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Hauck, C.A.

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OPERATING GUIDE FOR THE LBL 10x40 cm. LONG PULSE PLASMA SOURCE (LPS)/LONG PULSE ACCELERATOR (LPA)

C.A. Hauck, M.C. Vella, P.A. Pincosy and M.D. Williams

August 1984

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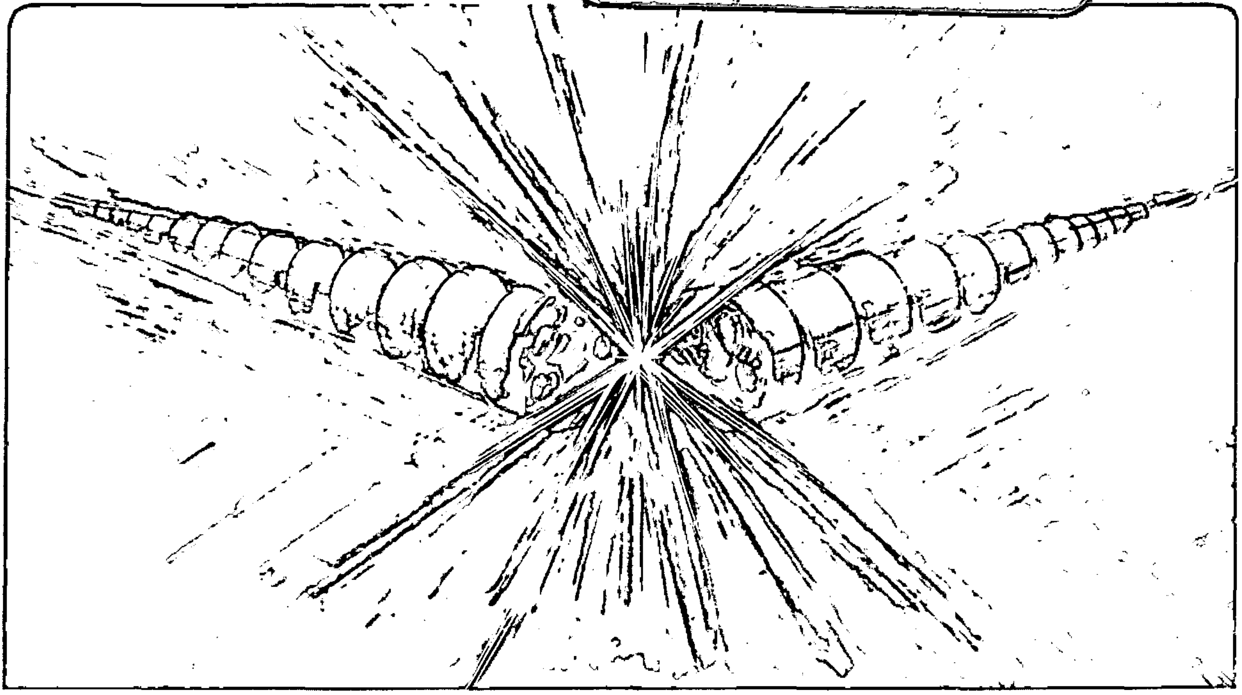

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Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

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LBL-18342**

OPERATING GUIDE FOR THE LBL 10X40 cm. LONG PULSE PLASMA SOURCE (LPS)/ LONG PULSE ACCELERATOR (LPA)*

C. A. Hauck, M. C. Vella, P. A. Pincosy, M. D. Williams

Lawrence Berkeley Laboratory
University of California
Berkeley, Ca. 94720

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* This work was supported by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

** Also, PUB-3039

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INTRODUCTION

This Operating Guide presents practical information for assembly, mounting, and operation of an LBL long pulse ion source. The presentation is sequential, assuming the source is new. Where possible, the sections have been made self-sufficient. This Guide was prepared as one part of the report on 80 kV, 30 second testing for the MFTF-B Project.[1] The Guide provides detailed information about the LBL 10 X 40 cm Advanced Positive Ion Source (APIS), which served as the prototype for the 12 x 48 cm Common Long Pulse Source (CLPS) designed for MFTF-B, TFTR, and Doublet. A significant amount of the information in this guide is taken from the Operating Guide for LBL 4-Grid Ion Sources.[2] Some details are specific to the APIS, but many of the procedures should carry over to the production Common Long Pulse Source (CLPS).

The APIS accelerator is a radiation hardened design, and is called the Long Pulse Accelerator (LPA).[3,4] The LPA was designed for up tp 150 keV operation in a reactor environment. It has a ceramic insulator and a hard brazed insulator stack. Compatability with TFTR required bringing in the grid cooling water at the narrow end of the insulator, and using some corona rings as water manifolds.

The APIS plasma generator is an arc chamber, called the Long Pulse Source (LPS),[5] which is generically an axial line cusp magnetic bucket. The LPS was specifically intended to meet MFTF-B requirements: 30 second deuterium operation; $\geq$ 80% atomic fraction; and a filament lifetime of 8×10^3 full power shots. The actively cooled backplate serves as both (partial) anode, and as a dump for backstreaming electrons from the accelerator. High deuterium species and long filament life required minimizing the total anode area, with the result that anode must be added for hydrogen operation. To add anode, the probe plate was connected to anode, with 80 milliohms of series resistance to limit the current. Filament lifetime is enhanced by running emission limited, with arc voltage ≥ 60 volts and ≤ 100 volts.

Most of the following procedures, as well as the results presented in Section 12, were obtained with the LPA, gapped for and operated at 80 kV, 40 Amps Deuterium on the Neutral Beam Engineering Test Facility (NBETF). NBETF, illustrated in Figure 1, is a long pulse test facility equipped with several diagnostics for analysis of beam characteristics. The quoted beam characteristics of the LPS/LPA were measured on NBETF. A picture of the source as mounted for testing is shown in Figure 2.

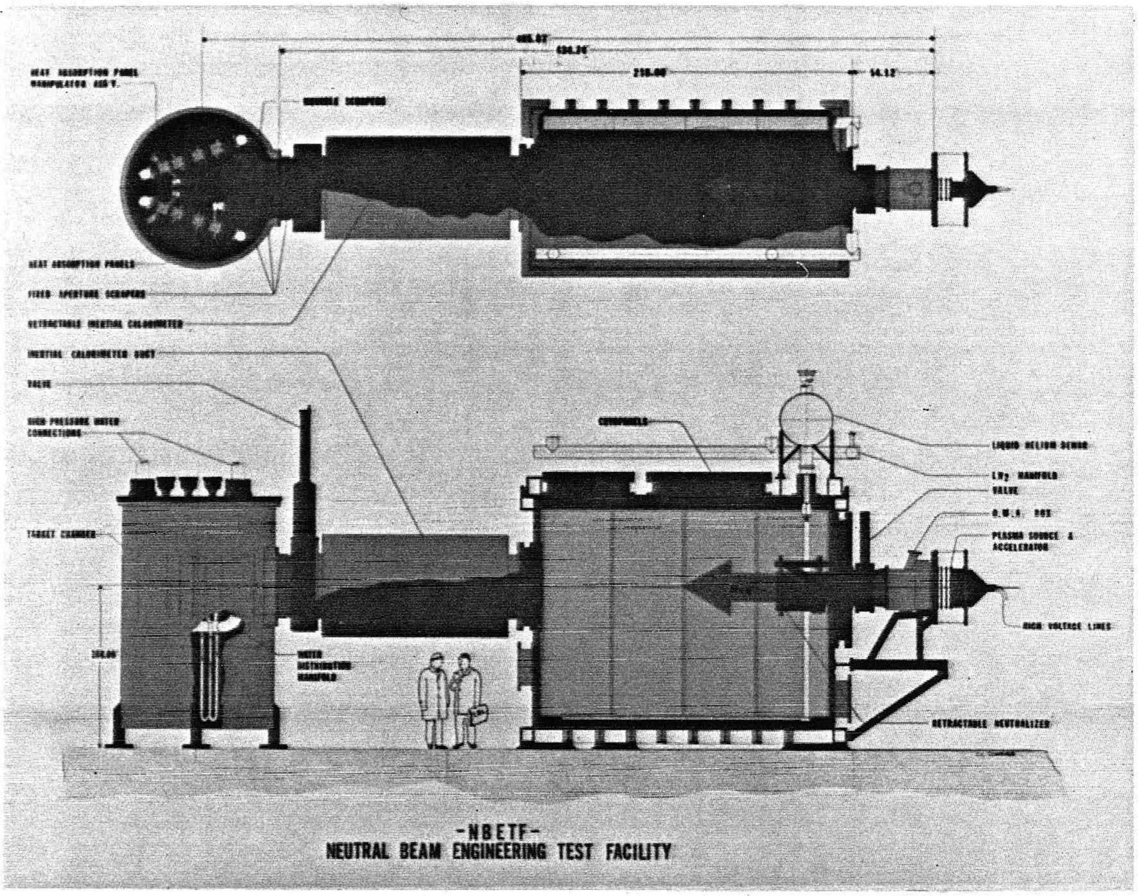

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Figure 1. Schematic of the Neutral Beam Engineering Test Facility (NBETF) with major beamline sections identified.

