LOSS OF COMPONENT COOLING WATER STUDY FOR RCP INTERNALS AND MOTOR BEARINGS

DUQUESNE LIGHT COMPANY

BEAVER VALLEY UNIT #2

MARCH 28, 1985

RECORD OF REVISIONS

Revision Number	Date	Revision	Revised By:
0	March 28, 1985	Original Issue	

ABSTRACT

This report documents studies performed to address an incident of loss of component cooling water to reactor coolant pump internals and reactor coolant pump motor bearings. The concern centers about the possibility of a locked rotor, or instantaneous shaft seizure, occurring as a result of this CCW loss.

Test summaries and data are included in addition to, where necessary, analytical studies.

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1.0 INTRODUCTION

Reactor coolant pump internals supplied to Duquesne Light Company for the Beaver Valley Unit #2 power plant are equipped with a radial bearing assembly lubricated and cooled with water.

The reactor coolant pump motors are provided with oil lubricated upper and lower bearing assemblies cooled by an external water supply.

Concern exists over the consequences of losing the cooling water during normal operation for 20 minutes. Both pump and motor have been reviewed with respect to this occurrence. Of specific concern is the possibility of having a locked rotor condition or instantaneous shaft seizure as a consequence of this loss.

Both pieces of equipment have been tested to investigate this situation. In addition, analyses have been performed to supplement some of the test data.

2.0 CONCLUSIONS

It is concluded that Beaver Valley Unit #2 RCP motors will successfully operate without CCW flow to the bearings for 20 minutes. Loss of CCW to the pump heat exchanger is of no operational concern and the pump internals are capable of operating indefinitely.

3.0 MOTOR LOSS OF CCW

3.1 Beaver Valley Unit #2 Study

3.1.1 Motor Description

Reactor coolant pump motors supplied to Duquesne Light Company for the Beaver Valley Unit #2 power plant are provided with oil lubricated upper and lower bearing assemblies.

The lower radial guide bearing consists of babbitted steel pads which are free to pivot. They are positioned by jackscrews and are held in place with lockplates. The entire lower guide bearing assembly is located in the lower oil reservoir (oil pot) which also contains an internal oil-to-water heat exchanger for cooling the bearing. The oil pot is an integral part of the lower bracket.

The upper bearing assembly contains two eight-shoe thrust bearings (upper and lower thrust bearings) and a seven-pad radial guide bearing (upper guide bearing). Kingsbury-type thrust bearing shoes are used above and below a common runner to accommodate thrust in either direction. The babbitted-steel shoes are mounted on equalizing pads which distribute the thrust load equally to all shoes. The shoes tilt and allow the oil to assume a thin wedge-shaped film between them and the shaft-mounted runner. An oil lift system provides the initial oil film during startup. Cooling is provided by an external

upper bearing oil cooler. The upper radial guide bearing consists of oil-lubricated pivoted pads similar to the lower guide bearing. The guide bearing runner is an integral portion of the thrust bearing runner.

The two bearing assemblies are described by Figures 1, 2, and 3.

During operation, the friction caused by the various bearing parts generates heat in the oil pots. As described above, both oil pots are cooled by heat exchangers supplied with an external cooling water supply. Without the cooling water, the heat produced by friction will cause the temperature of the oil in the pots to rise.

A hypothetical case involves loss of this external component cooling water (CCW) for a period of 20 minutes. The concern is that during this time, the oil temperature will rise to the point where the bearings no longer function adequately with respect to load carrying capability. The event postulated is that the bearing capability will deteriorate extensively enough to cause contact to occur between rotating and stationary components. This contact would then, potentially, lead to shaft seizure, an instantaneous locked rotor condition.

This portion of the report is intended to develop two points:

1. Under the conditions of loss of CCW for 20 minutes, there will be no deterioration of motor bearing capability to the point of metal-to-metal contact occurring.

2. Shaft seizure or instantaneous locked rotor condition would not be the result even if metal-to-metal contact occurs in motor bearings at rated speed and bearing loads.

It can be noted that illustration of premise no. 1 indicates that under the stated operating conditions and over the time period studied, the motor bearings should continue to operate with no adverse effects. Illustration of premise no. 2 indicates that if system transients occur either during or after the imposed time limit which cause bearing film deterioration to the point of metal-to-metal contact, the result will not be instantaneous shaft seizure.

3.1.2 Bearing Failure

The development of metal-to-metal contact in motor bearings, whether thrust or guide, would be expected in the form of a shearing action of the rotating surface against the relatively soft surface of the bearing shoe babbitt.

This condition could be created in one of two ways in the situation studied.

1. The combination of babbitt temperature and bearing surface loading reaches a condition such that, although an oil film is maintained, the soft babbitt metal begins to yield and disrupt the shoe surface profile. This would then be expected to cause the bearing shoe and runner surfaces to contact. A maximum allowable babbitt temperature would be exceeded.
2. Although temperatures in the babbitt may remain below levels which would cause metal failure, the oil film may become small

enough such that the required load could no longer be carried thus causing rubbing between stationary and rotating components. A minimum oil film thickness would not be maintained.

3.1.3 Beaver Valley Unit #2 Specifics

The Beaver Valley Unit #2 RCP motors were analyzed using a technique described in Section 3.2 of this report.

This study centered around the upper thrust bearing, the component most heavily loaded during normal operation. Backup tests studied all bearings, including both guide bearings. The loaded thrust bearing is found to have the highest measured surface temperature. This, combined with its known high loading, provides the basis for the assumption that as long as this bearing is found to be acceptable the others will be as well.

Manufacturing drawings were reviewed with respect to developing proper bearing geometry, heat sink sizes, and ambient cooling characteristics for use in the analysis.

The Duquesne Light Company and Mobil Oil Corporation were consulted concerning the properties of the lubricant used, Mobil SHC824. It is important that the actual lubricant used be modeled as critical properties may differ from fluid to fluid.

The pump hydraulics have been reviewed in order to accurately model the bearing loading.

The conditions of the study include:

1. Normal loop flow and pressure.
2. No. 1 seal operating.
3. All RCP motors operate under the same conditions, implying no backflow due to one or more motors being out of service.
4. Normal speed operation.
5. No coincident LOCA or seismic event occurs.
6. Conditions of maximum ambient temperature and maximum CCW temperatures are assumed at CCW loss initiation.

Figure 4 indicates the predicted temperatures for oil pot and bearing pad for the configuration and conditions described above. Note that the calculated curves include oil bath and maximum pad temperatures for a variation of +10% over the nominal design load. It is felt that such a variation is possible in this configuration. At the end of 20 minutes, the critical parameters are as follows:

1. Oil bath temperature = 71°C.
2. Maximum bearing shoe temperature = 127°C.
3. Minimum film thickness = .0011".

The above results indicate critical parameters of 127°C pad temperature and .0011" film thickness. Reviewing calculations for a load of 10% increase over nominal gives figures of 132°C and .0009" minimum film thickness. These figures are felt to be within the allowable limit for bearing operation under conditions postulated.

3.1.4 Conclusions

The Beaver Valley Unit #2 motors were studied based on analytical techniques described in the next section. Based on results obtained

from this analysis as well as observations made on the equipment these RCP motors will successfully operate without CCW flow to the motor bearings for 20 minutes, and subsequent coastdown to standstill will occur satisfying the limit curve specified for this unit.

3.2 Analytical Technique and Confirmation Testing

3.2.1 Introduction

A development project was devised to determine if RCP motors can withstand a loss of all cooling water flow to its oil-lubricated bearings for at least 30 minutes and still exhibit acceptable characteristics.

Assumptions for this study include:

1. No concurrent loss of pump injection water flow is anticipated.
2. No coincident seismic or LOCA event is anticipated.
3. The plant incident that is postulated is the loss of cooling water flow to all RCP motors simultaneously, followed by tripping of the motors after 30 minutes, and all motors coasting down together, with no backflow in any loop. The loss of only one motor because of loss of cooling water flow (with no coastdown because of loop backflow) is assumed not to occur.

3.2.2 Scope

The scope of the program essentially included two major parts.

3.2.2.1 Analysis

The basis of this part of the project was the development of a computer model which could be used to simulate the operating characteristics of an RCP motor during the loss of CCW incident.

