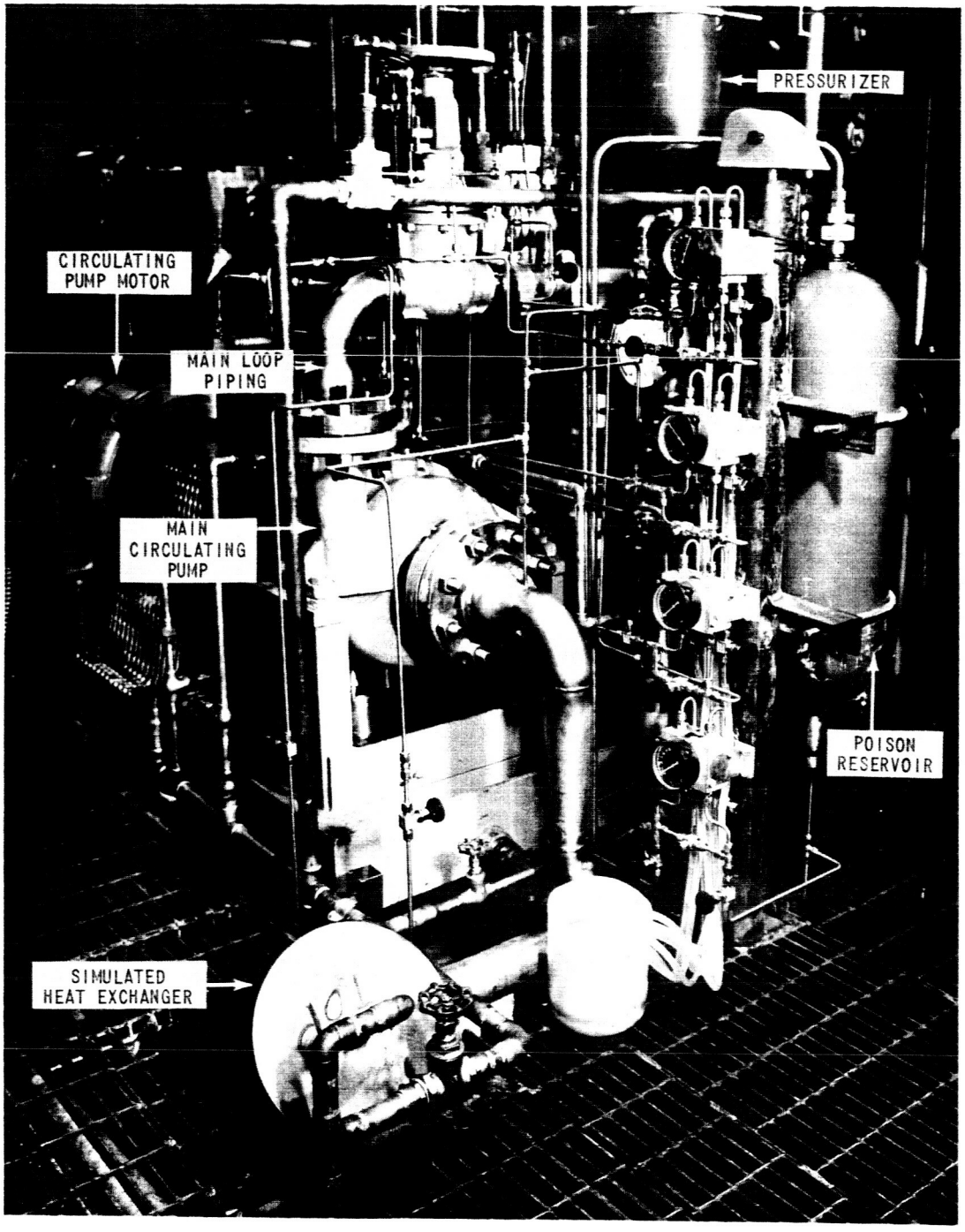


FIGURE 2

CPLS - LABORATORY VERSION
UPPER FRONT VIEW

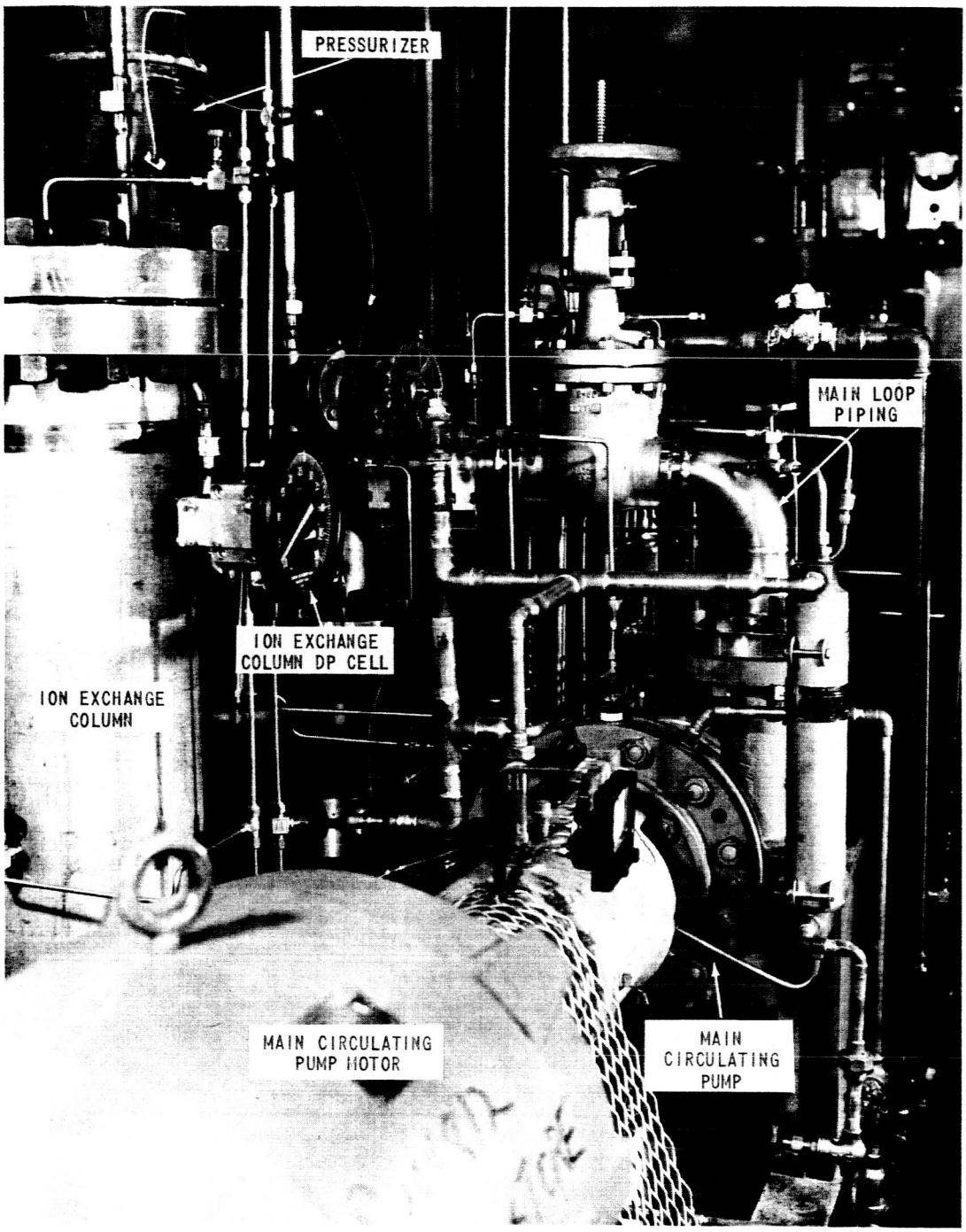


FIGURE 3

CPLS LABORATORY VERSION
UPPER REAR VIEW

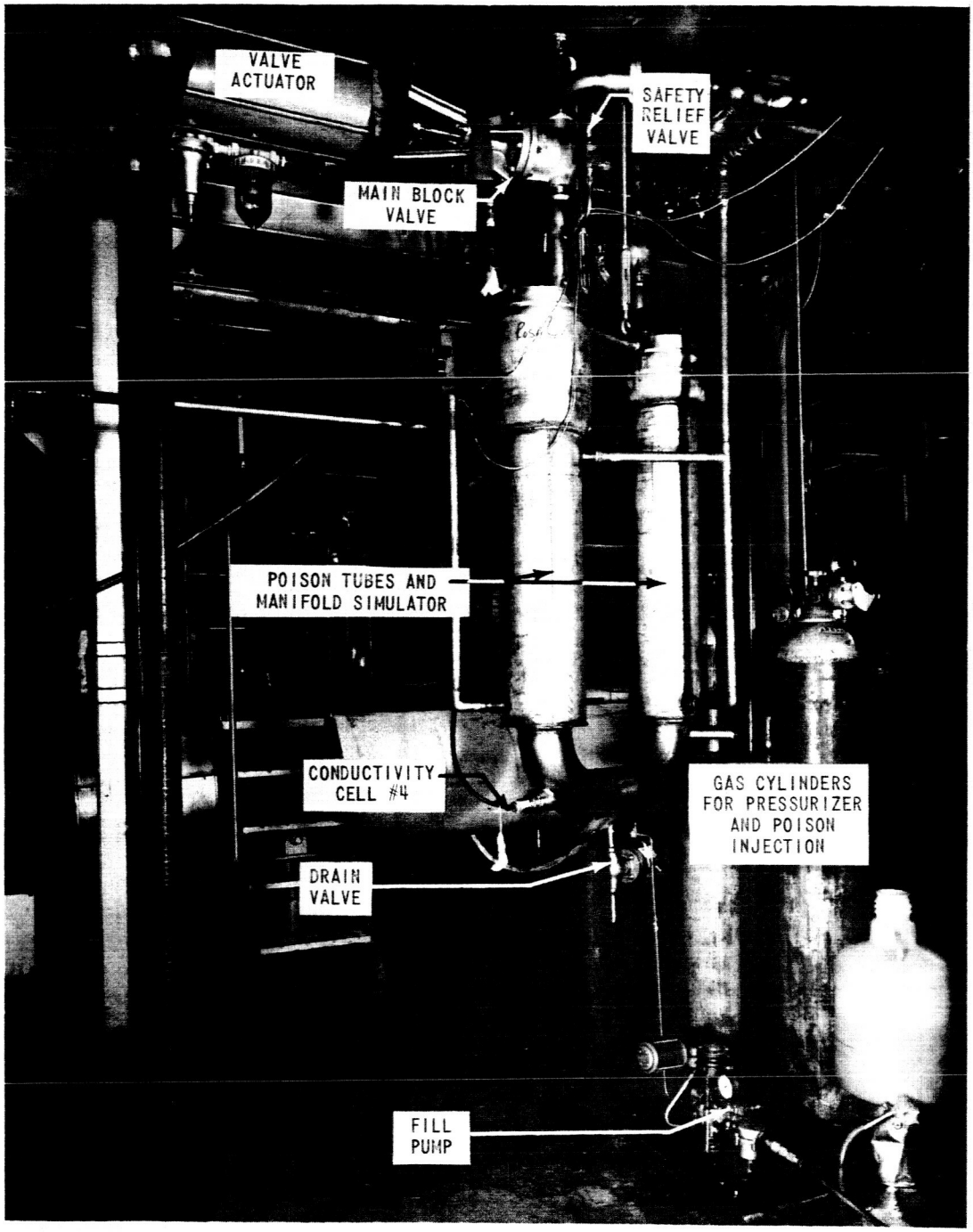


FIGURE 4

CPLS LABORATORY VERSION
LOWER VIEW

c. Addition of a cooler in the ion-exchange bypass line was necessary in order to cool the poison solution from main loop fluid temperature of 160°F down to 120°F or less for proper operation of the ion-exchange resin. Because of the piping connections to this cooler, 46 inches of 1/2 inch pipe were added.

d. No auxiliary pump was installed since it was considered unnecessary to evaluate its performance. Instead, the existing main loop pump was operated at reduced flow rates during the determination of time constants.

e. Addition of cooling jackets around the Poison Tubes and Manifold Simulator vertical pipe sections.

All main loop piping was fabricated by using butt welded construction except where flange joints were required. These exceptions were:

a. The pump's suction and discharge connections

b. Orifice plate housing, and

c. 3 inch turbine flowmeter connections

The main loop circulating pump was mounted on eight shock and vibration isolators which in turn were mounted on two 6 inch H-beams about 10 feet above the floor as shown in Figure 2 and 3. This was required because of the piping arrangements.

While the modifications made would change the absolute value of many of the system constants, e.g. system volume for lab system is 32 gallons compared to 22.5 for the flight system, it was not felt that they would affect principles. Furthermore, the performance of the Laboratory Version was to be predicted using the same analog models as for the reference system. By comparing experimental results with those of the analog, the accuracy of the analog could be determined and predictions of flight system performance could be made.

2. Instrumentation and Controls

A revision to the flow and instrumentation schematic of the Laboratory Version which was presented in the Task II Report (NASA CR 54420) is shown in Figure 5. A brief description of the instrumentation and its functions is given in Table 2. Figure 6 shows the Instrument Panel. Figure 7 is this panel's electrical schematic while Table 3 describes the panels' components. The revisions in instrumentation and control were:

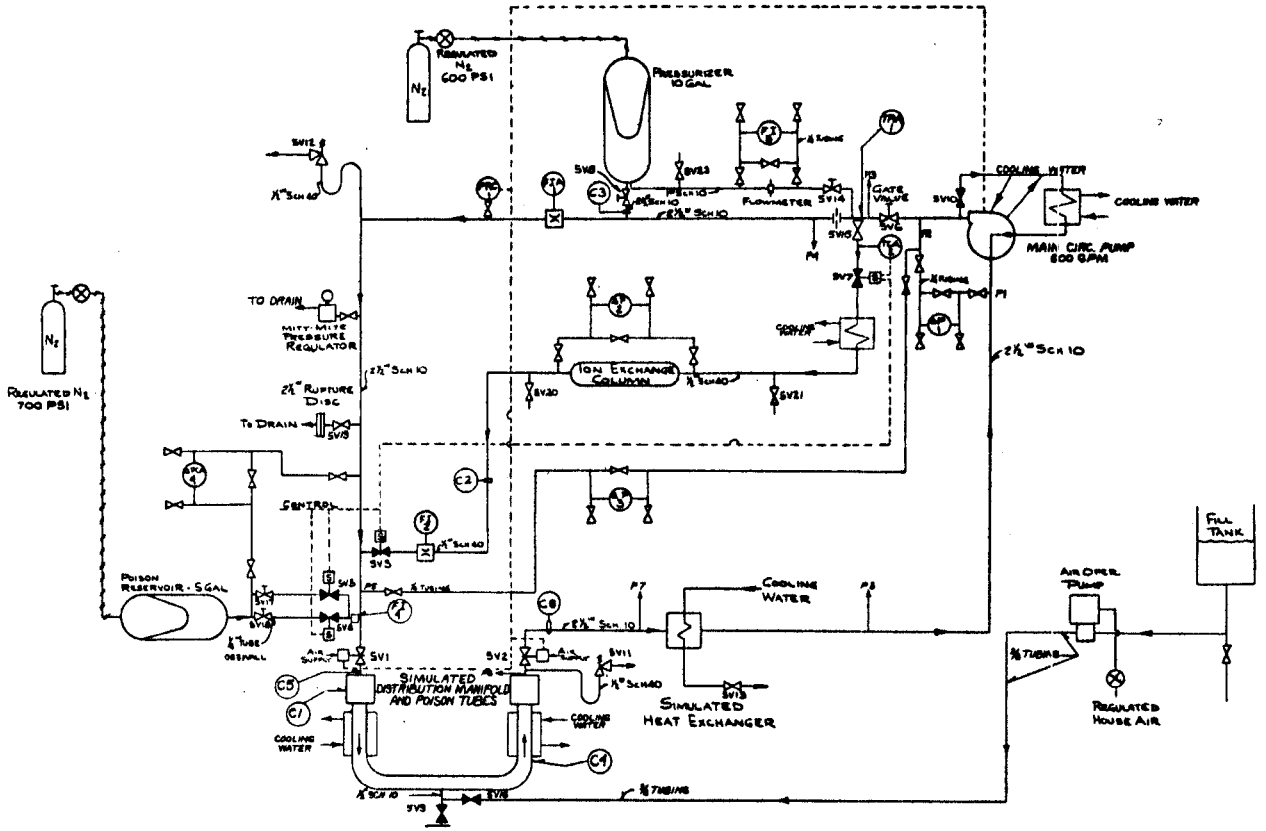


Figure 5

CPLS Laboratory Version Test Facility -
Revised Flow and Instrumentation Schematic

TABLE 2

CPLS Laboratory Version
Instrumentation and Controls

Symbol	Description	Manufacturer	Location	Function	Range
FIA-1	Turbine Flow Meter 3" Flange, Standard Model, 600 psi, 316 SS Indicator Model 581	Potter Aeronautical	Main Piping - Pump Discharge Instrument Panel	Measure and Indicate Loop Flow, Alarm on Low Flow	40 - 450 gpm
FI-2	Turbine Meter, Model MF-8S, ½" NPT, 650 psig, 316 SS Indicator Model 4100	Brooks Instrument	Ion Exchange Outlet Instrument Panel	Measure and Indicate Ion-Exchange Flow Rate	0.75/7.5 gpm
FR-4	Turbine Flow Meter, Micrometer Model MF-90-4161 Series 4000 Indicator Model 581 with 10-50 MA Analog Output	Potter Aeronautical	Poison Injection Line Instrument Panel	Measure and Indicate Poison Injection Rate	0.04/0.5 gpm
	Integrator, Model 66K-LR, Current to Pulse Counter - 6 Digit, Model E-16-11-253-24V	Foxboro Kessler-Ellis	Instrument Panel Instrument Panel	Accept Analog Output of Poison Injection Flow Rate Indicator. Present Totalized Poison Injection Flow	
PRC-1	Pressure Transducer, Model GP-750, #201-903, 316 SS Recorder - Two Pen Model 18-301-330-E29	Baldwin-Lima-Hamilton CEC/DeVar	Main Piping - Pump Discharge Instrument Panel	Measure and Record System Pressure, Alarms, Closes 5V1 and 5V2, and Trips Circulating Pump on Low Pressure	0-750 psig
ΔP-1	Differential Pressure Indicator Model 226, 1000 psig, 316 SS	Barton	Main Piping - Pump Suction and Discharge	Measure and Indicate Circulating Pump Head	0-200 psid
ΔP-2	Differential Pressure Indicator, Model 227, 6000 psi, 316 SS	Barton	Ion Exchange Column	Measure and Indicate Ion Exchange Column Differential Pressure	0-50 psid
ΔP-3	Differential Pressure Indicator, Model 226, 1000 psig, 316 SS	Barton	Main Piping	Measure and Indicate Pump Discharge to Poison Tube Inlet Differential Pressure	0-20 psid (Not Used)
ΔP-4	Differential Pressure Indicator, Model 226, 1000 psig, 316 SS	Barton	Main Piping	Measure and Indicate Poison Reservoir Versus Loop Differential Pressure	0-75 psid
FI-5	Differential Pressure Indicator, Model 226, 1000 psig, 316 SS	Barton	Pressurizer Piping	Measure and Indicate Pressurizer Recirculation Flow Rate	0-10 psid (0- gph)
TRA-1	Temperature Recorder, 2 Pen, Model 18-301-330-E29 (Second Channel of PRC-1)	CEC/DeVar	Instrument Panel	Measures and Records Loop Fluid Temperature. Alarms on High Temperature	0-250°F (I.C. Thermocouple)
TCA-2	Temperature Indicator-Contact Controller. Model 711	Barber-Coleman	Instrument Panel	Measures and Indicator Ion Exchange Stream Fluid Temperature. Alarms and Closes 5V3 & 5V7 to Block IX Flow on High Temperature	0-400°F 125°F Setpoint
C-1	Conductivity Cell, Model [illegible], 316 SS, 500 psi, 100°C	Industrial Instruments	Simulated Poison Tube Inlet Plenum	Measure Fluid Conductivity in Poison Tube Inlet Plenum. Output Recorded on Visicorder	1.0 Cell Constant
C-2	Conductivity Cell, Model [illegible] 316 SS, 500psig, 100°C with Integral Compensation.	Industrial Instruments	Ion Exchange Column Outlet Stream	Measure and Indicate Ion Exchange Outlet Fluid Conductivity	.004 Cell Constant
	Conductivity Bridge, Col-Meter, Model PA4-WA-14-CF, with Automatic Compensation	Industrial Instruments	Instrument Panel		0.5 to 10 megohm-cm
C-3	Conductivity Cell, Same as C1	Industrial Instruments	Ion Exchange Column Inlet Stream	Measure IX Column Inlet Fluid Conductivity	1.0 Cell Constant
	Conductivity Bridge, Col-Meter, Model PA4-WA-333-CF-1 (Spec) with Manual Temperature Compensation. 0-10 MVDC Output Signal Proportional to Scale Reading	Industrial Instruments	Instrument Panel		100 to 3000 micro-mhos/cm
C-4	Conductivity Cell, Same as C1	Industrial Instruments	Simulated Poison Tube	Measure Average Poison Tube Fluid Conductivity. Output Recorded on Visicorder	1.0 Cell Constant
C-5	Conductivity Cell, Same as C1	Industrial Instruments	Main Piping-at Entrance to Poison Tube Inlet Plenum	Measure Fluid Conductivity at Entrance to Poison Tube Inlet Plenum. Output Recorded on Visicorder	1.0 Cell Constant
C-6	Conductivity Cell, Same as C1	Industrial Instruments	Main Piping-at Exit of Poison Tube Outlet Plenum	Measure Fluid Conductivity at Exit of Poison Tube Outlet Plenum	1.0 Cell Constant
	Visicorder, Light Beam Galvanometer, 24 Channel	Heiland	Instrument Panel	Record Conductivity Cell Outputs from C1, C4, C5, C6	Calibrated for 400 to 5700 ohm-cm

