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SUBJECT: Analog Computer Study of the MSR-ORR In-Pile Pressurized Water Loop No. 1

TO: Distribution

FROM: S. J. Ball

SUMMARY

A study of the dynamic behavior of the Merchant Ship Reactor Pressurized Water Loop was made using the Reactor Controls Analog Facility. Computer curves show the predicted response of the loop temperatures to normal load changes and component failure accidents. Except for complete flow stoppage, which was not investigated here, the safety system was shown to be adequate in curbing loop temperature excursions due to postulated accidents.

DISCLAIMER

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I. INTRODUCTION

Provided that adequate information is available about the physical properties of a system, a computer can usually be programmed to give an indication of the dynamic behavior of the actual system. The ORNL analog computer was set up to simulate the MSR loop according to the data provided by the loop designers. Tests were made on the system at maximum design conditions: 144 KW of nuclear heat in the test section and 508°F mean in-pile water temperature. These represent the most severe conditions expected in the loop operation.

II. LOOP DESCRIPTION

The loop will be described with reference to the flow diagram, Fig. 1. The test section occupies two adjacent fuel rod positions (A1 and A2) in the ORR. The pressurized water coolant passes down one section, around a U-bend, and up the other. In each section there are three 1/2-in.-dia by 18-in.-long stainless steel clad fuel pins. The fuel is uranium oxide (UO_2) with approximately 4% enrichment.

The water heated in the test section then passes through 130 feet of 1-1/2-in. schedule-80 stainless steel pipe to a heat exchanger in the equipment room. From the heat exchanger the water passes thru a circulating pump, the 60 KW line heater, and then back thru 140 feet of piping to the test section. With a flow rate of 40 gpm, the loop transit time is about one minute.

Temperature control is achieved by varying the by-pass flow rate around the heat exchanger. The controlled variable is the water temperature immediately downstream of the by-pass or "mixing" valve. Though it would have been more desirable to hold the in-pile water temperature constant, the 30-sec transport delay between the heat exchanger and the in-pile section would have made the temperature control extremely sluggish.

III. COMPUTER SIMULATION

1. Test Section

It was assumed that the conductivity of the fuel rods was not a function of temperature and that heat generation was uniform, thus giving a parabolic cross-sectional temperature profile in the rod for steady-state conditions. This profile was approximated by generating the mean temperatures of three concentric cylindrical "lumps" of equal volume. Gamma heating in the fuel, the stainless steel parts of the test section, and the in-pile water was taken to be 10 watts per gram. Subsequent measurements have shown the gamma heating to be only 2 watts per gram, with the ORR operating at 20 megawatts, so the simulation is pessimistic.

2. Loop Heaters

The 60-kw (max.) electrical heaters have a relatively high heat capacity (102 BTU/$^{\circ}$F). The two 12-kw on-off heaters were considered as one unit, and the continuously-variable 36-kw heater as another.

3. Heat Exchanger

The heat exchanger is rated at 150 kw cooling power with a 300°F inlet temperature. According to the simulation, its cooling capacity is 300 kw at the normal 520°F inlet temperature. Figure 2 shows curves of cooling power vs. % flow thru the heat exchanger as derived from the computer. It may be seen that even at maximum heating conditions (144 kw nuclear heat and 60 kw from the heaters) only about 25% of the flow needs to be passed thru the heat exchanger. This means that although a lot of cooling is available for emergencies, control will be difficult for low power operation since the control valve will be operating at the extreme lower end of its range. An alternate method of control where only a fraction of the total by-pass flow is controlled is being considered.

4. Loop Piping

The transport delay time of the water passing thru the piping was simulated using the ORNL-built transport lag generators. These consist of capacitor storage units mounted on a rotating drum. A signal fed into the device is stored and read out a specified time later.

In addition to the transport lag, the "thermal lag" of the piping was also simulated. This effect is due to the fact that pipe temperature is carried along with the changing water temperatures. Since the piping heat capacity is a significant part of the total loop heat capacity it was important to consider this effect. Analog approximation circuits were determined by the method outlined in reference 1.

5. Controller

The 3-term Brown "Electronik" controller was simulated by a circuit which considered the effects of reset gain, derivative gain, and a limited controller output (Ref. 2). The settings used in the tests were as follows:

Controller gain: 7.5 ("proportional band" = 13%)
Reset rate: 6 repeats/min
Derivative time: 0.04 min
Reset gain: 150
Derivative gain: 10

6. Control Valve

An Annin model 4563 three-way valve controls the heat exchanger by-pass flow. The valve has linear characteristics for both flow directions. A second order analog system with heavy damping was used to simulate the dynamic characteristics of the pneumatic operator.