The motors of interest all have certain similarities that would allow a computer model to be developed which is appropriate for them all. Input was selected to cover these generic points. Included in the similarities are:

a. Kngsbury type babbitted thrust bearing.

b. Oil Lubrication.

c. Oil bath cooled by oil to water heat exchanger.

d. Oil bath contained within and supported by steel fabrications.

Basic calculations can be carried out for a range of parameter sizes for the above conditions.

3.2.2.2 Test

The second major portion of the project included the operation of a typical RCP motor in a full flow test loop, essentially under operating conditions. Component cooling water was turned off for various periods of time. Detailed data was taken during tests and compared to the computer model.

3.2.3 Computer Model

The computer model was the central portion of the project. Its successful development would enable a full range of RCP motor geometries to be simulated along with a full range of operating characteristics.

The basis for the computer program is one of developing models of the bearing and other functional heat producing areas and

introducing the methods of storing or removing this heat by way of metal, oil, and water masses, heat exchanger capability, and heat transfer to surroundings.

The flow chart, Figure 5, indicates the major steps in the program.

Following is a description of the major steps shown on the flow chart.

3.2.3.1 Heat Generation

3.2.3.1.1 Heat generated by sources other than the loaded thrust bearing is obtained by calculating friction losses developed between closely spaced components, one rotating and one stationary. Guide bearings, labyrinth seals, etc., fall into this category. Both laminar and turbulent flow is considered depending upon speed, viscosity, and clearance.

3.2.3.1.2 Heat generated by the loaded thrust bearing is calculated. In addition, critical bearing properties such as minimum film thickness, maximum bearing temperature, and temperature rise across the bearing pads are calculated.

3.2.3.2 Heat Dissipation

The heat generated by friction can be dissipated into the heat exchanger, the metallic structures, the oil, or into the surrounding air.

3.2.3.2.1 Oil-to-water heat exchanger heat transfer coefficients are provided by the heat exchanger manufacturer.

3.2.3.2.2 The method of calculation assumes that upon loss of CCW initiation, the colder water in the heat exchanger absorbs heat more rapidly

than the relatively warm metal/oil mass. At some point in time, the water and metal/oil mass attain the same temperature. From this time on the water, oil, and metal masses act together as a heat sink. They, together with losses to the air, dissipate the heat.

When the exchanger is not operating further (water temperature equals oil temperature) the heat dissipation is calculated as follows:

$$Q = M3Cw + M2Cpo(T) + M1.1Cpc + M1.2Cps + HdelT$$

where

Cw = water specific heat

Cpo(T) = oil specific heat (variable with T)

Cpc = copper specific heat

Cps = steel specific heat

H = oil-to-ambient heat transfer coefficient (accounting for fluid to/from metal heat transfer and heat conduction through metal walls as resistance to heat flow).

delT = difference between oil bath temperature and ambient temperature.

M3, M2, M.1.1, M.1.2 = respectively, actual water, oil, copper, and steel masses.

3.2.3.3 Oil Temperature

Oil temperature rise is calculated by accounting for the fraction of heat dissipated into the oil and applying the temperature dependent heat capacity (specific heat) value.

3.2.3.4 Calculation of Oil Properties

Oil viscosity, density, and heat capacity are a function of temperature. Known values are input to the data set and intermediate values are obtained by interpolation according to known relationships.

3.2.4 Motor Test

The motor test took place in three phases. First was a sequence of tests whereby the allowable babbitt temperature would be successively raised until a 30-minute loss of CCW was achieved without reaching the stated temperature limit. This initial series of tests constituted the first phase. The second phase of the test was generally a repeat of the first with some rather minor changes in procedure. The third phase introduced significant changes in test parameters, including an increase in the thrust bearing pressure loading.

The test procedure included the following general steps:

1. Operate pump/motor at standard loop conditions to obtain steady-state operating values.
2. Shut off CCW to oil coolers.
3. Monitor test parameters for specified period of time.
4. Initiate motor shutdown. This includes a variety of combinations of restoring CCW, initiating oil lift, and deenergizing the motor.

5. Post-shutdown test - brief tests indicating breakaway torque (ability of rotor to turn by hand with oil lift provided).
6. After a set number of tests, the bearings were disassembled for an in-depth inspection of critical bearing parts.

Phase I basically consisted of Steps 1 through 5 with CCW restored immediately upon breaker opening and no oil lift used. Phase 2 repeated Phase 1 tests except Step 4 involved use of oil lift and no restoration of CCW. Phase 3 consisted of Phase 1 altered to give higher bearing pressures than normally seen on the test loop.

In addition, Phase 3 eliminated oil lift upon coastdown. Step 6, inspection, was introduced between each phase.

3.2.4.1 Test Results

Figures 6 and 7 indicate the comparison between test data and analytical predictions for tests run at two different bearing loadings (Phase I and Phase 3 tests).

The graphs presented include measured oil bath temperature as well as measured maximum pad temperature. Added to these curves are those showing calculated oil and pad temperatures. Calculations were made which included a load variation of +10% to -10% of nominal. As indicated previously, this is a reasonable estimate of the potential load variation over design nominal. It is noted that although pad temperature varies with load, the oil bath temperature is basically unchanged over the range of load variation studied.

A coastdown speed vs. time plot was developed for ea test. Over a speed range of interest, the coastdown curves for all tests are very similar.

3.2.5 Comparisons of Computer Program to Other RCP Motor Tests

Following is a description of two tests which were run on various RCP motor/pump combinations. These tests were not necessarily run with the intention of producing a 30-minute loss of CCW situation with heavily instrumented bearing One case has heavily instrumented bearings while the other has a short loss of CCW situation. In addition, some test parameters were not measured which are necessary for a detailed comparison. Despite the lack of instrumentation which was used in the tests listed under 3.2.4, these other tests do indicate the general validity of the analytical techniques used.

3.2.5.1 Test #81355 (Figure 8)

This test was conducted over a 10-minute loss of CCW duration. Oil temperatures measured are temperatures at the cooler inlet, possibly a bit hotter than oil pot bulk temperatures. Maximum pad temperatures are extrapolated from standard RTD measurements.

It is noted that predicted bulk oil temperature is somewhat lower than cooler inlet, but this is to be expected. Pad temperatures correlate well considering extrapolation assumptions.

3.2.5.2 Test #86760 (Alternate Lubricant Test)

The following test involves a motor run to test a lubricant planned as a possible replacement for petroleum based oil. The interest in this test lies in the fact that density and heat capacity values vary from those for a petroleum based oil normally used.

The motor was heavily instrumented giving good readings for maximum pad temperatures as well as oil temperatures and heat losses. This test did not operate in a loss of CCW mode and was only used to arrive at equilibrium conditions.

The table below summarizes some pertinent data from the test and the equilibrium conditions predicted by the computer program.

TABLE 1

ALTERNATE LUBRICANT TEST

	TEST	COMPUTER
Oil Temp. (°C)	53	53.9
Maximum Pad (°C)	94	91.1
Losses	128.5 KW	141 KW

3.2.6 Test Summary

It should be noted that the tests described in Sections 3.2.4 and 3.2.5 have covered a range of bearing parameters. Included are variations in loading, speed, and lubricant properties. Figures referenced are located at the end of the report.

3.3 Experience of Metal-to-Metal Contact in RCP Motor Bearings

The second of two premises presented in Section 3.1.1 was that shaft seizure or instantaneous locked rotor condition would not be the result if metal-to-metal contact occurs in motor bearings at rated speed and bearing loads.

As described earlier bearing pads, the stationary load carrying components adjacent to the rotating components, consist of a steel block, machined to proper geometry, and coated with a layer of babbitt. This babbitt, either tin or lead base, constitutes the layer of material immediately adjacent to the rotating components. The rotating components are, typically, alloy steel forgings, significantly stronger and harder than the relatively soft babbitt material.

There has been occasion to observe, to various degrees, the action of the bearing under conditions of metal-to-metal contact. Included in these instances were the tests run in association with the project described in Section 3.2. Also, other actual situations have been observed and studied with respect to this situation. All details described below have occurred on full-size RCP motors operating at full speed with bearings loaded at or above expected operating loads.