FIGURE 6

CPLS LABORATORY VERSION
INSTRUMENT PANEL

Figure 7

CPLS Laboratory Version Test Facility - Control Panel Electrical Schematic

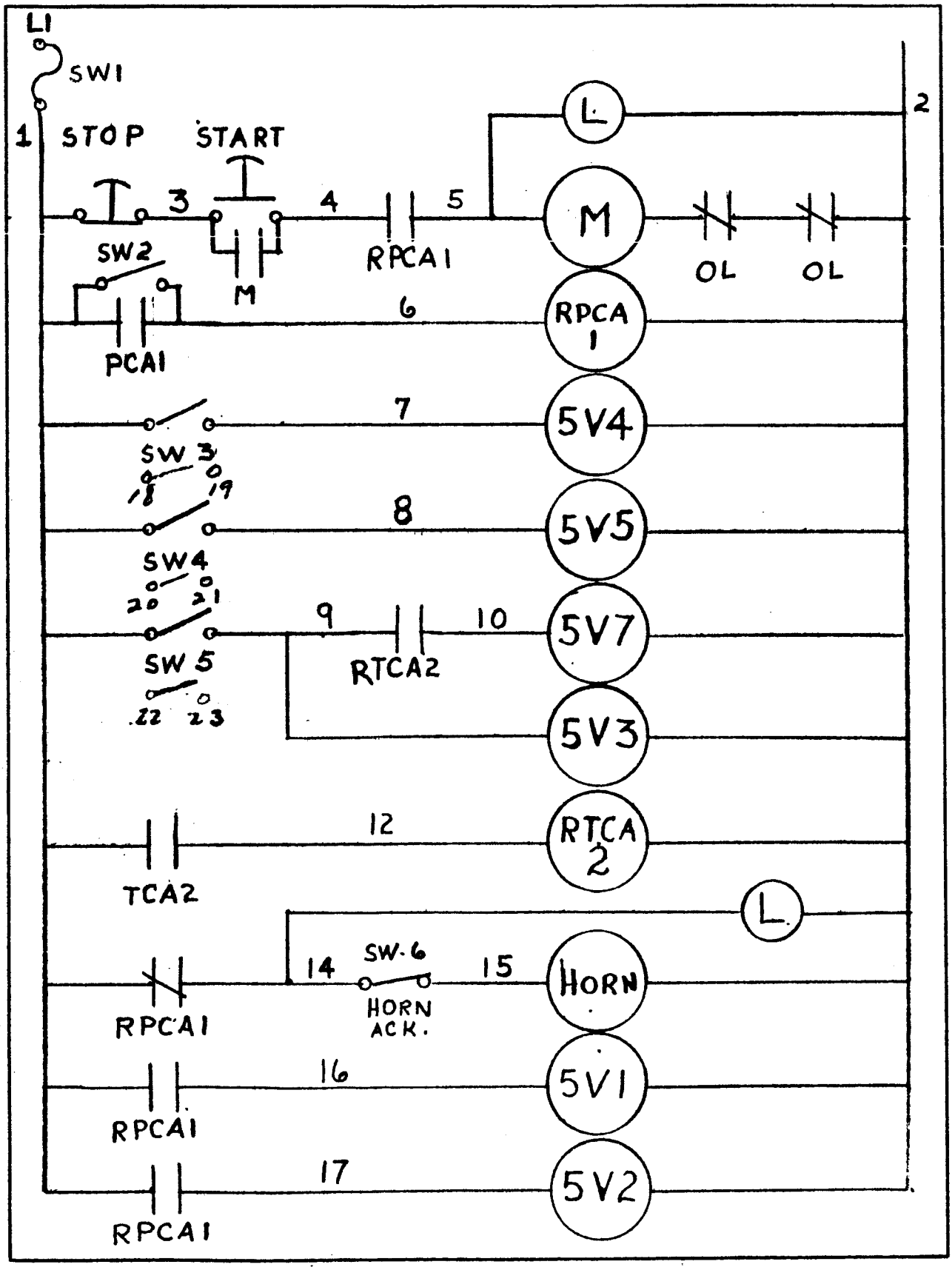


TABLE 3

CPLS Laboratory Version Control Component Identification

M	-	120 Volt Coil Main Circ. Pump Contactor
SW1	-	120 Volt Instrument Power Switch
SW2	-	Low Pressure Bypass Switch
SW3	-	Fast Poison Injection Control Switch
SW4	-	Slow Poison Injection Control Switch
SW5	-	Ion Exchange Column Solenoids Control Switch
SW6	-	Horn Acknowledge Switch
PCA1	-	CEC Loop Pressure Recorder
TCA2	-	Barber-Coleman Ion Exchange Temperature Indicator and Control
RPCA1	-	4 Pole Control Relay, on Low Pressure Signal from PCA1 - Trips Pump, Solenoid Valves SV1 and SV2 and Low Alarm Contact to Horn
RTCA2	-	2 Pole Control Relay, Operates Ion Exchange Solenoid 5V7
5V1	-	Air Operated Solenoids for Plenum Inlet and Outlet Block Valves
5V2	-	Air Operated Solenoids for Plenum Inlet and Outlet Block Valves
5V4	-	Fast Poison Injection Solenoid
5V5	-	Slow Poison Injection Solenoid
5V3	-	Ion Exchange Flow Solenoid
5V7	-	Ion Exchange Flow Solenoid Controlled by TCA2

a. The cooling water to the Simulated Heat Exchanger was not automatically controlled. It was regulated manually.

b. A single Turbine Micro Flowmeter was used to measure fast and slow poison injection flow rates, rather than one for each of the two injection lines.

c. The gas pressure to the poison reservoir was not controlled by a differential pressure transmitter and controller, but was performed manually.

d. Turbine type flowmeters were used instead of the magnetic type components. Because of their bulkiness, the magnetic type interferred with piping and component location in the out-of-core flight system.

3. Ion-Exchange Column Design and Testing

a. Design

A full size ion-exchange column was designed based on the results obtained from the reduced-scale model studies. A general assembly and detailed drawings of this component are shown in Figures 8 and 9. The column body consists of 46 inches of 10 inch schedule 40, seamless pipe. The bottom of the column is a 10 inch end cap, welded to the pipe. The cap contains a retaining Johnson type screen, used to prevent the ion-exchange resin particles from coming out of the column during operation. a 1/2 inch schedule 40 pipe welded to the end cap is used as the column outlet. The top of the column is made of a welded 300 lb. slip-on flange. The cover is a 300 lb. blind flange, with a top retaining Johnson type screen and piston assembly, a center guide post, and a spring. A 1/2 inch penetration with a nipple of 1/2 inch schedule 40 pipe, is used as the inlet. All these components are fabricated from 316 stainless steel material with the exception of the piston's Teflon, "O" rings. Figure 8 also shows the mounting iron flange, and the aluminum bracket, used to support the column during the G-loading and vibration tests.

b. Testing

Prior to the installation of the ion-exchange column in the Laboratory Version testing facility, it was subjected to hydraulic, G-loading and vibration tests. The sequence and results from these tests were as follows:

1) Loading of the column with 88.5 pounds of wet resin to a bed height of 36-3/4 inches.

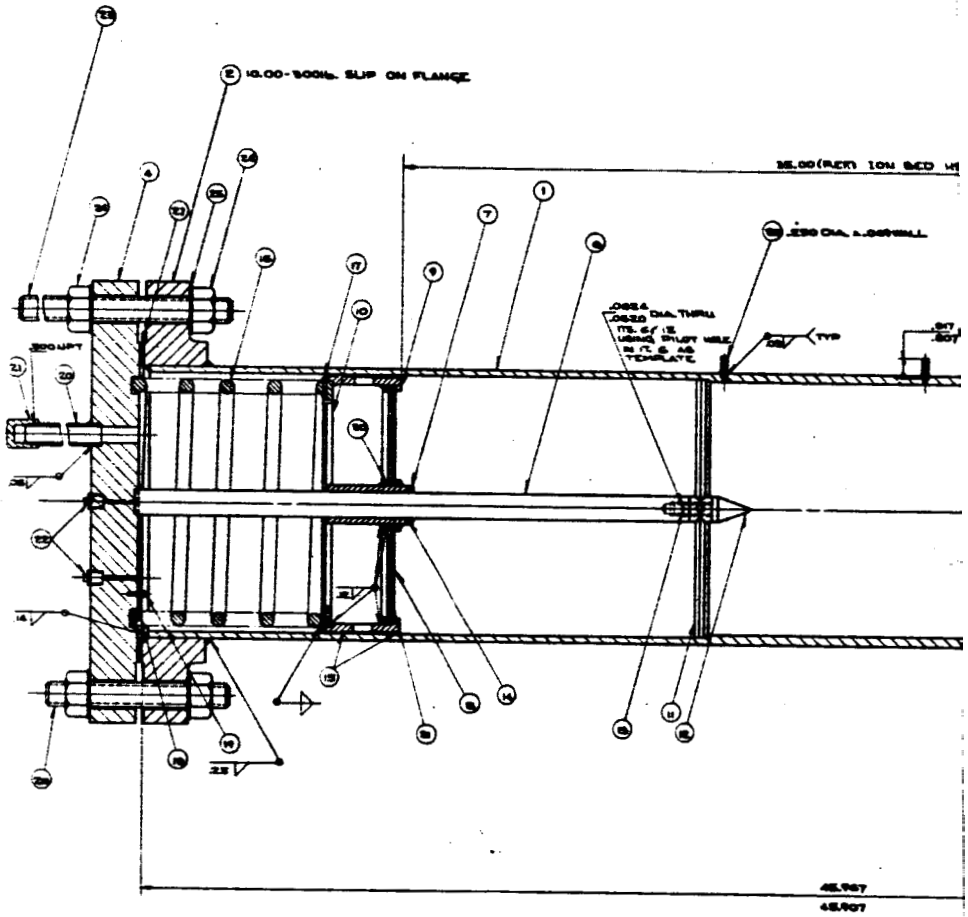
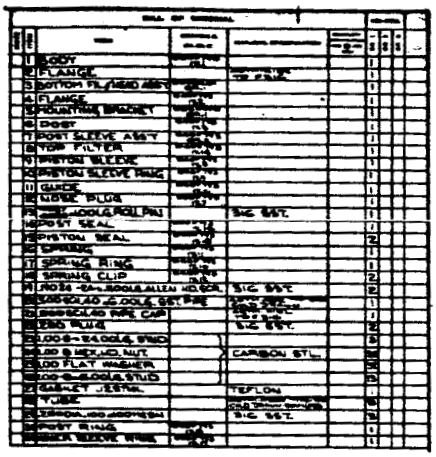
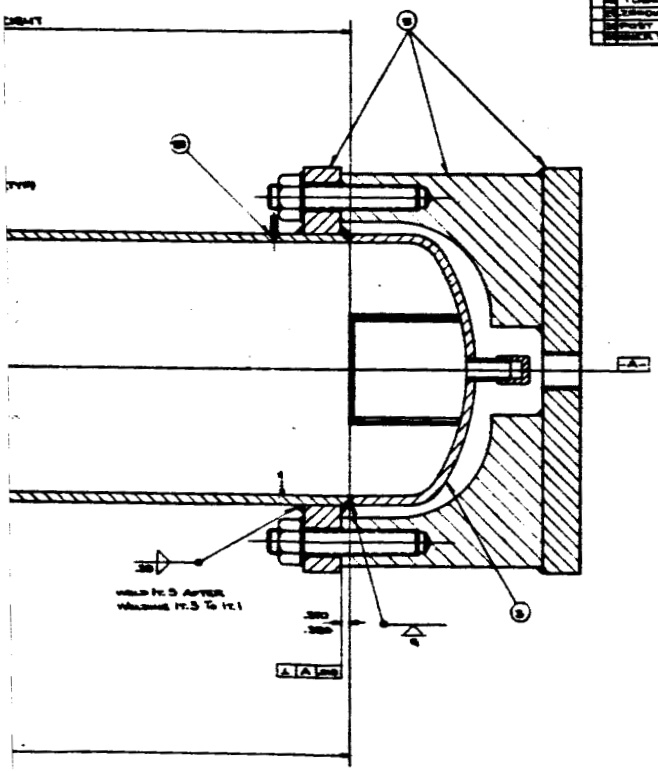


Figure 8

Ion Exchange Column - Ge





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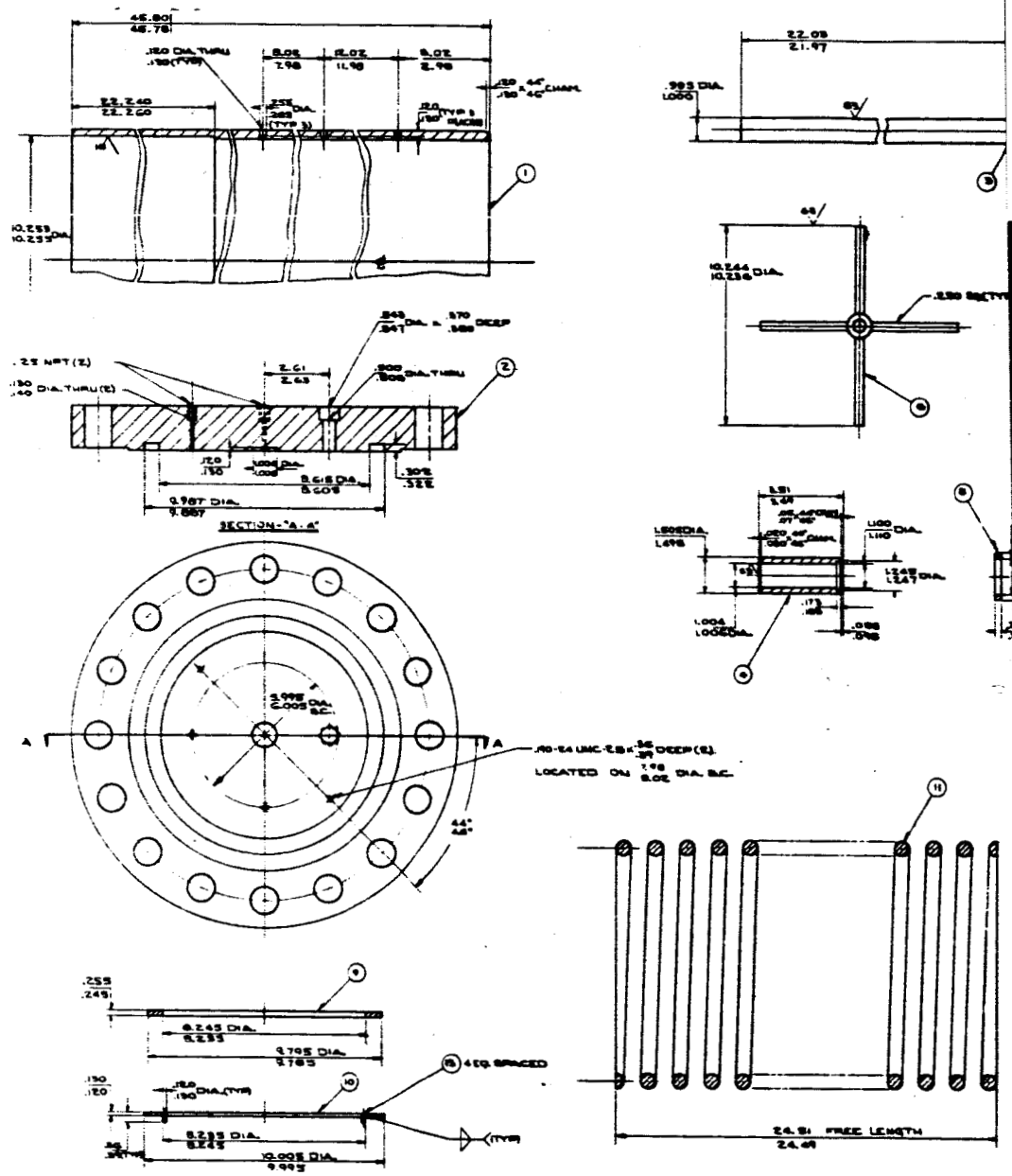
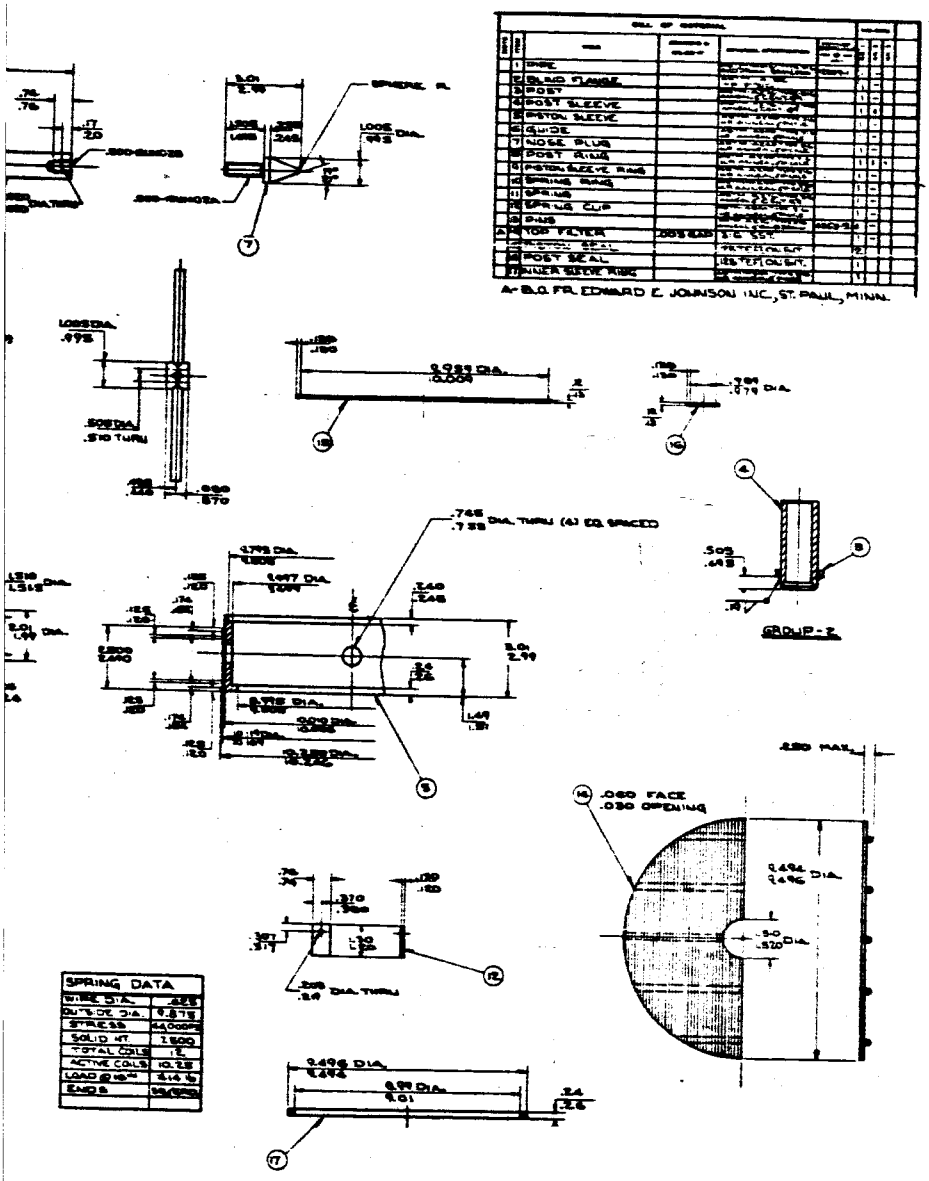
2



Figure

Ion Exchange Colum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GROUP-2
.060 FACE
.030 OPENING
SPRING DATA

n - Detail

2) Flow compaction at flow rates of 8.8 and 20 gpm per ft^2 without the spring and piston assembly. No significant bed compaction was observed.

3) Flow compaction at the same flows as in Item 2 with the spring and piston assembly installed inside the column. A bed compaction of about 1/2 inch was measured.

4) Pressure drop measurements across the column before G-loading and vibration tests. These measurements were made during the flow compaction tests.

5) G-loading and vibration tests in the longitudinal direction according to the following procedure:

   a) Three exploratory runs to determine a natural frequency or any significant harmonics. These runs consisted of:

      Run No. 1 at 1-G level with a sweep from 10 to 2000 cps for a period of 4.2 minutes.

      Run No. 2 at 5-G level with a sweep from 14 to 2000 cps, and 1/2 inch double amplitude from 10 to 14 cps for a total of 4.2 minutes.

      Run No. 3 a downward sweep at 0.3 G-level from 15 to 3 cps for 6.4 minutes.

   No natural frequency or significant harmonics were found during these tests.

   b) Two runs at the 10-G level at frequencies from 15 to 2000 cps for a total period of 22 minutes. Each run consisted of sweeping from 15 to 2000 and down to 15 cps for 11 minutes. A bed compaction of 1/8 inch was measured after these tests. No lateral G-loading and vibration tests were performed because when the reduced scale models were subjected to these tests, they did not show any appreciable compaction. Figure 10 illustrates the facility used in these G-loading and vibration tests.

6) Installation of the ion-exchange column in the Laboratory Version testing facility. Test results obtained during the operation of the column as part of this system are discussed in Section III B.