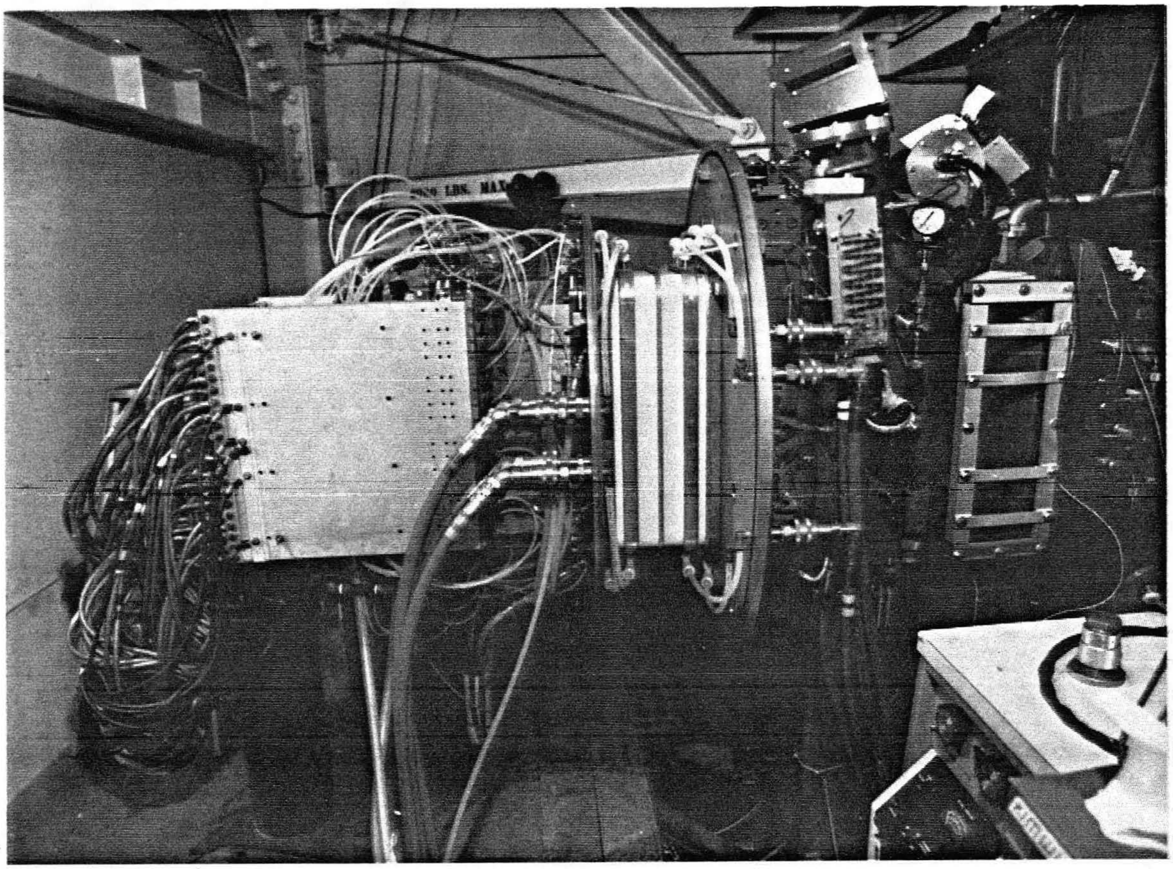

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Figure 2. Picture of the LPS/LPA mounted on NBETF, with all mechanical and electrical connections made.

KEY DEFINITIONS

DIVERGENCE

At LBL, beam divergence is measured by two types of diagnostics, calorimetric and optical. Overall beam power is measured from heat pattern on a calorimeter. The calorimeter data are then least squares fit to the heat profile expected for a beam made up of beamlets with Gaussian distribution of angular divergence at the location of the source. The quoted divergence angle is the 1/e half angle of the model Gaussian beamlets which gives the best least squares fit to the data.

The divergence of the various atomic and molecular components of hydrogen or deuterium beams are measured by the Optical Mass Analyzer (O.M.A.), discussed in Section 12. For the OMA, a least squares fit of the observed width of Doppler shifted spectral lines is compared to the line shape expected for a beam formed from beamlets with Gaussian divergence.

EMISSION LIMITED CATHODE

Arc operation in which the arc current is limited by cathode emission is called "emission limited". Electron emission is determined by the filament temperature, which is operationally set by the filament heater current. As the filament heater current is increased, both the filament temperature and arc current increase. The Long Pulse Plasma Source (LPS) discussed here is operated emission limited.

The alternative to emission limited is called "space charge limited" operation, which is used in LBL field-free sources. In space charge limited arc operation, the filaments are "over heated", in the sense that the filaments can provide electrons at a faster rate than the electrons can cross the plasma sheath; this limiting rate of electron emission across a plasma sheath is called the Child-Langmuir current. Thus, a space charge limited filament is insensitive to changes in the filament heater current. To be space charge limited, tungsten must be relatively hot, which increases evaporation and reduces lifetime. In practice, a space charge limited filament has some limited response to filament heater current, because the emitting area can change.

PERVEANCE

The Child-Langmuir law states that there is a simple relationship between accelerator current and voltage for optimum performance:

$$I = PV^{3/2}.$$

The constant P, called the perveance, depends on the source geometry and grid gap spacing. Perveance also depends on the mass of the extracted ions, but this is frequently ignored in day-to-day operation.

"Optimum perveance" is that ratio, $I/V^{3/2} = P_0$, for which beam divergence is a minimum. For a given accel voltage, if the plasma level is such that $I < P_0V^{3/2}$, the accelerator is said to be "underdense". If $I > P_0V^{3/2}$, the accelerator is said to be "overdense". (See Section 11 (F) for further discussion.) Accelerators of the type discussed here typically have a perveance of several x 10^{-6}, which is usually written in abbreviated form as, e.g., 1.7 μpervs.

1. LPS DESCRIPTION

The long-pulse plasma source is shown in Figure 3; labeled parts of the LPS are shown in Figure 11, Section 2. The plasma chamber, shown in Figure 4, has a cross section of 24 cm x 56 cm, and is 32 cm deep. It consists of a stainless steel reinforced, copper walled "magnetic multipole bucket" anode, lined with an axial array of 36 rows of samarium cobalt permanent magnets spaced between cooling channels. Thirty four filaments are used; each is 16-cm-long, 1.5-mm diameter tungsten, shaped in a "bent hairpin" configuration, as shown in Figure 5. The filaments are mounted on the water-cooled filament sandwich, shown in Figure 6, in a "racetrack" arrangement. The filament sandwich has a 3 cm thick copper spacer plate (electrically isolated with kapton on each side) between it and the bucket wall rear flange, and a 2 cm thick copper spacer plate (electrically isolated with kapton on each side) between the sandwich and the backplate. Recently, electrical grade 0.3 mm mylar has been substituted for kapton. The mylar is mechanically stronger, and the added thickness makes it less susceptible to shorting.

In the development source described here, 0.5 mm molybdenum shields covered the surfaces of the filament sandwich, as shown in Figure 6. The shields, which are radiatively cooled, reduce arc spotting by keeping plasma from the copper surface (cathode potential) and the insulator gaps. They are mechanically attached to the positive filament plate.

The actively cooled copper back plate, called the "electron dump", is shown in Figure 7. The back plate serves both as a dump for backstreaming electrons, and as part of the anode area. Located behind the water cooling channels in the electron dump are 56 samarium cobalt permanent magnets. The arrangement is illustrated in Figure 8, with a central row (at one polarity) and a loop row (at opposite polarity) on the border of the 10 cm x 40 cm region. The magnets should be checked to insure the proper polarity. Any magnet orientated in the improper direction affects the plasma profile adversely. The magnet plate bolts to the rails located behind the water-cooling channels in the electron dump. The installed magnet plate is shown in Figure 7. Mounted on the front bucket flange is a 2 cm thick copper probe plate, shown in Figure 9.

The probe plate provides mounting space for six water-cooled probes which are used to determine plasma uniformity. A water-cooled probe is illustrated in Figure 10. The probe plate is also used to provide additional anode when necessary, e.g., during hydrogen operation.