7. General

Since the response times in the loop were generally quite slow, the computer solution was sped up by a factor of six. The complete computer circuit diagram (REED Dwg. No. TD-E-5403) is available and may be obtained by calling Miss Ruby Brooks, Phone 7995.

IV. RESULTS OF COMPUTER TESTS

1. Reactor Power Level Changes

Figure 3 shows the response of some of the loop temperatures for + and - 25% reactor power level changes.

Response to a reactor scram is shown in Fig. 4. For this test the fission heat was cut off and the gamma heating reduced to 50% instantaneously. The gradual decay of the remaining gamma heating is not included.

2. Loop Safety Actions

The effects of turning off the electrical heaters (60 kw), and channeling 100% of the flow through the heat exchanger are shown in Fig. 5.

3. Partial Loss of Loop Flow

The effects of reduction of the loop flow rates were noted, and some of the resultant steady-state temperatures are tabulated. Over the range shown it was assumed that the water to metal heat transfer coefficients varied as the 0.8 power of mass flow.

	LOOP FLOW RATE		
	40 gpm (Normal)	30 gpm	20 gpm
Water Temperature at Outlet of In-Pile Section	522°F	538°F	565°F
Mean Fuel Cladding Temperature	565°F	595°F	643°F

4. Control Valve Failure

A failure in the mixing valve control system could cause all of the loop flow to be by-passed instantaneously. Figure 6 shows the response of some of the loop temperatures when no corrective action is taken, and Fig. 7 shows the effects of scramming the reactor and turning off the heaters. Note that the graphs indicate a continual rise in temperatures even with the heaters off and the reactor scrammed. This is because the heat loss from the loop (assumed constant at 23 kw) is less than the residual gamma-heating value used in the simulation (50% of the total or 44 kw). Since the experimentally determined value of gamma-heating is only 20% of the value used here, the heat loss assumed would be sufficient to cause the loop to cool down.

V. REFERENCES

1. Letter from S. J. Ball to Systems Analysis Group (3-25-60), "Determining Analog Approximation Circuits for Simulation of Fluid Flow Through Long Pipes."

2. Electronic Associates, Inc., "Applications Course Notes" (unpublished), Chapter 16.

VI. ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance of E. R. Mann, O. W. Burke, and R. L. Moore in making this study.

