SYSTEM 80+

REACTOR COOLANT PUMP SEAL

LOSS OF SEAL COOLING

TEST DATA REPORT

DCTR 12

Rev. 00

ABB-COMBUSTION ENGINEERING
NUCLEAR POWER SYSTEMS
WINDSOR, CONNECTICUT

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1.0 Purpose

The purpose of this report is to provide test data to document the capabilities of the System 80+ reactor coolant pump (RCP) seals to operate with loss of component cooling water or loss of seal injection water for various off normal plant operating conditions.

2.0 Introduction

In response to NRC Generic Safety Issue (GSI)-23, CESSAR-DC Amendment F states that RCP seal integrity is maintained for off normal plant operating conditions by assuring availability of seal cooling systems. The System 80+ RCP seals are normally cooled by component cooling water and seal injection water but are capable of operating with component cooling water only or seal injection water only.

The NRC's primary concern appears to be the capability of the RCP seals to withstand Station Blackout (SBO) conditions which involves potential loss of component cooling water and seal injection water in conjunction with loss of electrical power to the RCPs. In order to assure seal cooling during SBO conditions, the System 80+ seal injection supply system is designed to maintain seal injection water for a SBO. Seal injection water is provided by dual division Safety Class 3 centrifugal charging pumps which are part of the Chemical Volume Control System. The charging pumps are normally powered from non-safety grade electrical buses but are powered from an alternate AC (AAC) power supply for SBO conditions. The AAC power is also used to power the component cooling water system pumps during SBO conditions to ensure that component cooling water is furnished to the charging pumps. The AAC power source is described in CESSAR-DC, Chapter 8, Section 8.3.1.1.5, Non Class 1E Alternate AC Source Standby Power Supply.

The NRC staff is also concerned about loss of seal cooling for other off normal plant operating conditions. These conditions are addressed in ABB-CE response to NRC RAI 440.119. In order to verify the capability of the RCP seals to withstand these conditions, the NRC staff has requested test results from RCP test programs on production pump assemblies.

The System 80+ RCP design is the same as that used by the System 80 plants as represented by the RCPs at the Palo Verde Nuclear Generating Station. The Palo Verde RCPs were extensively shop tested including one 500 hour test plus 50 hour tests for the other pump assemblies. During these tests the response of the RCPs to various off-normal cooling events was documented. Specifically, the following tests were performed (Component Cooling Water is shortened to "cooling water"):

Case	Description
1.	Loss of cooling water to the pump seals, seal injection water available, pump stopped (equivalent to SBO conditions with AAC power supply).
2.	Loss of seal injection water, cooling water available, pump stopped.
3.	Loss of both seal injection water and cooling water to the pump seals, pump stopped (equivalent to SBO conditions prior to the start of AAC power supply).
4.	Loss of cooling water to the pump seals, seal injection water available, pump running.
5.	Loss of seal injection water, cooling water available, pump running.

3.0 Test Program - Loss of Cooling Water and Seal Injection Water to the RCP Seals

3.1 Description

The tests were performed on production pump assemblies in the ABB-CE test loop in Newington, N.H. The test loop is a closed loop, designed to operate at plant normal operating pressure and temperature. The pump can be tested at the full range of expected plant flow rates by varying loop system resistance by means of control valves in the test loop.

The arrangement of the shaft seal system is schematically shown in Figure 1. The reactor coolant pump has redundant seal cooling systems; the first uses cooling water to cool the high pressure cooler and the seal (throttle) coolers and the second is seal injection water which is introduced upstream of the high pressure cooler. Seal water temperatures are measured before and after the high pressure cooler and in each of the seal assemblies. Controlled leakage flow is also measured. Table 1 lists the above cited instrumentation along with other instrumentation used for the test.

3.1.1 Loss of Cooling Water to the Seals - Pump Stopped (Case 1)

With the system operating at normal conditions, the pump was shut down. Normal operating conditions are 2220 psia and 565°F. Cooling water to the seal cooling system (high pressure cooler and seal cooler) was reduced and isolated. When the seal temperatures had stabilized, the cooling water flow was resumed after two hours and twenty-nine minutes. Seal injection flow was maintained throughout the test.

3.1.2 Loss of Seal Injection Water - Pump Stopped (Case 2)

With the system operating at normal conditions, the pump was shut down. Seal injection was reduced and isolated. When the seal temperatures had stabilized, seal injection was resumed after one hour and twenty minutes. Cooling water to the seal cooling system (high pressure cooler and seal cooler) was maintained throughout the test.

3.1.3 Simultaneous Loss of Seal Injection Water and Cooling Water to the Seals - Pump Stopped (Case 3)

With the system operating at normal conditions, the pump was shut down. Both the seal injection flow and cooling water flow to the seal cooling system was reduced and isolated. After 36 minutes cooling water was restored and seal temperatures stabilized. Ten (10) minutes later or 46 minutes into the test seal injection was restored and seal temperatures returned to their initial values.

