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Water-cooled platinum C target

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WATER COOLED PLATINUM C TARGET

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Introduction:

We normally use Platinum as the production target in the slowly extracted beam in the AGS. Platinum was used because of it's desirable properties, high density (21.45 g / c.c.) and high melting point (1772 degree C). This is the standard target except for special cases when the target station is used solely for the high momentum production. In these cases Aluminum was used. Before the early 90's, the Platinum target was cooled by air and with aid of conduction to the Aluminum target holder. Depending on the beam size, these kind of target can withstand at most 10 TP (1TP = 1.0×10^{12} protons) incident primary proton beam. Although these targets were monitored with thermocouple and high temperature trip, many targets sustained damage.

With the AGS/Booster upgrade, the need for higher intensity targets became apparent. The current design was chosen for C target, which is, used primarily for BNL E787, an experiment measuring $K^+ \rightarrow \pi^+ + \nu + \nu$ branching ratio. The Platinum target was coupled to a water-cooled copper base. This note summarized the evolution and experience of the target used in the C line.

Parameter of the beam target interaction:

Table I lists the pertinent constants of Platinum and that of Gold, Tungsten and Copper. As far as I know, we used Platinum as the standard target material. The most obvious alternate target material is Tungsten. It has high melting point and better thermal conductivity. It was not used widely. All I could find out from people are that Tungsten target tend to disintegrate. They were used in the fast beam area. This is understandable, the stress is very high for a fast pulse. I was told that we used Heavy Mat target in the slow beam, and the target disintegrated. We know that some times, we could have melted the platinum target, due to insufficient cooling. This may be why the Heavy Mat target melted. We do not have solid evidence of failure of a pure tungsten target. It was clear that Tungsten is not a very favorable material for machining. It is not very easy to weld to other material. We did experience some problems with Platinum but most of the time the Platinum material stays intact with the target proper. Table I shows the properties of copper, gold, Tungsten and Platinum. Copper is used as base material and Gold was considered as another alternate target material to the platinum. As for particle production, the difference between gold and platinum is mainly in density. Platinum is 10% heavier. Since we only have limited longitudinal acceptance in the C4 line, we had to make up the difference by increasing the beam intensity. The thermal conductivity of gold is 4.4 times higher than that of the Platinum. The target temperature should be lower if we use gold as target. Unfortunately, the melting point of gold is 700 ^{0}C lower than that of the Platinum. The calculations indicated that there is no great improvement in intensity limit when we replace the Platinum by the Gold.

Table I Properties of the target material

Properties	Copper	Gold	Tungsten	Platinum	
Density	8.96	19.36	19.3	21.45	gr./c.c.

Melting Point	1083	1064	3410	1772	^{0}C
Interacting Length	15.1	9.56	9.59	8.84	Cm
Specific Heat	0.092	.031	.032	.032	Cal / gr. -^{0}C
Thermal Conductivity	0.96	0.75	.43	.17	Cal/cm – ^{0}C –Sec

For the purpose of rough estimation and some qualitative comparison of different effects let us calculate the temperature of the target without considering the heat conduction through water-cooling. We normally had more than 10^{13} proton (10TP) on the Platinum target. The beam size at the target is few mm in each dimension. Let us assume the beam size is 2 mm x 2mm and beam intensity is 10^{13}. For initial estimate, let's only consider the energy deposit of the Ionization loss of the proton only. The dE/dx is taken to be 2 Mev/gr. For 10^{13} proton, the energy deposited in the unit length of the Platinum is.

10^{13}x 2.0 Mev x 21.45=4.29 x 10^{20} eV/ cm=68.7 J / cm
= 68.7/4.18 cal = 16.4 cal/ cm.

The mass of the Platinum under Radiation heating is
0.2 x 0.2 x 1.0 x 21.45 = 0.858 gr.

Assuming there is no heat conduction, the temperature rise of target is

16.4 / (.032 x .858)= 597 ^{0}C

The maximum energy deposited could be as much as factor of two. If there is no heat conduction, a 10 TP pulse could raise the temperature to 1200 degree C, and a very short pulse of 15 TP beam would bring the Pt to the melting point. The latent heat of Pt. is 24 cal/gr., which is equivalent to the energy required to raise the Pt. Temperature by 750 degree C. The operating temperature will depend on the energy input (depends on the duty factor) and heat removable (depends on the target design). The heat input will be modified by the primary beam interaction. There will be a cascade of secondary charge and neutral particles produced by the proton beam interacting in the target. The charge secondary will deposit energy through ionization. The π^0 will decay immediately into photons and could produce an electromagnetic shower on the target. The photon conversion depends on the Radiation Length of the target material. In this case, Platinum and gold will capture more energy per gram than that of Copper. The final temperature depends on all the above mentioned condition and detail of the target geometry. The temperature rise due to dE/dx can only be used as a very rough initial estimate. The estimate of maximum energy deposit is factors of two more than the dE/dx agrees reasonable well with out observation of our target.

For the old air cool target, let us just assume there is only radiation cooling. These targets were about 1 cm wide. So, the area of radiation surface is about 2 cm^2 for each cm of length. The black body radiation :

W=5.678x10**$^{-12}$ x T**^{4} watt/cm**2

For 1770 degree K, W= 55.7 watt/cm**^{2}

Our beam cycle time is about 3 seconds and with beam on 1.5 second. The radiation area is about 2 cm^2 of area per cm long. The total energy emitted will be 55.7 x1.6 = 88 Jouls per pulse while beam is on, which is 30% more than the energy deposit through dE/dx of 10^{13} proton (68 Jouls). The real power of radiation is less because the emissivity of the Platinum is about 0.4. We relied on the conduction of the target to the Aluminum holder. Our experience is that the maximum intensity of the air cool Platinum target is about 7 TP.

If we choose Tungsten as the target, the energy radiated at the melting point should be 2^4 of that of the Platinum, 16 times. With that factor, we could easily take care of beam intensity more than 10 TP.

Radiation power at 3400 degree C = 88 Joule x 16= 1400 Joule
10 TP energy Deposit =68 Joule x 2 =136 Joule
limit 100 TP per pulse.

This is a very intriguing idea. I heard the Mu-E conversion experiment is considering this option. If enough parameters could be adjusted, i.e. beam size and target radiation surface, then this kind of target could be an acceptable for use up to 100 TP per pulse. We could overcome the objection of target brittleness by suspending the target in the gas. This way there would not be stress if the beam irradiates uniformly on the target. And we will have a 1000 Watt/cm light bulb. Of cause, a practical target has to satisfy many real life consideration. Tungsten target is a very "fragile" idea, but we should not dismiss it without rethinking about it's virtue and shortcoming.

Basic configuration:

The dimensions of the Platinum target used in the C line are 5 mm in width , 6 mm in height and 6 cm in length, which is 0.678 of a interaction length. (the interaction length of the Platinum is 189.7/21.45=8.843 cm). This is shorter than the normal target length, which is 3.5 inch (8.89 cm). The copper base is designed for normal target length and should not affect the conclusion of this observation. Fig. 1 shows the drawing of the present target and Fig. 2 shows the photograph of the latest target (used in 1996- 1997 run). The water line is 0.2 inch from the base of the target. The Platinum target is embedded in the .2 inch slot of the copper base and then bonded with silver solder. The target and the copper base are slotted every 1-cm to reduce stress produced by heat cycling caused by the beam. The present design was evolved from the first one with minor modification, such as target height and the number of slots along the length of the target. When a different target was used, we maintained the top of the target to be at the same height.