VII. LIST OF ILLUSTRATIONS

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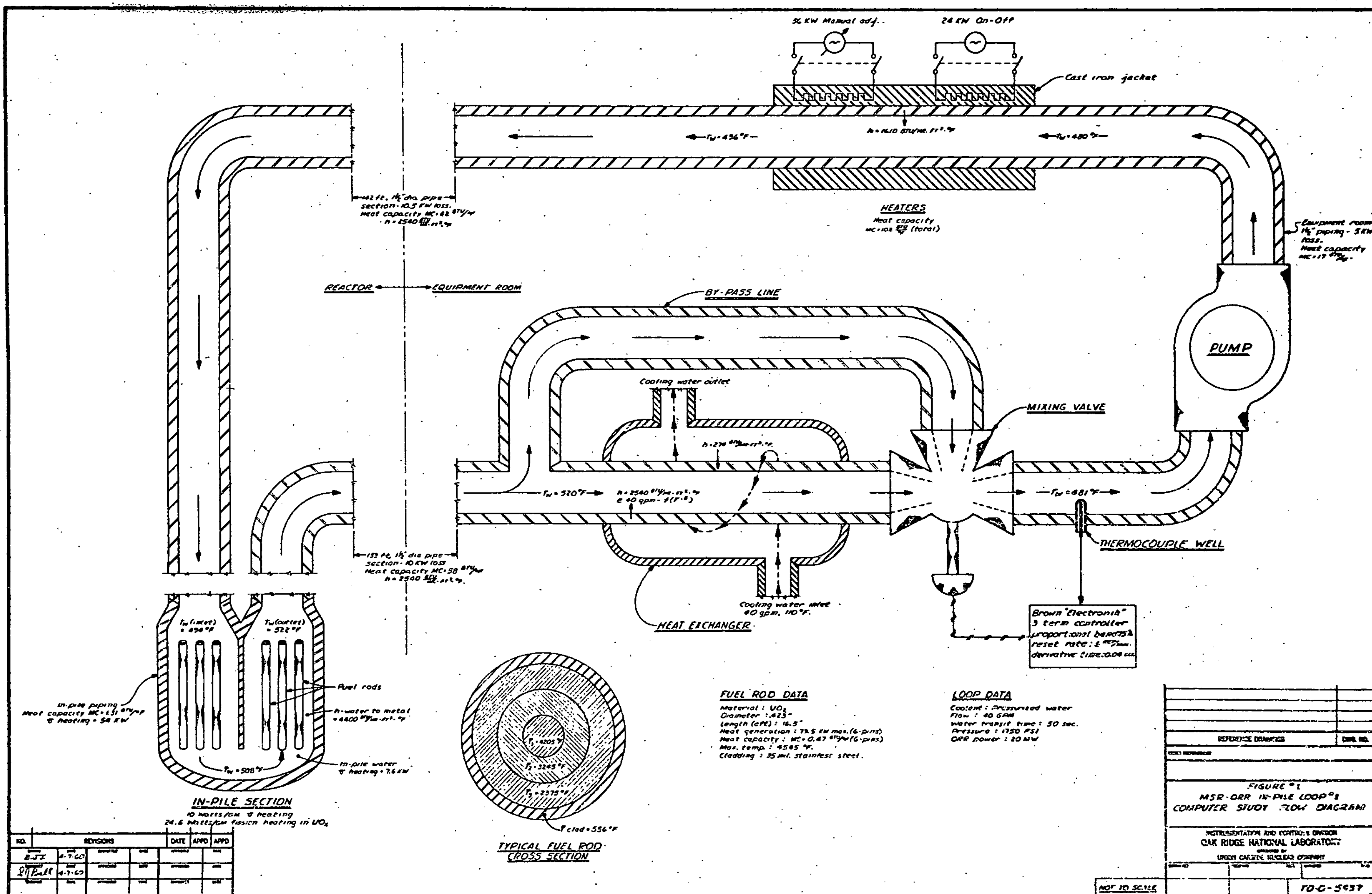
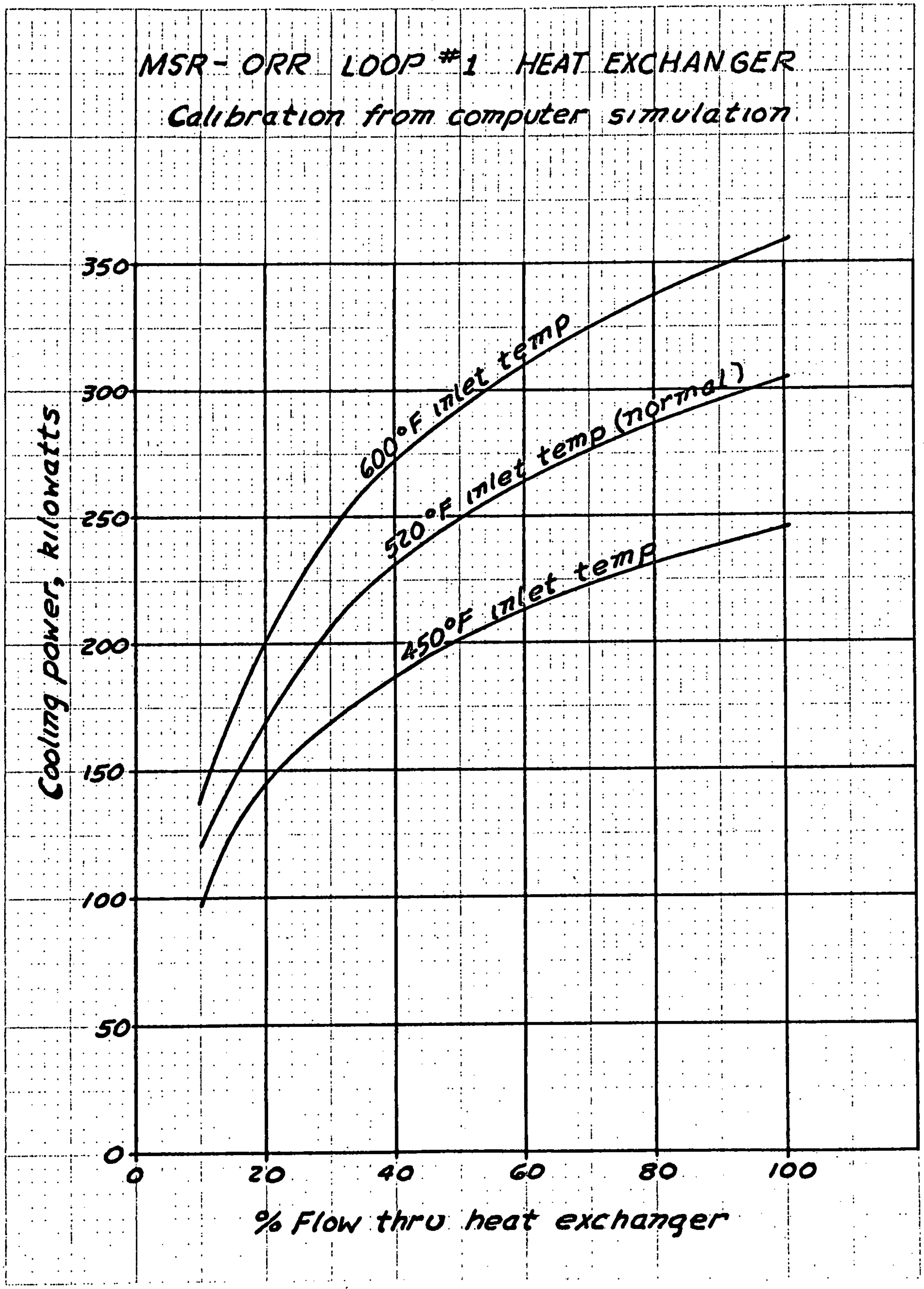