3.1.4 Loss of Cooling Water - Pump Running (Case 4)

With the pump operating at normal conditions, cooling water to the seal cooling system was reduced and isolated. After seal temperatures had stabilized, conditions were held stable for two hours, then cooling water was resumed at five hours and eighteen minutes into the test. Seal injection flow was maintained throughout the test.

3.1.5 Loss of Seal Injection Water - Pump Running (Case 5)

With the pump operating at normal conditions, the seal injection flow was reduced and isolated. After the seal temperatures had stabilized, conditions were held stable for one hour, then seal injection was resumed at two hours and twenty-one minutes into the test. Cooling water to the seal cooling system was maintained throughout the test.

3.2 <u>Results</u>

The results of the tests are shown in Figures 2 through Figure 6. The behavior of the cooling water temperature (T400), seal injection temperature (T225) and seal temperatures (T003, T004 and T005) are plotted. The controlled leakage flow (F275) is either plotted or reported in the text. Seal temperatures and controlled leakage flow are the critical parameters which determine seal performance during the loss of seal cooling tests. Cooling water flow (F404) or seal injection flow (F225) are either plotted or reported in the text. Results of the individual tests are reported as follows:

3.2.1 Loss of Cooling Water to the Seals - Pump Stopped (Case 1)

The pump was shut down at 88:00:00 hours into the 500 hour test. Approximately one half minute after shaft rotation ceased (88:04:45 hours), cooling water was reduced and isolated. It takes approximately four minutes for the pump to coastdown to a stop. At 90:23:30 hours, the seal temperatures had stabilized and cooling water was restored at 90:29:00 hours. Cooling water temperature was initially at 42°C (108°F) and seal injection temperature was 65°C (149°F).

The results of the test are shown in Figure 2 which is a plot of seal temperatures versus time. Seal temperature T005 is the most critical because it normally runs the hottest and it is the temperature in the last or top seal. T005 was initially at 52°C (126°F) and stabilized at 67°C (153°F) before cooling water was restored after 02:29:00 hours. The other seal temperatures (T003 and T004) stabilized at 64°C (147°F) and 60°C (140°F) respectively. The normal operating seal temperature limit is 70°C (158°F) with a pump shut down value of 80°C (176°F).

It should be noted that this test was run with seal injection water temperature at its maximum acceptable design value of 150°F instead of the normal operating range of 100°F to 120°F. If the test had been run with seal injection water in its normal temperature range the seal temperatures would have stabilized at several degrees above the corresponding seal injection inlet temperature and considerably below the measured seal temperatures in this test.

The test clearly shows that the pump seals are capable of withstanding a loss of cooling water with the pump idle and seal injection water available. This condition corresponds to what would occur in the System 80+ design during SBO conditions with seal injection water furnished by the charging pumps powered by the alternate AC power source.

3.2.2 Loss of Seal Injection Water - Pump Stopped (Case 2)

The pump was shut down at 108:53:00 hours. One minute after shaft rotation ceased (108:58:00 hours) seal injection was reduced and isolated. At 110:12:00 hours, the seal temperatures had stabilized and seal injection was resumed at 11C:18:00 hours. Seal injection water was off for a total of 01:20:00 hours. Seal injection temperature was initially at 65°C (149°F) and cooling water temperature was 42°C (108°F).

The results of the test are shown in Figure 3 which is a plot of seal temperature versus time. The temperature (T005) in the top seal stabilized at 55°C (131°F) which is well below the operating limit of 70°C (158°F).

The test shows the capability of the seals to withstand a loss of seal injection with cooling water available and the pump shut down.

3.2.3 Simultaneous Loss of Seal Injection and Cooling Water to the Seals - Pump Stopped (Case 3)

The pump was shut down at 85:10:00 hours. When shaft rotation ceased (85:14:00 hours), the seal injection flow and cooling water flow to the seal cooling system was reduced and isolated. Cooling water was restored at 85:50:00 hours and seal injection flow was restored at 86:00:00 hours. The seal cooling system was without cooling water for 36 minutes and seal injection flow was isolated for 46 minutes. Seal injection temperature was initially at 65°C (149°F) and cooling water was 41°C (106°F).

The results of the test are shown in Figure 4. The top or last seal temperature (T005), which was initially at 51°C (124°F), reached 57°C (135°F) at 36 minutes into the test when cooling water was restored. T005 then stabilized and seal injection was restored at 46 minutes into the test, after which seal temperatures returned to their initial values.

The purpose of this test was to show that the plant operator has at least 30 minutes to restore either cooling water or seal injection water with the pump shut down in a hot reactor coolant system.

The conditions of the test were similar to what would happen at the start of a station blackout (SBO) event prior to the start of the ACC. No attempt was made to extend the length of the test beyond 36-46 minutes. The loss of both cooling systems for longer than 30 minutes is beyond the System 80+ RCP seal cooling design basis.

For the above three tests the controlled leakage line was closed. The leakage through the last or top seal was measured and there was no change in leakage rate.

3.2.4 Loss of Cooling Water to the Seals - Pump Running (Case 4)

Cooling water to the high pressure cooler and seal cooler was shut off at 40:10:00 hours. After five hours and eighteen minutes cooling water was restored. Cooling water temperature was initially at 29°C (85°F) and seal injection temperature was 30°C (86°F).