3.3.1 <u>Thrust Bearing</u>

3.3.1.1 The thrust bearing shoes have been observed under varying conditions. One includes the situation where the thrust runner contacts the babbitt thereby creating a very high temperature readout in the bearing temperature instrument. In this case, the motor is generally shut down to determine the problem. Observations indicate that to one degree or another, the babbitt is partially sheared away, thus providing a plyable surface which the more durable runner "machines" away. Under no instances has the action here caused a locked rotor condition.

3.3.1.2 The experience above has been carried one step further. In a case where metal-to-metal contact was sensed by temperature rise, the motor was not shut down but continued to run at rated speed and load. The situation continued for some time. Upon motor shutdown, the thrust bearing was inspected. In this case, the extended operation had caused the entire babbitted layer to be wiped away, thereby causing the thrust runner to come in direct contact with the steel backing shoes. Severe wear on both runner and shoes existed to the extent that gouges up to 3/8" deep were worn in both.

Despite this very severe operation condition, the motor was shut down and brought to standstill in an orderly manner. An instantaneous locked rotor condition or shaft seizure did not occur.

3.3.2 <u>Guide Bearings</u>

The guide bearing, because it is located in a vertical machine, does not experience the extensive loading that the thrust bearing does. One way to obtain a metal-to-metal contact situation would be to "starve" the bearing of oil. This situation was created on a factory unit. The entire motor was operated at full speed with oil effectively shut off from the upper guide bearing.

This result was severe rubbing of the guide bearing babbitt, although steel was not exposed as in the case of the thrust bearing. Remedial action would have been necessary to return the runner and guide shoes to operating condition. However, no shaft seizure or instantaneous locked rotor condition existed.

3.3.3 Conclusion

The above discussion indicates that even under the most excessive conditions of motor bearing rubs, shaft seizure is not experienced. Therefore, under the most extreme conditions of loss of CCW, such a situation is not expected.

4.0 LOSS OF CCW TO THE PUMP HEAT EXCHANGER

Two tests have been documented on the effect of loss of component cooling water in a pump internal heat exchanger. The two tests are unique in that one resulted in an increase in the No. 1 seal leak-off up to the instructon book maximum of 5 gpm (the seal in use was a special modified design) while the other resulted in almost no change at all in the No. 1 seal leak-off. The later test demonstrates experimentally the relationship between No. 1 seal (and pump bearing) temperature and component cooling water flow rate through the heat exchanger with normal injection flow at the normal maximum temperature of about 130°F, steady state operation. The other test demonstrates a worst case steady state operation with maximum allowable seal flow and maximum injection temperature. In both cases, there is no possibility of exceeding instruction book allowables of No. 1 seal or pump bearing temperatures.

The test results for both tests are shown graphically in Figures 9 and 10. It is obvious, then, that total loss of CCW to the pump heat exchanger is of no operational and, hence, no safety concern, and the pump internals are capable of operating indefinitely under a total loss of CCW condition per these tests. (It is presumed that a simultaneous reduction of loss of injection has not occurred.)

For reference, Figure 11 is a view of the pump internals showing the position of the pump heat exchanger relative to the other internal parts. Refer to Instruction Book 5710-83G-A for a detailed description of RCP operation.

5.0 REFERENCES

1. Bahr, H.C. "Recent Improvements in Load Capacity of Large Steam Turbine Thrust Bea ings," ASME Journal, January 1961.

2. Booser, Ry_n, Linkinhoker, "Maximum Temperature for Hydrodynamic Bearings Under Steady Load," July 1970.

3. Neal, P.B., "Some Factors Influencing the Operating Temperature of Pad Thrust Bearings," Mechanical Engineering, 1979.

4. Elwell, "Thrust Bearing Temperature - Parts 1 & 2," Mechanical Design, June, July 1981.

5. "Evaluation and Test of Improved Fire-Resistant Flud Lubricants for Water Reactor Coolant Pump Motors," EPRI Report ND-1447, July 1980.