FIGURE 2


MSR- ORR LOOP #1 HEAT EXCHANGER
Calibration from computer simulation
600°F inlet temp
520°F inlet temp (normal)
450°F inlet temp
Cooling power, kilowatts
350
300
250
200
150
100
50
0
0
20
40
60
80
100
% Flow thru heat exchanger

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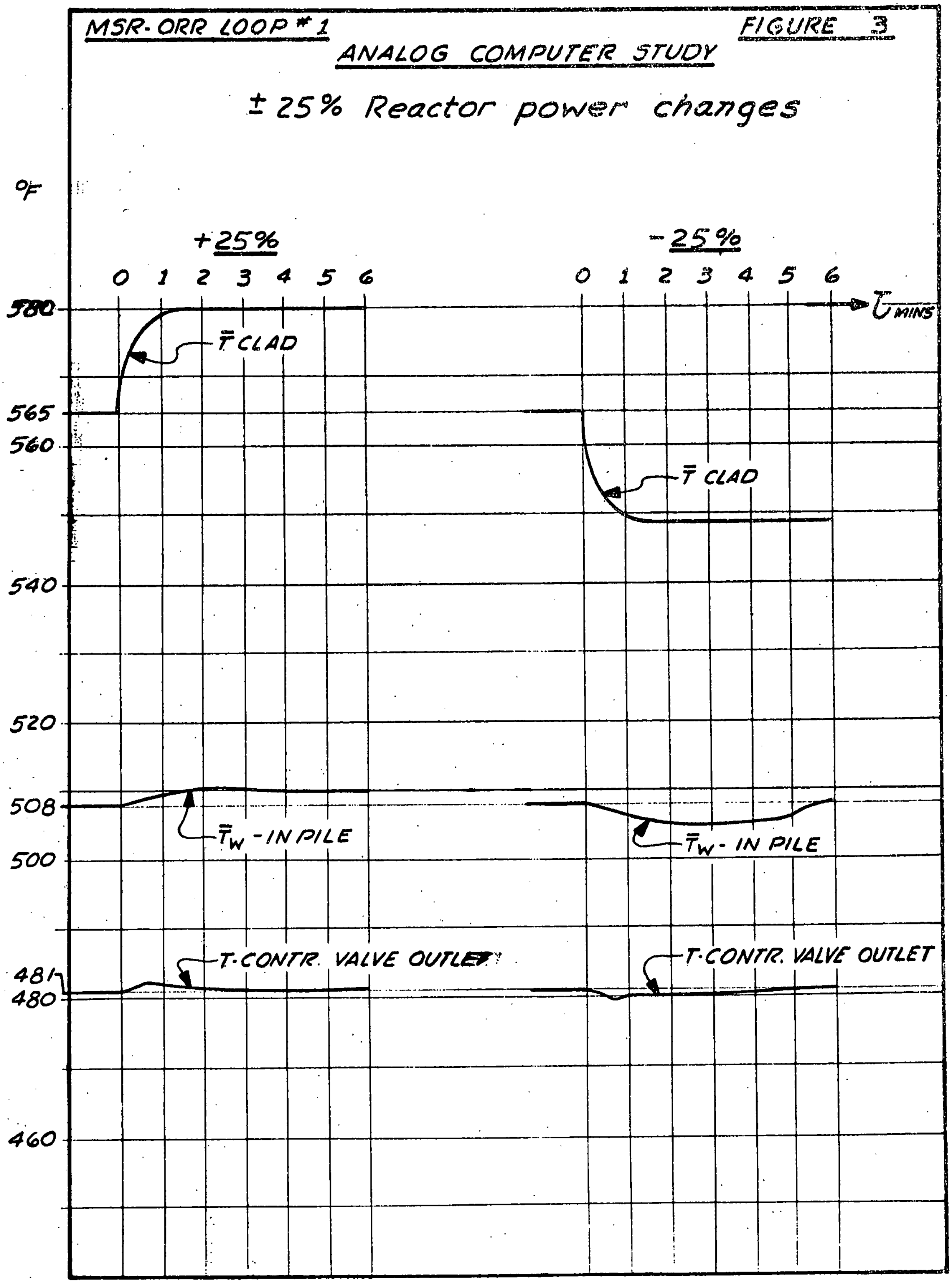