First and Second Target:

Fig. 3 shows the photograph of the target after FY94 run. The Platinum target was .2" wide and .4" height with .15" of Platinum embedded in the copper base. The target was slotted in two places and thermocouples were placed in the copper at the base of the

Platinum copper junction and far away from the Platinum. This target was used for the FY 94 and 95 runs. The maximum normal running intensity is 15 TP. There is a clear indication of melting near the top corner of the Platinum target. The coupling between Platinum and Copper shows some possible chemical change. At the end of 95 run, we installed a target with thermocouple in the target proper and in the copper near the base of the Platinum target. We did some short test runs up to 25 TP. Fig. 4 shows the first plot of target temperature with the beam intensity. This is done by reading the peak and valley reading with the Fluke meter on each beam cycle. The thermocouples we use are type K. This curve shows us that the temperatures do track with the amount of the beam and it is linear with beam intensity. Fig. 5 shows the photograph of the target II after the run is over. The target shows two vertical cracks. This confirmed the need of slotting the target to reduce the stress in the Platinum. This run, (FY 95 run) last about 24 weeks. Target I survived more than 3 millions pulses of beam of 15 TP. The curve of temperatures of target II, albeit very crude, provide us the information we need. The target could hold at least 25 TP (850 deg c, about 50% of the melting point of Pt). We learned the following from the Target I/II.

1. Thermodynamically, the target could be operated up to 40 TP, 80 % of the melting point. The weak point is the silver solder. It's melting point about 760 ^{0}C (1400 ^{0}F). There are some sign silver solder migration in the target. We need to make sure the temperature is not too high at the junction.
2. There is no "big" structural damage of the target, the material held up very well under the heat cycles for 3 million pulses.
3. There is some small damage, crack / melting. We could not identify the source.

Third Target:

In the FY96, We were doing some R&D on target construction. The Platinum target was Electron Beam welted to the copper base. The technique was applied to the C target. The target height was reduced from .6 cm to .38 cm. If the heat conduction was not drastically changed, the temperature should reduce by 1/3 (C. Pai, Mar. 1, 1996). The other advantage is that we did not have to use the silver solder. The white powder like material on the used target could be some kind of residue of the silver solder. According to the calculation, the top corner is a potential hot spot. The photograph of the FY95 target shows beads of material in the corner and this could be the melted Platinum. To reduce the stress of the material, both copper and Platinum, the number of slots was increased from 2 to 5.

From the previous run, we began to rely on the thermocouple reading from the target monitor. The Fluke 2645A NetDAQ system provides us a very convenient way of monitoring the target temperature. In the target 1, we only put a thermocouple at the base of the target and copper base. We then decided to put it at the side of the target where beam was supposed to hit. There are a total of two thermocouples installed in the segment 2 and 3 of the target right. The NetDAQ system was read by PC through an Ethernet connection. Data was stored in the disk and real time temperatures were displayed on the PC monitor. Figure 6a shows the temperature of the two thermocouples. Segment 3 shows higher temperature by 13%. After 2 weeks of running, the difference increased to 50 %. Fig 6b shows the plotted data. We did quite a few tests to convince ourselves that this was not an instrument error and the effect was due to poor heat conduction between Pt and Copper. We removed the target and inspected it visually. There is no sign of separation between target and copper base. The only reasonable explanation is that the weld opens in the middle.

We reinstalled the target I, so that the experiment could continue running. This target was replaced on 6/6/96. The target survived an additional two months of running without major problem.

Fourth Target,: Target used in FY97 run:

With all the experience we had, we decided to make a Silver-Soldered target with 5 slots and a round corner. Fig. 2 shows the photo of the target after the 1997 run. This target was installed near the end of the FY96 run. The target has three thermocouples. Two of them were embedded in segments 2 and 3 of the target from the beam right. These thermocouples leads are twisted together and then inserted into a hole drilled in the Platinum target. The third is an R&D thermocouple. The leads are the same but they were installed in different hole drilled in the Platinum. The idea is to check an assumption that the time response will be faster than the regular one because the thermocouple surface touched the target Platinum directly. The display program is call trandlink. The NetDAQ system, when activated, took the data continuously and store into the harddisk. TrendLink, was used to display the data from the real time data or the achieve data from the disk. Fig. 7a shows the fast thermocouple and "normal" thermocouple. The fast one indicated the temperature is more than 2000 degree C. We believe the real temperature is probably about 1400 ^{0}C. The high temperature reading was due to the fact that the contact between thermocouple and Platinum was open. The system interpreted that as a very high temperature. Fig. 7b shows another fast spike and the thermocouple recovered and function normally. This is the first time we could observe the short pulse effect on the target. The combination of the temperature and stress cause the contact to open up. The joint reseated right after the spike was over. Temperature interlock built was into the temperature monitor system. The response time of the system is about (200) ms (it takes time for the interlock signal to reach the AGS abort system). We installed a monitor, TP/second, to cut off the beam when it reached more than 100 TP/second. This device could turn off the beam in less than 100 ms.. With all these precaution and monitoring, the Target survived the FY 1997 run without damage.

Fig. 8 shows the temperature vs. intensity taken during the FY. 1996 run. The intensity is based on the SEC (secondary emission monitor). The intensity should be scaled up by about factor of 1.2. Our study shows that the secondary emission coefficient drops by 20% after $2x10^7$ TP proton exposure ($2x10^{19}$ Proton). Fig. 9 shows the efficiency degradation of 40 % as of May 31, 1997, one year after the Fig. 8 was taken.

Modeling:

E871 used a very special target, Platinum on Be. We did a lot of calculations for the target energy input and stress cause by the beam. We take advantage of the modeling effort. The energy input in the Platinum target are:

0 to 2.54 cm	780 Joule
2.54 to 5.08 cm	1053 Joule
5.08 to 6.0 cm	316 Joule

The calculations was done on the follow condition:

1. Beam intensity 30 TP
2. Platinum Target width .2 "
3. Copper base .5"x3"x2.34"
4. Target length 6 cm
5. Beam cycle time 3.2 second with the beam on time 1 second.

Case #	Target Height (inch)	Beam size (inch)	Number of slots	Depth of slot (inch0	Maxi. Temp. ^{o}C	Maxi. Stress Target Kpsi	Maxi. Stress. Body Kpsi	Note
1	.15	.2x.15	4	.42	338	7.5	8.2	
2	.15	.075x.075	4	.42	631	12.4	11.0	
3	.15	.075x.075	4	.2	603	14.5	19.0	
4	.40	.075x.075	2	.25	957	13.4	16.6	.15" pt under cu
5	.25	.075x.075	4	.25	781	13.5	16.9	.05" pt under cu

Case comparison.

Case 1 beam fill the target and case 2 is small beam at the top. The temperature increased from 338 to 631. Also, the stresses in Pt and copper are up.

Case 2 & 3: different number of slot change the stress. It also change the temperature slightly.

Case 3, 4 and 5: The Pt height above the copper are 0.15:0.25:0.20 = 1:1.66:1.33 and the maximum temperature ratio is 603:957:781=1:1.58:1.29. This is very instructive; the maximum temperature depends on the height of target above the copper. The silver solder and the amount of platinum under the copper did not affect the maximum temperature very much.

As mentioned in the previous section, we were considering gold as target material. We were told that this target will produce Radioactive Mercury and it might migrate to the environment. We did some comparison of the two with large beam size, .2" x .15". The maximum temperatures are 386, 220 for Platinum and gold respectively. The ratio is almost the same as that of the melting point. With more a more concentrate beam, the difference in maximum temperature may be much larger. Since gold target requires a completely different cycle of R&D, we did not pursue the gold target option.

We did check on the temperature of the Silver-Solder. With Platinum at 800 ^{0}C, the temperature of copper-Platinum junction is about 200 ^{0}C. The melting point of the

Silver Solder is 750 ^{0}C, we should have plenty of margin. The cause of the Silver Solder "migration" is still not understood.