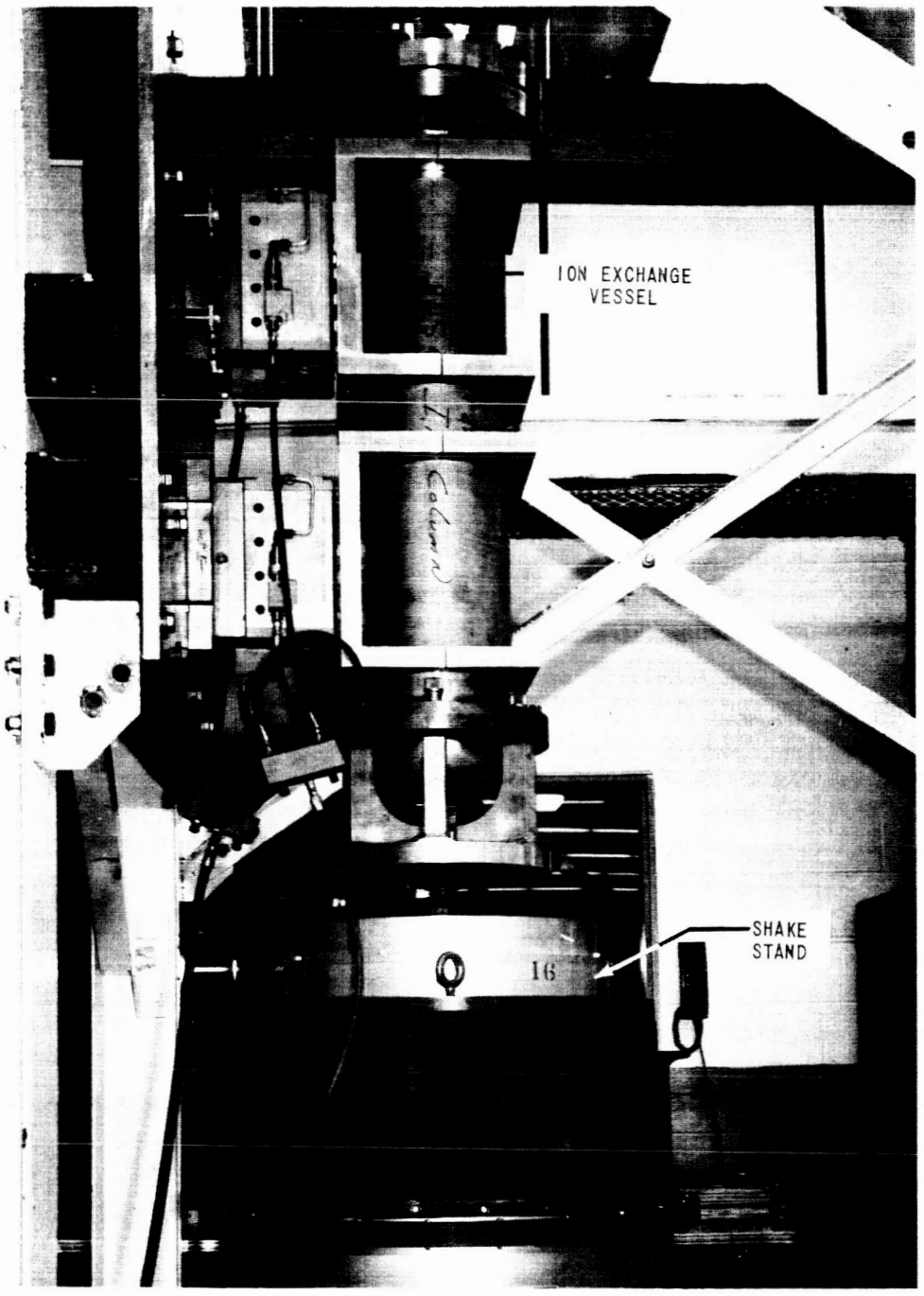


FIGURE 10

ION-EXCHANGE VESSEL SET UP FOR VIBRATION
& G-LOAD TESTS

4. Shakedown Operation

During the first shakedown runs the following problems were encountered:

a. The line bearing on the main circulating pump burned after only a half hour of operation. The pump was placed back in operation after changing this bearing twice and loosening the front oil seal. This seal was thought to be the cause of these failures because it was too tight around the pump shaft creating excessive amounts of frictional heat. To further prevent future failures, cooling water was provided to the oil bath housing and volute and the mechanical seal was continuously purged with cooled loop fluid passed through a small cooler (see Figure 3). After these modifications the pump ran properly.

b. During the initial shakedown runs, the main loop turbine flow meter lost all of its turbine blades. The meter was repaired and recalibrated, and put back in operation. However, the same problem occurred again. The probable cause of these failures was the impingement on the blades fluid jet with a velocity exceeding the maximum design velocity of 28 ft/sec at 650 gpm for this meter. One of the factors contributing to formation of this jet was the meter location, about 3-1/2 pipe diameters downstream from the orifice plate. In addition, since the inside diameter of the flow meter is equivalent to a 3 inch schedule 40 pipe, a transition fitting was made at the inlet flange connection. The situation could have been improved by locating the flow meter at least 10 pipe diameters downstream of the transition piece, and using flow straighteners. However, this was not done because it would have increased the loop piping length, therefore increasing the loop volume, and it would have required major piping modifications. It was decided to remove the flow meter from the system and replace it with a 3-inch pipe spool of the same length. Then, the loop flows were set by using the circulating pump manufacturers' curve of Total Developed Head vs. flow. Calibration data for this curve was obtained from the manufacturer for this particular pump, and it was considered reliable, being certified at $\pm$ 1% accuracy.

c. The loop temperature increased to 236°F in about 45 minutes of running time due to heat induced by the pump during trial runs. There was a lack of heat removal capacity area in the simulated heat exchanger with only water being circulated on the tube side. Therefore, cooling jackets were welded around the vertical 5" pipe legs of the poison tube-manifold simulator. The additional cooling provided by these jackets

in conjunction with the pump's volute, bearing housing and mechanical seal coolers, and the simulated heat exchanger, was sufficient to lower the loop fluid temperature to a maximum of about 150°F during normal operation. Because of the 150°F loop fluid temperature and the maximum operating temperature of 140°F for the ion-exchange resin, a cooler was installed in the ion exchange column bypass line which lowered the fluid temperature of 120°F or less in that line during extended system operation.

d. Valves 5V17 and 5V18 controlling the fast and slow poison injection flows were originally 1/4 inch valves (Whitey #0 Series) with a "Vec" stem. This type of stem did not offer adequate flow control because with a single full turn of the handle 92% of the flow was obtained. Therefore, these valves were replaced with valves having "micro-regulating" stems. However, the pressure drop across the valves increased. This required that the gas pressure of the poison reservoir be raised to 100 psig above the loop operating pressure.

III. TEST PROGRAM AND RESULTS FOR THE CPLS LABORATORY VERSION

The test program performed on the Laboratory Version was directed toward obtaining as much new information as possible which could be used in determining the feasibility of controlling the TWMR by such a system. Some of the test objectives have already been described in the previous section because they were performed during the system shakedown operations. The detailed proposed program is listed in Section II D of the Task II Report NASA-CR-54420 and will not be repeated here.

A. Tests of Poison Injection System

The poison injection system was used to introduce concentrated cadmium sulfate solution into the main flow stream. How consistently and with what repeatability this system was operating could be measured by:

1. measuring the injection flowrate,
2. measuring the main stream change of cadmium concentration with time,
3. measuring the injection system pressure variations as injection was in progress.

The poison concentrate solution could be injected into the main flow stream through either one of two paths. During the shakedown phase of operation, one path was set to deliver 0.25 gpm with a 100 psi overpressure. The other path would deliver one fourth of this or 0.0625 gpm with the same 100 psi overpressure. These injection rates are referred to as the fast rate and slow rate respectively on the chronological history curves, Figures 11, a) thru c). The initial series of injections was used to establish proper functioning of conductivity cells and recording equipment, for conductivity cell calibration and to answer the questions of the consistency and repeatability of the system.

These early injection runs were also used to obtain data to evaluate the performance of the manifold-poison tube simulation of the system. As previously indicated, the 198 poison tube in-core array and two manifolds were simulated in the Laboratory Version by a pair of mixing chambers and a single 5" I.D. U-bend pipe. Certain of the data taken were compared with data from the operation of the plexiglas model, reported in NAS -CR-54994. Specifically, the data from Injection #8 of the Laboratory Version was compared with the data from Run #25 of the plexiglas model (see page 25, Figure IV-12, NASA-CR-54994). The point of comparison selected was the manifold outlet leg conductivity cell from both runs. This point was selected as that reference which would indicate most adequately the overall mixing performance of both the plexiglas model and the poison tube-manifold simulator. The trace of conductivity versus time for that cell as transferred from the visicorder trace with proper calibration data is shown in Figure 12 and the data comparison is discussed in Section IV-A.

Figure 11a

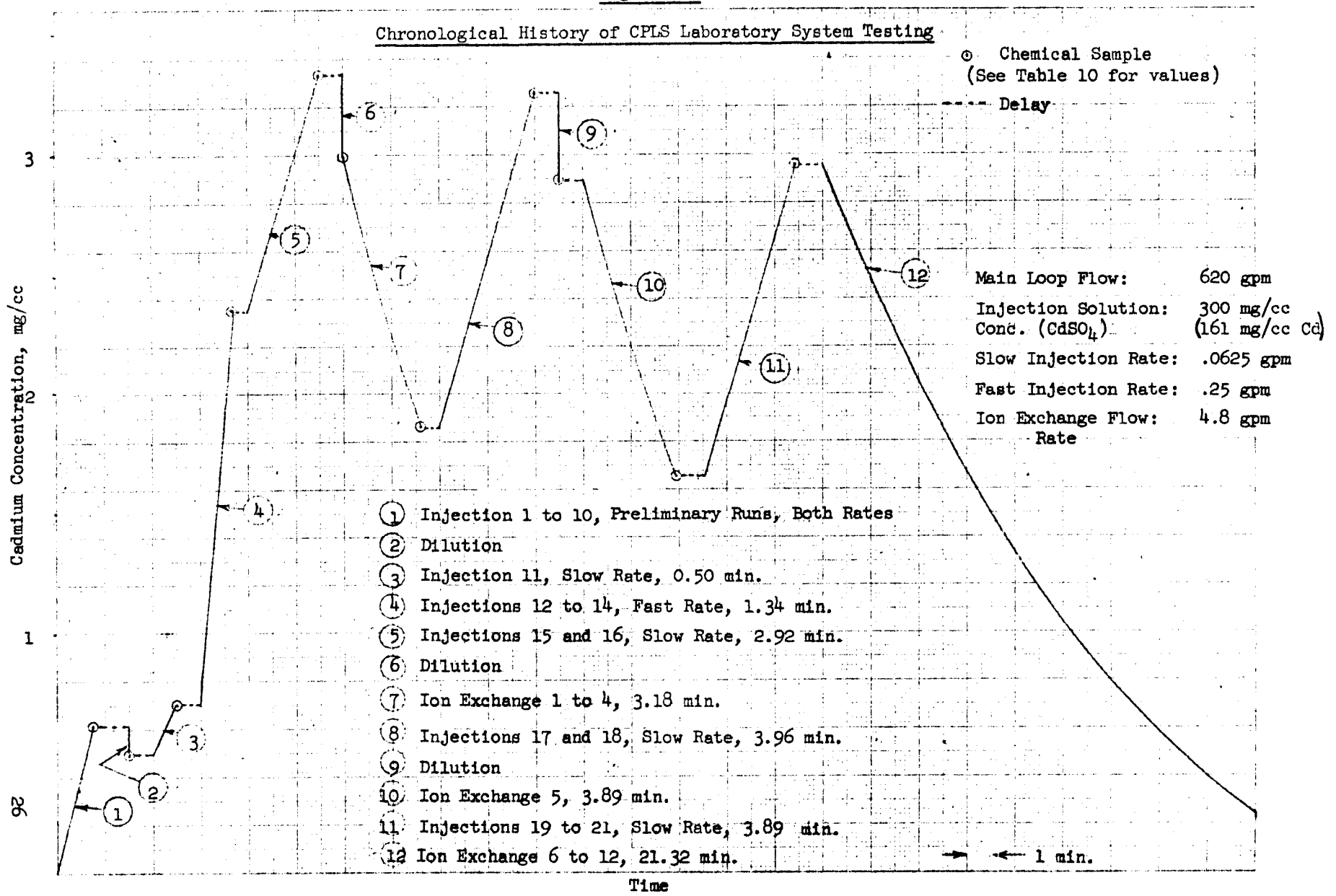

Chronological History of CPLS Laboratory System Testing
Chemical Sample
(See Table 10 for values)
Delay
Cadmium Concentration, mg/cc
3
2
1
26
Time
Main Loop Flow: 620 gpm
Injection Solution Conc. ($CdSO_4$): 300 mg/cc (161 mg/cc Cd)
Slow Injection Rate: .0625 gpm
Fast Injection Rate: .25 gpm
Ion Exchange Flow Rate: 4.8 gpm
1 Injection 1 to 10, Preliminary Runs, Both Rates
2 Dilution
3 Injection 11, Slow Rate, 0.50 min.
4 Injections 12 to 14, Fast Rate, 1.34 min.
5 Injections 15 and 16, Slow Rate, 2.92 min.
6 Dilution
7 Ion Exchange 1 to 4, 3.18 min.
8 Injections 17 and 18, Slow Rate, 3.96 min.
9 Dilution
10 Ion Exchange 5, 3.89 min.
11 Injections 19 to 21, Slow Rate, 3.89 min.
12 Ion Exchange 6 to 12, 21.32 min.
1 min.

Figure 11b

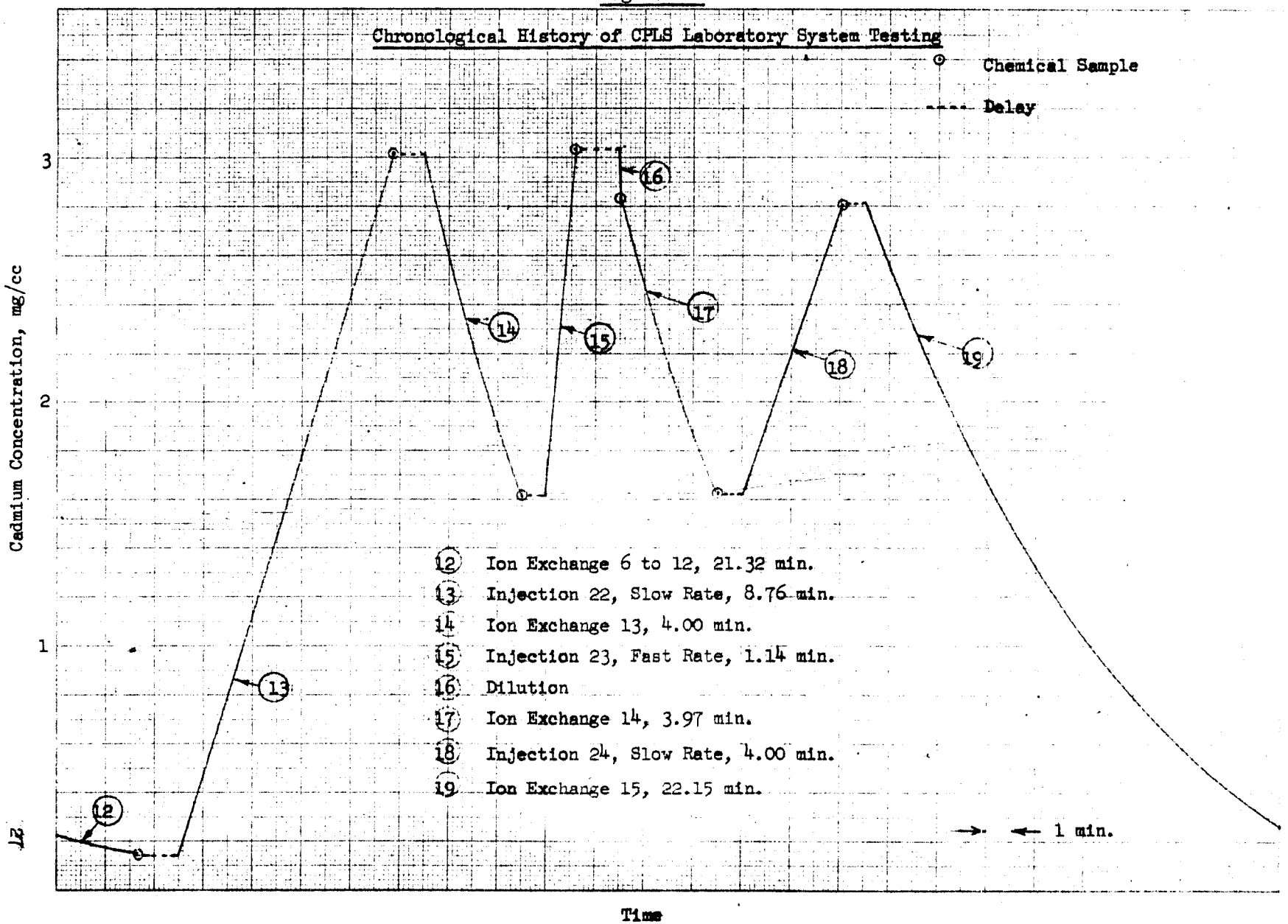

Chronological History of CPLS Laboratory System Testing
Chemical Sample
Delay
Cadmium Concentration, mg/cc
3
2
1
0
Time
12 Ion Exchange 6 to 12, 21.32 min.
13 Injection 22, Slow Rate, 8.76 min.
14 Ion Exchange 13, 4.00 min.
15 Injection 23, Fast Rate, 1.14 min.
16 Dilution
17 Ion Exchange 14, 3.97 min.
18 Injection 24, Slow Rate, 4.00 min.
19 Ion Exchange 15, 22.15 min.
1 min.

Figure 11c

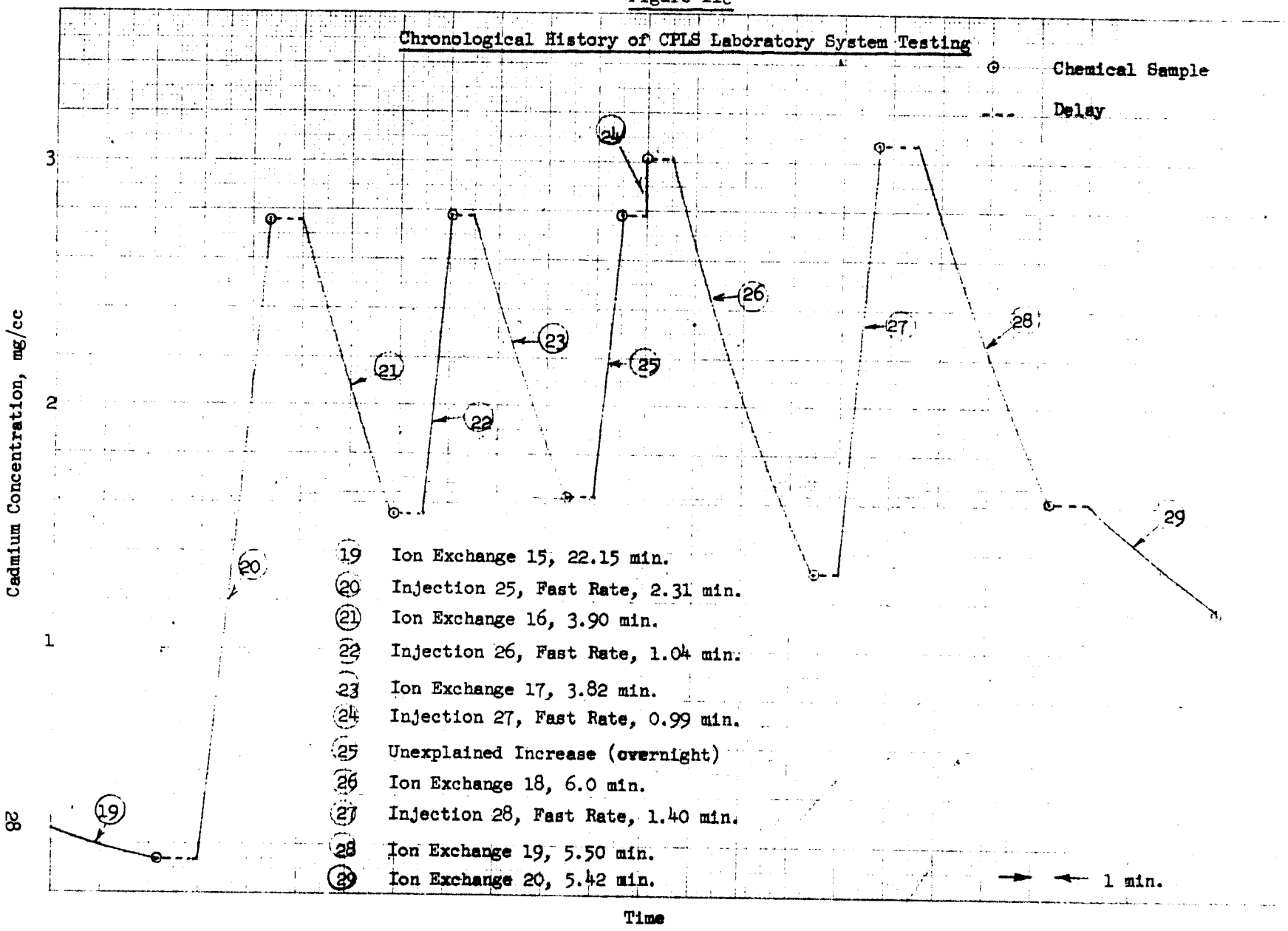
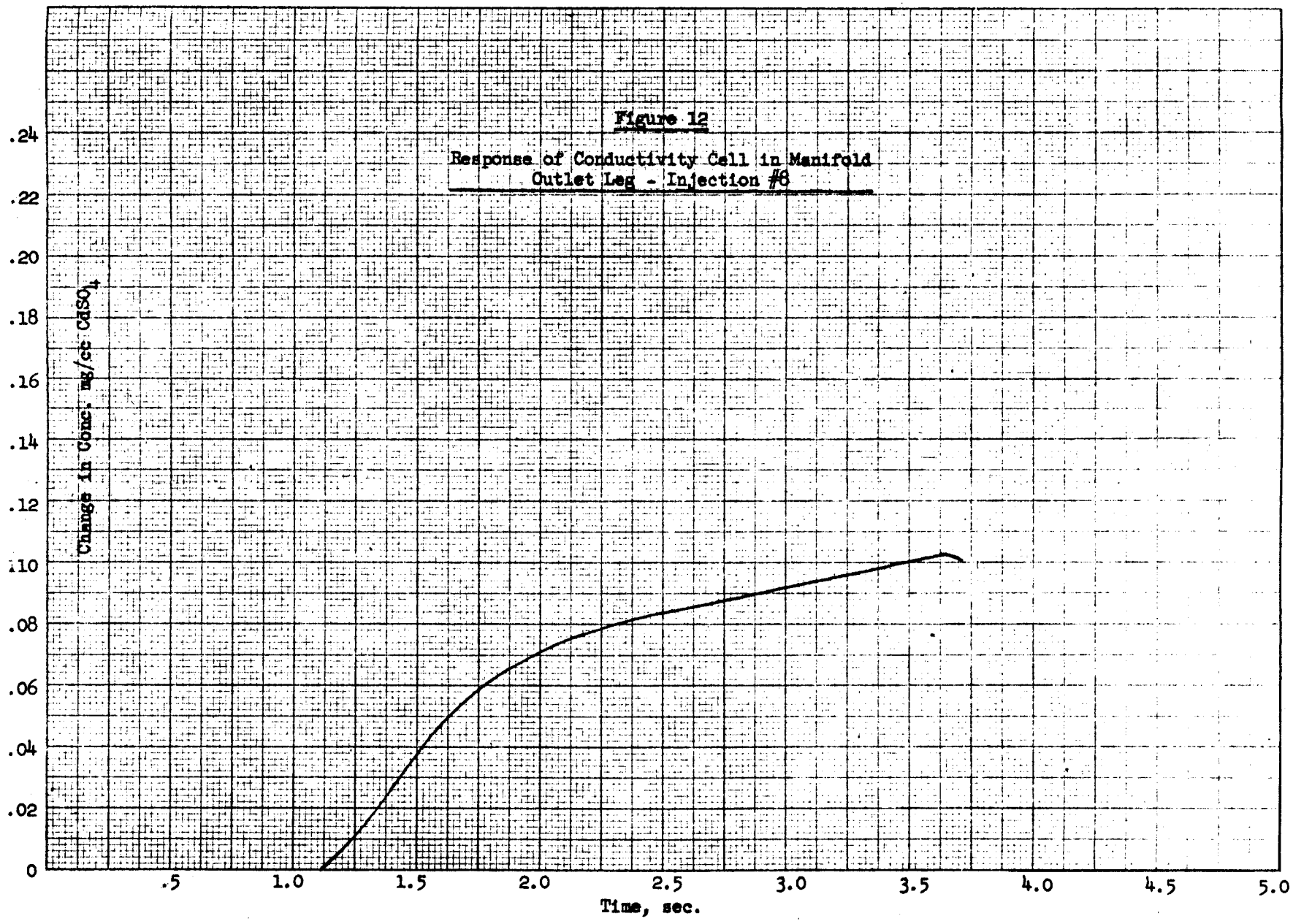