6. Letter of January 25, 1985, E.F. Kurtz, Jr., to T. Lex.

7. U.S.N.R.C. Standard Review Plan NUREG-0800, Rev. 2, of April 1984.

6.0 FIGURES

FIGURE 1

MOTOR GENERAL ASSEMBLY

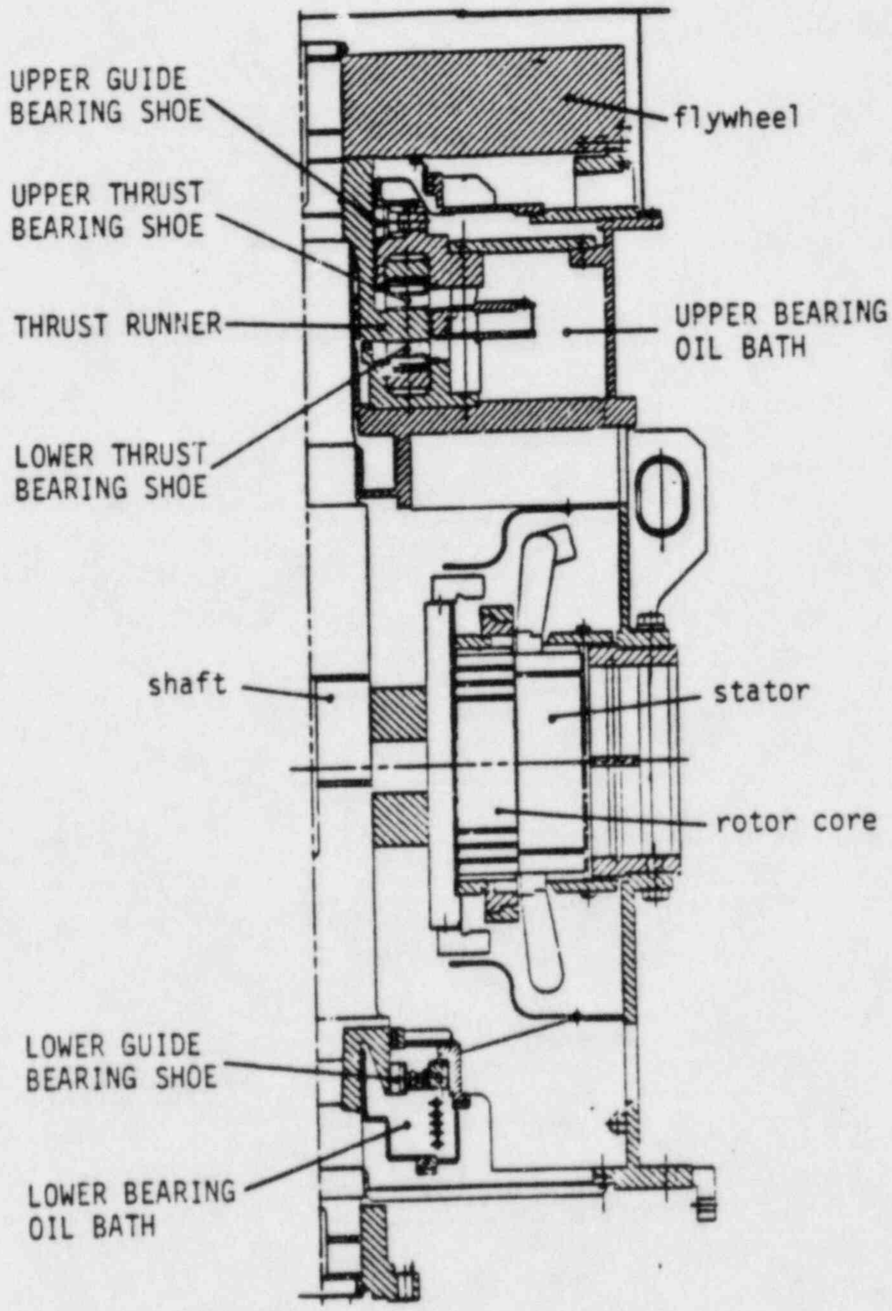


FIGURE 2

UPPER BEARING ASSEMBLY

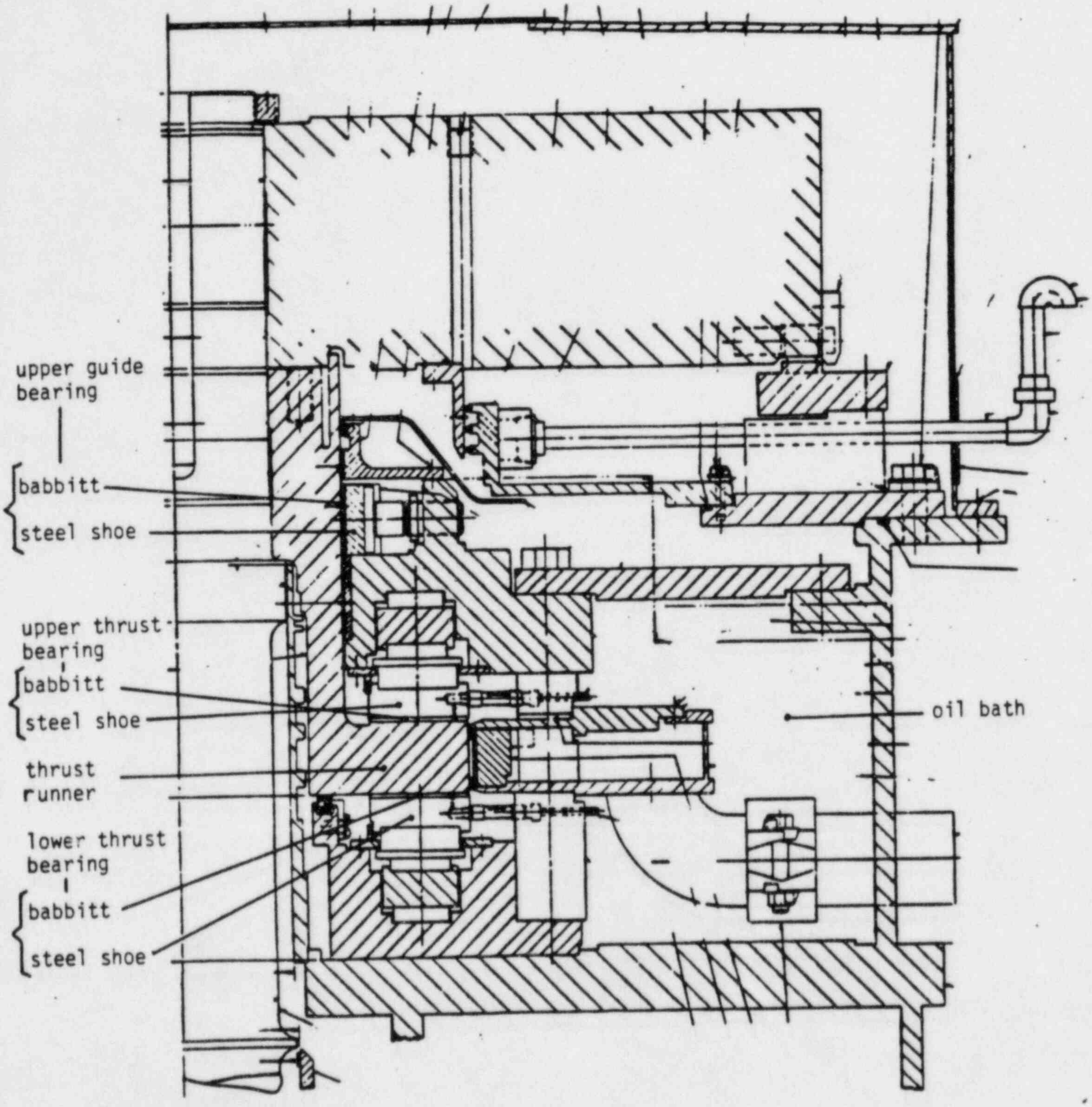
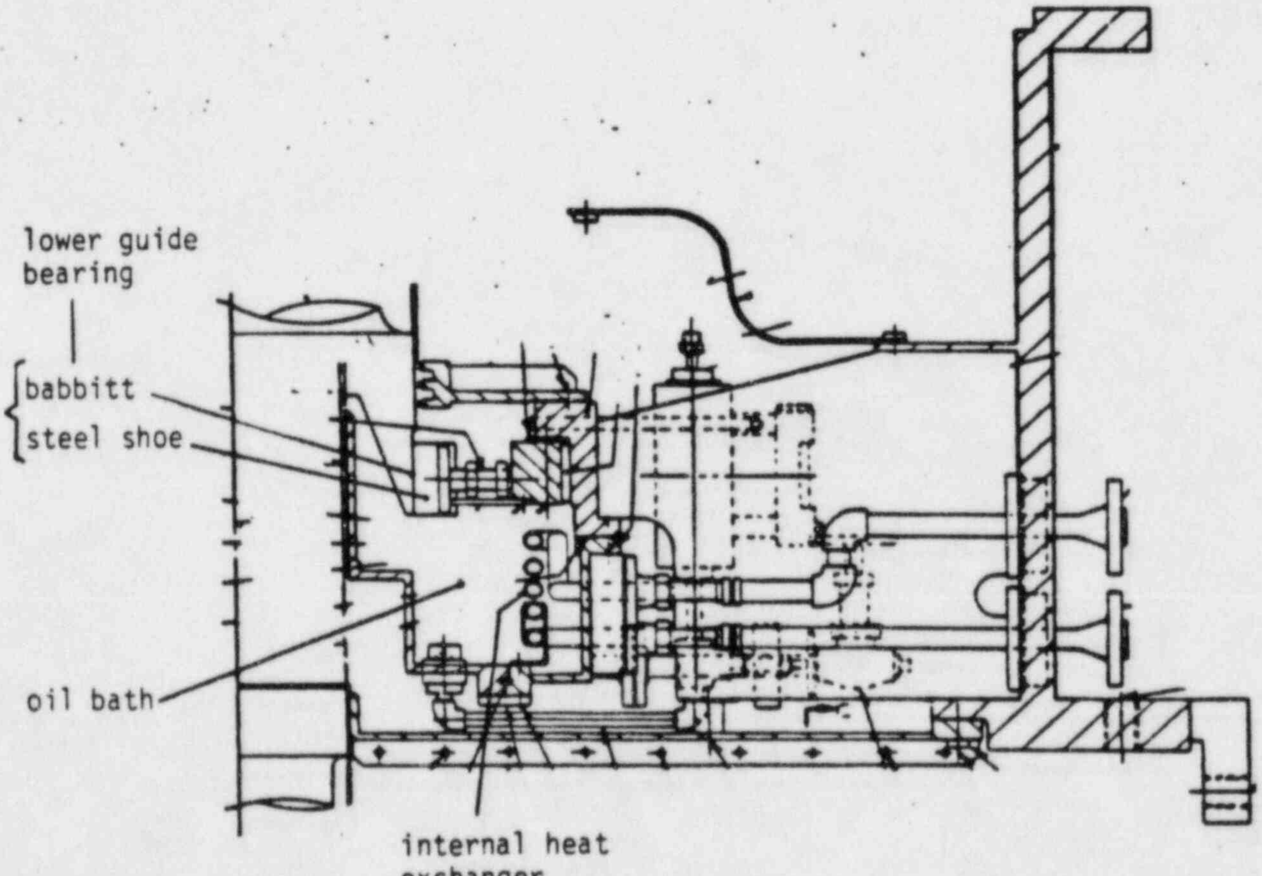