The results of the test are shown in Figure 5 which is a plot of the seal temperatures versus time. When cooling water was isolated, the top seal temperature (T005) was initially at 40°C (104°F). After approximately one hour and twenty minutes T005 stabilized at 60°C (140°F). At that time seal injection water temperature was raised from 30°C (86°F) to 39.5 (103°F) and maintained until seal temperatures stabilized. After seal temperatures stabilized and approximately two hours and twenty minutes further into the test, T005 stabilized at 70°C (158°F) which is the seal normal operating limit. After five hours and eighteen minutes component cooling was re-established.

Controlled leakage was measured throughout the test and remained essentially constant between 0.685 and 0.705 m^3/hr (3.02 and 3.10 gpm). The nominal design value for controlled leakage flow is 3.0 gpm with a maximum allowable value of 5.0 gpm.

The results of the test demonstrate that with loss of cooling water to the pump seal assembly, the pump will continue to function without exceeding design seal leakage limits and without exceeding seal temperature limits. Based on the slow rate of temperature rise shown in Figure 4 the plant operator will have far in excess of 30 minutes to initiate suitable action after a loss of cooling water.

The pump oil lubricated bearing assembly is furnished with oil cooler cooling water from the same source as the seal high pressure cooler and seal coolers. The operating limit for the bearings without cooling water is 10 minutes to avoid any bearing damage and 30 minutes without damage which could adversely affect pump coastdown flow. Therefore, the bearings are more limiting than the seals for the condition of loss of cooling water with the pump running.

The results of this particular test were previously reported to the NRC in References (1) and (2) as part of the licensing effort for the System 80 plant.

3.2.5 Loss of Seal Injection Water - Pump Running (Case 5)

The seal injection flow was reduced and isolated at 22:12:15 hours. At 23:30:00 hours, the seal temperatures had stabilized and conditions were held stable for one hour. At 24:33:15 hours, seal injection was resumed and adjusted to 1.5 m^3/hour. Seal injection was off for a total of 2:21:00 hours. Seal injection temperature was initially at 60°C (140°F) and cooling water temperature was approximately 38°C (100°F).

The results of the test are shown in Figure 6. The seal temperatures (T003, T004 and T005) stabilized at between 59°C (138°F) and 61°C (142°F), well below the 70°C (158°F) operating limit. Controlled leakage flow (F275) was measured throughout the test and remained essentially constant at approximately 0.78 m^3/hr (3.4 gpm).

The test shows the capability of the seals to withstand a loss of seal injection water with the pump running and cooling water available.

3.3 Conclusion

System 80+ RCP seal integrity is maintained for the off normal seal cooling operating events. This is accomplished by providing independent and redundant seal cooling via the component cooling water system and the dual division seal injection system. This capability has been demonstrated by a series of test performed on production pump assemblies in the ABB-CE test loop located in Newington N.H. The tests covered five different loss of cooling conditions and demonstrate the diverse capabilities of the RCP seals.

4.0 References

1. CE Topical Report, Performance of CE System 80 Reactor Coolant Pump with Loss of Component Cooling Water, CENPD-201-A, dated March 1976.

2. CENPD-201-A, Supplement 1, System 80 Reactor Coolant Pump Loss of Component Cooling Water Test Report.

Table 1

TEST LOOP INSTRUMENT LIST

RCP SEALS

INSTRUMENT TAG NUMBER	DEVICE	DESCRIPTION	UNITS
T001	RTD	HP Cooler Inlet Temperature	C
T002	RTD	HP Cooler Outlet Temperature	C
T003	RTD	Seal No. 1 Outlet Temperature	C
T004	RTD	Seal No. 2 Outlet Temperature	C
T005	RTD	Seal No. 3 Outlet Temperature	C
T225	RTD	Seal Injection Water Inlet Temperature	C
T400	RTD	Component Cooling Water Outlet Temperature	C
T104A	RTD	Test Loop Temperature	C
F275	Rotameter	Controlled Leakage Flow	Cubic Meters per hour
F225	Rotameter	Seal Injection Water Flow	Cubic Meters per hour
F404	Rotameter	Component Cooling Water Flow	Cubic Meters per hour