Chronological History of CPLS Laboratory System Testing
Chemical Sample
Delay
Cadmium Concentration, mg/cc
3
2
1
19 Ion Exchange 15, 22.15 min.
20 Injection 25, Fast Rate, 2.31 min.
21 Ion Exchange 16, 3.90 min.
22 Injection 26, Fast Rate, 1.04 min.
23 Ion Exchange 17, 3.82 min.
24 Injection 27, Fast Rate, 0.99 min.
25 Unexplained Increase (overnight)
26 Ion Exchange 18, 6.0 min.
27 Injection 28, Fast Rate, 1.40 min.
28 Ion Exchange 19, 5.50 min.
29 Ion Exchange 20, 5.42 min.
1 min.
Time

Figure 12

Response of Conductivity Cell in Manifold Outlet Leg - Injection #6



The flow rate measurements made during the various injections indicated that once the initial flow rates were accurately set, activation of the solenoid valve in the line would always result in the same injection rate. It took a fraction of a second for the flow indicator to reach its predetermined value after the solenoid was activated. There was about the same time delay for the indicator to drop to zero flow once the solenoid was deactivated. The accuracy of the injection flows was confirmed by taking liquid samples of the loop contents periodically during some of the longer injection runs. The change of system cadmium concentration was consistent with the loop volume; injection time and flow rate, and the concentration of the solution in the poison concentrate tank.

The pressure gauge installed on the poison concentrate tank was monitored during both short and long injections. The pressure in this tank was preset to 700 psi (100 psi above the loop pressure) before each injection, by adjusting the regulator on the argon gas cylinder connected to the secondary side of the bladder in the tank. The tank pressure did not vary by more than 5 psi during any of the injections, whether at the slow or fast rate.

During most of the injections, a calibrated direct reading meter, connected to conductivity cell #3, was continuously monitored. When the desired level of cadmium concentration was reached, the injection solenoid valve was closed. At the time of closing, a cadmium concentration gradient existed in the system. Since the concentration at the measuring point was lower at that instant of time than most of the rest of the system, the eventual equilibrium system concentration, indicated on the meter, existing a few seconds after shutoff would be slightly higher than at shutoff. This was partially avoided later by anticipating the conductivity meter and shuting-off the solenoid a few seconds before reaching the desired level.

B. Tests of the Ion Exchange System

The ion exchange system must be capable of removing enough cadmium from the loop solution to allow the TWMR to go from shutdown to hot critical and from shutdown to a xenon override critical the desired number of times. During its lifetime, it must be capable of withstanding vibrational loads as well as longitudinal G-loads, its hydraulic characteristics must be predictable and remain relatively unchanged, its capacity to remove the poison salt from solution must be predictable and adequate, and the time required to remove this salt must be predictable and consistent.

Before the CPLS ion exchange system was designed, small scale tests were required to determine the ion exchanger geometry, capacity, hydraulic characteristics, and behavior under vibration and G-load conditions.

Bench scale ion exchange tests were run early in the program to determine the capacity of ion exchange resin for cadmium as the sulfate under conditions similar to those anticipated in the CPLS. The tests and results were fully described in the Task II report, NASA-CR-54420. Table 4 and Figure 13 have been taken from that report in order to

Table 4

Test Conditions and Results of Bench-Scale Ion Exchange Evaluations

Cadmium Sulfate

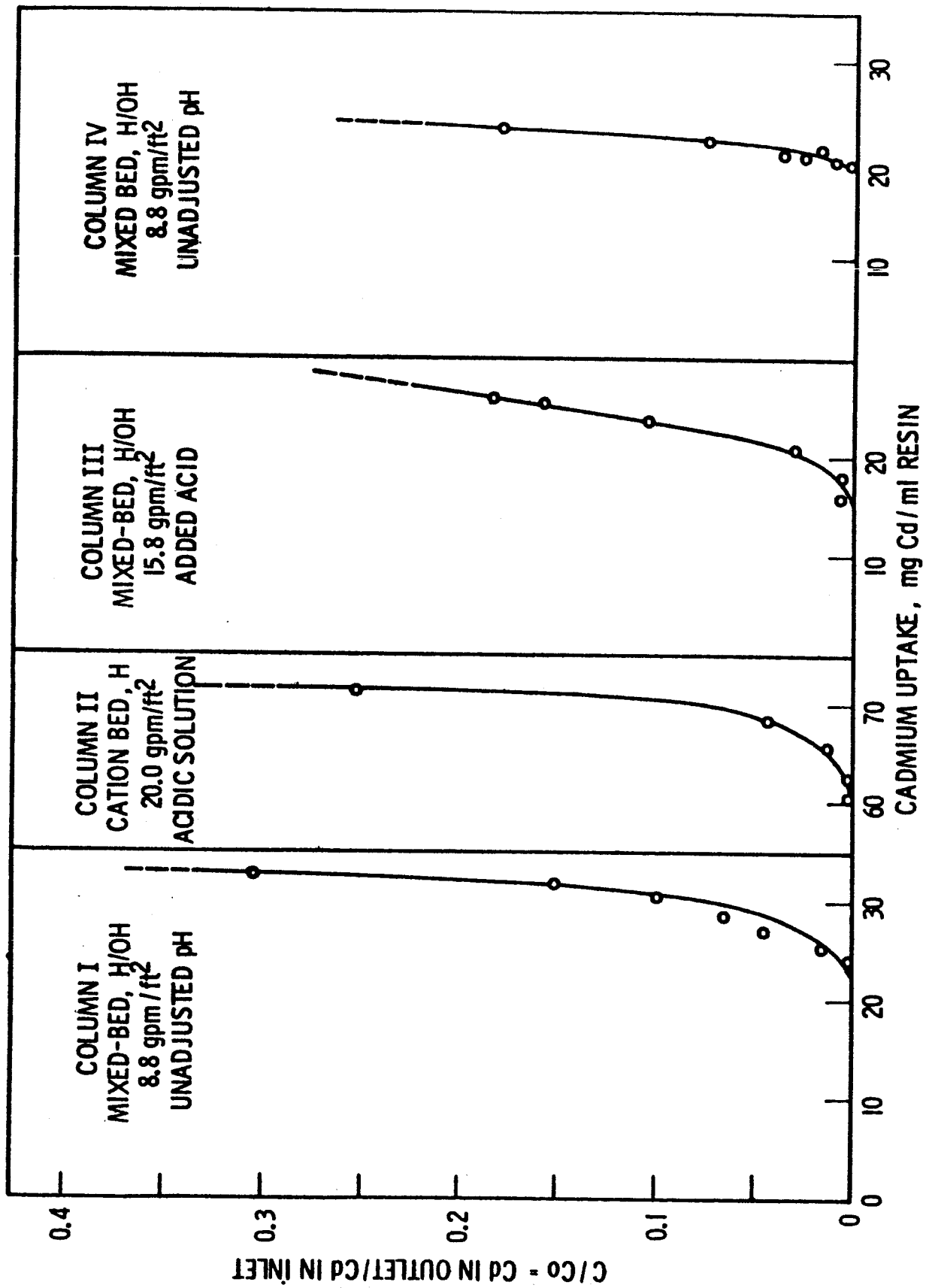
Test Number	I	II	III	IV
I-X Resin	Mixed-Bed Xe-150,H/OH	Cation Bed Xe-77,H	Mixed-Bed Xe-150,H/OH	Mixed-Bed Xe-150,H/OH
I-X Flow, gpm/ft^2	8.8	20.0	15.8	8.8
I-X Resin Initial Volume, cc	170	170	165	382
I-X Bed Size, diam., in.	0.813	0.813	0.813	0.97
Initial length, in	20	20	19.25	30.5
Loop Solution Chemistry	Unadj. $CdSO_4$	Unadj. $CdSO_4$	Acidic $CdSO_4$	Unadj. $CdSO_4$
Nominal pH	6.0	6.0 to 1.0	4.4 to 2.5	6.0
Nominal conductivity, mMhos/cm	2.5	2.7 to 3.5	2.7 to 3.4	2.5
Loop Solution Volume, cc	620	910	800	730
Cadmium Concentrations (design)*				
Shutdown, mg Cd/cc	2.6	2.6	2.97	2.97
Hot Critical, mg Cd/cc	1.87	1.87	1.65	1.65
Xenon Override, mg/cc	0.244	0.244	0.126	0.126
Number of Startup Cycles				
To Hot Critical	4	6	3	6
To Xenon Override	2	2	1	2
Total Cd on Resin, mg	5510	12162	5024	9128
mg Cd/cc Resin	32.4	71.5	30.4	23.9
Final Resin Volume, cc	138	158	128	273
Breakthrough Concentration				
mg Cd/cc Resin	22	60	15	20
Volume of Resin Required				
For CPLS**(at breakthrough), liters.	34	13	50	37

*Design values changed following the second test.

**Based on the requirement to remove 7.45×10^5 mg Cd during 4 startups to hot critical and 1 startup to xenon override, for a CPLS solution volume of 24 gallons.

Figure 13

Bench Scale Ion Exchange - Cadmium Sulfate - Breakthrough Curve



compare with CPLS Laboratory System results which will be discussed later. Additional test results to determine ion exchange capacity for the backup poison, boric acid solution, are reported here in Table 5 and Figure 14 having not been previously reported.

Reduced scale tests were also described in the Task II report. They were run to determine the hydraulic characteristics of the resin bed and support fixtures and the resin capacity, and how these factors are affected by the vibration and G-load levels to be experienced in the flight system. The pressure drop data is shown in Table 6 and Figure 15 and 16. The capacity and breakthrough data is shown in Figures 17 and 18. The resin from columns II and III were later sieved, dried and weighed to determine particle distribution. The results are shown in Table 7. The vibration and G-load test procedure followed is listed in Table 8.

The Laboratory Version Ion Exchanger was initially filled with XE-150 (H-OH form) resin to a height of 36-3/4" or a volume of 48.4 liters. It was vibrated and shaken following the same procedure as listed in Section II, B, 3,b. The vessel was installed in the CPLS and used to remove the cadmium sulfate from solution during the runs shown in the chronological history, Figure 11.

Some of the information gathered during this portion of the tests included the hydraulic characteristics of the ion exchange system, the capacity of the resin for cadmium, and the time required to reduce the cadmium concentration in the loop system from shutdown to hot critical and from shutdown to xenon override critical.

Some of the pressure drop measurements taken during various phases of testing are shown in Figure 19. The total pressure drop of the column as filled and with the spring installed was greater than 10 psi and the data were not included in Figure 19. It was considered that those data were in error, probably due to an inaccurate instrument. This was considered a reasonable assumption since later data points were in the expected range.

The bed height measurements are shown in Table 9. After installing the spring, measurements were taken through a fitting in the top flange. A rod was inserted and a measurement made of its penetration to the top of the screen on the piston. If the piston followed the resin bed surface down as it shrinks, the measurement was an accurate reflection of the bed height. If, the piston hung up, and did not follow the resin, the measurements were inaccurate. Two factors lead to the conclusion that the measurements taken with the spring were inaccurate. First is the apparent drop of 2 11/16"in bed height upon removing the spring. This is just not possible. Secondly, the spring appeared to have relaxed as was evidenced by its failure to spring back to its original length after removal from the system. The length from the top flange to the

TABLE 5

Test Conditions and Results of Bench-Scale Ion Exchange Evaluations
Boric Acid

Test Number	I-B 117333-25	II-B 117333-44	III-B 117333-52
IX Resin	DUOLITE A-101-D	AMBERLITE IRN-150	AMBERLITE IRN-78
IX Flow, gpm/ft^2	8.8	8.8	8.8
IX Resin Initial Volume, cc	304	302	306
IX Bed Size, (Initial)			
Diameter, inches	0.97	0.97	0.97
Length, inches	25.12	25.0	25.25
Loop Solution Chemistry	Boric Acid	Boric Acid	Boric Acid
Nominal pH at 25°C	5.05	5.1	5.1
Nominal Conductance, μ Mhos/cm	4	3	3.8
Loop Solution Volume, cc, Average	824	830	840
Boron Concentrations, nominal, ppm			
Shutdown (design ≈ 1275)	1250	1270	1150
Hot Critical (design ≈ 835)	690	700	775
Xenon Override (design ≈ 64)	193	-	400
Number of Startup Cycles			
To Hot Critical	3	10	10
To Xenon Override	1	-	9
Total Boron on Resin, mg	2445	4413	9650
Specific Uptake, mg B/cc Resin (Initial Volume)	8.05	14.6	31.5
Uptake at Breakthrough, mg B/cc Resin (Initial Volume)	≈6	≈10	≈26
Final Resin Bed Length, Inches	24.81	21.63	24.25
Volume of Resin Required for CPLS, Liters, (based on breakthrough uptake)*	45.0	27.0	10.4

*Based on removal of 2.70×10^5 mg B during 4 startups to hot critical and 1 startup to xenon override, for a CPLS solution of 24 gallons.