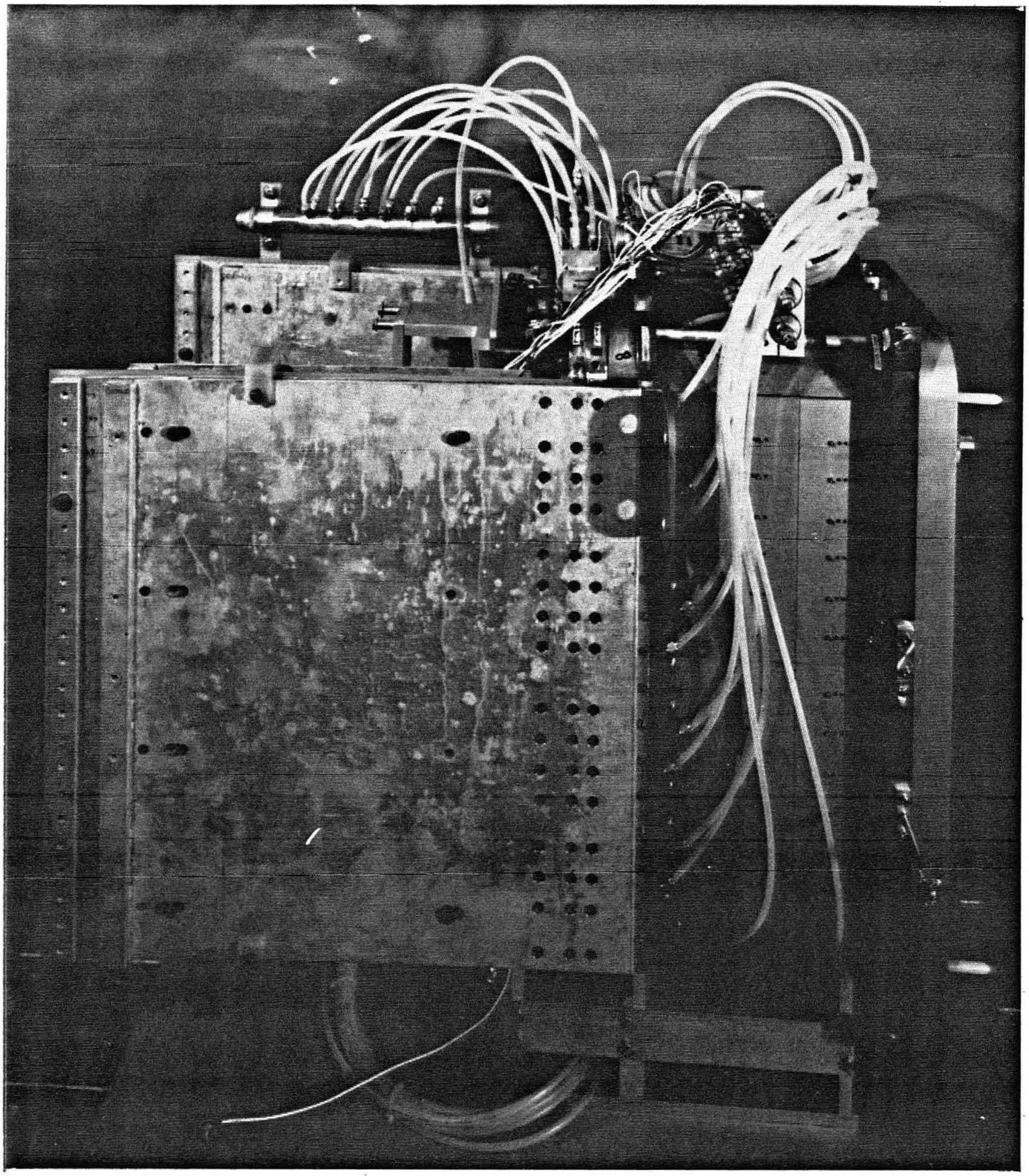

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Figure 3. Picture of the long pulse plasma source (LPS). The fixture at the bottom is used to hold the source vertical when it is removed from the accelerator.

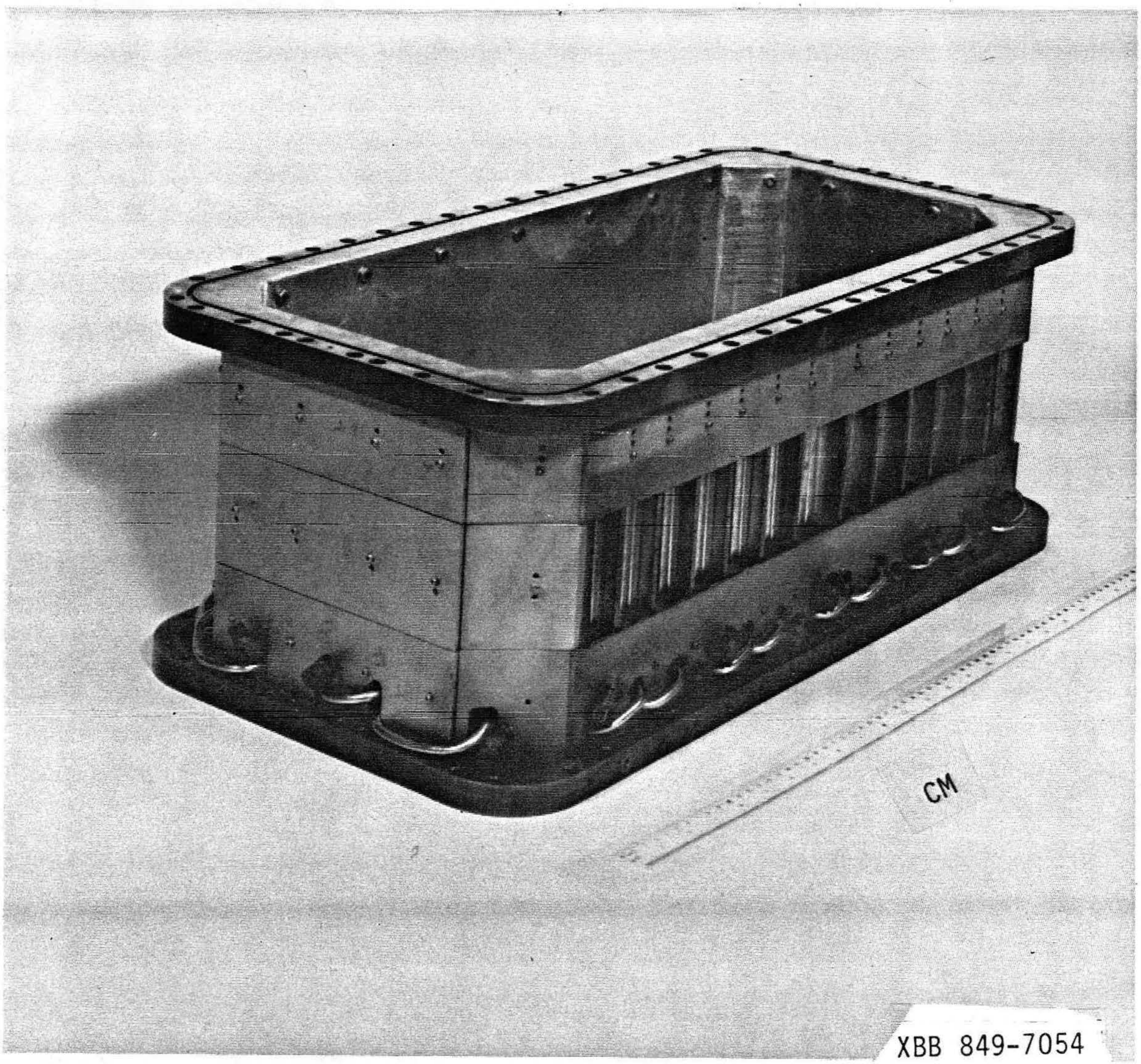

Figure 4. Picture of the plasma chamber (also called arc chamber), with some of the magnets and iron backing plates removed, to show the water cooling channels.

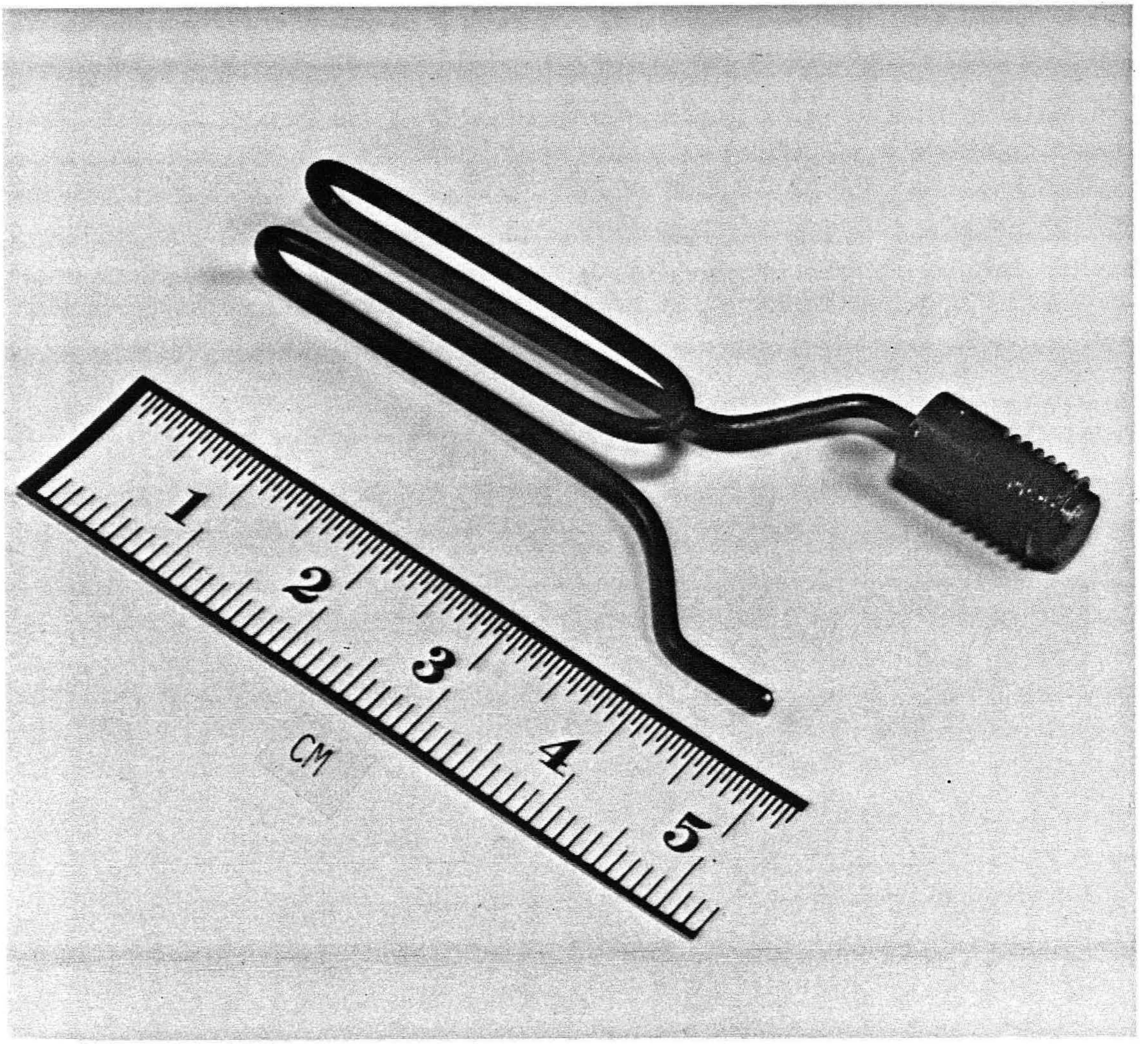

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Figure 5. Picture of a 1.5 mm tungsten filament showing the "bent hairpin" configuration and a molybdenum chuck.

