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Operated by
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Division of Union Carbide Corporation

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SUBJECT: MSRE - Analog Computer Simulation of a Loss of Flow Accident in the Secondary System and a Simulation of a Controller Used to Hold the Reactor Power Constant at Low Power Levels

TO: G. A. Cristy

FROM: O. W. Burke

ABSTRACT

These analog computer studies had two major aims. The first aim was to give the MSRE design personnel an indication of the time-temperature relationship of the secondary salt as a result of loss of flow in the secondary system. The second aim was to check the feasibility of a closed loop primary pump speed controller to hold the reactor power constant at a low power level.

The secondary system flow loss was simulated, and the secondary salt temperature at the radiator outlet reached the freezing point in thirty (30) seconds. The radiator fan remained in operation.

The above mentioned flow controller was simulated. The gain, damping, etc., were varied over a wide range, seeking a stable controller. The controller could not be made to operate in a stable manner.

I. INTRODUCTION

From an earlier investigation reported in ORNL C.F. 60-6-110, the reactor system designers reached the conclusion that the primary salt temperatures attained with loss of primary flow would cause no difficulty.

The designers were concerned about the very definite possibility that the secondary salt would freeze subsequent to a loss of flow accident in either the primary system or the secondary system. The freezing would be caused by the continued operation of the radiator fan after a loss of flow accident.

During a preliminary investigation using the analog computer, it was determined that the secondary salt temperature would reach the freezing point much sooner for loss of flow in the secondary system than it would for loss of flow in the primary system. In view of this fact, only results obtained as a result of loss of flow in the secondary system will be included in this report.

The designers of the reactor system proposed using flow control in the primary system as a means of holding the reactor power constant at a low power level. This controller was simulated on the computer.

II. DESCRIPTION OF THE SYSTEM SIMULATED

A. Thermal System

The thermal system was based on the latest design information and it differed appreciably from that used in the preliminary simulation that was reported upon in ORNL C.F. 60-6-110. The design information used in this simulation is included in this report on pages 5 and 6.

In order to preserve design point temperatures around the primary loop, the "after heat" was added as if it were all released inside the reactor. Of course, this is not true; however, the error appears to be very small. Pipe losses, which were ignored, would tend to offset the "after heat" generated outside the reactor.

The loss of flow occurred exponentially on a three (3) second period. At this time there was no available pump "run-down" information.

The heat transfer coefficients between the secondary salt and the primary heat exchanger wall and between the secondary salt and the radiator wall were made to vary with flow rate in accordance with the curve shown in Figure 1.

The temperature differential between the hot and cold legs in the secondary system produces a force due to the density differences in these legs. This force induces flow in the system. This phenomenon was incorporated into the simulation.

B.   Nuclear System

The delayed neutrons were lumped into one weighted group.
Using the values from document LA-2118, dated 1957, λ for
the one group was found to be 0.0769 sec.$^{-1}$ and β was found
to be 6.4 x 10^{-3}. Using the given fuel transit times and the
curves in ORNL-LR-Dwg. 8919, β' was found to be 1.800 x 10^{-3},
where

$$\beta' = \sum_{i=1}^{6} \alpha_i \beta_i$$

α_i is the ratio of the population of the ith group of de-
layed neutrons inside a circulating fuel reactor to the popula-
tion of this group in an equivalent stagnant reactor.

In the simulation, the delayed neutron contribution varied
with primary flow rate. The simulation method was admittedly
not precisely correct, but it was considered a good approxima-
tion. The delayed neutron contribution is correct at design
point steady state and at zero primary flow. The variation of
the delayed neutron contribution between these two points is
only an approximation.

III.   ANALOG COMPUTER PROGRAM

The analog computer programs of this simulation are filed as ORNL
drawings, numbers E-40327 and E-40328.

The program for loss of flow in the primary is drawing number
E-40327. The power level controller program is also on this
drawing. The program for loss of flow in the secondary is drawing
number E-40328.

Copies of the above drawings may be obtained from the Print Files
in the E & M Division.

IV.   PROCEDURE

These studies were conducted in three phases. These phases were:

1.   Loss of flow accident in the primary system.

2.   Investigation of the characteristics of proposed power level
controller.

3.   Loss of flow accident in the secondary system.

The following procedures were employed:

1.   Loss of flow accident in the primary system.

With the simulator in steady state operation at design point,
the primary flow rate was decreased to zero, exponentially on
a three second period. The secondary flow was not disturbed.

Pertinent temperatures and nuclear power were recorded versus time. Runs were made for three different graphite temperature coefficients of reactivity.

