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Blowdown/reflood testing of two heater rods containing laser welded thermocouple attachments is described. Two series of tests were conducted, one of three and another of nine blowdowns. Test parameters were controlled such that the blowdown/reflood cycles duplicated those predicted for the LOFT reactor.

Thermocouple performance throughout the test series was very good in that the only failures observed were caused by bowing of the heater rod. Data from all tests are included as are photographs of laser welds taken at various times during the test series. Although heater rod bowing did cause failure of some of the welds, actual fuel pins are restrained and thus not expected to bow to this extent. When weld failure does occur it appears in the form of a separation at the bond between the Titanium fillet and Zircaloy. This does not impair either the performance or the integrity of the fuel cladding in any way.

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HEATER ROD BLOWDOWN TESTS

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1.0 INTRODUCTION

A series of heater rod blowdown and reflood tests was originally planned as a "proof" test of the laser welded thermocouple attachments. Although separate effects tests, such as long term corrosion and thermal cycle, do much to demonstrate the reliability of the attachment welds, an integrated test incorporating as many of the required operating parameters as possible is also desirable. An integrated test was accomplished by laser welding LOFT fuel clad thermocouples to an electrically heated fuel pin simulator (heater rod) and then running the instrumented heater rod through a series of blowdown and reflood tests. By controlling such parameters as heatup rate, peak temperature, blowdown time, ECC injection rate, and water chemistry, a reasonable simulation of the reactor test series could be obtained. Thus, heater rods having dimensions and thermal properties similar to those of the LOFT fuel pins were obtained and a test program was outlined.

The first heater rods were obtained from Wattlow Electric Manufacturing Company to a modified Semiscale specification. Preliminary testing of these rods indicated that their Zircaloy cladding was very brittle and that it consistently failed during the blowdown tests. It was suspected that the material became brittle as a result of work hardening from swaging during manufacturing. Attempts to anneal the finished rods were unsuccessful and it was decided to purchase new heater rods made to a different specification.

The new heater rods were similar to the original ones except that the cladding was not swaged. Insulation compaction density was attained only by tamping during fabrication of the rod. This method was attempted by RAMA Corporation and it resulted in a compaction density of about 85% of the theoretical maximum. This is of the same order as that obtained by many vendors through swaging. The Zircaloy tubing which served as the heater rod cladding was annealed prior to assembly of the rod. The specification for the fabrication of these rods is presented in Appendix A.

Some problems were encountered in making seal welds between the cladding and rod end plug, and between the heating element wire and end plug. These resulted in failure of the first rod of the new type. Modification of the end plug design eliminated these problems and the test series was resumed.

A series of 21 tests was originally planned for each heater rod. This included tests at 1100, 1400, 1500, 1600, and 1700°F. Heater rods were to be instrumented with either two or four thermocouples in an identical manner to actual fuel pins. The test plan which was prepared for the test series is included as Appendix B of this report.

As a result of the delay experienced due to the heater rod problems it was necessary to accelerate the test program. This was done by eliminating the 1400 and 1600°F tests (5 at each temperature) thus, shortening the series to 11 tests for each instrumented heater rod. At this point the situation was complicated further by a change in the laser weld specifications. Separate effects tests had shown that it was necessary to increase the laser beam energy from about four joules to 6.5 joules. Since a heater rod was available which had four thermocouples attached with four joule welds it was decided to run a very limited test series to verify heater rod and blowdown/reflood system performance. This was done prior to testing a rod welded using the new (6.5 joule) weld parameters.

Three blowdown tests were conducted with peak temperatures reaching 1400, 1600, and about 1900°F. All systems behaved properly and no weld failures occurred during these tests. A report of the weld inspections performed during these tests is presented in Section 3 of this report while the blowdown parameter data is contained in Appendix C.

Following the successful three test series the heater having 6.5 joules welds was subjected to the abreviated 11 test series. This series proceeded well until the heater rod failed during reflood on the nineth test. Again the laser welds withstood the tests well with the only failures caused by severe bending of the heater rod. A detailed discussion of the 9-test series is presented in Section 4 of this report. A presentation and discussion of temperature measurement and blowdown facility data collected during these tests is presented in Appendix D. In addition to the tests discussed, it is planned to continue testing of heater rods including these having only two thermocouples attached 180° apart.

2.0 SUMMARY

The use of the single pin blowdown facility provided an excellent means of proof testing laser welded thermocouple attachments. By using heater rods having chopped cosine power distributions, and also with the same dimensions as the LOFT fuel pins, the reactor thermocouple installation was precisely duplicated. Tests were initiated after the system coolant temperature reached 600°F. A blowdown time of 20 to 30 seconds (from 2250 psia to ambient) was used to simulate the predicted LOFT blowdown time. Heatup rate on the surface of the heater rod was about 20°F/second which is also typical of PWR accident conditions. A reflood rate of 2 inches/second was selected as being typical of the desired test conditions. By inspecting the thermocouple attachment welds periodically during the test series a good indication of their ability to survive a series of actual reactor blowdown tests was obtained.

Test results indicate that the 6.5 joules laser welds are entirely capable of surviving such a series of tests. No weld failures occurred which could be attributed to the thermal history accumulated during the tests. A few welds did break loose from the heater sheath as a result of rather severe bowing of the rod during the tests. This bowing was attributed to normal heater rod behavior and not to the presence of the thermocouples. Because of their construction and the way in which they are restrained actual fuel pins are not expected to bow to the extent the heater rods did. When bowing did cause weld failure it occurred in the form of a separation of the bond between the Titanium fillet and the Zircaloy clad. This does not alter the performance or the integrity of the fuel clad in any way.

Weld strength measurements following the series of blowdown tests indicated that hot spot welds retained only about 20% of their initial strength. Welds located on cooler sections of the rod experienced correspondingly less loss of strength as a result of a less severe thermal history and thus less corrosion.

Examination of metallurgical sections through the welds following the test series revealed little or no corrosion of the fillet material. Thus, it was concluded that for a series of tests similar to those experienced by the heater rods, that thermocouple atttachment weld strength and durability is adequate. That is, the 6.5 joules weld energy represents a good compromise between strength and corrosion resistance. Such welds should also prove adequate for the series of tests expected in the LOFT reactor.

3.0 WELD INSPECTION FOLLOWING BLOWDOWN TESTS OF HEATER ROD LH-1

This rod was subjected to a series of three blowdown/reflood tests in the Semiscale Single Pin Facility. Thermocouples attached to the rod were welded at a laser beam energy of approximately 4 joules. Sections of welds on another heater rod (LH-3) welded at the same time revealed that only 3 to 5% weld penetration existed in the Zircaloy clad. Mechanical strength of welds on the LH-3 heater rod was very low.

Although weld energy and hence penetration has been increased, and thus the LH-1 rod welds were nontypical, it was decided to test that heater rod. Previous experience with these rods had not been good due to a series of end cap weld leaks. Although it appeared that all problems of this nature had been solved, it was felt that performance data on both the heater rod and the Semiscale Blowdown/Reflood System would be of value. Thus, a series of three blowdown tests was initiated with the understanding that the laser welded thermocouple attachments might fail.

Tests were to be conducted as originally planned (Appendix B) except that only one blowdown was required at each of the following peak heater rod clad temperatures: 1100, 1400, and 1700°F. The tests were completely successful in terms of heater rod performance with peak clad temperatures reaching 1390, 1640, and 1940°F on the three tests. In addition to the successful heater rod operation, no failures were observed in the thermocouple attachment welds. Inspections of the welds and the heater rod were performed after each of the three tests. Following are brief descriptions of the status of welds and of the heater rod for each inspection.

Inspection Following 1390°F Test

No change could be detected in the dimensions or overall appearance of the heater rod. Only a darkened appearance resulting from the formation of ZrO_2 under these conditions could be seen. The rod did not appear to be warped or bowed. Growth between the two inch scribe marks located in the region of peak temperature was less than 0.005 inch. Thermocouple welds had only darkened in appearance and no failures had occurred. Cracking or checking at the edges of the welds could not be seen.

Inspection Following 1640°F Test

Again very little change in either the heater rod or the thermocouple welds could be detected. Approximately 0.005 inch growth could be measured between the two inch scribe marks located at the rod peak temperature region. A visual examination of the rod indicated that little or no bowing had occurred.

Thermocouple welds did not display any cracks or corrosion flaking. No weld failures had occurred.

Inspection Following 1940°F Test

Inspection following the final test revealed that some rod bowing had occurred but was of the nature of that expected under the thermal conditions experienced by the rod. Previous experience with heater rods indicates that bowing will occur even in rods which do not have thermocouples attached. Total rod growth over the two-inch section located in the hot region had reached 0.015 inch. Separate effects tests indicate that Zircaloy tube exposed to three 0.5 minute thermal cycles, at temperatures similar to those experienced by the heater rod, will increase in length by 0.015 inch (per 2 inches). This represents extremely good agreement between the heater rod and separate effects tests.

Thermocouple welds did not show any adverse effects from the test series. No failures had occurred and no cracking or flaking could be detected. Photographs of welds on both sides of the spade junction located at the hot spot (28 inch location) are shown in Figures 1 and 2. As can be seen, only a light oxide film covers the weld and no cracking or lifting can be seen.

Results of the rod temperature and blowdown loop parameter measurements made during these tests are presented in Appendix C.

4.0 NINE BLOWDOWN TESTS OF HEATER ROD LH-4

Heater rod number LH-4 experienced a total of nine blowdown/reflood tests at temperatures ranging from 1300 to 1750°F. The rod contained four thermocouples welded at a laser beam energy of 6.5 joules. The energy was measured at the work station location with the objective lens removed and the beam defocussed. Thermocouple locations were identical to those on a Type III fuel rod in an "A" assembly. That is, measuring junction locations were at 10, 28, 43, and 60 inches from the bottom of the heater rod. Testing of the rod was terminated by failure of its heating element. Although some welds were broken as a result of severe bending or bowing of the heater rod, none failed as a result of corrosion or other weaknesses produced by the test environment. Heating element failure was also believed to have resulted from bowing of the rod. It is believed that bowing results from either the creation or relief of thermal stresses in the rod.

4.1 Weld Inspections

Weld inspections were performed periodically during the blowdown tests. These were accomplished by examining individual welds under a binocular microscope and making macrophotographs of the individual welds. Of particular interest were the thermocouple measuring junction welds since precise temperature histories were available at those locations. Thus, while all welds were examined during each inspection, photographs were made only of junction welds and of any defective welds which were on the rod. A schedule of tests and inspections for the series of tests is given in Table I. This table contains the actual peak temperature attained by the rod and a summary of the appearance of the welds at the rod hot spot for each inspection.

A photograph of the attachment weld for the thermocouple junction located at the rod hot spot (28 inches) is shown in Figure 3. This shows the weld as it appeared before the test series started. This same weld is shown as it appeared during inspection B in Figure 4. At this time the rod had one blowdown at 1300°F and two at 1500°F. As can be seen, no weld deterioration is evident at this time. The surface of all materials were covered by thin oxide films. Three more tests were conducted at 1500°F before inspection C was performed. A photograph of the 28 inch junction weld taken during inspection C is shown in Figure 5. At this point the weld still looks good, however some corrosion can be seen starting at the Zircaloy edge of the fillet.

Testing was continued as scheduled with two 1700°F tests completed prior to inspection D. A photograph of the 28-inch junction weld taken during this latter inspection is shown in Figure 6. At this time the extremely thin edge of the fillet at the Zircaloy interface has corroded away making the fillet-to-Zircaloy bond line very apparent. The final inspection of this weld performed after one additional 1700°F test is shown in Figure 7. This is the "sister" weld on the opposite side of the thermocouple from that shown in the previous figures. The "sister" weld is shown here because it had lifted from the zircaloy at its leading edge. Other than the lifting of a single weld spot on one side of the thermocouple, the attachment welds on the hot spot thermocouple appear to be in good condition.

Because of the cosine type power distribution in the heater rod, the four thermocouple junctions were exposed to temperatures differing by as much as 400°F. Thus, thermocouple junctions at the other three locations on the rod experienced less severe test conditions that the one at the 28-inch location. Temperature histories for each thermocouple location is given in Appendix D. A view of the 10-inch junction is shown in Figure 8. This was taken during the final inspection and is a weld which had been repaired. Repair was accomplished by rewelding over the original weld. This technique should not be used because it results in excessive mixing of the titanium filler and Zircaloy base metals. Previous experience has shown that mixtures of these materials have accelerated corrosion rates in high temperature oxidizing environments. Examination of Figure 8 reveals that excessive corrosion did occur in the repaired portion of the weld.

Photographs taken during the final inspections of thermocouple junction welds at the 43 and 60-inch locations are shown in Figures 9 and 10 respectively. These junctions were located on relatively cool portions of the rod and the tests have had little apparent effect on them.

The effect of rewelding a defective weld can clearly be seen in Figures 11 and 12. These are photographs of a repaired weld taken after two and three 1700°F tests respectively. Thus, the effect of one additional high temperature exposure can be seen. The accelerated corrosion rate on the rewelded portion of the weld is very evident.

Weld appearance at the conclusion of the series of nine tests was in general very good. No failures were noted which could be attributed to corrosion or weak bond strength of the laser welds. Excessive corrosion occurred only on the few welds which had been repaired by rewelding over the original weld.

4.2 Torque Tests of Laser Welds

The method of torque testing individual laser welds devised by R. D. Wesley and D. W. Hood was applied to the control samples which are made when the heater rod is welded, and also to welds on the rod after the tests were complete. A description of the torque test apparatus and test procedure is presented on pages 62 through 68 in LTR 141-4.

Torque strength values obtained from the control samples ranged from 45 to 65 in.lbs. Torque strength data obtained from welds on the heater rods at the conclusion of the tests can be summarized as follows:

1.	Near the 10-inch TC location	25-35 in lbs.
2.	Near the 28-inch TC location	5-10 in lbs.
3.	Near the 43-inch TC location	10-20 in lbs.
4.	Near the 60-inch TC location	40-50 in lbs.
5.	Top of rod above heated region	45-50 in lbs.

Thus, it can be seen that weld strength is reduced in proportion to the severity of the thermal exposure accumulated during the tests. Welds having strengths of less than 15 or 20 in lbs. can be broken from the cladding relatively easily.

4.3 Metallurgical Examinations

Following the series of blowdown tests metallurgical sections were made through each of the four thermocouple junctions and through other selected welds on the heater rod. These examinations verified visual weld inspection data in that corrosive attack of the welds could not be detected. Although some weld differences were noted from side-to-side on individual thermocouples the basic weld penetration appeared to be satisfactory. Tipping up of one side of the weld spade was also noted on some of these welds. An effort should be made to eliminate this problem through more precise installation techniques.

A section through the thermocouple junction located 10 inches from the bottom of the heater rod is shown in Figure 13. This section has been polished back beyond the thermoelement junction thus, showing the two wires. The tantalum barrier is clearly shown in the section. No weld fillet corrosion can be seen in the section. The spade junction located at the 28-inch elevation (hot spot) is shown in Figure 14. This junction shows a high degree of tip-up. This probably contributed to the incomplete filler wire melting seen in the right-hand weld. These relatively poor welds did a remarkable job of surviving the test series at the rod hot spot.

The 43-inch elevation thermocouple junction section is shown in Figure 15. Although these welds appear to be normal, some corrosion did occur at their edges. A 200-power enlargement of the left-hand weld is shown in Figure 16. Corrosion working under the leading edge of the fillet can be clearly seen. The thermocouple located at the 60-inch elevation did not experience very high temperatures and thus evidenced little effect from the tests. A section of this junction is shown in Figure 17. A 200 power enlargement of the left-hand fillet is shown in Figure 18. No corrosion can be seen in this fillet.

Results similar to those observed in the junction welds were also observed in other attachment welds on the heater rod. That is, most looked very good but a few showed signs of corrosion along the leading edge of the fillet. No welds were observed which had failed either by corrosion or by bond line separation.

4.4 Heater Rod Growth and Temperature Profile Data

Prior to installing thermocouples on the heater rod it is operated at low temperature (200-300^{o}F) to determine the rod axial temperature profile. This is done as part of the acceptance tests of the heater rods in order to eliminate those which have non-typical cosine power distributions and to locate accurately the region of peak temperature. Temperature profile data are collected by applying a small voltage to the rod and then allowing its temperature to stabalize at some temperature such that the hot spot is in the 200 to 300^{o}F range. The surface temperature of the rod cladding is then measured at each two-inch increment along the length of the rod. By plotting temperature vs rod elevation the temperature profile is obtained. Such a plot for this heater rod is shown in Figure 19.

In addition to temperature profile data the history of rod dimension changes was also tabulated. This was accomplished by placing small scribe marks two inches (2.000) apart along the entire length of the heater rod cladding. This was done after the thermocouples were installed but prior to any blowdown testing. The distance between adjacent scribe marks was then measured during each inspection of the heater rod. The combination of the temperature profile and growth history then provides temperature dependent growth data for the rod during the test series. The results of growth measurements taken at the rod hot spot during each inspection are given in Table II. These growth data agree very well with earlier separate effects tests of Zircaloy growth in similar environments.

TABLE II

Hot Spot Growth Resulting From Blowdown Tests

Inspection	Length of 2.000-Inch Section Located at the Rod Hot Spot
A	2.000*
B	2.005
C	2.015
D	2.026
E	2.025**

* Not Detectable
** Located on inside of rod bow and therefore decreased in length.

Growth data for each two-inch increment along the rod were obtained at the conclusion of the tests. These are also plotted on Figure 19 and it can be seen that they generally follow the temperature profile of the rod. Again, this agrees well with separate effects growth data. The correlation between separate effects growth data and those obtained from the heater rod test is shown in Figure 20.

4.5 Thermocouple Performance

Throughout the blowdown tests thermocouple performance was consistently good. Data obtained from the thermocouples are presented in Appendices C and D. Small diameter stainless steel sheathed, chromel/alumel thermocouples were installed near the junction of the titanium sheathed thermocouple located at the 28-inch elevation. Data from the stainless sheathed monitor thermocouples indicated that the titanium sheathed thermocouples performed well during the entire test series.

The only problem which occurred with the thermocouple during testing of the two heater rods occurred in a region of severe bowing of rod LH-4. Bowing of the heater rod caused one of the thermocouples (10 inch elevation) to bow out away from the rod. A small crack developed in the thermocouple sheath at this point. The effect of the crack on thermocouple performance could not be determined because a connector external to the test vessel also failed at this time. Because of the schedule it was decided not to repair the connector since only three 1700°F tests remained in the series. As it turned out only one more was conducted because the heater failed. A photograph of the bowed thermocouple cable and the sheath crack is shown in Figure 21.

5.0 EVALUATION OF HEATER FAILURE

Heater rod failure was attributed to excessive bowing in an isolated region near the 28-inch hot zone. Approximately, a one-inch bow appeared in a relatively short (6-8 inch) length of rod immediately below the high flux region. This caused excessive stress in the thermocouple cable and the failure of some attachment welds in that region.

Thermocouple cable located on the side of the rod in the direction of bow displayed extreme bow (away from rod) and weld failure. The thermocouple located 180° from this one evidenced very little bow while moderate bow occurred in both 90° cables. Weld failure (bond line) occurred only in the cable having extreme bow between welds. Maximum bow was about 0.051 inch measured between TC sheath and Zircaloy clad. Photographs of the thermocouple bow (between welds) and of a failed weld appear in Figures 22 and 23 respectively. These were taken at the conclusion of the test series.

A photograph of the bow in the sheath of the thermocouple located 180° from the direction of rod bow is shown in Figure 24. The maximum separation between the thermocouple sheath and the heater rod is about 0.008 inch. Bow in the two thermocouple cables located 90° from the direction of bow is shown in Figures 25 and 26. Only 0.013 to 0.015 inch separation between thermocouple and heater clad occurred in these thermocouples.

It is believed that localized bowing of the heater rod created stresses in the heating element which eventually led to its failure. The heating element did not shift and contact the heater sheath but appeared to have developed a "hot spot" which eventually burned out. A photograph of the failed region of the heating coil is shown in Figure 27. It was a simple coil failure with no evidence of interaction with either the boron nitride insulation or with the heater sheath.

Bowing of heater rods when exposed to blowdown/reflood conditions is very common as is heating element failure. This has been observed many times during testing of heater rods for the PWR and BWR FLECHT Programs. Thus, it is believed that heater rod bowing and failure observed in these tests was normal and not related to the thermocouple attachments.

6.0 CONCLUSIONS

Several conclusions concerning the thermocouple attachment welds can be drawn as a result of the heater rod blowdown tests. These, and also conclusions pertaining to the heater rods, are listed below:

(1) Thermocouple performance does not appear to be altered by either the heater rod attachment or by the blowdown tests. Performance was good throughout all tests.

(2) The 6.5 joule weld energy is well-suited for this application in that no weld corrosion nor bond line failures were attributed to the effects of the blowdown tests.

(3) Bond line failures did occur as a result of bowing of the heater rod. This amount of bowing is not expected with actual fuel pins. Weld failure does not effect the condition or performance of the Zircaloy clad material.

(4) Weld repairs made by rewelding over an existing weld should not be used. This causes excessive mixing of the base metals and thus accelerated corrosion. Repairs should be made adjacent to, rather than over defective welds.

(5) Torque tests of individual welds conducted after nine blowdown tests indicate that welds located in the hot spot decreased in strength.

(6) Metallurgical examinations of welds after the tests reveal no serious corrosion problems.

(7) Heater rod failure was a result of normal rod limitations and not related to the thermocouples.

(8) It is recommended that further testing be done to better define the heater rod bowing mechanism. This will require the testing of rods with and without thermocouples.

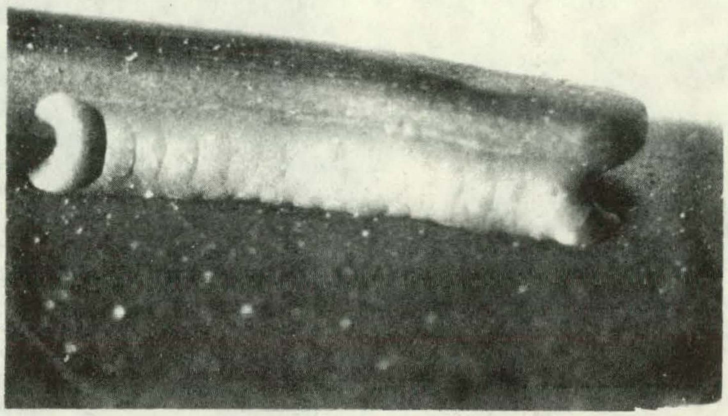


Figure 1. Thermocouple spade attachment weld after the three blowdown tests.

Figure 2. Opposite side of spade attachment weld shown in Figure 1.

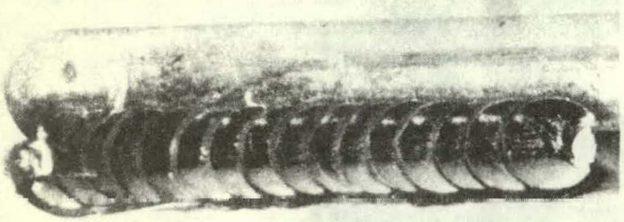


Figure 3. Thermocouple spade junction located at the 28-inch elevation before testing.

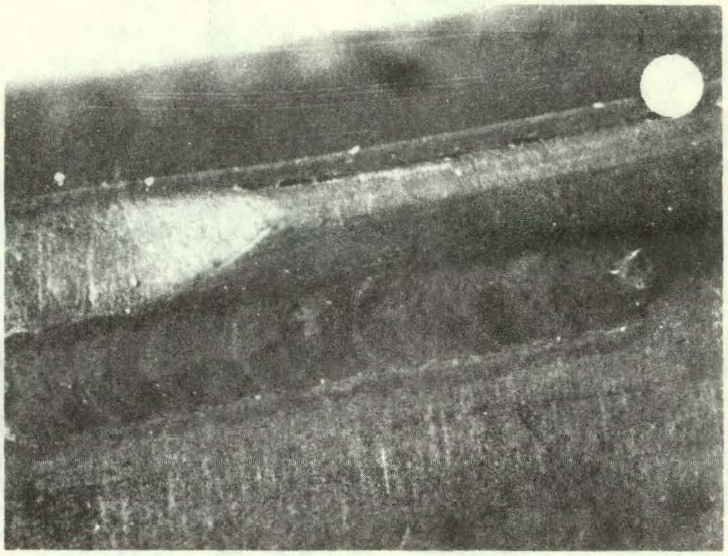


Figure 4. 28-inch junciton at Inspection B. One 1300 and two 1400°F tests.

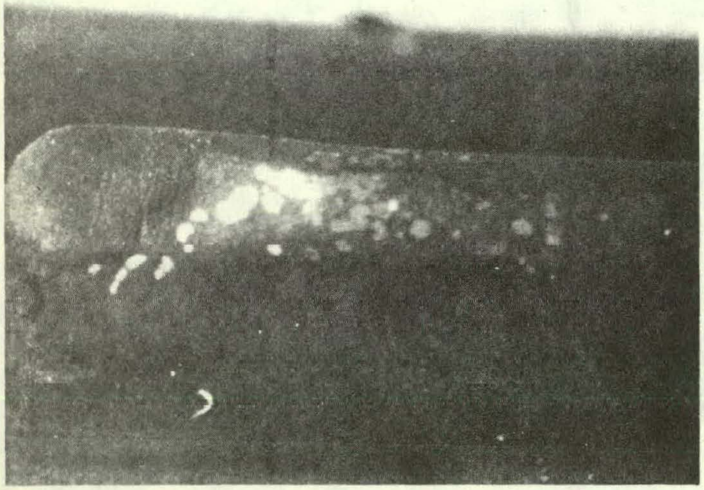


Figure 5. 28-inch junction at Inspection C. Three additional 1400°F tests.

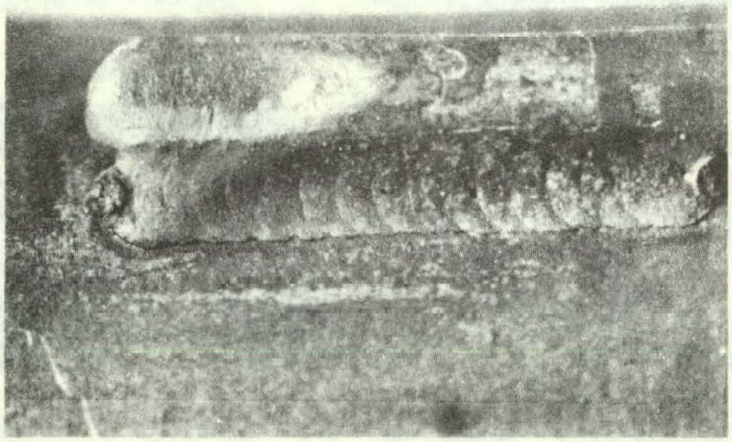


Figure 6. 28-inch junction at Inspection D. One additional 1600 and one additional 1750°F test.

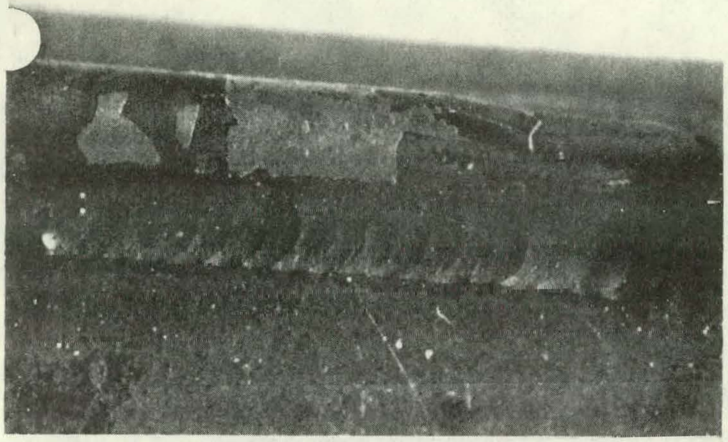


Figure 7. Final inspection of 28-inch junction. One additional 1700°F test.

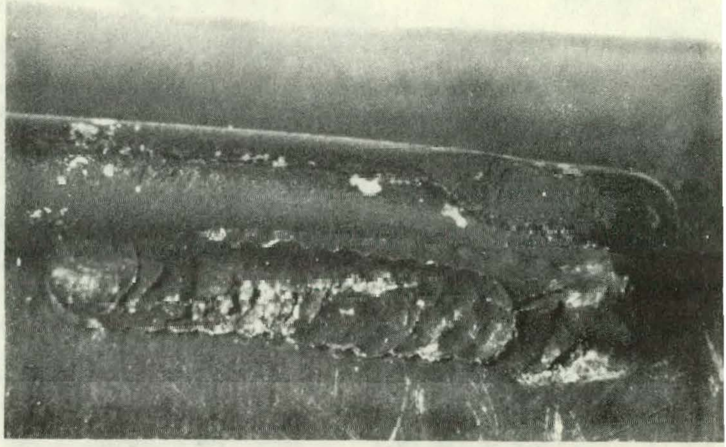


Figure 8. Final inspection of junction at the 10-inch elevation. This side was a reweld and corroded more than did normal welds.

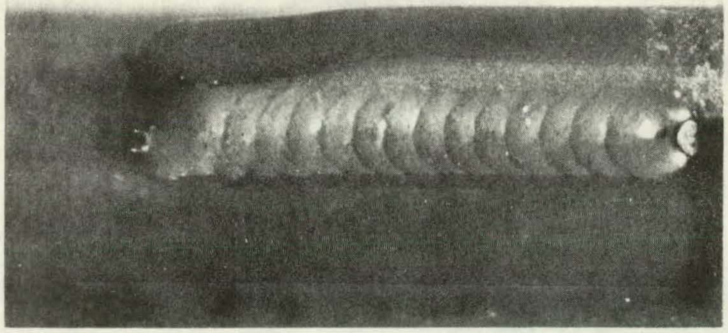


Figure 9. Final inspection of the junction at the 43-inch elevation.

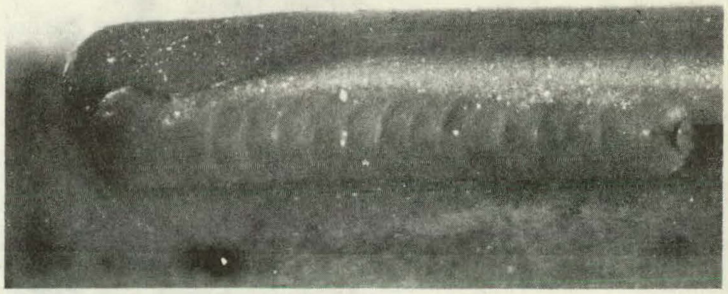


Figure 10. Final inspection of the junction at the 60-inch elevation.

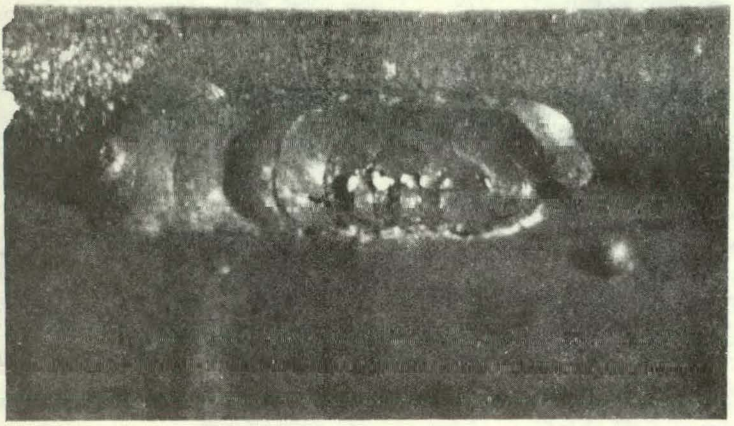


Figure 11. Repaired weld (reweld over original) at Inspection D.

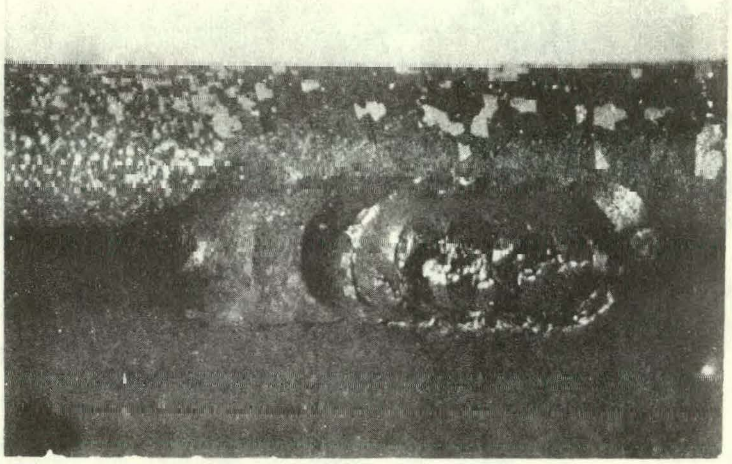


Figure 12. Weld shown in Figure 11 after one additional 1700^{o}F test.

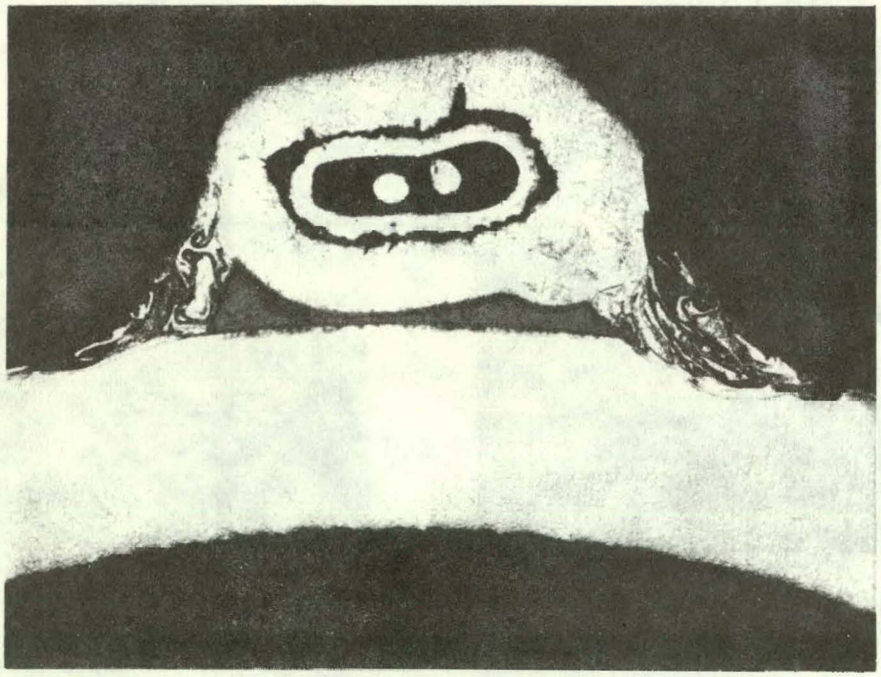


Figure 13. Section through spade junction located at the 10-inch elevation. The tantalum barrier which serves to prevent reactions between the thermocouple wires and the Titanium sheath can be clearly seen. This barrier exists only at the junction where the grounded construction causes contact between the different metals.

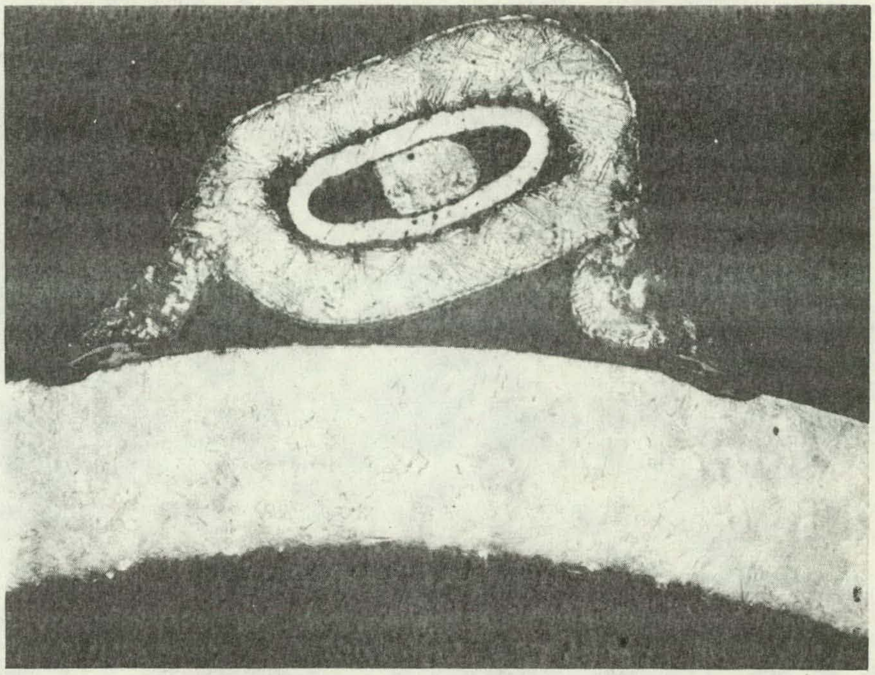


Figure 14. Section through spade junction located at the 28-inch elevation.

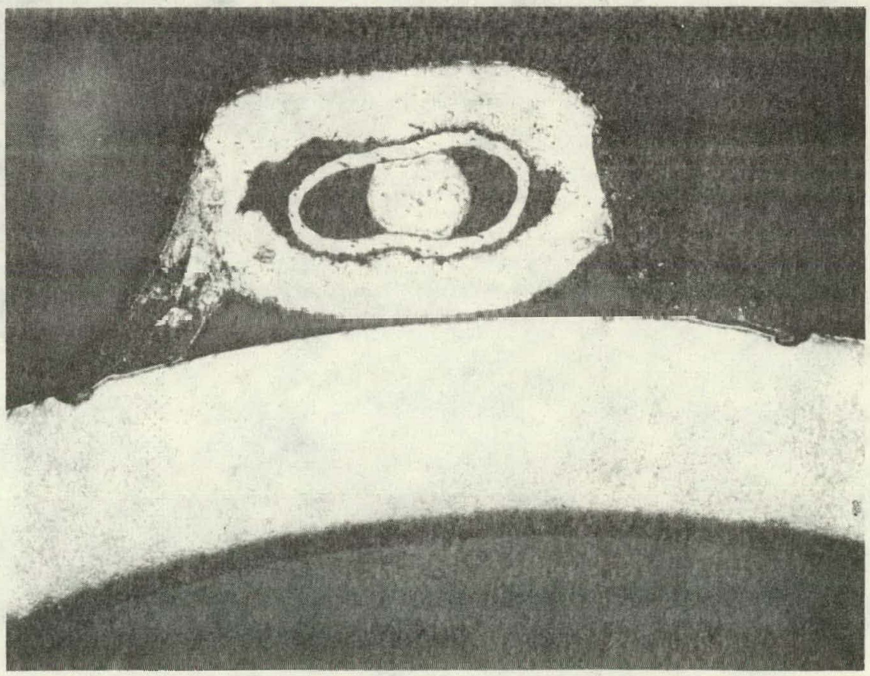


Figure 15. Section through spade junction located at the 43-inch elevation.

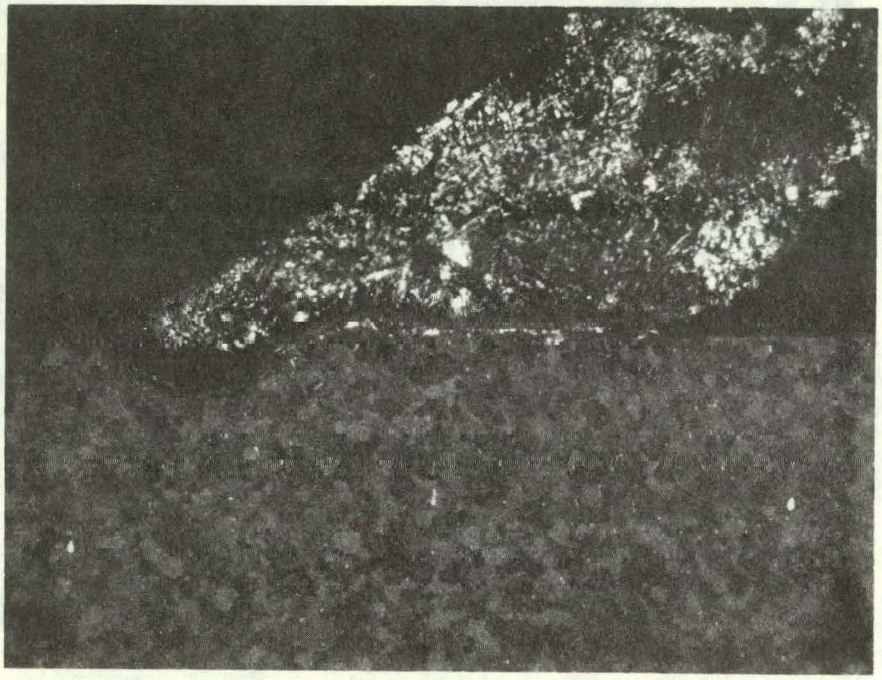


Figure 16. A 200 power enlargement of one side of the weld fillet on the 43-inch junction.

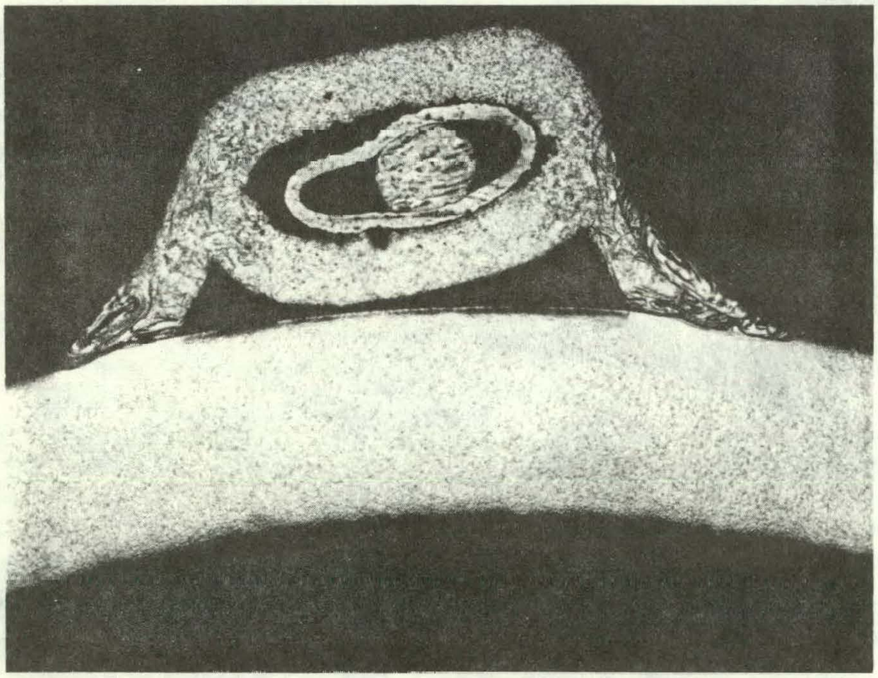


Figure 17. Section through spade junction located at the 60-inch elevation.

Figure 18. A 200 power enlargement of one side of the weld fillet on the 60-inch junction.

Figure 19. Axial temperature profile and axial growth data for heater rod LH-4.