FIGURE 3

LOWER BEARING ASSEMBLY



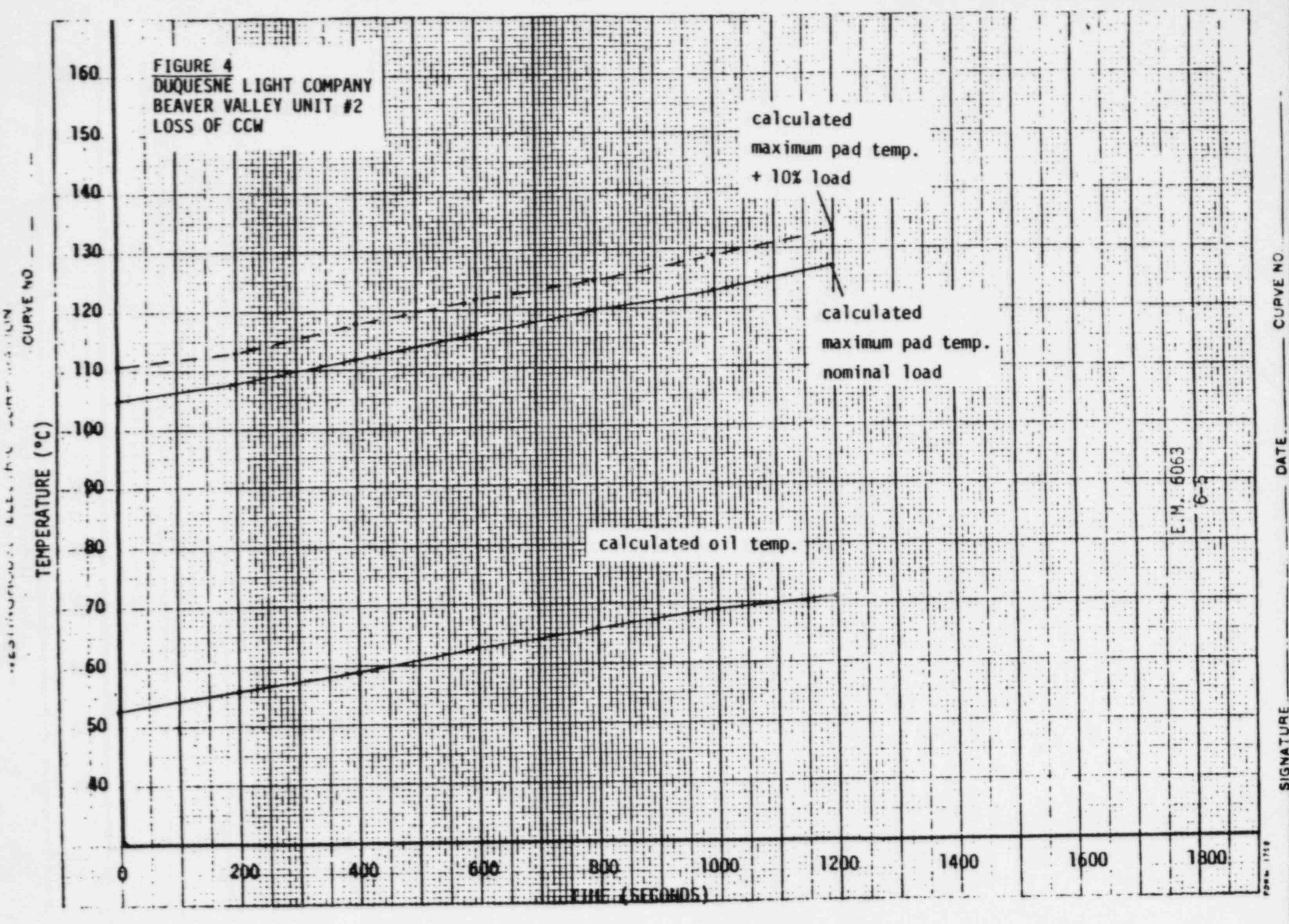
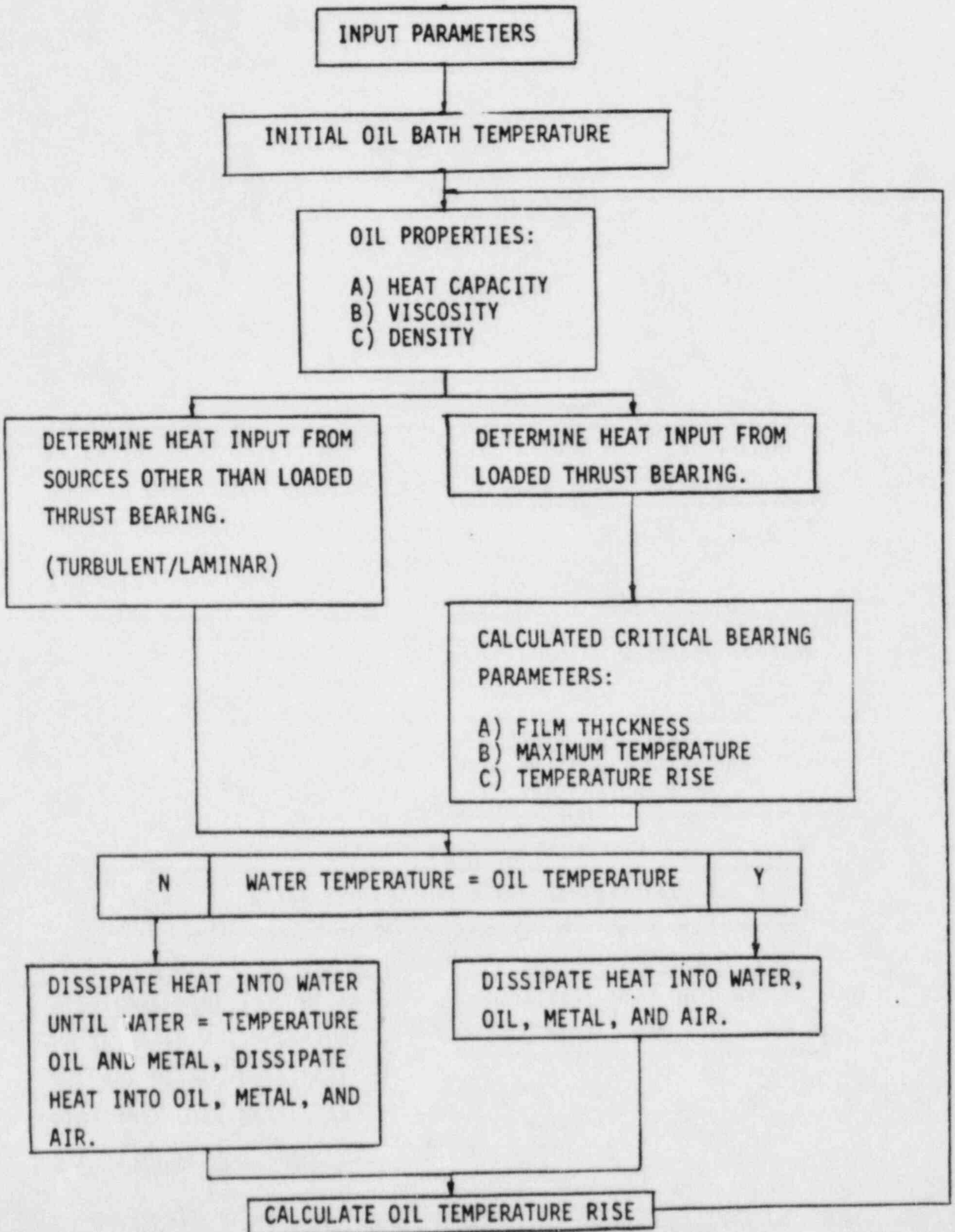


FIGURE 4
DUQUESNE LIGHT COMPANY
BEAVER VALLEY UNIT #2
LOSS OF CCW
calculated
maximum pad temp.
+ 10% load
calculated
maximum pad temp.
nominal load
calculated oil temp.
TEMPERATURE (°C)
160
150
140
130
120
110
100
90
80
70
60
50
40
0
200
400
600
800
1000
1200
1400
1600
1800
TIME (SECONDS)
E.M. 6063
6-5
CURVE NO
DATE
SIGNATURE