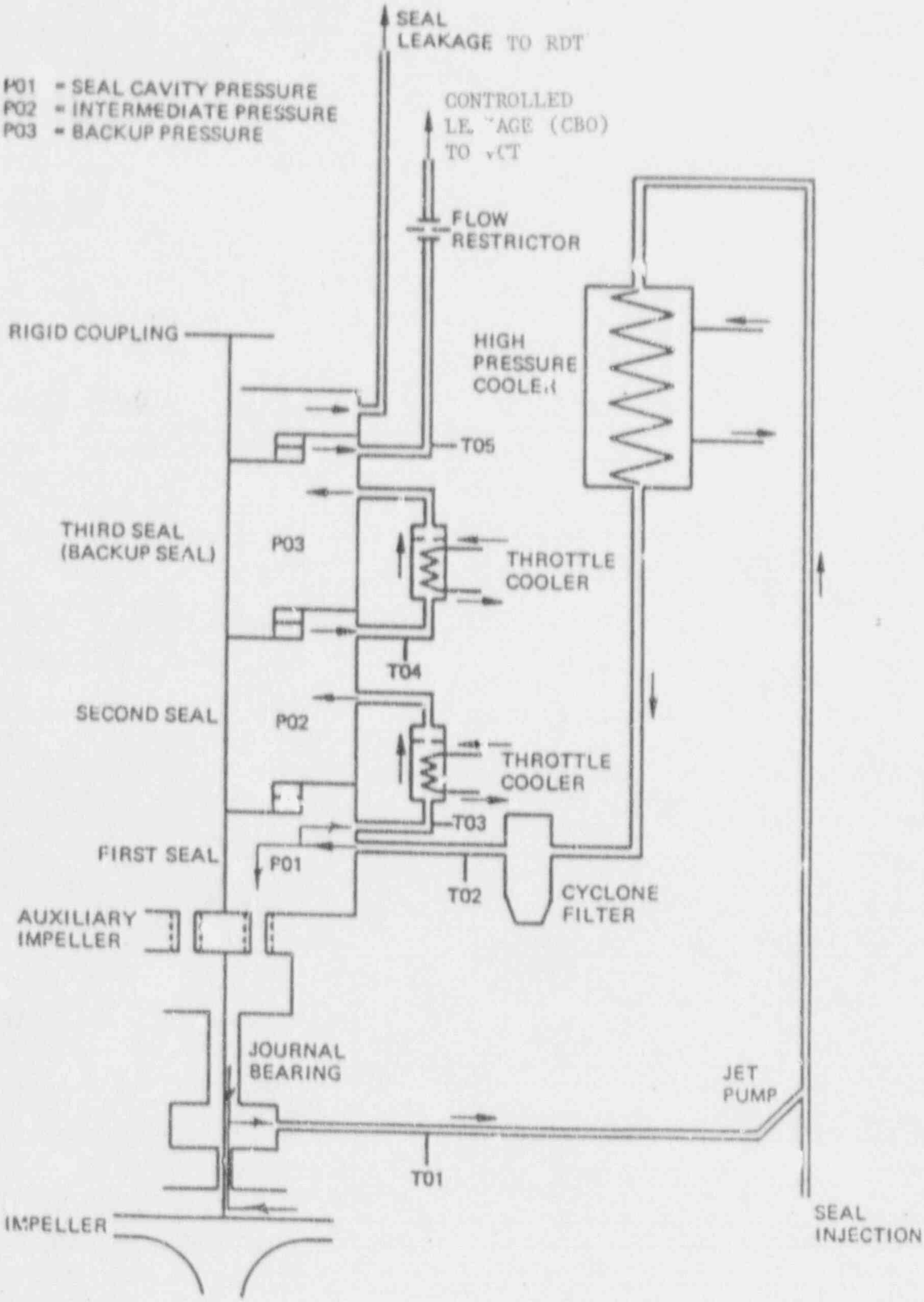

Figure 1 Flow Diagram for Hydrodynamic Shaft Seal System.