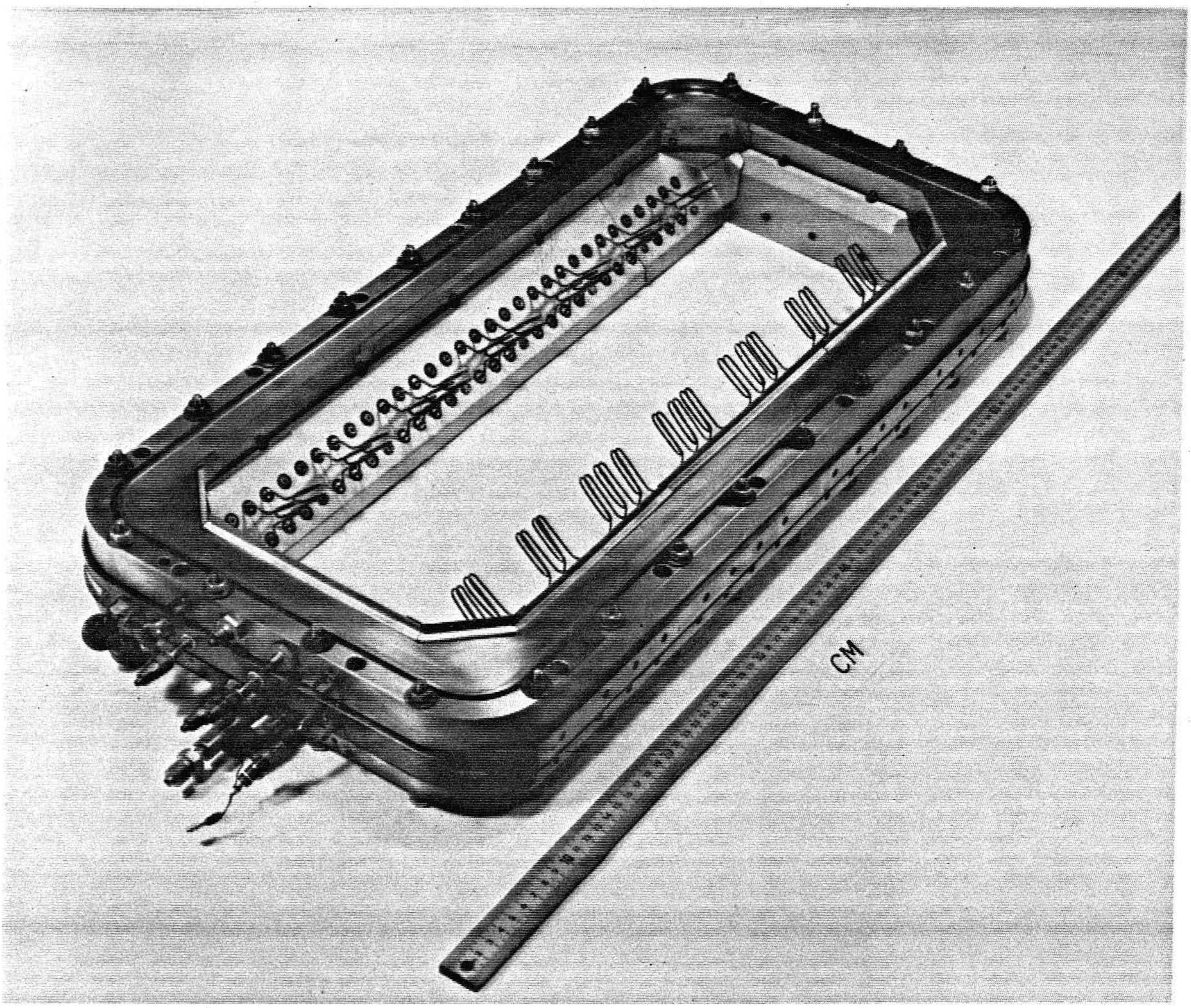

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Figure 6. Picture of the filament sandwich with the filaments installed. The moly shields, shown mounted on the positive filament plate, were the 0.5 mm experimental version. Due to excessive warping of these shields, a newer version, using 3.2 mm moly plates, was used on NBETF.

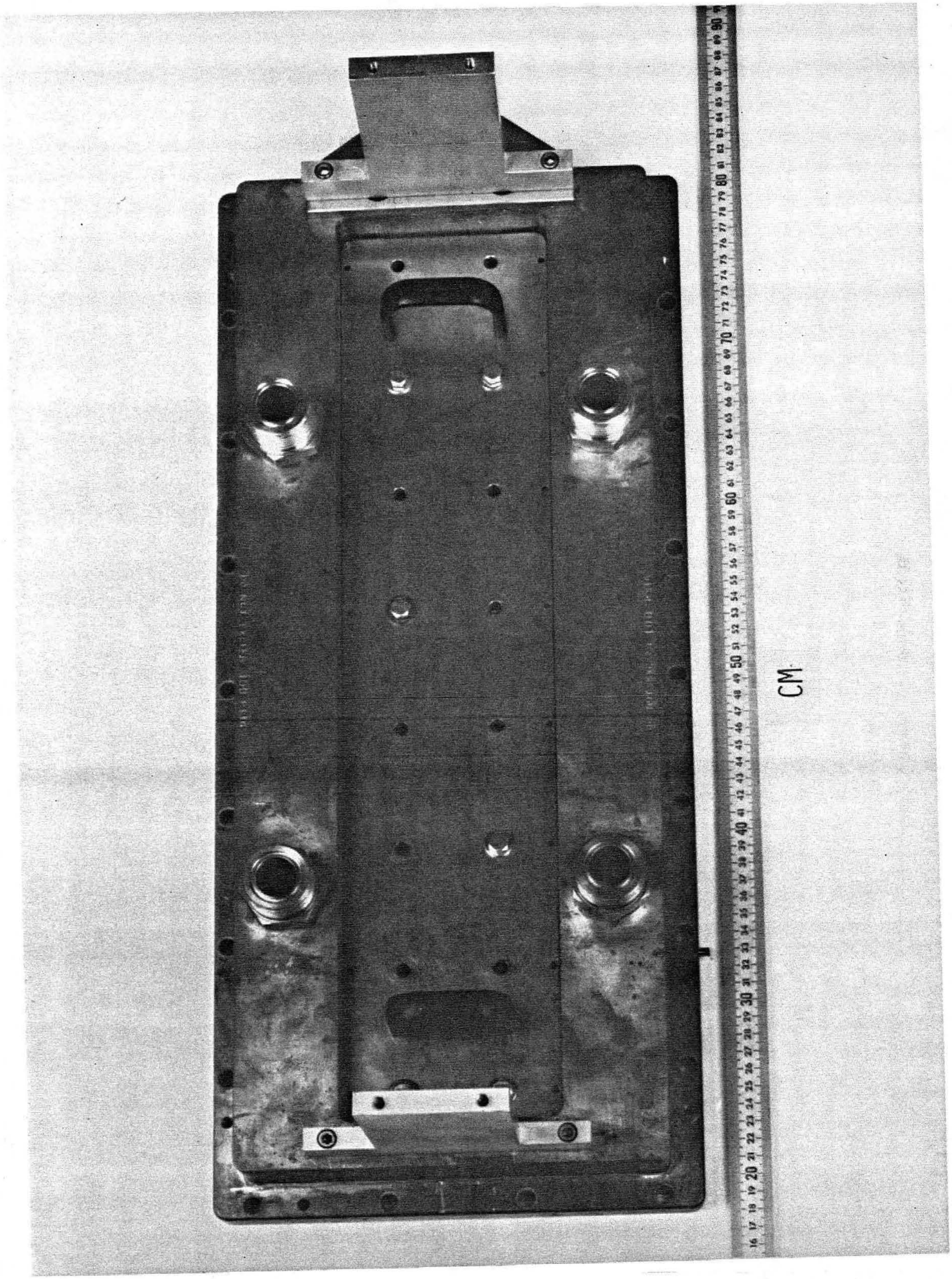

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Figure 7. Picture of the actively cooled copper Electron Dump with the Back Plate magnets installed. This Back Plate is also used as partial anode.