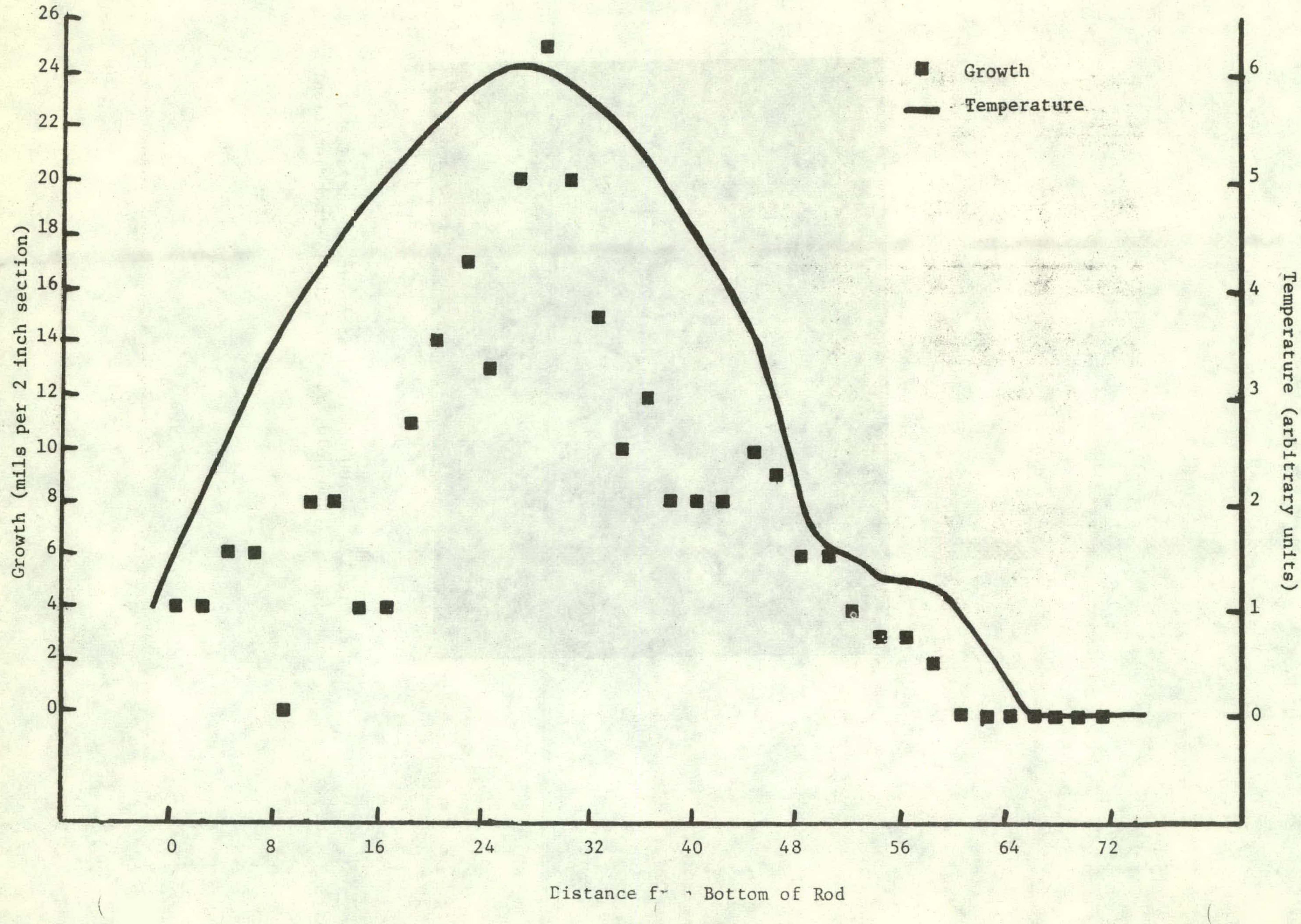
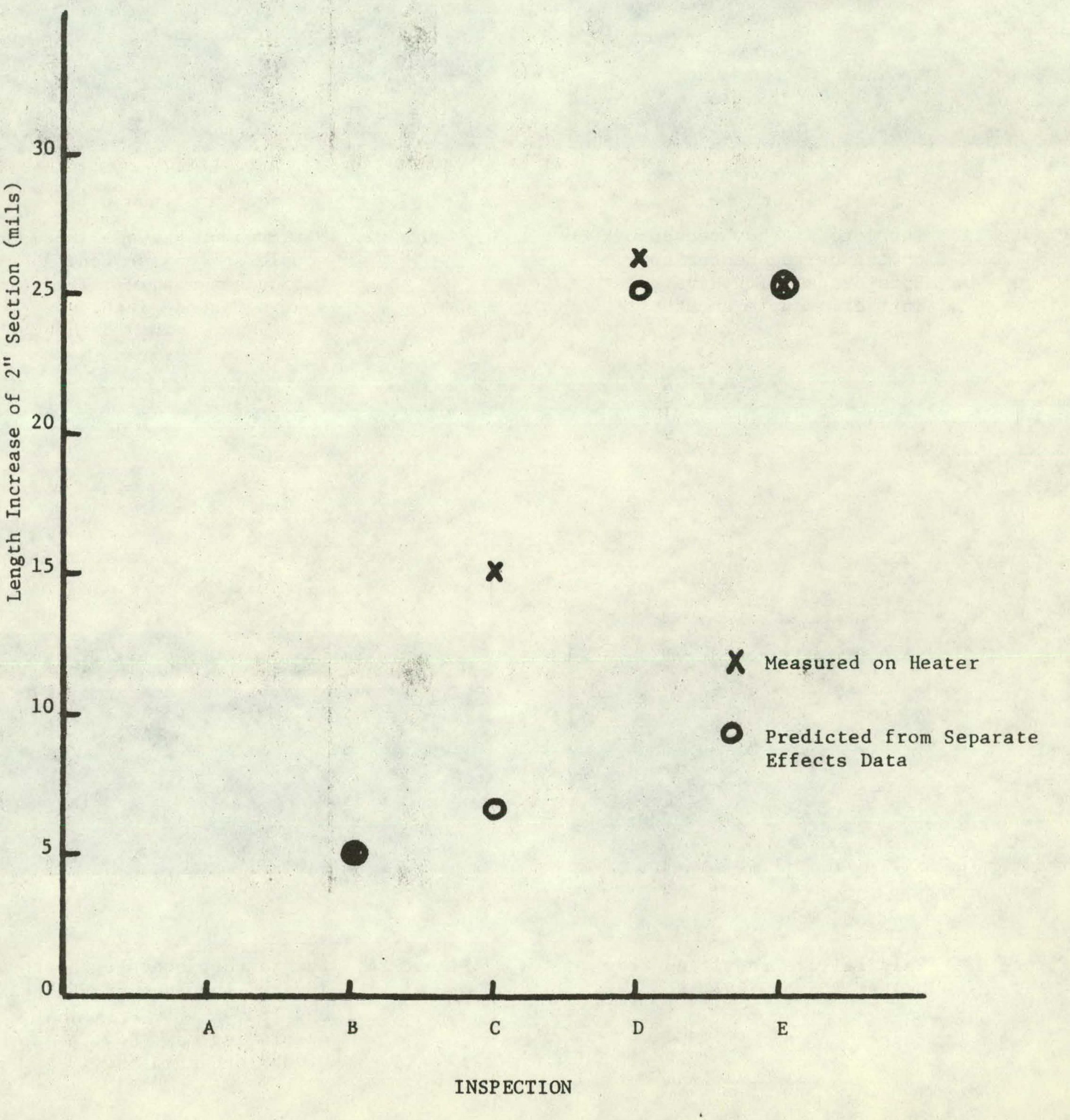


Figure 20. Correlation of heater rod growth data with that obtained from separate effects tests.



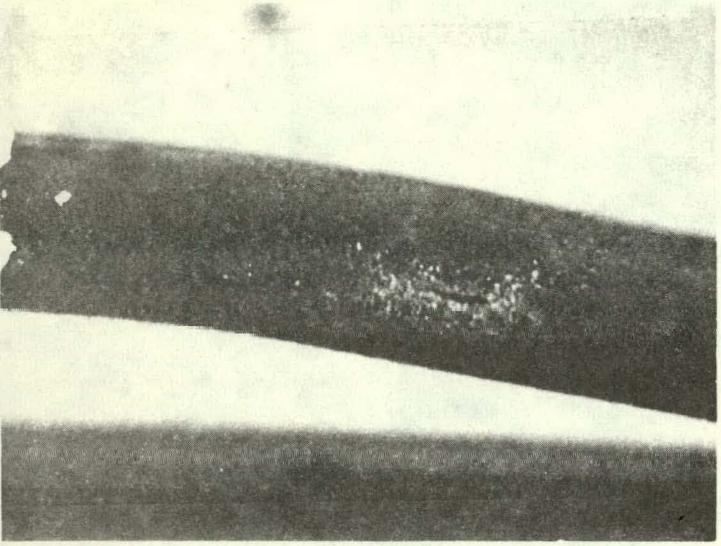


Figure 21. Thermocouple bow caused by bowing of the heater rod. Note crack which developed in thermocouple sheath.

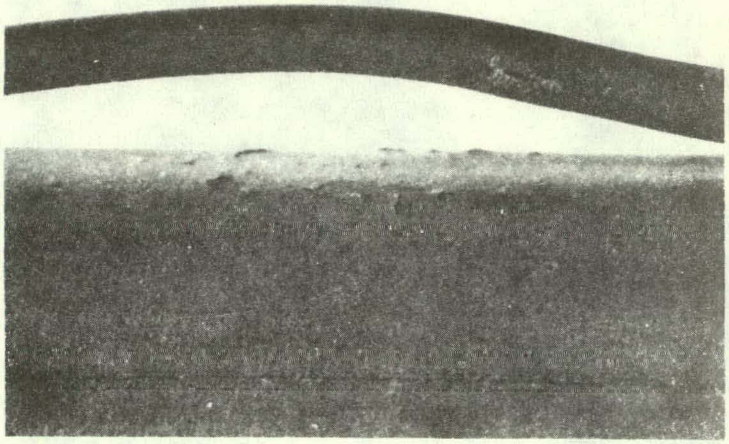


Figure 22. Maximum bow between thermocouple and heater rod. About 0.051 inch maximum. The weld spacing is one inch.

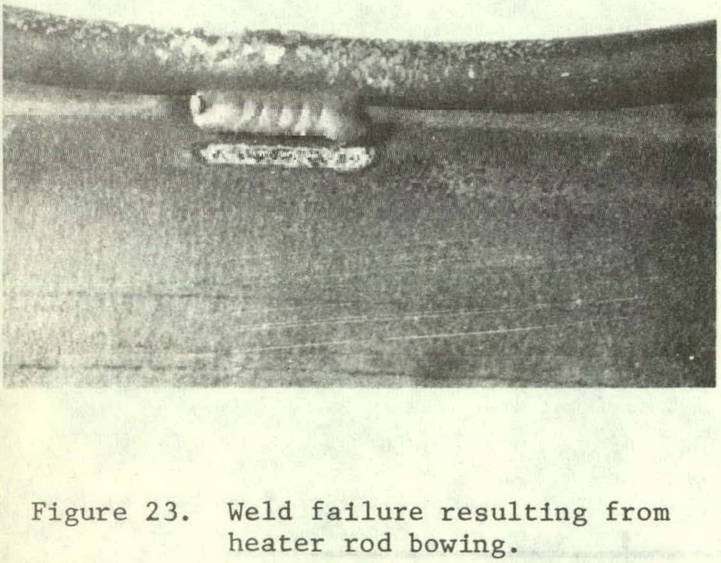


Figure 23. Weld failure resulting from heater rod bowing.

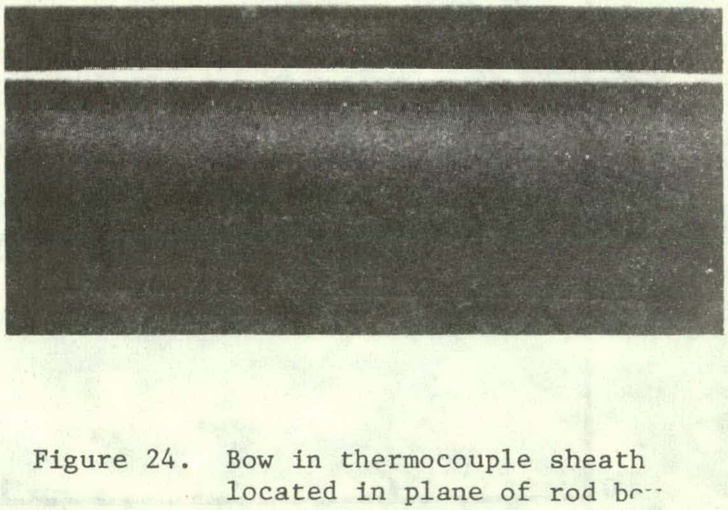


Figure 24. Bow in thermocouple sheath located in plane of rod bo-- and 180^{o} from thermocoupl displaying max. bow. About 0.008 inch max. bow.

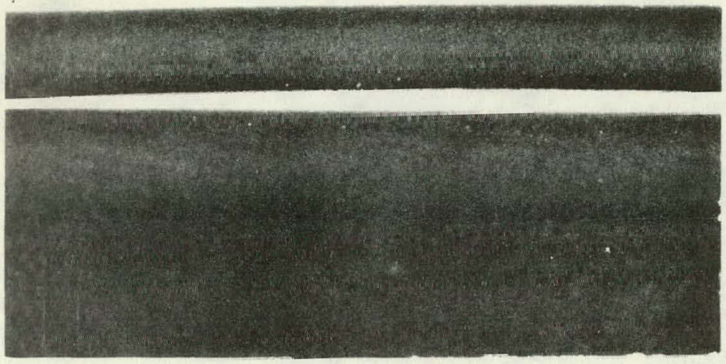


Figure 25. Thermocouple located 90^{o} from direction of rod bow. About 0.015 inch max. bow.

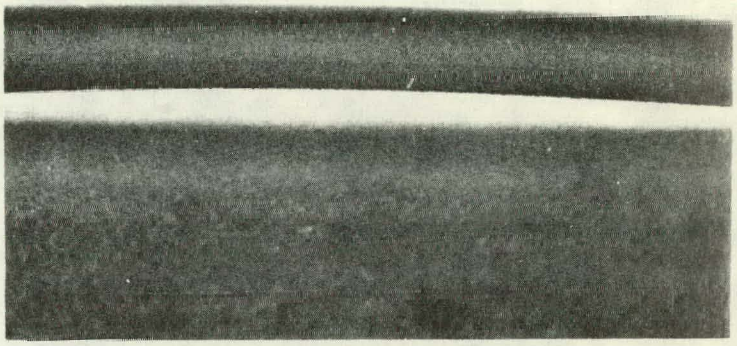


Figure 26. Thermocouple located 90^{o} from direction of rod bow. About 0.012 inch max. bow.

Figure 27. Photograph of failed heating element from rod LH-4.

TABLE I

Test Parameter and Inspection Data For Rod LH-4

Test No.	Predicted	Actual
1	1100°F	1310°F
A	Inspection	No effect, only light oxide. Film on metals.
2	1500°F	1410°F
3	1500°F	1420°F
B	Inspection	No effect. Rod still straight. Oxide film on metals.
4	1500°F	1410°F
5	1500°F	1400°F
6	1500°F	1410°F
C	Inspection	Some corrosion at edges of welds. Rod bowing at hot spot. Welds still look good. Some TC bow between welds.
7	1700°F	1600°F
8	1700°F	1750°F
D	Inspection	Rod bow ~1" at hot spot. .035" TC bow between some welds. Hole in TC sheath. Welds still look good, only small corrosion.
9	1700°F	1725°F
10	1700°F	No test.
11	1700°F	No test.
E	Inspection	Heater Rod Failed. Very large Rod bow - caused TC bow and weld failure. All other welds still look good.

APPENDIX A

Specification for LOFT Heater Rods

SPECIFICATION FOR LOFT HEATERS

(Vibrated & Tamped)

1.0 SCOPE

This specification defines the criteria for electrical heater rods. During normal operations, the heaters will be in a pressurized water environment (2250 psig) with an average sheath temperature of 600°F. During test conditions, the water will be expelled and the sheath temperature will reach 1500°F.

2.0 GENERAL DESCRIPTION

The heater shall consist of a straight cylindrical metal sheath encasing a formed resistance wire embedded in a compacted dielectric. Metal rods (electrodes) shall be provided to conduct the current through the inactive portion of the heater rod. The resistance wire shall be brazed to the upper electrode. The upper electrode shall be compacted with the same dielectric material used in the active zone. At the upper end, a moisture seal shall be provided for the dielectric. The upper electrode shall protrude through the moisture seal and extend beyond the heater sheath. The lower end closure shall consist of a "temporary" moisture-excluding device through which the electrode protrudes for 1.00/2.00 inches.

3.0 MATERIALS

The heater rod sheath material shall be Zircaloy-4.

The heater resistance material shall be AWG #14, 55 copper/45 nickel alloy.*

The upper electrode material shall be nickel-clad OFHC copper.

The heater rod dielectric shall be boron nitride.

The moisture seal shall be inorganic bonded mica tube.

The braze material shall be AWS-ASTM-BAu4 (82 gold/18 nickel).

All materials will be furnished by buyer.

4.0 DIMENSIONS

The heater rods shall conform to the following finished dimensions.

The overall length of the heater rod sheath shall be 84.0 in. ± 2.0 in.

---

*Common names for the 55 Cu 45 Ni alloy include: Constantan, Cupron, Advance, Copel, etc.

The upper electrode and resistive element outside dimension shall be 0.230 in. ± 0.005 in.

The upper electrode shall protrude from the sheath 6.0 in. ± 1.0 in.

The outside diameter of the sheath shall be 0.422 in. ± 0.002 in.

The sheath wall thickness shall be 0.025 in. ± 5%.

Length and resistive requirements of the resistive element for each region of the active zone are shown in Attachment 1. Variations in length in any region shall not exceed ± 0.5 in. The pitch shall be uniform in each region such that no variation greater than ±5% of the average pitch shall be permitted.

5.0 POWER REQUIREMENTS

The heater rods shall be capable of producing 9.48 KW ±5% with an excitation voltage of 93 volts dc.

Power distribution requirements are detailed in Attachment 1.

6.0 FABRICATION REQUIREMENTS

The heater element shall be a continuous wound 55 cu/45 ni alloy. To allow for more precise matching of the power profile in the lower power regions, a dual-wire configuration shall be permitted.

Upon completion of the heater element fabrication (winding and stretching) and prior to filling operations, the heater element shall be annealed for three to five minutes at 1700°F in an argon atmosphere.

The Boron Nitride dielectric material shall be "baked out" at a temperature of not less than 250°F and for a period of not less than two hours prior to the rod filling operation. It shall be immediately transferred to a heated loading container and maintained at a temperature of not less than 250°F throughout the filling operation.

The heater sheath and resistive element shall be heated to a temperature of not less than 250°F and for a period of not less than 30 minutes prior to the filling operation. The heater sheath and resistive element shall be maintained at a temperature of not less than 250°F throughout the filling operation.

Upon completion of the filling process the heater shall be sealed or placed in a dry inert atmosphere until final sealing to preclude further moisture absorption. No violation to the integrity of the moisture seal shall be permitted.

The Boron Nitride density of the completed heater rod shall be not less than 1.5 g/cc. The Boron Nitride density of each completed heater rod shall be documented by analog recorder records of grams of dielectric versus axial distance, and also the frequency and amplitude of the compacting head displacement versus axial distance shall be provided for verification of dielectric homogeneity.

7.0 TEST AND INSPECTION

7.1 At the Seller's Plant

The heater rod shall be inspected at the seller's plant to show compliance with this specification. Inspections shall include (but not be limited to) the following.

(a) The completed heater rod will be x-rayed at the buyer's plant along its entire active length to show concentricity of the resistive element, region lengths, winding densities, and uniformity of winding densities. Copies of the x-rays will be furnished to the seller.

The electrode and resistive element shall be concentric with the heater sheath ID and shall not vary greater than ±0.010 in. as measured from the heater rod centerline.

The Boron Nitride wall thickness, as measured between the electrode and the resistive element, and the inner sheath wall, shall be no less than .065 in. at any point throughout the entire heater rod length.

The region lengths shall show no variation greater than 0.50 in.

The winding pitch per region, as measured from the x-rays, shall show no variation greater than 5% of the specified winding pitch.

No variation in winding pitch per region, greater than 5% of the average winding pitch per region, shall be permitted.

It shall be the option of the buyer to witness inspections perormed at the seller's plant.

Certified inspection of test results shall be furnished to the buyer to show full compliance to this specification. Said certified inspection shall accompany completed rod shipments.

Approval of said certification shall not constitute the sole basis for acceptance of any item.

7.2 At the Buyer's Plant

The buyer will inspect and test the heater rods upon receipt at the buyer's plant. These tests and inspections will be comprised of those specified in 7.1 and an air profile test. The tests and inspections performed at the buyer's plant will be the basis of final acceptance.

It shall be the option of the seller to witness tests and inspections at the buyer's plant.

The air profile tests will be conducted by:

(a) attaching a thermocouple on the sheath at the centerline of each region,

(b) placing heater rod in an argon atmosphere,

(c) raising the temperature of the rod by its own power, and

(d) recording temperatures of all thermocouples to establish power profile.

The power profile shall not vary more than 5% of the calculated power profile.

8.0 IDENTIFICATION

The seller will identify each heater rod with a serial number. The serial number will be stamped on the rod at a distance no further than three inches from the top of the sheath.

9.0 SPECIFICATION CHANGES

No exceptions or changes to this specification shall be permitted without the written approval of the buyer.

ATTACHMENT 1

RESISTANCE AND POWER REQUIREMENTS

LOW POWER HEATER RODS

Region	Inches (From Top of Heated Length)	Resistance In Ohms @ 70°F
1	0.0 - 17.5	0.0905
2	17.5 - 22.5	0.072
3	22.5 - 27.5	0.0931
4	27.5 - 32.5	0.106
5	32.5 - 42.5	0.230
6	42.5 - 47.5	0.106
7	47.5 - 52.5	0.0931
8	52.5 - 57.5	0.072
9	57.5 - 66.0	0.0517
	TOTAL	0.9144

ATTACHMENT 2

TESTS AND INSPECTION

A. Pre-Assembly Inspection — Serial # ______

1. Resistive Element

   a. Anneal ______

   b. Overall Element Resistance ______ Ω

   c. Segment Resistances

1) ______ Ω	4) ______ Ω	7) ______ Ω
2) ______ Ω	5) ______ Ω	8) ______ Ω
3) ______ Ω	6) ______ Ω	9) ______ Ω

2. Bakeout

   a. Dielectric ______

   b. Heater Sheath and Resistive Element ______

B. Post-Assembly Inspection

1. Resistive Element

   a. Overall Resistance ______ Ω

   b. Overall Length ______ "

   c. Segment Lengths

1) ______ "	4) ______ "	7) ______ "
2) ______ "	5) ______ "	8) ______ "

   d. Concentricity ______ $\pm$0.005 in.

2. Heater Sheath

   a. Overall Length ______

   b. Diameter ______ "

   c. Dye Penetrant Check (Sheath and End Weld) ______

3. Electrode

   a. Upper electrode Length (Above Sheath) ______ "

4. Dielectric

   a. Density ______ g/cc

C. Identification

1. Heater Rod Serial Number ____________

2. Power Designation ____________

D. Test

1. Hipot

a. Applied Voltage ____________

b. Current Leakage ____________

APPENDIX B

Test Plan

Heater Rod Blowdown and Reflood Tests

TC 6.3 HEATER ROD BLOWDOWN AND REFLOOD TESTS

Revision 1 November 7, 1972

The series of tests will constitute proof tests of the fuel rod clad thermocouple installation. Heater rods will be instrumented with thermocouples in the same manner as actual fuel rods. The instrumented heater rods will be installed in the single rod blowdown loop located in the semiscale facility at TAN. After steady state operation at 600°F is achieved, the blowdown will be initiated and the heater rod clad temperature will be allowed to rise. After reaching a preselected peak temperature ranging from 1100 to 1700°F flooding will be initiated. The objective is to verify that the thermocouple installations will withstand a series of blowdown and reflood tests similar to those expected in LOFT.

Heater Rod Preparation

Prior to instrumentating the heater rods with thermocouples they must be prepared and qualified for the blowdown tests. This is accomplished by first measuring the temperature profile of each of the rods during low temperature operation. This is to be accomplished in the following manner.

A single heater rod is supported in a horizontal position on insulating (fire brick) supports. A DC power supply is used to heat the rod. By applying 12 V at about 8 amps the rod will be heated to nominally 250°F. The clad surface temperature is measured at each two inch increment starting at the top (electrode) end of the rod. A Chromel-Alumel thermocouple mounted in a metal ring which slips over the heater rod is used to make the temperature measurements. As the thermocouple is moved to each new location the temperature is allowed to stabalize before the thermocouple output, as indicated by a digital voltmeter, is recorded.

After all thermocouple outputs have been converted to temperatures, a plot of clad surface temperature vs distance from the heater rod end is made. In this manner the rod axial temperature distribution can be determined. These plots are later used to determine the uniformity of the cosine type temperature distribution.

Heater Rod and Thermocouple Cleaning

Full length cleaning of the heater rods, thermocouples, and filler wire will be done in accordance with procedures furnished by Jersey Nuclear Company. In part, these procedures are as follows:

Zircaloy Clad Heater Rods

1. Scour rods prior to etching with an alumina abrasive or silicon carbide pads.
2. Wipe rods with acetone or alcohol moistened clean wipes.
3. Rods must be handled with clean cloth or nylon gloves to prevent fingerprints.
4. Etch rods to produce surface metal removal of about 0.0005 inch.
5. The etch solution shall consist of the following:

a. 39$\pm$ 2 volume % of HNO_3 (70 wt. %) technical grade.
b. 4 $\pm$ 0.1 volume % of HF (48-52 wt. %) reagent grade
c. Balance, deionized water
d. Solution temperature should be 90 $\pm$ 20°F
e. Rods shall be continuously agitated during etching.
f. Rods shall be transferred to the stop solution within 10 sec. after completion of etching.

6. The stop solution shall consist of the following:

a. 13 $\pm$ 5 wt. % Al $(NO_3)_3 \cdot 9H_2O$
b. Balance, deionized water
c. Stop solution temperature shall be 90 $\pm$ 20°F
d. Rods shall be transferred to the first rinse within 20 sec. after exiting the stop solution.

7. Rinse rods in hot flowing water.

a. Rinse water temperature shall be 120 $\pm$ 25°F
b. Rinse water shall be changed on a steady flow basis.
c. Residence time in the rinse water shall be $\geq$ 2 minutes.
d. Rods shall be transferred to a deionized water rinse in time to prevent drying of residual rinse water and spotting of the rods.

8. Rods shall be rinsed in deionized water prior to drying.

a. Residence time in the deionized water shall be $\geq$ 1 minute.
b. Rods shall be dried with clean, alcohol-soaked paper wipes. This shall be done before the rinse water can dry and spot the rod.

9. Throughout the process the rods shall be handled with clean gloves. Following drying the rods are to be stored in clean, sealed plastic bags.

Titanium-Sheathed Thermocouples and Titanium Filler Wire

1. If necessary, components may be scoured or brushed to improve etch uniformity.
2. Abraded material shall be wiped from the components with acetone or alcohol moistened clean wipes.
3. The components shall be handled with clean gloves throughout the cleaning operation.
4. Components shall be etched to remove $\leq$ 0.001 in. from the surface.
5. The etch solution shall consist of the following:

a. 30 $\pm$ 2 wt. % HNO_3 technical grade (23.5 volume %)
b. 1.6 $\pm$ 0.1 wt. % HF reagent grade (1.5 volume %)
c. Balance, deionized water
d. Etch solution temperature shall be 90 $\pm$ 20°F

6. Etched components shall be transferred to a stop scluiton within 10 seconds after completion of etching.

7. The stop solution shall consist of the following:

   a. 13 $\pm$ 5 wt. % Al $(NO_3)_3$ 9 H_2O
   b. Balance, deionized water
   c. The stop solution temperature shall be 90 $\pm$ 20°F
   d. Components shall be agitated in the stop solution for $\geq$ 1 min.
   e. Components shall be transferred to the first rinse water within 20 seconds after exiting the stop solution.

8. Rinse

   a. Components shall be rinsed in hot flowing water to remove residual stop solution.
   b. Residence time in the rinse water shall be $\geq$ 2 minutes.
   c. Transfer components to deionized water rinse in time to prevent drying of residual rinse water.

9. Components shall be dried with clean, alcohol-soaked paper wipes. This shall be done before the rinse water can dry and spot the components.

10. Throughout the process the components shall be handled with clean gloves. Following drying the components are to be stored in clean, sealed plastic bags.

Welding Thermocouples to Heater Rods

All welding will be done in accordance with the latest draft of the following documents:

1. ANC-60081, Process Specification: Laser Welding Thermocouples to Fuel Rods and Guide Tubes.
2. LMP-211, Procedure for Laser Welding Thermocouples to Zircaloy Rods and to Zircaloy Guide Tubes.

Thermocouples used will be the 0.046 inch diameter titanium-sheathed devices. described in ANC-50053, Thermocouples, Titanium-Sheathed, Types K and S, For Use In The LOFT Program. They are made from titanium tubing which has been oxygen cleaned for one hour at 1200°F. All thermocouples will have tantalum junction barriers. These junctions are described in LMP -214, Procedure to Fabricate Tantalum-Barrier Junctions for LOFT Cladding Thermocouples.

A permanent record of the laser power for each weld spot shall be made as the heater rods are instrumented. This, and any quality control procedures outlined in ANC-60081 and LMP-211 shall be adhered to during instrumentation of the rods.

Instrumented rods shall be handled with clean gloves and stored in plastic bags until used.

Heater Rod Test Samples

Following is a description of the thermocuple locations for each of three heater rods. Two additional rods are available and can be used if results from the first three tested indicate that additional testing is required. If it is necessary to use the additional rods an amendment to this test plan will be issued to cover the additional testing. In addition to temperature measurements the dimensional changes in the heater rods will be determined. This will be done as follows.

Each heater rod shall have scribe marks placed at each two inch increment starting at the top end and continuing to the bottom of the rod. The marks must be placed on the rod in such a manner so as not to interfere with thermocouples which are attached to the rod, i.e., between adjacent thermocouples. Distances between each two adjacent scribe marks shall be measured and recorded during each inspection following rod tests. Scribing and measuring is to be done in addition to the overall rod length and diameter measurements.

Heater Rod No. 1

This rod is to be used as a control and will be tested with no thermocouples installed by laser welding. Instead, four stainless steel sheathed, Chromel-Alumel (Type K) thermocouples will be attached to the rod by spot welding. The measuring junctions of these thermocouples will be attached at the same locations as the thermocouples of a Number 3 rod in a Type A assembly in LOFT. For the heater rod these locations are 12, 28, 43, and 60 inches from the bottom end cap. Radial locations will be as specified for the A assembly, No. 3 rod also.

These stainless steel sheathed thermocouples shall have only their measuring junctions attached solidly to the heater rod. The remainder of the cable shall be loosly strapped to the rod to allow for differential expansion etc.

This rod will undergo a series of blowdown and reflood tests which are typical of those expected in LOFT. These tests will be conducted in the following manner:

1. Record total length of clad portion of the rod.
2. Record diameter of the clad at a point 55 inches from the top of rod.
3. Install rod in single-rod blowdown facility. Loop water shall meet LOFT water chemistry specifications.
4. Make rod power and thermocouple connections. Thermocouple signals will be recorded on the semiscale data system.
5. Stabalize the blowdown loop at a temperature greater than 600^{o}F.
6. Initiate blowdown and if necessary increase rod power until clad temperature reaches 1100 $\pm$ 25^{o}F.
7. When peak temperature is reached initiate flooding at a rate of 2 in/sec and remove rod power.
8. After the facility has cooled, remove rod, inspect thermocopples, and record length and diameter data.
9. Repeat Steps 3 through 8 with a peak clad temperature of 1400 $\pm$ 25^{o}F.
10. Repeat Steps 3 through 8 with a peak clad temperature of 1700 $\pm$ 25^{o}F.

Heater Rod No. 2

This rod will be tested with four laser welded, titanium sheathed, Type K thermocouples attached. Thermocouple locations will be as for the Number 3 rod in A assembly described above. Thus measuring junction will be at the same locations as those on the No. 1 heater rod. Dummy sections of thermocouple cable will be welded to the rod just as for the actual fuel pins.

In addition to the titanium-sheathed thermocouples which are laser welded to the heater rods, each rod will contain two monitoring thermocouples. These two thermocouples will be 0.020 inch diameter stainless steel-sheathed, Chromel-Alumel having grounded junctions. One will be attached (by spot welding) to the titanium thermocouple sheath immediately behind the titanium spade junction. The other will then be attached to the Zircaloy at the same axial location as the other monitoring thermocouple, and at a radial location not to exceed 45 degrees from that thermocouple. All monitoring thermocouples shall be attached at the titanium thermocouple located 28 inches above the bottom end cap. Output signals are to be recorded for both monitor thermocouples and all Ti-sheathed, laser welded thermocouples.

This rod shall be subjected to testing as outlined in the following steps.

1. Each rod shall experience a single blowdown and reflood at a peak centerline temperature to 1100°F.
2. Following inspection of the rod after the 1100°F test, three tests will be conducted at 1400°F. The rod will be inspected only after the third 1400°F test.
3. Following this last inspection, two more 1400°F tests will be conducted followed by a rod inspection.
4. A series of three 1500°F tests, followied by a single inspection, will then be conducted.
5. After inspection, two more 1500°F tests will be conducted and an inspection performed.
6. This same sequence will be followed for tests at 1600 and 1700°F. Table 1 contains the test sequence required for each of the heater rods. Table 1 is to be used to record actual peak temperatures for each test and to note weld failures at the appropriate sequence inspection.

NOTE: Actual procedures for conducting the blowdown tests are to be furnished by Nuclear Safety Development in accordance with the letter "LOFT Heater Pin Testing", Hou-54-72, dated July 12, 1972.

Heater Rod No. 3

This rod will be instrumented exactly like Rod No. 2 and will be tested only if testing of Rod No. 2 is unsuccessful. Each rod will be examined closely for failures in weld regions. Metallurgical examinations will be performed on any region which indicates failure or near failure.

Testing of the remaining two heater rods will be dictated by the results of the above tests. Should additional testing be required amendments covering the additional tests will be issued for this test plan.

TABLE 1

Heater Rod Test Sequence					
Test Temperature	Rod Number				
	-1	-2	-3	-4	-5
1100					
Inspect					
1400					
1400					
1400					
Inspect					
1400					
1400					
Inspect					
1500					
1500					
1500					
Inspect					
1500					
1500					
Inspect					
1600					
1600					
1600					
Inspect					
1600					
1600					
Inspect					
1700					
1700					
1700					
Inspect					
1700					
1700					
Inspect					

Aerojet Nuclear Company

Interoffice Correspondence February 21, 1973

J. W. McConnell
TAN-607

HEATER ROD BLOWDOWN TEST PLAN CHANGE - Mes-7-73

Because of the critical nature of the schedule associated with the heater rod blowdown tests it is desirable to shorten the length of the forthcoming test series. LOFT Project and the AEC have agreed to an abreviated series of tests to accomplish accelerated corrosion of the thermocouple attachment welds. In addition to fewer blowdown tests, other procedural changes should be made for the next test series. The latter changes are a result of information gathered during the three tests of the previous heater rod. Following is a list of changes which are to be made in test plan TC 6.3, Heater Rod Blowdown and Reflood Tests, At the present time these changes apply only to testing of heater rod LH-4.

1. Tests will be conducted at only three temperatures: 1100, 1500, and 1700°F. One test will be conducted at 1100°F and five each at 1500 and 1700°F. The same 200°F temperature overshoot will be allowed on the 1100 and 1700°F tests, however, no overshoot is allowed on the 1500°F tests. This is to prevent problems which may arise on reaching the Zircaloy phase change which occurs somewhat above 1500°F. Thus, the acceptable temperature range for 1500°F tests shall be 1500, +0, -100°F. The range for all other tests shall be -100, +200°F. The test and inspection sequence for these tests is given in Table I.

2. Based upon the results of the first three heater rod blowdown tests the rod power should be reduced from the present 15% to give a slower heatup rate. A heatup rate of about 20°F/sec is required. Past tests at 15% power have resulted in heatup rates of 60 to 80°F/sec.

3. It is also desirable to leave some power on the heater rod during blowdown and reflood to be more consistant with the LOFT application. Please address this problem and determine an acceptable steady state power level for this portion of the blowdown test.

4. Previous results have indicated a varying reflood rate. It is desirable to keep this rate constant at about 2 inches/second.

All other phases of this test program are to be as previously outlined. Again, we stress the critical nature of completing this test series as quickly as practical.

R H Meservey

R. H. Meservey
Measurements Engineering Section

lh

Attachment

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R. D. Wesley
L. J. Ybarrondo
R. H. Meservey - 2

TABLE I

Test and Inspection Sequence

Inspection Number	Test Temperature (^{o}F)
	1100
1	Inspect
	1500
	1500
2	Inspect
	1500
	1500
	1500
3	Inspect
	1700
	1700
4	Inspect
	1700
	1700
	1700
5	Inspect

APPENDIX C

Temperature and Blowdown Parameter Data

For Heater Rod LH-1

(Three Tests)

TEST DATA FOR

LOFT HEATER PIN LH-1

TEST NUMBER 7A

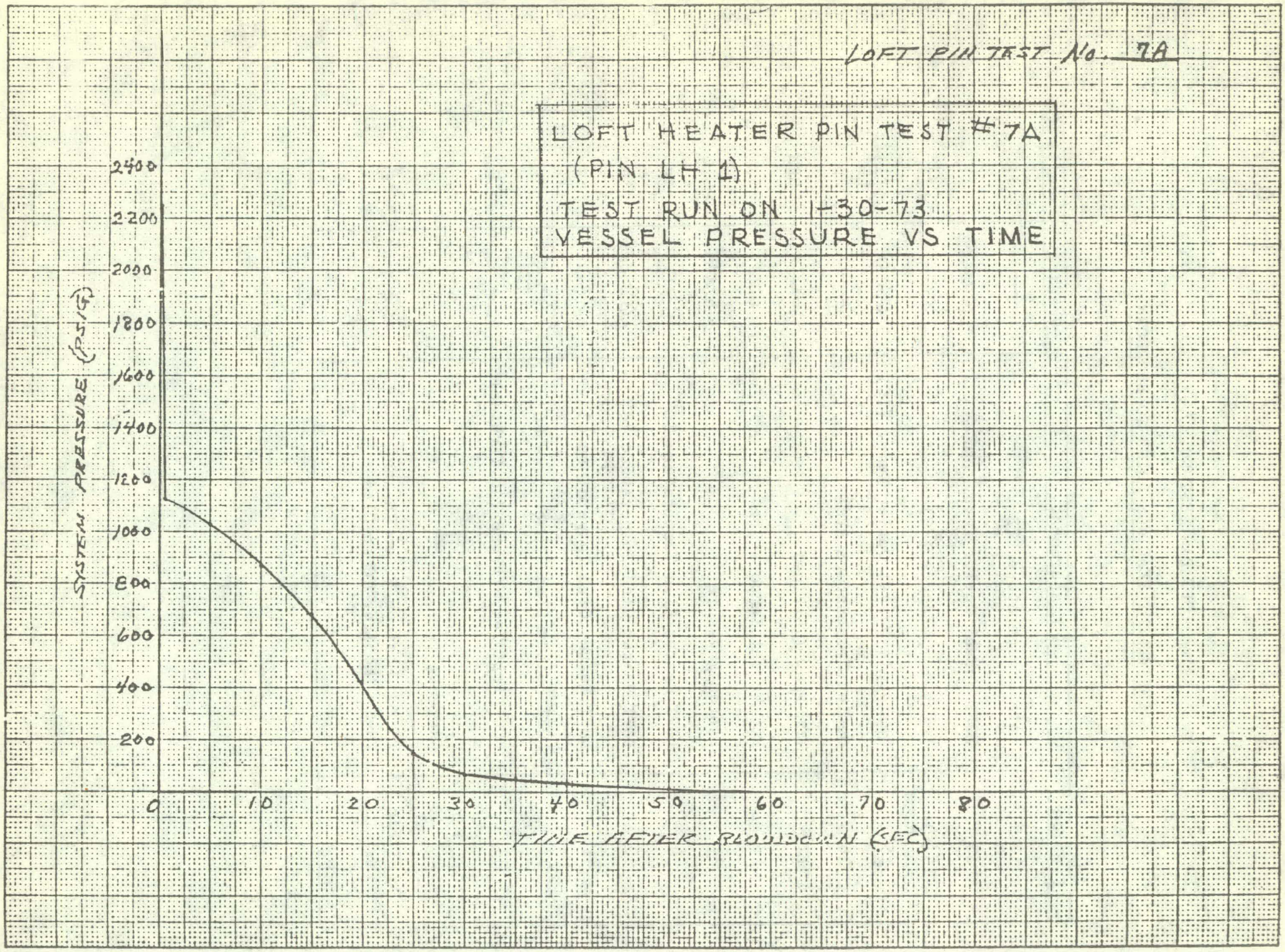
1/30/73

1-30-73

LOFT PIN TEST NO. 7A

INSTRUMENT READINGS PRIOR TO BLOWDOWN

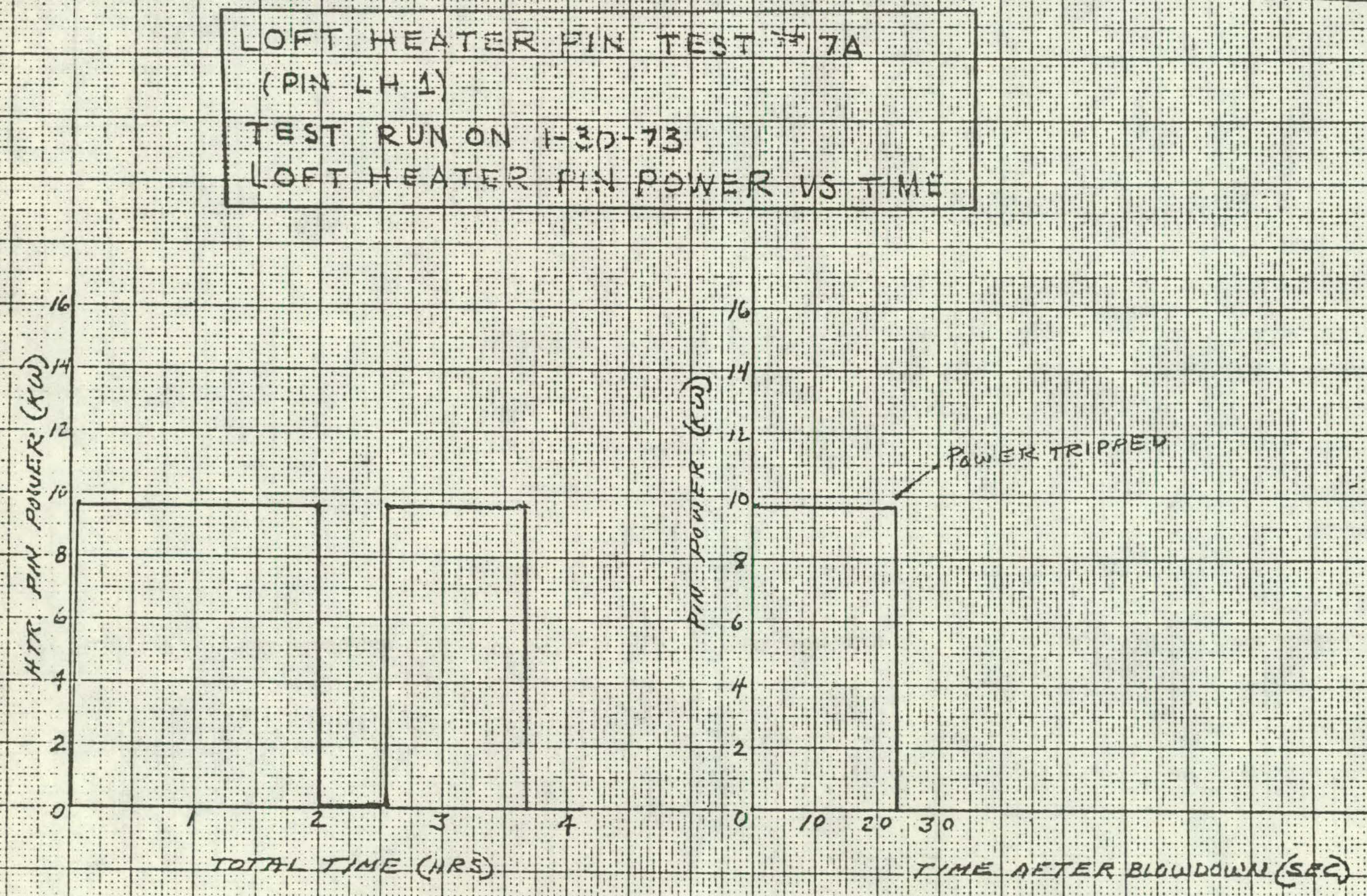
Station	Measurement	Reading	Units
12	Inlet Temperature RTB	—	°F
13	LOFT Vessel Outlet Temp. (TC)	600	°F
14(A)	Inlet Temperature (TC)	550	°F
15	Semiscale Vessel Outlet Temp. (TC)	580	°F
16	Outlet Temperature RTB	—	°F
17	ECC Flow (Turbine)	-----	GPM
18	ECC Vessel Temperature	142	°F
24	System Pressure	2250	PSIG
29	LOFT Heater Clad Temperature 10"	590	°F
30	LOFT Heater Clad Temperature 28"	620	°F
31	LOFT Heater Clad Temperature 43"	630	°F
32	LOFT Heater Clad Temperature 60"	625	°F
33	ECC Fluid Temperature (At Turbine)	68	°F
LOFT Pin	Voltage Current	97 100	Volts Amps
LOFT Pin	TM-TC Monitor TC on Sheath TM-S Monitor TC on Clad	600 645	°F °F


LOFT PIN TEST No. 7A
LOFT HEATER PIN TEST # 7A
(PIN LH 1)
TEST RUN ON 1-30-73
VESSEL PRESSURE VS TIME
SYSTEM PRESSURE (PSIG)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
80
TIME AFTER BLOWDOWN (SEC)

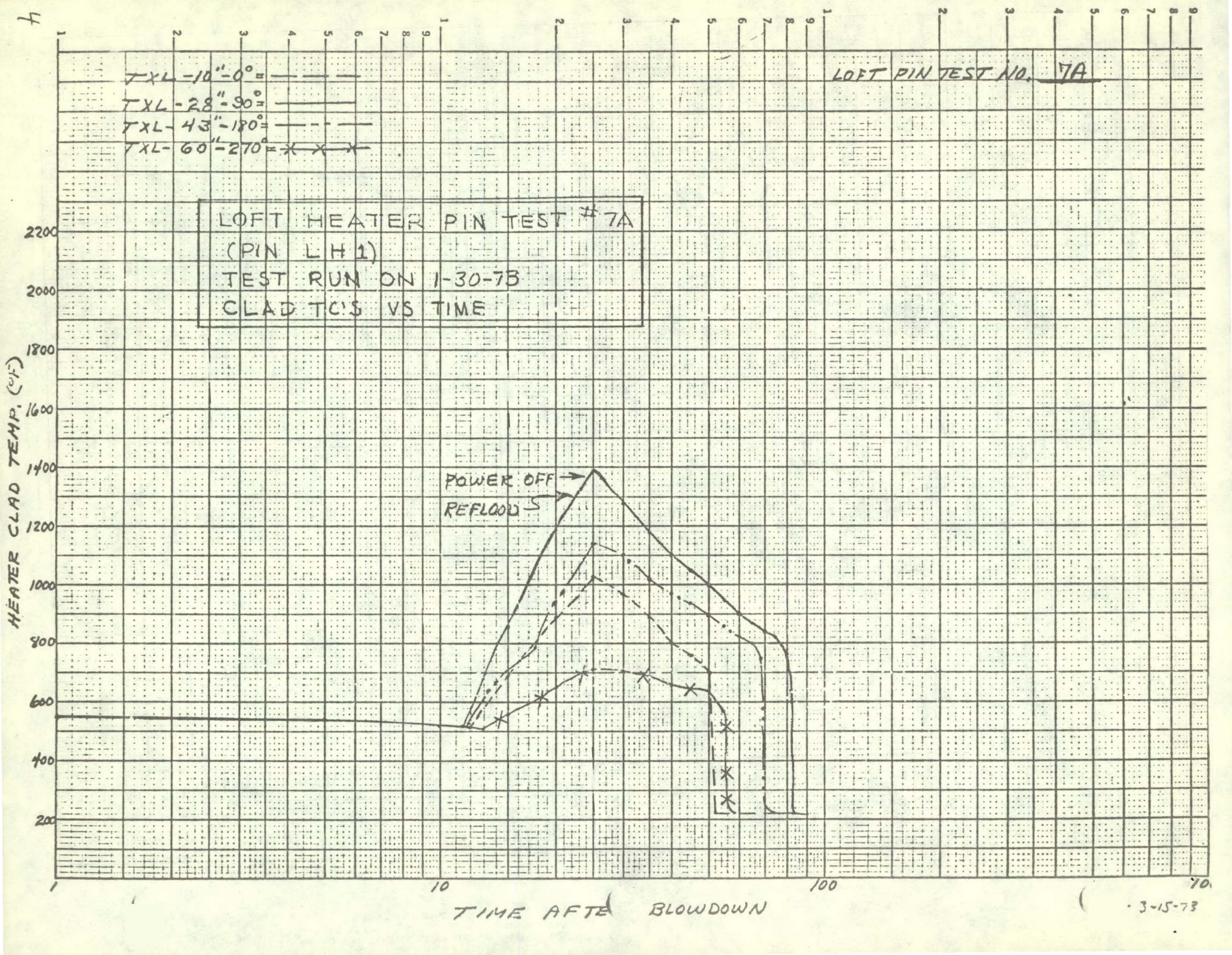
MFJ 3-14-73

K•E 10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM. MADE IN U.S.A.
KEUFFEL & ESSER CO.