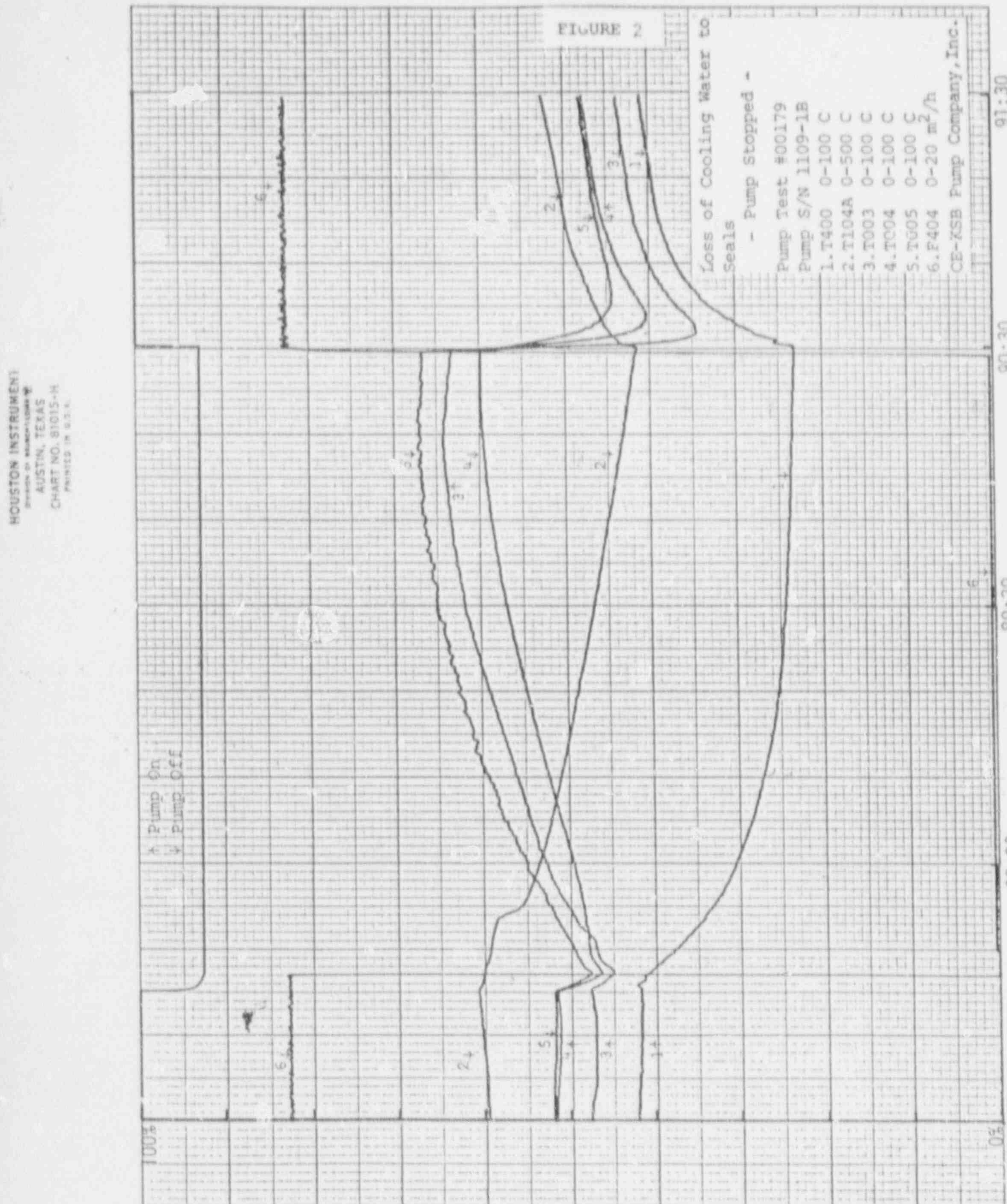
HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 81015-H
PRINTED IN U.S.A.
FIGURE 2
Loss of Cooling Water to Seals
- Pump Stopped -
Pump Test #00179
Pump S/N 1109-1B
1.T400 0-100 C
2.T104A 0-500 C
3.T003 0-100 C
4.TC04 0-100 C
5.TG05 0-100 C
6.F404 0-20 m²/h
CE-KSB Pump Company,Inc.
↑ Pump On
↓ Pump Off
100%
0%
87:30
88:30
89:30
90:30
91:30
TEST TIME - hours

FIGURE 2

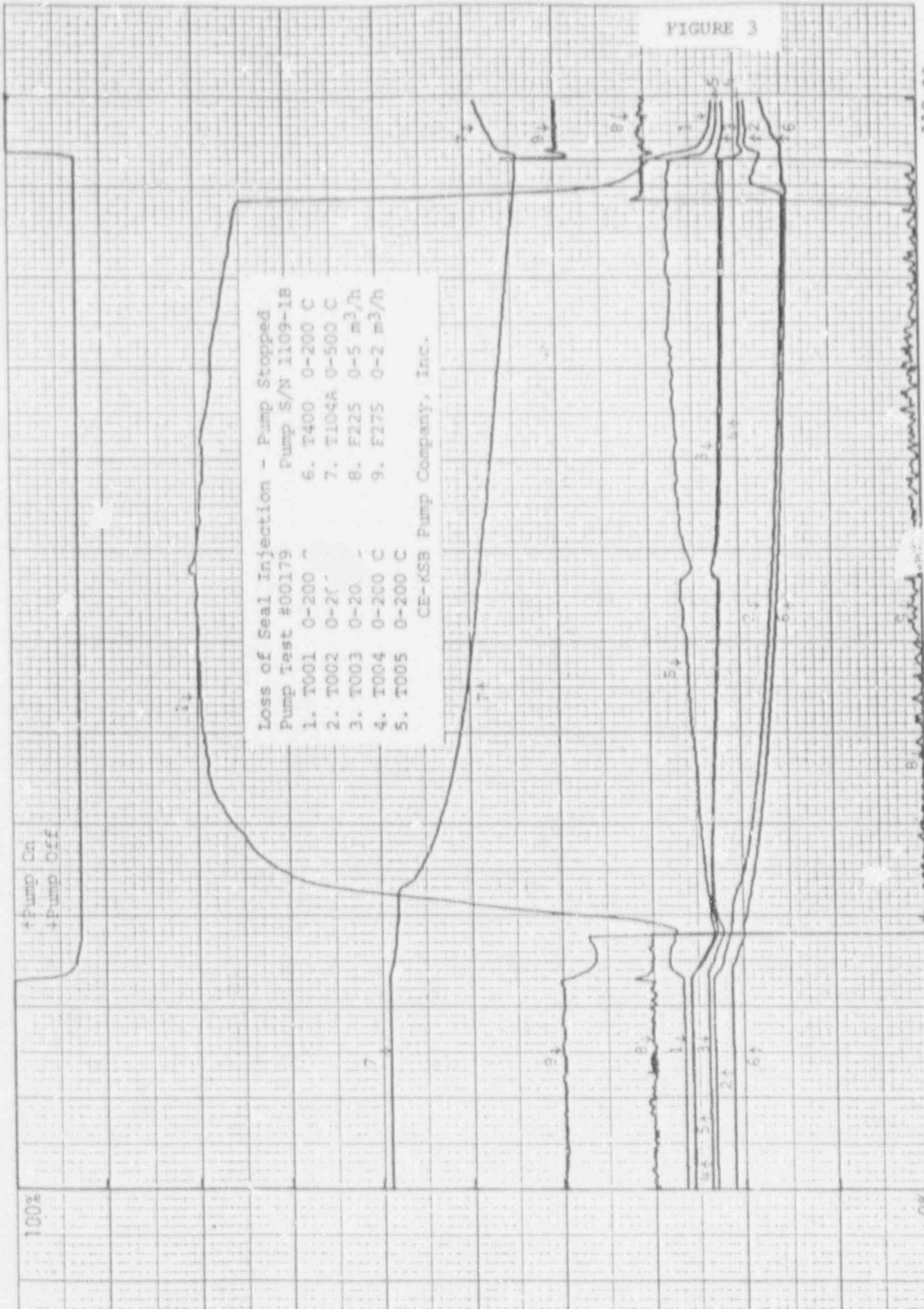
FIGURE 3
Loss of Seal Injection - Pump Stopped
Pump Test #00179 Pump S/N 1109-18
1. T001 0-200
2. T002
3. T003
4. T004 0-200 C
5. T005 0-200 C
6. T400 0-200 C
7. T104A 0-500 C
8. F225 0-5 m³/h
9. F275 0-2 m³/h
CE-KSB Pump Company, Inc.
Pump On
Pump Off
100%
0%
108:30
109:00
109:30
110:00
110:30
TEST TIME - hours