2. Investigation of power level controller characteristics.

The controller was simulated so that its gain, damping, and response time were variables which could be changed by changing a potentiometer setting. With these pots set at given values, and the reactor simulator in steady state operation with no temperature coefficients of reactivity, a small perturbation was introduced into the system. The effect of this perturbation on the nuclear power level was observed. This procedure was repeated for a number of potentiometer settings in an attempt at determining optimum settings.

3. Loss of flow accident in the secondary system.

With the simulator in steady state operation at design point, the flow rate in the secondary system was decreased exponentially on a three second period. The primary flow rate was not disturbed. Pertinent temperatures and nuclear power were recorded versus time.
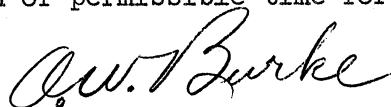
V. SUMMARY OF RESULTS

With loss of primary flow, the temperatures attained were of the same order of magnitude as those recorded in ORNL C.F. 60-6-110.

Three runs were made, using graphite temperature coefficients of reactivity of -2×10^{-4}, -1×10^{-4}, and -4×10^{-4} $\partial k/k$ °F. The maximum primary temperatures attained in these three runs had a spread of only 20°F. Loss of primary flow was simulated in these three runs. Due to the large heat capacity of graphite, the temperature of the graphite changed very little and the rate of change of temperature was very low.

The power level controller showed a tendency to be oscillatory and it could not be stabilized (see memo from E. R. Mann to J. R. Tallackson, dated September 12, 1960, entitled "Closed Loop Pump Speed Controller to Hold the MSRE Power Constant at Low Level").

In the simulation of secondary flow loss, the radiator fan continued in operation. The temperature of major concern was that of the secondary salt at the radiator outlet, since this was the coldest point in the system. This temperature reached the freezing point (860°F) thirty (30) seconds after initiation of the flow loss (see Figure 2). This gives an indication of permissible time for corrective action.

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OWB:njn

<u>Updated Computer Information to Ray Mann, 3rd Issue</u>

Reactor inlet temperature: $1175^{\circ}F$

Reactor outlet temperature: $1225^{\circ}F$

Mean graphite temperature: $1230^{\circ}F$

Residence time in reactor: 2.02 sec

Film drop from graphite to fuel: linear with power

Heat capacity of graphite: $4040 \frac{Btu}{^{\circ}F}$ (cp = .425 $\frac{Btu}{lb\ ^{\circ}F}$

Prompt γ and neutron heating in graphite: 6% of 10 Mw power

Residence time in piping from reactor outlet to H.E. inlet   3.56 sec

Residence time in H.E.   1.62 sec

Heat capacity of metal in H.E. $200 \frac{Btu}{^{\circ}F}$

Avg. film drop between primary coolant and metal at D. P. $55.2^{\circ}F$

Avg. drop in metal at D. P. $56.7^{\circ}F$

Avg. film drop between metal and secondary coolant at D. P. $26.1^{\circ}F$

Film drop between primary coolant and metal as function of flow:
See graph, displace curve if necessary so that at 7.5 fps velocity $t = 55.2^{\circ}F$

Mean secondary coolant temp. at D. P. $1062^{\circ}F$

Residence time in piping between H.E. outlet and reactor inlet
(including coolant annulus)   5.76 sec

Total circulation time   13.0 sec

Temp. coeff. of reactivity of graphite: -2×10^{-4} $\frac{\partial K}{K} \cdot ^{\circ}F$

Temp. coeff. of reactivity of fuel: $-4.5 \times 10^{-5} \frac{1}{^{\circ}F}$

Melting point of primary coolant: $842^{\circ}F$

Melting point of secondary coolant: $860^{\circ}F$

Check points:

Thermal resistances: $\left(\frac{ft\ hr\ ^{\circ}F}{Btu}\right)$

     in primary coolant film: 3.28×10^{-4}

     in metal: 3.32×10^{-4}

     in secondary coolant film: 1.56×10^{-4}

The rate of heat removal in thermal convection follows the correlation (for the primary circuit)

$$4.48 \times 10^4 \ \Delta t \left(\frac{q}{\Delta t}\right)^{-1.0} - 9.15 \times 10^{-3} \times \left(\frac{q}{\Delta t}\right)^{0.8} = 4.14$$

where Δt is the temp. differential between the hot and cold leg ($^{\circ}F$) and q is the rate of heat removal from the primary system ($\frac{Btu}{hr}$)

Simulator data for secondary loop

Air temperature rise in radiator	200°F
Air suction temp.	100°F
Air flow	166,000 cfm ($7.11 \times 10^5 \frac{lb}{hr}$)
Heat capacity of radiator	$242 \frac{Btu}{^\circ F}$
Heat capacity of secondary salt	$0.57 \frac{Btu}{lb\ ^\circ F}$
Density of secondary salt	$120 \frac{lb}{ft3}$