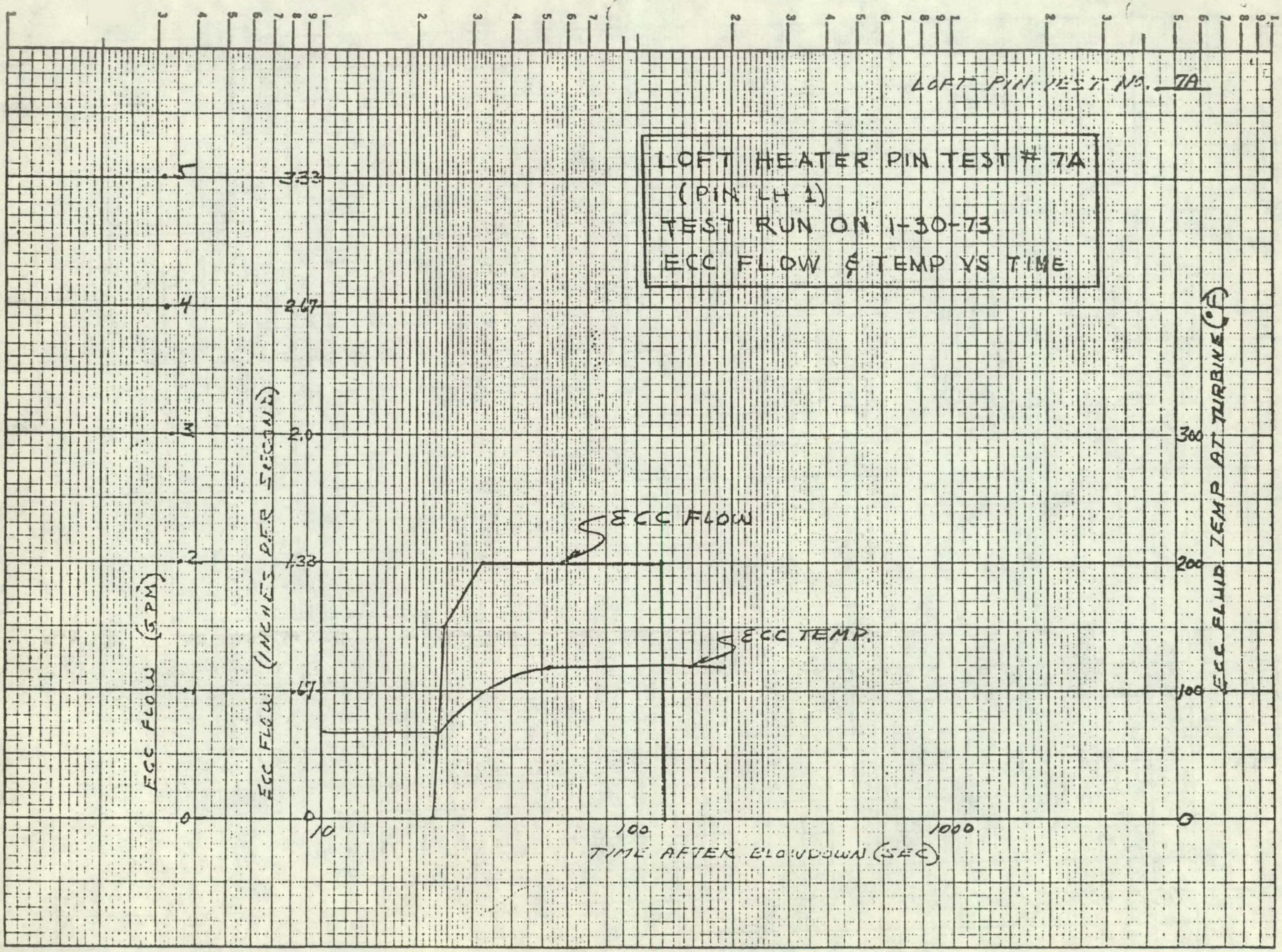
LOFT PIN TEST NO. 7A



3


4
LOFT PIN TEST NO. 7A
TXL-10"-0° = — — —
TXL-28"-90° = ————
TXL-43"-180° = — - - —
TXL-60"-270° = -x-x-x-
LOFT HEATER PIN TEST #7A
(PIN LH 1)
TEST RUN ON 1-30-73
CLAD TC'S VS TIME
POWER OFF
REFLOOD
HEATER CLAD TEMP. (°F)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
100
TIME AFTER BLOWDOWN
3-15-73

K&E SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS



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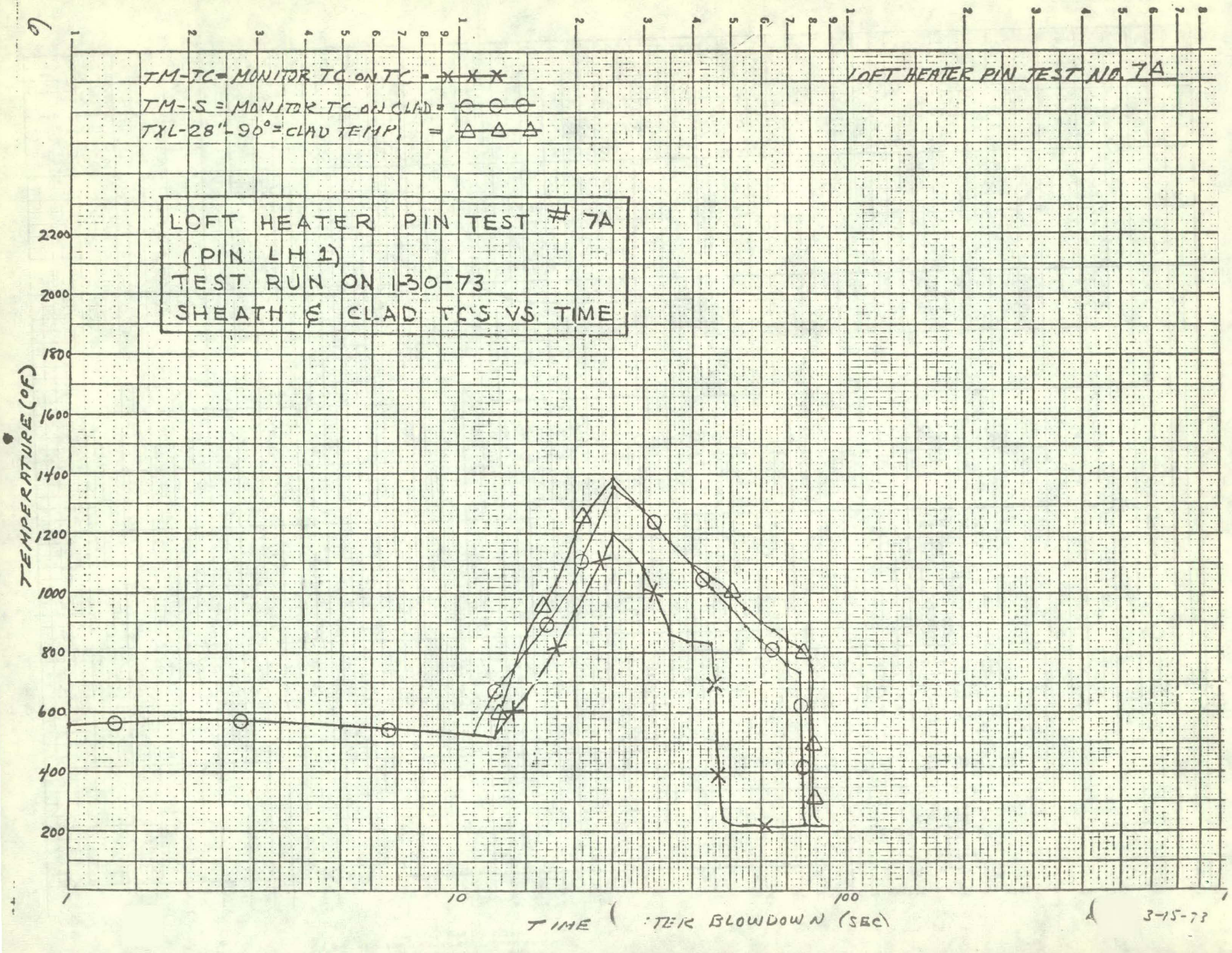
MFS 3-14-73


TM-TC = MONITOR TC ON TC = X X X
TM-S = MONITOR TC ON CLAD = O O O
TXL-28"-90° = CLAD TEMP. = △ △ △
LOFT HEATER PIN TEST NO. 7A
LOFT HEATER PIN TEST # 7A
(PIN LH 1)
TEST RUN ON 1-30-73
SHEATH & CLAD TC'S VS TIME
TEMPERATURE (°F)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
100
TIME (TER BLOWDOWN (SEC)
3-15-73

TEST DATA FOR

LOFT HEATER PIN LH-1

TEST NUMBER 8

1/31/73

1-31-73

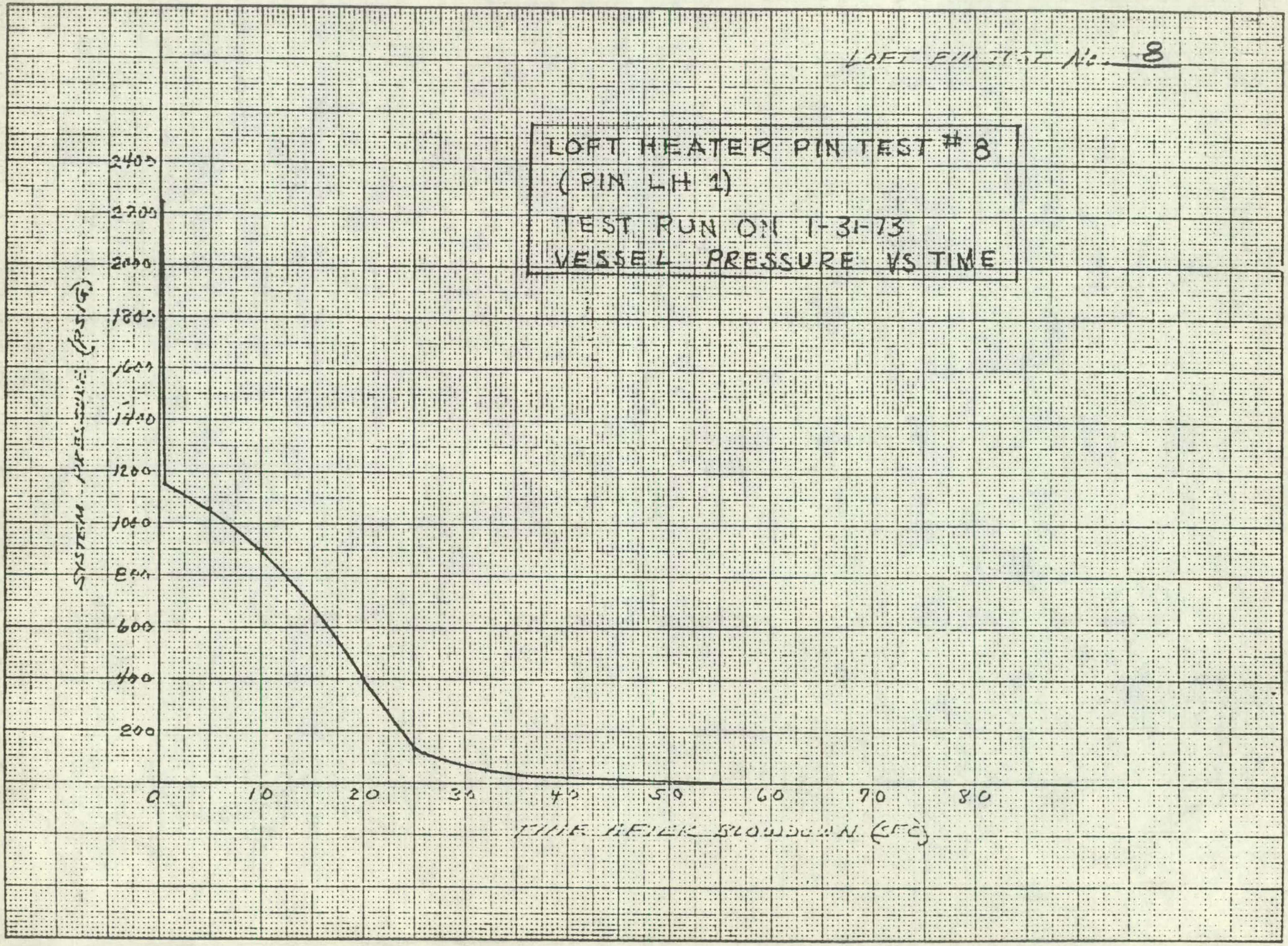
LOFT PIN TEST NO. 8

INSTRUMENT READINGS PRIOR TO BLOWDOWN

Station	Measurement	Reading	Units
12	Inlet Temperature RTB	—	°F
13	LOFT Vessel Outlet Temp. (TC)	600	°F
14(A)	Inlet Temperature (TC)	550	°F
15	Semiscale Vessel Outlet Temp. (TC)	590	°F
16	Outlet Temperature RTB	—	°F
17	ECC Flow (Turbine)	-----	GPM
18	ECC Vessel Temperature	148	°F
24	System Pressure	2240	PSIG
29	LOFT Heater Clad Temperature 10"	600	°F
30	LOFT Heater Clad Temperature 28"	620	°F
31	LOFT Heater Clad Temperature 43"	625	°F
32	LOFT Heater Clad Temperature 60"	620	°F
33	ECC Fluid Temperature (At Turbine)	70	°F
LOFT Pin	Voltage Current	96 98	Volts Amps
LOFT Pin	TM-TC Monitor TC on Sheath TM-S Monitor TC on Clad	610 660	°F °F

2

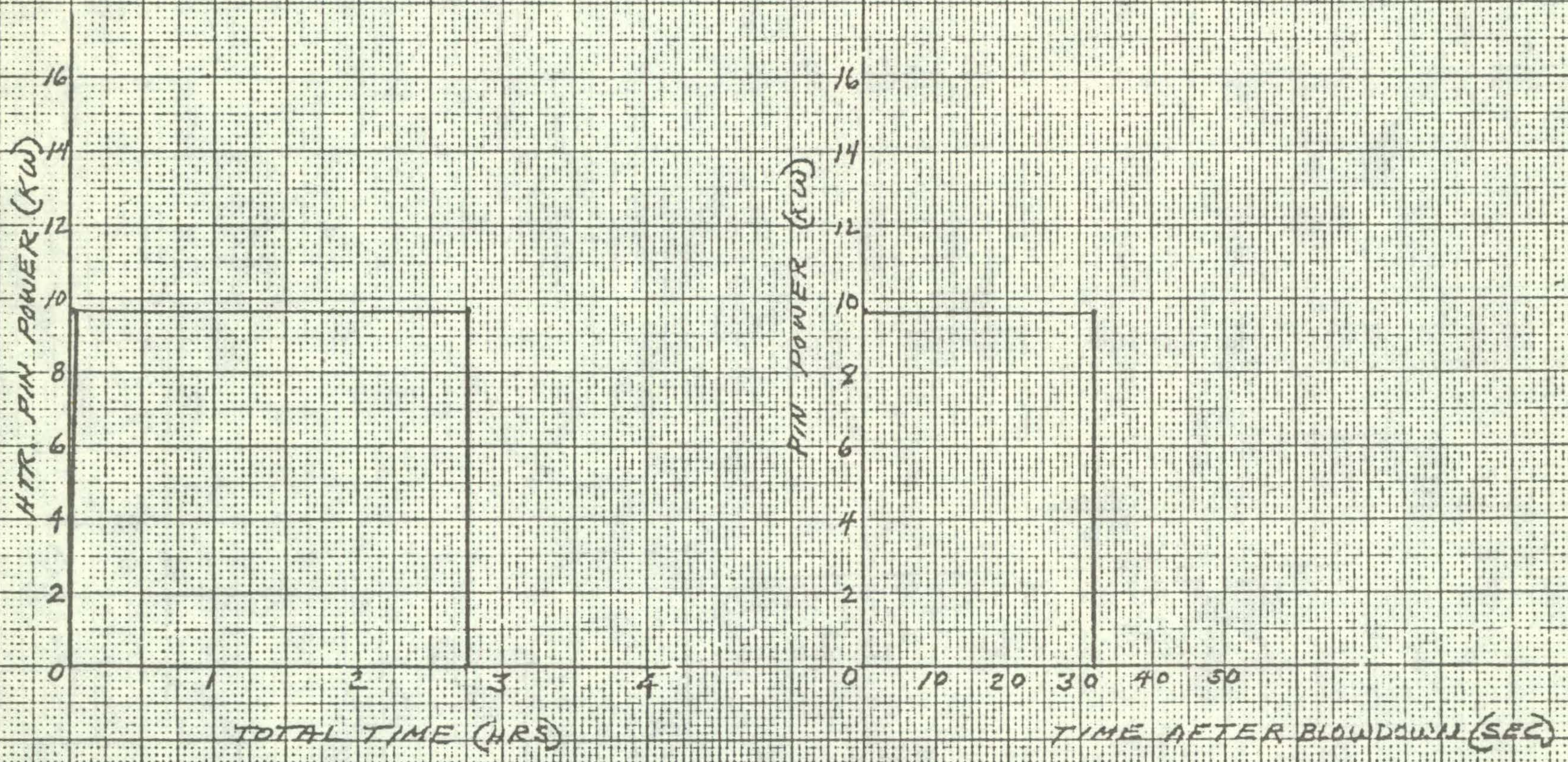
KEUFFEL & ESSER CO.



MFJ 3-14-73

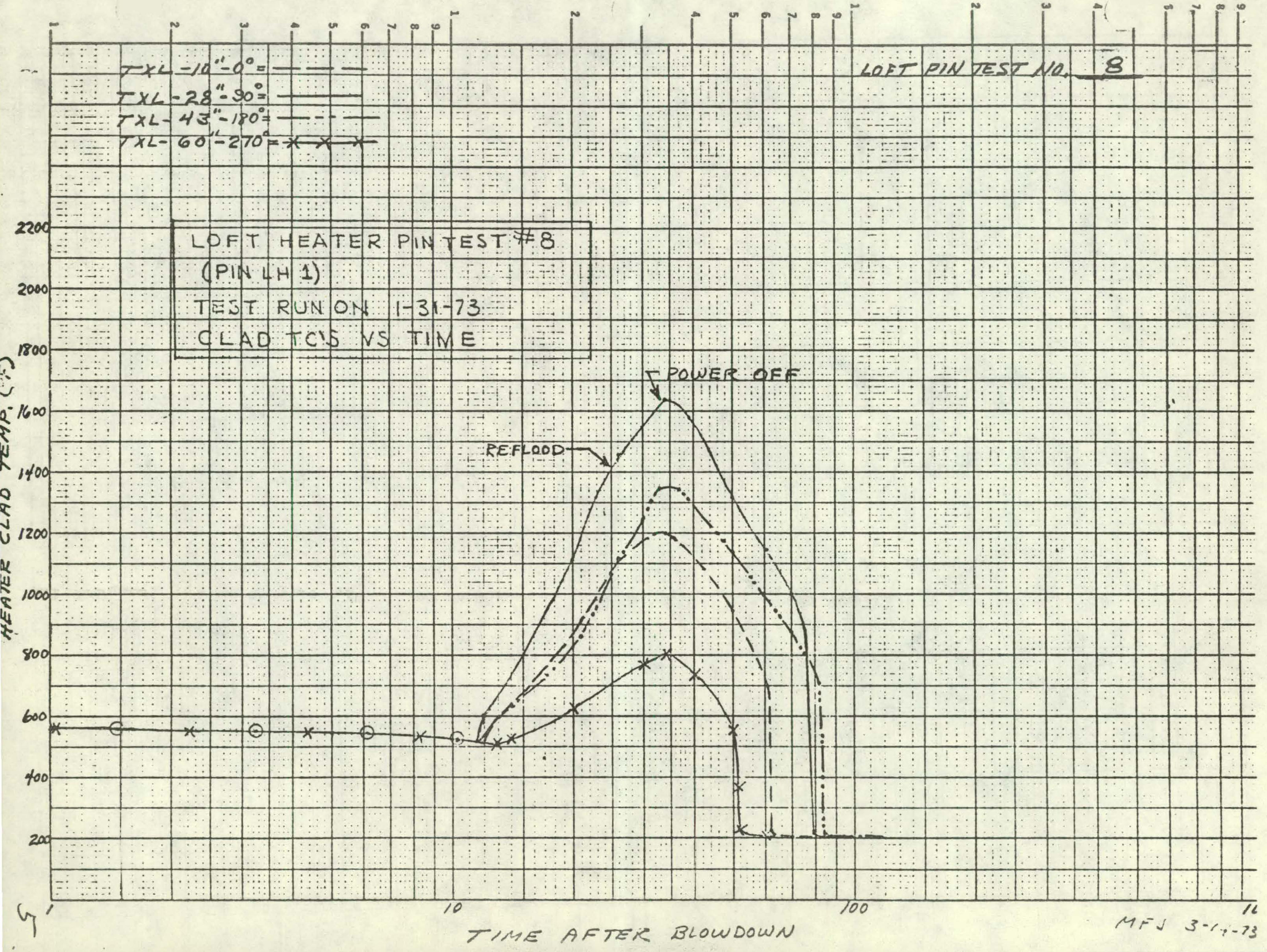
LOFT PIN TEST NO. 8

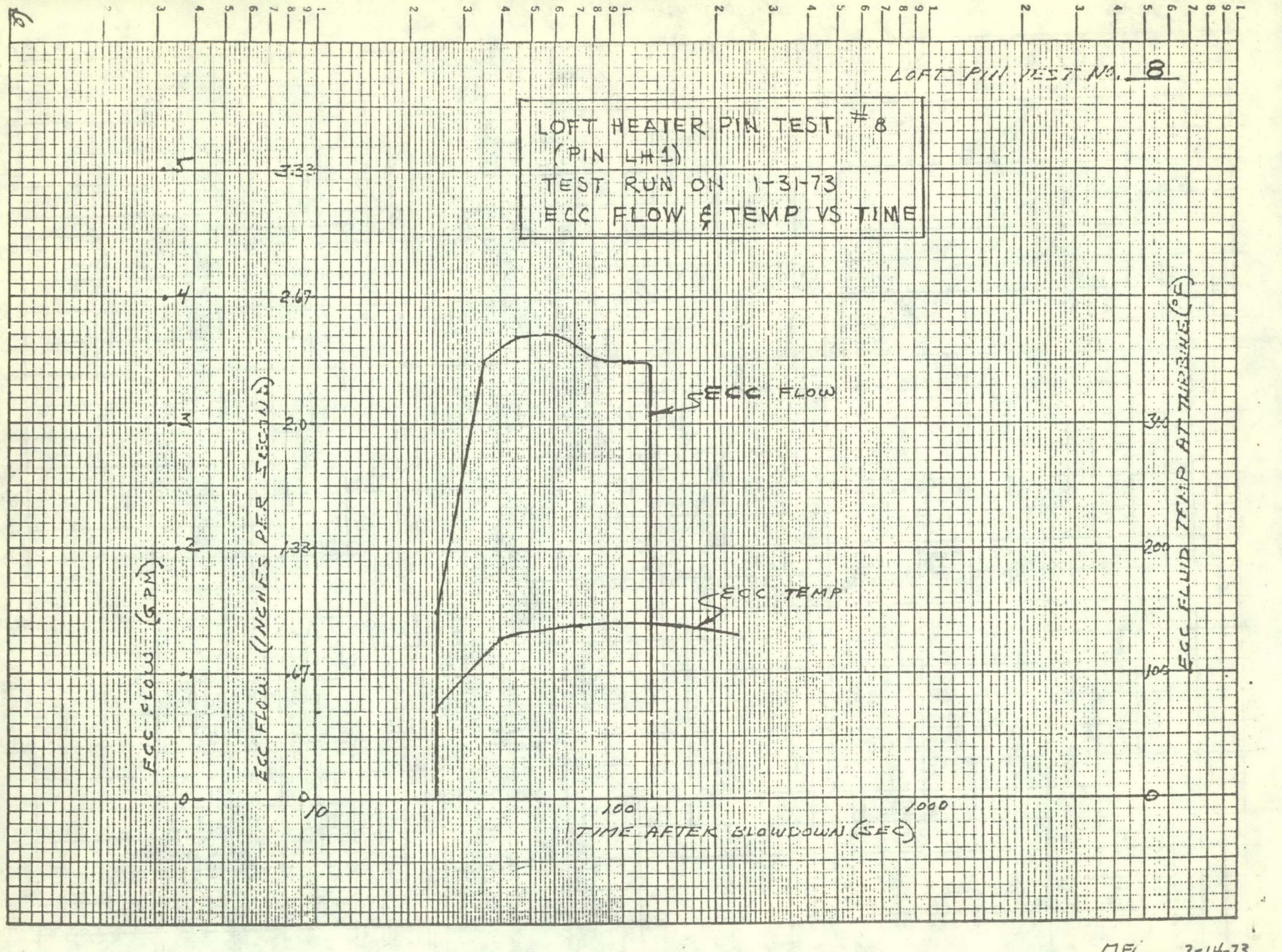
LOFT HEATER PIN TEST #3
(PIN LH 1)
TEST RUN ON 1-31-73
LOFT HEATER PIN POWER VS TIME



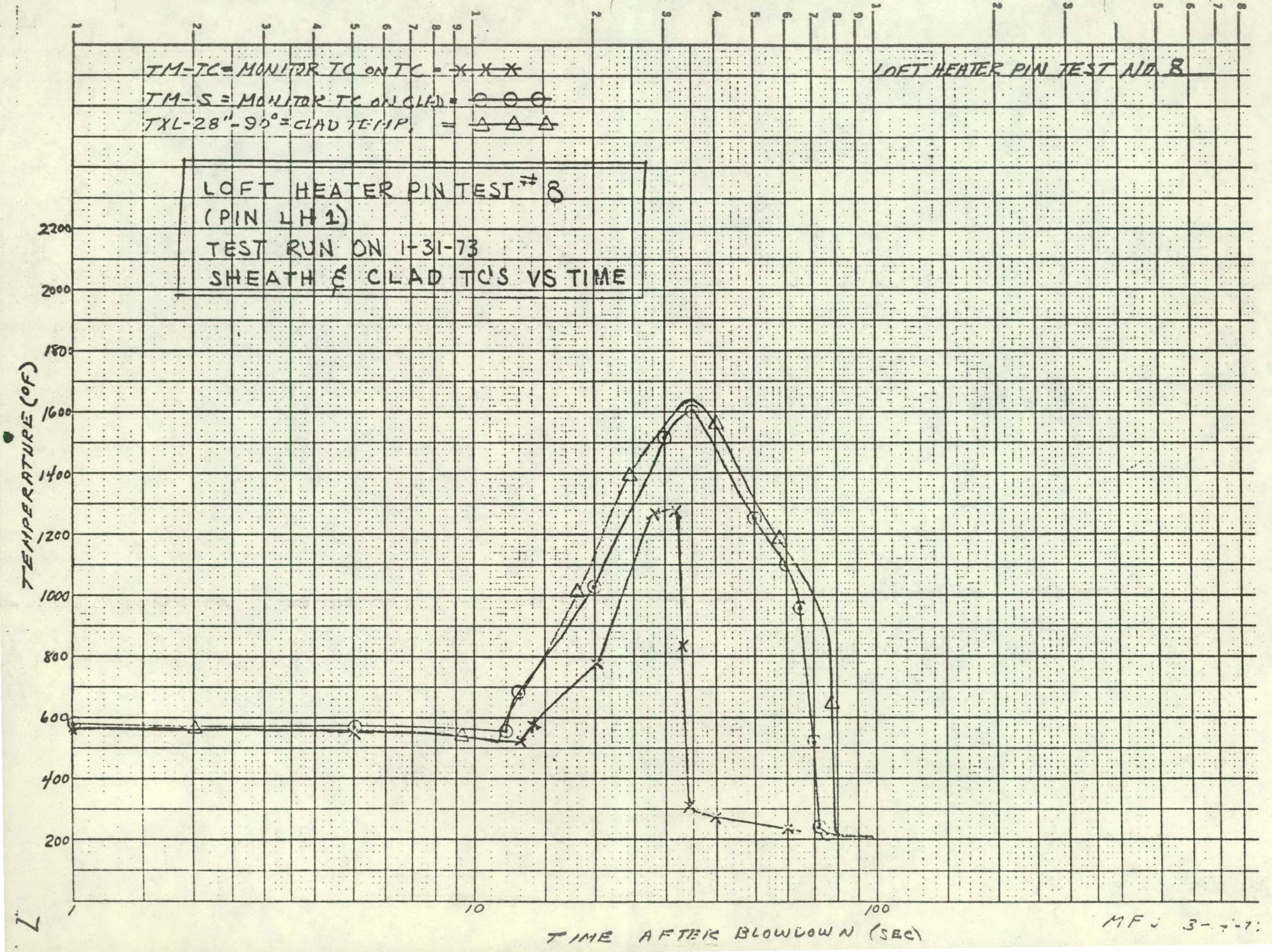
MA 2-14-73

KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 140 DIVISIONS





LOFT PIII TEST NO. 8
LOFT HEATER PIN TEST #8
(PIN LH-1)
TEST RUN ON 1-31-73
ECC FLOW & TEMP VS TIME
ECC FLOW
ECC TEMP
ECC FLOW (GPM)
ECC FLOW (INCHES PER SECOND)
ECC FLUID TEMP AT TURBINE (°F)
TIME AFTER BLOWDOWN (SEC)
10
100
1000
0
1
2
3
4
5
.67
1.33
2.0
2.67
3.33
105
200
0
MF
3-14-73


TM-TC = MONITOR TC ON TC = X X X
TM-S = MONITOR TC ON CLAD = O O O
TXL-28"-90° = CLAD TEMP. = △ △ △
LOFT HEATER PIN TEST NO. 8
LOFT HEATER PIN TEST # 8
(PIN LH 1)
TEST RUN ON 1-31-73
SHEATH & CLAD TC'S VS TIME
TEMPERATURE (°F)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
100
TIME AFTER BLOWDOWN (SEC)

MFJ 3-?-7?

TEST DATA FOR

LOFT HEATER PIN LH-1

TEST NUMBER 9

2/2/73

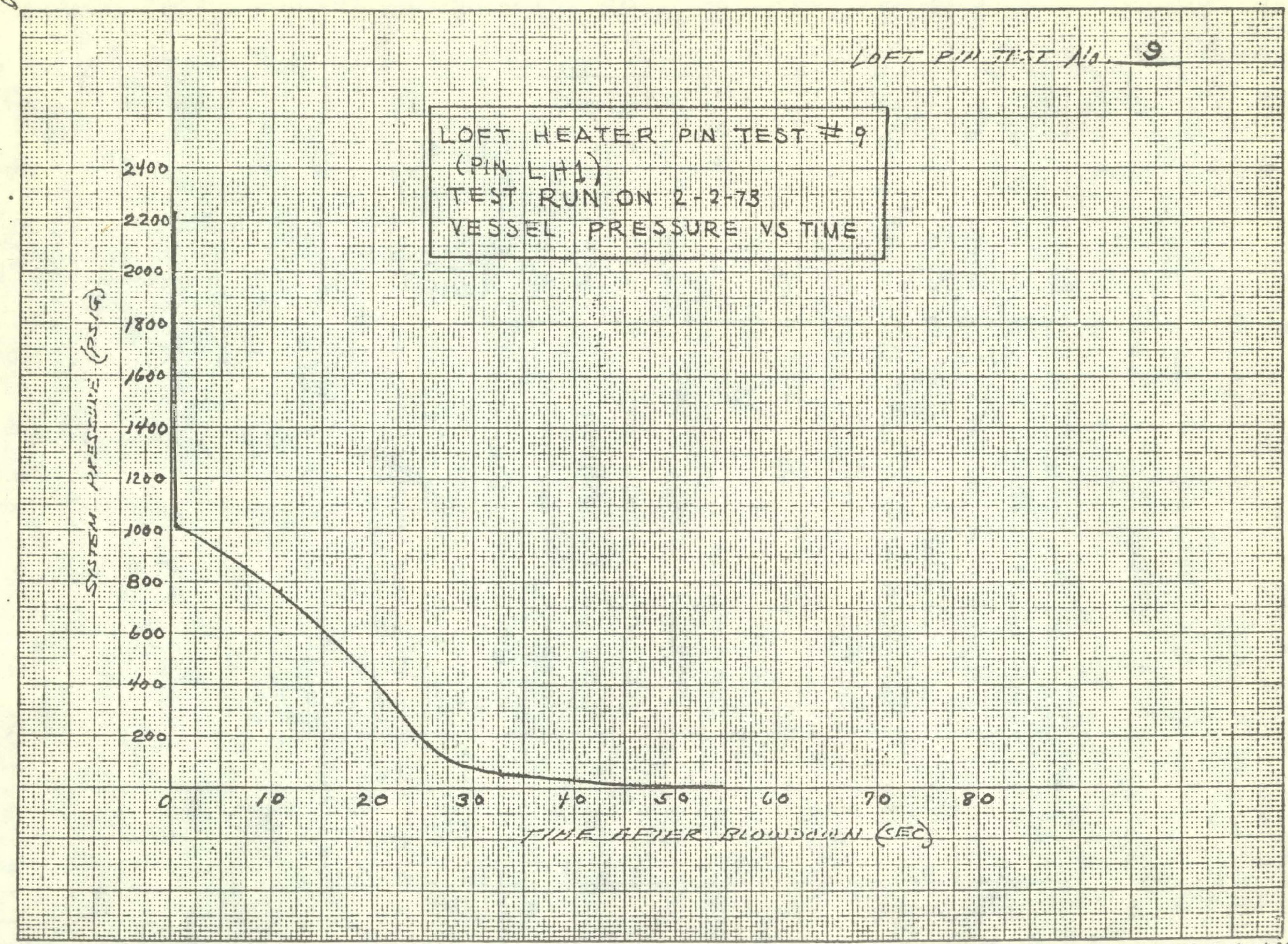
8

2-2-73

LOFT PIN TEST NO. 9

INSTRUMENT READINGS PRIOR TO BLOWDOWN

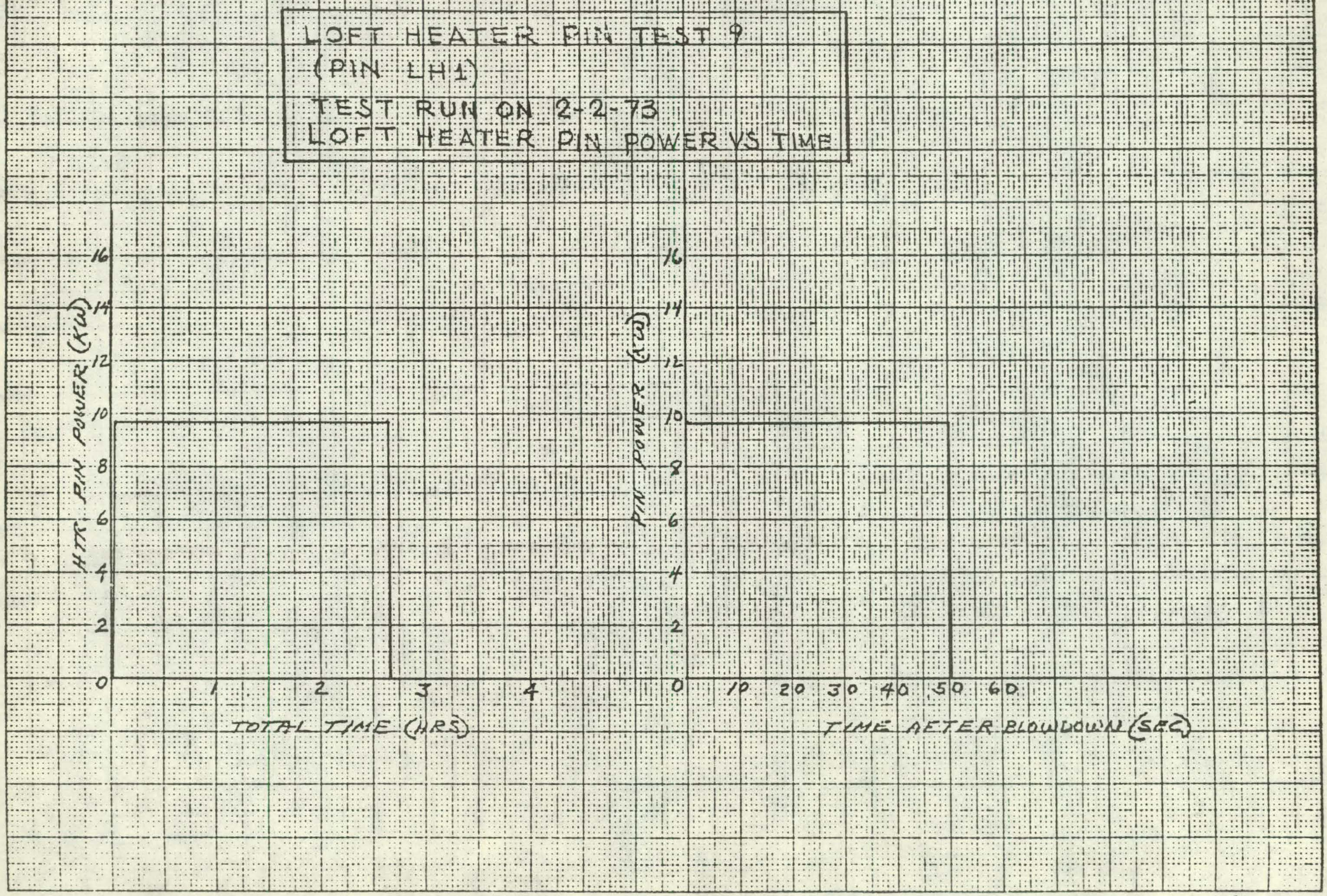
Station	Measurement	Reading	Units
12	Inlet Temperature RTB	—	°F
13	LOFT Vessel Outlet Temp. (TC)	600	°F
14(A)	Inlet Temperature (TC)	550	°F
15	Semiscale Vessel Outlet Temp. (TC)	590	°F
16	Outlet Temperature RTB	—	°F
17	ECC Flow (Turbine)	-----	GPM
18	ECC Vessel Temperature	130	°F
24	System Pressure	2225	PSIG
29	LOFT Heater Clad Temperature 10"	610	°F
30	LOFT Heater Clad Temperature 28"	620	°F
31	LOFT Heater Clad Temperature 43"	620	°F
32	LOFT Heater Clad Temperature 60"	610	°F
33	ECC Fluid Temperature (At Turbine)	78	°F
LOFT Pin	Voltage Current	97 99	Volts Amps
LOFT Pin	TM-TC Monitor TC on Sheath TM-S Monitor TC on Clad	580 640	°F °F


LOFT PIN TEST No. 9
LOFT HEATER PIN TEST # 9
(PIN LH1)
TEST RUN ON 2-2-73
VESSEL PRESSURE VS TIME
SYSTEM PRESSURE (PSIG)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
80
TIME AFTER BLOWDOWN (SEC)

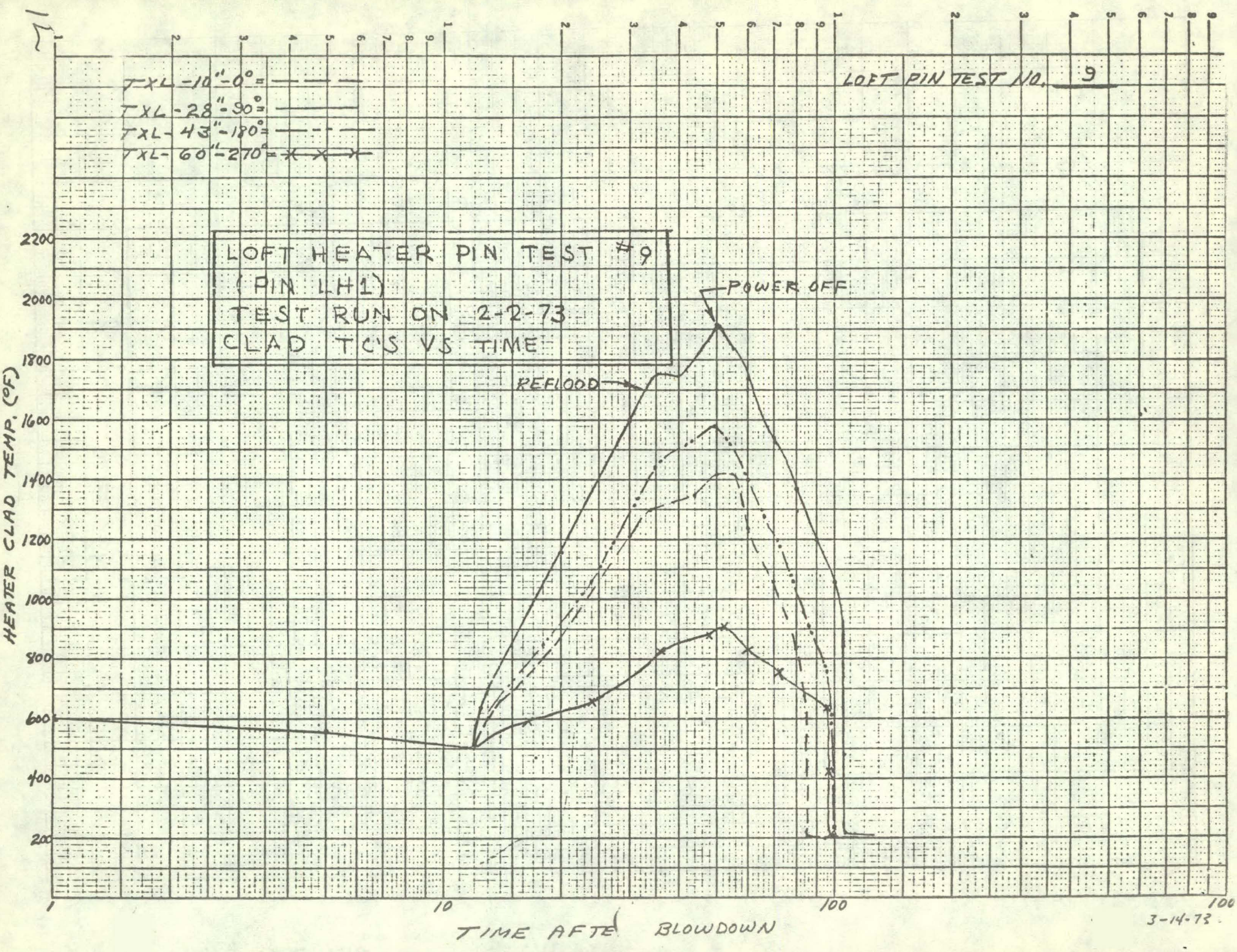
MFJ-3-14-73

K•E 10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM. MADE IN U.S.A.
KEUFFEL & ESSER CO.