Figure 14

Bench Scale Ion Exchange - Boric Acid - Breakthrough Curves

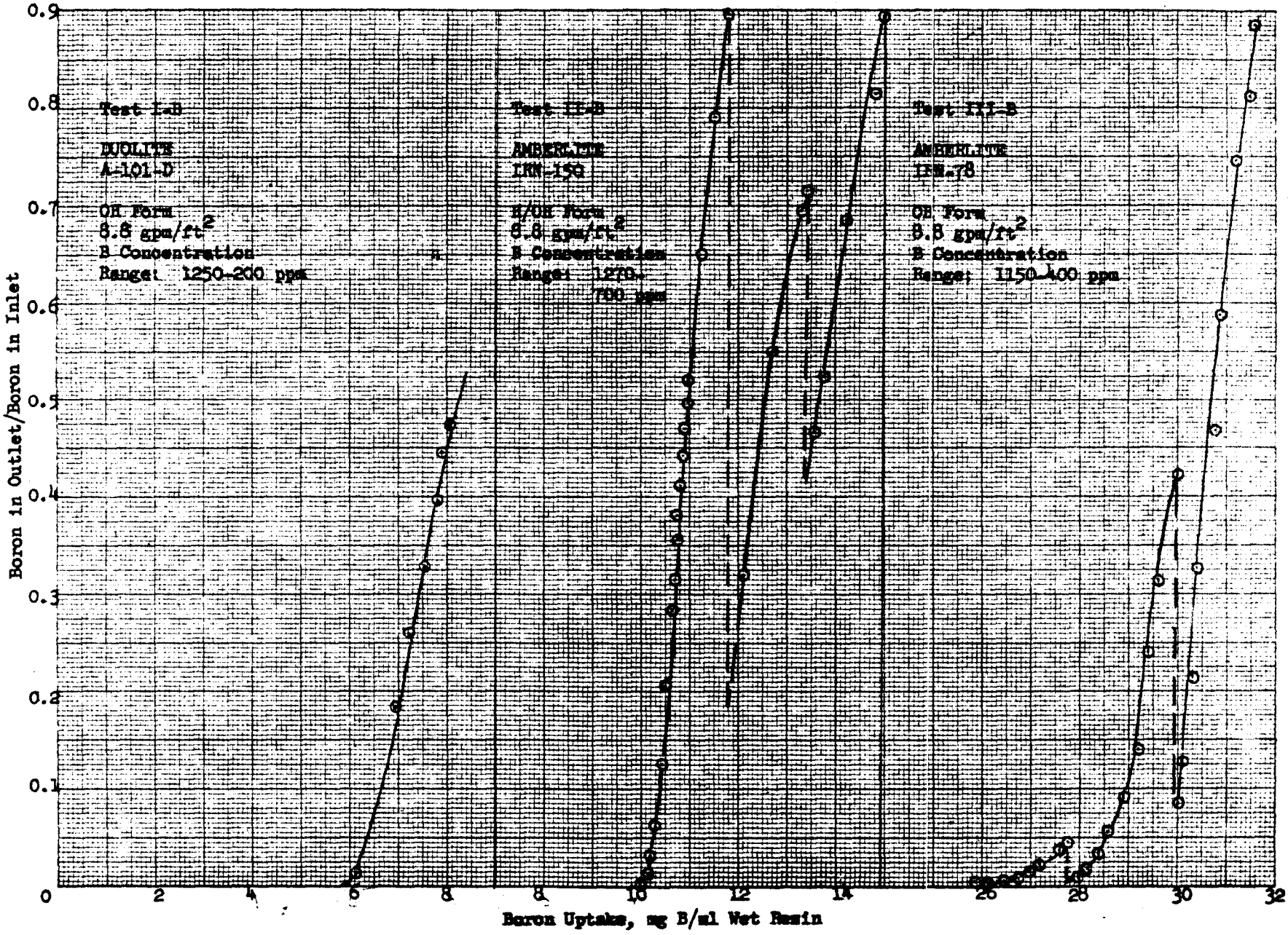


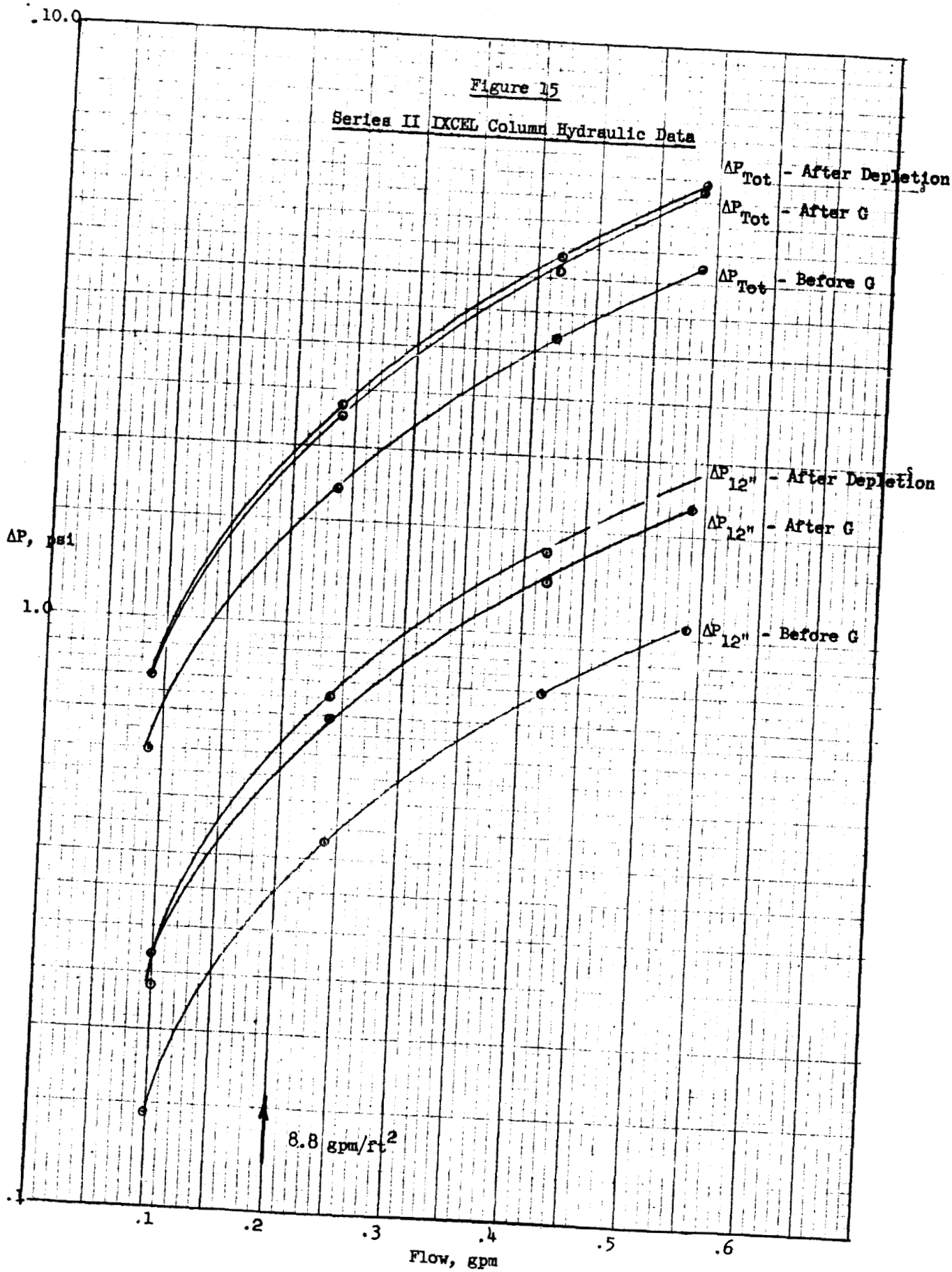
TABLE 6

IXCEL Hydraulic Data

Init. Bed Height	40	38	41
Height After 20 Min. @ 20 gpm/ft^2	38-1/4	35-3/8	35-3/8
Height After Spring Insertion	37-3/16	34-7/8	35-1/4
After 20 gpm/ft^2	37-1/16	34-25/32	35-1/8
ΔP_{tot} 8.8 gpm/ft^2	1.6	1.4	1.32
$\Delta P_{12"}$ 8.8	0.37	0.35	0.35
Height After Shake	Not Appl.	32-9/16	33-13/16
ΔP_{tot} 8.8	Not Appl.	2.0	1.8
$\Delta P_{12"}$ 8.8	Not Appl.	0.58	0.54
Height After ΔP	Not Appl.	32-5/8	33-1/2
Height After Exhaust	Not Appl.	29-1/2	29-7/8
ΔP_{tot} Exhaust	Not Appl.	1.9	2.0
$\Delta P_{12"}$ Exhaust	Not Appl.	0.62	0.67
Height After ΔP	Not Appl.	28-7/8	29-9/16
Height After Adding Additional Deplet. Resin	Not Appl.	Not Appl.	35-1/2
ΔP_{tot} 8.8	Not Appl.	Not Appl.	2.9
$\Delta P_{12"}$ 8.8	Not Appl.	Not Appl.	0.72
Height After ΔP	Not Appl.	Not Appl.	35-1/2
Height After 2nd Shake	Not Appl.	Not Appl.	35-1/8
ΔP_{tot} 8.8	Not Appl.	Not Appl.	$\approx$ 3.6
$\Delta P_{12"}$ 8.8	Not Appl.	Not Appl.	0.87
Height After ΔP	Not Appl.	Not Appl.	35-1/8
mgCd/cc Resin at Breakthrough (based on preshaken volume)	Not Appl.	$\approx$28	$\approx$30

Figure 15

Series II IXCEL Column Hydraulic Data



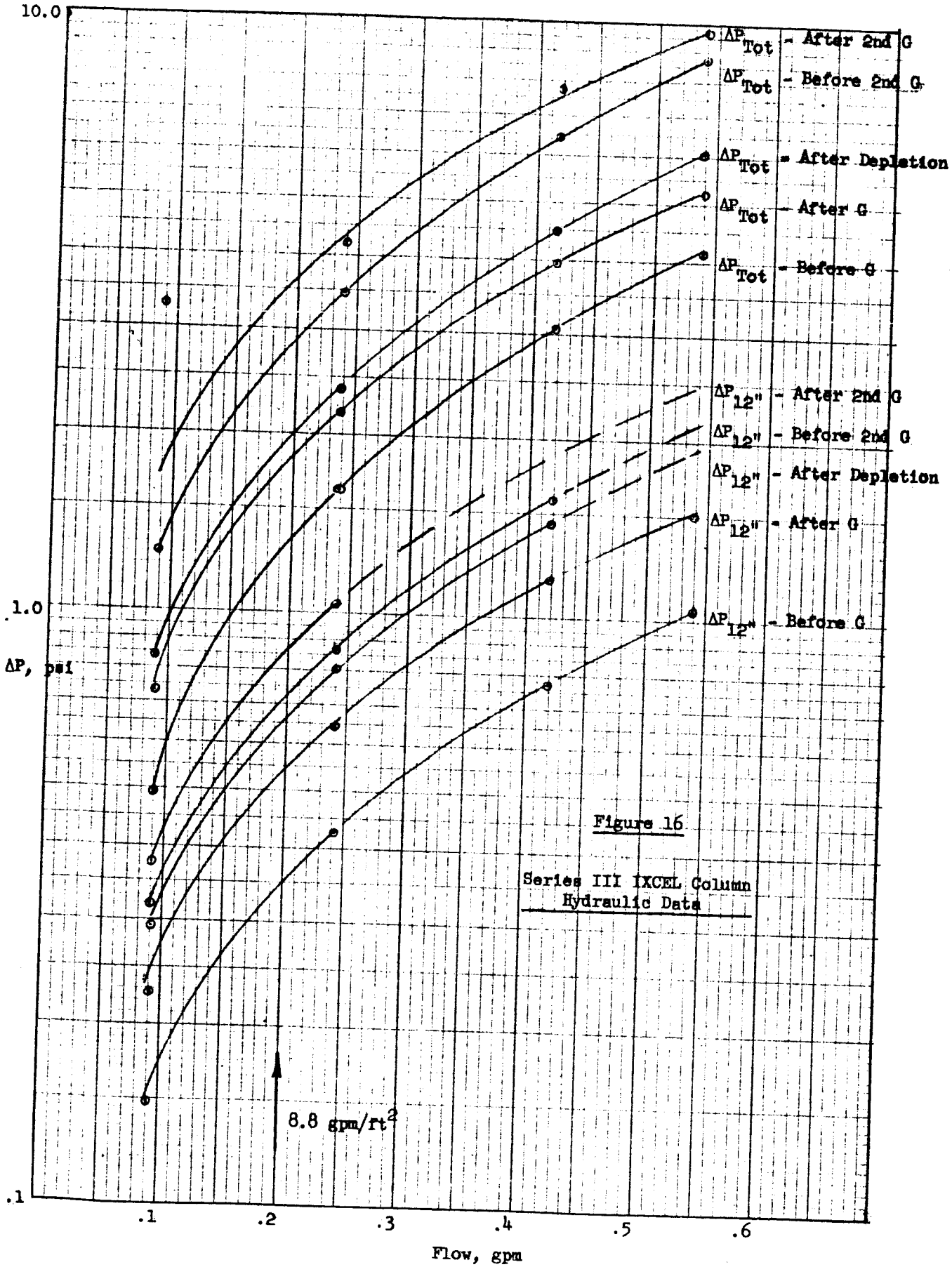


Figure 16

Series III IXCEL Column
Hydraulic Data

Figure 17

Series II IXCEL IX Column - Breakthrough Curve

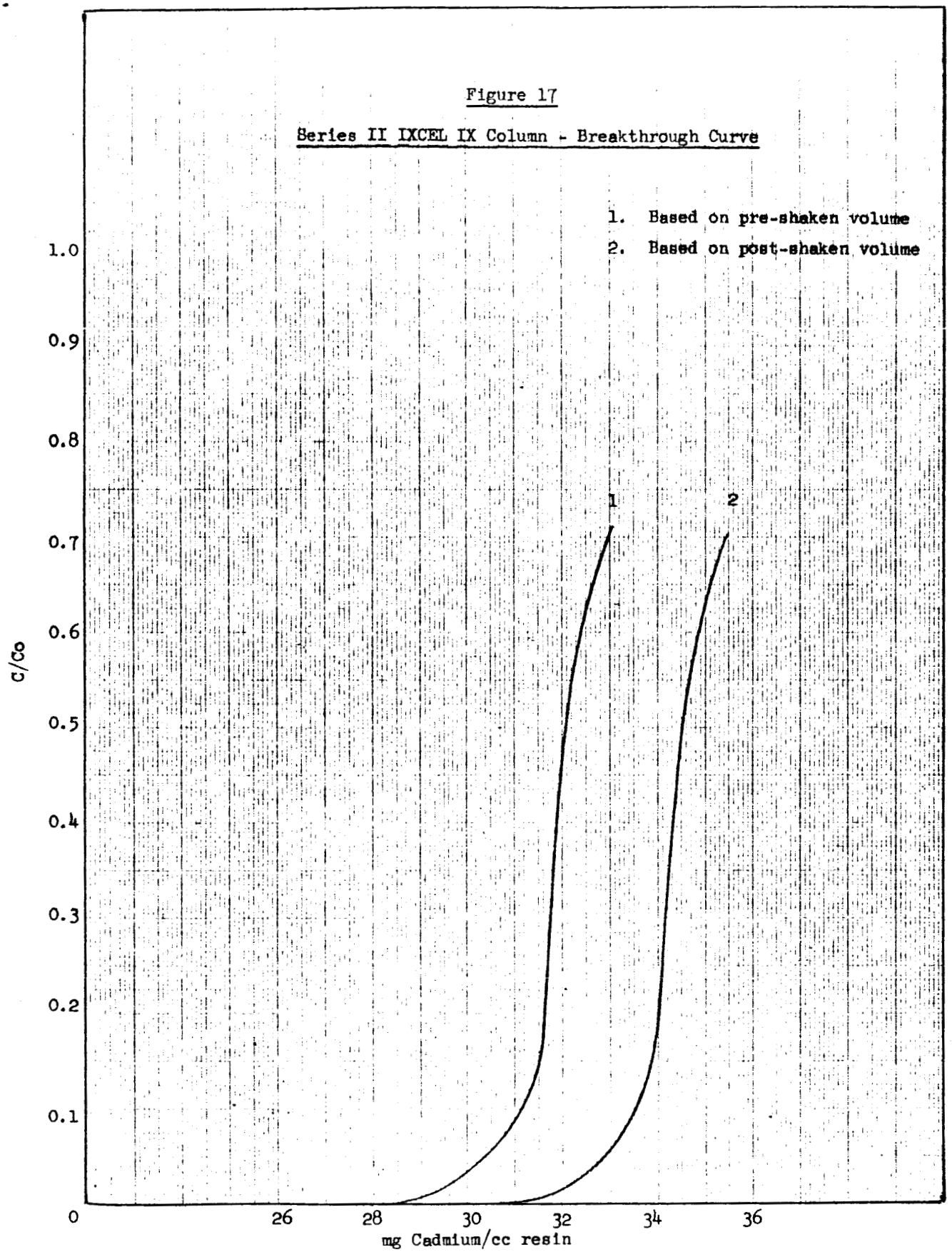


Figure 18

Series III IXCEL IX Column - Breakthrough Curve

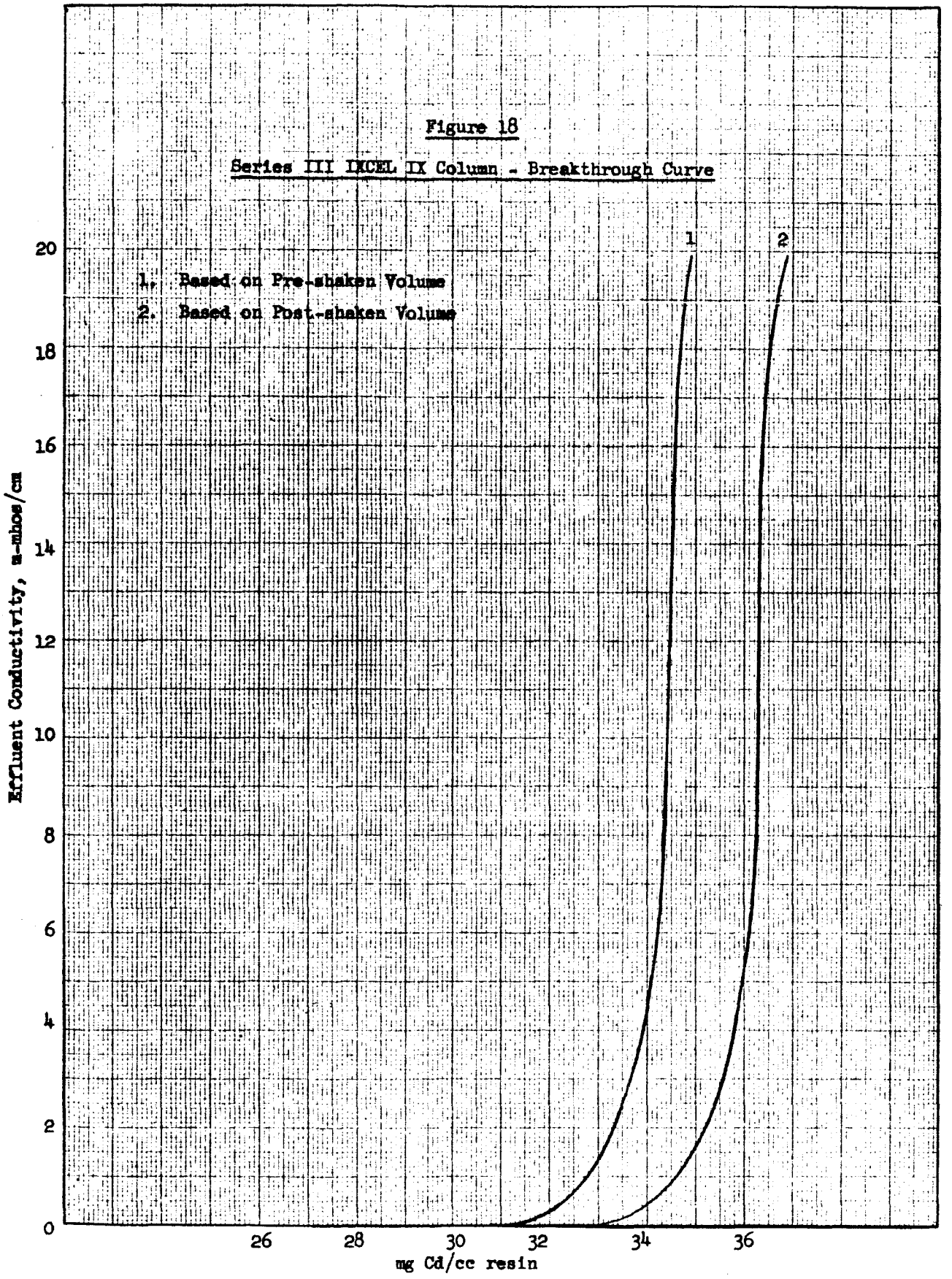


Table 7

Results of Sieving of Resin

	Weight Percent Retained on Screens		
	> 50 mesh	50-100 mesh	< 100 mesh
Depleted, Unshaken Resin	99.96	0.02	0.02
Totals for Column II	99.30	0.36	0.34
Top 14 inches	98.79	0.63	0.57
14-30 inches	99.76	0.13	0.14
Totals for Column III	98.48	0.81	0.65
Top 6 inches	98.78	0.82	0.38
6-16 inches	95.61	2.43	1.93
16-36 inches	99.74	0.06	0.13

TABLE 8

G-Loading and Vibration Test Procedures for IXCEL Columns

A. Unexhausted Resin

1) Run an exploratory test, at a low g-level, from the minimum possible frequency up to 2000 cps in the longitudinal and lateral directions. This test will (1) reveal critical longitudinal frequencies and (2) compact the bed as a result of lateral and longitudinal loading.

20 mins. Total test time

2) If the natural frequency (first harmonic) occurs, run at this frequency for 10 minutes at twice the corresponding g-level (given for Saturn V booster in RN-DR-0020, Design Specifications, Engine Rocket, Nuclear, Nerva Program).

3) If other critical frequencies are significant, run the highest frequency at twice the corresponding g-level for 10 minutes. If only the natural frequency occurs, then run a sweep at 10 g from 25-2000 cps.

B. Exhausted Resin

1) For the exhausted resin, fill column to same initial height as unexhausted resin.

2) Repeat shake tests as described in A. 1-3.

3) Critical frequencies may not be the same as for unexhausted resin.

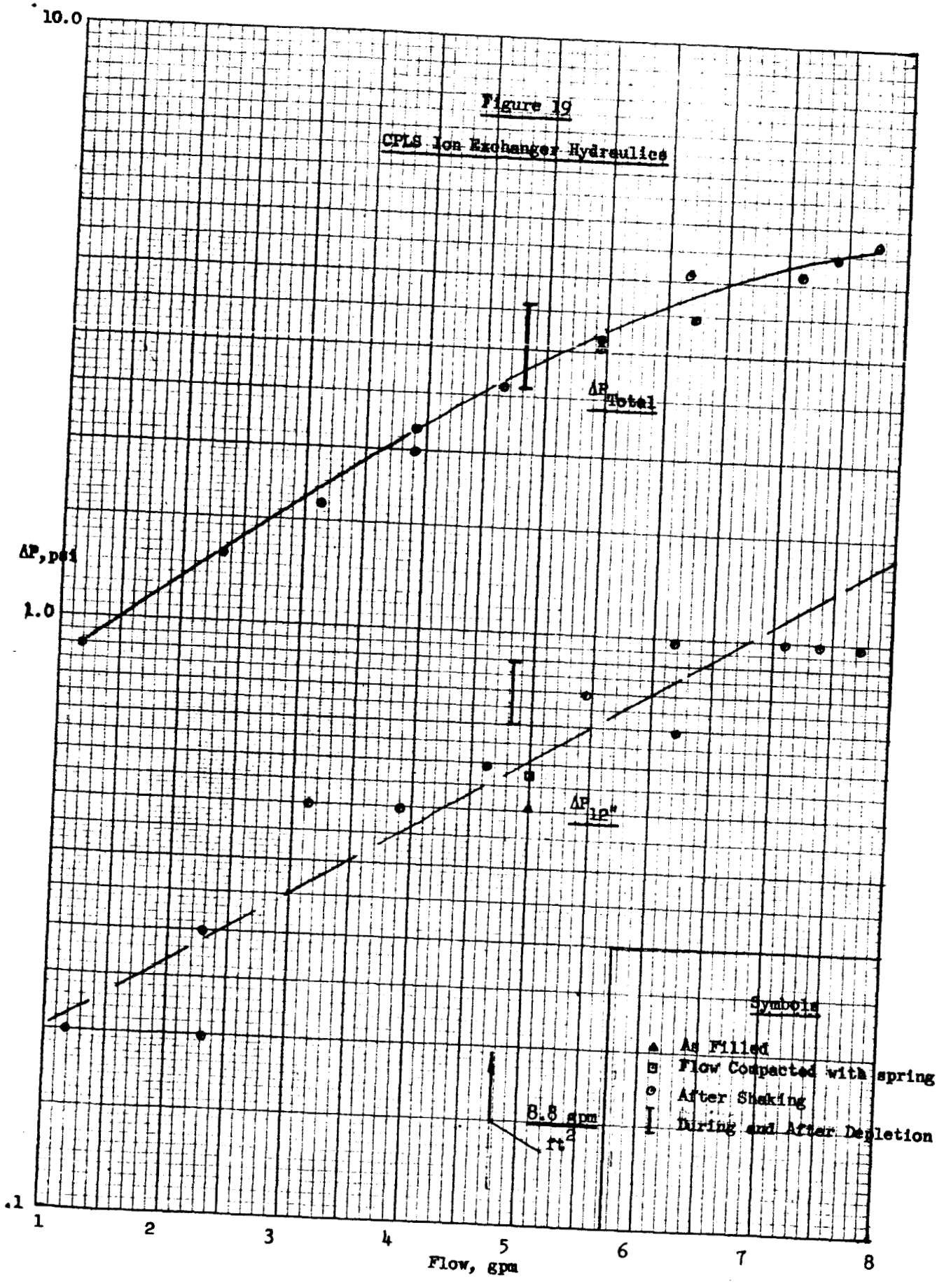


Figure 19
CPLS Ion Exchanger Hydraulics
10.0
ΔP, psi
1.0
.1
ΔP Total
ΔP 12"
Symbols
As Filled
Flow Compacted with spring
After Shaking
During and After Depletion
8.8 gpm/ft²
1
2
3
4
5
6
7
8
Flow, gpm

TABLE 9

CPLS Laboratory Version - IX Column Bed Height Measurements

Condition	Height, Inches
Initial Bed Height	38-1/16"
Height After Flow Packing	38-7/8"
New Height After Sucking Out Resin from Top	36-3/4"
Installed Spring Height	36-1/4"
Height After Shaking	36-1/8"
Height As Installed in CPLS	35-13/16"
Height After IX #5	35-3/4"
Height After IX #13	35-11/16"
Height After IX #20	35-11/16"
Height After IX #22 and Rapping	35-11/16"
Height of Resin After Removing Spring and Piston	33"

piston screen was only 5/16" longer than when installed in the column and it should have grown about 8 inches when removed.