FIGURE 3

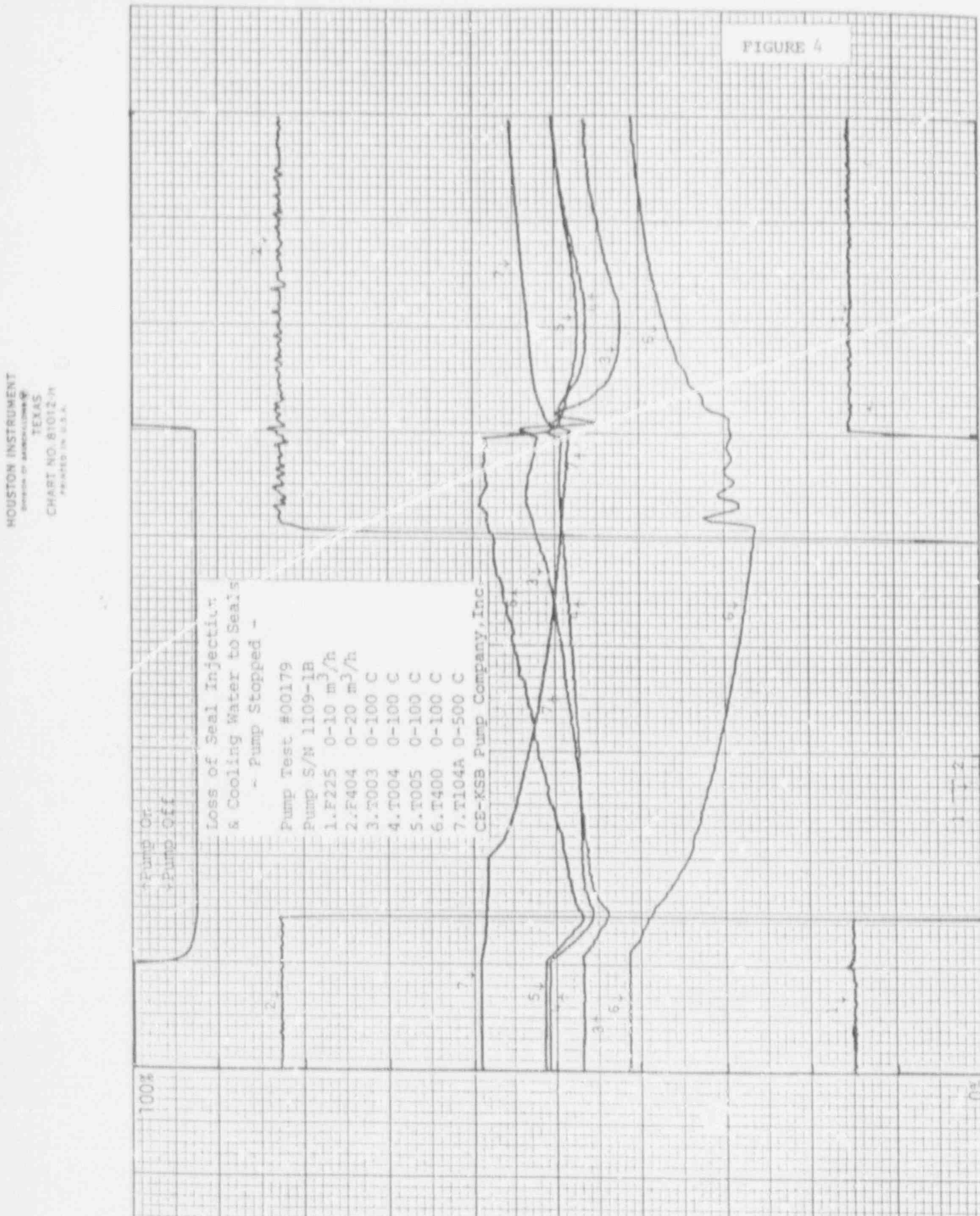
HOUSTON INSTRUMENT
TEXAS
CHART NO. 81012-H
FIGURE 4
Loss of Seal Injection
& Cooling Water to Seals
- Pump Stopped -
Pump Test #00179
Pump S/N 1109-1B
1.F225 0-10 m3/h
2.F404 0-20 m3/h
3.T003 0-100 C
4.T004 0-100 C
5.T005 0-100 C
6.T400 0-100 C
7.T104A 0-500 C
CE-KSB Pump Company, Inc.
Pump On
Pump Off
100%
0%
85:00
35:30
86:00
86:30
TEST TIME - hours