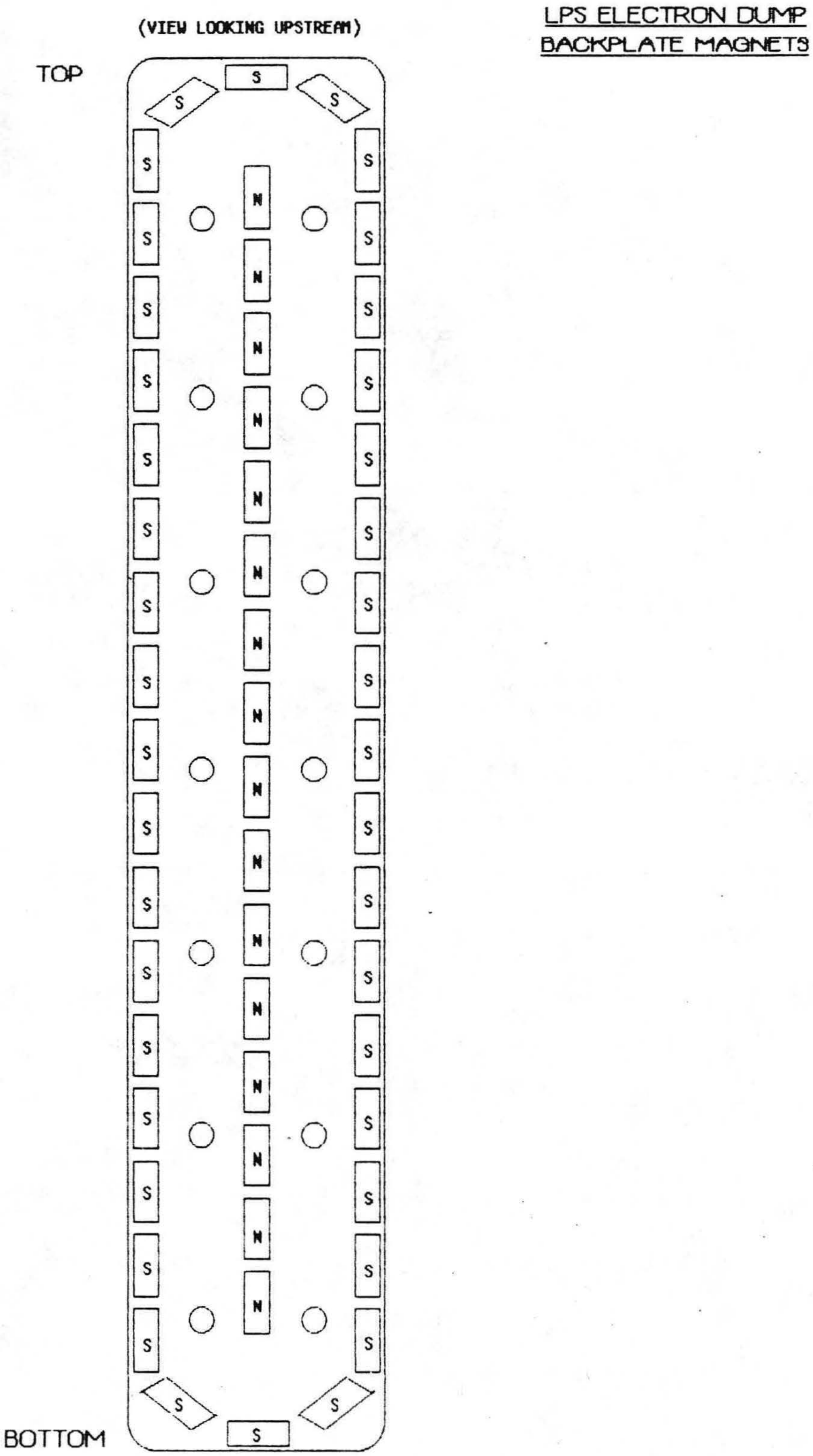

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Figure 8. Schematic of the magnet polarities and arrangement on the Electron Dump.

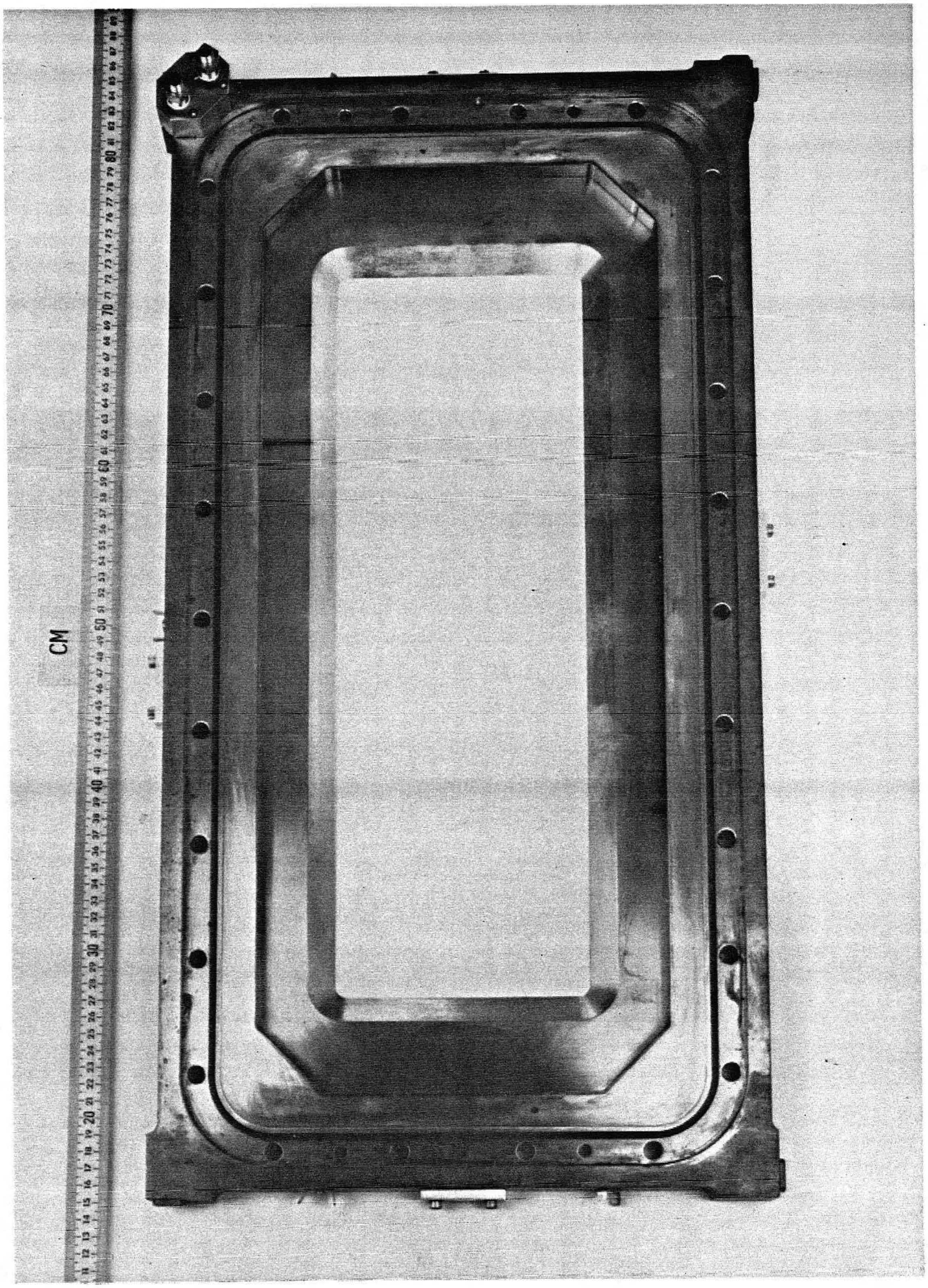

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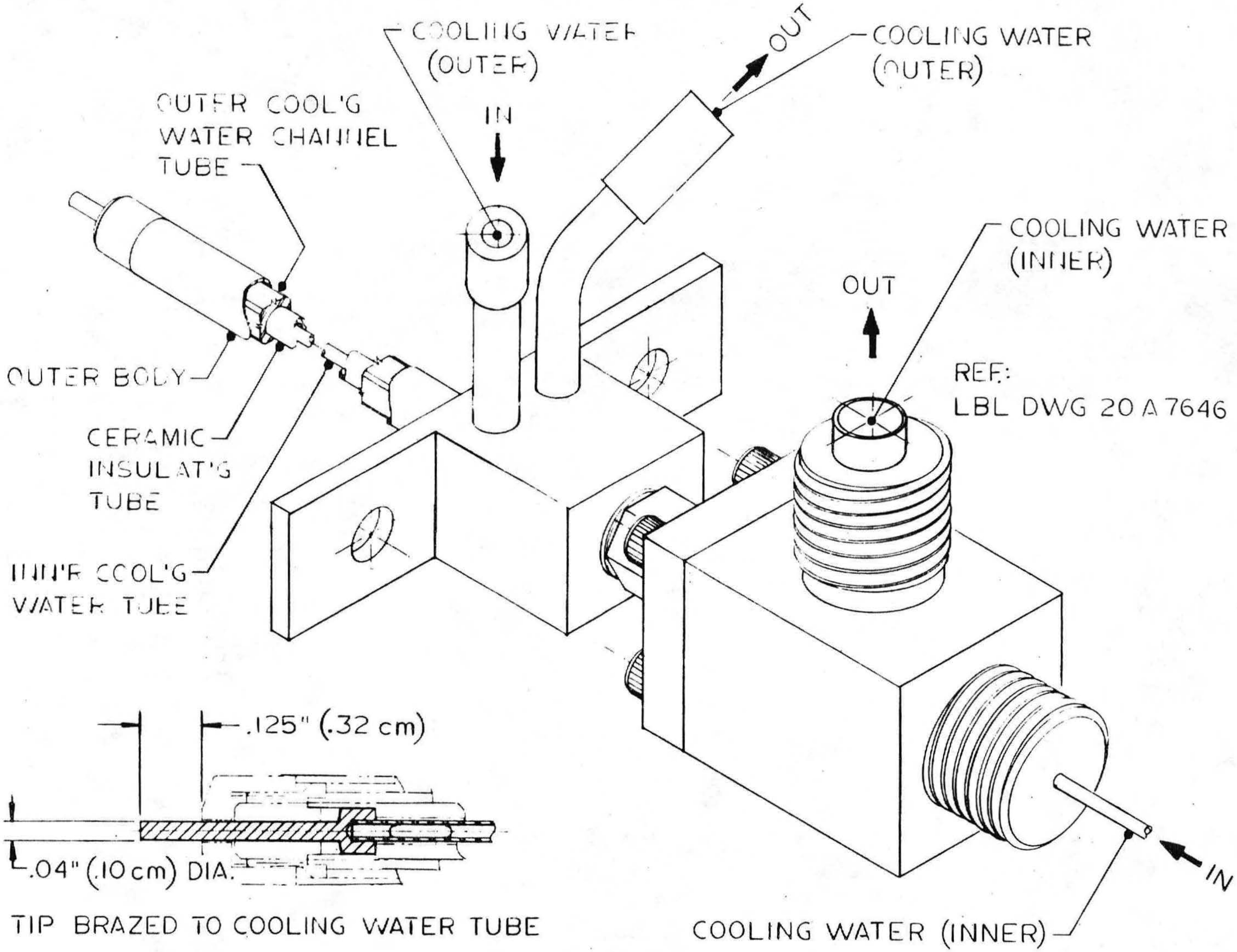
Figure 9. Picture of the water-cooled Probe Plate.



XBL 847-2994

Figure 10. Drawing of the water-cooled probe.

2. LPS ASSEMBLY PROCEDURE

The LPS is assembled by bolting together subassemblies, then forming the entire plasma chamber from the subassemblies.