The capacity of the resin for cadmium is shown in Figure 20. The volume of resin used in the calculation is the 48.4 liters, the as filled and flow packed volume. Periodic samples of the ion exchange effluent were taken during the various runs to determine the C/Co. A sample core of resin was removed from the bed after depletion and was analyzed for its cadmium content. Two analyses resulted in a content of 37.6 and 39.3 mg cadmium per cc of resin. This agrees quite closely with the material balance maintained during the tests, which indicated a total capacity of 41.1 mg Cd/cc resin when the testing was completed. Breakthrough appeared to occur at about 32 mg Cd/cc which agrees quite adequately with the reduced scale column results. (Figures 17 and 18)

The time required to reduce the loop system cadmium concentration from one point to any other must be predictable. For these tests, it was required to determine the time it would take to go from 2.97 mg Cd per cc of solution to 1.65 mg/cc and from 2.97 to 0.126. With an ion exchange flow rate of 4.8 gpm and a system volume of 32 gallons. Calculations were within 7.5% of the actual time required to ion exchange. This is shown in Table 10. The spread between calculated time and actual time only increased when breakthrough began. The data is also shown in Figure 11.

In addition, the ion exchange effluent was periodically monitored to determined solution pH and conductivity. These results are shown in Table 11.

C. Establishment of System Time Constants

There were six conductivity cells installed in the system at the points indicated in Figure 5. The signals from cells number 1, 4, 5, and 6 were continuously recorded on the Visicorder. Cells 2 and 3 were connected to a switch which would allow sending the signal either to the Visicorder or to a conductivity meter which indicated but did not record.

Short burst injections from the poison concentrate tank into the primary loop were made while the primary fluid was flowing at various rates. The opening of the solenoid valve in the poison injection line was recorded on the visicorder chart along with the signal from cells 1, 4, 5 and 6. The time from initiation of injection of poison until the signal from the cell changed, was measured from the chart and tabulated in Table 12. The data from cells 4 and 6 is also plotted in Figure 21. The time it takes to reach the bottom of the tubes appears to be in good agreement at the higher flow rates with the results obtained from the plexiglas model tests. At lower flow rates the results

Figure 20

CPLS Ion Exchange Capacity

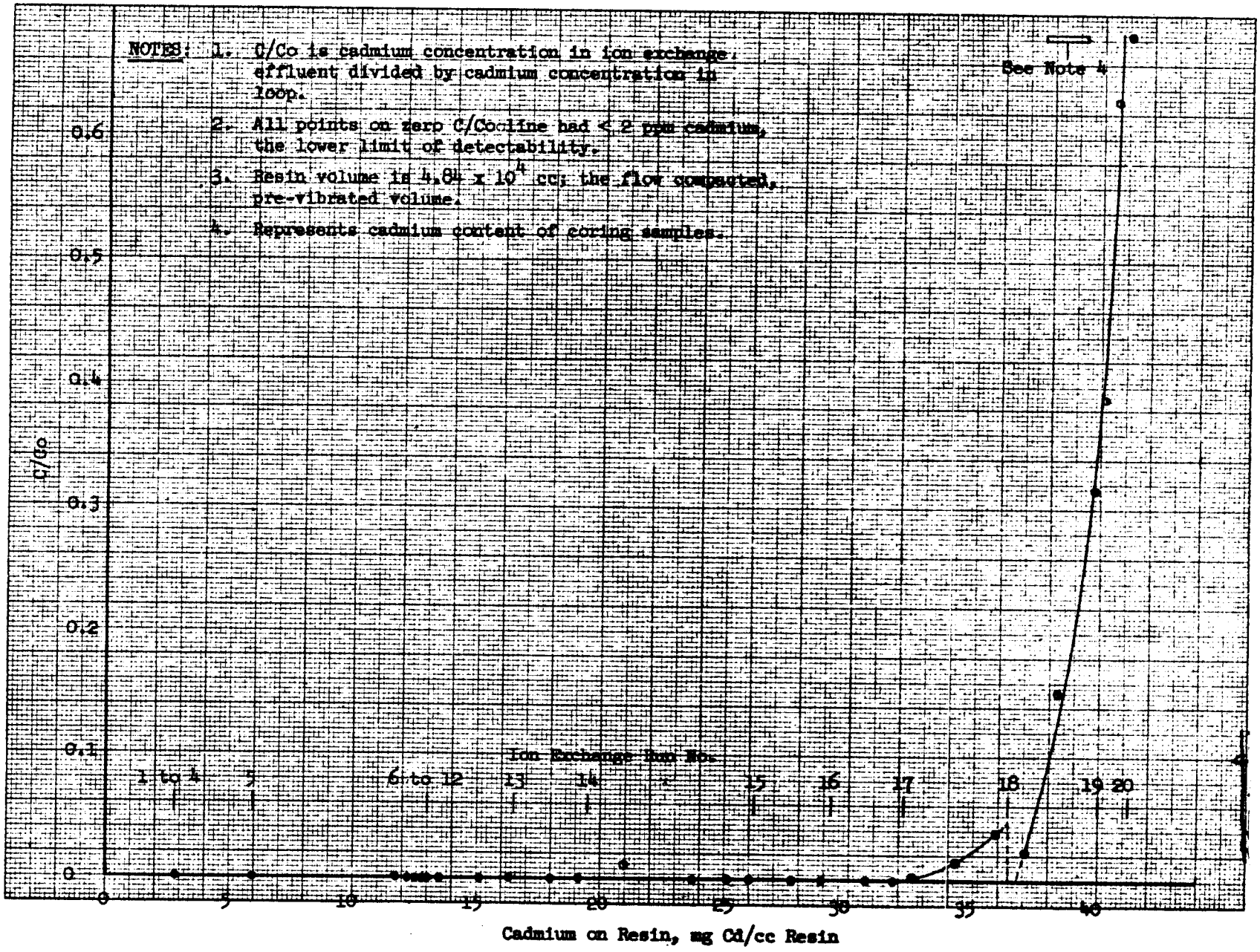


TABLE 10

CPLS Laboratory Version - Ion Exchange Data

IX Run	Type	Cdi, mg/cc	Cdf mg/cc	ΔCd mg/cc	Time Secs.	Cdf / Cdi	Time[(1)] Calc	Time act / Time calc	Δmgs Cd x 10^{-5}	Cum Δmg Cd x 10^{-5}	mg Cd / cc Resin
1-4	Short	2.990	1.860	1.130	190.5	.622	190.0	1.003	1.369	1.369	2.83
5	Short	2.890	1.645	1.245	233.2	.569	225.5	1.031	1.510	2.879	5.95
6-12	Long	2.950	0.138	2.812	1285.4	.0468	1224.0	1.050	3.402	6.281	13.00
13	Short	3.015	1.610	1.405	240.0	.534	251.0	0.956	1.701	7.982	16.50
14	Short	2.830	1.625	1.205	238.0	.574	222.0	1.072	1.461	9.443	19.52
15	Long	2.800	0.128	2.672	1328.8	.0457	1236.0	1.075	3.235	12.678	26.20
16	Short	2.775	1.550	1.225	234.2	.559	232.5	1.007	1.485	14.163	29.3
17	Short	2.780	1.625	1.155	229.0	.585	214.5	1.067	1.400	15.563	32.2
18	Inter.	3.015	1.320	1.695	359.5	.438	330.0	1.089	2.055	17.618	36.4
19	Short	3.070	1.610	1.460	330.1	.5245	258.0	1.280	1.770	19.388	40.0
20	Short	1.610	1.170	0.440	324.9	.727	127.7	2.55	0.533	19.921	41.2

(1) $Cd_f/Cd_i = e^{-\frac{Ft}{V}}$

where F = 4.8 gpm

V = 32 gallons

TABLE 11

CPLS Laboratory Version - IX Column Effluent Chemistry

IX No.	Time Into Run, Secs.	Cd Conc	Cond μ-mhos	pH	Cd Conc Loop	x 10^{-5} mgs Cd	mg Cd cc Resin
1-4	No Samples		-	-	-	1.369	2.83
5	No Samples		-	-	-	2.879	5.95
6-12	645.3	< 2 ppm	2.30	6.02	0.63	5.691	11.76
	795.3	< 2 ppm	5.08	6.18	0.44	5.921	12.23
	945.3	< 2 ppm	8.95	6.22	0.32	6.067	12.54
	1095.3	< 2 ppm	10.67	6.20	0.218	6.190	12.79
	1270.3	< 2 ppm	9.73	6.36	0.142	6.281	12.98
13	25	< 2 ppm	1.98	6.78	2.82	6.517	13.46
	125	< 2 ppm	1.47	6.38	2.17	7.305	15.09
	225	< 2 ppm	1.39	6.12	1.67	7.911	16.34
14	100	< 2 ppm	178	9.48	2.24	8.697	17.97
	200	< 2 ppm	37.6	7.28	1.78	9.255	19.12
15	100	26 ppm	85.3	6.45	2.22	10.146	20.96
	400	< 2 ppm	3.41	6.98	1.11	11.491	23.74
	700	< 2 ppm	3.96	6.51	0.55	12.170	25.14
	1100	< 2 ppm	1.51	6.58	0.22	12.570	25.97
16	100	< 2 ppm	9.18	6.38	2.16	13.423	27.73
	200	< 2 ppm	3.82	6.68	1.69	13.993	28.91
17	100	< 2 ppm	14.6	7.39	2.20	14.866	30.71
	200	< 2 ppm	6.92	7.76	1.74	15.423	31.87
18	26	5 ppm	13.3	9.08	2.84	15.775	32.59
	150	31	64.1	4.70	2.14	16.623	34.34
	300	58.5	0.530m-mhos	3.09	1.52	17.379	35.91
19	50	58.5	0.50 m-mhos	3.18	2.78	17.969	37.13
	150	347	2.10 m-mhos	2.55	2.29	18.563	38.35
	300	541	1.92 m-mhos	2.59	1.71	19.266	39.81
20	32	609 ppm	1.75 m-mhos	2.80	1.56	19.449	40.18
	150	871	1.71	2.89	1.38	19.667	40.63
	300	820	1.81	2.93	1.20	19.885	41.08

TABLE 12

Time from Injection to Change of Conductivity Cell Signal

Injection No.	Flow, gpm	Inj. Time Sec.	Time to Record Change on Cond Cell, Sec. #5	#1	#4	#6
29	200	2.13	0.08_2	0.26	0.91	1.66
30	200	1.31	0.07_6	0.25	0.91	1.59
31	300	1.62	0.08_7	0.28	0.88	1.57
32	300	1.48	0.07_6	0.23	0.85	1.47
33	400	1.36	0.08_1	0.26	1.02	1.45
34	400	2.23	0.08_2	0.28	0.90	1.43
35	500	1.69	0.09_0	0.26	0.78	1.21
36	500	1.51	0.06_0	0.25	0.76	1.22
37	600	1.51	0.06_5	0.21	0.71	1.16
38	600	1.55	0.06_0	0.22	0.68	1.12
39	600	1.4	-	-	0.620	1.275
40	500	1.4	-	-	0.775	1.400
41	400	1.4	-	-	0.900	1.650
42	300	1.2	-	-	0.875	1.675
43	200	1.10	-	-	0.950	1.775
44	200	1.50	-	-	0.970	1.880
45	300	1.30	-	-	0.925	1.725
46	400	1.50	-	-	0.875	1.650
47	500	1.50	-	-	0.800	1.475
48	600	1.58	-	-	0.575	1.275

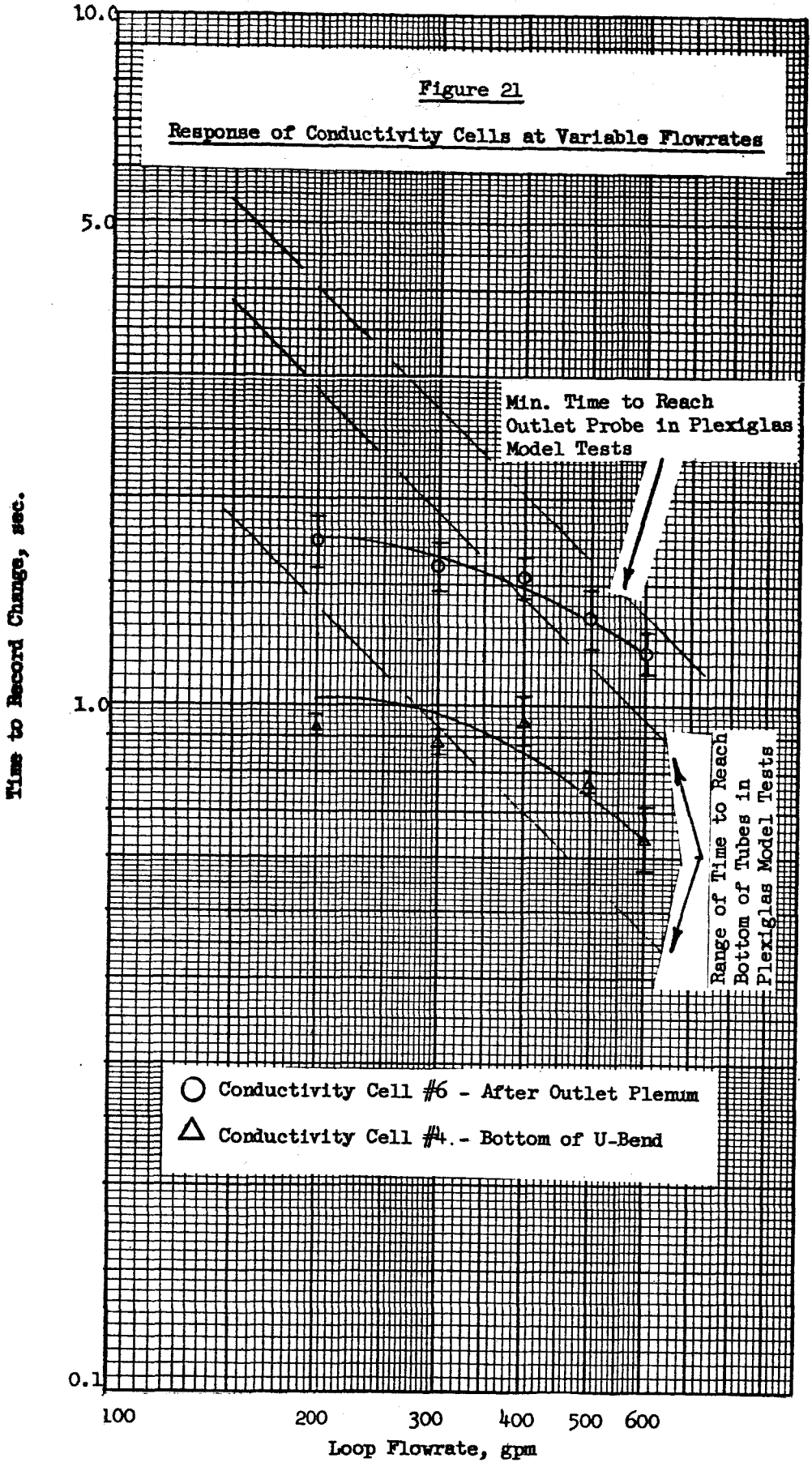


Figure 21
Response of Conductivity Cells at Variable Flowrates
10.0
5.0
1.0
0.1
Time to Record Change, sec.
Min. Time to Reach Outlet Probe in Plexiglas Model Tests
Range of Time to Reach Bottom of Tubes in Plexiglas Model Tests
Conductivity Cell #6 - After Outlet Plenum
Conductivity Cell #4 - Bottom of U-Bend
100
200
300
400
500
600
Loop Flowrate, gpm

show a leveling off of the curve of time versus flow rate. This is due to the increased forward diffusion of the concentration change in the manifold-poison tube simulator due to the large pipe size used as opposed to the smaller tubing in the plexiglas model.

Some of the early injections were also of the short burst variety in order to determine the rate at which various conductivity cells changed. A typical injection is number 8, the results of which are shown in Figure 22. The loop flow rate was 620 gpm using the slow injection rate for 2.1 seconds. The curves shown in this figure were taken off the Visicorder Chart and corrected, based upon the individual calibrations. It can be seen that while the ramps of cells 4 and 6 are quite similar, that of cell 3, in the pressurizer, is of a lower slope initially, but then gradually increases. This will be discussed in the next section.

D. Tests of the Pressurizer

The pressurizer, as its name implies, is used to maintain a relatively constant system pressure despite changes of volume caused by temperature fluctuations or injection of solution. It performed this function quite adequately. The original intent was to have a gas supply system such, that a constant loop pressure was always maintained. However, the gas supply was of the nature that a pressure was regulated before testing began and neither gas addition or removal was performed during subsequent operations of a given test. This worked out quite well, since the pressure fluctuations in the system were less than 5 psi even during solution injection.

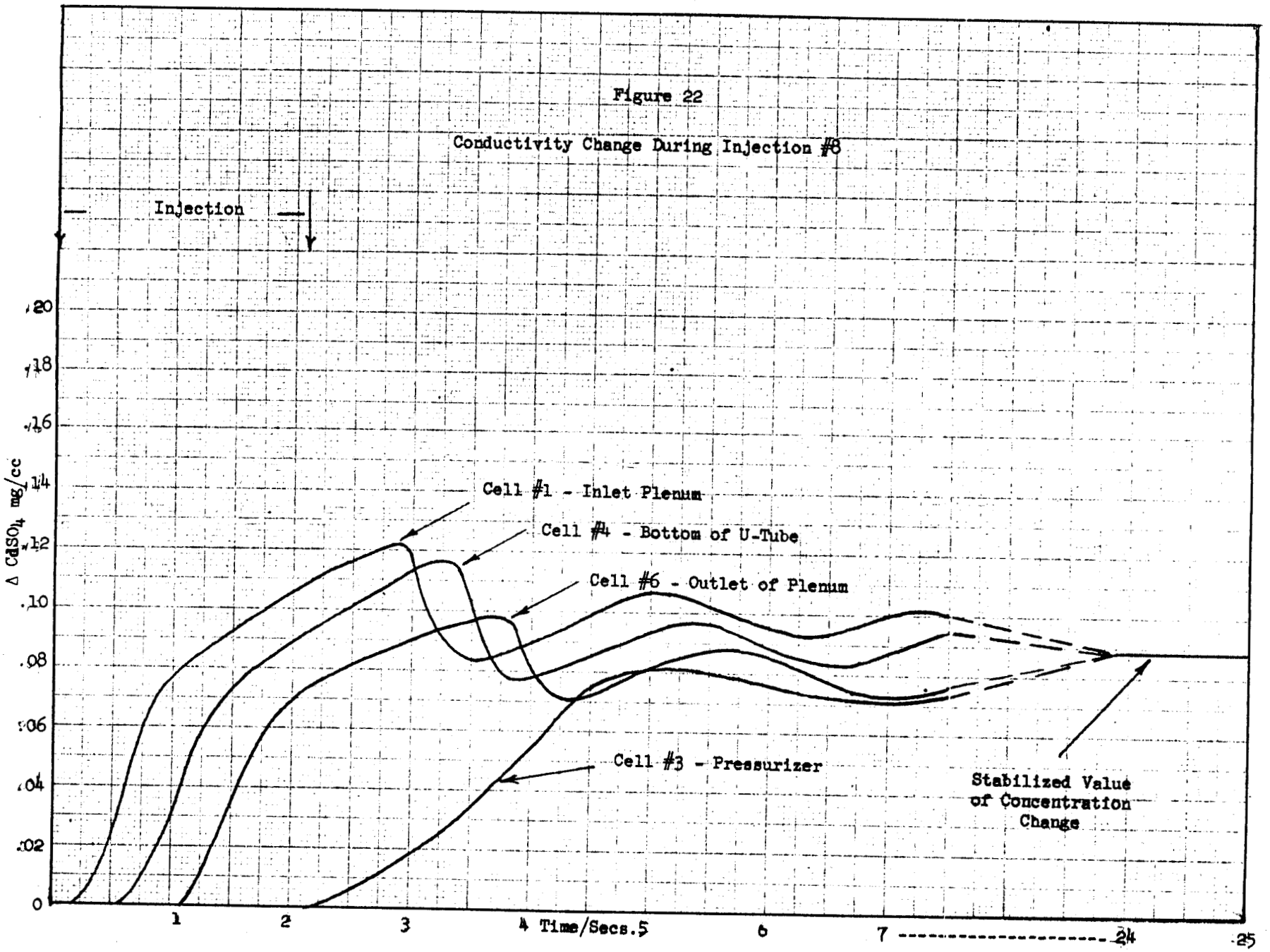
The primary side of the pressurizer was continually supplied with a purge flow of about 30 gpm, or about 5% of the loop flow rate. This was done to insure adequate mixing in the pressurizer during ion-exchange or solution injection operations. A typical delay in the initiation of mixing in the pressurizer and the ramp of concentration change that followed was shown in Figure 22 of the previous section. The change of concentration began with a fixed delay from the system change. The initial ramp of concentration change in the pressurizer is considerably lower than that in the loop system, but rapidly increases to a rate such that within a few loop time constants, it has reached steady state concentration.