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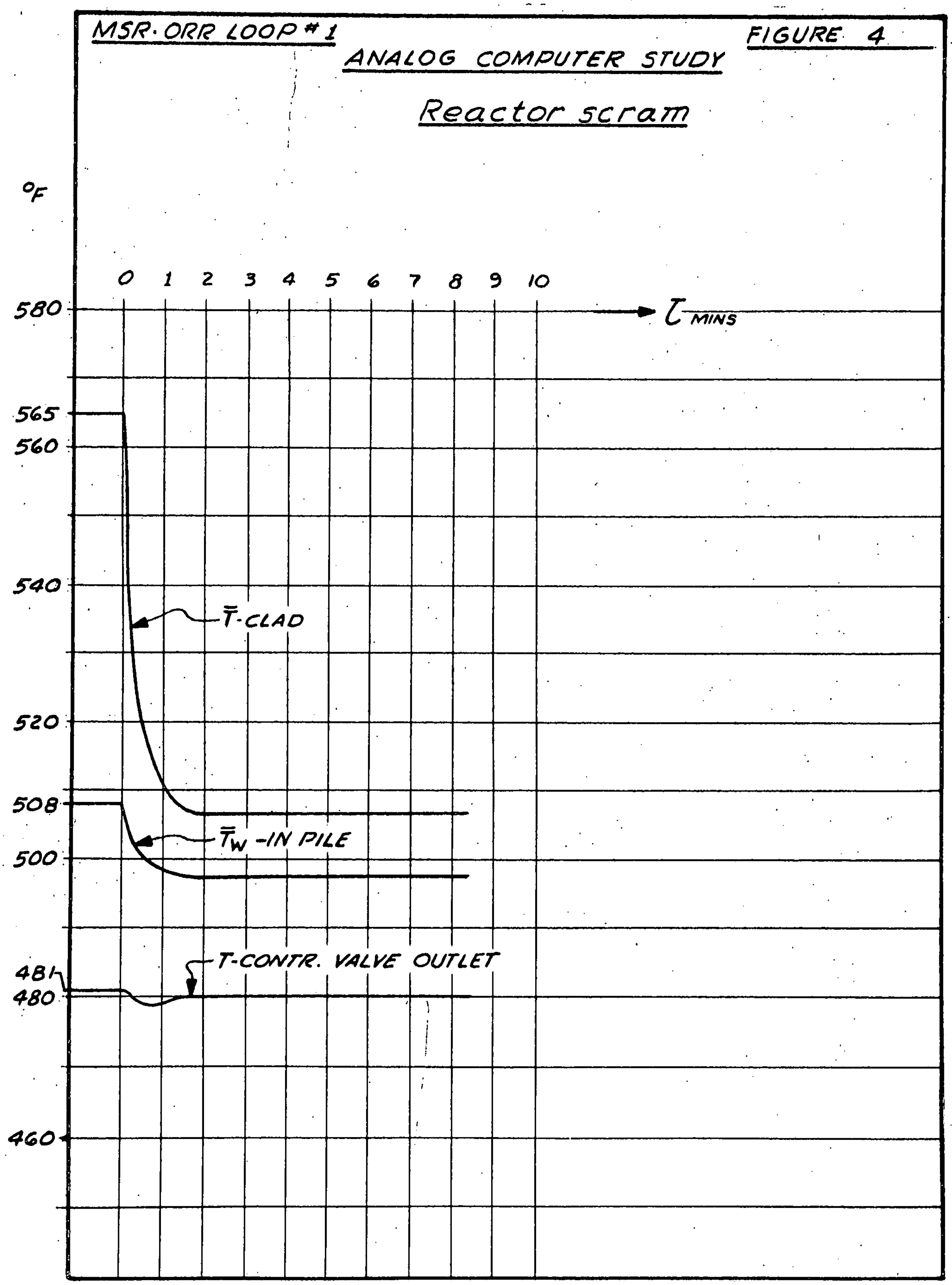