LOFT PIN TEST NO. 9

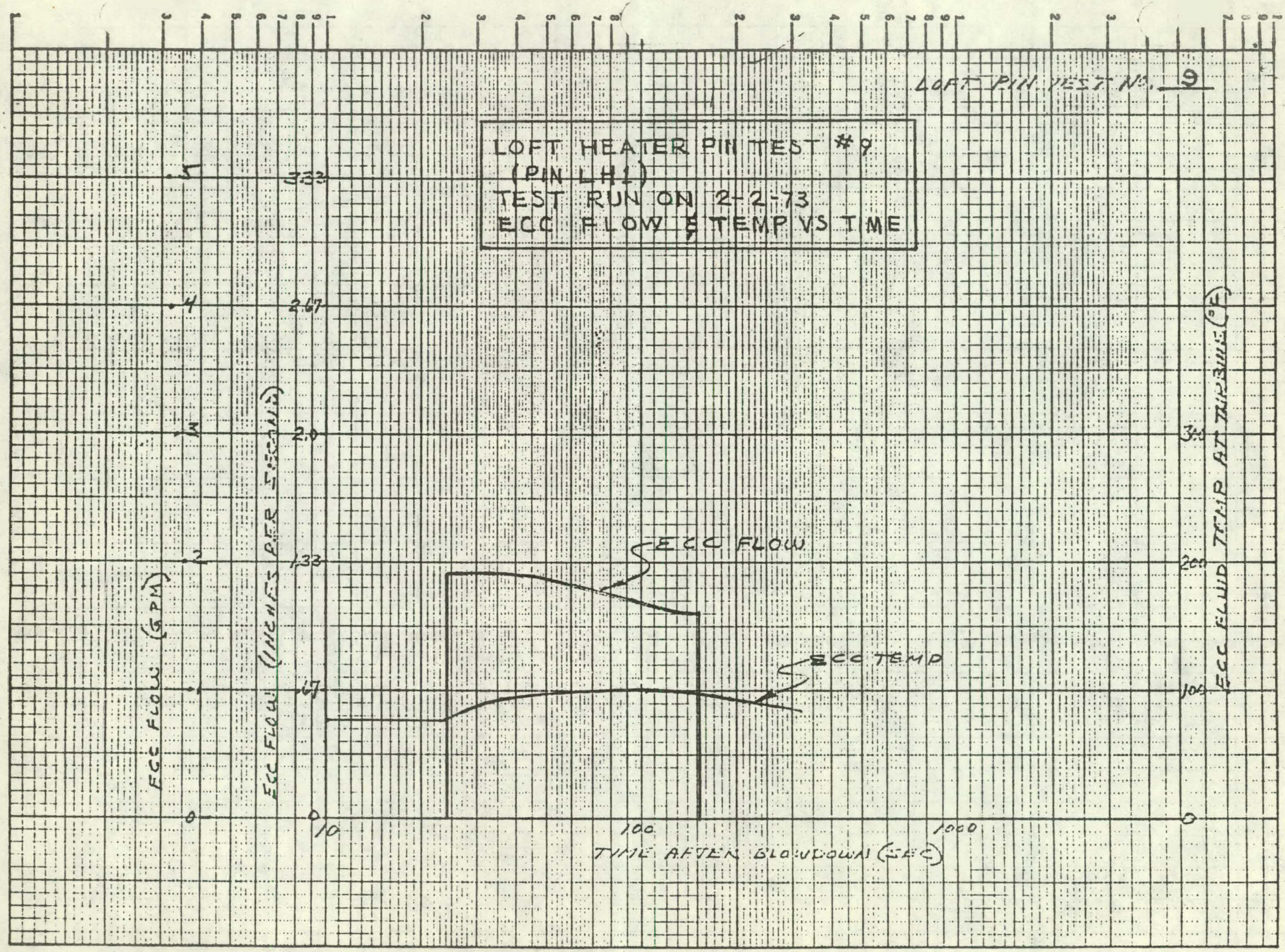


MFJ 3-1-73



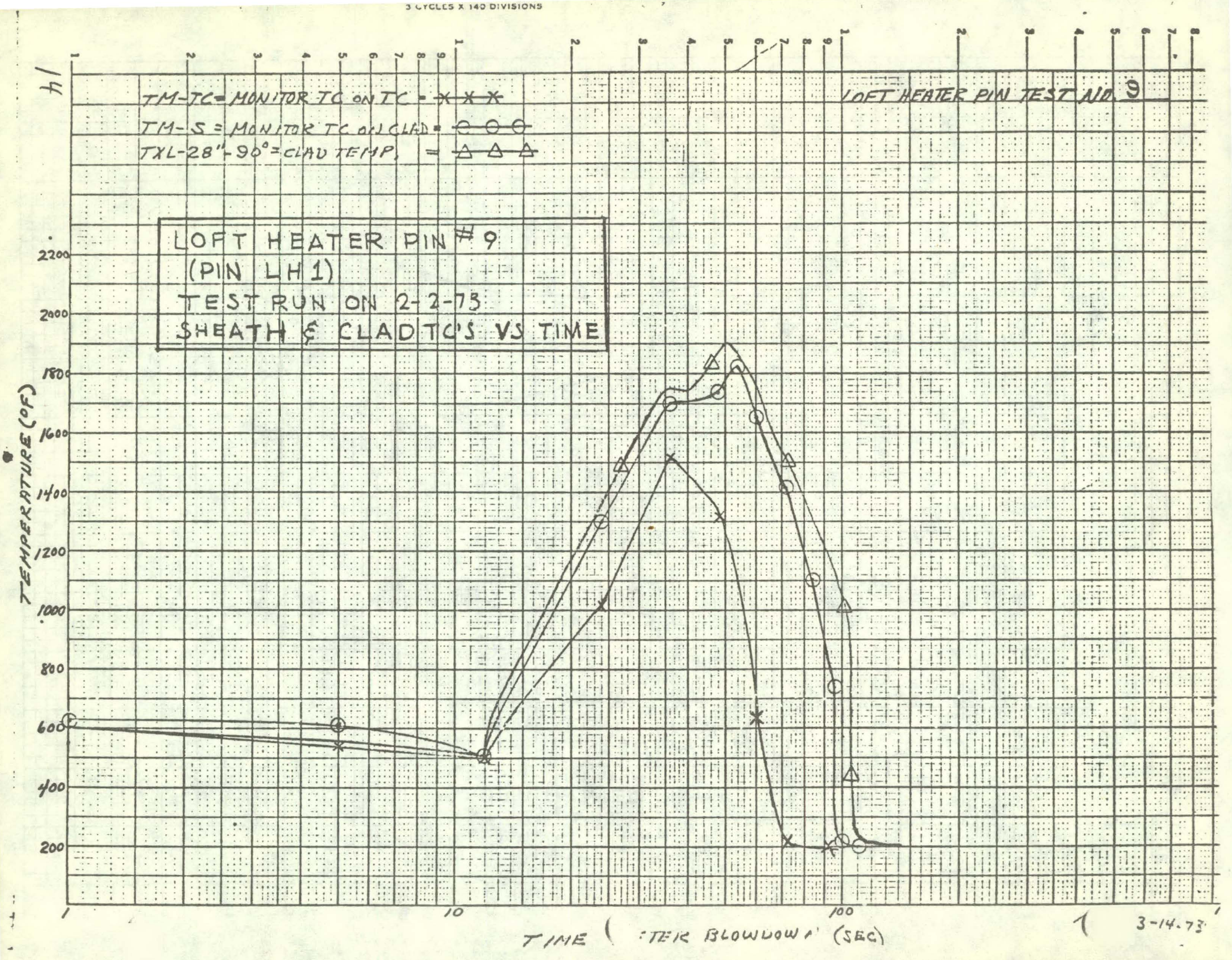
LOFT PIN TEST NO. 9
TXL-10"-0° =
TXL-28"-90° =
TXL-43"-180° =
TXL-60"-270° =
LOFT HEATER PIN TEST #9
(PIN LH1)
TEST RUN ON 2-2-73
CLAD TC'S VS TIME
POWER OFF
REFLOOD
HEATER CLAD TEMP. (°F)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
100
100
TIME AFTER BLOWDOWN
3-14-73

K•Σ SEMI-LOGARITHMIC KEUFFEL & ESSER CO. MADE IN U.S.A. 4 CYCLES X 70 DIVISIONS



MFJ 3-14-73

13


14
TM-TC = MONITOR TC ON TC = X X X
TM-S = MONITOR TC ON CLAD = O O O
TXL-28"-90° = CLAD TEMP. = △ △ △
LOFT HEATER PIN TEST NO. 9
LOFT HEATER PIN #9
(PIN LH 1)
TEST RUN ON 2-2-73
SHEATH & CLAD TC'S VS TIME
TEMPERATURE (°F)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
100
TIME (AFTER BLOWDOWN) (SEC)
3-14-73

APPENDIX D

Temperature and Blowdown Parameter Data

For Heater Rod LH-4

(Nine Tests)

LOFT HEATER PIN TEST REPORT NO. 2

1.0 INTRODUCTION

This report covers the testing of LOFT heater pin No. LH-4. This heater pin was subjected to blowdown and reflood tests that were designated as qualification tests for the heater itself and for the method of attaching thermocouples to the heater clad material. These tests were conducted for the LOFT Program under authorization of GWA No. 58110-810-026 in accordance with test plan TC 6.3, "Heater Rod Blowdown and Reflood Tests" and changes thereto as transmitted by Mes-7-73, "Heater Rod Blowdown Test Plan Change", dated February 21, 1973. Mr. R. H. Meservey of the Instrument and Controls Equipment Branch was the coordinating authority for these tests and approved the test plan.

Eleven tests (10 through 20) were specified in this phase of the test program. The tests are listed in Table 1 with the major test parameters:

Table 1
LOFT HEATER TEST PARAMETERS

Test No.	System Pressure at Blowdown (psig)	System Temperature at Blowdown (°F)	Heater Clad Temperature at Reflood (°F)	Comments
10	2250	600	1100 + 200 − 100	Inspect after test
11	2250	600	1500 + 0 − 100	
12	2250	600	1500 + 0 − 100	Inspect after test
13	2250	600	1500 + 0 − 100	
14	2250	600	1500 + 0 − 100	
15	2250	600	1500 + 0 − 100	Inspect after test
16	2250	600	1700 + 200 − 100	
17	2250	600	1700 + 200 − 100	Inspect after test
18	2250	600	1700 + 200 − 100	
19	2250	600	1700 + 200 − 100	
20	2250	600	1700 + 200 − 100	Inspect after test

This report contains a brief summary of the tests conducted, a description of the hardware involved and a discussion of the test results. The Appendix (Section 4.0) to this report contains plots constructed from the data charts. Also included is a typical data chart showing heater clad temperature vs. time after blowdown for Test No. 14.

2.0 SUMMARY

Nine of the eleven tests were completed. The heater element failed late in the reflood cycle of the ninth test (No. 18) preventing any further testing of the rod. Fifteen percent power (9.7 KW) was maintained on the rod during each run until 6 seconds following blowdown. At this point, the power was reduced to 5 percent (3.2 KW) on the first seven tests (10 through 16) and to 10 percent (6.4 KW) on the remaining tests requiring a 1700°F clad temperature at reflood. Five percent decay power was not sufficient to maintain a cladding heat-up rate of 20°F per second at the higher temperatures. On Test No. 16, for instance, the clad temperature leveled off at 1600°F so ECC was initiated at that point.

Control of the ECC flood rate (.2 in/sec) was very difficult throughout the test series and although three different control valves were used during the series, the problem was never completely eliminated and manual adjustements were necessary. The flooding rate on Test No. 10 was only approximately 10 percent of the planned rate and was not adequate to turn the clad temperature over before reaching the power trip point. Tests 11 through 16 all successfully quenched the pin with 5 percent decay power on. Test No. 17 (at 10 percent decay power) tripped the power at 1750°F before quenching of the pin occurred. The trip point was inadvertantly set at 1750°F instead of 1850°F. Test No. 18 had the pin well into the quench period (the 60" Thermocouple had already quenched) when failure of the pin occurred.

Table 2 summarizes the major events of the tests.

Table 2
MAJOR EVENTS OF LOFT PIN TESTS

Test No.	Clad Temp. at Reflood (°F)	Time of Reflood After Blowdown (sec)	Max. Clad Temp. (at 28" TC) (°F)	Time After Blowdown of Max. Clad Temp. (sec)	Power Off Time After Blowdown (sec)	Quench Time After Blowdown (at 28" TC) (sec)	Decay Power Level (%)
10	1180	42	1310	56	52	380	5
11	1400	58	1410	61	216	182	5
12	1400	62	1420	63	198	170	5
13	1400	67	1410	70	182	170	5
14	1395	66	1405	69	141	130	5
15	1400	69	1412	72	144	135	5
16	1600	255	1605	262	420	400	5
17	1700	65	1750	122	122	150	10
18	1700	66	1725	71	*138	157	10

* Heater Element Failed

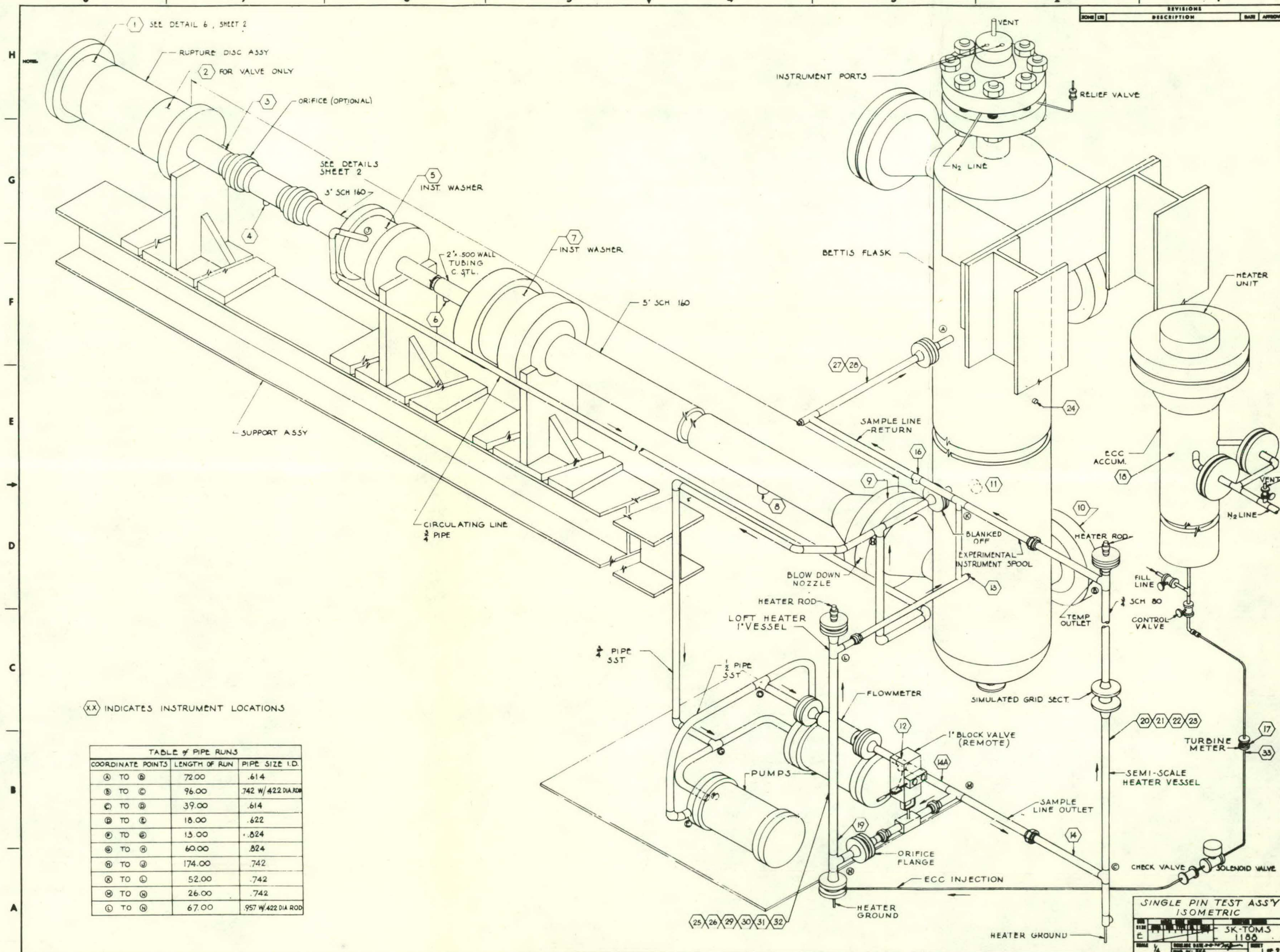


TABLE of PIPE RUNS		
COORDINATE POINTS	LENGTH OF RUN	PIPE SIZE I.D.
Ⓐ TO Ⓑ	72.00	.614
Ⓑ TO Ⓒ	96.00	.742 W/ .422 DIA ROD
Ⓒ TO Ⓓ	39.00	.614
Ⓓ TO Ⓔ	18.00	.622
Ⓕ TO Ⓖ	13.00	.824
Ⓖ TO Ⓗ	60.00	.824
Ⓗ TO Ⓙ	174.00	.742
Ⓚ TO Ⓛ	52.00	.742
Ⓜ TO Ⓝ	26.00	.742
Ⓛ TO Ⓝ	67.00	.957 W/ .422 DIA ROD

FIGURE 1

The heater rod was removed from the test vessel at the specified intervals and inspected by I&CE and QA personnel. All thermocouple welds remained intact although some cracking was evident. The cladding thermocouple located 10" from the bottom of the heater failed to operate following Test No. 16, but the problem was later found to be outside the pressurized environment. Inspection of the rod following Test No. 17 revealed a change in resistance through the rod from .8993 ohms (before testing began) to .9103 ohms. A bend in the rod at 30 inches and considerable "sagging" of the TC cables between welds was also present. Final inspection of the rod following its failure indicated a "hot spot" occurred at the 30" location.

An increase in the flooding rate during reflood of Test 18 from 2 inches per second to 2.99 inches per second corresponds in time with the pin failure and could be a contributing factor along with the degradation from the previous high temperature tests indicated by the increase in coil resistance.

3.0 DISCUSSION

3.1 Facility

The single pin facility located in Building 609 is shown in Figure 1. In its present condition, this facility is capable of accepting heater pins at three locations. The LOFT heater test vessel is made up of a length of 1" Schedule 80 pipe with a special flanged head at the top which provides access for instrument leads and quick removal of the heater pin for inspection without removing the leads. Guide pins are located at intervals along the length of the vessel to hold the heater centered within the vessel. Water is circulated through the LOFT heater vessel at a minimum rate of 1 gpm during operation to allow the pin to be operated at 15% power (9.7 KW). This flow is controlled by an orifice at the inlet to the vessel. The remainder of the total flow in the system is directed through the Semiscale heater test vessel which contains the heater used to bring the system up to operating temperature. ECC water is injected into the LOFT heater vessel from the bottom at a pre-set flow rate. A block valve is closed immediately upstream of the vessel inlet just prior to ECC injection to insure flooding of the vessel only.

Blowdown of the system is accomplished through a rupture disc assembly on a nozzle extending from the base of the Bettis flask as shown in Figure 1.

3.2 Specimen Description

The test specimen was a grounded type heater rod furnished by the LOFT Program (Serial No. LH-4). This rod has four laser welded, titanium sheathed, type K thermocouples located 10, 28, 43 and 60 inches from the bottom end cap. In addition to the above thermocouples, the rod contains two monitoring thermocouples. One is attached, by spot welding, to the titanium thermocouple sheath immediately behind the titanium spade junction and the other is located adjacent to it on the Zircaloy cladding of the heater rod. These thermocouples are located 28" from the bottom of the heater. Total length of the heater clad was 85-1/6 inches. Resistance of the coil before testing was .8993 ohms. A power profile of the heater is shown in Figure 2.

3.3 Instrumentation

In addition to the thermocouples on the test heater, several instruments were used throughout the system for control of the test. Instrument locations are shown in Figure 1 by circled numbers. The following list indicates the measurements that were taken and the location of the measurement on the test loop.

Measurement	Station
Inlet Temperature	12
LOFT Vessel Outlet Temperature (Fluid)	13
Semiscale Vessel Inlet Temperature	14A
Semiscale Vessel Outlet Temperature	15
Outlet Temperature (RTB)	16
ECC Flow (Turbine)	17
ECC Vessel Temperature	18
System Pressure	24
LOFT Heater Clad Monitor TC	25
LOFT Heater Sheath Monitor TC	26
LOFT Heater Clad Temperature (10")	29
LOFT Heater Clad Temperature (28")	30
LOFT Heater Clad Temperature (43")	31
LOFT Heater Clad Temperature (60")	32
ECC Fluid Temperature (at Turbine)	33
Voltage and Current	LOFT Pin
Voltage and Current	S.S. Pin

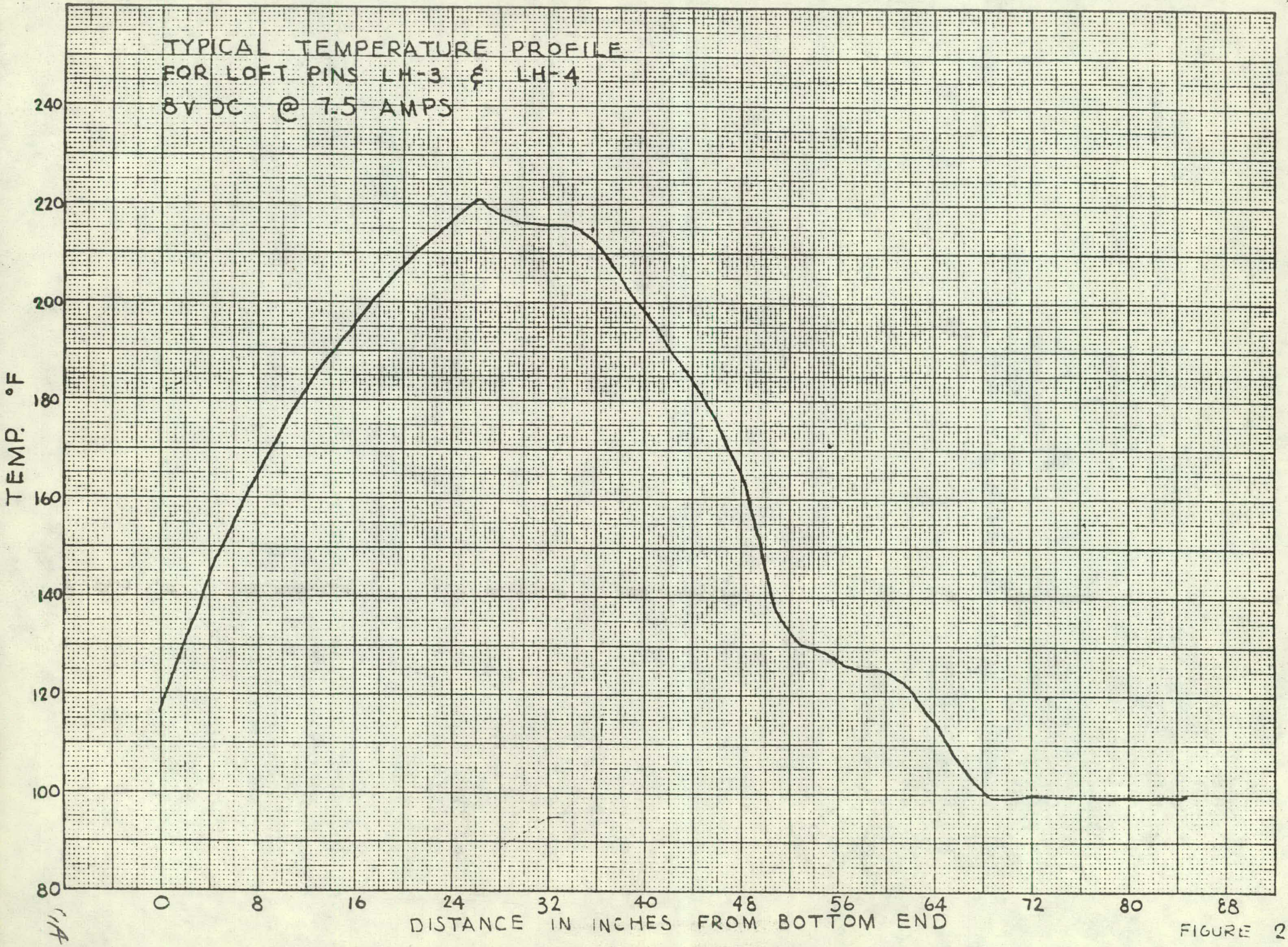
The thermocouples used for fluid temperature measurement are chromel alumel exposed junction type and have a range of 0 - 2000°F with an accuracy of ±1% of full scale.

The system pressure is measured with a Norwood pressure transducer having a range of 0 - 2500 psig with an accuracy of ±1% of full scale.

The turbine meter used for ECC flow is ranged from 0 - 1 gpm with an accuracy of ±1% of full scale.

3.4 Data Acquisition

All data were recorded on strip chart recorders except the back-up inlet and outlet temperatures (RTB's) and the power to the Semiscale heater. These data were logged in the operator's log at specified intervals. Plots of the test data were made from the strip charts and are included in Section 4.0 (Appendix) of this report.



TYPICAL TEMPERATURE PROFILE
FOR LOFT PINS LH-3 & LH-4
8V DC @ 7.5 AMPS
TEMP. °F
240
220
200
180
160
140
120
100
80
0
8
16
24
32
40
48
56
64
72
80
88
DISTANCE IN INCHES FROM BOTTOM END

FIGURE 2

3.5 Test Procedure

The specified heater clad temperatures at ECC injection for these tests were 1100°F $^{+200}_{-100}$, 1500°F $^{+0}_{-100}$, and 1700°F $^{+200}_{-100}$. The tests were conducted in accordance with the following basic steps. A detailed operation procedure is followed during test operation to assure that these steps are followed:

1. Check out all instrumentation.

2. Fill system liquid full with "mixed" water in accordance with the approved water chemistry procedure.

3. ECC accumulator should be pressurized to 200 psig and set at 2 in/sec flooding rate for the LOFT vessel. ECC water temperature in the accumulator must be maintained at 130°F.

4. Start pumps and circulate water through system with 1-inch block valve open.

5. Bring system pressure up to 2250 psig and temperature up to 600°F simultaneously while maintaining a subcooled condition. Maintain an inter-disc pressure as required to prevent premature rupture of the upstream disc. NOTE: Do not exceed 620°F fluid temperature at outlet of Semiscale heater.

6. Use up to 60 KW on the Semiscale heater to reach test conditions. NOTE: Both heaters in the loop must have clad thermocouples connected to a high temperature trip. The following settings are required for each heater:

   (a) Semiscale 1300°F
   (b) LOFT Heater 200°F above specified clad temperature

7. Maintain a 15% power level (9.75 KW) on the LOFT pin throughout heat-up.

8. When steady-state has been reached at 600°F LOFT pin water outlet temperature, start data tapes and allow warm-up of 1.5 minutes.

9. Initiate rupture and stop pumps simultaneously. Assure that power is off on Semiscale pin and on at 15% on LOFT pin.

10. At blowdown plus 6 seconds, reduce power on LOFT pin to specified decay power level.

11. At the specified LOFT pin clad temperature, close the block valve, and initiate ECC injection.

12. Shut off power to the LOFT pin when pin is quenched or when the condition in 6(b) is reached.

13. Secure test.

NOTES:

(1) Use LOFT pin 28-inch thermocouple for control. If this thermocouple is lost, the 43-inch thermocouple may be used for control. In this case, the maximum temperature must be adjusted 250°F lower than specified for the 28-inch thermocouple.

3.6 Test Results

Generally speaking, the tests were successful and the objectives were met. The thermocouple welds held up under a rigorous blowdown environment and adequate data was gathered to evaluate the integrity of the heater.

Failure of the heater coil occurred 138 seconds after blowdown on Test No. 18. A maximum clad temperature of 1725°F had been reached and ECC had been injected for 70 seconds prior to failure. The appendix to this report contains plots of system pressure, heater power, heater clad temperature, ECC flow and ECC temperatures versus time constructed from the data charts.

Aside from the problem of ECC flow control, only one equipment failure occurred during the test series. A regulator on the power control system for the LOFT pin blew a diaphram early in the heat-up period of Test No. 11, resulting in a momentary power spike of 19 KW on the pin. The regulator was replaced and heat-up was continued with a total down time of only a few minutes.

The only instrument failure was the loss of the 10-inch clad thermocouple just prior to Test No. 17. This same thermocouple caused a power trip when it went upscale during heat-upf of Test No. 13. It was disconnected from the trip circuit and the test was resumed. It was later brought back on scale and operated without further incident until its eventual failure. The problem was later discovered to be with the alumel lead in the plotted plug just outside the pressurized test vessel. Some noise appeared on the 43-inch clad thermocouple trace during heat-up for Test No. 16, but was minimized with replacement of the low level amplifier.

Several attempts were made during the test series to correct the ECC control problem including replacement of control valves and regulator but none were 100 percent successful and manual corrections were required during each test except No. 13. Even these were difficult because of the small flow rate, remote conditions, and fluctuations in the regulator controlling the head. A complete renovation of the ECC injection system will be required to get precise automatic control of the flow.

Table 3 is a tabulation of the total time power was on the heater and the maximum condition imposed during each test.

Table 3

POWER-ON HISTORY OF HEATER

Test No.	Power On Time @ 15% (Min.)	Power On Time @ 5% (Sec.)	Power On Time @ 10% (Sec.)	Maximum System Pressure (psig)	Maximum System Temperature (°F)	Maximum Clad Temp. (°F) (28")
10	177	44	---	2250	600	1310
11	144	209	---	2250	600	1410
12	141	192	---	2245	600	1420
13	171	174	---	2250	605	1410
14	168	135	---	2250	600	1405
15	177	138	---	2285	607	1412
16	168	414	---	2300	600	1605
17	141	---	116	2300	600	1750
18	168	---	132	2290	600	1725

Test No. 10

Test No. 10 was run on February 26, 1973. Heat-up to 600°F fluid outlet temperature was achieved in 177 minutes without incident, with the LOFT pin at 15% power. Power was reduced to 5% at 6 seconds after blowdown. ECC was initiated at a clad temperature of 110°F and power was shut of manually at 1300°F. The temperatur econtinued to rise to a maximum level of 1310°F before falling off. The ECC system did not function properly for this test and only 10% of the required flow was achieved. Following this test, a new control valve was installed in the ECC line.

Test No. 11

Test No. 11 was run on February 27, 1973. An inadvertant power spike of 19 KW was applied to the heater pin at the beginning of system heat-up when a diaphram blew in the regulator that controls the power supply to the pin. The regulator was replaced and heat-up was accomplished in 144 minutes without further incident. Reflood was initiated at 1400°F and the clad temperature peaked out at 1410°F. Flood rate was still low on this test at 1.43 inches per second. Further adjustment was made while the system was still hot to bring it up to 2 inches per second.

As on the previous test, power was reduced to 5 percent at six seconds after blowdown and was terminated after all thermocouples indicated the heater was quenched. It should be noted here that it takes four seconds for the power reduction from 15 to 5 percent to occur. This is shown in the power vs. time plot that is included in the Appendix.

Test No. 12

Test No. 12 was run on February 28, 1973, and heat-up was accomplished in 141 minutes without incident. Power was reduced to 5% at 6 seconds after blowdown and reflood was initiated at 1400°F clad temperature. The peak temperature was 1420°F and power was termianted after quench of the pin occurred. The reflood rate again come on well below the preset value and adjustment had to be made manually.

Test No. 13

Test No. 13 was conducted on March 1, 1973. Heat-up of the system was accomplished in 171 minutes. The 10" clad thermocouple shot up scale and tripped the power off early in the warm-up period. Power was restored and heat-up was completed without further incident. The thermocouple was brought back on scale through adjustment of the amplifiers and operated properly for the remainder of the test.

Power was reduced to 5% at 6 seconds after blowdown and reflood was initiated when the clad temperature reached 1400°F. The temperature turned over at 1410°F and power was terminated after quench.

The reflood rate came on at 2 inches per second without any problems with the ECC system. However, it fell off to a low of 1.8 inches per second at quench indicating a manual standby was still required.

Test No. 14

Test No. 14 was run on March 2, 1973, without incident. Heat-up was accomplished in 168 minutes. Power was reduced to 5 percent at 6 seconds after blowdown and reflood was initiated at 1400°F. Peak temperature was 1405°F and power was terminated after quench. The reflood rate came on strong at 3.2 inches per second and was manually adjusted back to 2 inches per second.

Test No. 15

Test No. 15 was run on March 5, 1973. Heat-up took 177 minutes. Power was reduced to 5% at blowdown plus 6 seconds and reflood was initiated at 1400°F. Maximum clad temperature was 1412°F and power was terminated after quench. The reflood rate was adjusted manually after initiation. Manual adjustments are not precise because a reaction time is involved. The adjustment is made in the test cell and the rate of flow is being read in the control room necessitating use of the intercom system to make the adjustment.

Test No. 16

Test No. 16 was run on March 6, 1973. Heat-up was completed in 168 minutes. A disturbance in the 43" thermocouple trace was present for approximately 15 minutes during the heat-up period. It was corrected by replacing the low level amplifier. Power was reduced to 5 percent at 6 seconds after blowdown and the heater clad temperature increase leveled off to a rate of .65°F per second above 1500°F so reflood was initiated at 1600°F instead of the planned level of 1700°F. Maximum clad temperature reached was 1605°F and power was terminated after quench of the heater rod had occurred. The reflood rate was manually controlled at 2 inches per second.

Following this test, R. H. Meservey was contacted by phone and agreement was reached to increase the decay power level from 5 percent to 10 percent for the remainint tests in order to maintain as close as possible a 20°F per second increase in the clad temperature to 1700°F.

Test No. 17

Test No. 17 was run on March 6, 1973. Thermocouple TXL-10"-0° was inoperable at the beginning of this test. An electrical check indicated the alumel lead was "open". A post-test check indicated the failure was not within the pressurized environment of the rod but was in the area of the potted connector outside the test vessel.

Heat-up was completed in 141 minutes. Power was reduced to 10 percent (6.4 KW) at 6 seconds after blowdown. The reduction to this new level of simulated decay power took 3 seconds to complete. Reflood was initiated at 1700°F and power was tripped off at 1750°F by the high temperature trip circuit which was inadvertantly set 100 degrees low. Maximum clad temperature was 1750°F. Reflooding was manually controlled at a rate of 2 inches per second. The temperature rise rate of the heater clad was maintained close to 20°F per second on this test due to the increase in decay power.

A measurement of the heater rod coil resistance following this test showed an increase from .8993 ohms (before Test No. 10) to .9103 ohms after Test No. 17 was completed. Also some bending of the rod was apparent with the sharpest bend at 30 inches from the bottom of the rod. "Sagging" of the thermocouple cables between welds also existed.

Test No. 18

Test No. 18 was conducted on March 7, 1973. Heat-up was completed without incident in 168 minutes. Power was reduced to 10 percent at 6 seconds after blowdown and the clad temperature rise averaged approximately 20 degrees per second. Reflood was initiated at a clad temperature (at 28" thermocouple) of 1700°F. The temperature peaked out at 1725°F before reversing. Power was terminated as a result of pin failure at 138 seconds after blowdown.

Reflood was adjusted manually but a suspected increase in head through the regulator caused an increase in flow rate up to 2.99 inches per second before it could be checked manually. This peak in flow rate corresponds to the time of pin failure.

Inspection of the heater indicated an apparent "hot spot" on the clad at 30 inches from the bottom which corresponds to the location of maximum bending following the previous test. Further inspection results of the rod will be reported by R. H. Meservey of the I&CE Branch.

4.0 APPENDIX

The following information is contained herein for each test:

1. Table of instrument readings just prior to blowdown.

2. Plot of system pressure vs. time after blowdown.

3. Plot of power on the LOFT pin vs. time.

4. Plot of heater cladding temperatures vs. time after blowdown.

5. Plot of ECC flow and fluid temperature vs. time.

6. Plot of heater cladding and thermocouple sheath temperatures vs. time after blowdown.

7. Also included is a typical data chart showing temperature of cladding vs. time for Test No. 14.

LOFT PIN TEST NO. 10

INSTRUMENT READINGS PRIOR TO BLOWDOWN

Station	Measurement	Reading	Units
12	Inlet Temperature RTB	548	°F
13	LOFT Vessel Outlet Temp. (TC)	600	°F
14(A)	Inlet Temperature (TC)	550	°F
15	Semiscale Vessel Outlet Temp. (TC)	585	°F
16	Outlet Temperature RTB	587	°F
17	ECC Flow (Turbine)	-----	GPM
18	ECC Vessel Temperature	130	°F
24	System Pressure	2250	PSIG
29	LOFT Heater Clad Temperature 10"	605	°F
30	LOFT Heater Clad Temperature 28"	638	°F
31	LOFT Heater Clad Temperature 43"	645	°F
32	LOFT Heater Clad Temperature 60"	625	°F
33	ECC Fluid Temperature (At Turbine)	65	°F
LOFT Pin	Voltage Current	95 100	Volts Amps
LOFT Pin	TM-TC Monitor TC on Sheath TM-S Monitor TC on Clad	620 655	°F °F

TEST DATA FOR

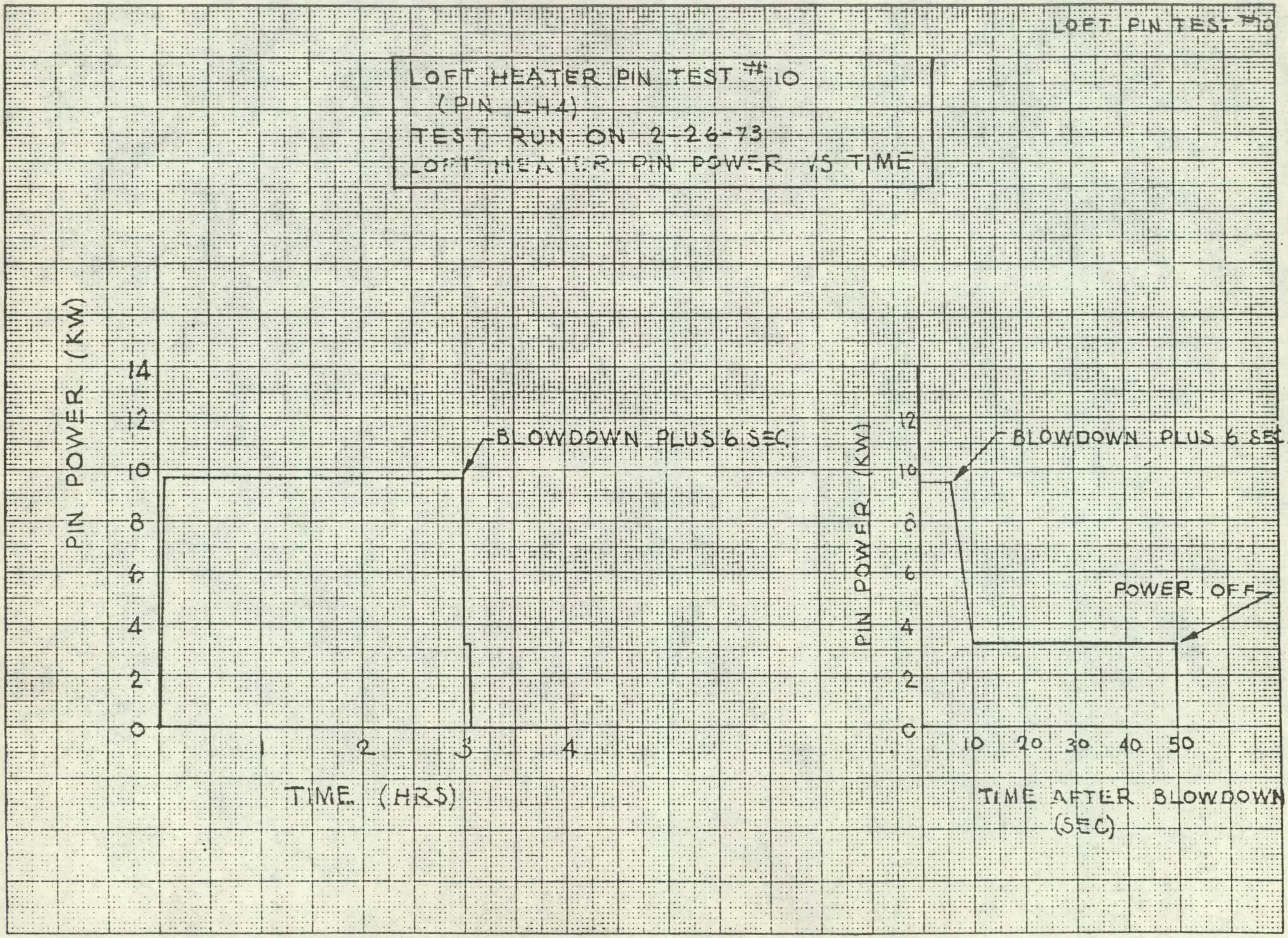
LOFT HEATER PIN LH-4

TEST NO. 10

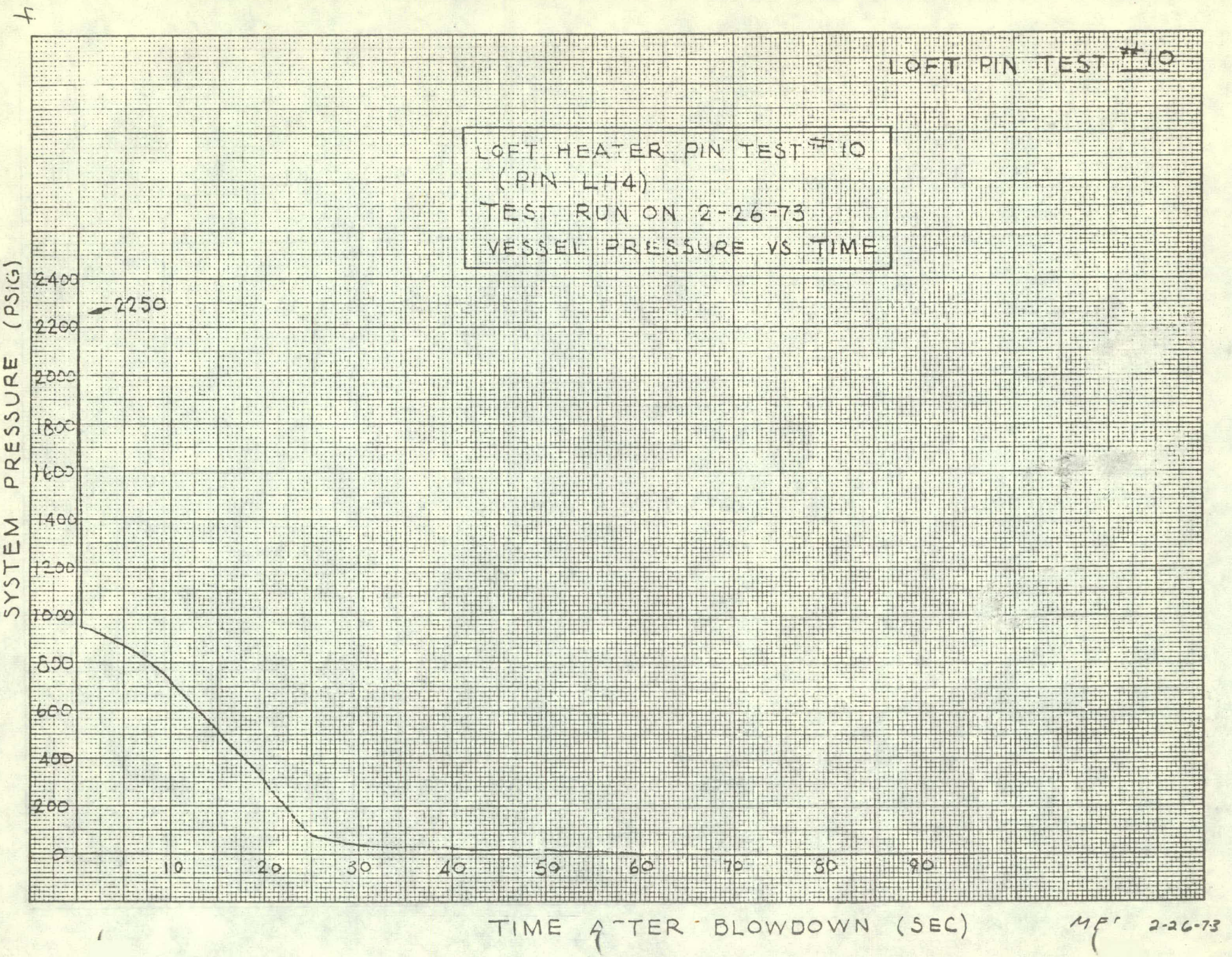
2/26/73

2

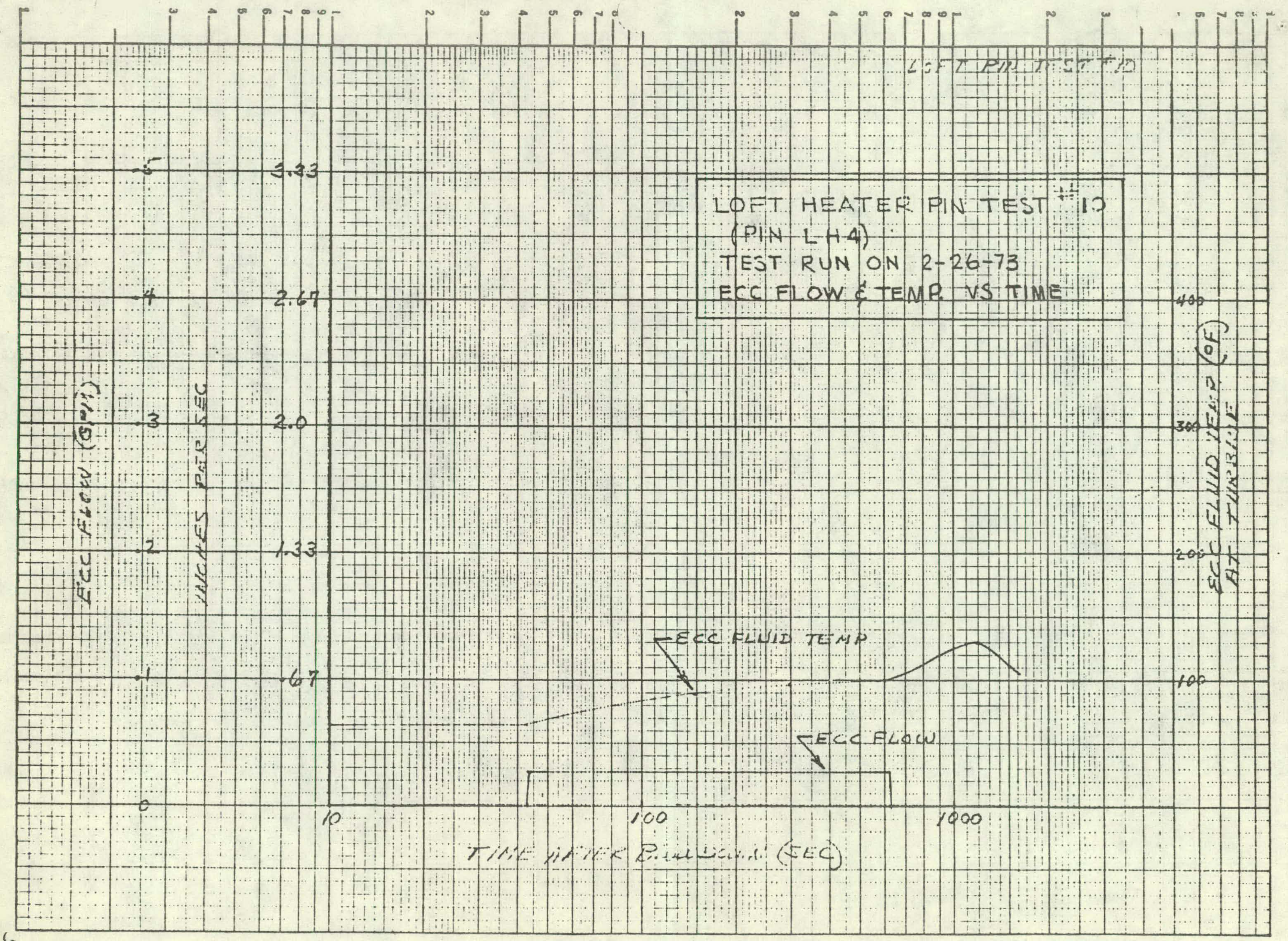
18 X 25 CM MADE IN U.S.A.
KEUFFEL & ESSER CO.