E. Control of System Chemistry

Some of the items listed on the Task II report under this general heading, were performed as required in order to obtain meaningful test data. This included careful preparation of solutions, use of proper loop filling procedure, and periodic chemical sampling to determine solution cadmium content.

Figure 22

Conductivity Change During Injection #8



A calibration curve was established, by wet chemical analyses, for the conductivity meter connected to Cell #3, during injection Runs 1 through 16 (see Figure 11). Further analyses were taken during subsequent runs as a check on the calibration. As the program progressed, corrosion product levels increased in the solution, as evidenced by solution discoloration. This increase in corrosion products resulted in an increase in system conductivity without an increase in cadmium content. This was manifested in an apparent "drift" in the calibration. This was compensated for by applying a correction factor to the conductivity meter reading, determined from the wet chemistry results taken at the end of each run.

The ion exchange bed was sampled in-situ after depletion. A 5/8" diameter tube, the lead end of which had been sharpened, was inserted into the bed and slowly rotated downward. The tube became very difficult to move as it was lowered through the bottom half of the bed, even though the column was filled with solution during the insertion. The solution was drained with the tube still inserted. The resin core sample appeared to be only a few inches long.

The column was again filled with solution after first removing the sampling tube. This time the solution was very slowly pumped in through the bottom port and up through the bed. The purpose was to loosen the compacted bed.

Another sample was taken in a different position using the same technique. Again the tube insertion was difficult for the bottom half of the bed height. This time the sample was 23-1/2 inches long out of a possible 33 inches. This sample was then analyzed for cadmium. No attempt was made to determine cadmium distribution along the height. The results, shown in Figure 20 agree with the results obtained from the cadmium solution material balance. The difficulty in obtaining a totally representative bed sample probably accounts for the low value as compared to the curve.

F. System Hydraulic Tests

Many of these tests were performed during the system shakedown operations and are reported in that section of the report. However, in order to operate the system at flow rates below 500 gpm additional studies were required. The D-P cell used to measure the head of the pump was not capable of measuring pump heads in the desired low flow rate range. Therefore, pressure drop measurements were made at flow-rates between 485 and 625 gpm. These results are shown in Table 13. There was good agreement between the pump head, ΔP 1-2 and the system pressure drop, the sum of ΔP 2-3 and ΔP 3-1. The sum of these two measurements, each of which was on scale at flow rates as low as 200 gpm, was then used for any test where lower-than-reference flow was required. The positions of the pressure taps are shown in Figure 5.

TABLE 13

CPLS Laboratory System Pressure Drops

Temp, ^{o}F	143	143	146	148	147.5	145	142	150
ΔP_{1-2} psi	200	193	184.5	188	199			
ft	470	453	434	442	468			
ΔP_{2-3} psi	74	45	4.0	23	74.5	116	127	140
ΔP_{3-4} psi	56	63	81.5					
ΔP_{3-5} psi	57	68	83.5					
ΔP_{6-8} psi	33	38	46					
ΔP_{7-8} psi	24	28	34					
ΔP_{3-1} psi	123	146	181	164.5	123.5	90	82.5	71
Q (from ΔP_{1-2}) gpm	485	555	625	600	495			
$\Delta P_{2-3} + \Delta P_{3-1}$	197 463	191 449	185 435	187.5 440.5	198 465.5	206 484	209.5 492	211 495.5
Q (from $\Delta P_{2-3} + \Delta P_{3-1}$) gpm	515	510	625	605	505	400	300	200

The power input to the motor driving the pump could be used as a measure of the flowrate. The power measurements and the respective efficiencies are shown in Table 14. Although this data was collected, it was not used to control the flow rates. However, the good agreement between the two values of pump efficiency (Items 5 and 6) as calculated and measured, gave added confidence in the validity of the ΔP readings being used to measure flow.

TABLE 14

Power Measurements to the Loop Circulating Pump

1.	Flow Rate, gpm	605	505	400	300	200
2.	ΔP_{2-3} plus ΔP_{3-1}, psi	187.5	198	206	209.5	211
3.	Horsepower Produced (1 x 2)	66.1	58.3	48.0	36.6	24.6
4.	Brake Horsepower (Pump Test Data)	92.0	81	71.0	63.0	55.0
5.	Pump Efficiency (3/4)	0.719	0.719	0.676	0.581	0.447
6.	Pump Efficiency (Pump Test Data)	0.733	0.731	0.685	0.581	0.435
7.	Power Input, kw	81.0	75.6	69.3	68.1	65.4
8.	Horsepower Input (7 x 1.341)	108.8	101.4	92.9	91.3	87.6
9.	Motor Efficiency (4/8)	0.846	0.799	0.765	0.690	0.628
10.	Overall Efficiency (3/8)	0.609	0.575	0.517	0.401	0.281

IV. ANALYSIS OF RESULTS AND CONCLUSIONS

A. Poison Injection System

As was mentioned earlier the poison injection system performed satisfactorily during the testing. One of the results was data for comparison of the laboratory version, 5" O.D. simulation of the manifold-poison tube with the plexiglas model of the actual 198 tube array. Data from Injection #8 was presented in Figure 12. Data from Run #25 of the plexiglas model program (NASA-CR-54994) was converted into equivalent terms and the results superimposed on Figure 23 following. The data from Run #25 had to be converted since it had not utilized the same parameters. A comparison of test parameters is given in the table below:

	Run #25 - Plexiglas Model	Injection 8, Lab. Version
Flow, gpm	600	620
Injection Rate, gpm	.825	.250
Injection Concentration, mg/cc	.250	.300

To effect this conversion the data from Run #25, concentration change versus time, was multiplied by 600/620 to compensate for the difference in main loop flow, by .250/.825 to compensate for the difference in injection flow and by .300/.250 to compensate for the difference in injection concentration, in the process. The results are in fairly good agreement, showing however that the simulation had a greater mixing effectiveness than the plexiglas model. This is undoubtedly due to the fact that greater diffusion of the concentration wave front occurred in the 5" O.D. pipe of the simulation than in the small poison tubes of the plexiglas model, which should be expected. This greater diffusion would also account for the initial arrival of poison at the outlet cell in the simulation being earlier than in the plexiglas model. It was therefore concluded that the simulation was sufficient and the remaining testing proceeded.

Performance of the poison injection system was also evaluated by comparing the change in concentration with predictions based on the mathematical analog developed and reported in the Task I report. New model constants were established based upon the laboratory system actual dimensions, which, as indicated in Section II-B were not identical to the CPLS-Flight System. Calculations were then made and the curve of concentration change versus time were drawn and shown in Figure 24. These show that a change in concentration from xenon override to cold shutdown should take 140 seconds. This compares very favorably with the measured time of 149 seconds shown on Figure 11 (injection Run #25 extrapolated to 2.97 mg/cc, final value).

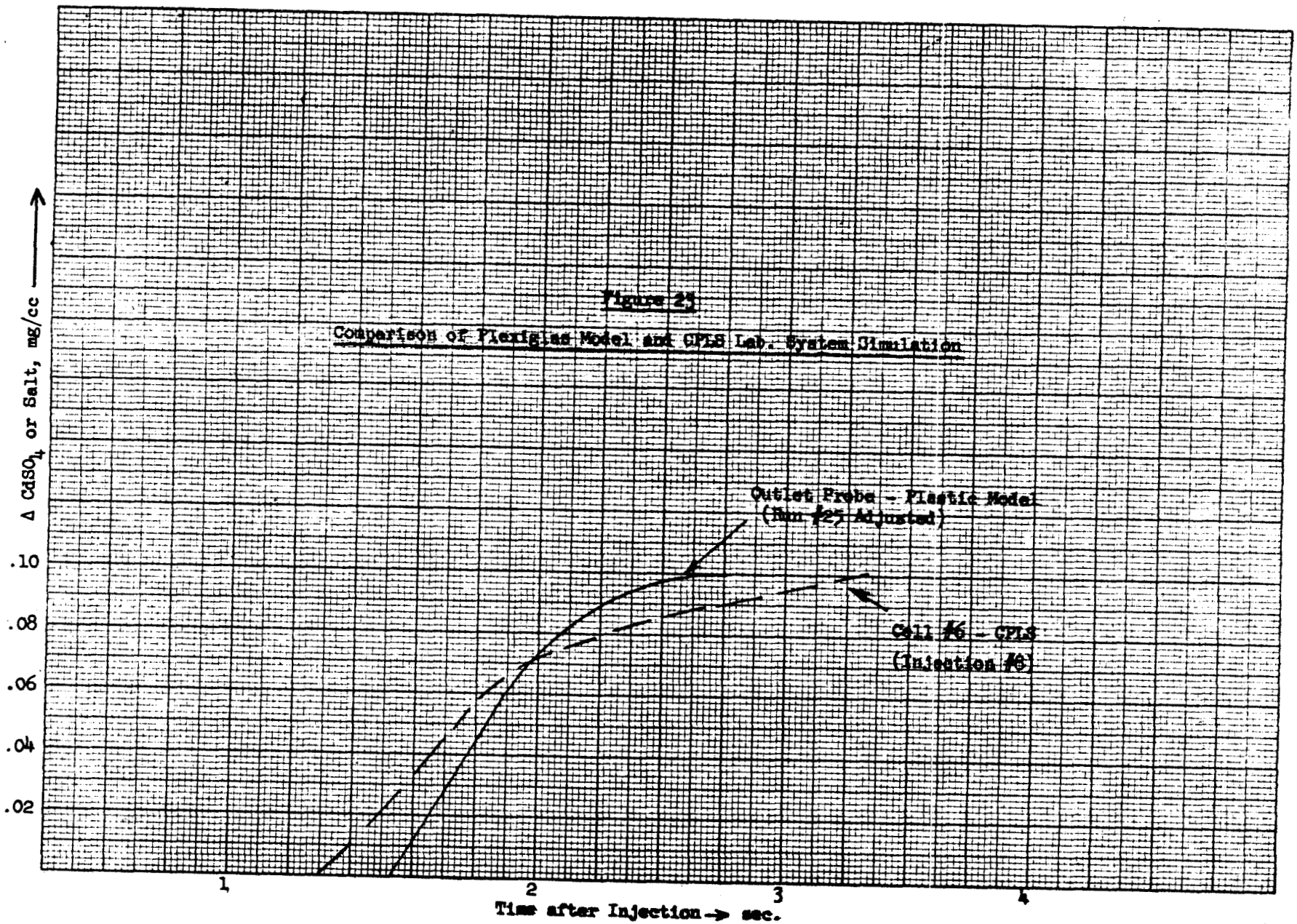
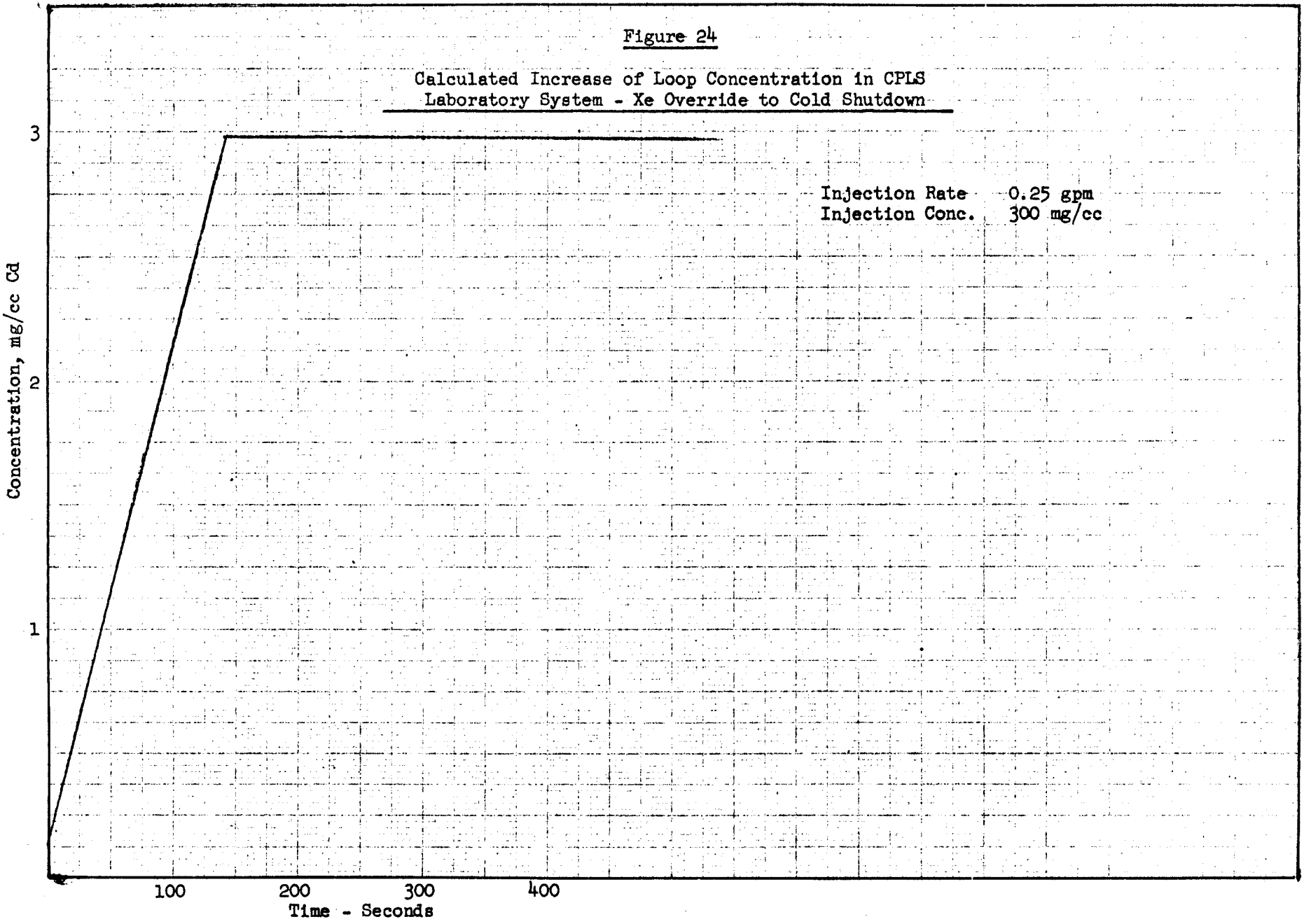


Figure 25

Comparison of Plexiglas Model and CPLS Lab. System Simulation

Figure 24

Calculated Increase of Loop Concentration in CPLS
Laboratory System - Xe Override to Cold Shutdown



As to overall operation of the poison injection system, certain comments are in order. Small needle valves were used in the two injection lines to have flexibility in the Laboratory Version to set flow rates. These valves showed some tendency to move slightly during runs, causing a small variation in flow, which was detectable but did not particularly affect overall performance, as it was random and varied in both directions. Since the Flight System would use fixed orifices for flow rate control, this difficulty would not exist. Even if controllable flow might be desired, satisfactory valves of higher quality could be obtained which would not be subject to variation.

The results also indicate that it would not be necessary to have the elaborate control of pressure between the injection system and the mainstream as was specified for the Flight System. The Lab System performed well with a fixed initial ΔP between the main stream and the injection system. The small (up to 5 psi) drop which occurred during injection did not seem to affect the flow rate measurably.

As to the control of injection time so as to effect proper changes in concentration without under- or overshoot, this can only be settled when the reactor control system is finalized. As is shown in Figure 22, the system concentration will tend to oscillate for several cycles after termination of an injection (it usually took about 5 cycles to damp out completely). The first cycle has the greatest amplitude and for the case in Figure 22, the maximum to minimum variation was about 0.038 mg/cc $CdSO_4$, in about 0.5 seconds. This would represent about 1.25% of the normal operating concentration of 3.05 mg/cc $CdSO_4$. With a simple on-off system for injection, such fluctuations as demonstrated, will occur no matter what control changes may be made to compensate for over- or undershoot. Whether this presents a problem is outside the scope of the studies discussed here.

B. Ion Exchange System

The ion exchange system in effect operates as a negative poison injection system, so that from a dynamic point of view much of the analysis is the same as in the above.

A similar comparison was made of the ion exchange (poison removal) system in comparison with a mathematical model plot. The calculated curve of poison removal is shown in Figure 25. A comparison of this curve shows good agreement with Figure 11, Runs #6-12 and 15, from the experimental runs. The shape is exponential and the time from cold shutdown to xenon override compares very favorably.

No particular problems were experienced in setting and maintaining flow. The importance of using degassed solutions was shown during initial shakedown runs when fluctuation in flow occurred due to a high content of air in the system. This was eliminated by refilling with degassed, demineralized solution.

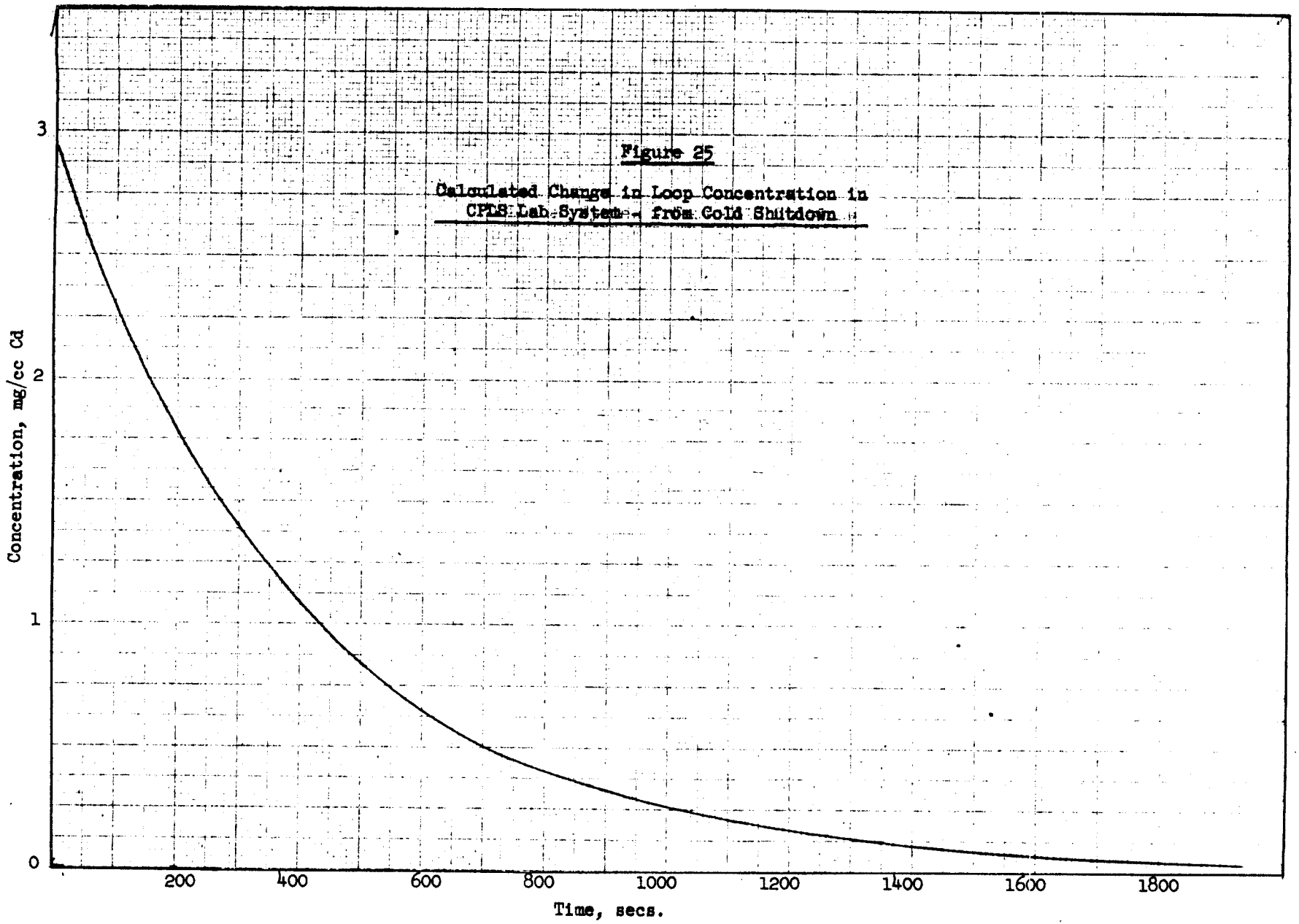


Figure 25

Calculated Change in Loop Concentration in CPTS Lab System from Cold Shutdown

The inherent exponential characteristic of the poison removal system was demonstrated in the tests as is shown in Figure 11. Once, again however, an under or overshoot of poison concentrate level will occur as discussed under the poison injection system above with the same conclusions as to capacity of the system.

As to the effect of the G-load environment, there seems to be little of consequence. Actually the G-loads tend to add to bed compacting from other sources. There seems to be no deleterious effect on resin capacity. The binding of the spring in the full size vessel used in the Lab System can be handled by a revision in the design for the Flight System. Mechanically the system seems adequate.

C. Tests of the Pressurizer

The pressurizer evidenced essentially perfect action during the testing. Pressure was maintained as required. A slight ($\approx$ 5 psi) increase in system pressure was noted whenever the poison injection system was in operation. Since the specified control of injection pressure versus loop pressure was not used on the Laboratory Version, such a rise was natural.

The average rate of change of poison concentration in the pressurizer was essentially the same as experienced in the overall system. The change began to occur with a fixed delay from the overall system change. Because of this delay, at the end of a transient, the pressurizer concentration was either higher or lower than the overall system average. Therefore, in the few loop transient times after cutoff of injection or removal, the stabilization of system concentration was influenced in a small way by the pressurizer. This effect is really a part of the overall over- or undershoot problem which should not present a problem.