FIGURE 4

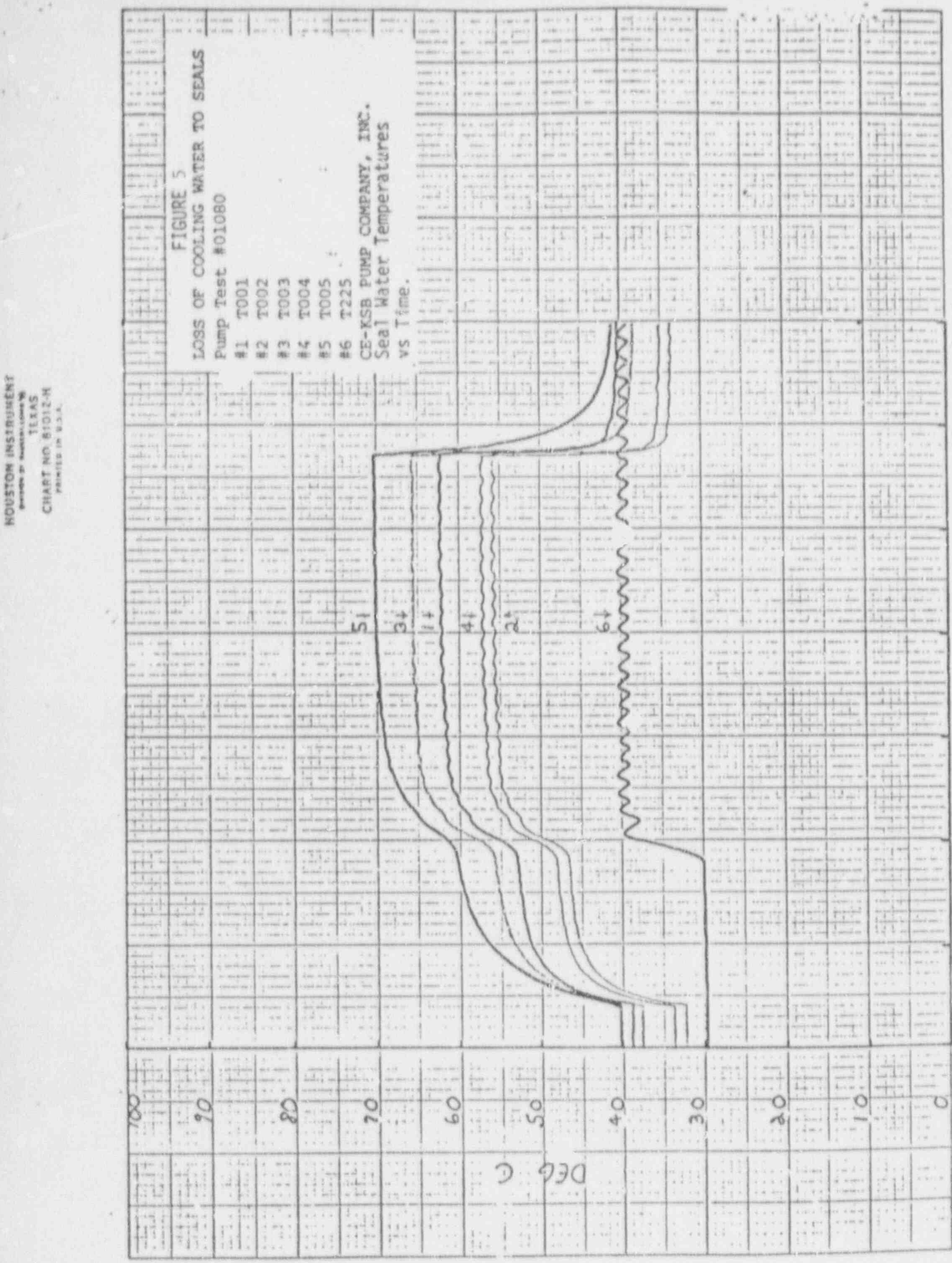
HOUSTON INSTRUMENT
TEXAS
CHART NO. 81012-H
FIGURE 5
LOSS OF COOLING WATER TO SEALS
Pump Test #01080
#1 T001
#2 T002
#3 T003
#4 T004
#5 T005
#6 T225
CE-KSB PUMP COMPANY, INC.
Seal Water Temperatures
vs Time.
DEG C
100
90
80
70
60
50
40
30
20
10
0
39:45
40:45
41:45
42:45
43:45
44:45
45:45
46:45
TEST TIME - HRS
5
3
1
4
2
6
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FIGURE 5