MPS 2-26-73

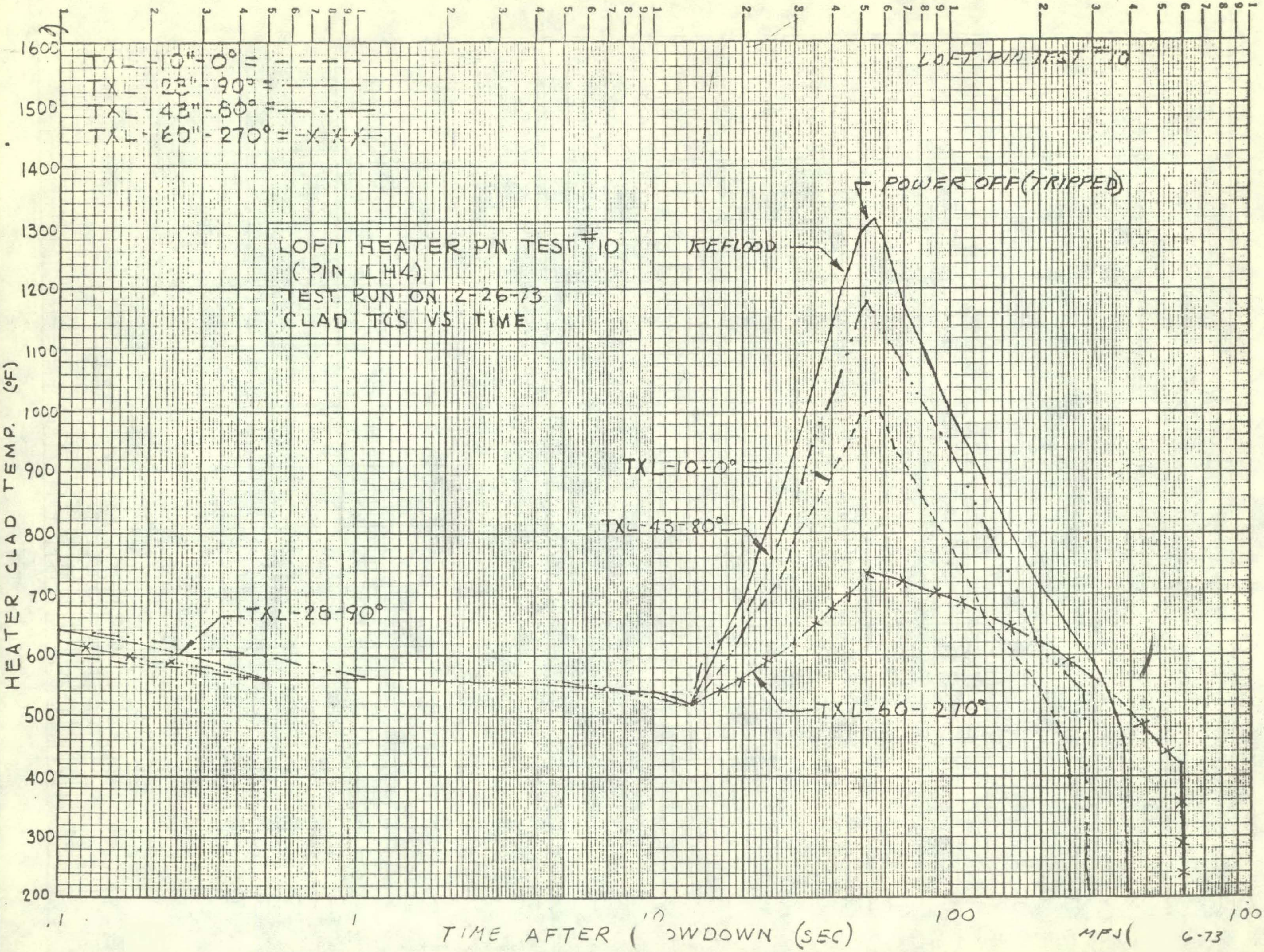

LOFT PIN TEST #10
LOFT HEATER PIN TEST #10
(PIN LH4)
TEST RUN ON 2-26-73
VESSEL PRESSURE VS TIME
2250
SYSTEM PRESSURE (PSIG)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
80
90
TIME AFTER BLOWDOWN (SEC)
2-26-73

K+E SEMI-LOGARITHMIC
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS



MFC 2-26-73

4 CYCLES X 70 DIVISIONS



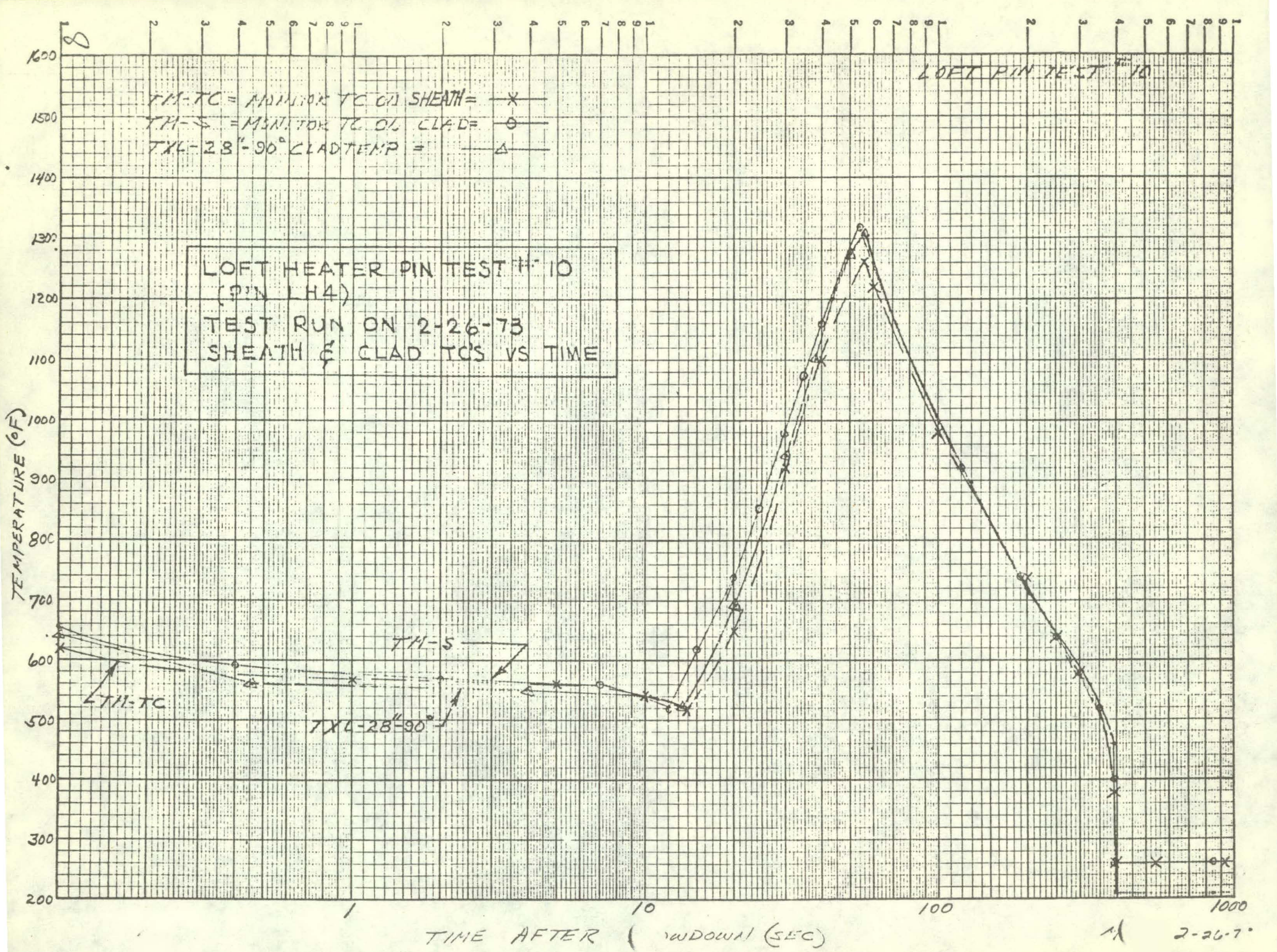
MFS 6-73

TEST DATA FOR

LOFT HEATER PIN LH-4

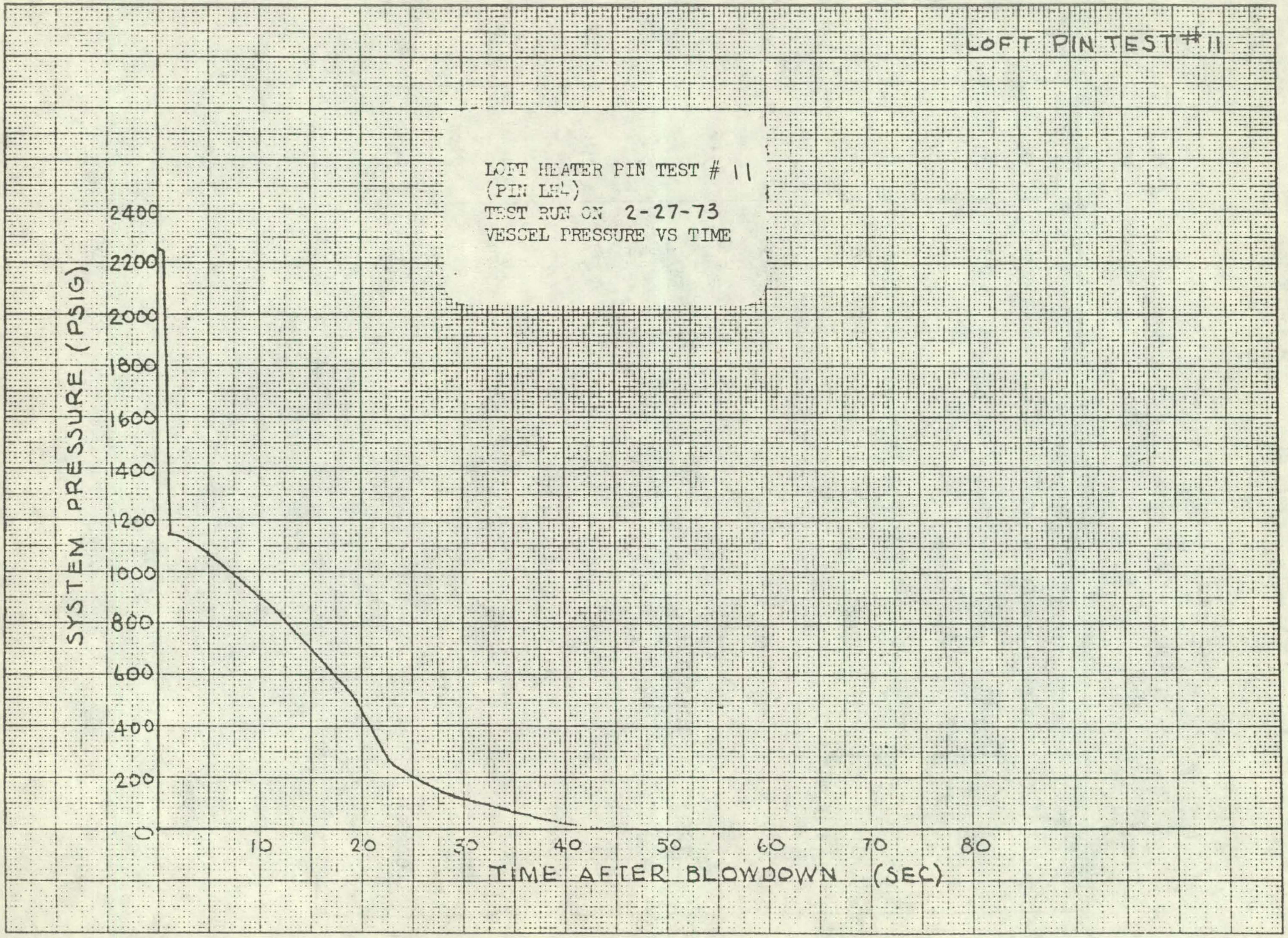
TEST NO. 11

2/27/73


8
LOFT PIN TEST # 10
TM-TC = MONITOR TC ON SHEATH = —X—
TM-5 = MONITOR TC ON CLAD = —O—
TXL-28"-90° CLAD TEMP = —Δ—
LOFT HEATER PIN TEST # 10
(PIN LH4)
TEST RUN ON 2-26-75
SHEATH & CLAD TC'S VS TIME
TM-5
TM-TC
TXL-28"-90°
TEMPERATURE (°F)
TIME AFTER (OWDOWN (SEC)
2-26-7

K+E 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.

LOFT PIN TEST # 11



MFJ 2-27

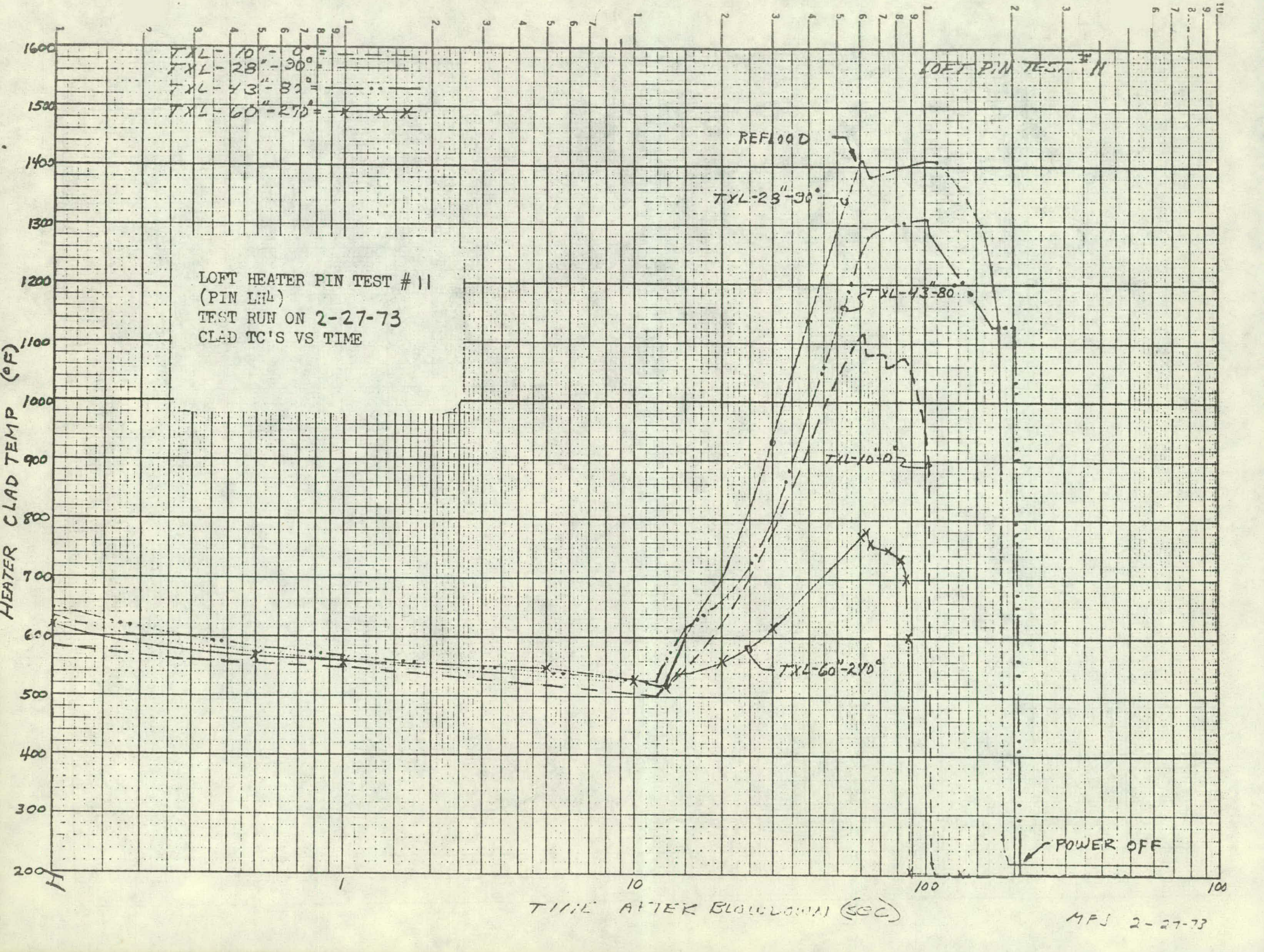
2-21-75

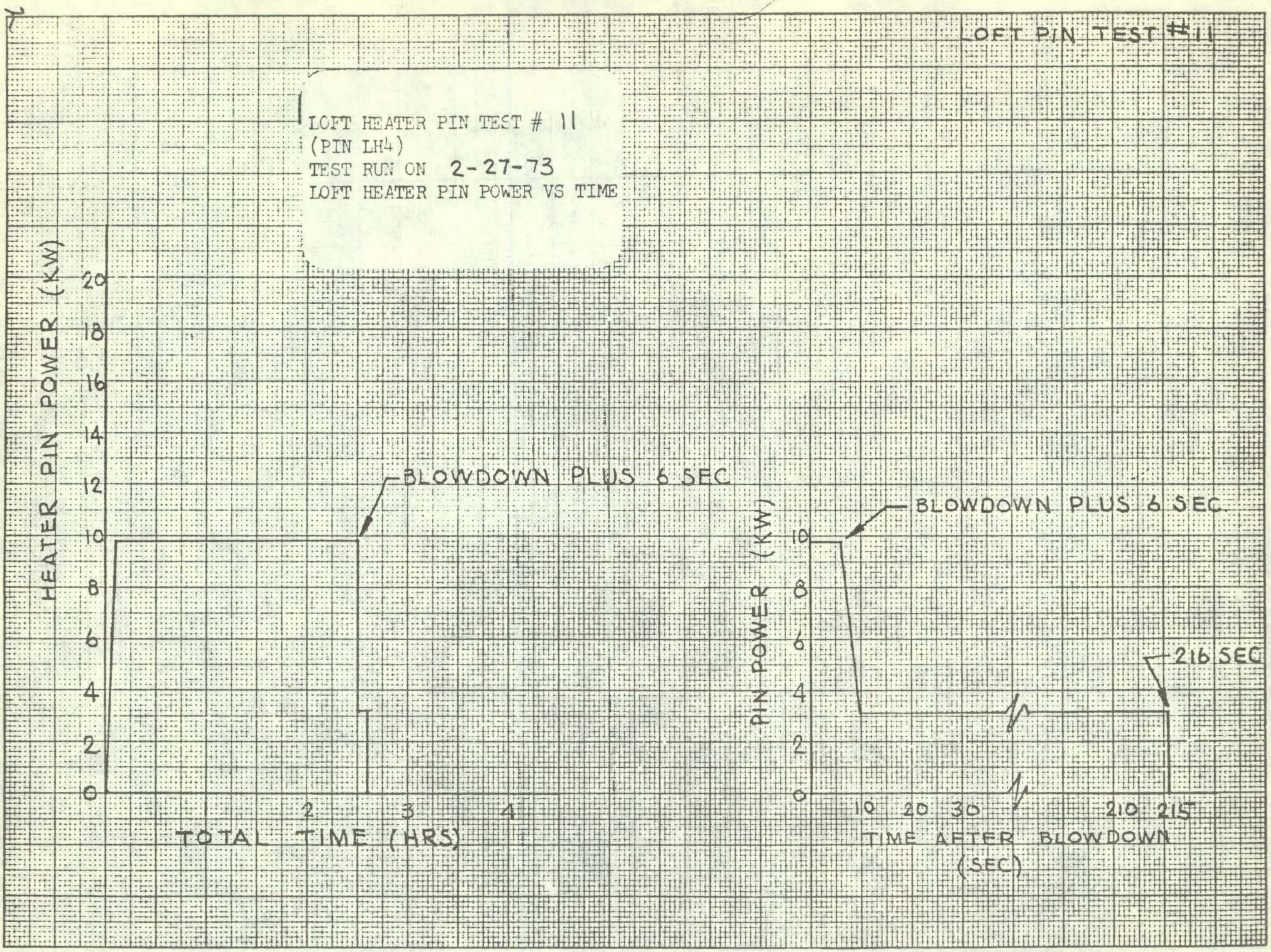
LOFT PIN TEST NO. 11

INSTRUMENT READINGS PRIOR TO BLOWDOWN

Station	Measurement	Reading	Units
12	Inlet Temperature RTB	548	°F
13	LOFT Vessel Outlet Temp. (TC)	600	°F
14(A)	Inlet Temperature (TC)	550	°F
15	Semiscale Vessel Outlet Temp. (TC)	580	°F
16	Outlet Temperature RTB	579	°F
17	ECC Flow (Turbine)	-----	GPM
18	ECC Vessel Temperature	130	°F
24	System Pressure	2250	PSIG
29	LOFT Heater Clad Temperature 10"	595	°F
30	LOFT Heater Clad Temperature 28"	630	°F
31	LOFT Heater Clad Temperature 43"	645	°F
32	LOFT Heater Clad Temperature 60"	622	°F
33	ECC Fluid Temperature (At Turbine)	68	°F
LOFT Pin	Voltage Current	97 101	Volts Amps
LOFT Pin	TM-TC Monitor TC on Sheath TM-S Monitor TC on Clad	610 645	°F °F

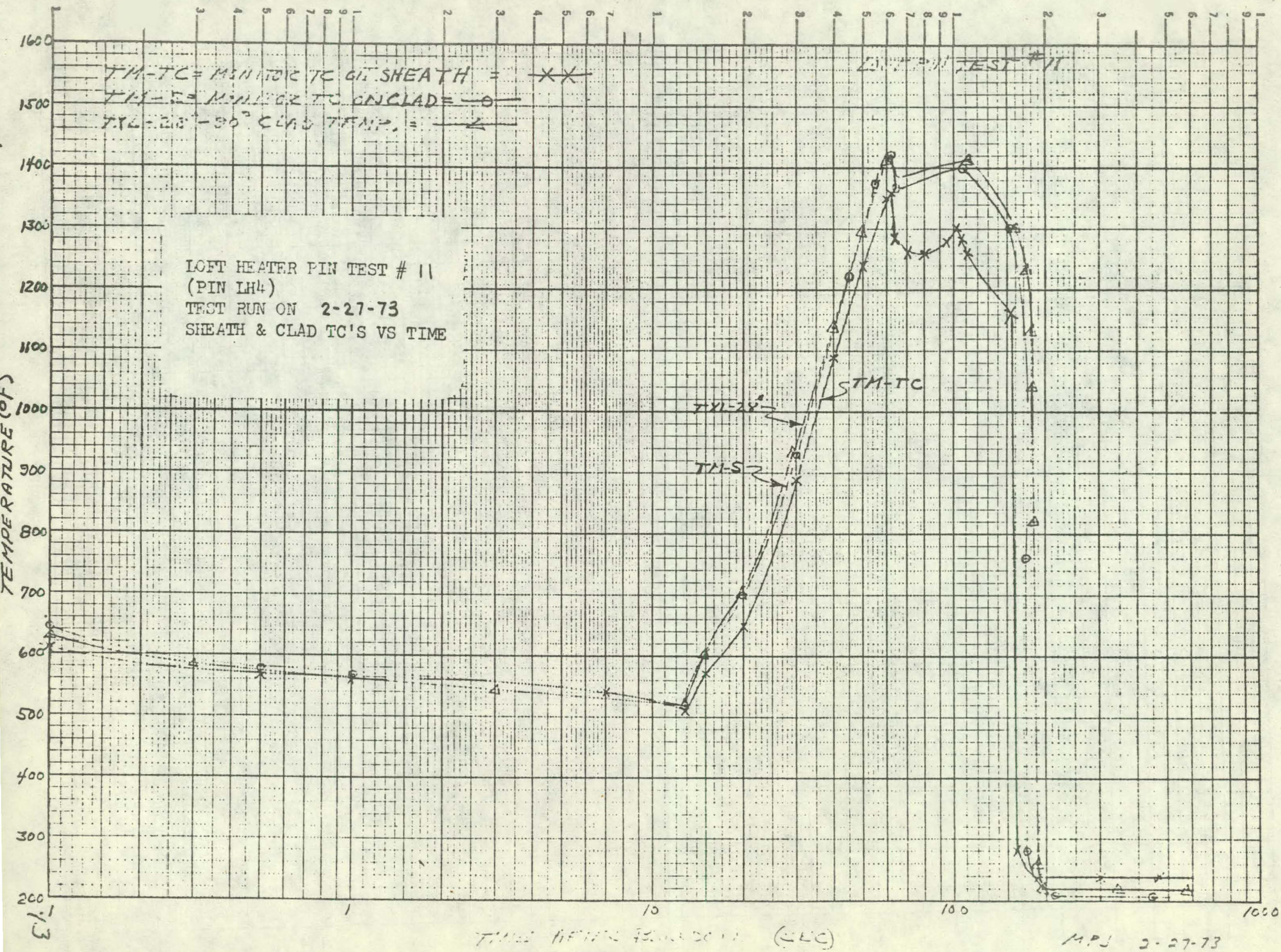
KEUFFEL & ESSER CO.



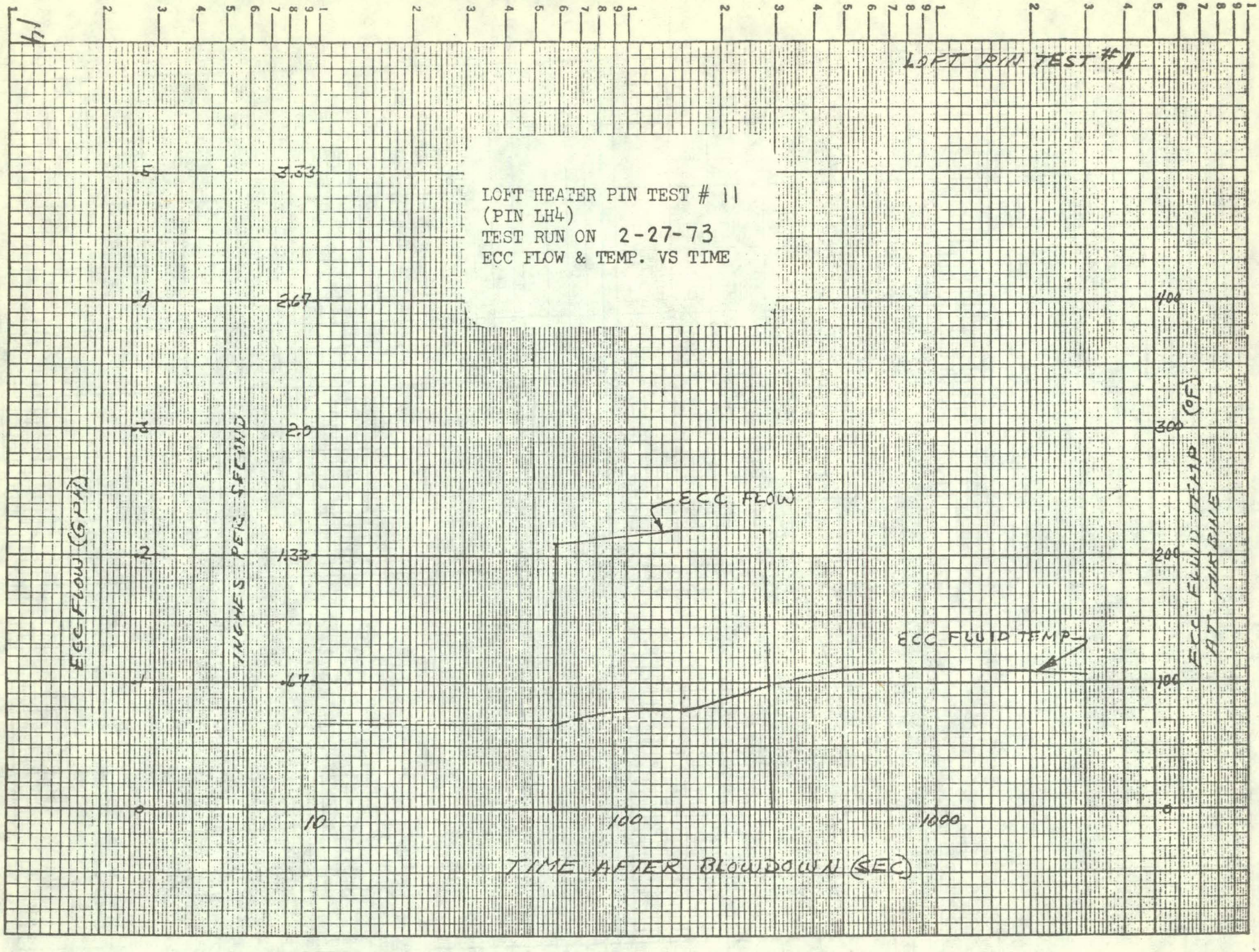

LOFT PIN TEST #11
LOFT HEATER PIN TEST # 11
(PIN LH4)
TEST RUN ON 2-27-73
LOFT HEATER PIN POWER VS TIME
HEATER PIN POWER (KW)
20
18
16
14
12
10
8
6
4
2
0
BLOWDOWN PLUS 6 SEC
2
3
4
TOTAL TIME (HRS)
PIN POWER (KW)
BLOWDOWN PLUS 6 SEC
216 SEC
10 20 30
210 215
TIME AFTER BLOWDOWN (SEC)

MPS 7-73

N°2 KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS



MPJ 2-27-73


LOFT PIN TEST # 11
LOFT HEATER PIN TEST # 11
(PIN LH4)
TEST RUN ON 2-27-73
ECC FLOW & TEMP. VS TIME
ECC FLOW
ECC FLUID TEMP
ECC FLOW (GPM)
INCHES PER SECOND
ECC FLUID TEMP AT TURBINE (°F)
TIME AFTER BLOWDOWN (SEC)
10
100
1000
3.33
2.67
2.0
1.33
.67
400
300
200
100
0

MPJ -73

LOFT PIN TEST NO. 12

INSTRUMENT READINGS PRIOR TO BLOWDOWN

Station	Measurement	Reading	Units
12	Inlet Temperature RTB	550	°F
13	LOFT Vessel Outlet Temp. (TC)	600	°F
14(A)	Inlet Temperature (TC)	550	°F
15	Semiscale Vessel Outlet Temp. (TC)	580	°F
16	Outlet Temperature RTB	585	°F
17	ECC Flow (Turbine)	-----	GPM
18	ECC Vessel Temperature	130	°F
24	System Pressure	2245	PSIG
29	LOFT Heater Clad Temperature 10"	595	°F
30	LOFT Heater Clad Temperature 28"	630	°F
31	LOFT Heater Clad Temperature 43"	650	°F
32	LOFT Heater Clad Temperature 60"	625	°F
33	ECC Fluid Temperature (At Turbine)	68	°F
LOFT Pin	Voltage Current	96 101	Volts Amps
LOFT Pin	TM-TC Monitor TC on Sheath TM-S Monitor TC on Clad	620 650	°F °F

TEST DATA FOR

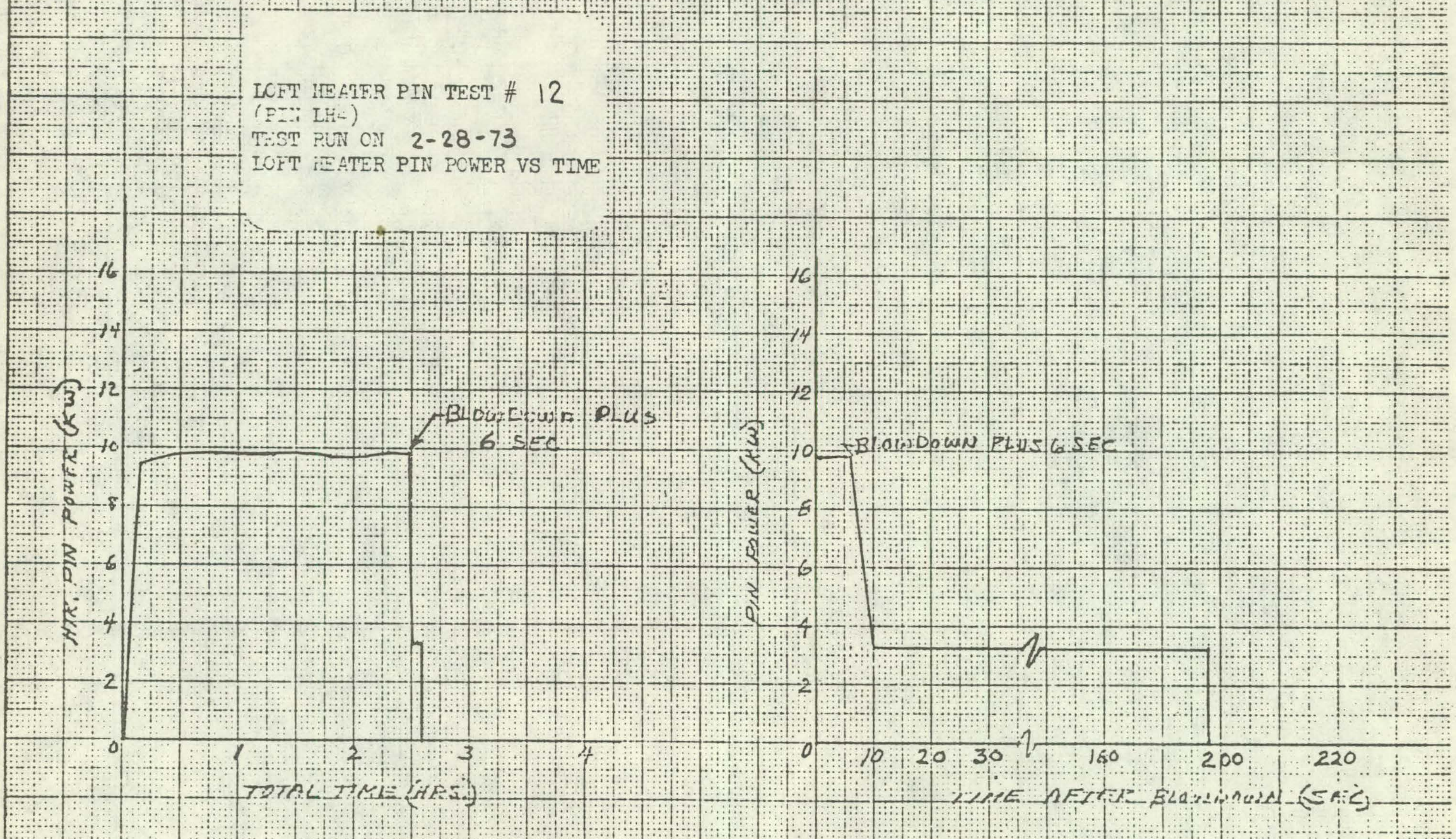
LOFT HEATER PIN LH-4

TEST NO. 12

2/28/73

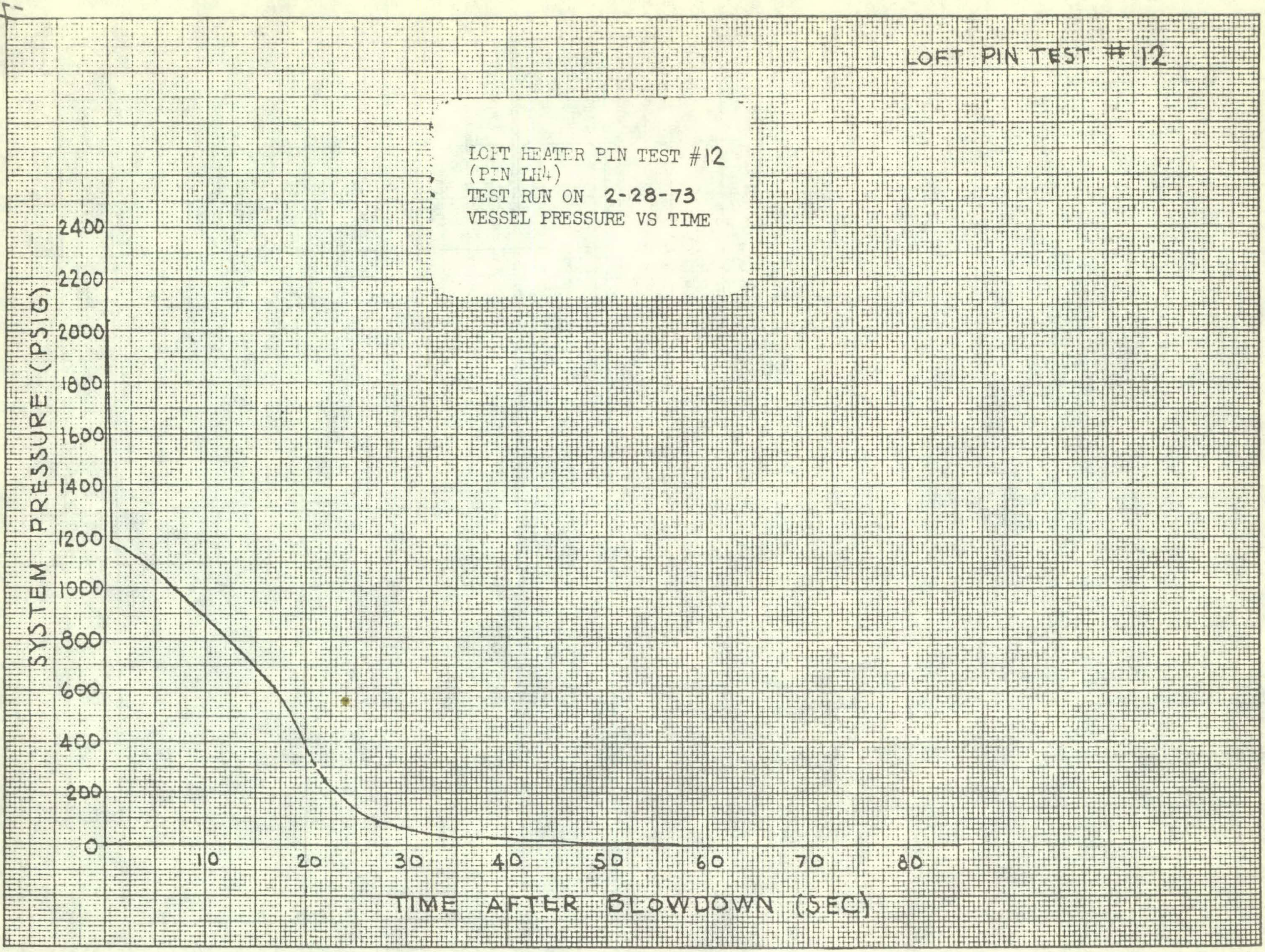
2

LOFT PIN TEST NO. 12



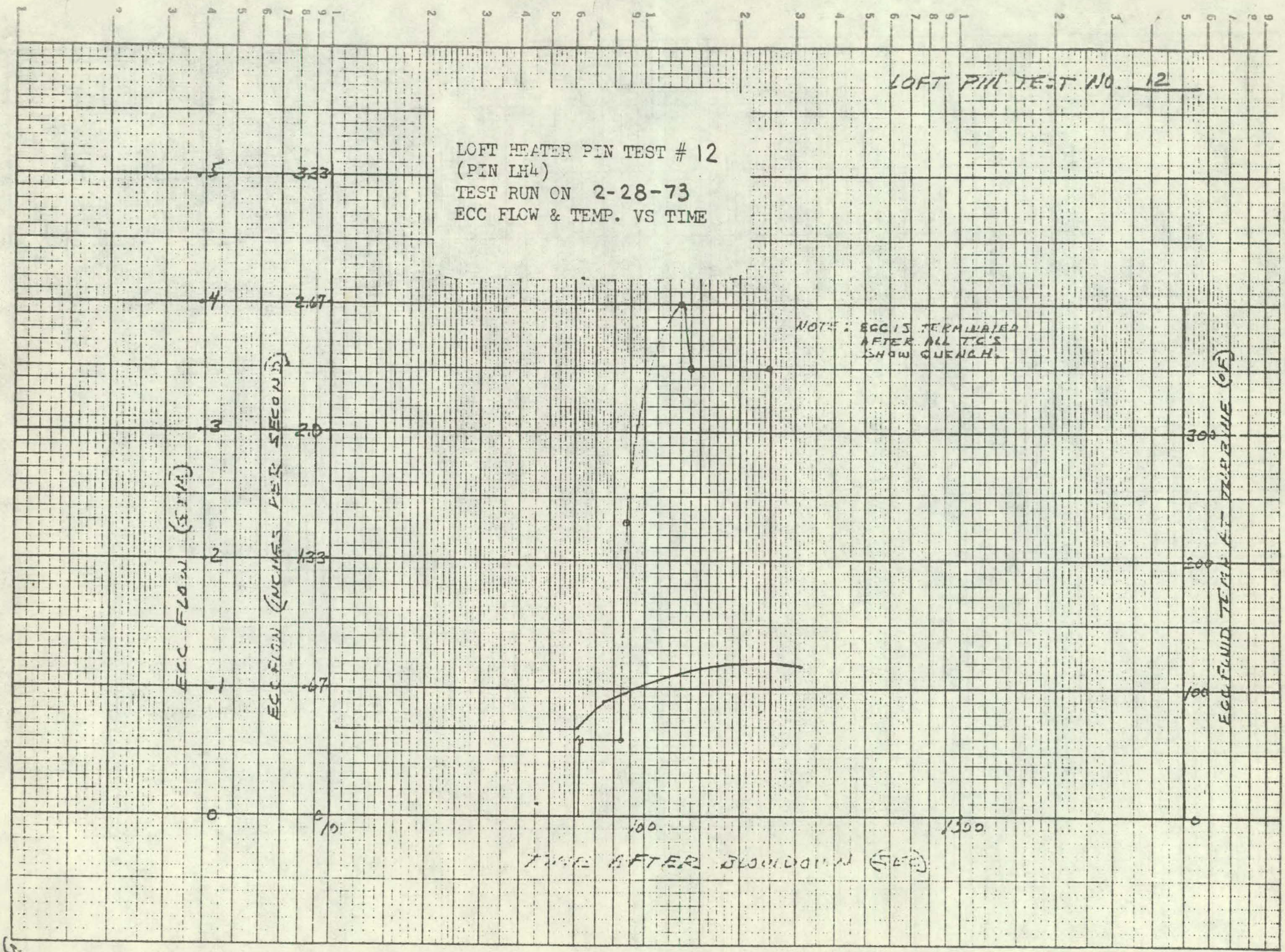
3

MFJ 2-28-73


LOFT PIN TEST # 12
LOFT HEATER PIN TEST #12
(PIN LH4)
TEST RUN ON 2-28-73
VESSEL PRESSURE VS TIME
SYSTEM PRESSURE (PSIG)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
80
TIME AFTER BLOWDOWN (SEC)

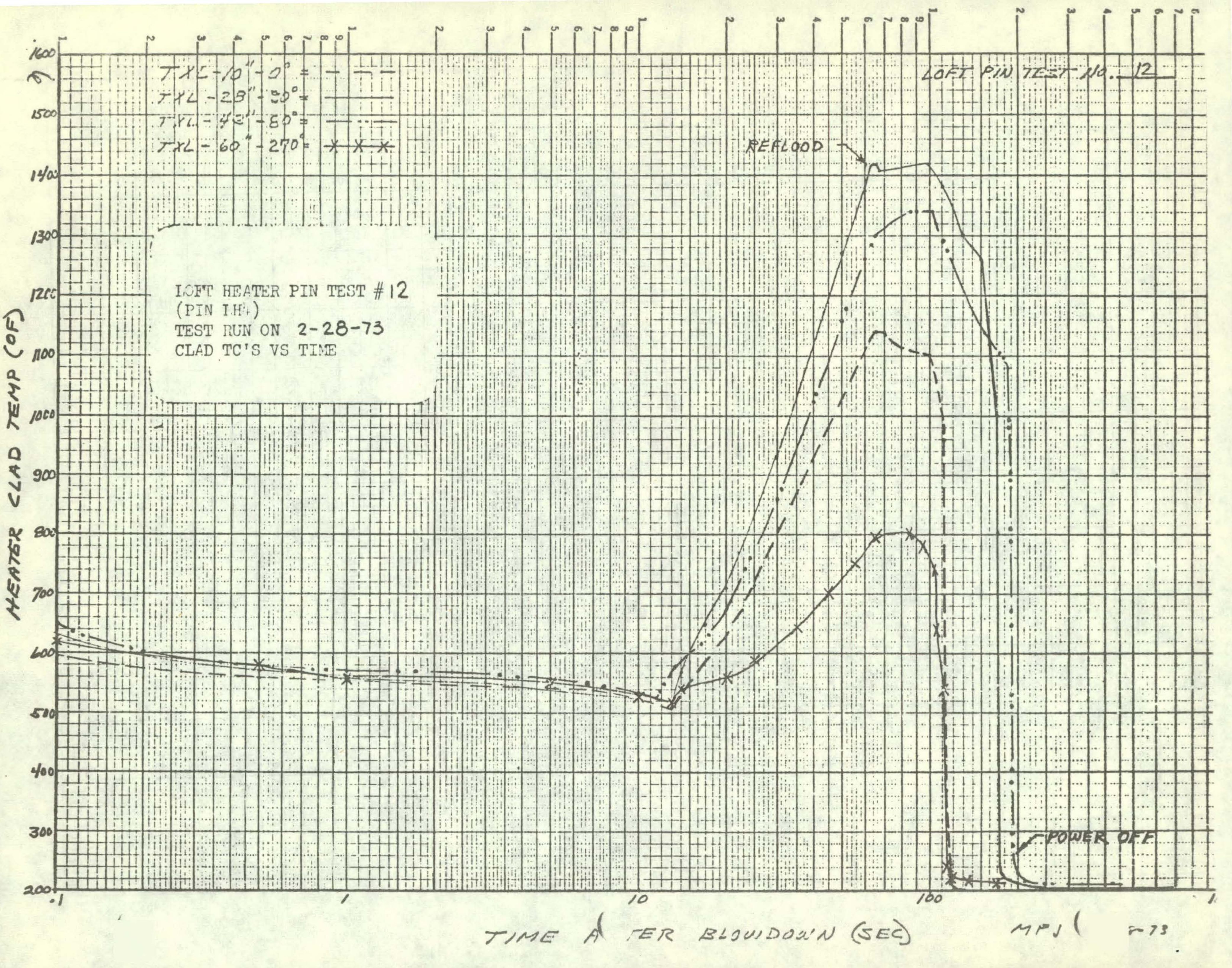
MPS

K+E SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS



G-1

2-2?-73

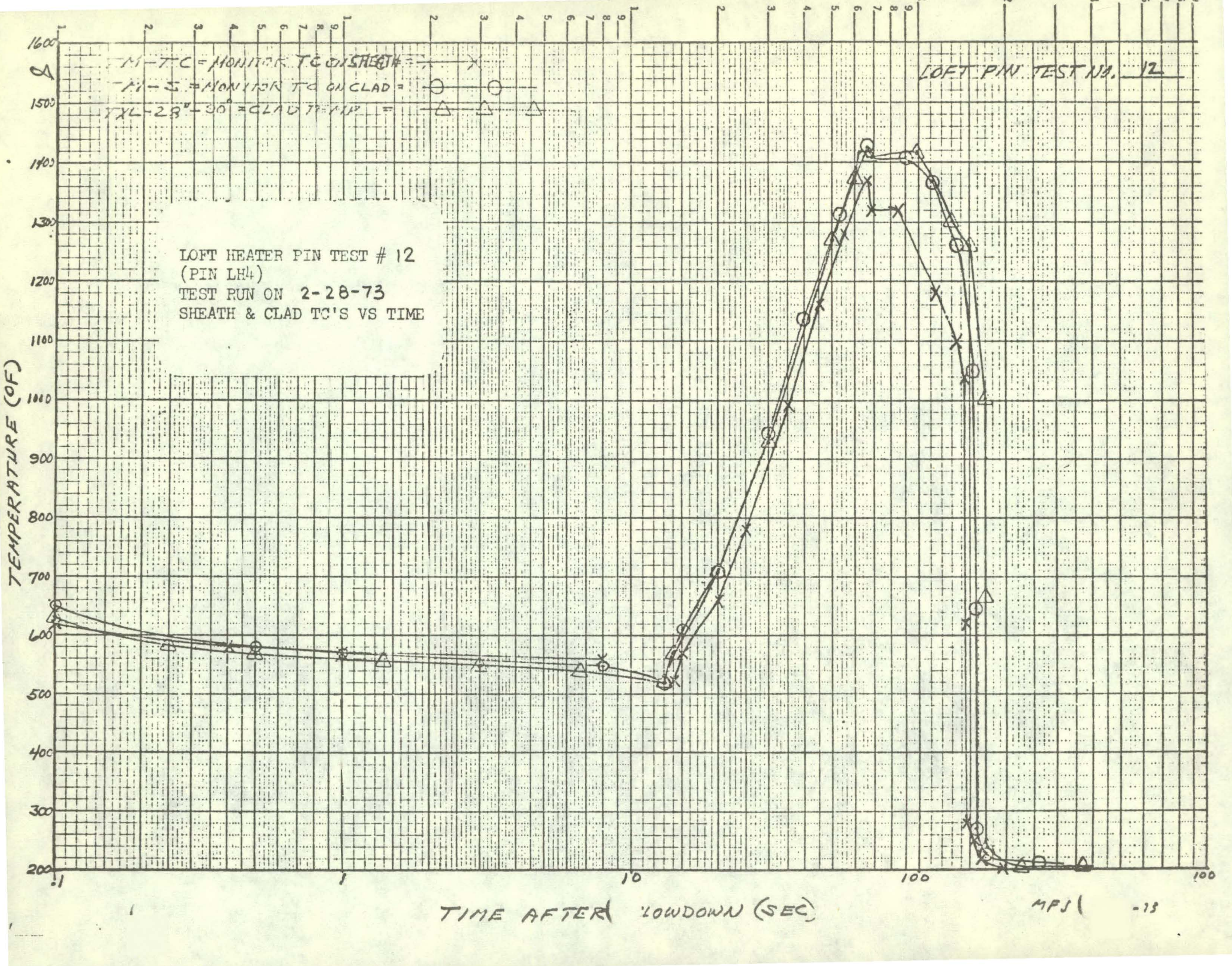

TXL - 10" - 0° =
TXL - 28" - 90° =
TXL - 42" - 80° =
TXL - 60" - 270° =
LOFT PIN TEST NO. 12
REFLOOD
LOFT HEATER PIN TEST #12
(PIN I.H4)
TEST RUN ON 2-28-73
CLAD TC'S VS TIME
POWER OFF
HEATER CLAD TEMP (°F)
TIME AFTER BLOWDOWN (SEC)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
.1
1
10
100

TEST DATA FOR

LOFT HEATER PIN LH-4

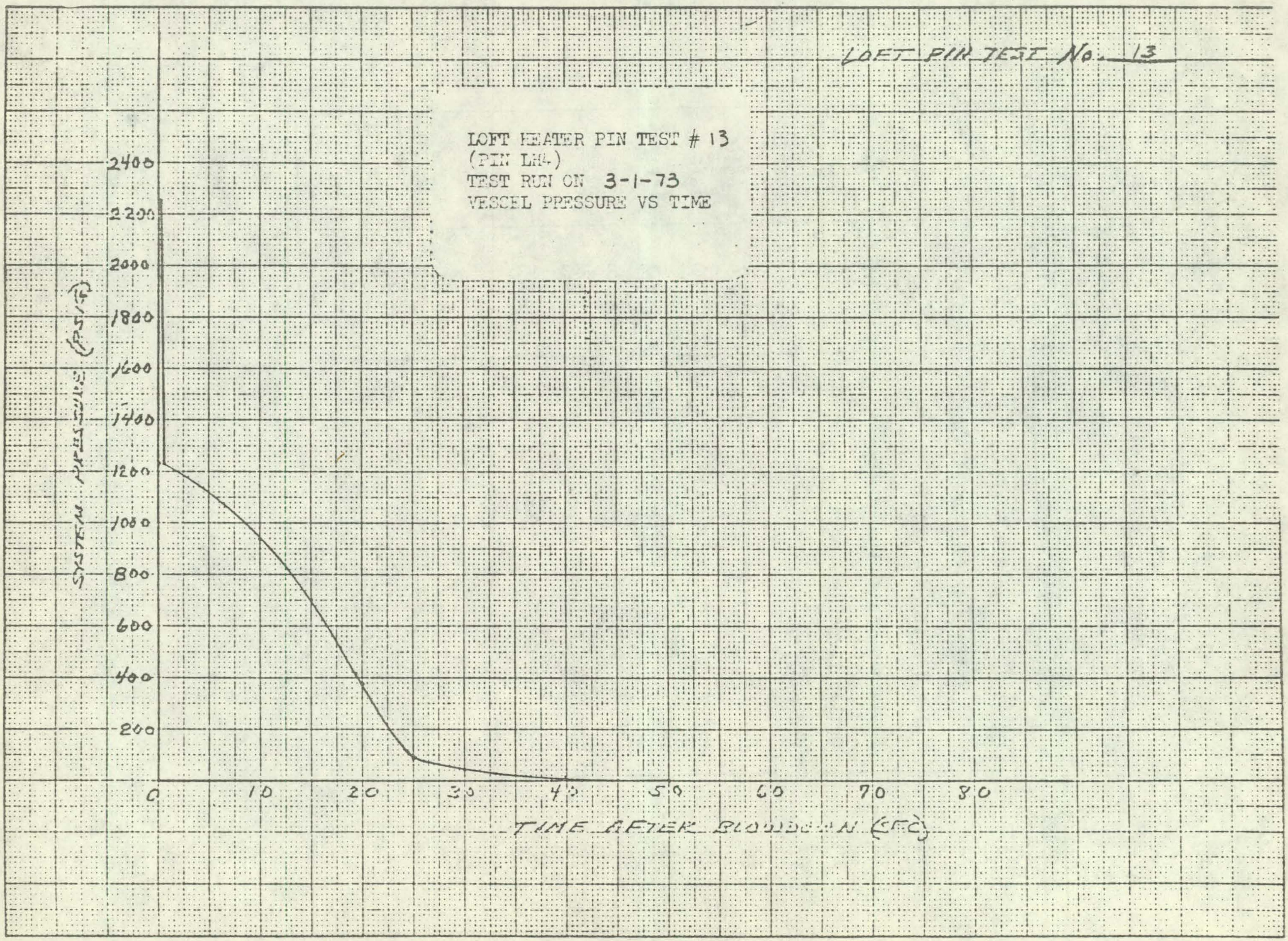
TEST NO. 13

3/1/73



LOFT PIN TEST NO. 12
M-TC = MONITOR TC ON SHEATH
M-S = MONITOR TC ON CLAD
TXL-28"-30° = CLAD TEMP
LOFT HEATER PIN TEST # 12
(PIN LH4)
TEST RUN ON 2-28-73
SHEATH & CLAD TC'S VS TIME
TEMPERATURE (OF)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
.1
1
10
100
1000
TIME AFTER BLOWDOWN (SEC)

KEUFFEL & ESSER CO.