D. System Time Constants

The times required for changes in solution concentration to reach various regions of the actual manifold and tube assembly were well determined by the tests on the Plexiglas model and are reported in NASA CR-54994. A comparison of the transient times of the simulator and the Plexiglas model at various flows is given in Figure 21. At 600 gpm, the time to reach the bottom of the tube simulator is .65 seconds compared to an average of .70 seconds in the Plexiglas. It takes 1.2 seconds to reach the simulator outlet compared to 1.67 seconds for the Plexiglas.

As was previously indicated, the difference in detailed behavior of the simulator appears to be due to the greater diffusion of the concentration wave front in the simulator. The five-inch diameter pipe which represents the sum of all the 1/2 inch tubes allows this difference. The low flow comparison is consistent with this explanation. As flow decreases from 600 to 400 gpm, an approximately linear increase in time required to reach various points occurred. As flow was decreased further, the rate of increase of time became smaller.

At the lower flows, mixing was so effective in the five-inch diameter pipe that the whole simulator started to act as a fairly ideal plenum and the time for the poison to arrive at a given point became practically independent of velocity. The Plexiglas model did not allow such effective mixing as is indicated from the test results shown on Figure 21.

E. Comparison with Analog Model

As was shown in Sections IV, A and B, the long time performance of the laboratory version in both injection and ion exchange modes of operation was adequately calculated using the analog model. There are additional areas of possible concern, the first is the ability of the model to predict the overall behavior of the manifold and tube assembly.

A comparison was setup of the change in concentration at the exit of the manifold for the analog, the Plexiglas and the laboratory system test results. All the results were adjusted for the same flow rates and concentrations and are shown in Figure 26. The shapes of both experimental curves agree fairly well with the analog results and both are displaced in the direction of longer time constants.

The more gradual initial change in concentration for the experimental results is probably due to forward diffusion in the piping leading to the manifold. Such mixing is neglected in the analog.

The earlier arrival for the analog is the result of the assumption that the inlet and outlet plena have no pure time delays, i.e. the output concentration from the plena is the same as would occur with uniform mixing within the plena at all times. The shift is less for the laboratory system than for the Plexiglas because of the better mixing in the five-inch diameter tube simulator.

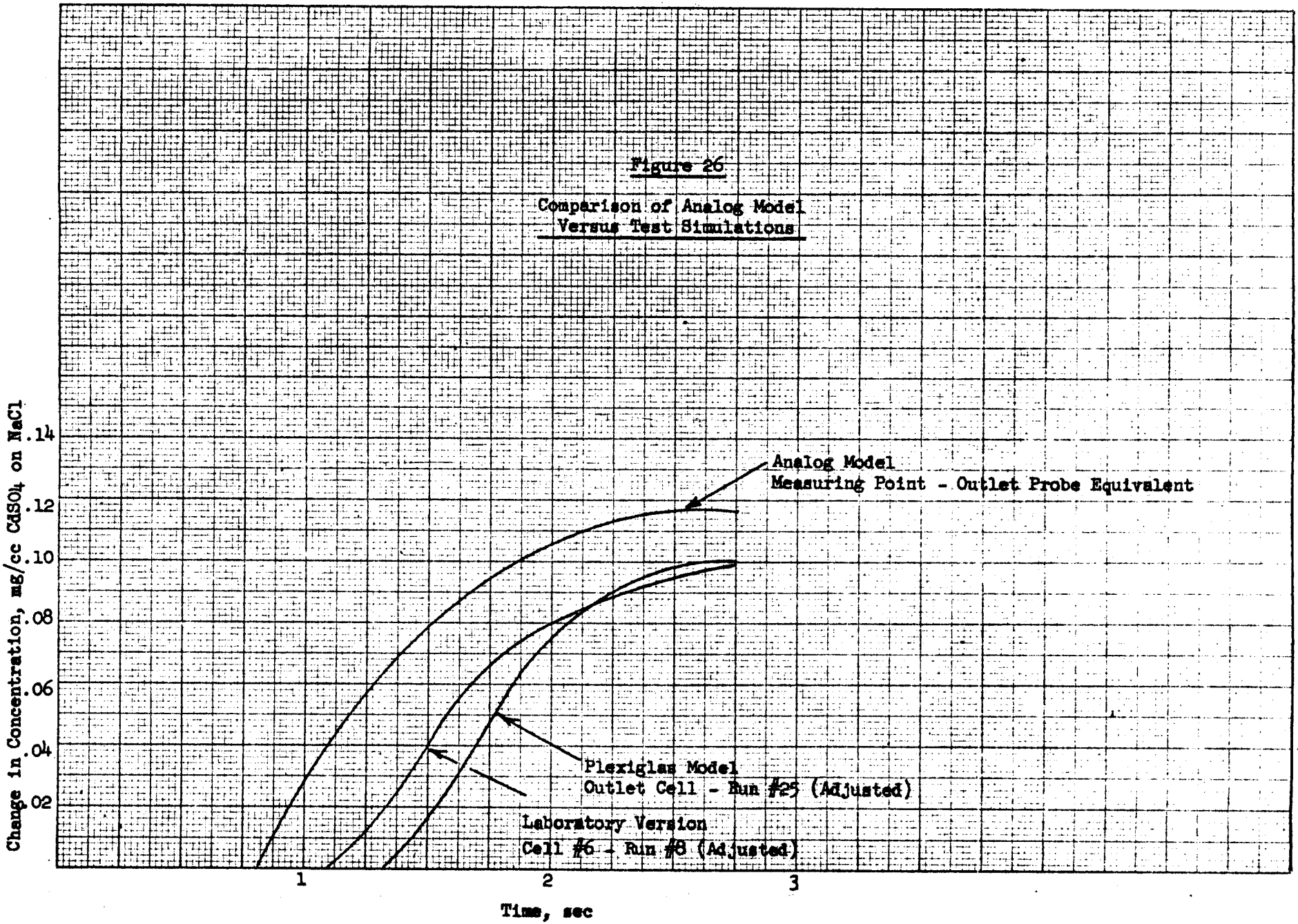
The analog can be brought into better agreement with the test results for the Plexiglas model by inserting a pure time delay into the representation of the two plena. The total or such time delay should be about 0.5 seconds. Better agreement with the lab system would require insertion of a pure time delay of about 0.25 seconds.

A second area of concern is the ability of the analog to predict the overall behavior of the loop after the termination of injection or ion exchange as is indicated in Figure 22. As has been stated, there will always be some gradient in the loop at such termination and the magnitude and duration of the resulting oscillations in core reactivity may be important.

A measure of the analogs ability to predict detailed loop behavior during the first few cycles of poison injection should be indicative of its ability to predict terminal oscillations. In order to evaluate this aspect, one of the early injection runs, used to evaluate the performance of laboratory-system manifold-poison-tube simulation, was analyzed.

Figure 26

Comparison of Analog Model
Versus Test Simulations



Specifically, the response of conductivity cell #1 during run #6 of about 5 seconds injection time was studied. The response is plotted in Figure 27, curve #1. Using the analog model, the predicted response for the same point in the system, i.e. the entrance to the poison tubes, was calculated, and is also shown on Figure 27, curve #2. No adjustments were made in the analog constants. As can be seen, the magnitude of the concentration oscillations is greater than was experimentally detected, i.e. less mixing is predicted by the analog. Also, the period of the oscillation is shorter than in the experiment, i.e. the pure time delay in the analog is less. As was pointed out in the discussion of Figure 26, the comparison is reasonable inasmuch as the analog model assumed no mixing in the loop piping as well as no pure time delay in the plena.

Since the experimental-analog comparisons give a reasonable means to predict the added mixing and pure time delays which could not originally be conveniently calculated, such adjustments in the analog constants were made. To allow for additional mixing in the inlet piping, 0.2 seconds was added to the mixing constant for the inlet plenum τ_4. To allow for additional mixing in the remaining piping, 0.433 seconds was added to the outlet plenum, τ_5. To allow for the additional pure time delay in the inlet plenum 0.1 seconds was added to the constant for the inlet piping. To allow for the additional pure time delay in the outlet manifold and heat exchanger, 0.2 seconds was added to the constant for the remaining system piping, τ_3. A comparison of the constants used in plotting the original analog and the modified is given below.

Analog Constant	Original (secs.)	Modified (secs.)
τ_1	.085	.185
τ_2	.635	.635
τ_3	.696	.496
τ_T	1.516	1.216
τ_4	.434	.234
τ_5	1.340	.907

The analog, with modified constants, was then used to calculate a new response which is shown on Figure 27, curve #3. As can be seen the modifications serve to bring the calculated response into close agreement with the experimental response.

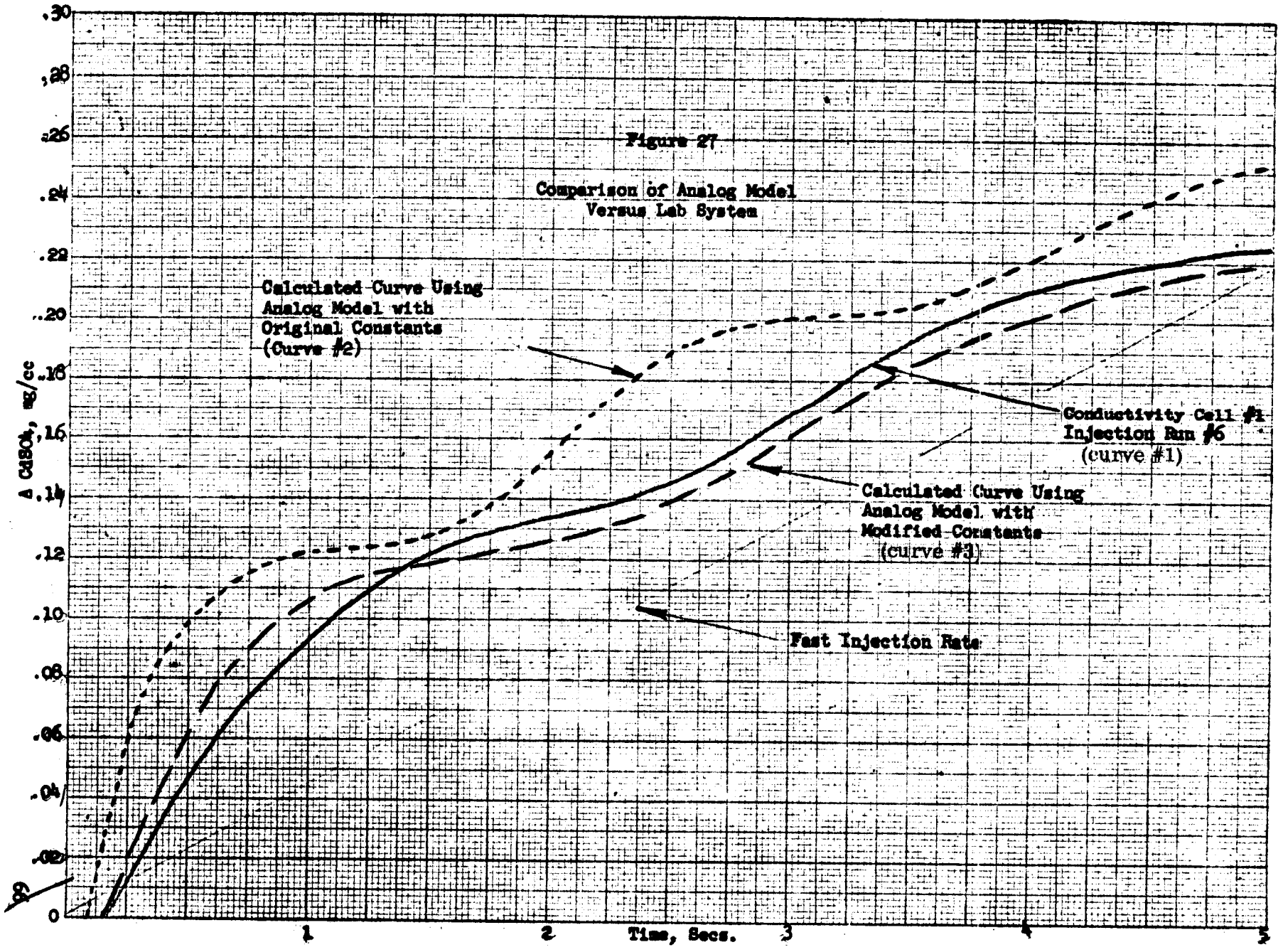


Figure 27
Comparison of Analog Model
Versus Lab System
Calculated Curve Using
Analog Model with
Original Constants
(Curve #2)
Conductivity Cell #1
Injection Run #6
(curve #1)
Calculated Curve Using
Analog Model with
Modified Constants
(curve #3)
Fast Injection Rate
Δ CuSO4, mg/cc
Time, Secs.
.30
.28
.26
.24
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
1
2
3
4
5

From the foregoing, certain conclusions can be drawn. First, the assumptions that no mixing occurs in piping and no pure time delays occur in plena result in transient predictions from the analog which are more severe than will actually occur and are therefore conservative. Second, if experimental results coupled with judgement thereof are utilized to modify the analog constants, calculated transient results can be brought into much closer agreement with experimental results. It can therefore be expected that analogs of this type with constants modified through experimental results can be expected to give very good predictions of terminal concentration oscillations in the Reference Flight System, or like systems.

V. OVERALL CPLS FEASIBILITY

A. Introduction

With the data and analysis presented in Sections I-IV of this report, the scope of work planned under the contract has been completed. It now remains to assess the overall CPLS feasibility by comparing requirements with tested performance, by outlining a final reference design and by indicating needs for further development work.

B. System Design Requirements and Performance

The CPLS design requirements were originally spelled out in Article IC1 of the contract and were further interpreted and restated in part in the Task I report, NASA-CR-54291 (WCAP-2690).

To assess performance in meeting these requirements, they will be quoted below as a "Requirement" and discussed immediately following under "Performance".

1. Requirement:

The Chemical Poison Loop System is designed to maintain the desired steady-state concentration of poison in solution and to effect changes in concentration from one steady state concentration to another, as indicated in the following table:

Steady State Condition	Poison Concentration mg/cc Cd Enriched to 90% Cd^{113}
At Shutdown	2.97
At Hot Critical	1.65
At Xenon Override	0.126
Change Rates	**mg/cc-sec**
From Shutdown to Hot Critical or Xenon Override	0.0119 max
From Xenon Override or Hot Critical to Shutdown - Fast	0.0236
- Slow	0.0059

The CPLS is required to change concentration as indicated for five reactor startups from shutdown (one of these involving overriding xenon) and five reactor shutdowns. Operation at hot critical will be for a total of 10 hours.

Performance: During the performance of testing in the CPLS Laboratory Version (Section III of this report), the system was maintained at steady state concentrations without difficulty. There were a few instances in the test apparatus where the concentration experienced unscheduled changes, but these were generally accounted for as the result of demineralized water addition to makeup for pump seal leakage.

The rates of increase and decrease in poison concentration as shown on Figure 11, were in excellent agreement with those predicted by the analog model, Figures 24 and 25. These rates were actually slower than the reference system requirements. This is because the injection and removal flow rates and main loop flow were established at the reference system values but the laboratory system volume was greater thus increasing the time constant. Since the analog model predicted the laboratory system rates, the analog-predicted-rates for the reference design system with its smaller volume should be achievable.

2. Requirement:

The CPLS is designed to dissipate the heat generated within its own system fluid volume by exchange to the hydrogen propellant or water moderator. At power operation, approximately 8.0 megawatts of heat must be so dissipated.

Performance:

This requirement was not evaluated as a part of the test program but was treated by calculation as reported in the Task I Report. In that report it was shown that the 8.0 megawatts could be dissipated to the propellant or moderator through the provision of a heat exchanger on the outlet leg of the CPLS through which about 14% of the hydrogen propellant would be passed.

3. Requirement:

The maximum delay between demand signal and entrance of modified poison concentration into the poison tubes is

Ion Exchange Effluent	0.3 sec.
Normal Poison Insertion	0.2 sec.
Fast Poison Insertion	0.2 sec.

Performance: Meeting this requirement was demonstrated in the manifold model testing reported in the Task 3A report, NASA-CR-54994. Therein it was demonstrated that a modified poison concentration (in that case an injection

of concentrated salt) would reach the tops of about 18% of the poison tubes within 0.2 seconds. Those tubes first receiving the changed concentration are all those centrally located in the core. Thus the portion of the core where poison is most effective would receive poisoning first which is desirable.

4. Requirement:

During steady state or transient operation of the system the concentration in the poison tubes in the reactor is the same within $\pm$ 5%.

Performance:

During the manifold model testing it was shown that a time lag existed between the passage of a poison concentration change through the various poison tubes in the core array. This results in a variation in poison concentration at the extremes of the array at any given time in a transient. The worst case exists during the first pass of the poison through the system when a given tube has undergone the change associated therewith, before another tube has seen any change. It was shown, however, that, under the rates of change used in the CPLS, this difference could not exceed the specified $\pm$ 5%, except in one instance. At xenon override concentration, 0.126 mg/cc, a fast injection of poison will cause a momentary situation where the variation exceeds $\pm$ 5% of the bulk concentration, but this situation will only last for a few seconds until the loop concentration builds up and the mixing in the loop becomes effective.

5. Requirement:

Within the pressure vessel, the CPLS is exposed to the inlet hydrogen gas at approximately -175°F around the distribution manifold and upper portion of the poison tubes. The remainder of the poison tubes are immersed in the moderator at an average temperature of approximately 220°F. Outside the pressure vessel, an ambient space environment exists assuming no heat loss or input to the CPLS, except in the heat exchanger where 14% of the inlet hydrogen at approximately -175°F is bypassed through the tubes of the exchanger.

Performance:

Such environmental conditions were outside the scope of testing. However, calculations were performed and were reported in the Task I Report. The need was indicated for some radiation shielding around the ion exchange column to prevent overheating during operation with no flow through the column.

6. Requirement:

Pressures

During operation, hydrogen gas at 725 psi exists in upper portion of reactor vessel. In the moderator region pressure is maintained at 600 psi nominal. Outside pressure vessel, pressure is 0 psi.

Performance:

Such environmental conditions were outside the scope of testing. System pressure in the CPLS Lab. System testing was maintained at 600 psi, however. The system was designed to take 600 psi internal pressure regardless of the external pressurization from the hydrogen propellant.

7. Requirement:

G-Forces

For the booster portion of the flight when the reactor is not in operation, maximum steady accelerative loads in the flight axial direction will be + 5.0 g's. There may also be $\pm$ 1.0 g load normal to the flight axis. Maximum vibratory loads will be 5 g's at frequencies up to 2000 cps. All boast phase loads are acting for two five minute periods.

During reactor operation, the maximum steady accelerative load will be 2.0 g's in the flight axial direction and $\pm$ 1 g normal to be flight axis.

Performance:

Testing performed on the full scale ion exchange vessel showed that it could withstand the simulated G-forces associated with launch and operation. There was no deleterious effect on the ion exchange capacity. Zero-G testing was, of course, not performed, but the ion exchange system and other components were designed for such operation.

8. Requirement:

The poison solution will be circulated during shutdown at such a rate as to safely dissipate heat generated in the fluid by gamma heating.

Performance:

While no heat dissipation testing was included in the scope, reduced flow (150 - 600 gpm) tests were performed on the manifold model program, Task 3A report. These runs showed at flow distribution to the core poison tubes was unaffected by lowered flow rates so that no problems of flow starvation (overheating) is anticipated for "off-design" low flow rates.

9. Requirement:

In the event of a sudden system pressure drop, provision shall be incorporated to seal the system and de-energize the pump. The CPLS shall be "fail-safe", i.e. no accident shall result in a fast decrease in poison to the reactor core.

Performance:

In the tests performed on the Laboratory Version, rupture discs were used to give a sudden pressure drop. The stop valves provided closed almost instantaneously, stopping all flow.

10. Requirement:

The poison solution shall fulfill cross section requirements within the solubility limits. It shall be compatible with other materials in the system and shall be stable in the environment.

Performance:

At normal operating temperature, the reference poison solution, cadmium sulfate, appears to be marginal for application to the CPLS. While no corrosion problems were found with any material tested, the solution evidenced thermal instability increasing with temperature, and seemingly influenced by heat flux and surface to volume ratio. More details can be found in the Task 3B report, NASA-CR-54494.

C. Final Reference System

In the Task I Report (NASA-CR-54290) a Reference Design for the CPLS was presented. As a result of the tests performed and reported on in subsequent reports, it is now possible to assess the Reference Design and to indicate changes if any.

In general the tests indicate no changes in the Reference Design which are mandatory. Certain optional changes are indicated and will be discussed below.

The Reference Design CPLS schematic presented as Figure 1 of this report remains unchanged. As to specific system components, the following comments are in order:

a. Poison Reservoir Pressure

The Reference Design includes a system for maintaining a fixed differential pressure between the reservoir and the main loop. Such a system was not used on the Laboratory System, i.e. a fixed reservoir pressure was set, and the results were excellent. However, since it is not necessarily clear at this time that the CPLS will always be at 600 psi when poison injection is required, it would seem advisable to leave the pressure control as a feature of the reference design so that the desired driving head for injection is insured.

b. Ion Exchange Vessel

The test results indicated excess capacity in the ion exchange system. However, a specific reduction in size is not recommended. Engineering judgement would indicate that some excess capacity be available. Some allowance would be in order to accommodate for small adjustments which might be made in concentration, so that a specific sizing at this stage is academic.

With the capacity per volume measurements established in all the testing, a specific size for the ion exchange vessel can be readily established, based upon overall control considerations and the disposition of such factors as "overshoot" or "undershoot" on concentration changes other than the foregoing, no other optional changes would appear to be in order based upon the tests performed.

The marginal thermal stability demonstrated by the $CdSO_4$ at normal operating conditions would indicate that additional testing must be performed in this area before an entirely conclusive judgement of feasibility of the reference design can be justified.