Conclusion:

The last target T112 held up very well for a normal 20 TP run. We did run up to 30 TP for a short time at the end of FY1997. There is no sign of damage to the target. At the end of FY1997, the SEC should be scale up by 1.4, see Fig. 8. The 20 TP run is about 30 TP. And the 30 TP test is equivalent to 40 TP. The temperature did not reach more than 800 ^{0}C for the "30 TP" test. This implies we could use this target for up to 50 TP or more. Our protection system is at 1200 ^{0}C and we still could count on the short spill protection at the C10 SEC. One interesting fact over the pass few year is that we have not observed a much higher temperature than 800 ^{0}C on Fig. 4, (25 TP). For the same intensity, without 20% correction of FY96, we saw a T2 max of 650 ^{0}C. This may have been due to instrumentation effect or change of beam size. For the FY 96 and 97, the TC was calibrated, while the 95 data is not. There is another factor. We did retune our switchyard. The Emittance of the higher intensity beam in FY96-97 may be larger than that of the FY95. As pointed out in the model section, the case 1 and case 2 difference is due to the beam size. The temperature changed by almost a factor of 2.

The 30 TP temperature is 760 0C for the fast TC and 650 ^{0}C for the normal TC. We scaled up by 1.2 to get the real intensity of 36 TP. Extrapolating it to 50 TP we get 1050 ^{0}C . We did not take into account that the Emittance will be bigger so the temperature will be lower. Also, if we lengthen the spill we will reduce the temperature. Reduction of the Platinum target height could also reduce the temperature. The 800 ^{0}C target will have maximum stress/strain of 13 kpsi and17 kpsi on the Pt and copper respectively. They all exceed the soft yield strength but are well below the hard yield strength of 27 kpsi and 40 kpsi for Pt and copper. Increase the temperature by 40% still under the hard yield strength. May be the proper way of setting the limit is by temperature. The maximum temperature of 1200 ^{0}C is a next step. We should try to reach this temperature with gradual increases in intensity.

Bm Line 'C'