MFS 3-1-73

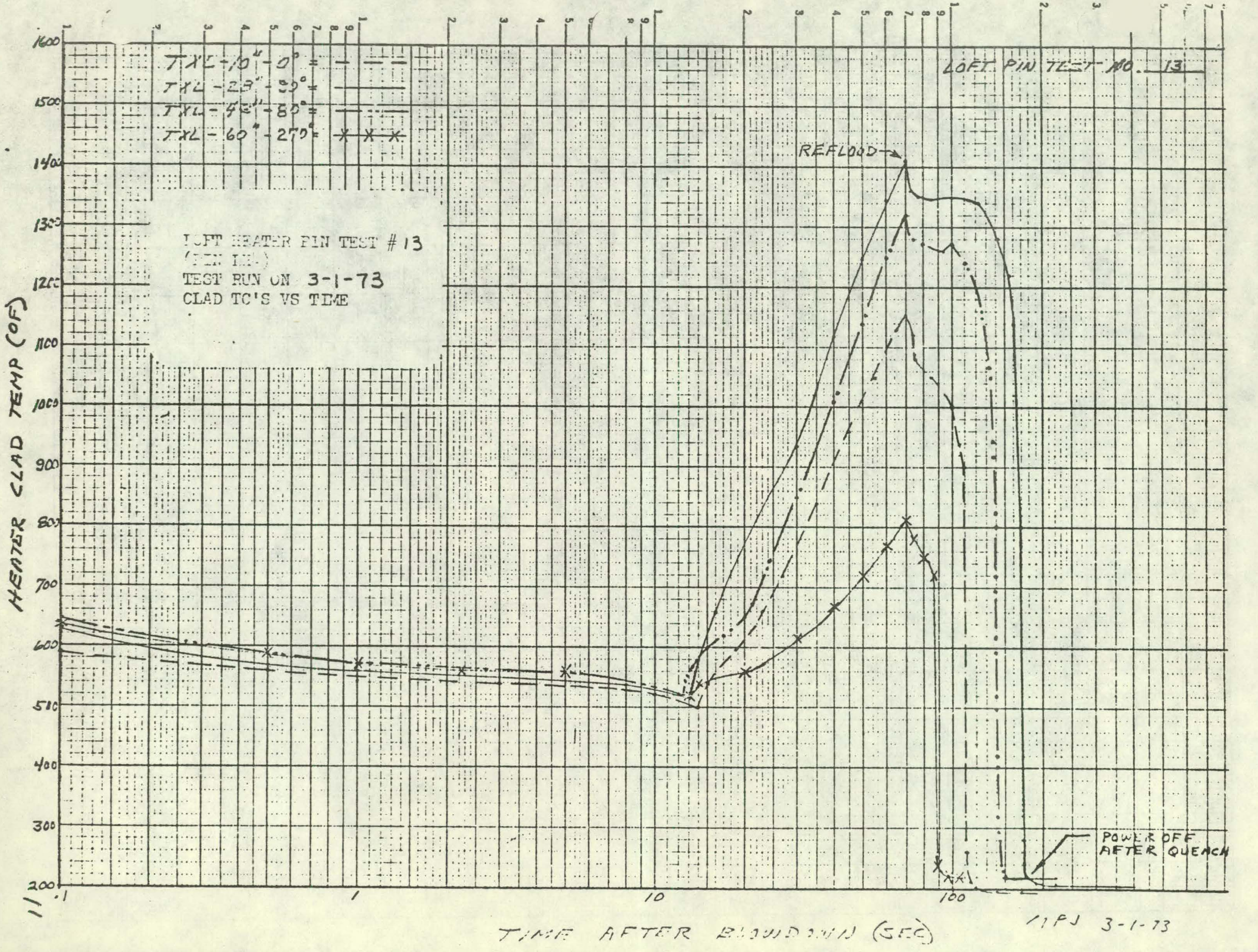
3-1-73

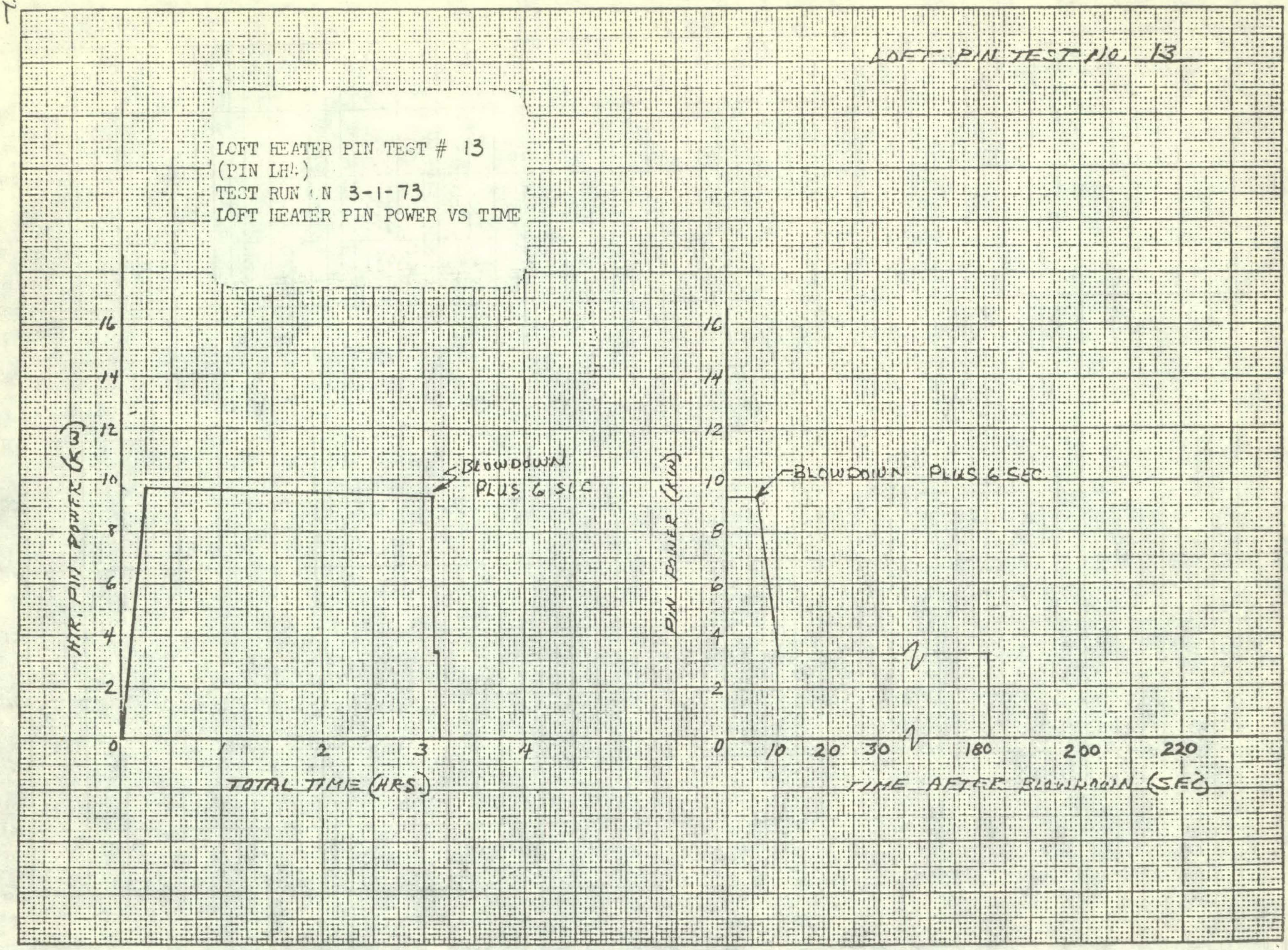
LOFT PIN TEST NO. 13

INSTRUMENT READINGS PRIOR TO BLOWDOWN

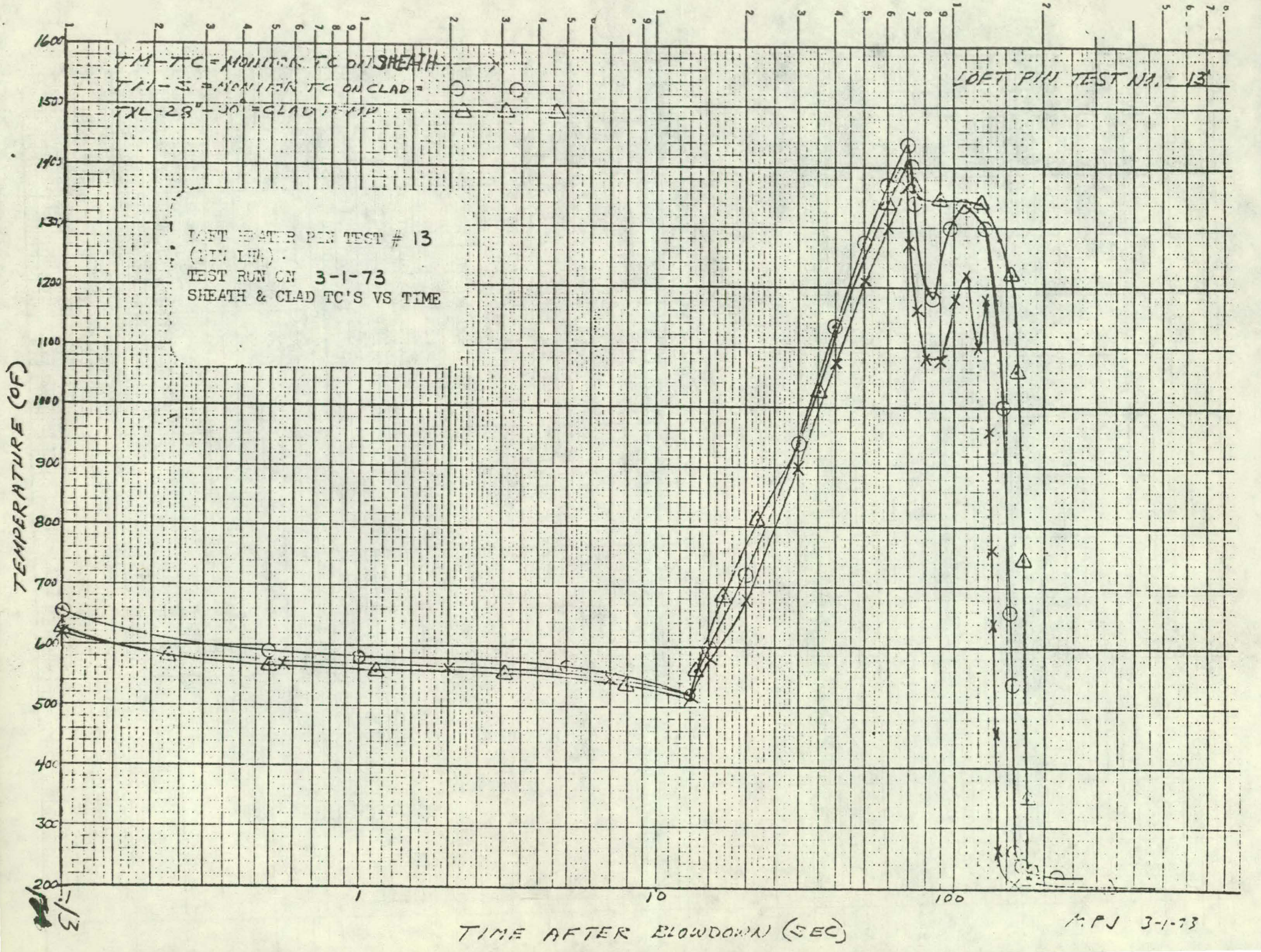
Station	Measurement	Reading	Units
12	Inlet Temperature RTB	561	°F
13	LOFT Vessel Outlet Temp. (TC)	605	°F
14(A)	Inlet Temperature (TC)	560	°F
15	Semiscale Vessel Outlet Temp. (TC)	585	°F
16	Outlet Temperature RTB	591	°F
17	ECC Flow (Turbine)	-----	GPM
18	ECC Vessel Temperature	139	°F
24	System Pressure	2250	PSIG
29	LOFT Heater Clad Temperature 10"	590	°F
30	LOFT Heater Clad Temperature 28"	630	°F
31	LOFT Heater Clad Temperature 43"	645	°F
32	LOFT Heater Clad Temperature 60"	635	°F
33	ECC Fluid Temperature (At Turbine)	72	°F
LOFT Pin	Voltage Current	95 98	Volts Amps
LOFT Pin	TM-TC Monitor TC on Sheath TM-S Monitor TC on Clad	620 658	°F °F

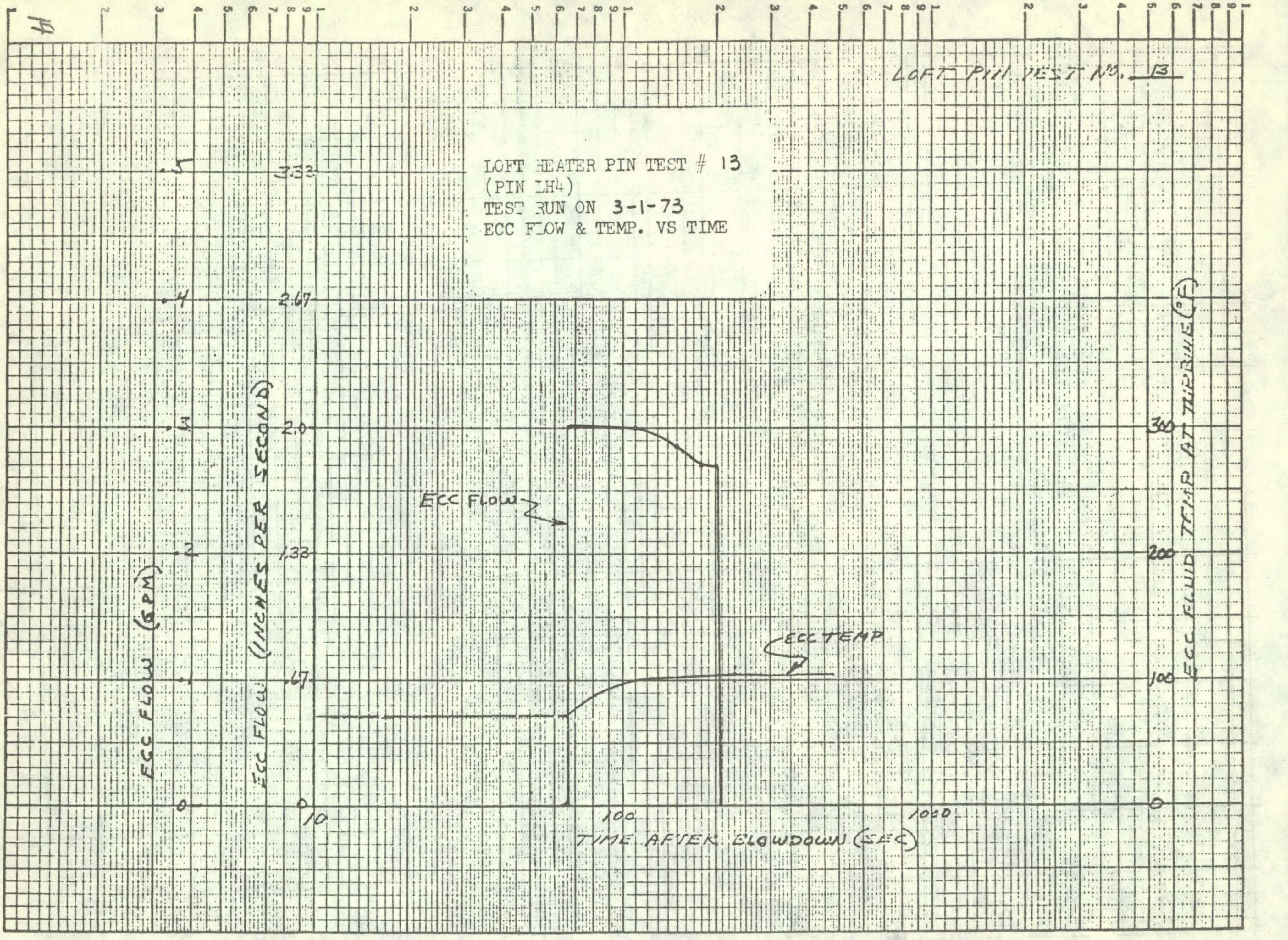
10


TXL-10"-0° =
TXL-28"-90° =
TXL-45"-80° =
TXL-60"-270° =
LOFT PIN TEST NO. 13
LOFT HEATER PIN TEST #13
TEST RUN ON 3-1-73
CLAD TC'S VS TIME
REFLOOD
POWER OFF AFTER QUENCH
HEATER CLAD TEMP (°F)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
.1
1
10
100
TIME AFTER BLOWDOWN (SEC)
3-1-73


LOFT PIN TEST NO. 13
LOFT HEATER PIN TEST # 13
(PIN LH4)
TEST RUN ON 3-1-73
LOFT HEATER PIN POWER VS TIME
HTR. PIN POWER (KW)
TOTAL TIME (HRS.)
BLOWDOWN PLUS 6 SEC
PIN POWER (KW)
TIME AFTER BLOWDOWN (SEC)
0
2
4
6
8
10
12
14
16
1
2
3
4
10
20
30
180
200
220

MFJ 3


TM-TC = MONITOR TC ON SHEATH
TM-S = MONITOR TC ON CLAD
TXL-28"-90° = CLAD TEMP
LOFT PIN TEST NO. 13
LOFT HEATER PIN TEST # 13
(PIN LHM)
TEST RUN ON 3-1-73
SHEATH & CLAD TC'S VS TIME
TEMPERATURE (°F)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
.1
1
10
100
TIME AFTER BLOWDOWN (SEC)
MPJ 3-1-73



LOFT PIN TEST NO. 13
LOFT HEATER PIN TEST # 13
(PIN LH4)
TEST RUN ON 3-1-73
ECC FLOW & TEMP. VS TIME
ECC FLOW
ECC TEMP
ECC FLOW (GPM)
ECC FLOW (INCHES PER SECOND)
ECC FLUID TEMP AT TURBINE (°F)
TIME AFTER BLOWDOWN (SEC)
.5
3.33
.4
2.67
.3
2.0
.2
1.33
.1
.67
0
0
10
100
1000
300
200
100
0

MPS '73

3-2-73

LOFT PIN TEST NO. 14

INSTRUMENT READINGS PRIOR TO BLOWDOWN

Station	Measurement	Reading	Units
12	Inlet Temperature RTB	553	°F
13	LOFT Vessel Outlet Temp. (TC)	600	°F
14(A)	Inlet Temperature (TC)	555	°F
15	Semiscale Vessel Outlet Temp. (TC)	575	°F
16	Outlet Temperature RTB	587	°F
17	ECC Flow (Turbine)	-----	GPM
18	ECC Vessel Temperature	134	°F
24	System Pressure	2250	PSIG
29	LOFT Heater Clad Temperature 10"	610	°F
30	LOFT Heater Clad Temperature 28"	625	°F
31	LOFT Heater Clad Temperature 43"	635	°F
32	LOFT Heater Clad Temperature 60"	620	°F
33	ECC Fluid Temperature (At Turbine)	73	°F
LOFT Pin	Voltage Current	96 100	Volts Amps
LOFT Pin	TM-TC Monitor TC on Sheath TM-S Monitor TC on Clad	615 640	°F °F

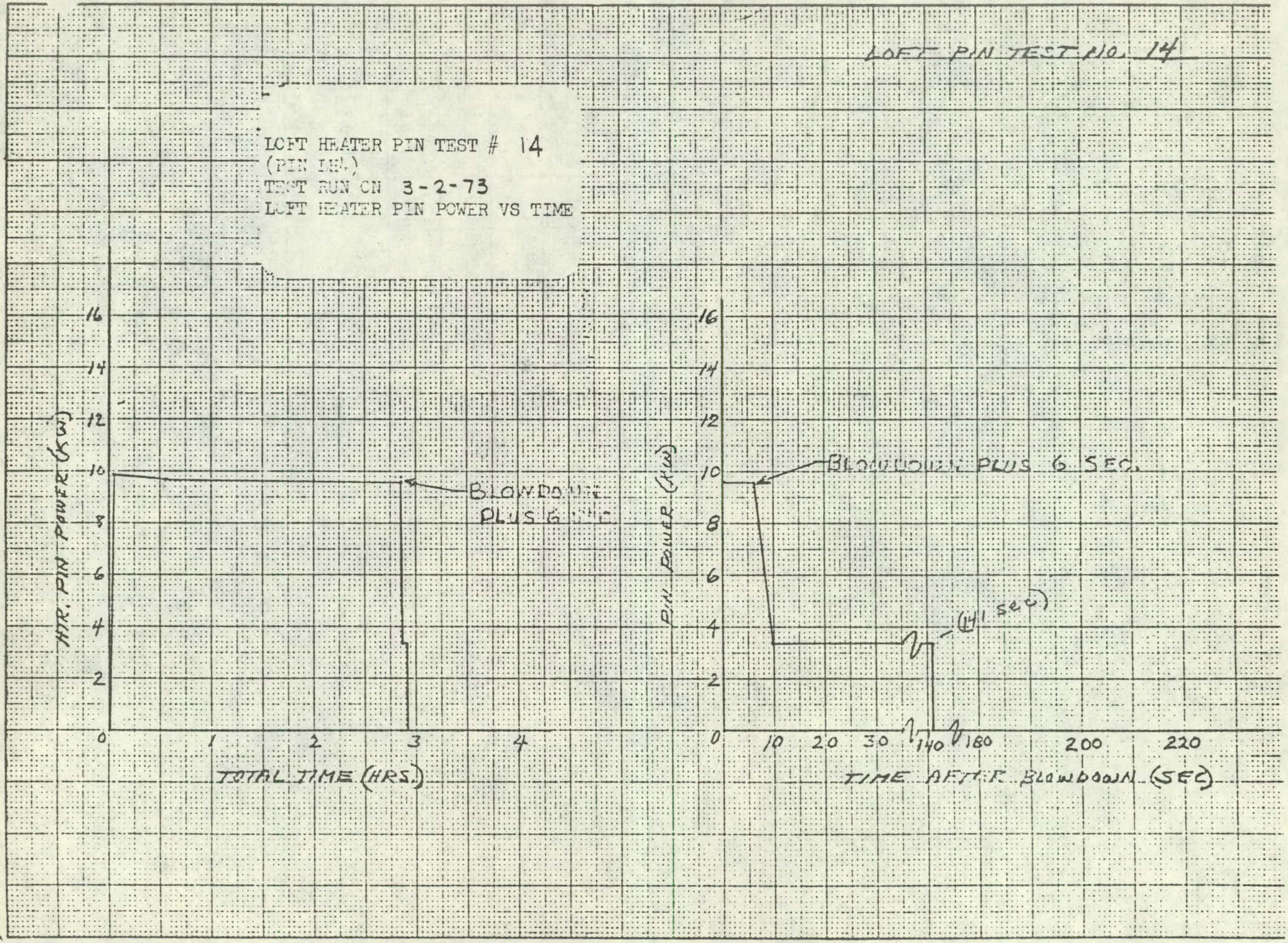
TEST DATA FOR

LOFT HEATER PIN LH-4

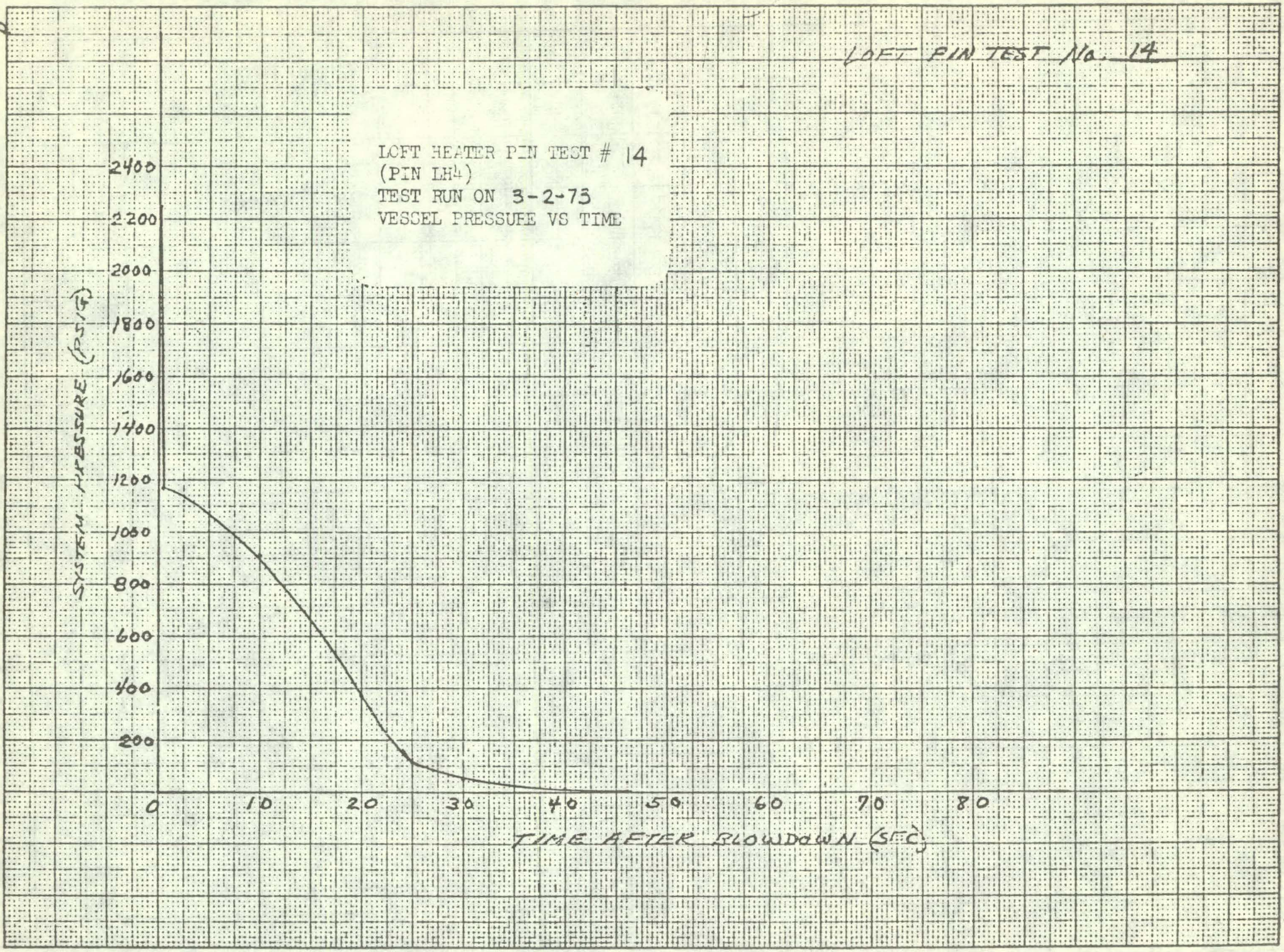
TEST NO. 14

3/2/73

16

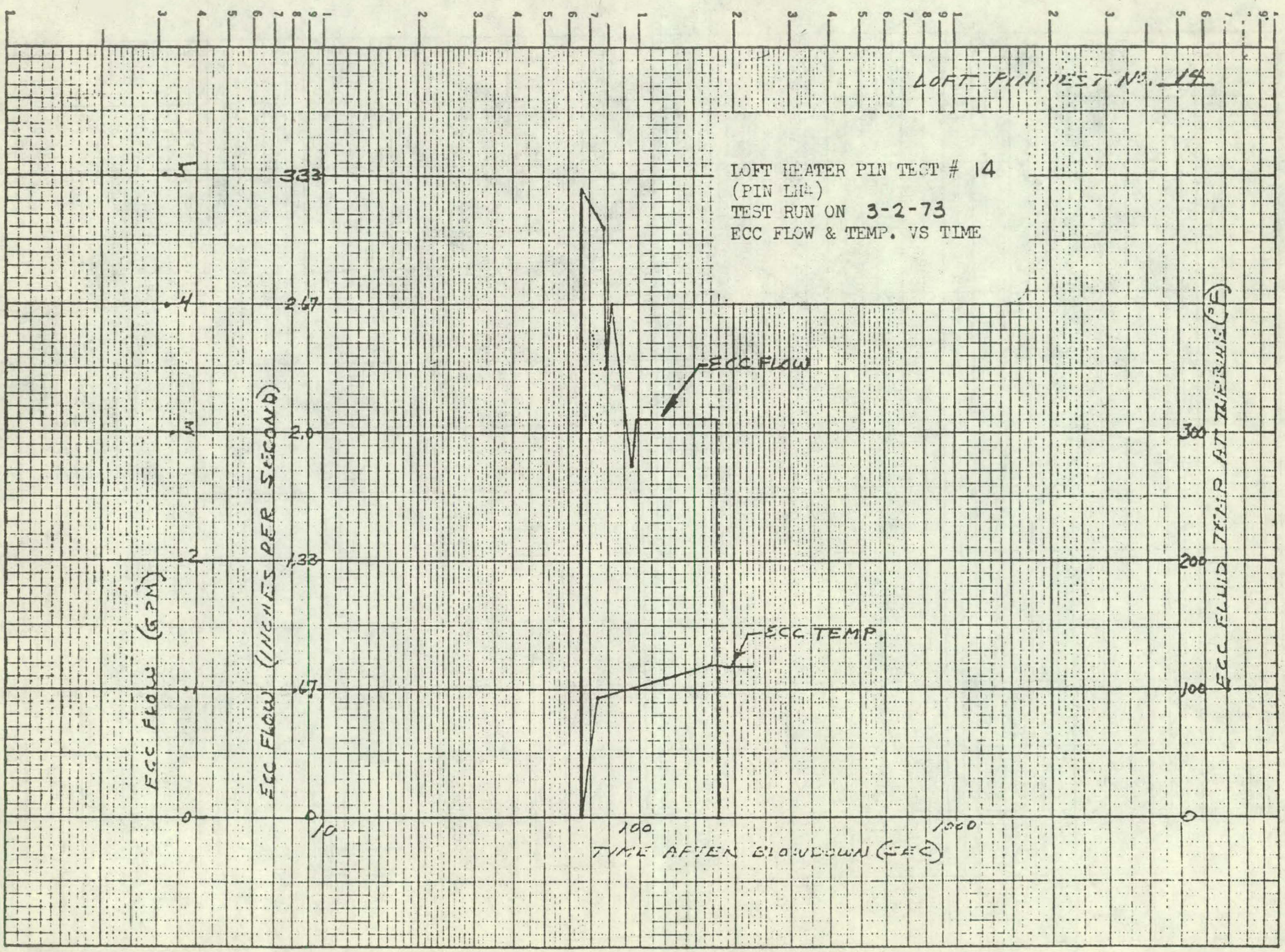

LOFT PIN TEST NO. 14
LOFT HEATER PIN TEST # 14
(PIN LH4)
TEST RUN ON 3-2-73
LOFT HEATER PIN POWER VS TIME
HTR. PIN POWER (KW)
16
14
12
10
8
6
4
2
0
1
2
3
4
BLOWDOWN PLUS 6 SEC
TOTAL TIME (HRS.)
PIN POWER (KW)
BLOWDOWN PLUS 6 SEC.
(141 sec)
10
20
30
140
180
200
220
TIME AFTER BLOWDOWN (SEC)

3-2-73

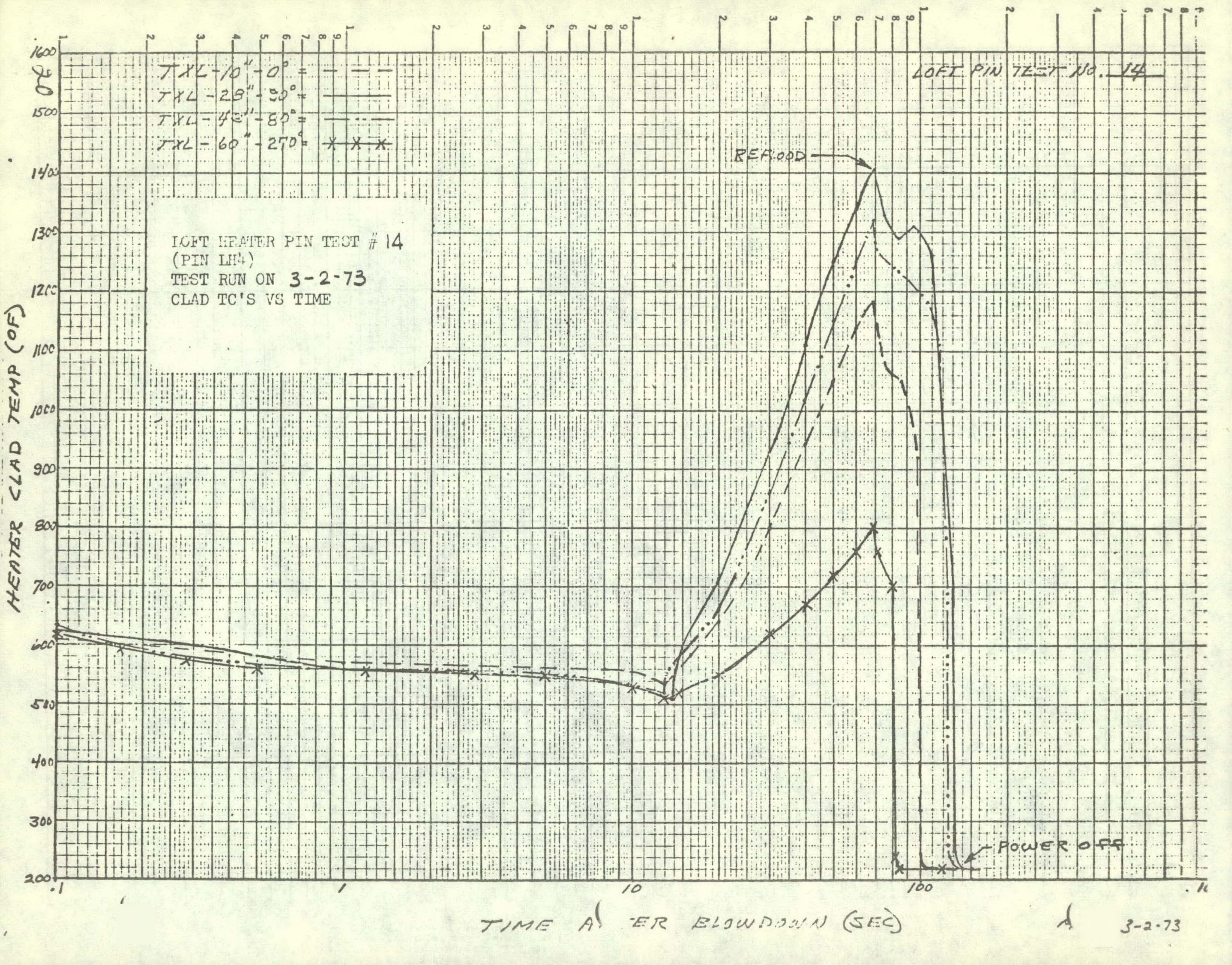

LOFT PIN TEST No. 14
LOFT HEATER PIN TEST # 14
(PIN LH4)
TEST RUN ON 3-2-73
VESSEL PRESSURE VS TIME
SYSTEM PRESSURE (PSIG)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
80
TIME AFTER BLOWDOWN (SEC)

MPJ (-73

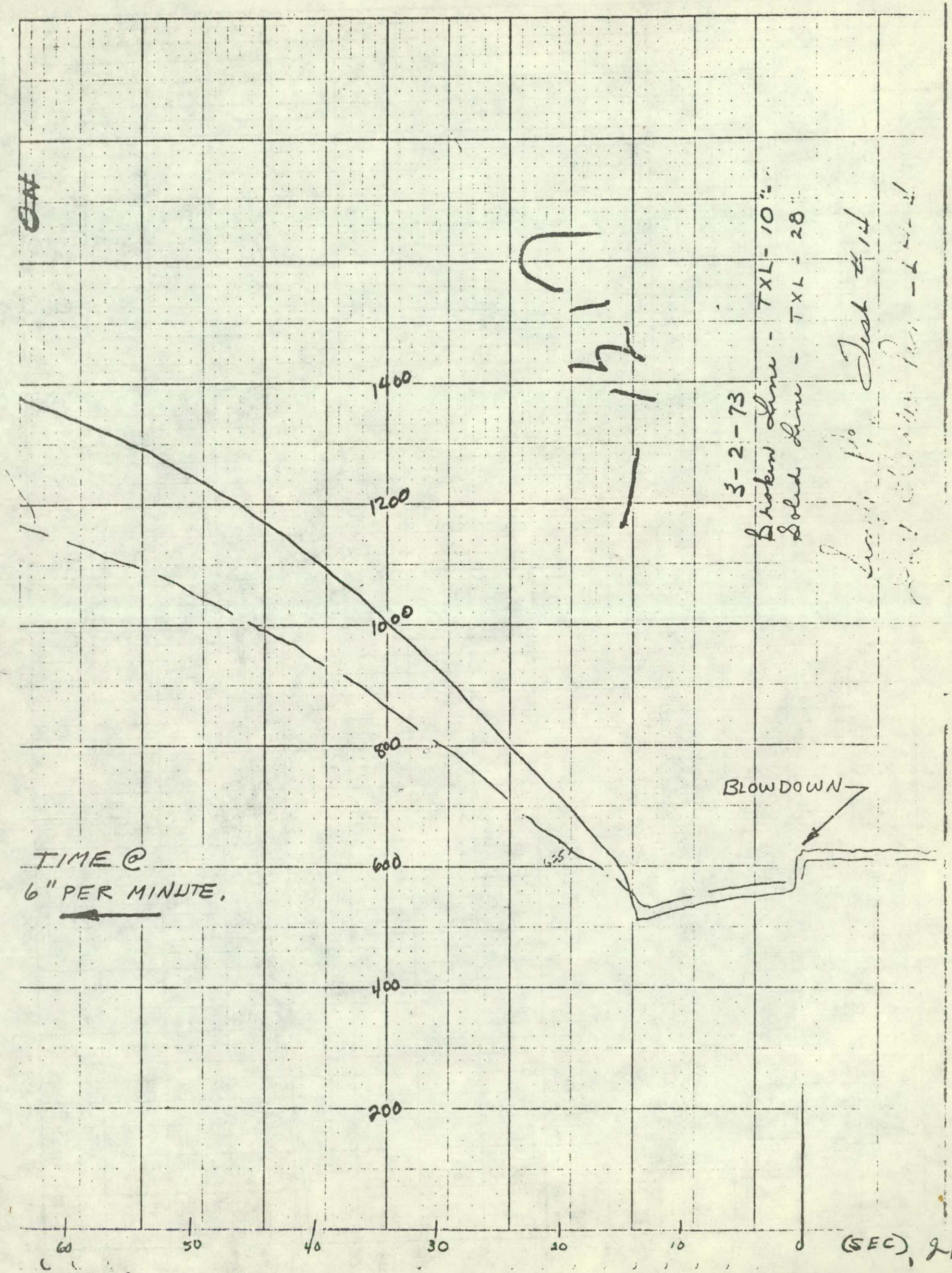
K&E SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS

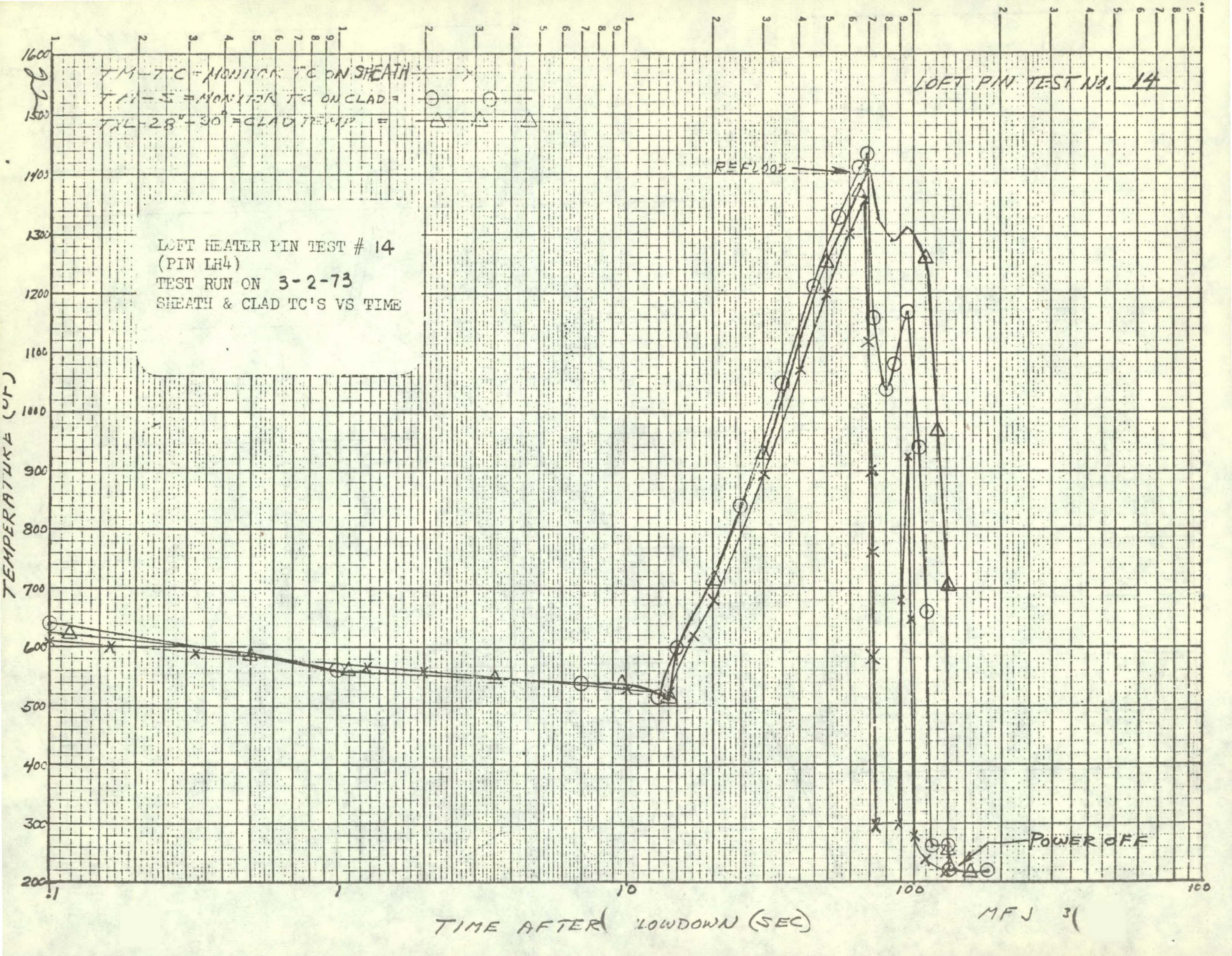


MFJ 3-2-73



TXL-10"-0° = — — —
TXL-28"-90° = ———
TXL-42"-80° = —··—
TXL-60"-270° = ×—×—×
LOFT PIN TEST NO. 14
LOFT HEATER PIN TEST # 14
(PIN LH4)
TEST RUN ON 3-2-73
CLAD TC'S VS TIME
REFLOOD
POWER OFF
HEATER CLAD TEMP (OF)
TIME AFTER BLOWDOWN (SEC)
3-2-73


3-2-73
Broken Line - TXL-10"
Solid Line - TXL-28"
Test #1
1400
1200
1000
800
600
400
200
BLOWDOWN
TIME @
6" PER MINUTE.
60
50
40
30
20
10
0
(SEC)



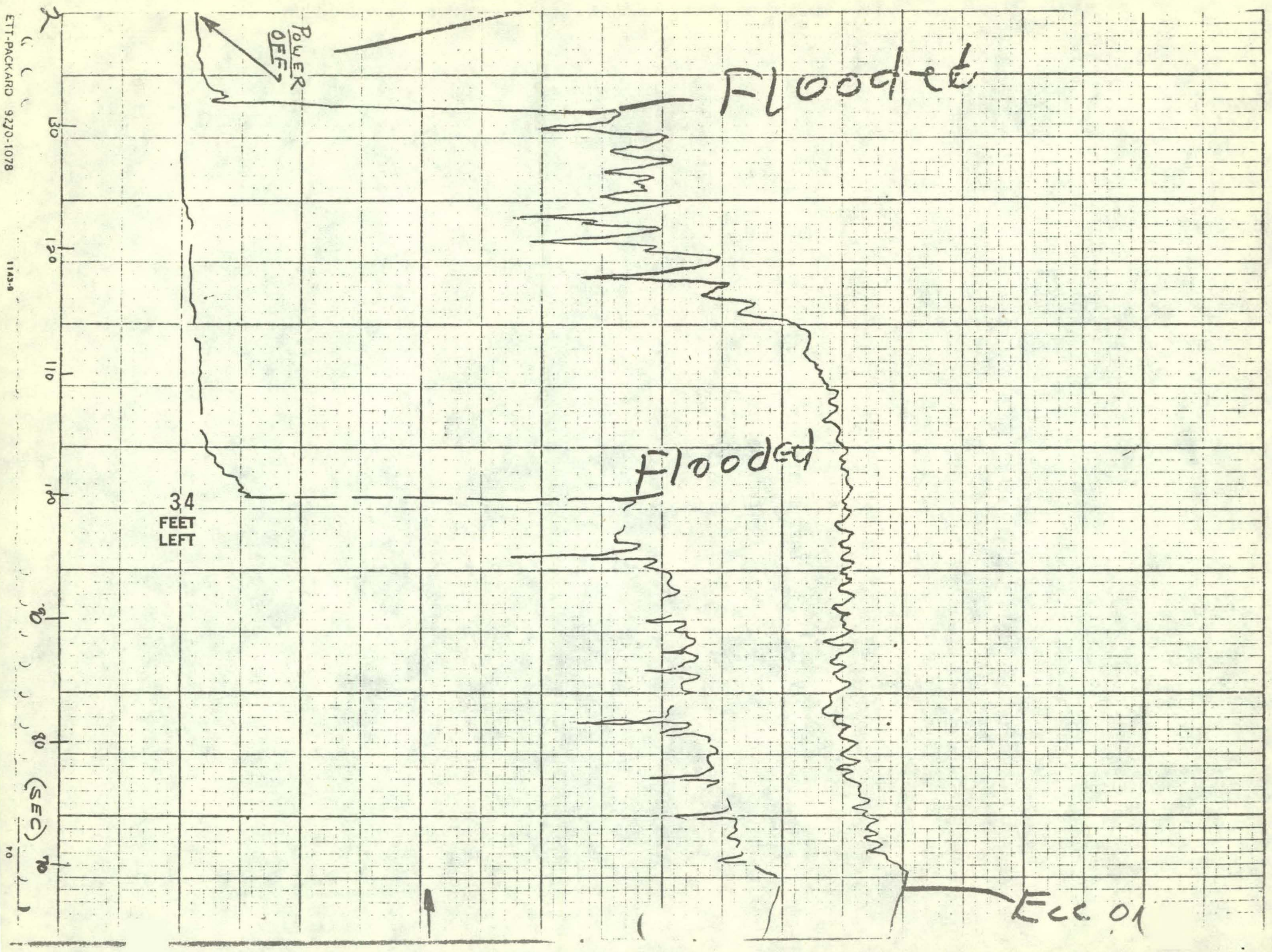
TM-TC = MONITOR TC ON SHEATH
TM-5 = MONITOR TC ON CLAD
TXL-28°-30° = CLAD TEMP
LOFT PIN TEST NO. 14
REFLOOD
LOFT HEATER PIN TEST # 14
(PIN LH4)
TEST RUN ON 3-2-73
SHEATH & CLAD TC'S VS TIME
POWER OFF
TEMPERATURE (°F)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
.1
1
10
100
TIME AFTER BLOWDOWN (SEC)
MFJ

TEST DATA FOR

LOFT HEATER PIN LH-4

TEST NO. 15

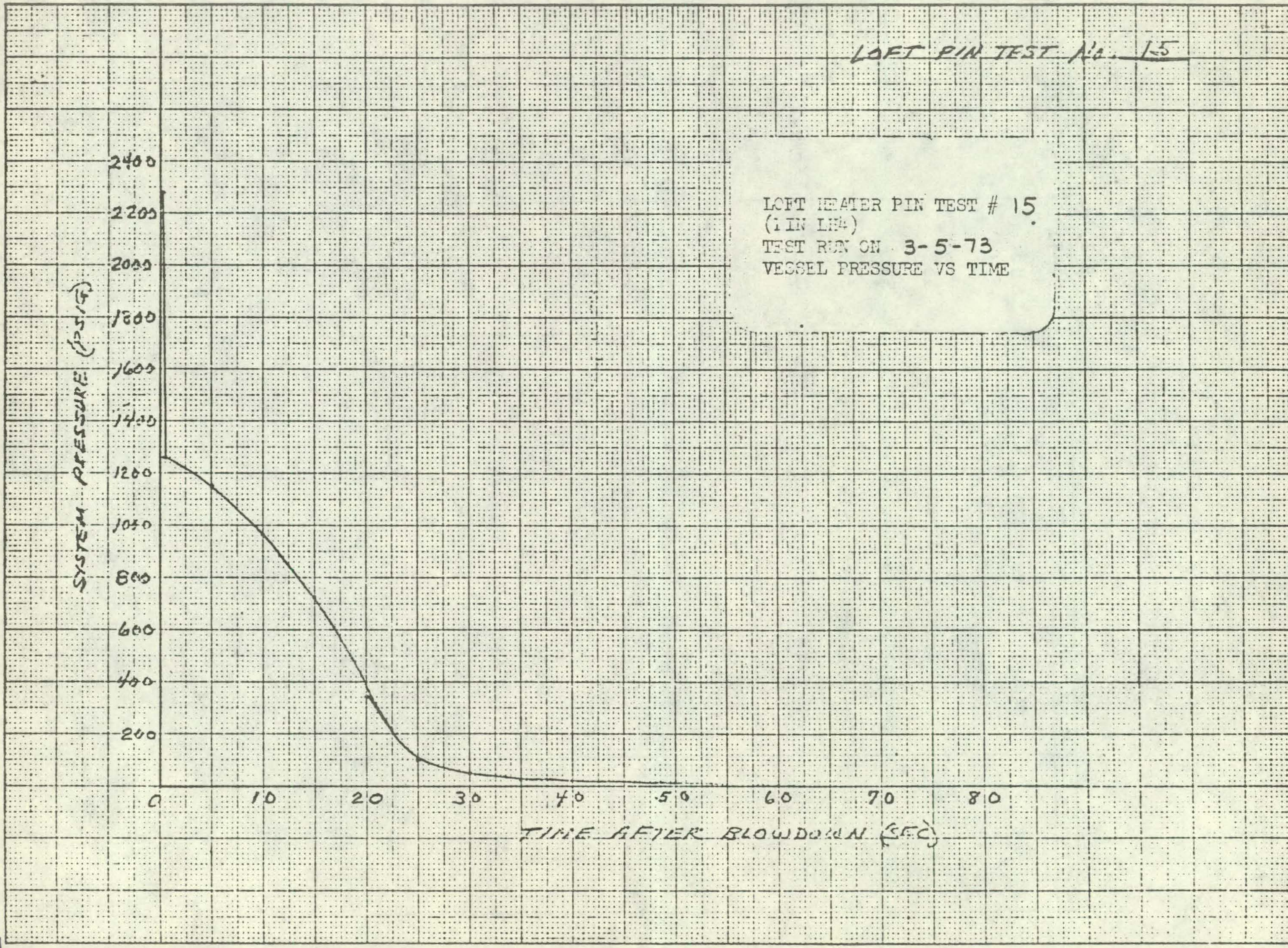
3/5/73



POWER OFF
Flooded
Flooded
34 FEET LEFT
Ecc 01
(SEC)
ETT-PACKARD 9270-1078

KEUFFEL & ESSER CO.

LOFT PIN TEST No. 15



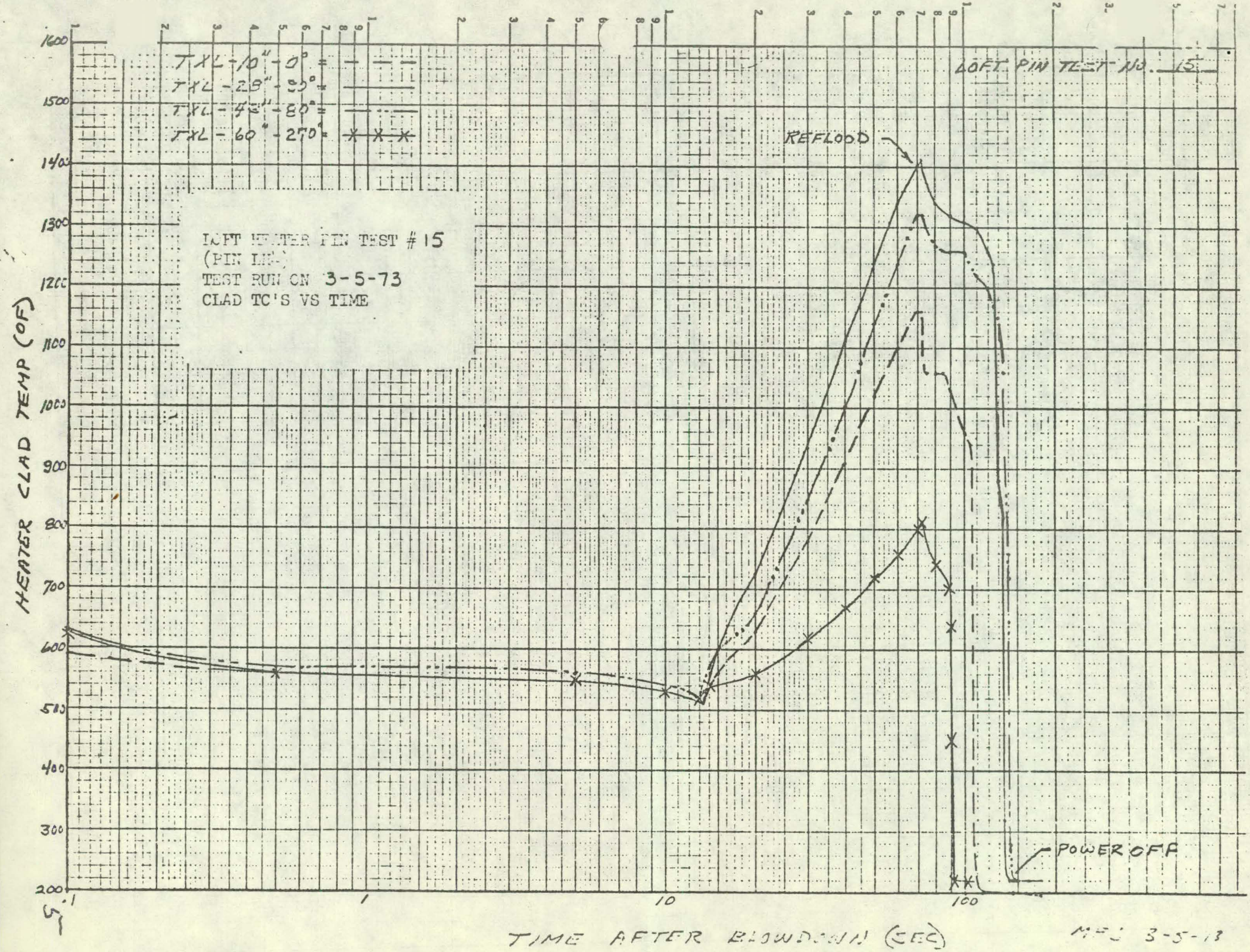
MP 3-5-73

3-5-73

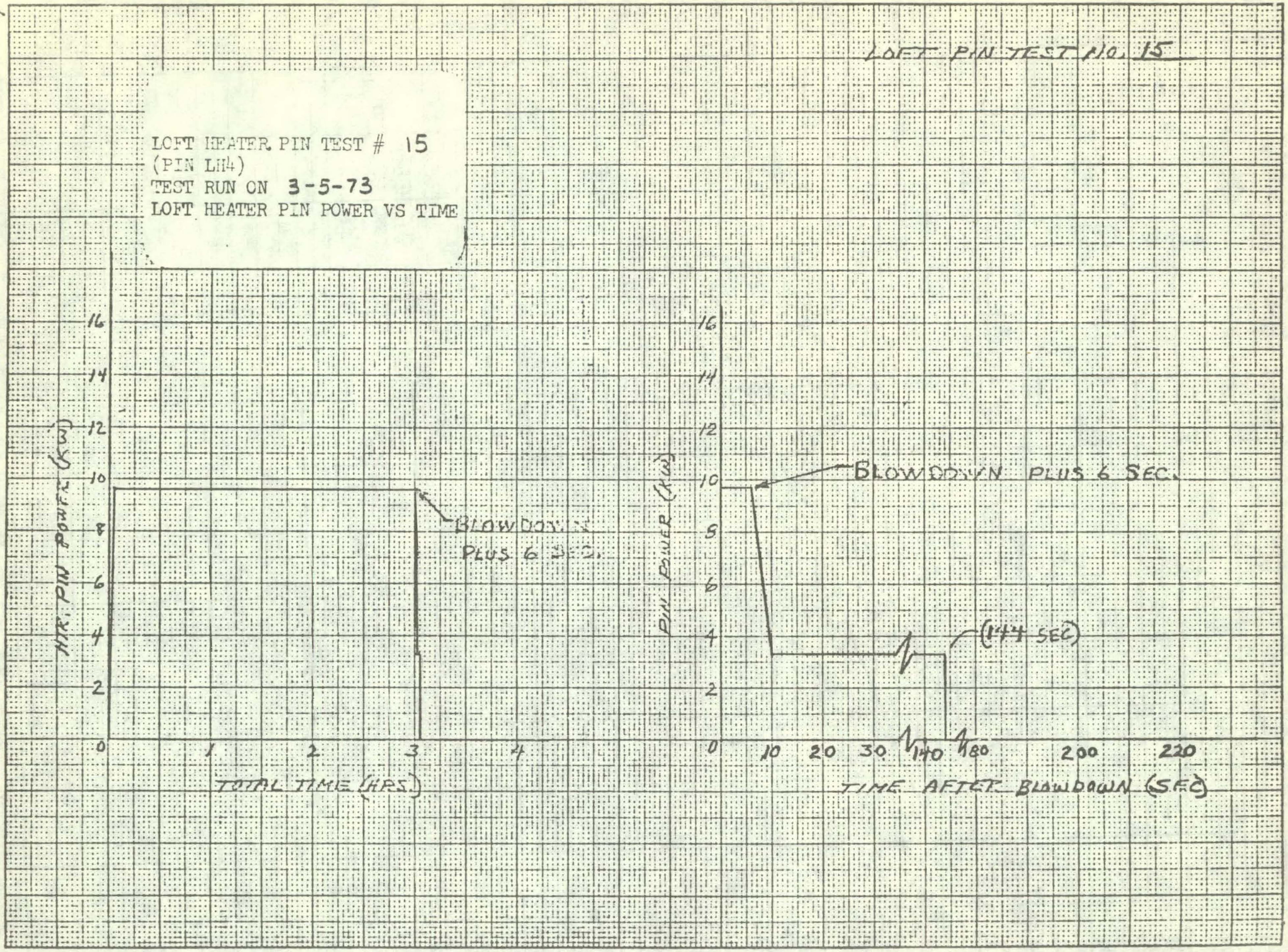
LOFT PIN TEST NO. 15

INSTRUMENT READINGS PRIOR TO BLOWDOWN

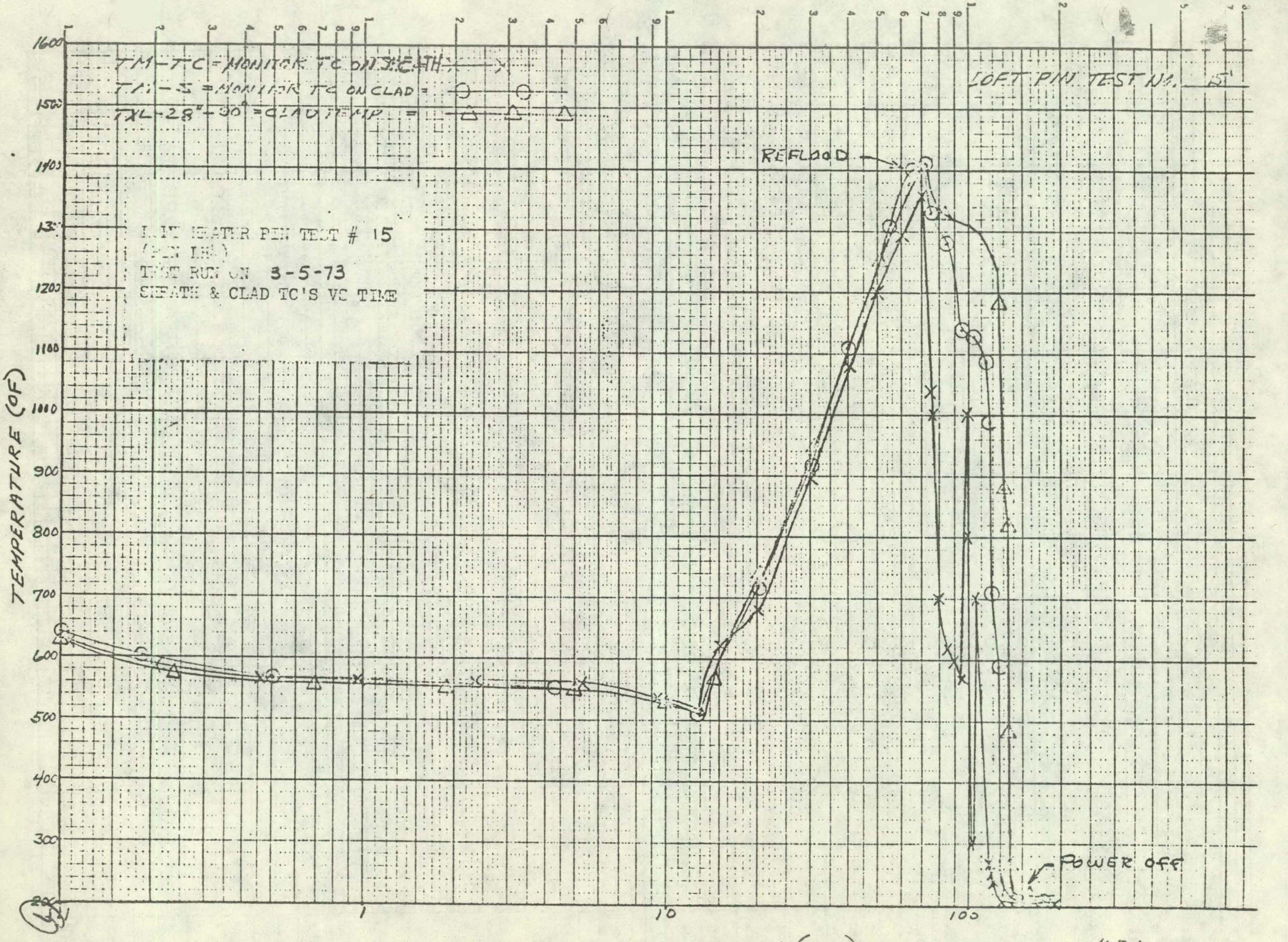
Station	Measurement	Reading	Units
12	Inlet Temperature RTB	556	°F
13	LOFT Vessel Outlet Temp. (TC)	607	°F
14(A)	Inlet Temperature (TC)	555	°F
15	Semiscale Vessel Outlet Temp. (TC)	590	°F
16	Outlet Temperature RTB	591	°F
17	ECC Flow (Turbine)	-----	GPM
18	ECC Vessel Temperature	134	°F
24	System Pressure	2285	PSIG
29	LOFT Heater Clad Temperature 10"	590	°F
30	LOFT Heater Clad Temperature 28"	630	°F
31	LOFT Heater Clad Temperature 43"	630	°F
32	LOFT Heater Clad Temperature 60"	625	°F
33	ECC Fluid Temperature (At Turbine)	77	°F
LOFT Pin	Voltage Current	97 101	Volts Amps
LOFT Pin	TM-TC Monitor TC on Sheath TM-S Monitor TC on Clad	625 640	°F °F



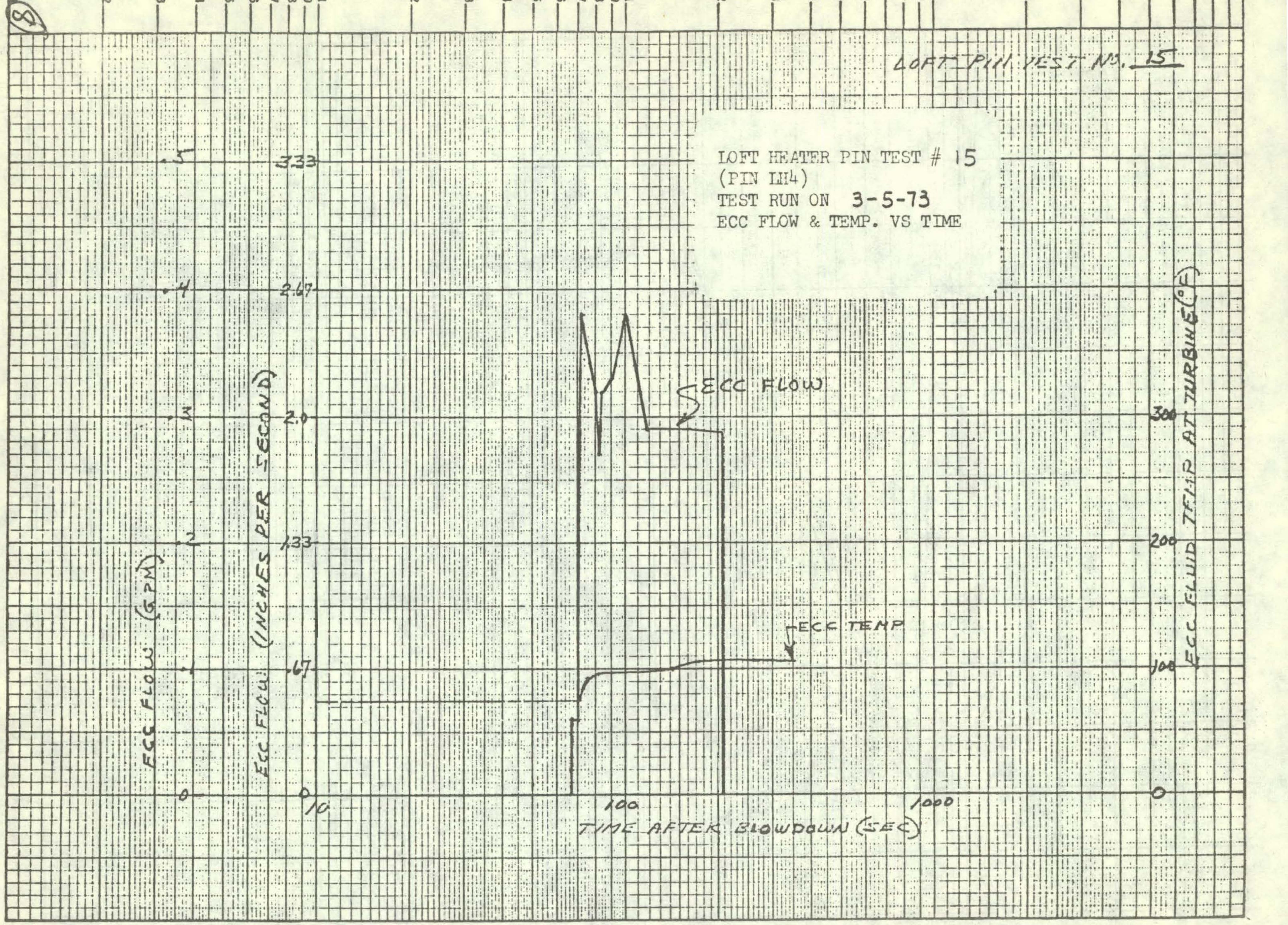
TXL - 10" - 0° =
TXL - 28" - 90° =
TXL - 43" - 80° =
TXL - 60" - 270° =
LOFT PIN TEST NO. 15
LOFT HEATER PIN TEST # 15
(PIN LE-)
TEST RUN ON 3-5-73
CLAD TC'S VS TIME
REFLOOD
POWER OFF
HEATER CLAD TEMP (°F)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
.1
1
10
100
TIME AFTER BLOWDOWN (SEC)
MFJ 3-5-73


LOFT PIN TEST NO. 15
LOFT HEATER PIN TEST # 15
(PIN LH4)
TEST RUN ON 3-5-73
LOFT HEATER PIN POWER VS TIME
HTR. PIN POWER (KW)
16
14
12
10
8
6
4
2
0
1
2
3
4
TOTAL TIME (HRS)
BLOWDOWN
PLUS 6 SEC.
PIN POWER (KW)
BLOWDOWN PLUS 6 SEC.
(144 SEC)
10
20
30
140
180
200
220
TIME AFTER BLOWDOWN (SEC)

MPJ 3-5-73


TM-TC = MONITOR TC ON SHEATH = —x—
TM-S = MONITOR TC ON CLAD = —○—○—
TXL-28"-90° = CLAD TEMP = —△—△—△—
LOFT PIN TEST No. 15
LOFT HEATER PIN TEST # 15
TEST RUN ON 3-5-73
SHEATH & CLAD TC'S VS TIME
REFLOOD
POWER OFF
TEMPERATURE (°F)
TIME AFTER BLOWDOWN (SEC)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
1
10
100

MPJ 3-5-73



8
LOFT PIN TEST NO. 15
LOFT HEATER PIN TEST # 15
(PIN LH4)
TEST RUN ON 3-5-73
ECC FLOW & TEMP. VS TIME
ECC FLOW
ECC TEMP
ECC FLOW (GPM)
ECC FLOW (INCHES PER SECOND)
ECC FLUID TEMP AT TURBINE (°F)
TIME AFTER BLOWDOWN (SEC)
.5
.4
.3
.2
.1
0
3.33
2.67
2.0
1.33
.67
0
10
100
1000
300
200
100
0
MPS 3-7

TEST DATA FOR

LOFT HEATER PIN LH-4

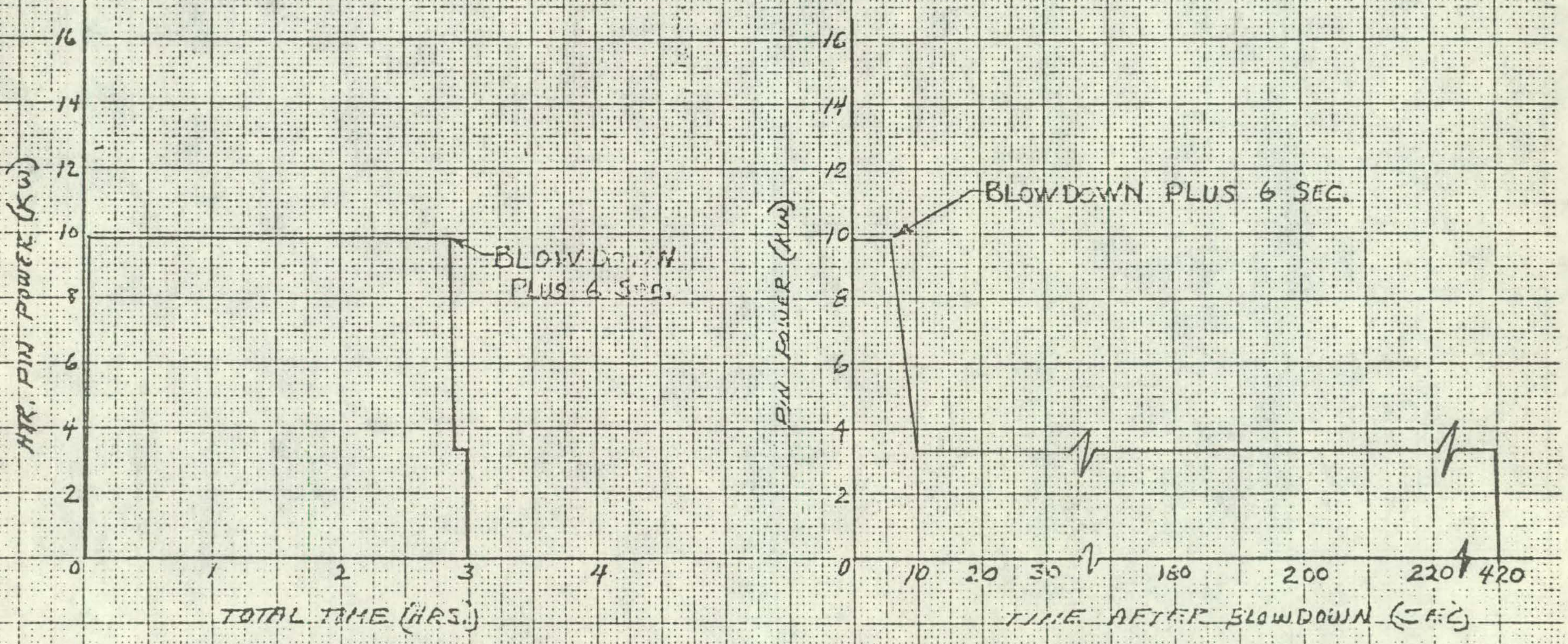
TEST NO. 16

3/6/73

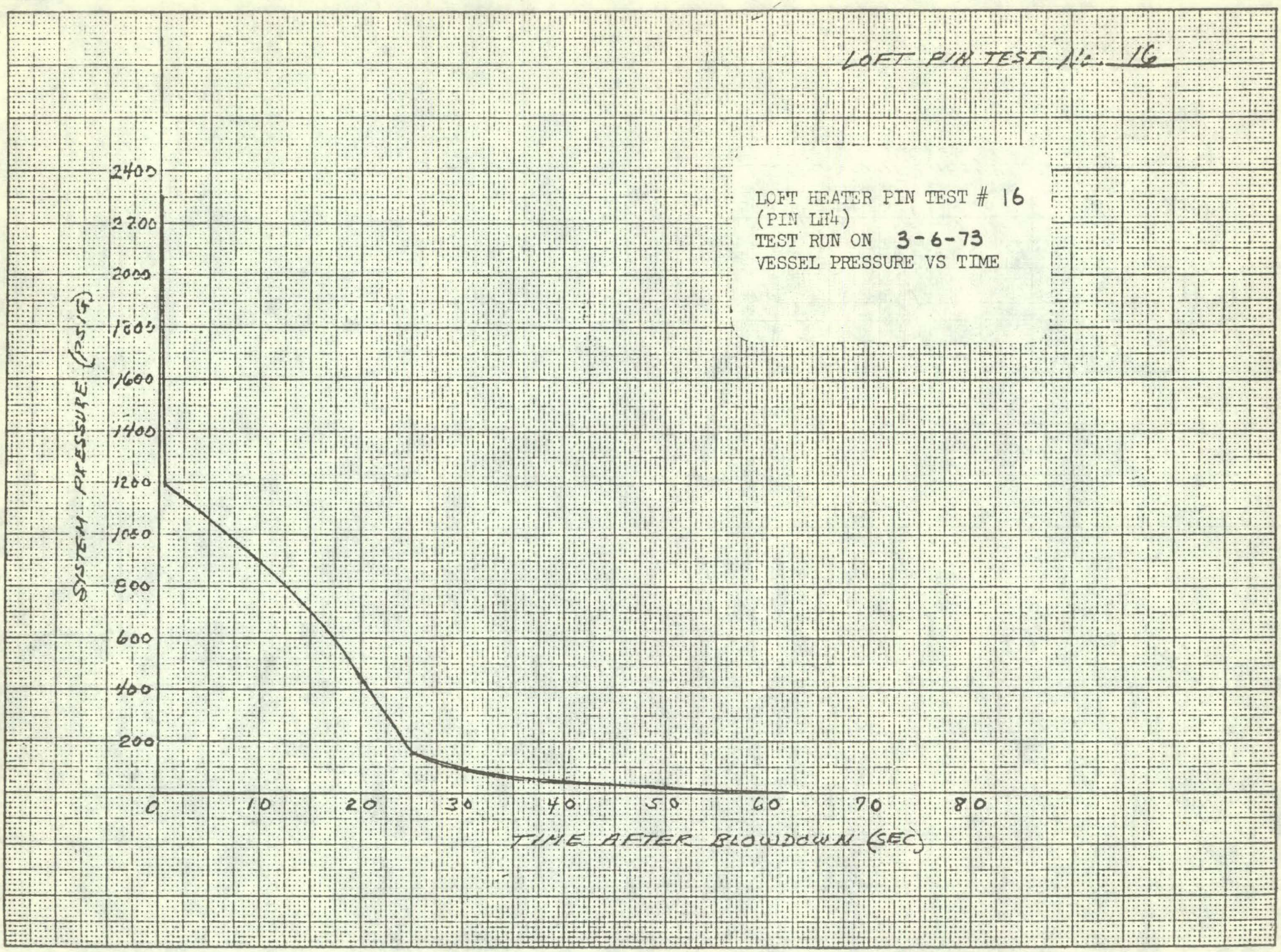
K&E 10 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.

LOFT PIN TEST NO. 16

LOFT HEATER PIN TEST # 16
(PIN LH4)
TEST RUN ON 3-6-73
LOFT HEATER PIN POWER VS TIME



MFJ 3-6-73

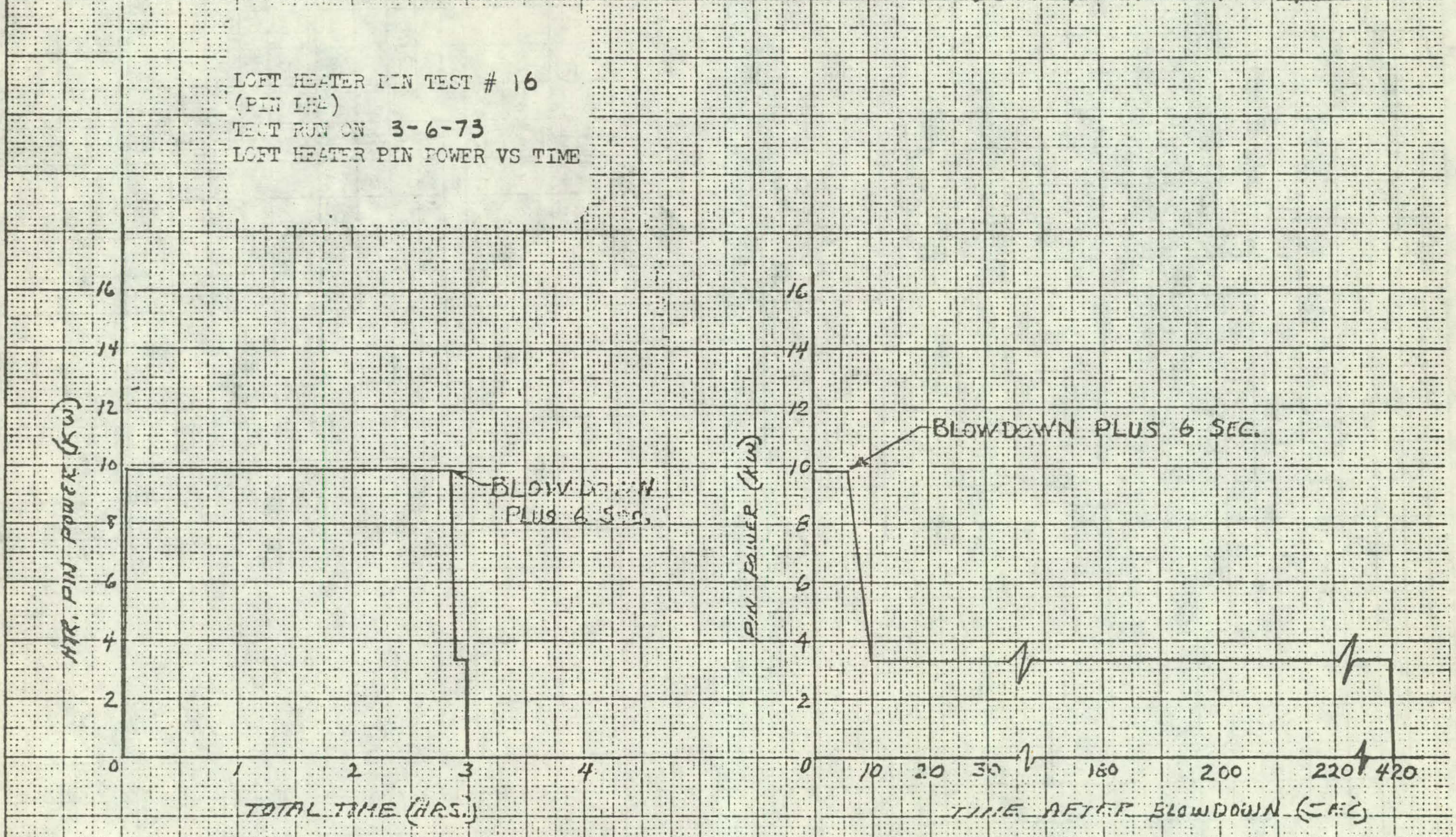


LOFT PIN TEST No. 16
LOFT HEATER PIN TEST # 16
(PIN LH4)
TEST RUN ON 3-6-73
VESSEL PRESSURE VS TIME
SYSTEM PRESSURE (PSIG)
2400
2200
2000
1800
1600
1400
1200
1050
800
600
400
200
0
10
20
30
40
50
60
70
80
TIME AFTER BLOWDOWN (SEC)

MFJ (· 73

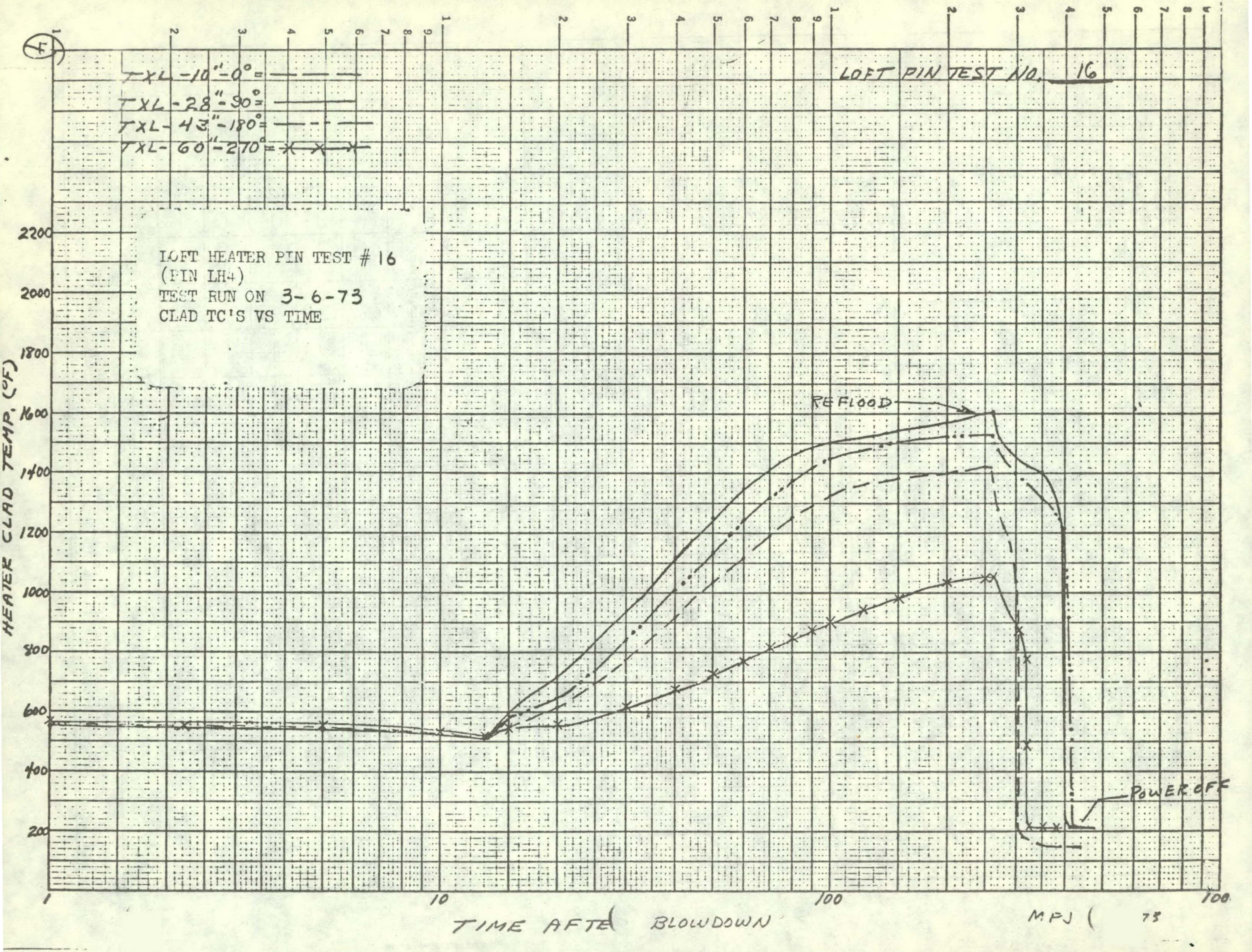
KEUFFEL & ESSER CO. 10 X 25 CM MADE IN U.S.A.