The parts of the LPS, illustrated in Figure 11, are:

1. Probe Plate
2. Magnetic Bucket
3. Forward Copper Spacer
4. Filament Negative Plate
5. Filament Positive Plate
6. Rear Spacer
7. Backplate (Electron Dump)
8. Backplate Magnets
9. Current Sheets
10. Kapton Gaskets
11. Molybdenum Shields
12. 1.5 mm Tungsten "Bent Hairpin" Filaments

When assembling the source, it is important to ensure that all the parts are clean and free of any debris. One of the problems encountered in using kapton gaskets between the plates is that debris (metal chips, lint etc) clings to the kapton. If the debris is metallic there is a good possibility of developing a short between two plates, due to possilbe penetration of the kapton. This often occurs after the source is under vacuum. Since kapton has been a problem, alternative insulators, such as electrical grade mylar, are being investigated.

The Probe Plate is bolted (with electrically insulating bolts) to the front Magnetic

Bucket flange with a 0.12 mm kapton gasket in between, forming one of the subassemblies. This should be checked with an ohmmeter to be sure the Probe Plate is isolated from the Magnetic Bucket.

The next subassembly is the Filament Sandwich which consists of the Forward Copper Spacer, kapton gasket, Filament Negative Plate, another kapton gasket, and Filament Positive Plate. These parts should be bolted tightly together with electrically insulating bolts, then checked with an ohmmeter to ensure that there are no shorts before installing the filaments. The Forward Copper Spacer should not be shorted to the Filament Negative Plate since it is intended to be an electrically floating element of the source. Likewise, there should be no short between the + and - Filament Plates.

Once the Filament Sandwich is assembled the moly shields can be installed. The moly shields are connected on some of the positive filament chucks. Additional moly shields (with a lip) are attached to the Forward Spacer. Another check for shorts is then performed, in addition to a visual inspection of the moly shields, to see whether any one of them is close enough to cause a short.

The next step is to install thirty-four 1.5 mm tungsten filaments. The filament is held via spring action of the split chuck. Be sure that the filament fits tightly in the filament chuck, and that it is snug against the copper insert in the chuck. Avoid lateral forces which may overstress and mechanically yield the sections of the chuck. The filaments are orientated in a "racetrack" configuration, i.e., the bent over portion of each filament faces in the same direction as the filament preceeding it, all the way around the perimeter of the filament sandwich. The filaments are strategically positioned in the source so they are protected from backstreaming electrons, if the source is operated without the Backplate magnets. The Filament Sandwich is now ready to be bolted, with insulated bushings, to the rear Magnetic Bucket flange, with a kapton gasket in between.

The third subassembly is the Rear Spacer, kapton gasket, and Electron Dump. These parts are bolted together, checked for shorts, then bolted, with insulated bushings and a kapton gasket in between, to the Filament Sandwich. The Backplate magnet plate can be bolted to the Electron Dump, now, or after arc conditioning (Section 10 (A)).

The entire LPS Assembly is now ready to be attached to the LPA, with insulated bushings and a kapton gasket between the LPS and the LPA.

Another ohmmeter check should be done with the source under vacuum, before attaching the Current sheets, M.O.V.-Diode Circuits, and connecting up the water lines and electrical connections.

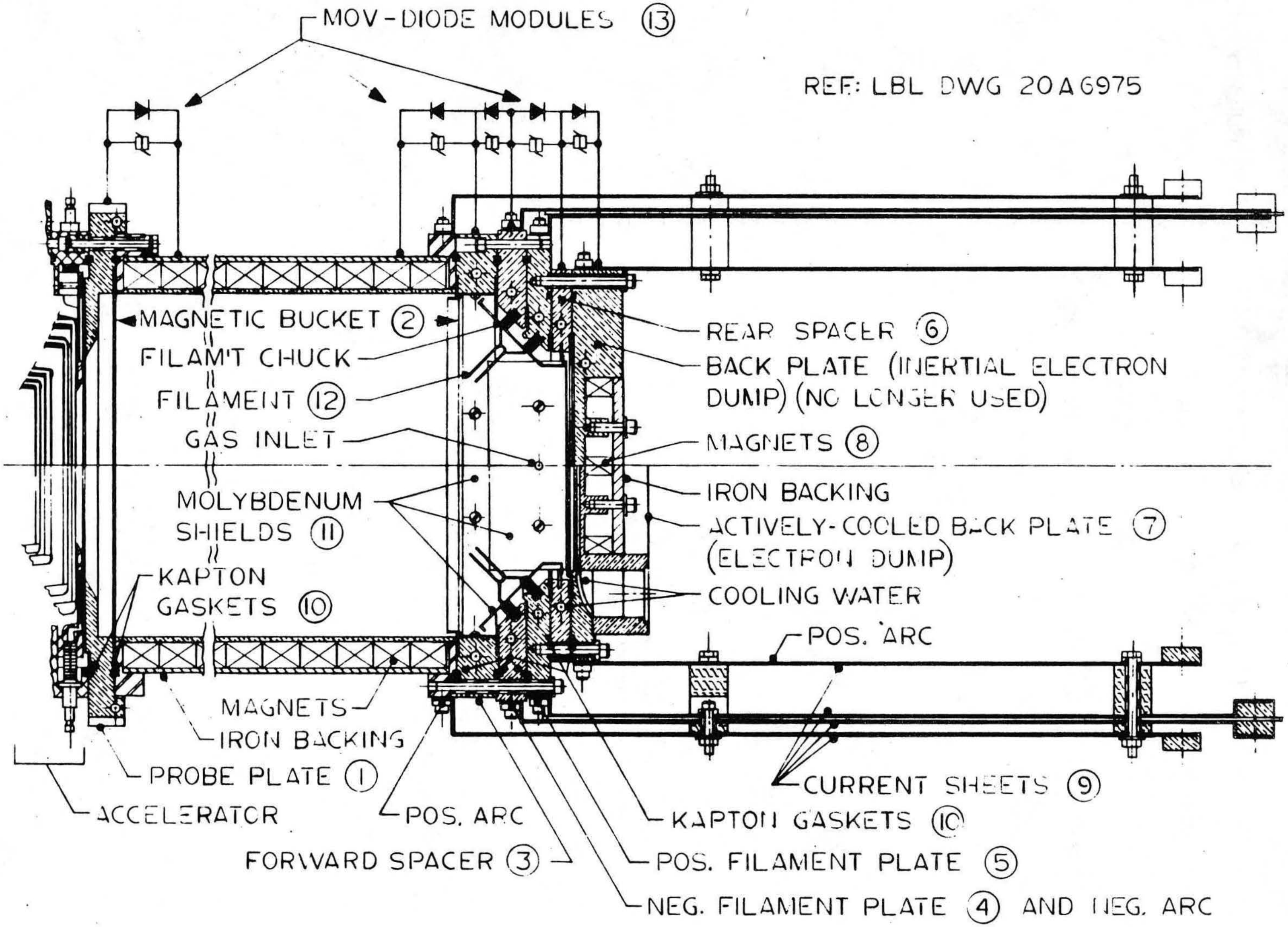


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Figure 11. Schematic of the LPS with labeled parts.

3. LPA DESCRIPTION

The 10 X 40 cm LPA accelerator is shown in Figure 12. The 80 kV gaps are illustrated in Figure 13. In this form, it delivered 40.5 Amps (deuterium) at optimum perveance. Each of the four grid assemblies consists of an array of forty-four shaped, water-cooled molybdenum tubes, with a wall thickness of 0.5 mm. Layouts of the grids are shown in Figures 14 and 15 in Section 6. Grid transparency is 60%.

The insulator assembly consists of brazed alumina sections, with corona shields. In the LPA, these shields also served as water manifolds to route the water to the grid tubes in order to meet TFTR space constraints. Grid water is split into halves, in the long dimension, i.e., each of the four grids has two separate cooling circuits. Heat loads are measured on each half of each grid, which provides a minimal check of plasma uniformity. The grids were designed assuming a uniform heat load of 2 kW/rail. The heat loads are measured by water flow calorimetry, using the computer program in Appendix 1.

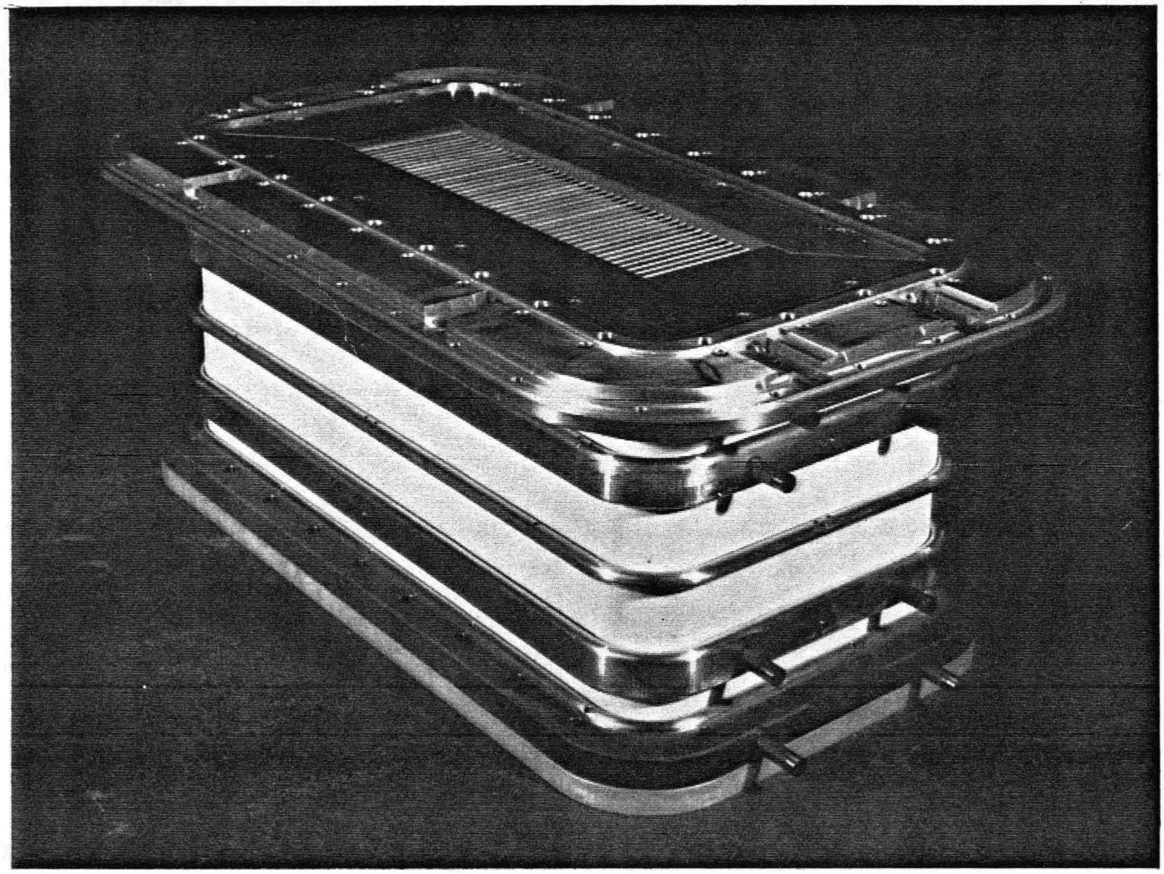

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Figure 12. Picture of the long pulse accelerator (LPA).