Residence times of secondary salt:

in primary heat exchanger	0.92 sec
in piping to radiator	2.56 sec
in radiator	4.85 sec
in piping from radiator	4.72 sec
Total	13.05 sec

Residence time of air in radiator	0.01 sec

Temperature differences in radiator:

in salt film	22°F
in tube wall	78°F
in air film	762°F

FIG. 1
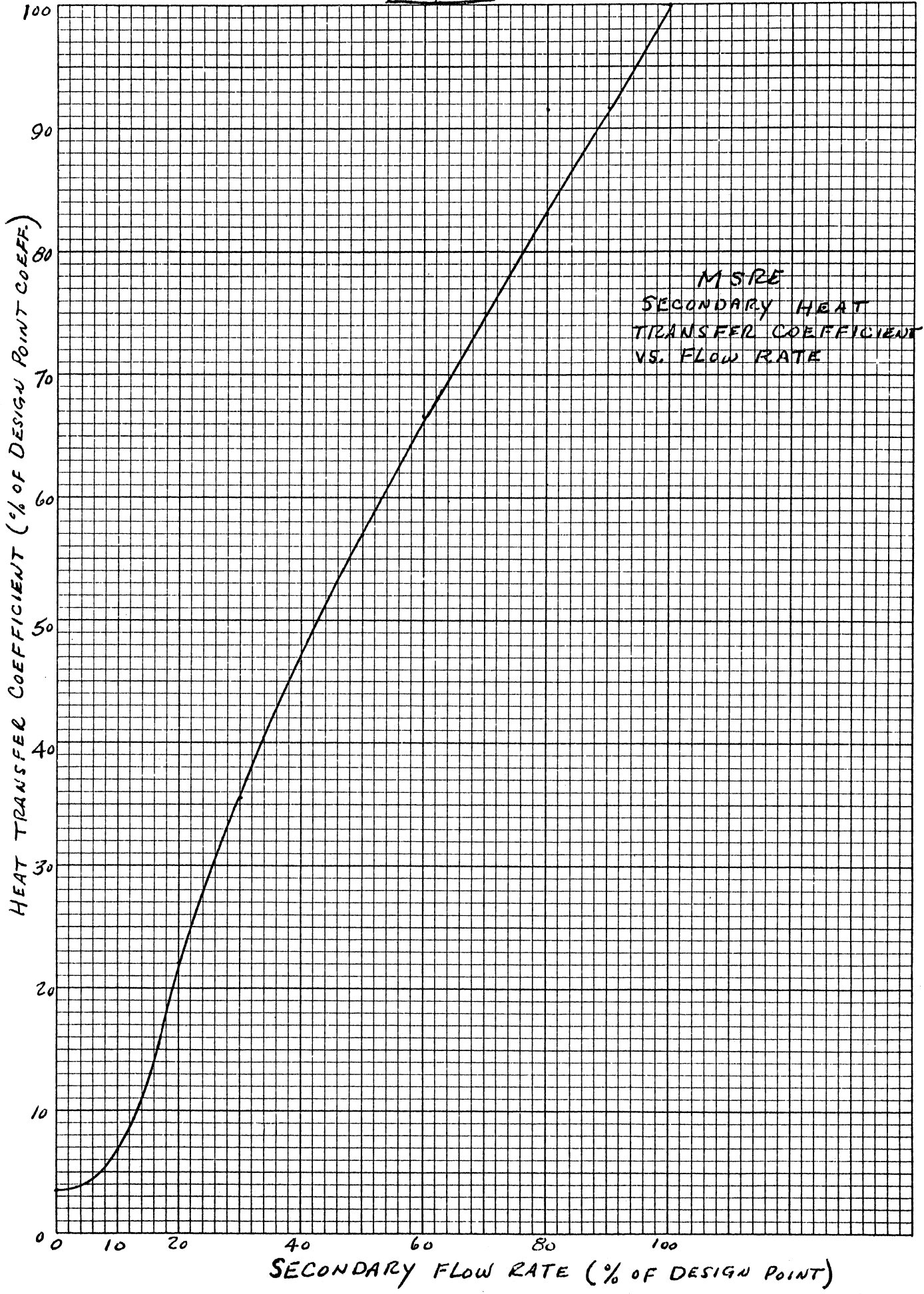
MSRE
SECONDARY HEAT
TRANSFER COEFFICIENT
VS. FLOW RATE

HEAT TRANSFER COEFFICIENT (% OF DESIGN POINT COEFF.)

SECONDARY FLOW RATE (% OF DESIGN POINT)

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