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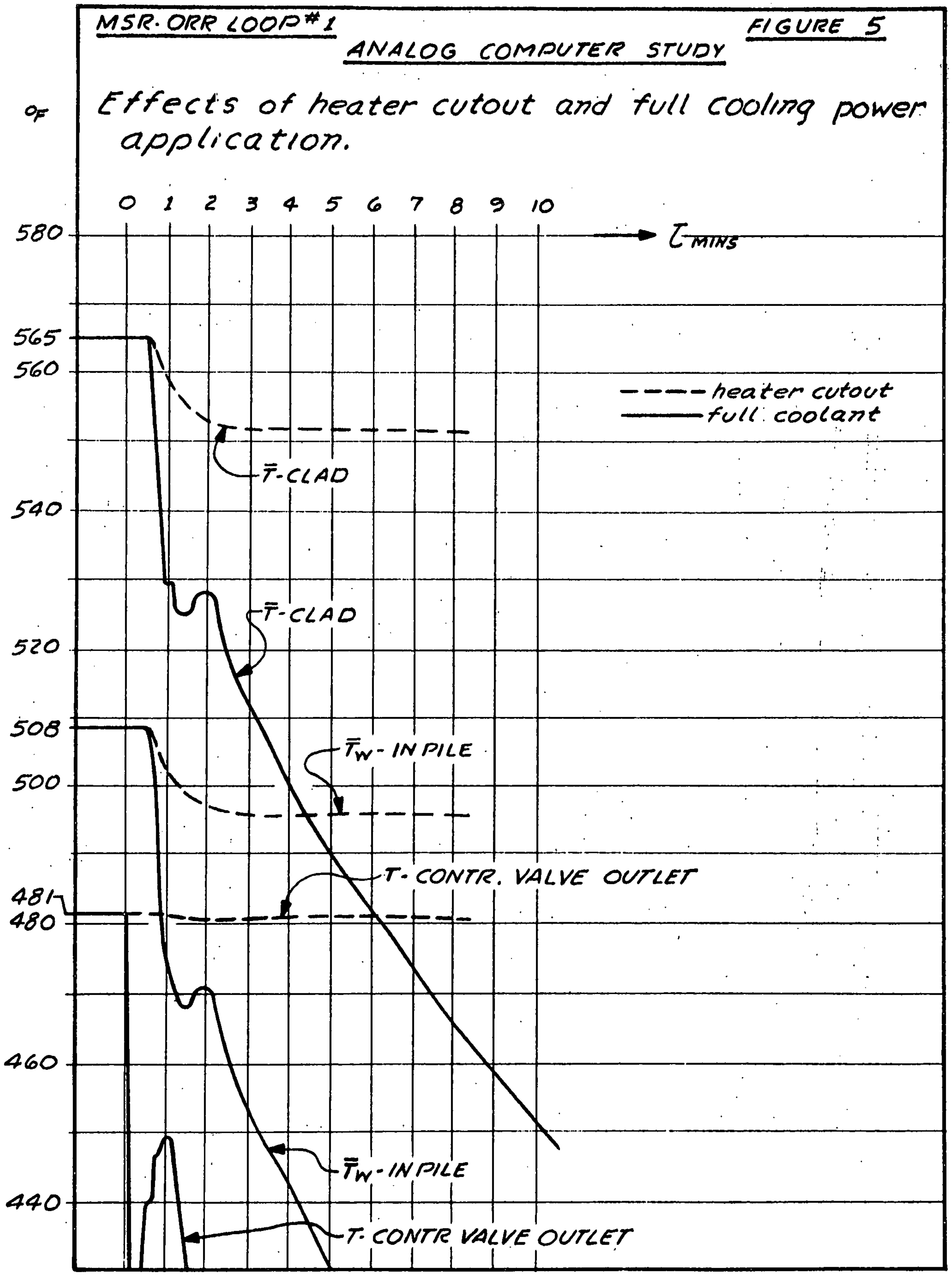