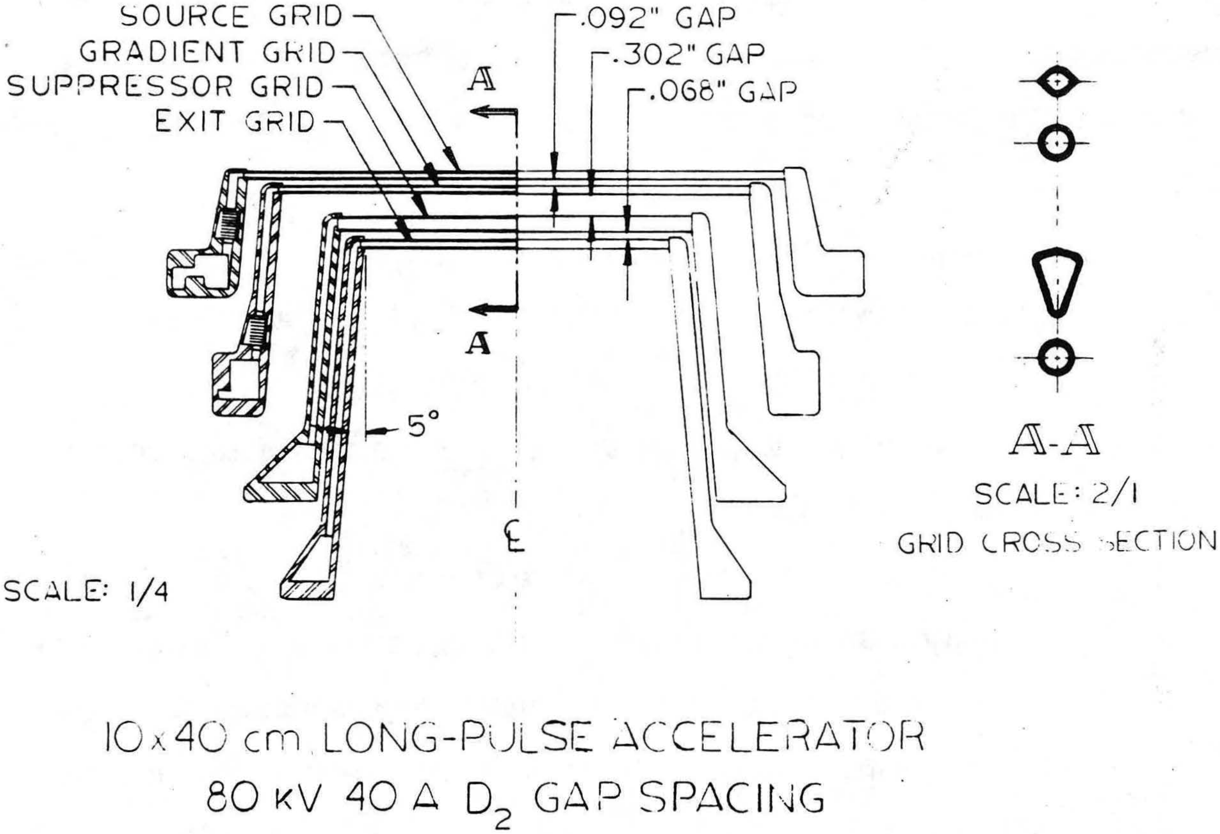

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Figure 13. Schematic of the LPA grid rail shapes and gap spacing.

4. LPS/LPA MOUNTING PROCEDURE

4 (A) HANDLING TECHNIQUES

The brazed construction of the LPA ceramic insulator stack requires certain handling techniques when mounting the accelerator to the beamline. To ensure that the accelerator brazed alumina joints are not stressed while installing the LPA, we use a dynamometer. The following procedure is used to mount the LPA to the NBETF beamline:

1. Install the lifting fixture on the accelerator.
2. Place a dynamometer between the lifting fixture and the crane hook. (Weight of the prototype LPA with lifting fixture is 300 pounds). The dynamometer will register the weight of the accelerator and lifting fixture.
3. Clean all surfaces of the accelerator. Check the o-rings and the o-ring grooves. Grease the o-rings with minimal amounts of vacuum grease as excessive grease could contaminate the accelerator.
4. Bolt the front flange of the accelerator to the matching surface of the beamline.
5. Before the LPS can be mounted to the LPA, the accelerator must be supported. (A heavy duty lab jack is used for this purpose on NBETF). Caution must be used so that at no time is a shear load applied to the accelerator by this support. Place the jack under the flange of the LPA that the LPS will be bolted to. Never place the support against the ceramic surface of the accelerator. Make sure that the support is just touching the flange and not applying pressure, by adjusting the jack

screw until the dynamometer registers a reading of zero.

6. When the dynamometer registers the correct reading with the support installed, remove the crane, dynamometer, and lifting fixture from the accelerator.
7. At this point the LPS can be bolted to the accelerator. Pick up the LPS with the crane. Move it into position for mounting and install the bolts to mount it to the LPA. Avoid introducing any forces on the accelerator while mounting the LPS.
8. CAUTION : Don't remove the crane from the LPS or the support from the accelerator until the entire unit is under vacuum.
9. When venting the accelerator, either intentionally, or on an up to air accident, the support should be reinstalled immediately.

After the LPS/LPA is mounted on the beamline, recheck the spacer elements with an ohmmeter to be sure that no shorts have developed during handling.

4 (B) PUMP DOWN AND LEAK CHECK

Connect the gas valve to the source. Make sure the valve on the gas bottle is closed. Polyethylene tubing is used between the source gas valve and the gas bottle to isolate the bottle from high voltage. This line should be evacuated, after installation, to eliminate any contaminants. It can be pumped out when the entire LPS/LPA is pumped down, by activating the source gas valve 5 or 6 times with the gas bottle valve closed.

Pump down the source and accelerator on the beamline. Again check for shorts. Sometimes a short develops when the system is under vacuum, and a quick check at this time may save having to remove water lines and electrical connections. When the LPS/LPA is under vacuum, we always perform a helium leak check of the system to verify that there are no vacuum to air leaks. Likewise, the accelerator grids should be checked for possible pressurized water leaks by putting 100 psia helium on each circuit during the system leak check. Any detectable leak should be repaired before proceeding.

After verifying that there are no shorts and no leaks, the gas lines should be pressurized with the appropriate gas, and the Grids are ready to be hipotted.

5. HIPOTTING THE ACCELERATOR

If possible, a D.C. hipotter should be used to check the voltage holding capability of the grids. This should be done when the accelerator is under vacuum, before the water lines and electrical cables are connected. The accelerator is hipotted before the water lines are connected, to reduce the load on the hipotter, and before the electrical cables are connected, to hipot the accelerator only. This method assures that all the current seen on the hipotter is accelerator related, and not due to water paths or power supplies. D.C. hipotting is the first step in conditioning the grids. It is also a quick check for assembly errors, or pieces that might have come loose during handling.

Begin by electrically connecting together all elements on either side of the gap under test to minimize corona and sparking. Keep the clip leads at low inductance. This is to prevent damages from breakdown (or breakdown transients) to insulators designed to hold off lower voltages. We use a total of 7 K ohms resistance in series with the hipotter to prevent overcurrent damage to the source and hipotter.

The gas feed lines should be pressurized with gas, since a partial vacuum constitutes a breakdown path.

The technique of hipotting is to lower the voltage when a corona discharge in the grid region is loading down the hipotter; check for diminished drain current with successive tries. The current should increase linearly with voltage, non-linearity suggests corona.

CAUTION : Be sure to use the appropriate polarity when hipotting, since the opposite polarity from that of the operating potential degrades the voltage holding capability of the gap.

The three gaps should be able to hold off voltage 5 to 10% above their design operating potential and are typically taken up to the breakdown limit when conditions permit. Hipotting the second gap above 80kV requires a sulfurhexaflouride environment (to avoid break-overs on the air side of the ceramic).

The LPA 80 kV, 40 AMP deuterium gapped accelerator had the following characteristics:

	SPACING (mm)	VOLTAGE (kV)	CURRENT DRAIN (mAMPS)
Gap 1	2.34	37	0.1
Gap 2	7.67	78	0.1
Gap 3	1.73	-6	0.05

6. LPS/LPA WATER AND ELECTRICAL CONNECTIONS

6 (A) WATER CONNECTIONS AND FLOW REQUIREMENTS

The LPS/LPA uses Low Conductivity Water (LCW) which has passed through a deionizer and an oxygen scrubber. Deionization is required to minimize high voltage power loss to ground through the water lines. Oxygen scrubbing is required to prevent corrosion of the molybdenum accelerator grid tubes. The working specifications for water used at LBL are resistivity, 3 - 10 MΩ-cm and oxygen, 9 ppb. If the resistivity is much higher than 10 MΩ-cm, source corrosion could be a problem. Various types of materials were used in tubing and connectors: polyethylene; PVC (nylon reinforced); nylon; and reinforced non-conducting, synthetic hose. Note: rubber develops carbonized conducting tracks and should not be used in high voltage applications.