LOFT PIN TEST NO. 16



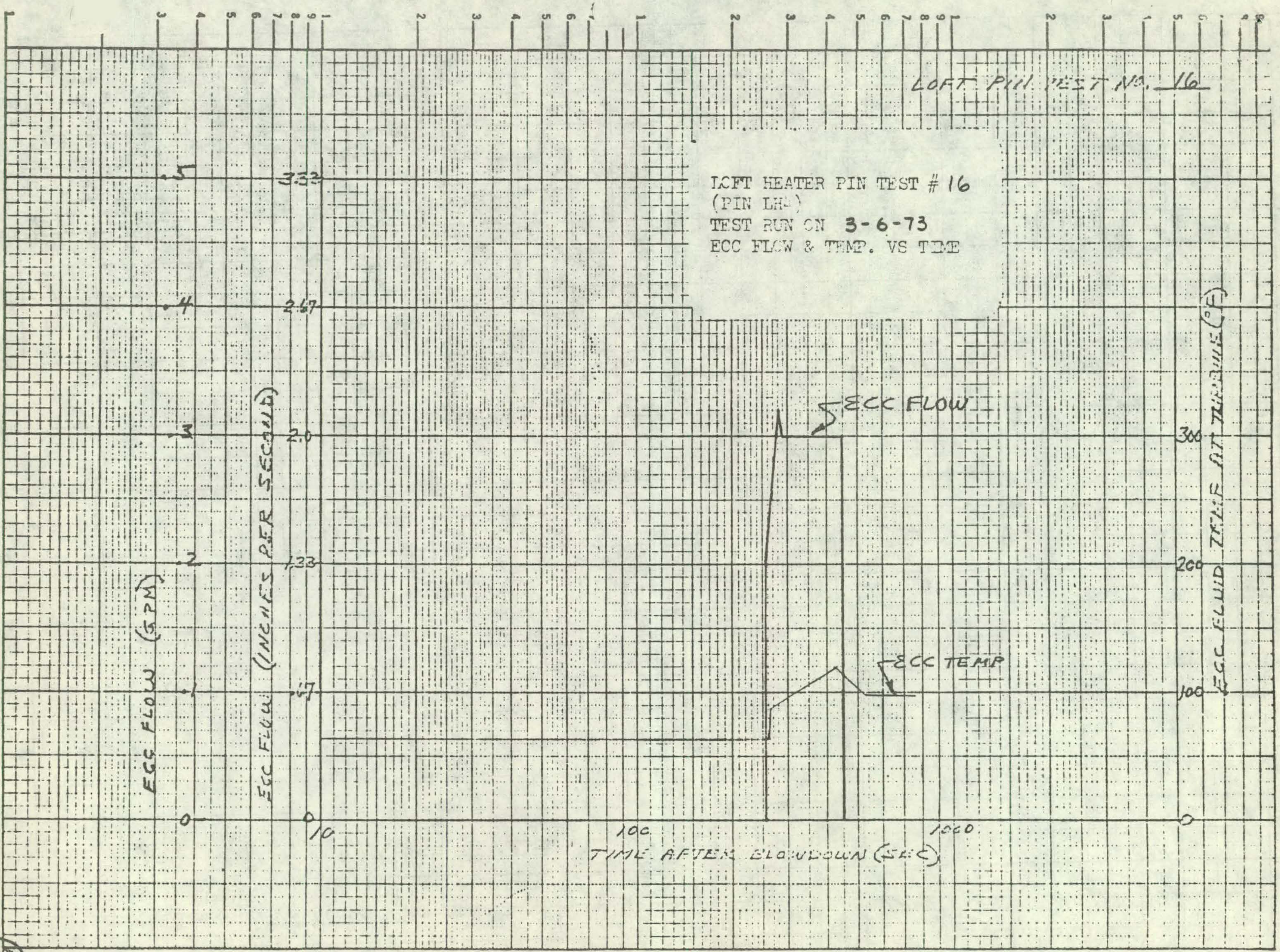
MFJ 3-6-73

(3)

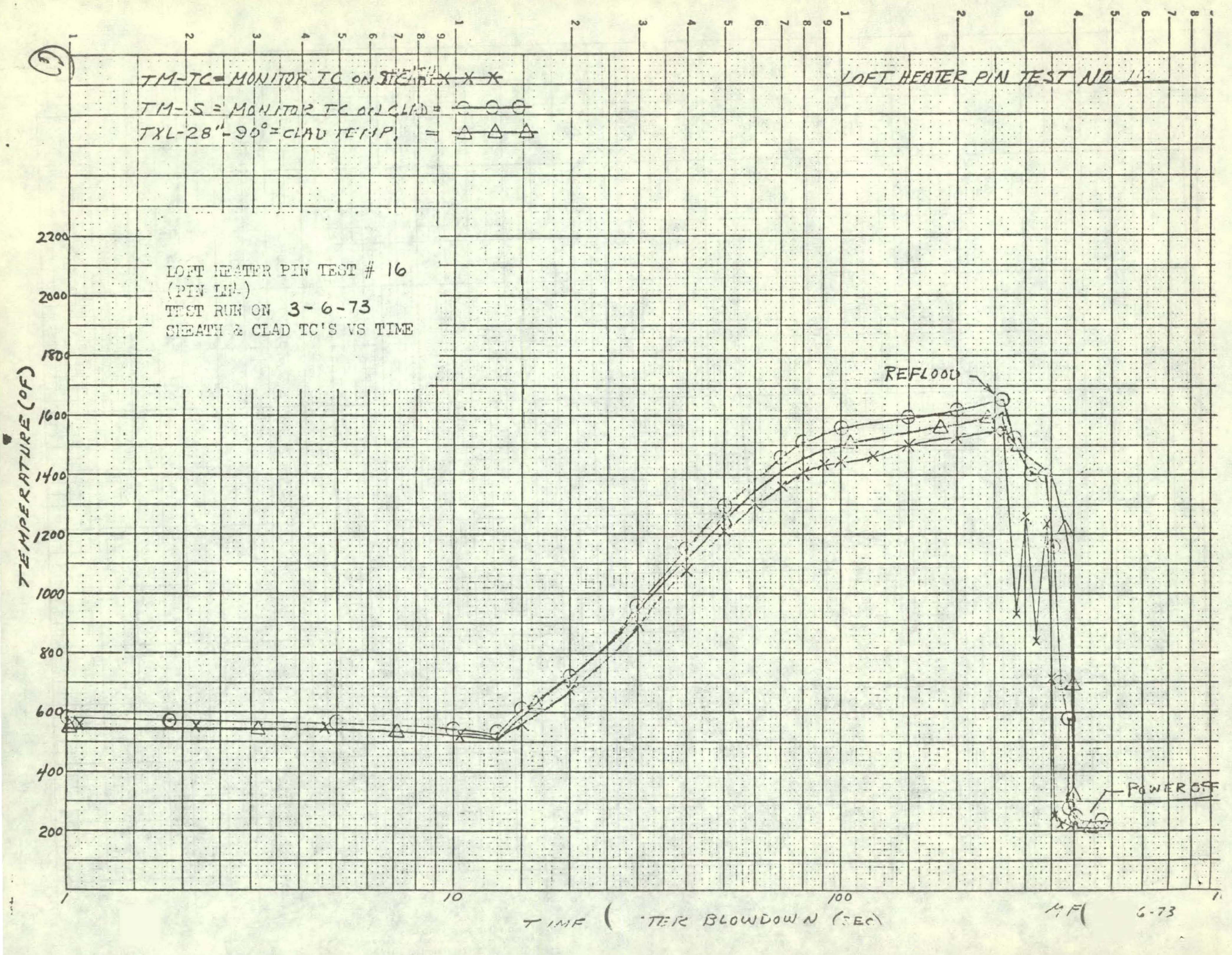


LOFT PIN TEST NO. 16
TXL-10"-0°
TXL-28"-90°
TXL-43"-180°
TXL-60"-270°
LOFT HEATER PIN TEST # 16
(PIN LH4)
TEST RUN ON 3-6-73
CLAD TC'S VS TIME
REFLOOD
POWER OFF
HEATER CLAD TEMP. (°F)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
100
TIME AFTE BLOWDOWN
MPJ (73

K+E SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS



MFS 3-6-73


TM-TC = MONITOR TC on SHEATH = X X X
TM-S = MONITOR TC on CLAD = O O O
TXL-28"-90° = CLAD TEMP. = △ △ △
LOFT HEATER PIN TEST NO. 16
LOFT HEATER PIN TEST # 16
(PIN LH-)
TEST RUN ON 3-6-73
SHEATH & CLAD TC'S VS TIME
REFLOOD
POWER OFF
TEMPERATURE (°F)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
100
TIME AFTER BLOWDOWN (SEC)
6-73

TEST DATA FOR

LOFT HEATER PIN LH-4

TEST NO. 17

3/6/73

3-6-73

LOFT PIN TEST NO. 17

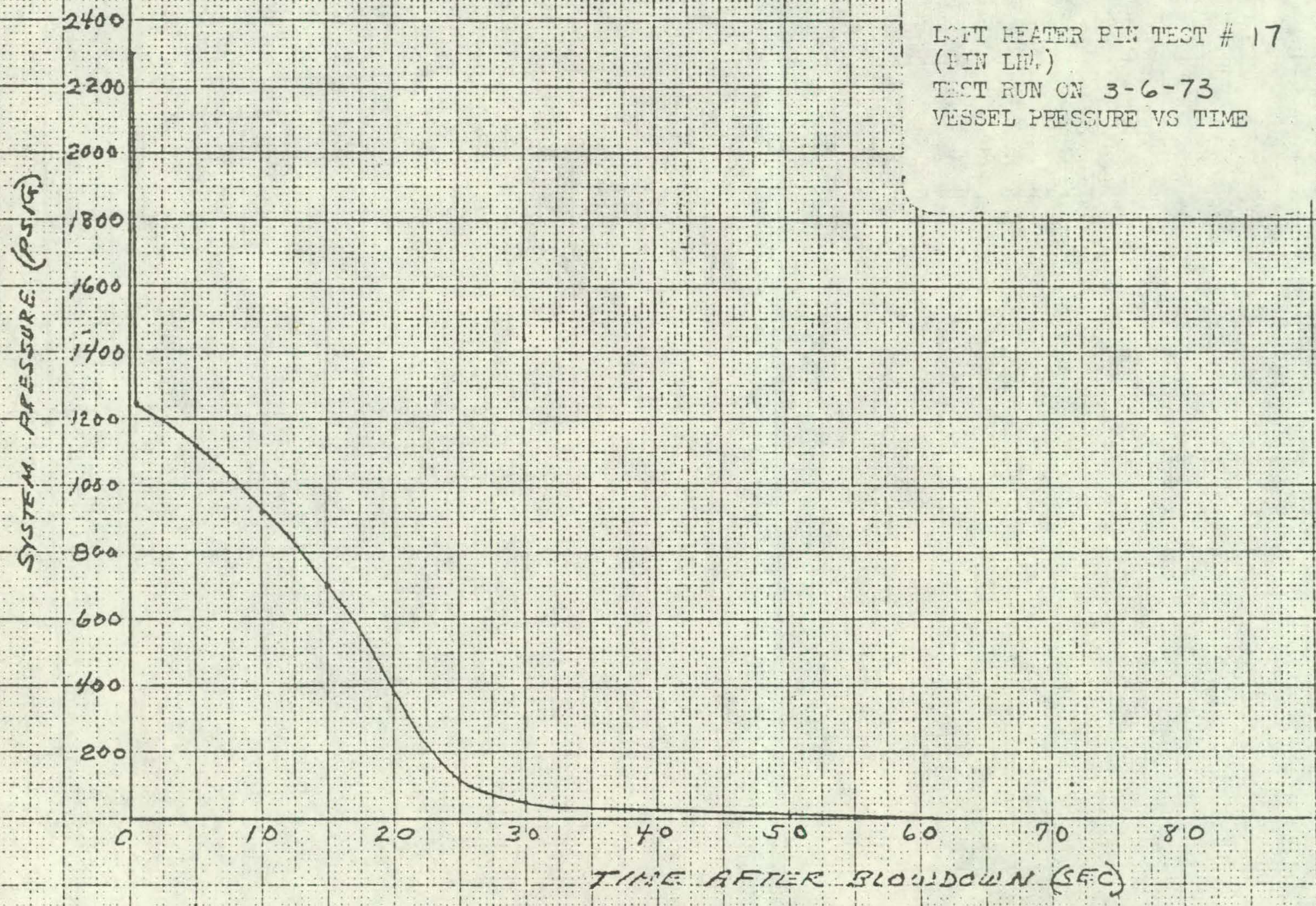
INSTRUMENT READINGS PRIOR TO BLOWDOWN

Station	Measurement	Reading	Units
12	Inlet Temperature RTB	554	°F
13	LOFT Vessel Outlet Temp. (TC)	600	°F
14(A)	Inlet Temperature (TC)	553	°F
15	Semiscale Vessel Outlet Temp. (TC)	580	°F
16	Outlet Temperature RTB	589	°F
17	ECC Flow (Turbine)	-----	GPM
18	ECC Vessel Temperature	148	°F
24	System Pressure	2300	PSIG
29	LOFT Heater Clad Temperature 10"	LOST	°F
30	LOFT Heater Clad Temperature 28"	620	°F
31	LOFT Heater Clad Temperature 43"	622	°F
32	LOFT Heater Clad Temperature 60"	625	°F
33	ECC Fluid Temperature (At Turbine)	54	°F
LOFT Pin	Voltage Current	97 100	Volts Amps
LOFT Pin	TM-TC Monitor TC on Sheath TM-S Monitor TC on Clad	605 650	°F °F

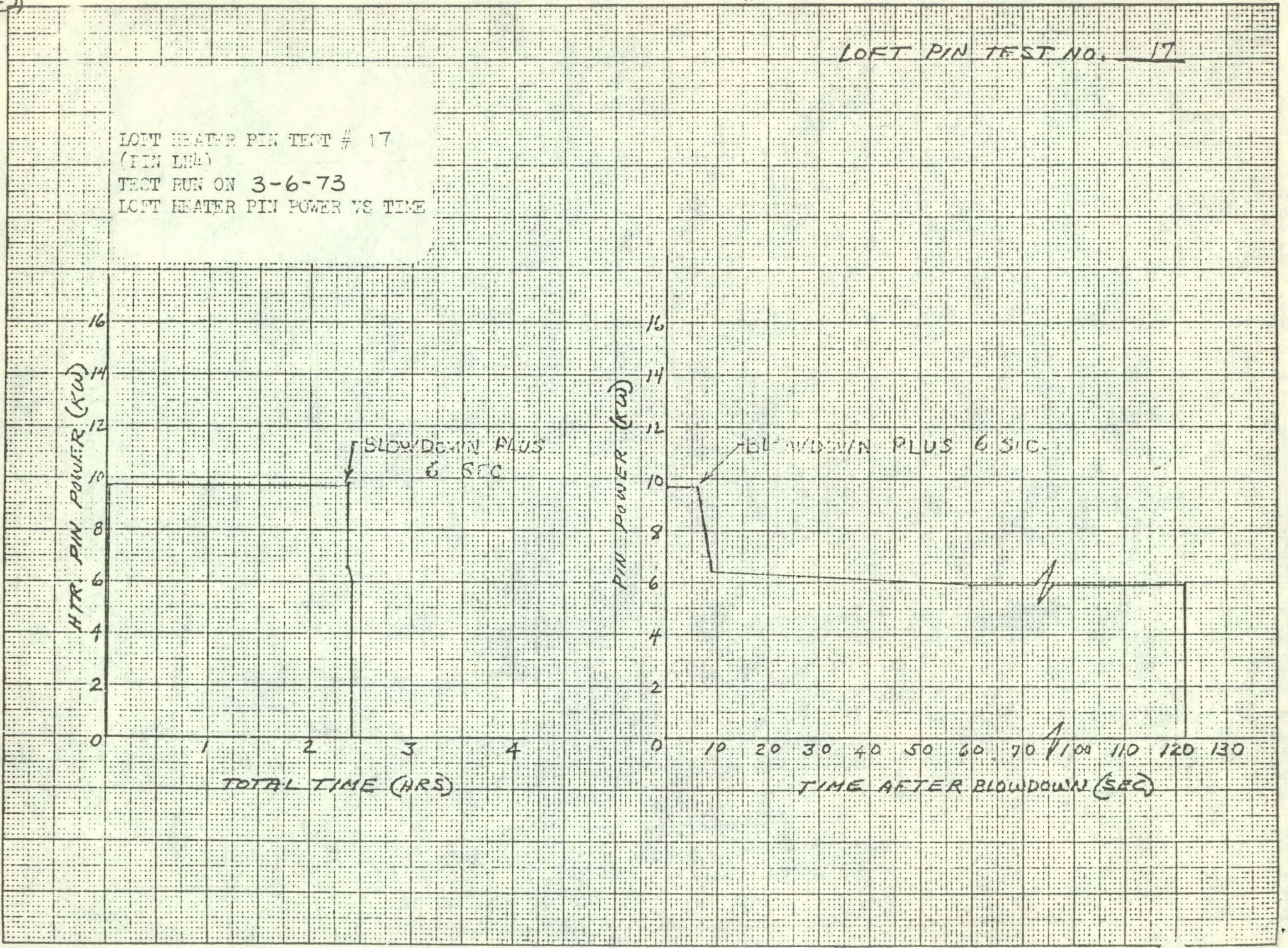
KEUFFEL & ESSER CO. MADE IN U.S.A.

LOFT PIN TEST No. 17

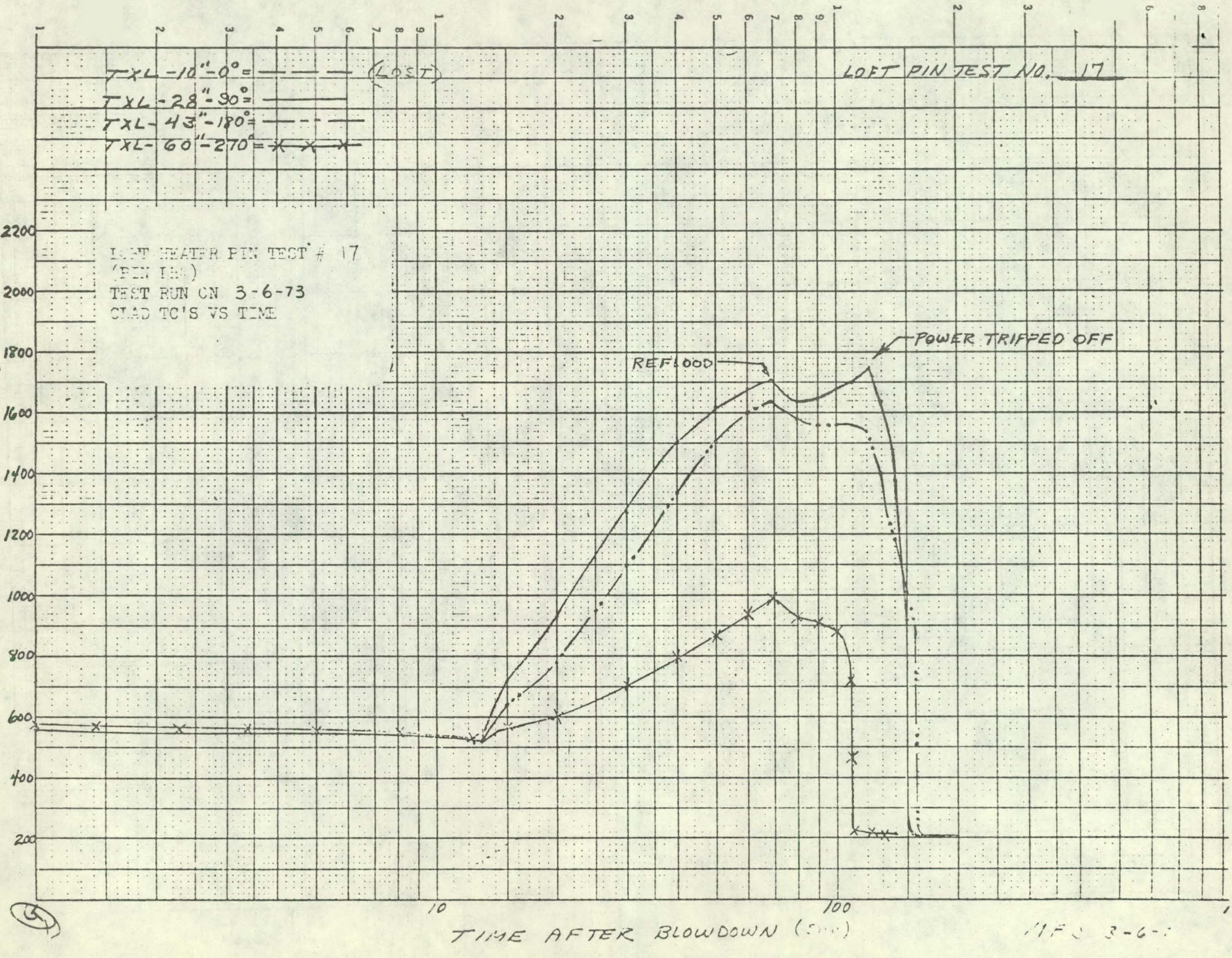
LOFT HEATER PIN TEST # 17
(PIN LH4)
TEST RUN ON 3-6-73
VESSEL PRESSURE VS TIME

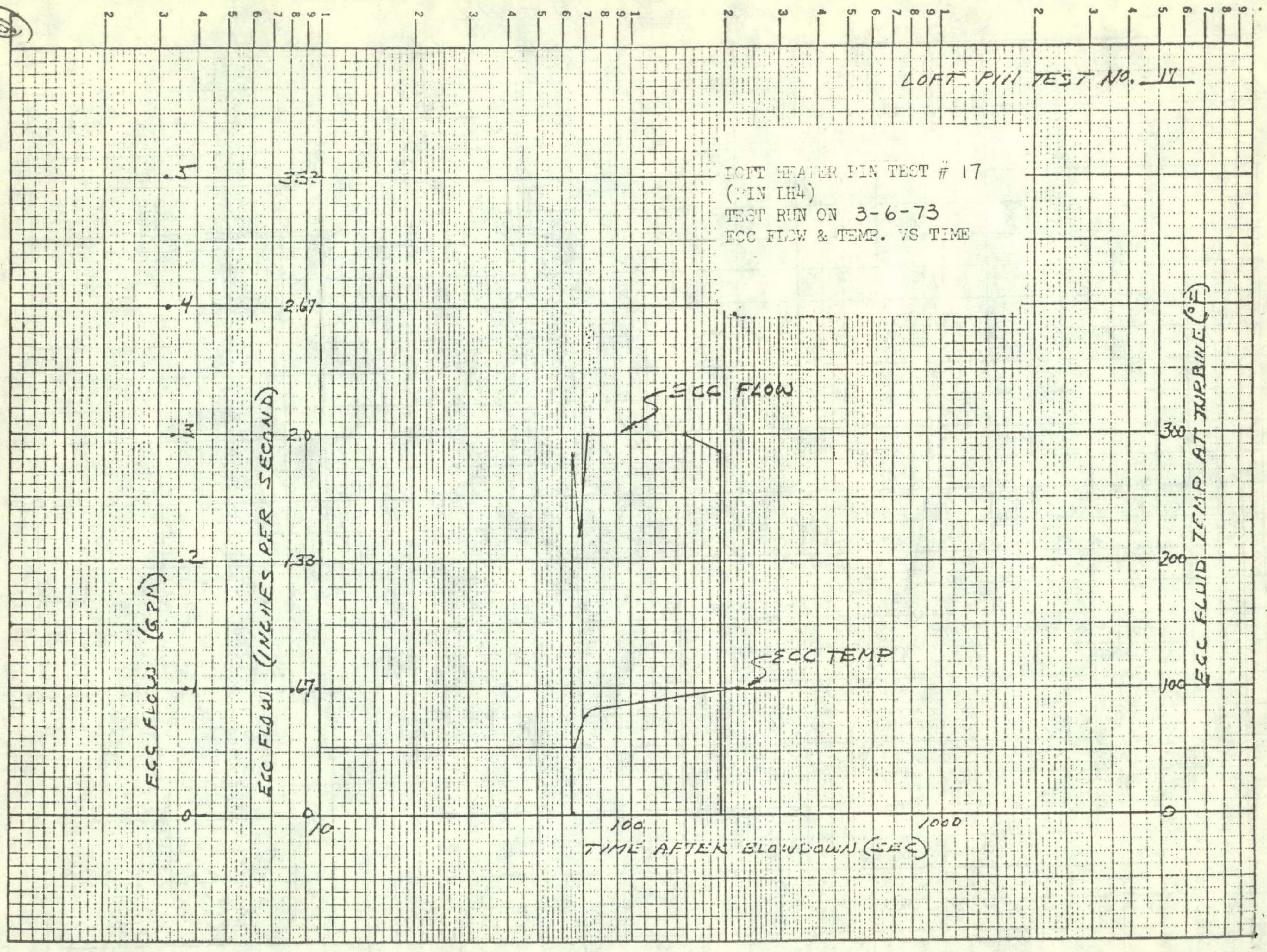


MFJ 3-6-

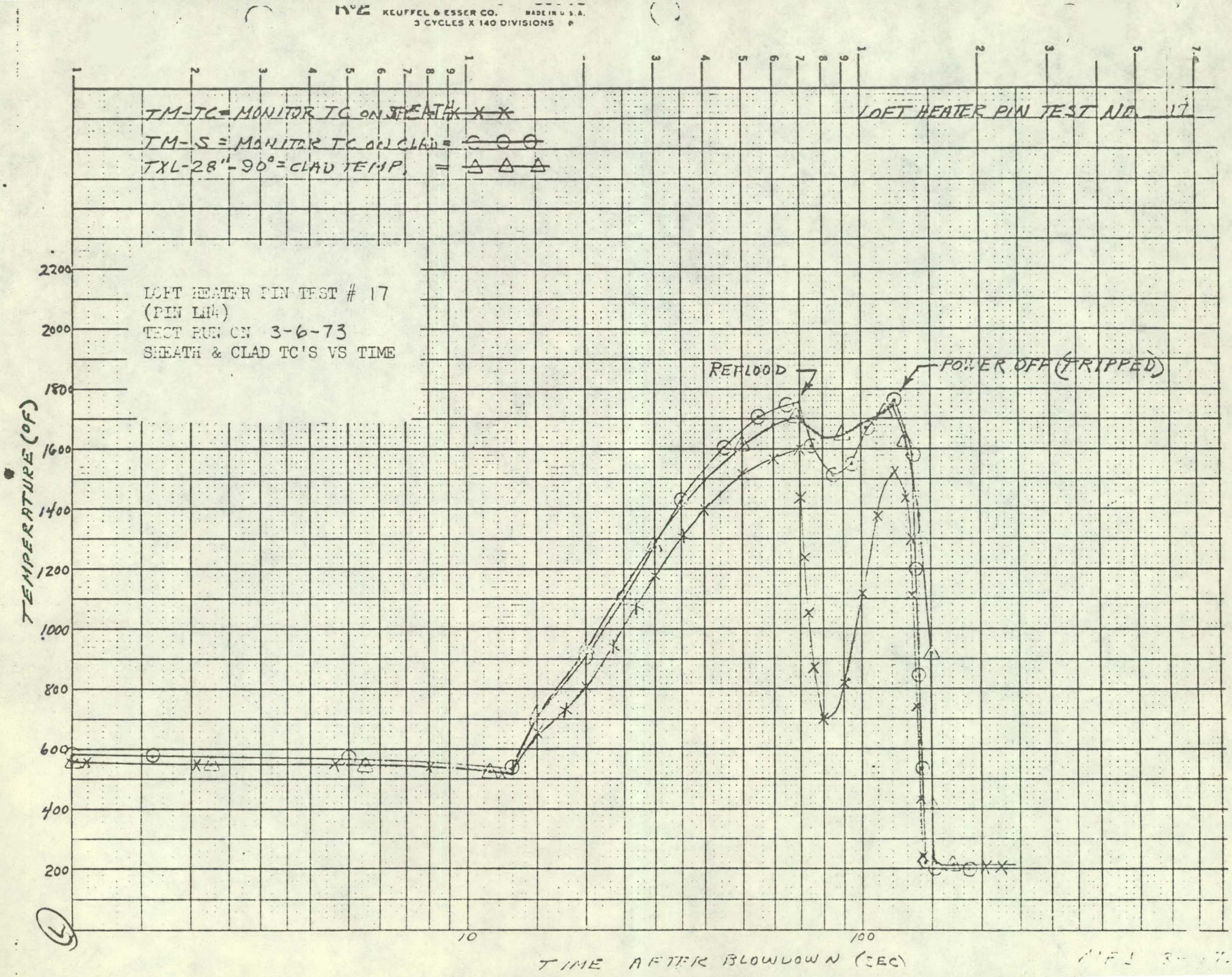


LOFT PIN TEST NO. 17
LOFT HEATER PIN TEST # 17
(PIN LH4)
TEST RUN ON 3-6-73
LOFT HEATER PIN POWER VS TIME
HTR. PIN POWER (KW)
BLOWDOWN PLUS 6 SEC
TOTAL TIME (HRS)
PIN POWER (KW)
BLOWDOWN PLUS 6 SEC.
TIME AFTER BLOWDOWN (SEC)


TXL-10"-0° = (LOST)
TXL-28"-90° =
TXL-43"-180° =
TXL-60"-270° =
LOFT PIN TEST NO. 17
LOFT HEATER PIN TEST # 17
(PIN 1R4)
TEST RUN ON 3-6-73
CLAD TC'S VS TIME
POWER TRIPPED OFF
REFLOOD
HEATER CLAD TEMP. (°F)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
10
100
TIME AFTER BLOWDOWN (sec)
MF 3-6-


LOFT PIII TEST NO. 17
LOFT HEATER PIN TEST # 17
(PIN IH4)
TEST RUN ON 3-6-73
ECC FLOW & TEMP. VS TIME
ECC FLOW
ECC TEMP
ECC FLOW (GPM)
ECC FLOW (INCHES PER SECOND)
ECC FLUID TEMP AT TURBINE (°F)
TIME AFTER BLOWDOWN (SEC)
10
100
1000
0
1
2
3
4
5
.67
1.33
2.0
2.67
3.33
100
200
300

MF (-6-73


K&E KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 140 DIVISIONS
TM-TC = MONITOR TC ON SHEATH = X X X
TM-S = MONITER TC ON CLAD = ⊙ ⊙ ⊙
TXL-28"-90° = CLAD TEMP. = △ △ △
LOFT HEATER PIN TEST NO. 17
LOFT HEATER PIN TEST # 17
(PIN LH4)
TEST RUN ON 3-6-73
SHEATH & CLAD TC'S VS TIME
REFLOOD
POWER OFF (TRIPPED)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
TEMPERATURE (°F)
10
100
TIME AFTER BLOWDOWN (SEC)

TEST DATA FOR

LOFT HEATER PIN LH-4

TEST NO. 18

3/7/73

(8)

3-7-73

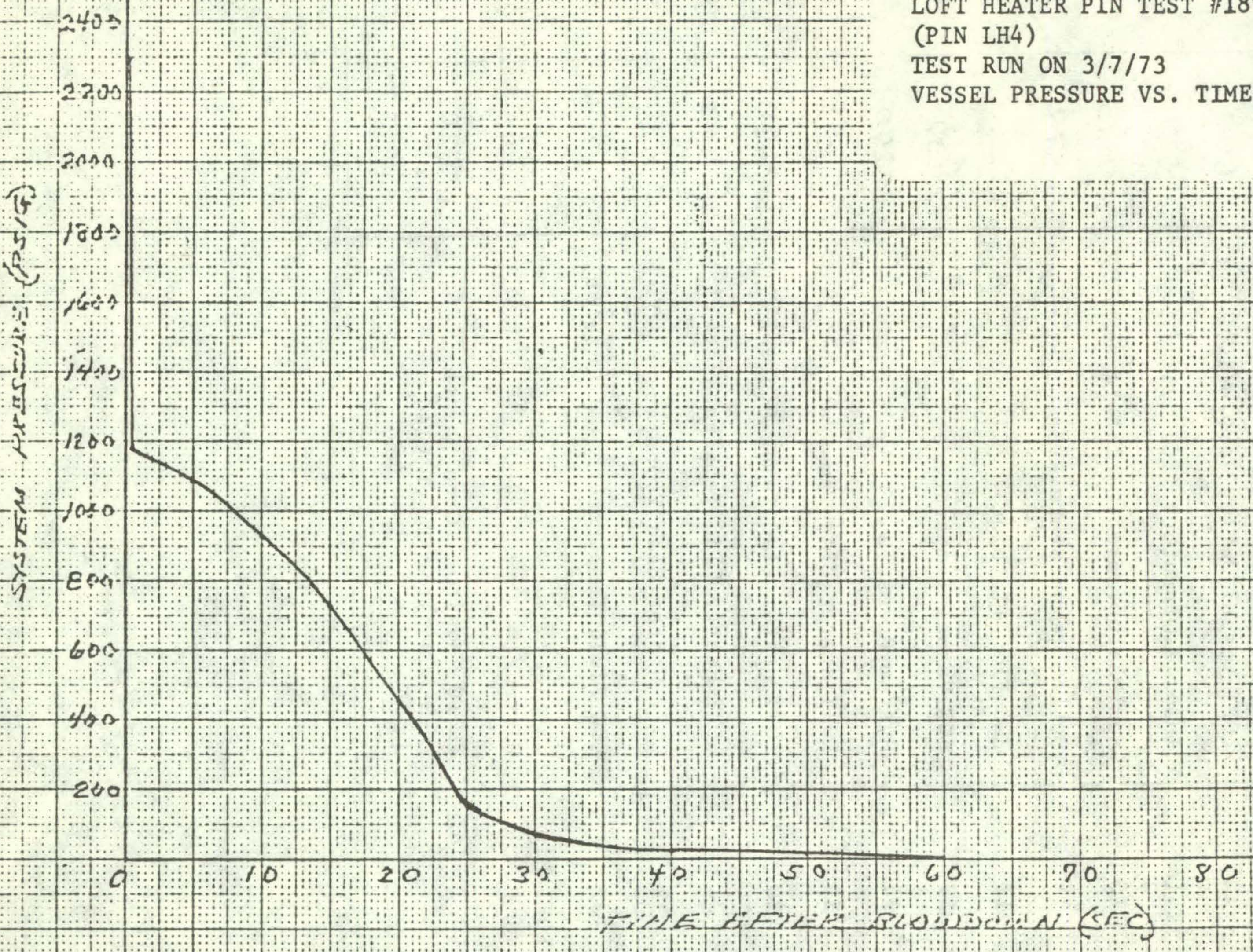
LOFT PIN TEST NO. 18

INSTRUMENT READINGS PRIOR TO BLOWDOWN

Station	Measurement	Reading	Units
12	Inlet Temperature RTB	546	°F
13	LOFT Vessel Outlet Temp. (TC)	600	°F
14(A)	Inlet Temperature (TC)	550	°F
15	Semiscale Vessel Outlet Temp. (TC)	575	°F
16	Outlet Temperature RTB	579	°F
17	ECC Flow (Turbine)	-----	GPM
18	ECC Vessel Temperature	132	°F
24	System Pressure	2290	PSIG
29	LOFT Heater Clad Temperature 10"	(LOST)	°F
30	LOFT Heater Clad Temperature 28"	620	°F
31	LOFT Heater Clad Temperature 43"	640	°F
32	LOFT Heater Clad Temperature 60"	620	°F
33	ECC Fluid Temperature (At Turbine)	76	°F
LOFT Pin	Voltage Current	97 98	Volts Amps
LOFT Pin	TM-TC Monitor TC on Sheath TM-S Monitor TC on Clad	620 650	°F °F

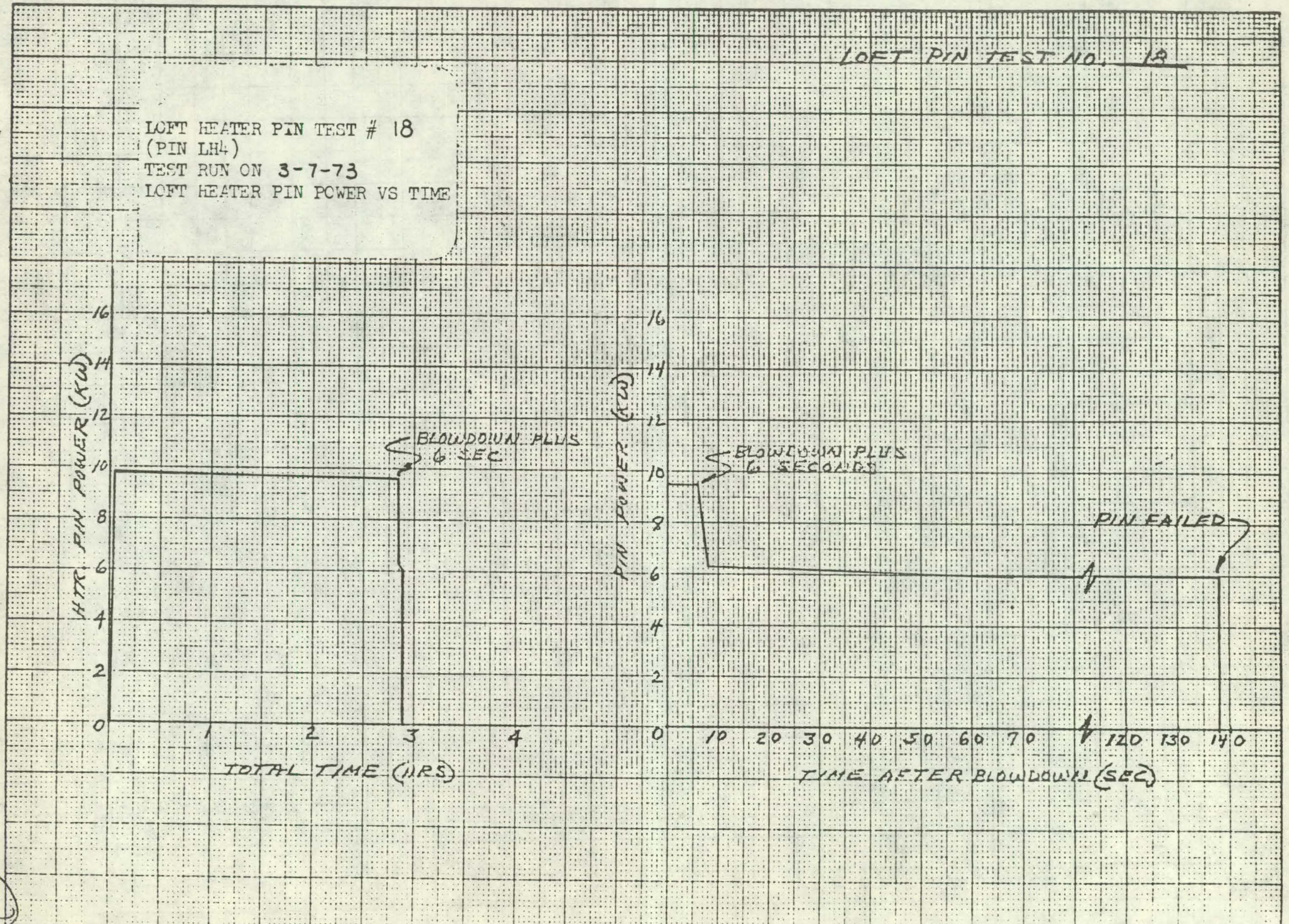
LOFT PIN TEST No. 18

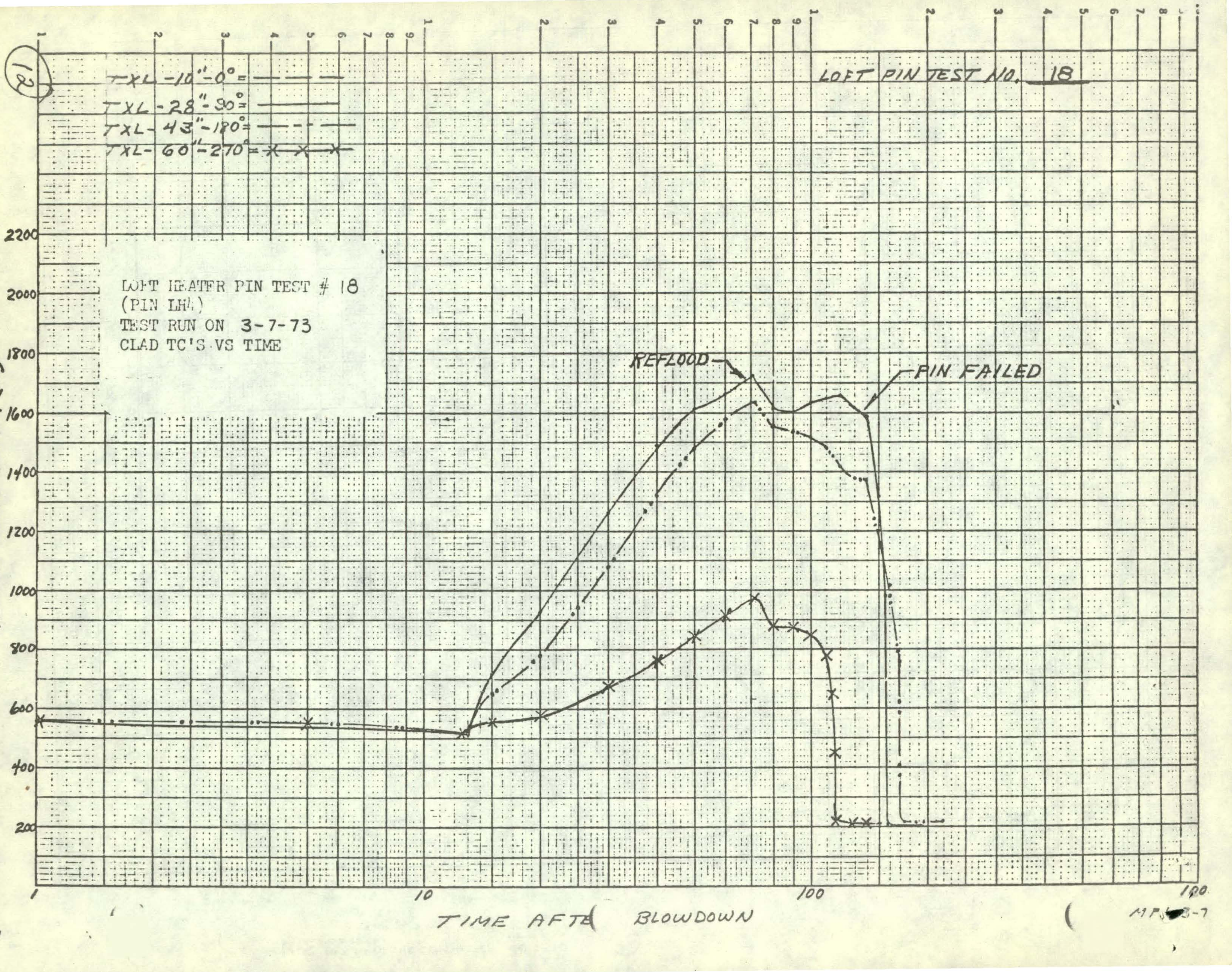
LOFT HEATER PIN TEST #18
(PIN LH4)
TEST RUN ON 3/7/73
VESSEL PRESSURE VS. TIME



MPf 3-7-73

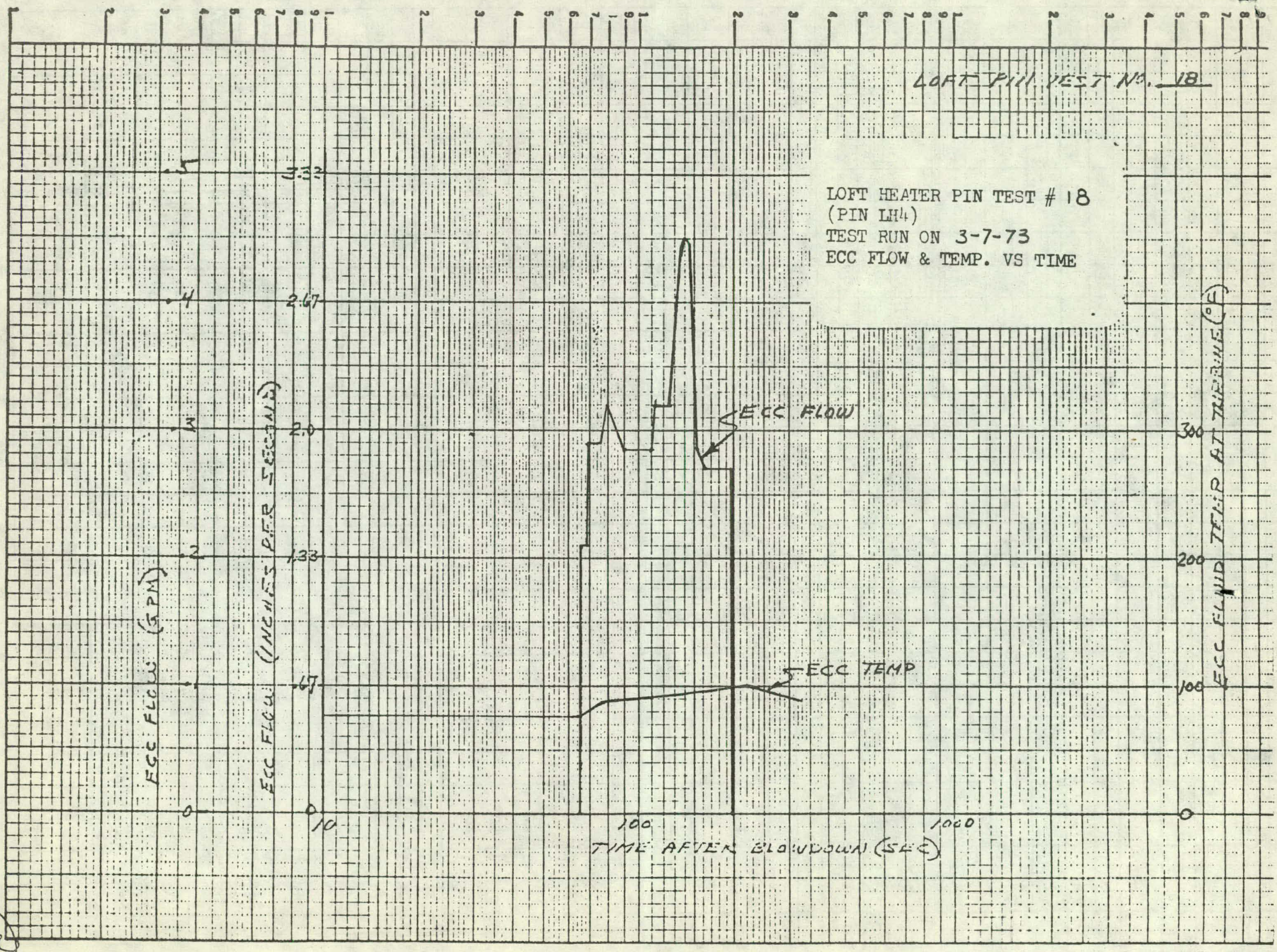
K•E 10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM. MADE IN U.S.A.
KEUFFEL & ESSER CO.





(12)
TXL -10"-0° =
TXL -28"-90° =
TXL- 43"-180° =
TXL- 60"-270° =
LOFT PIN TEST NO. 18
LOFT HEATER PIN TEST # 18
(PIN LH4)
TEST RUN ON 3-7-73
CLAD TC'S VS TIME
REFLOOD
PIN FAILED
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
HEATER CLAD TEMP. (°F)
1
10
100
1000
TIME AFTER BLOWDOWN

K+E SEMI-LOGARITHMIC 358-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS



MFJ 3-7

3 CYCLES X 140 DIVISIONS