TARGET MAT - Plat - .2"w x .25"h x 2.4"L

TYPE - WATER Cooled

drwg # - D13-M-

TARGET ID
T-112

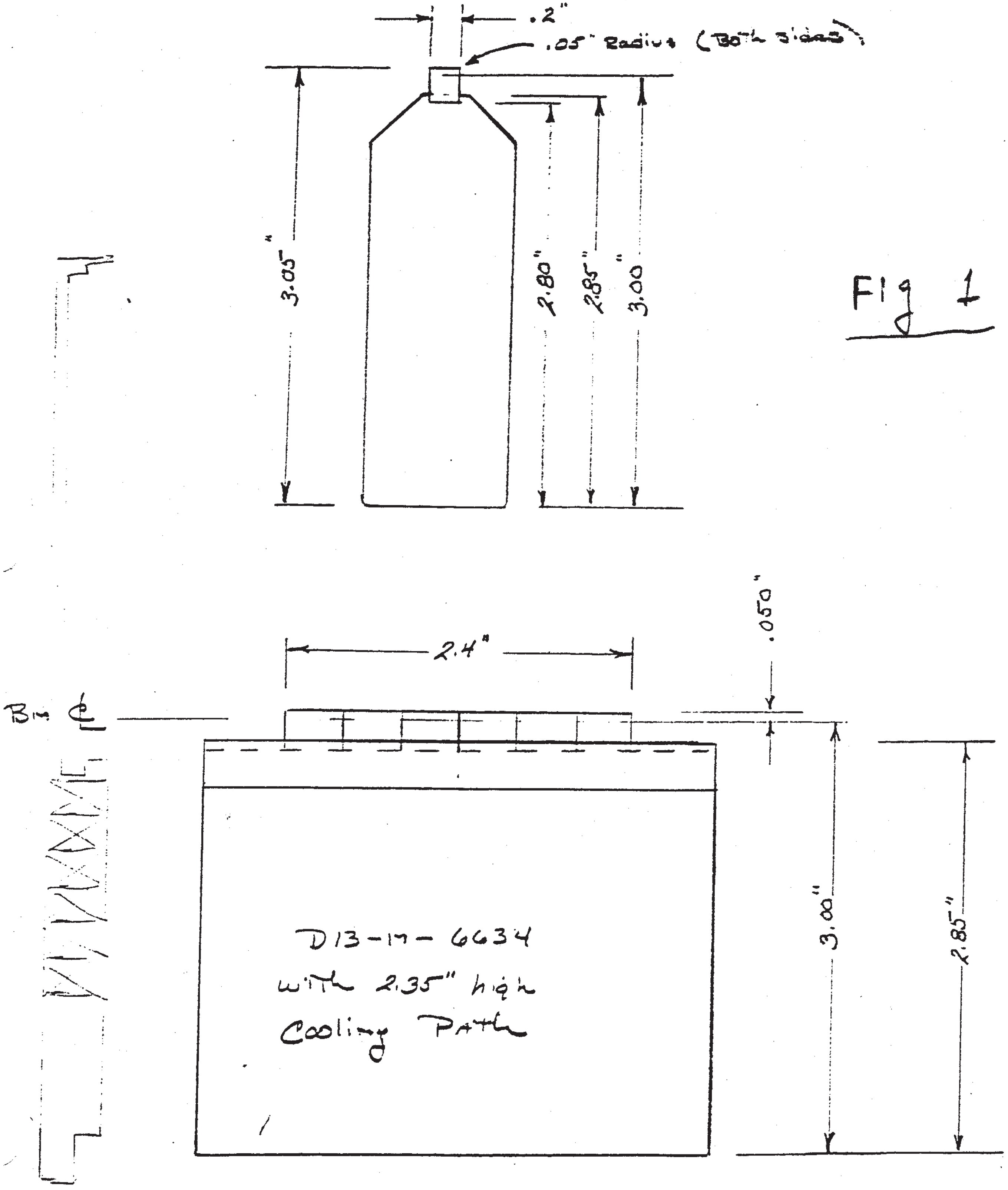


Fig 1

93.1 Gms —
STOCK WIDTH = .394
6 (.394) = 2.364
ie .036 SHORT (OR .007 GAPS)

By AL PENDZICK
5/14/96

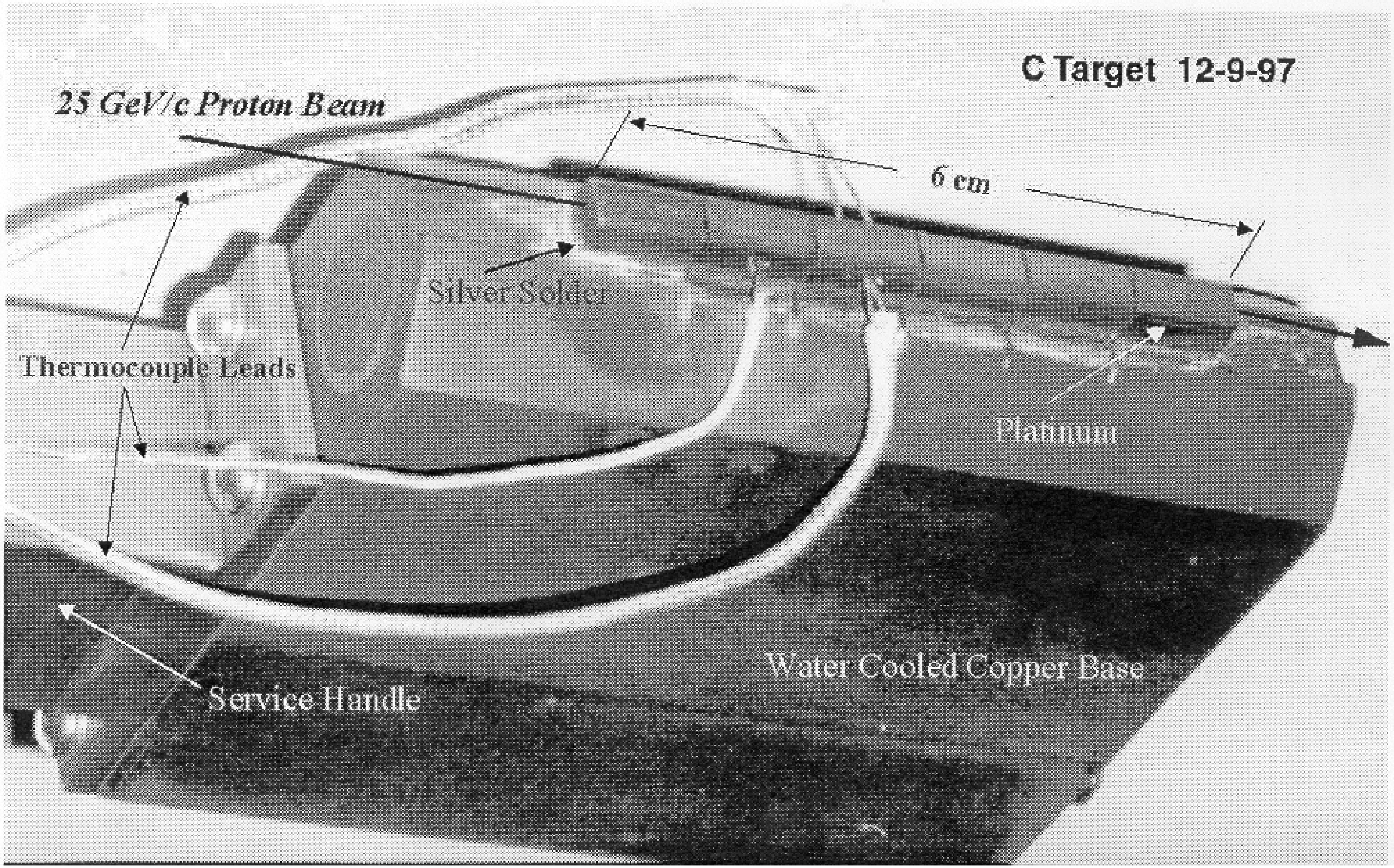

C Target 12-9-97
25 GeV/c Proton Beam
6 cm
Silver Solder
Thermocouple Leads
Platinum
Water Cooled Copper Base
Service Handle