FIGURE 5

PROGRAM FLOW CHART



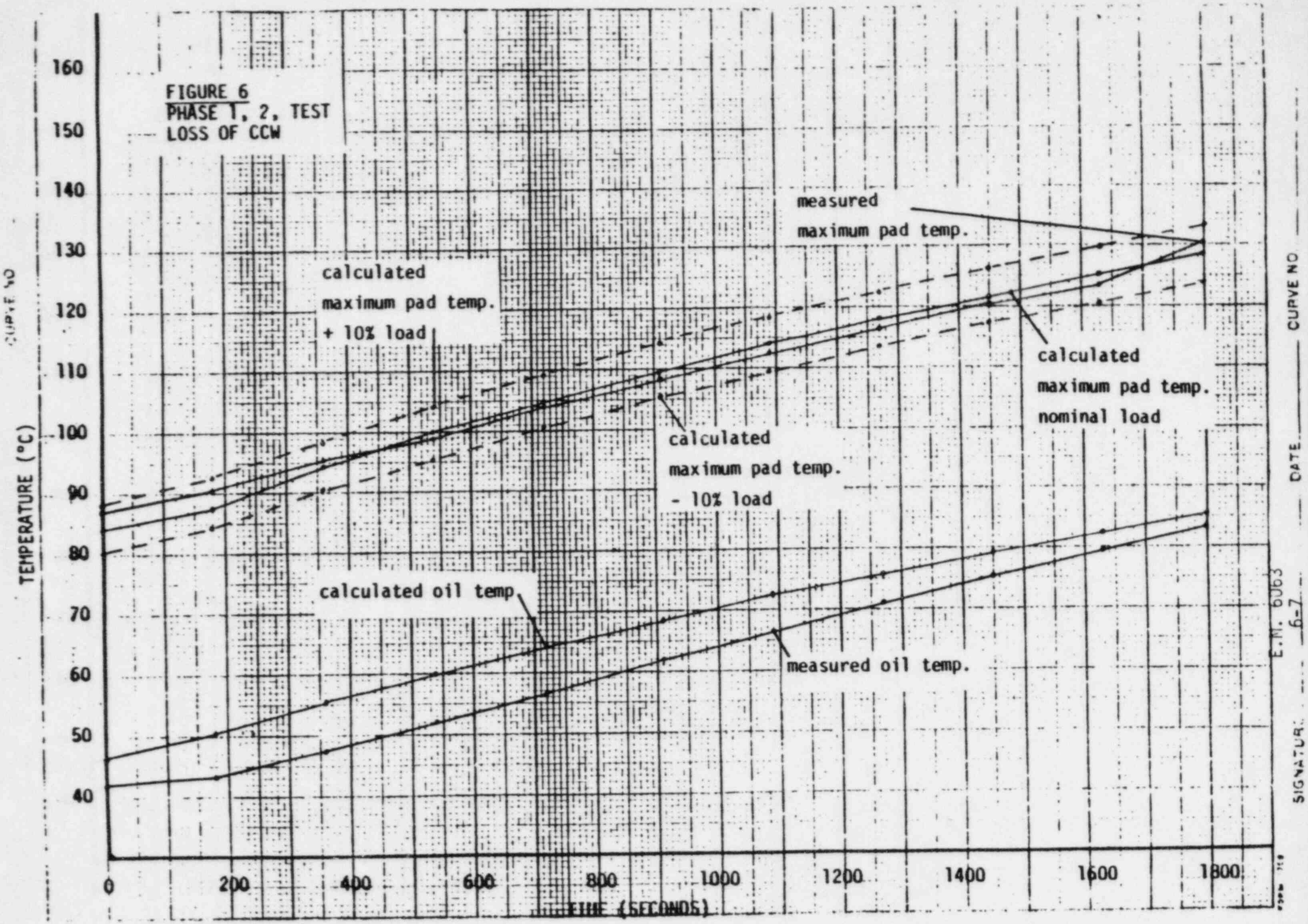


FIGURE 6
PHASE 1, 2, TEST
LOSS OF CCW
measured
maximum pad temp.
calculated
maximum pad temp.
+ 10% load
calculated
maximum pad temp.
nominal load
calculated
maximum pad temp.
- 10% load
calculated oil temp.
measured oil temp.
TEMPERATURE (°C)
TIME (SECONDS)
160
150
140
130
120
110
100
90
80
70
60
50
40
0
200
400
600
800
1000
1200
1400
1600
1800
CURVE NO
DATE
SIGNATURE
E.M. 6063
6-7

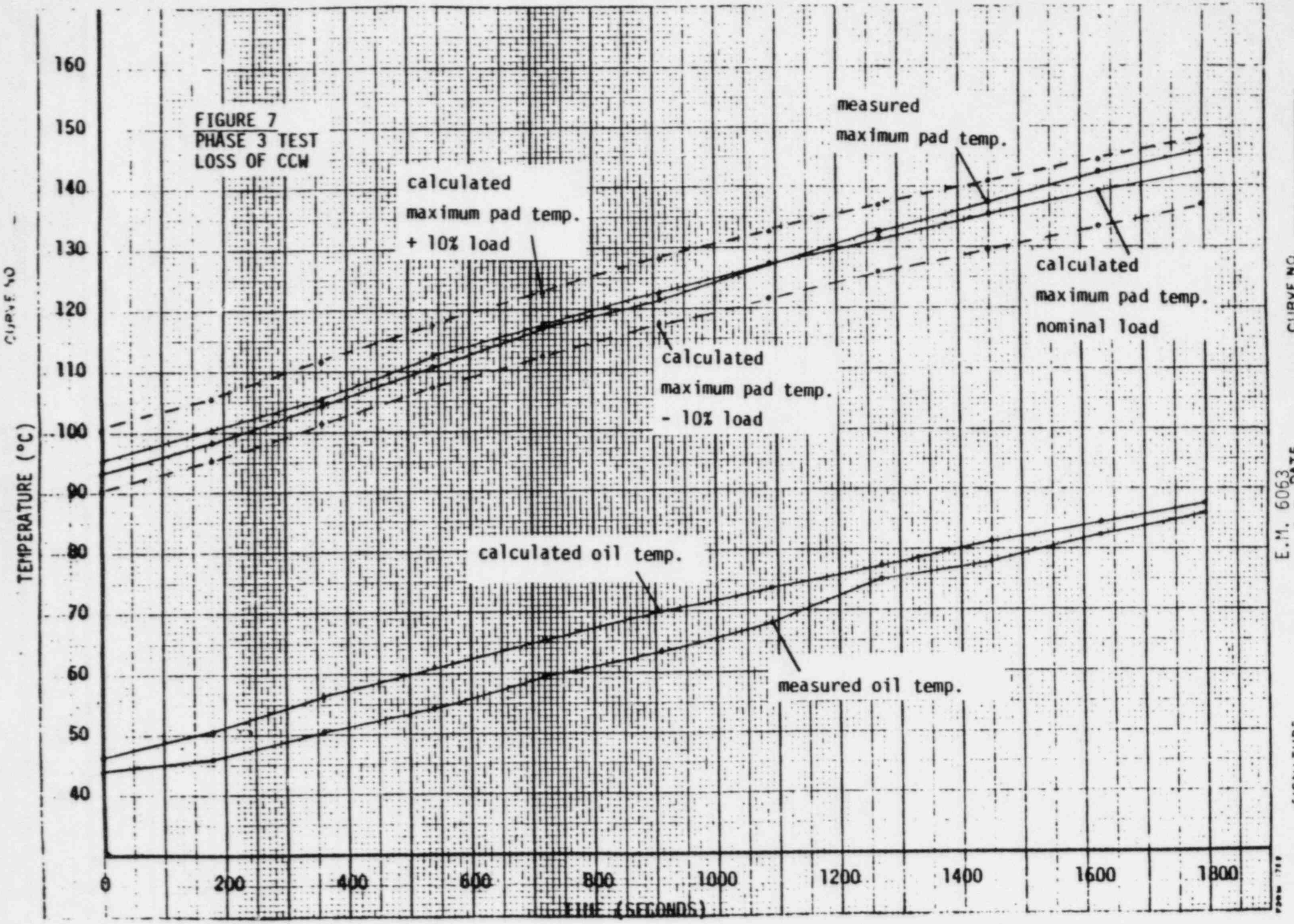


FIGURE 7
PHASE 3 TEST
LOSS OF CCW
measured
maximum pad temp.
calculated
maximum pad temp.
+ 10% load
calculated
maximum pad temp.
nominal load
calculated
maximum pad temp.
- 10% load
calculated oil temp.
measured oil temp.
TEMPERATURE (°C)
TIME (SECONDS)
160
150
140
130
120
110
100
90
80
70
60
50
40
0
200
400
600
800
1000
1200
1400
1600
1800
E.M. 6063
6-3
CURVE NO.
DATE
SIGNATURE