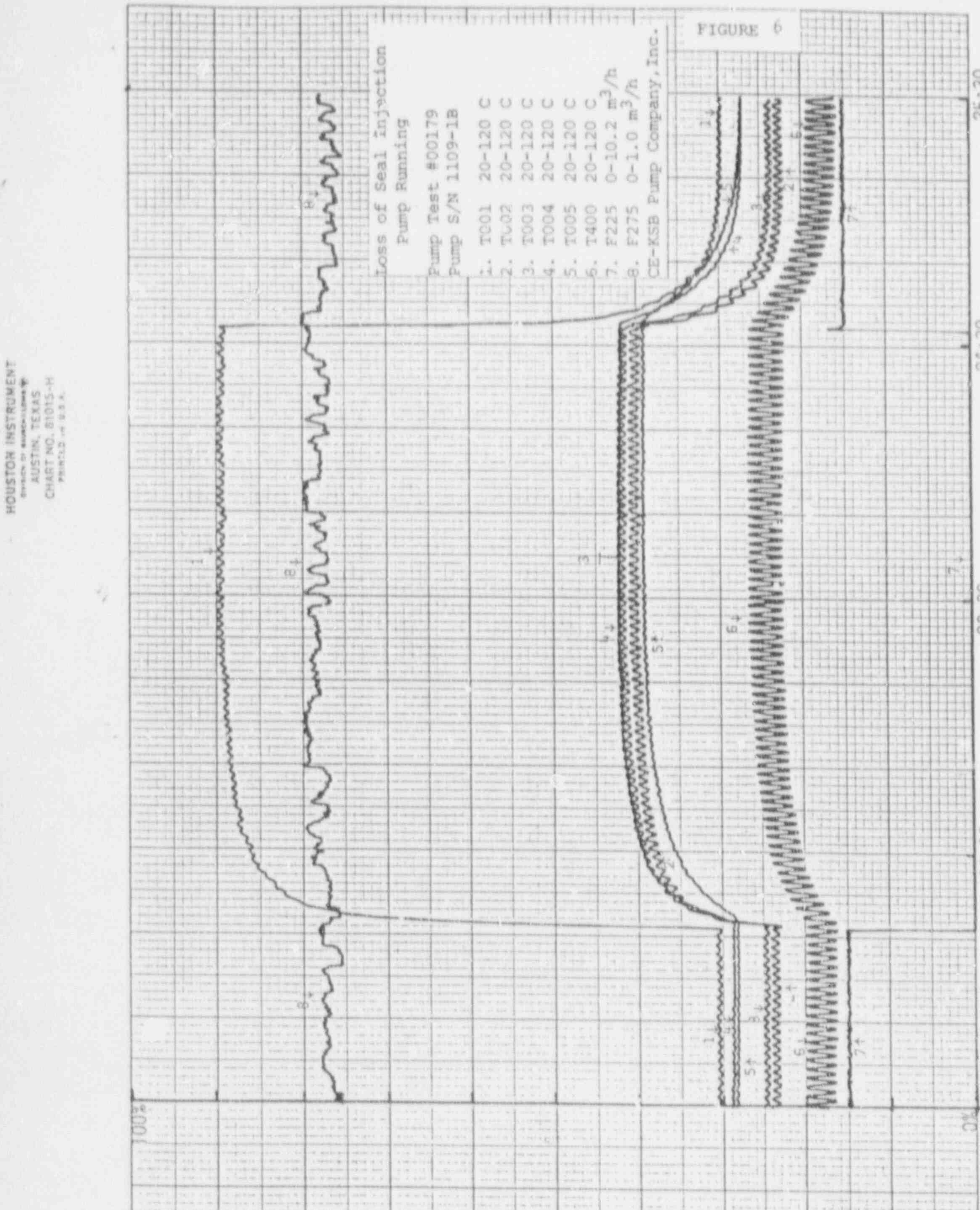
HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 81015-H
FIGURE 6
Loss of Seal Injection
Pump Running
Pump Test #00179
Pump S/N 1109-1B
1. T001 20-120 C
2. T002 20-120 C
3. T003 20-120 C
4. T004 20-120 C
5. T005 20-120 C
6. T400 20-120 C
7. F225 0-10.2 m3/h
8. F275 0-1.0 m3/h
CE-KSB Pump Company, Inc.
100%
0%
21:30
22:30
23:30
24:30
25:30
TEST TIME - hours

FIGURE 6

ATTACHMENT 2

SYSTEM 80+ DESIGN SPECIFICATION PREPARATION LOGIC