Fig. 2

Fig. 3

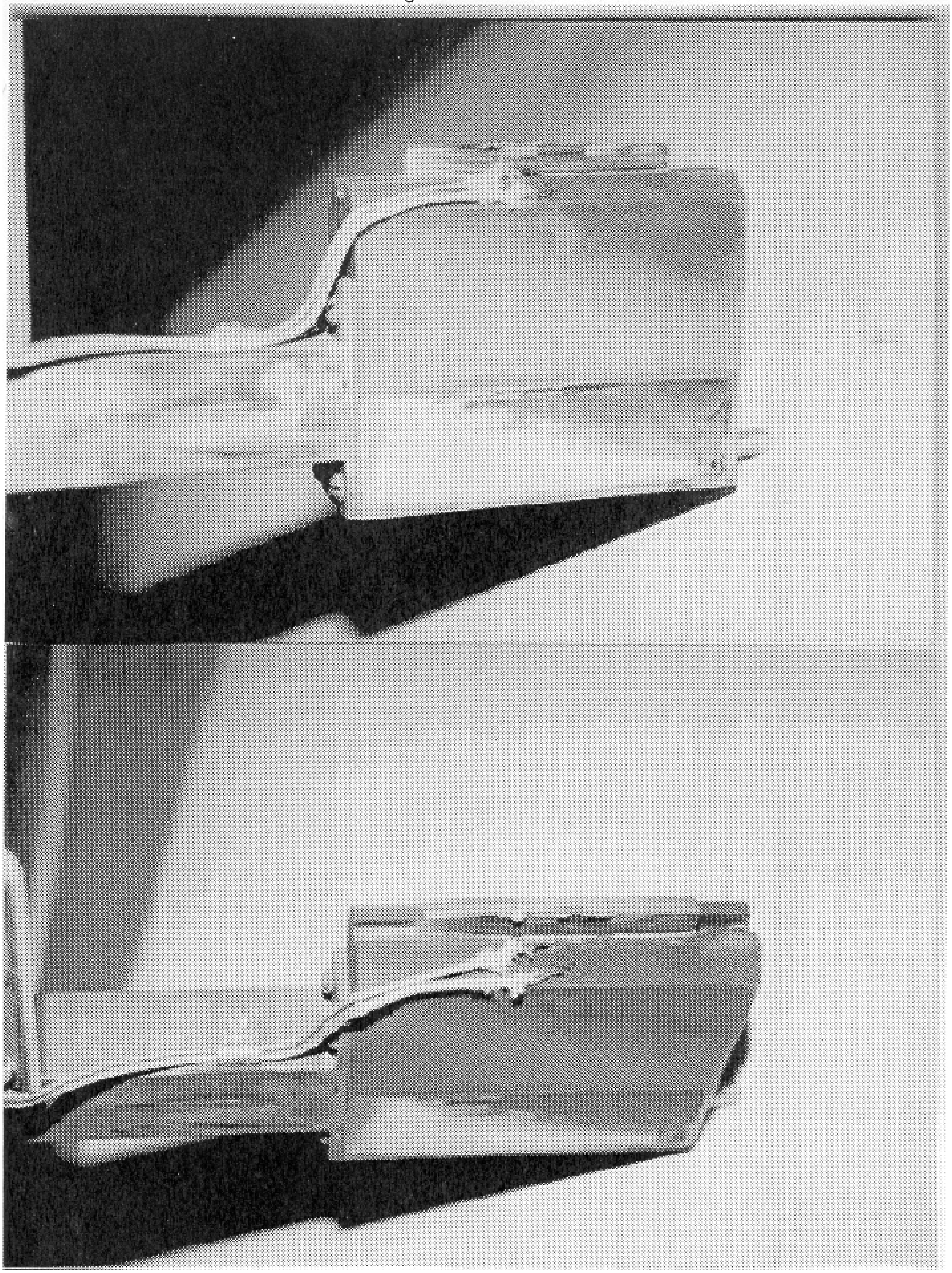
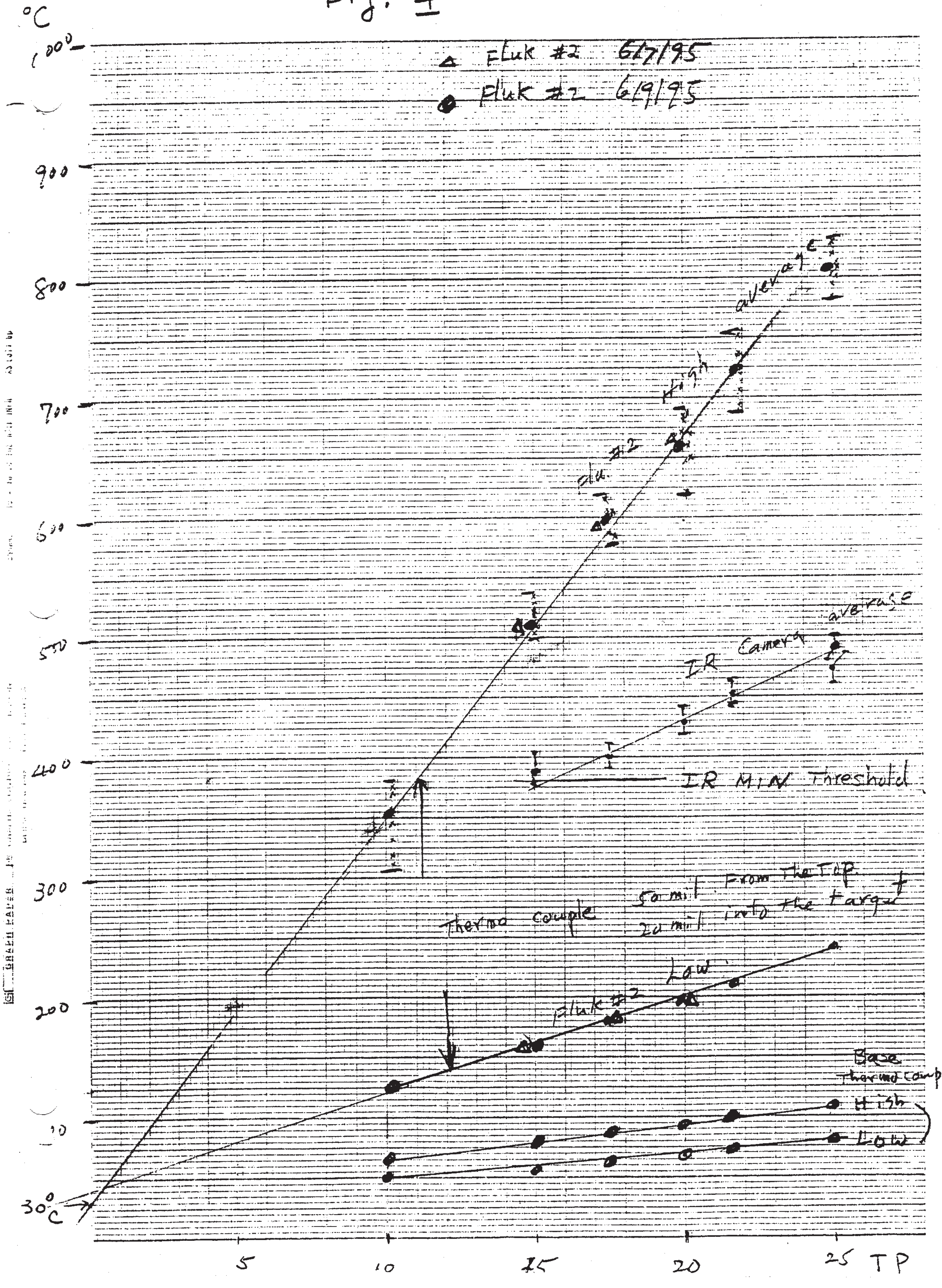
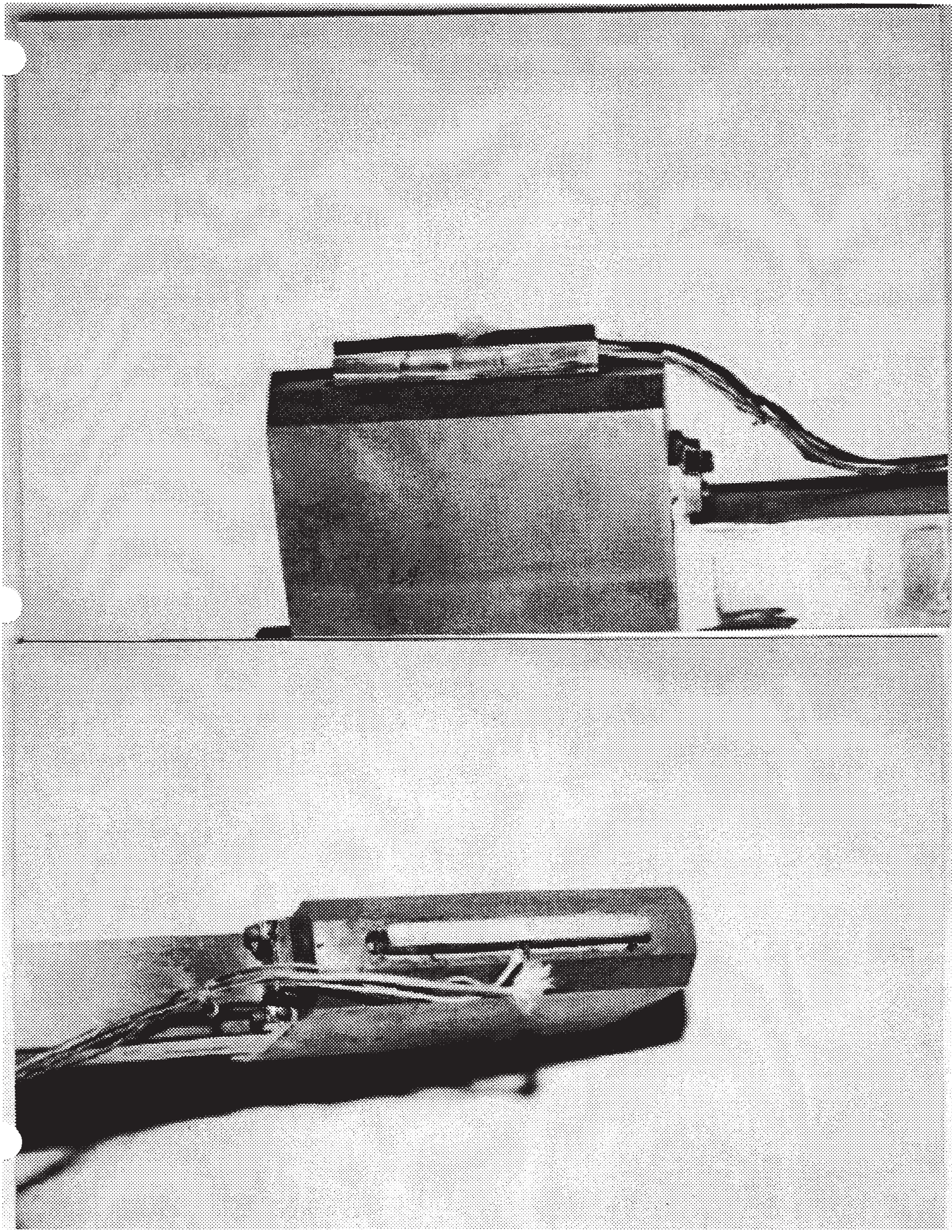


Fig. 4



°C
1000
900
800
700
600
500
400
300
200
10
30°C
△ Fluk #2 6/7/95
● Fluk #2 6/9/95
average
High
Fluk #2
IR Camera average
IR MIN Threshold
Thermo couple
50 mil from the top
20 mil into the target
Low
Fluk #2
Base Thermo couple
High
Low
5
10
15
20
25
TP