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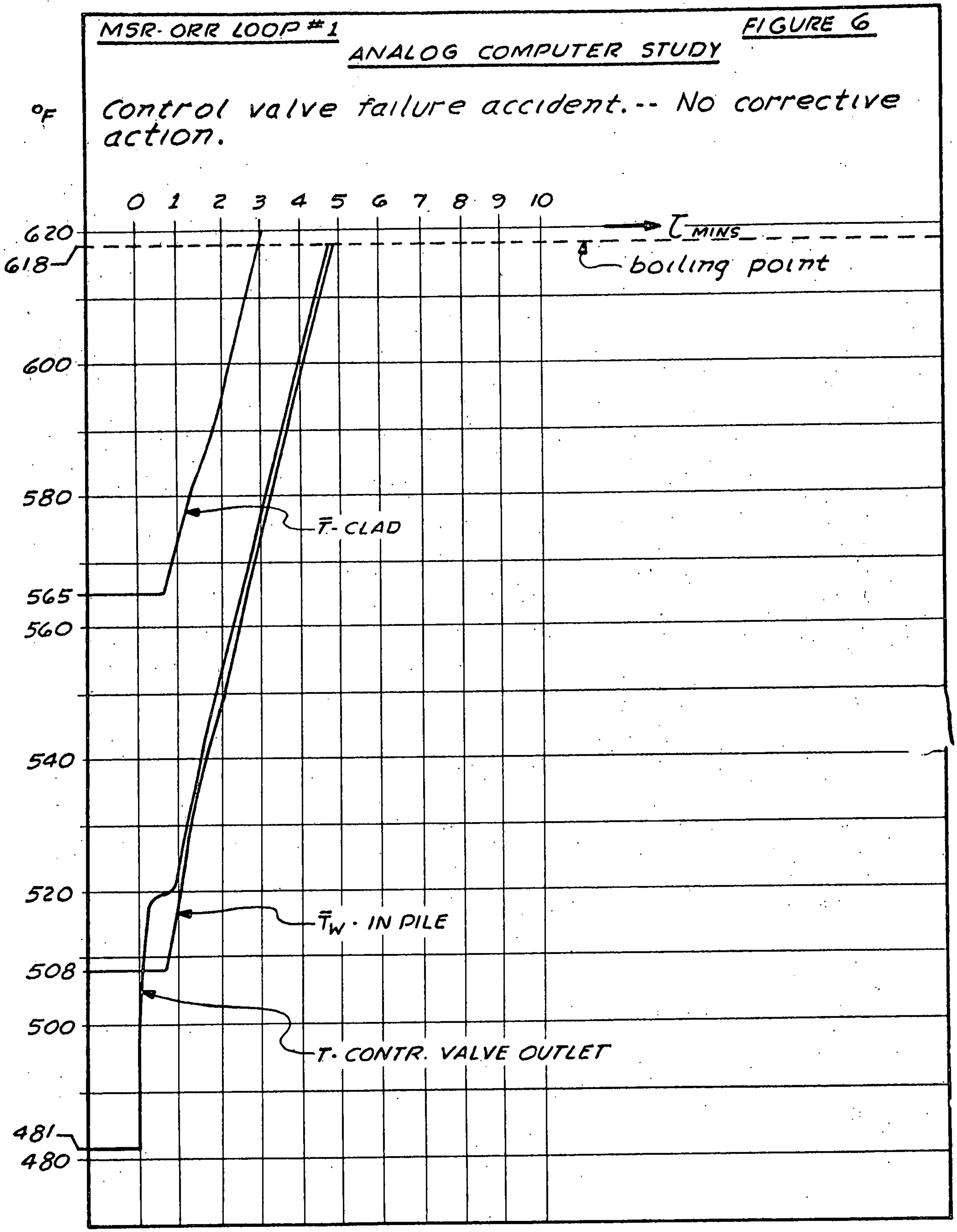

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