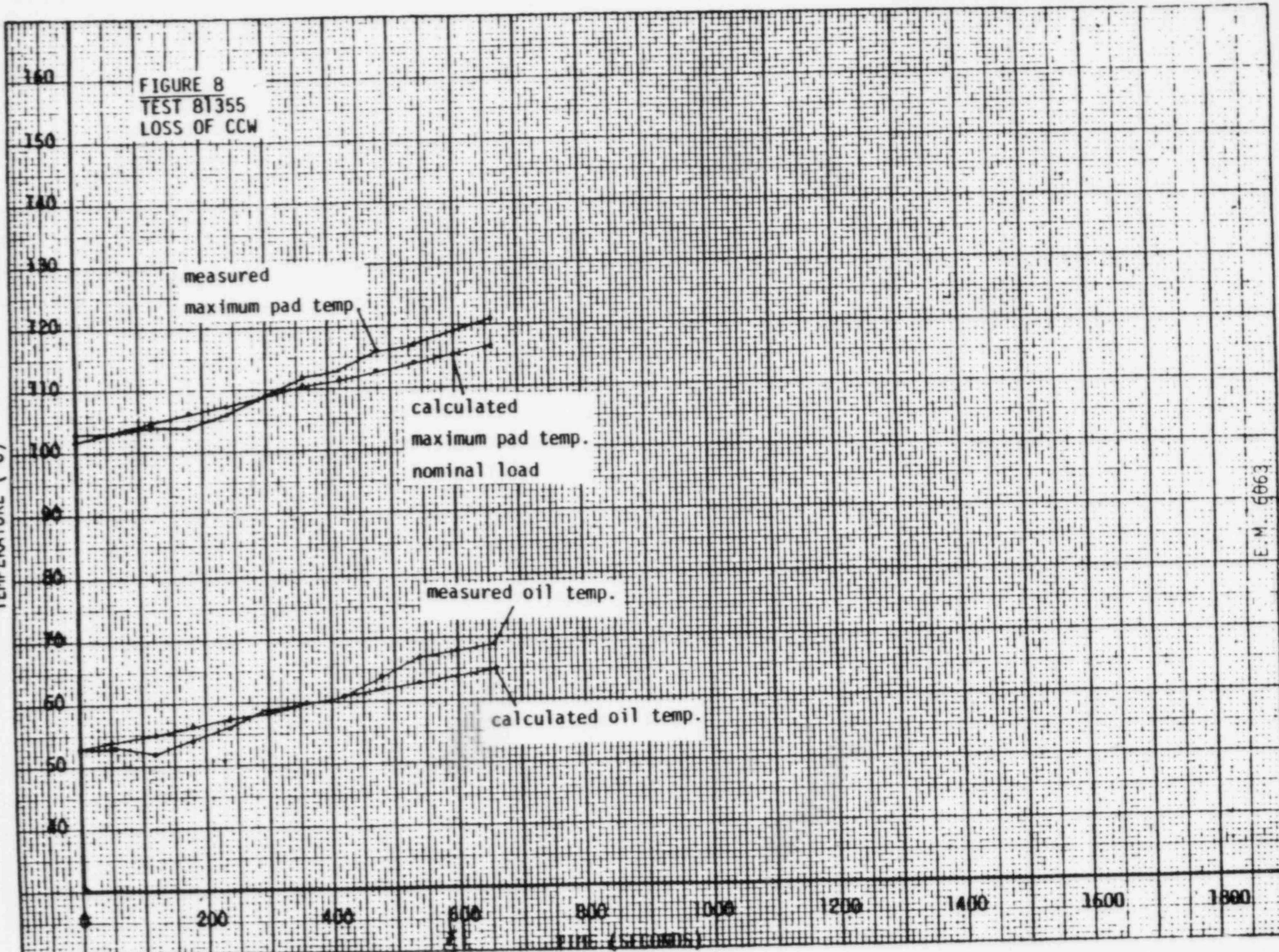
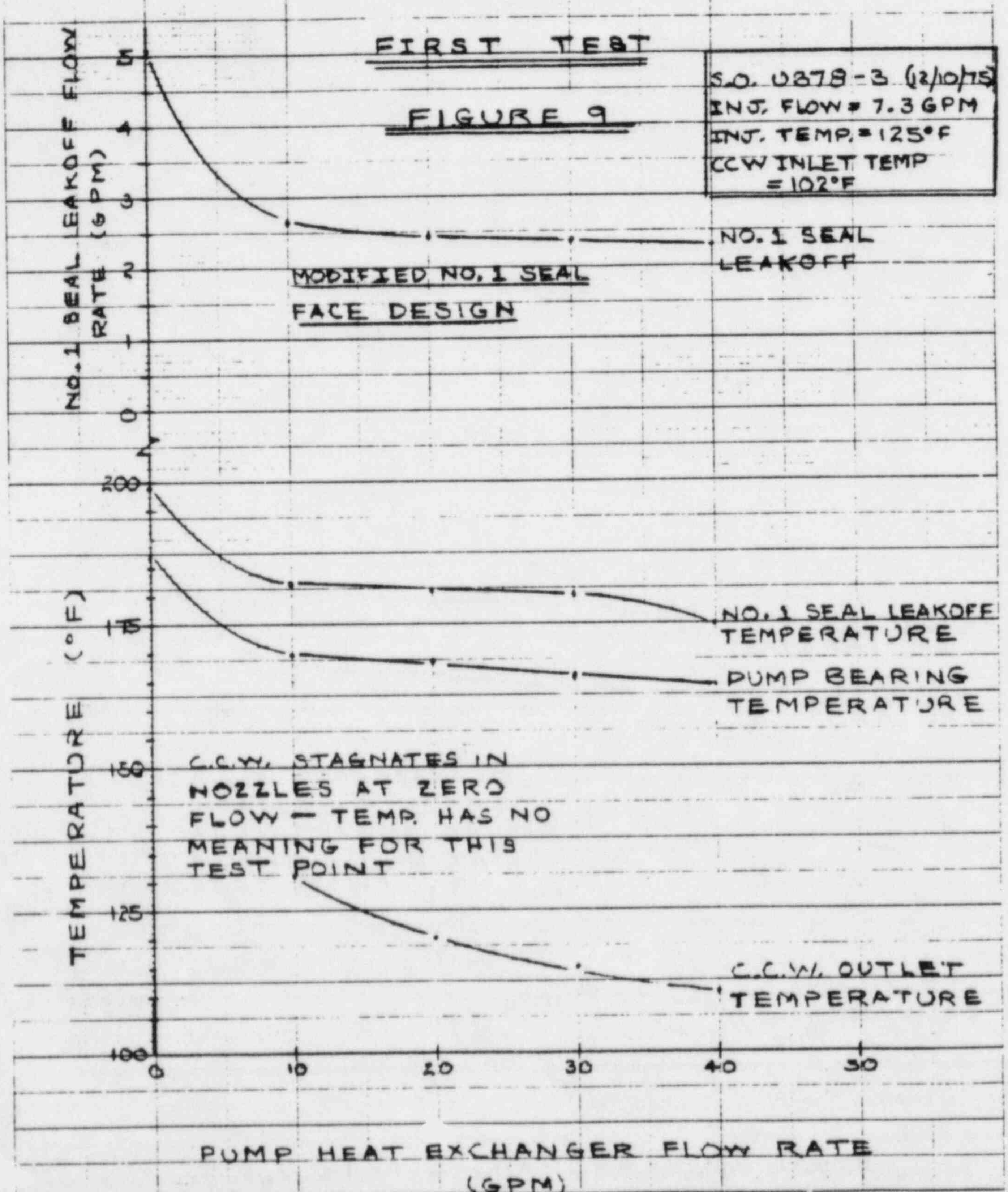


FIGURE 8
TEST 81355
LOSS OF CCW
TEMPERATURE (°C)
160
150
140
130
120
110
100
90
80
70
60
50
40
measured
maximum pad temp.
calculated
maximum pad temp.
nominal load
measured oil temp.
calculated oil temp.
0
200
400
600
800
1000
1200
1400
1600
1800
TIME (SECONDS)
E.M. 6063
6-9