Fig. 5



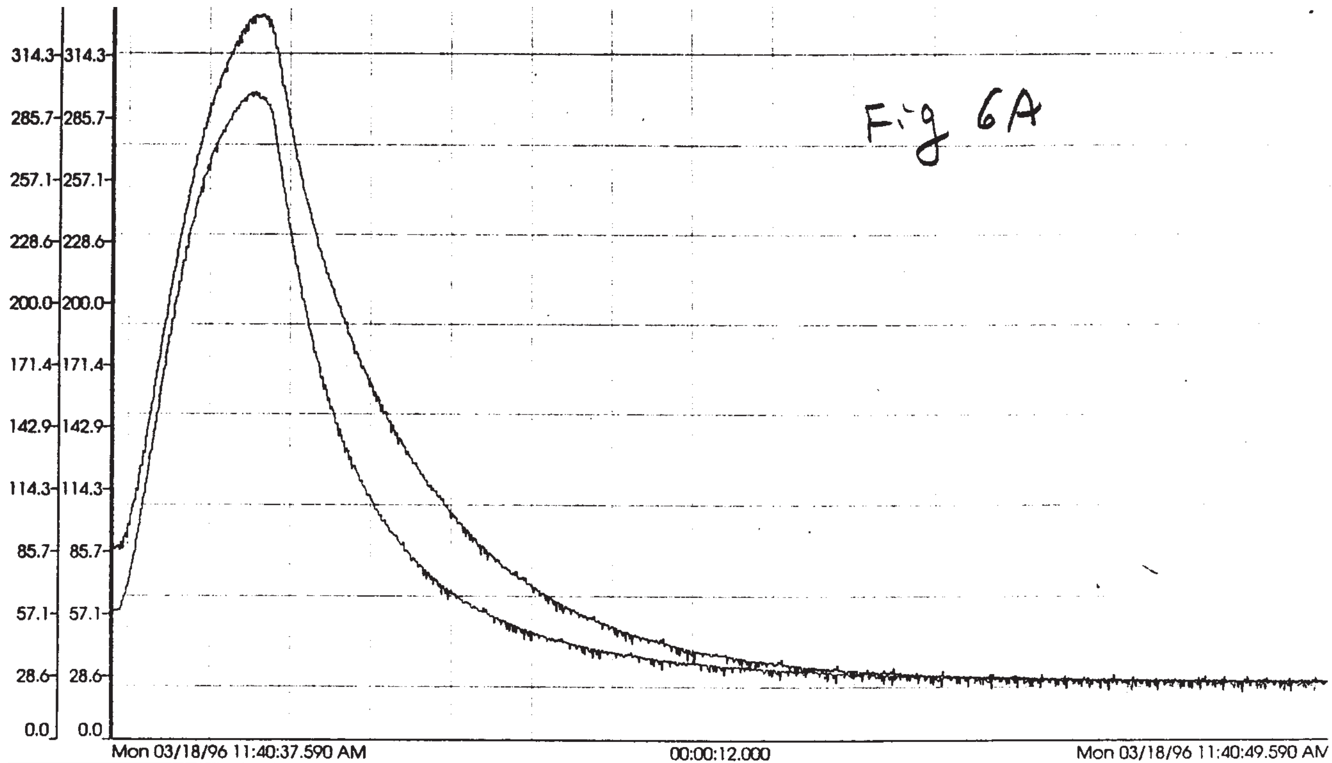


Fig 6A

Tag Name	Description	Scale Range	Eng. Units	Last Value
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lh1.set:0103	Label	0.0/400.0	°C	25.5

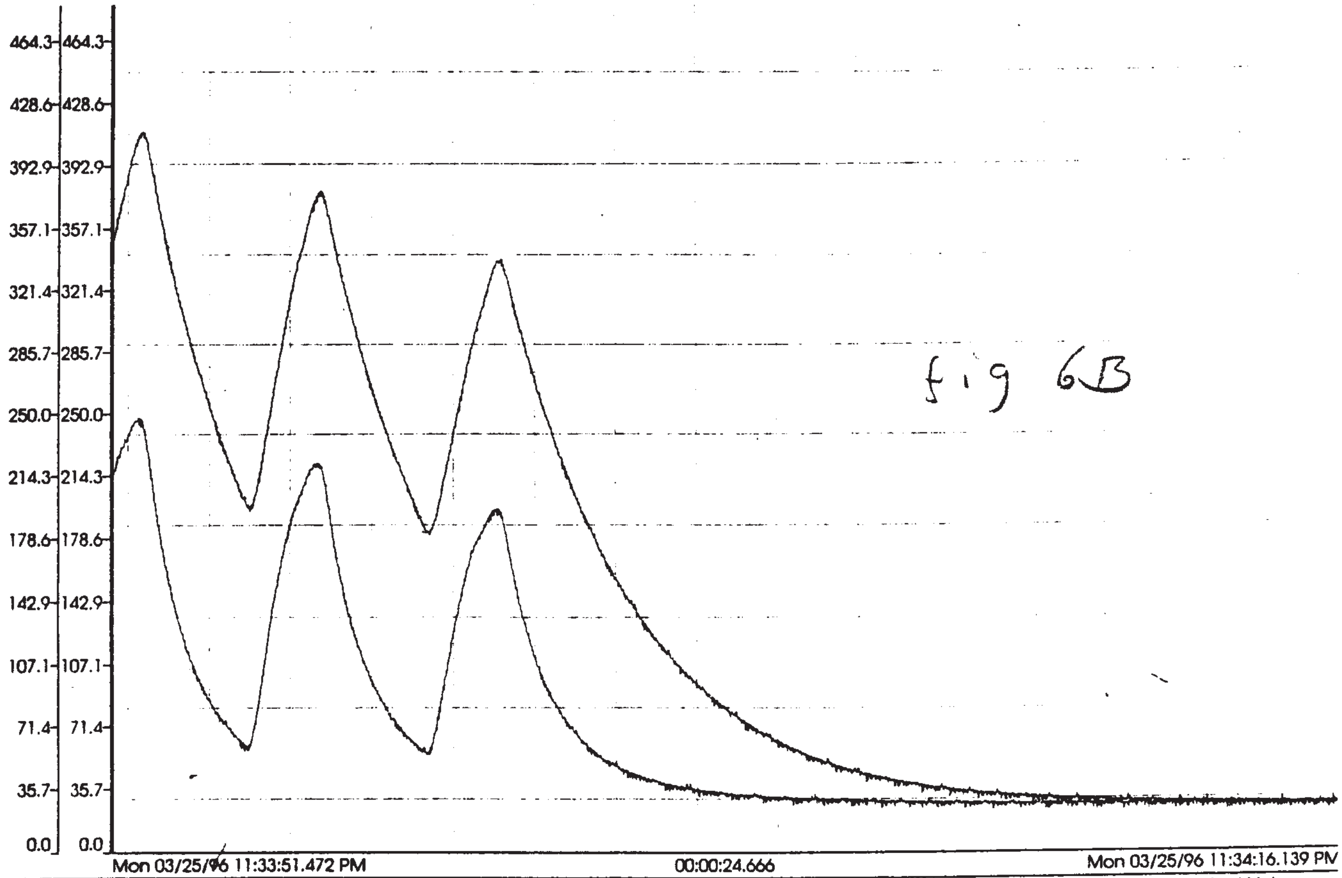
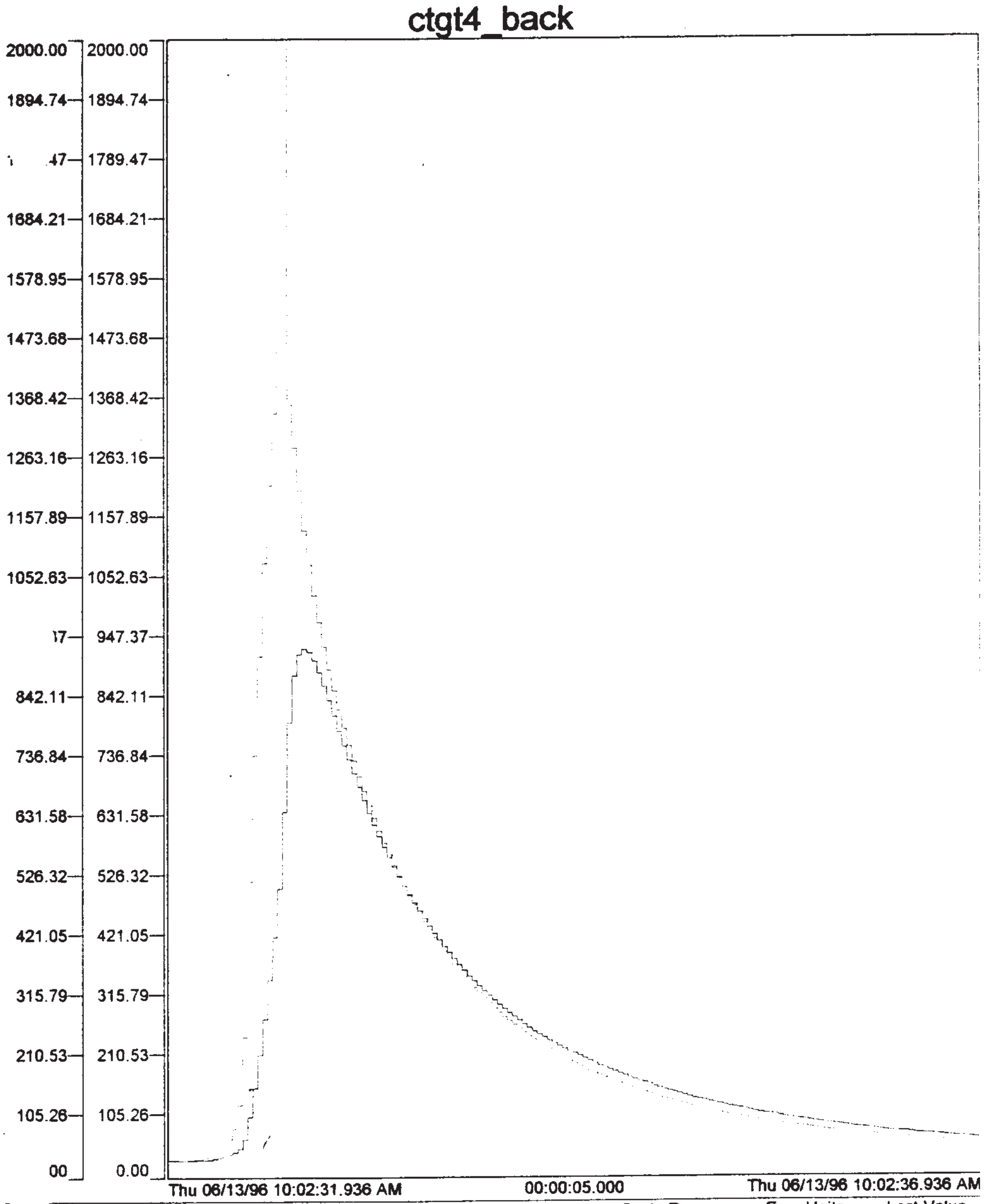


fig 6B

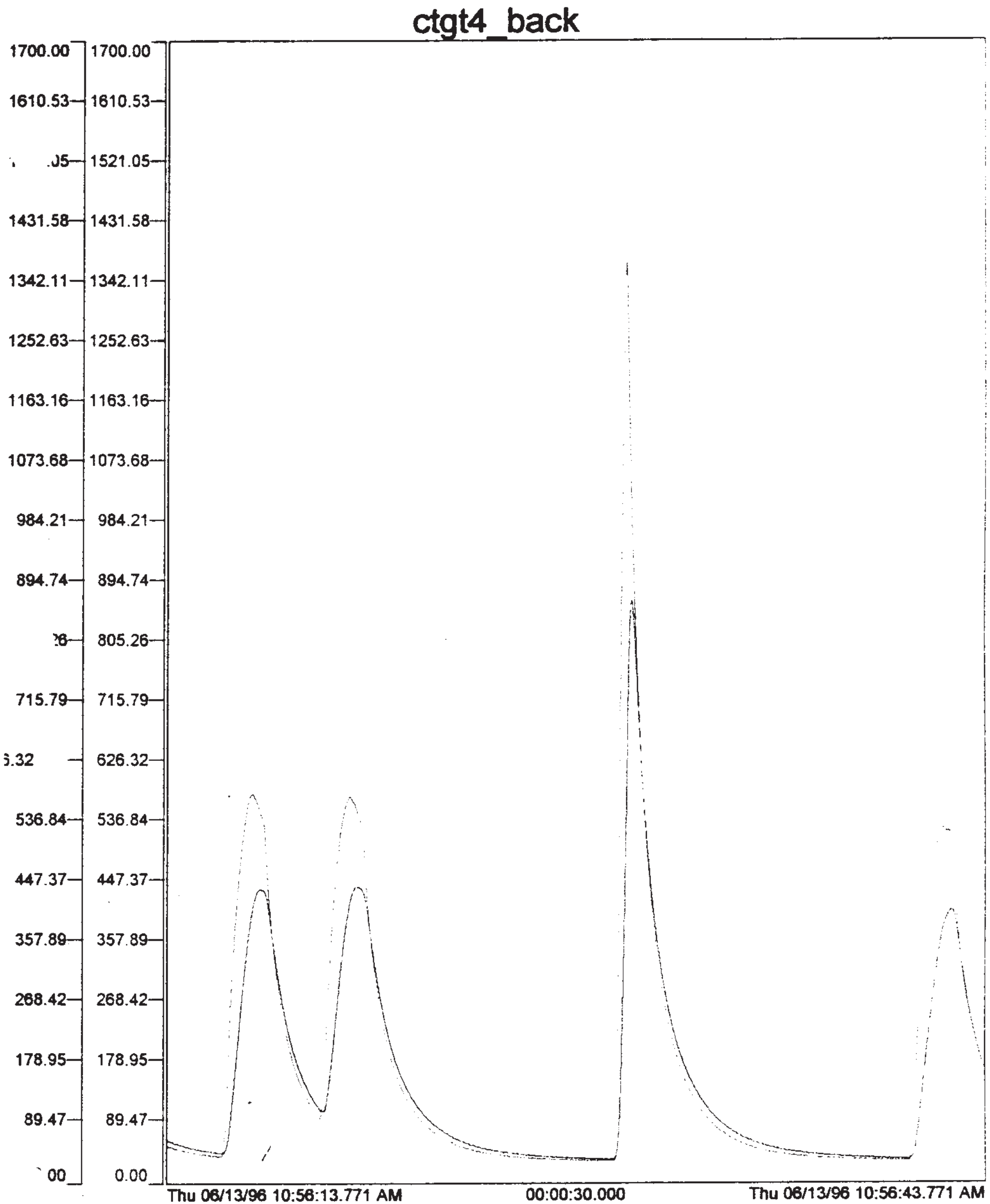
Tag Name	Description	Scale Range	Eng. Units	Last Value
lh1.set:0102	Label	0.0/500.0	°C	26.6
lh1.set:0103	Label	0.0/500.0	°C	26.1