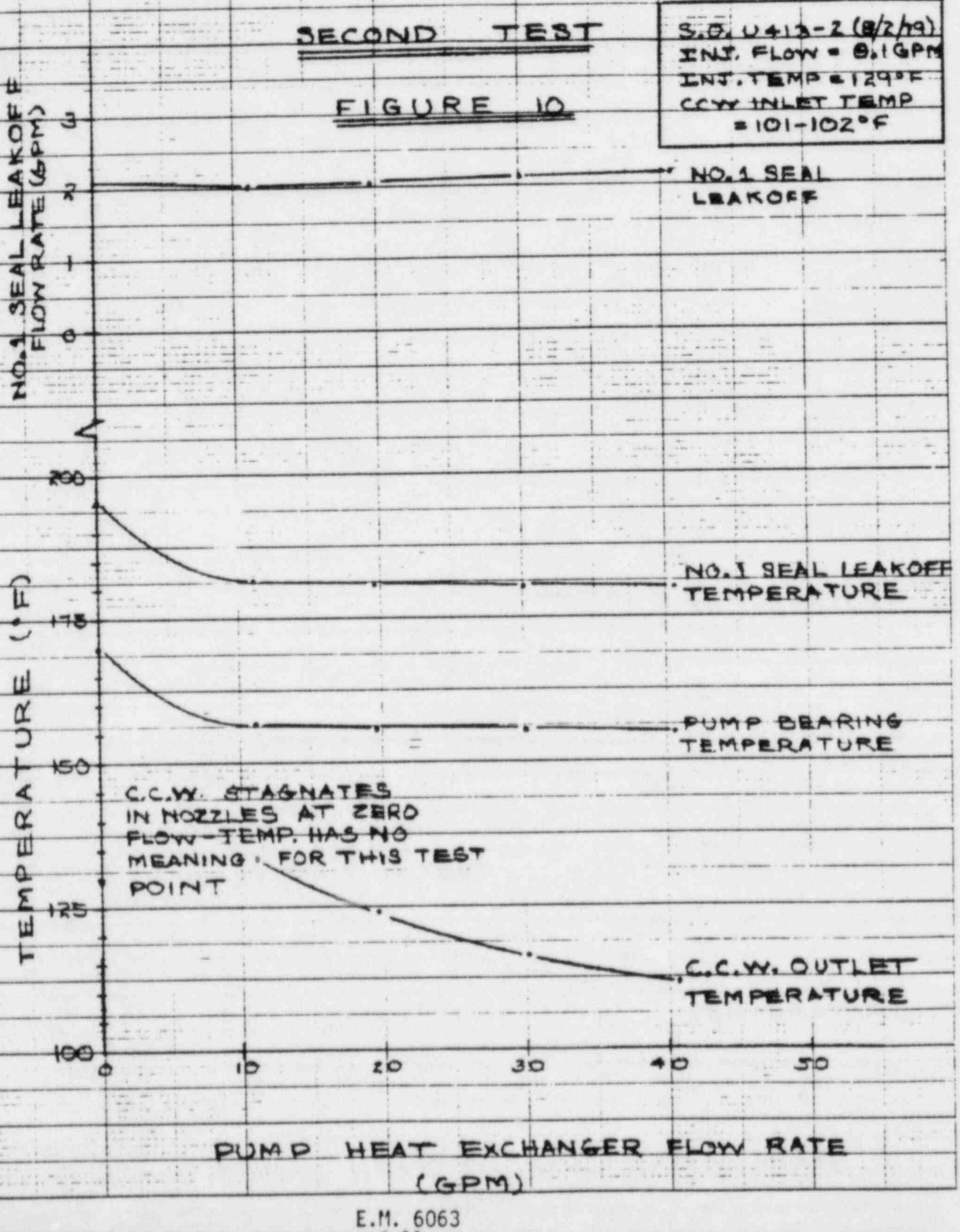
IMPACT OF REDUCTION IN PUMP HEAT EXCHANGER COMPONENT COOLING WATER FLOW RATE ON NO. 1 SEAL LEAKOFF, PUMP BEARING WATER AND COMPONENT COOLING WATER OUTLET TEMPERATURES



IMPACT OF REDUCTION IN PUMP HEAT EXCHANGER COMPONENT COOLING WATER FLOW RATE ON NO.1 SEAL LEAKOFF, PUMP BEARING WATER, AND COMPONENT COOLING WATER OUTLET TEMPERATURES

SECOND TEST

FIGURE 10



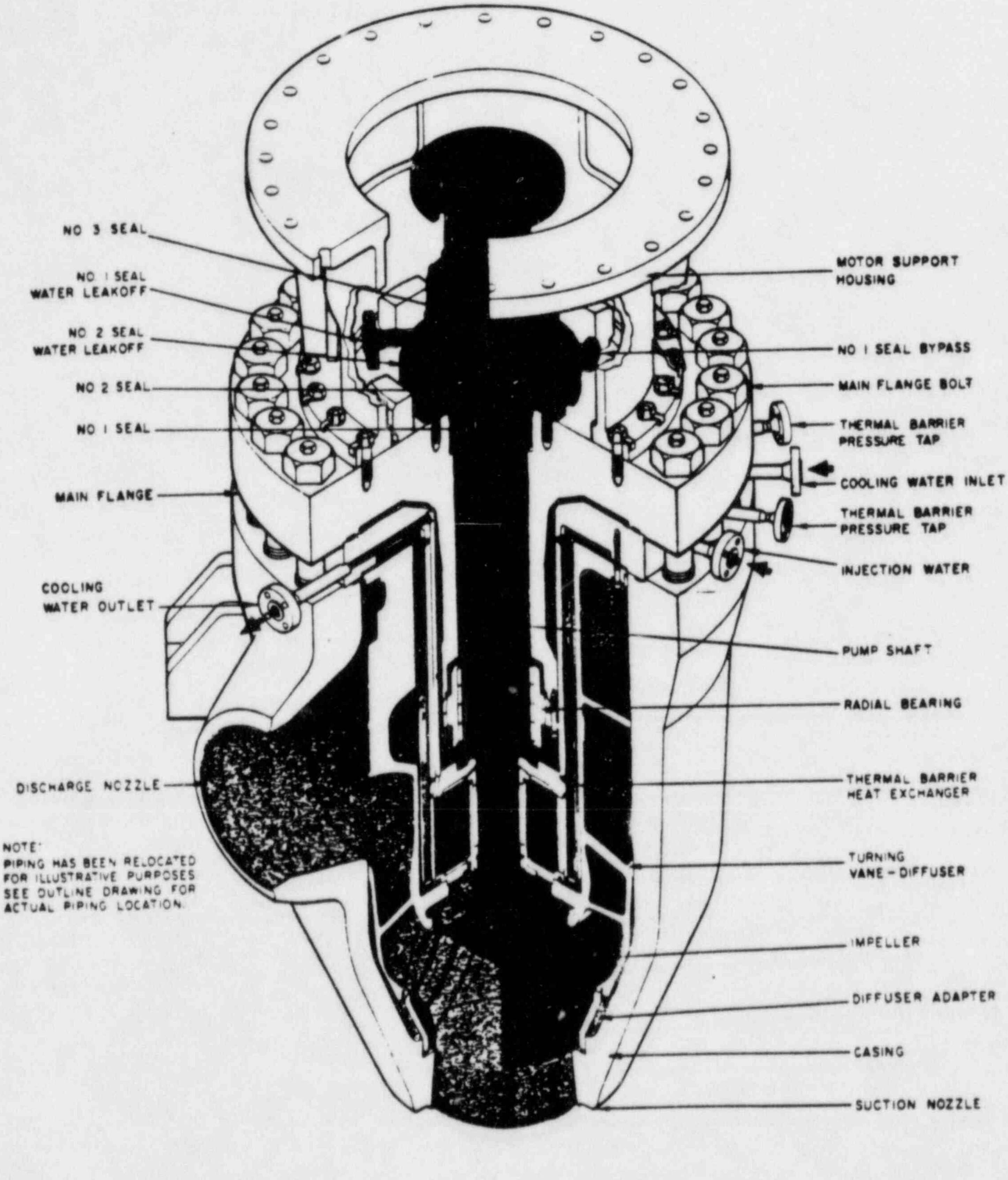


FIGURE 1 1 Cutaway View