Fig. 7a



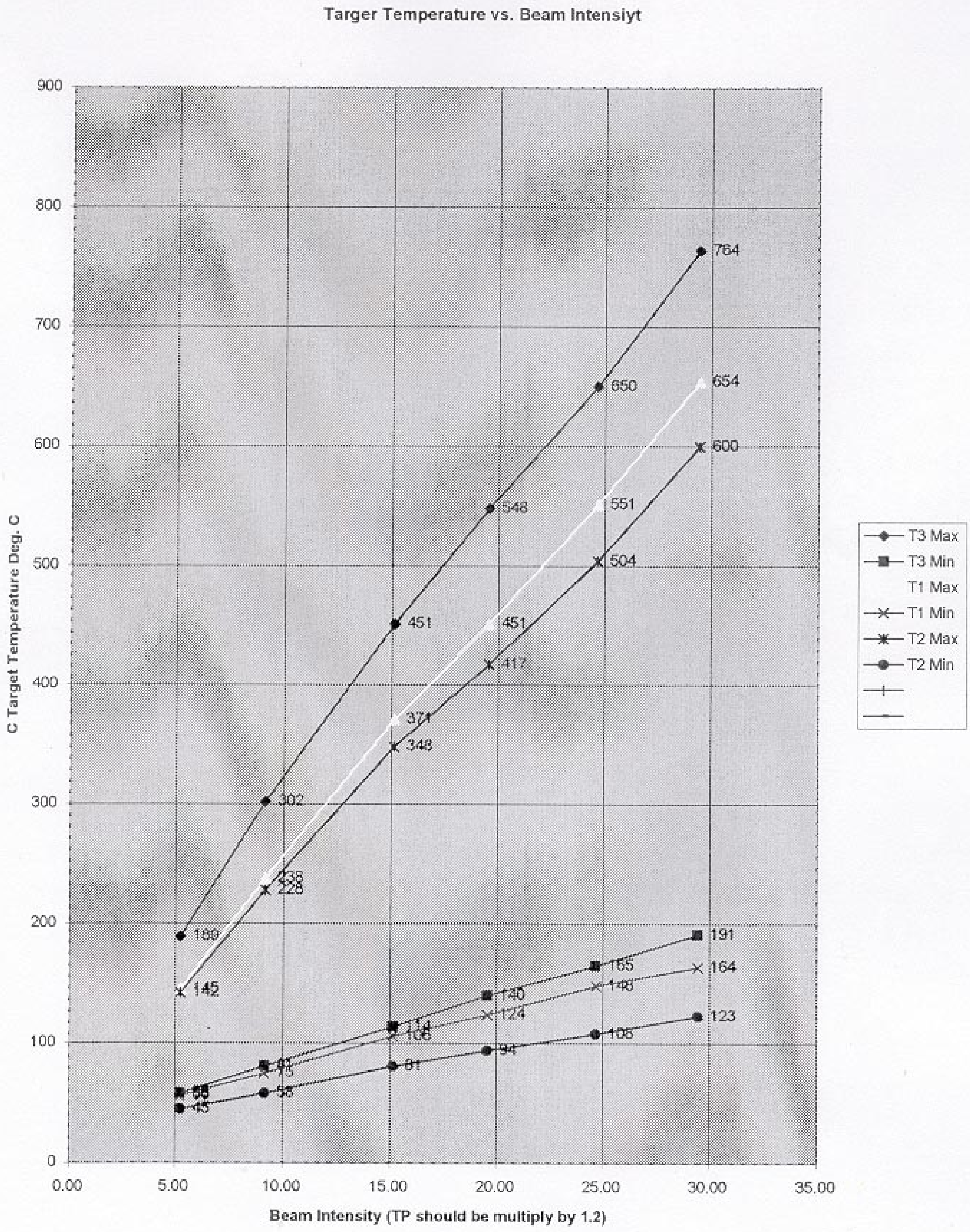
Tag Name	Description	Scale Range	Eng. Units	Last Value
ctgt4.set:0102	seg #2	0.00/2000.00	°C	65.13
ctgt4.set:0104	probe	0.00/2000.00	°C	57.22

Fig 7b



Tag Name	Description	Scale Range	Eng. Units	Last Value
ctgt4.set:0102	seg #2	0.00/1700.00	°C	169.60
ctgt4.set:0104	probe	0.00/1700.00	°C	156.23

Fig. 8


Targer Temperature vs. Beam Intensiyt
C Target Temperature Deg. C
900
800
700
600
500
400
300
200
100
0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
Beam Intensity (TP should be multiply by 1.2)
T3 Max
T3 Min
T1 Max
T1 Min
T2 Max
T2 Min
764
650
548
451
302
189
654
551
451
371
238
145
600
504
417
348
228
142
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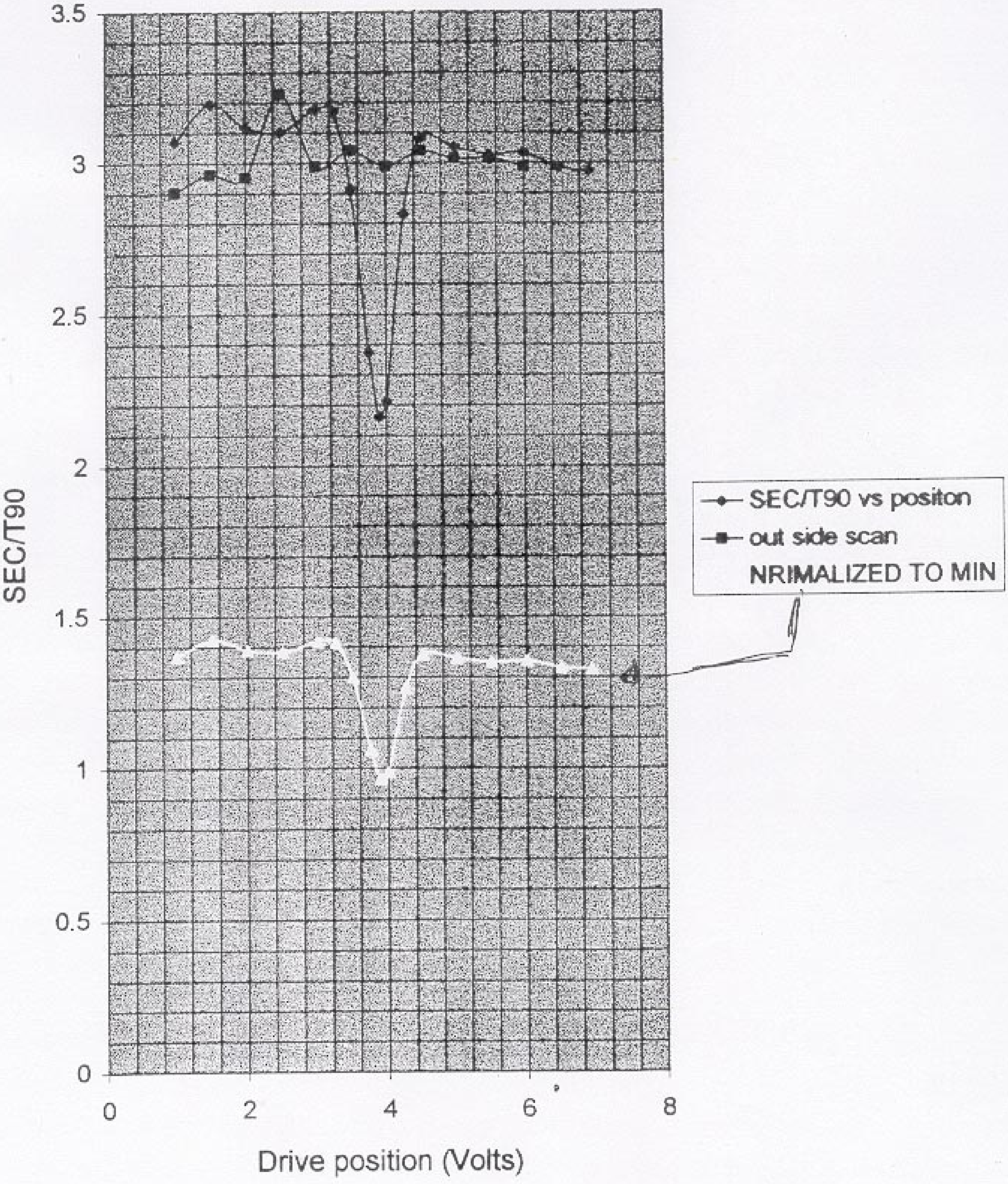
108
94
81
58
45

Fig. 9



SEC/T90 VS POSITON/ May 31,1997