The LPS has four separate water manifolds. Two manifolds are for the flow supply and return to the Magnetic Bucket (39.7 liters/minute), and two manifolds are for the Filament Sandwich, Probe Plate, and Spacers (17.4 l/m). In addition, there are separate supply and return LCW connections for the Electron Dump (136 l/m). The large supply and return lines are at least 5 feet long for insulation. They act as voltage dividers to the couplings between floating potential and ground. **WARNING** : It is extremely important to ensure that the water lines are connected properly, that is, all the supply lines are connected to the inlets and all the return lines are connected to the outlets of the source. This can be verified by flowing air through each circuit, if there is any doubt. Examples of the LPS water flow calorimetry[6] are shown in Section 12.

At LBL, the LPA water goes through a High Pressure Water Cart, which has eight supplies and eight returns, with individual manual valves and flow meters. Water flow through the grids of a 150 kV, 65 Amp deuterium conceptual design is illustrated in Figures 14 and 15; water flow in the LPA is the same. The Cart was located about 15m from the test stand; it had a supply pressure of ≈ 285 psig and a return pressure of ≈ 65 psig. The Cart supply pressure was determined by the water circuit impedance to the source and back. The required Cart return pressure was determined by the impedance of the return circuit to the pump reservoir, and was set by a back pressure regulator in the return circuit. Each half of each grid has one supply and one return, with a ΔT block for grid calorimetry which is located about two meters from the source below the high voltage platform. A Basic program, developed for measuring the heat loads on the grids with a Hewlett-Packard 9845 B, is included in Appendix 1. An example of the LPA calorimetry using this program is shown in Figure 16. All water lines should be clearly marked for connection to the proper grid.

The LPA grids were designed to have turbulent flow, i.e., no boiling. Testing revealed that most of the water circuit pressure drop occurred in water lines and fittings. The water flow and pressure requirements for the 10 x 40 cm LPA are listed below:

	Flow Rate per Half	Calorimetry Channel	Grid Module Δ-Pressure
Grid 1 (Accel Grid)	22.7 l/m	1	45 psi
	22.7 l/m	2	45 psi
Grid 2 (Gradient Grid)	22.7 l/m	3	12 psi
	22.7 l/m	4	12 psi
Grid 3 (Suppressor Grid)	39.7 l/m	5	20 psi
	39.7 l/m	6	20 psi
Grid 4 (Exit Grid)	22.7 l/m	7	18 psi
	22.7 l/m	8	18 psi

A system independent requirement is for 75 psia back pressure at the rail exit, to prevent boiling.

Although grid water flow calorimetry is not a strict operational requirement, at LBL grid calorimetry was a reliable accelerator diagnostic. Because the flow of each grid is split into halves, grid calorimetry provided an effective indication of gross plasma nonuniformity when plasma probe data were unavailable. At LBL grid calorimetry often served as the basis for a final go/no go decision during development testing. Grid calorimetry is most useful if flow through each individual grid is balanced so that any beam heat imbalance is easily recognized on the waterflow calorimetry data.

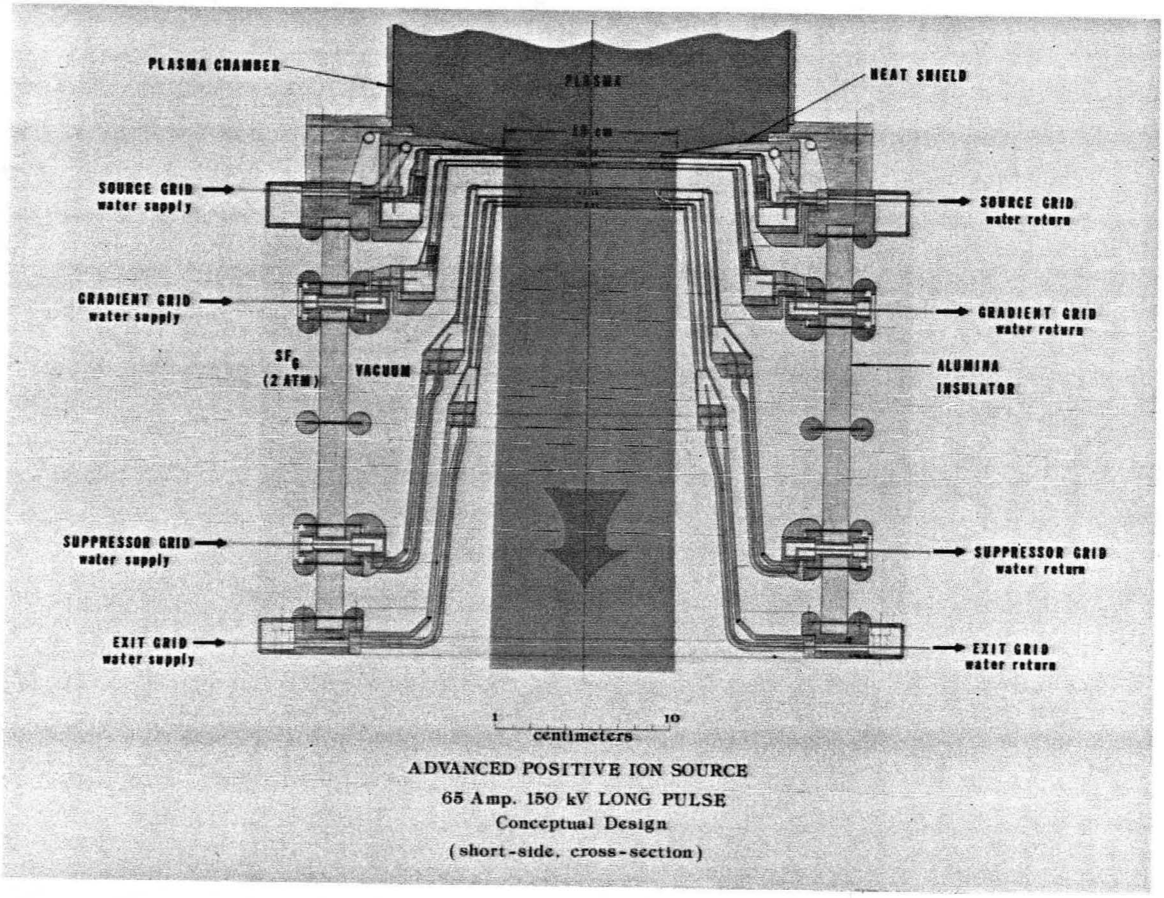

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Figure 14. Illustration of water flow in the APIS Conceptual Design (short-side, cross section). Water flow in the LPA is the same.

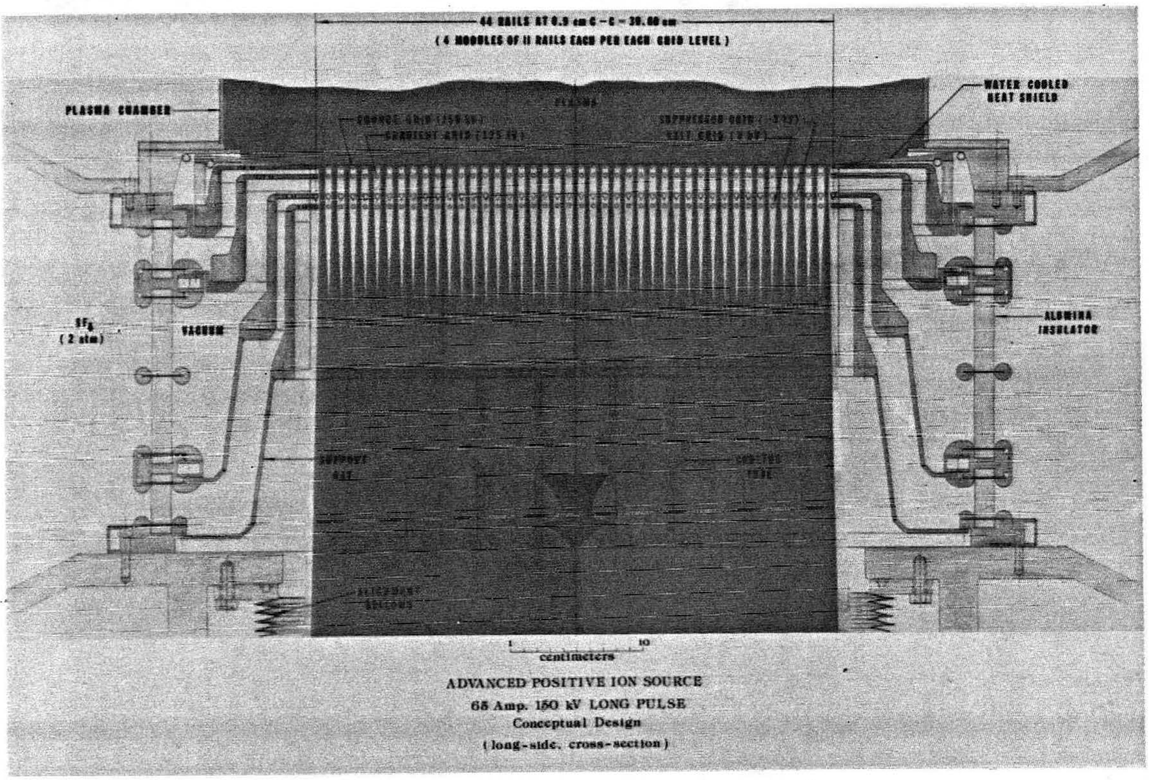

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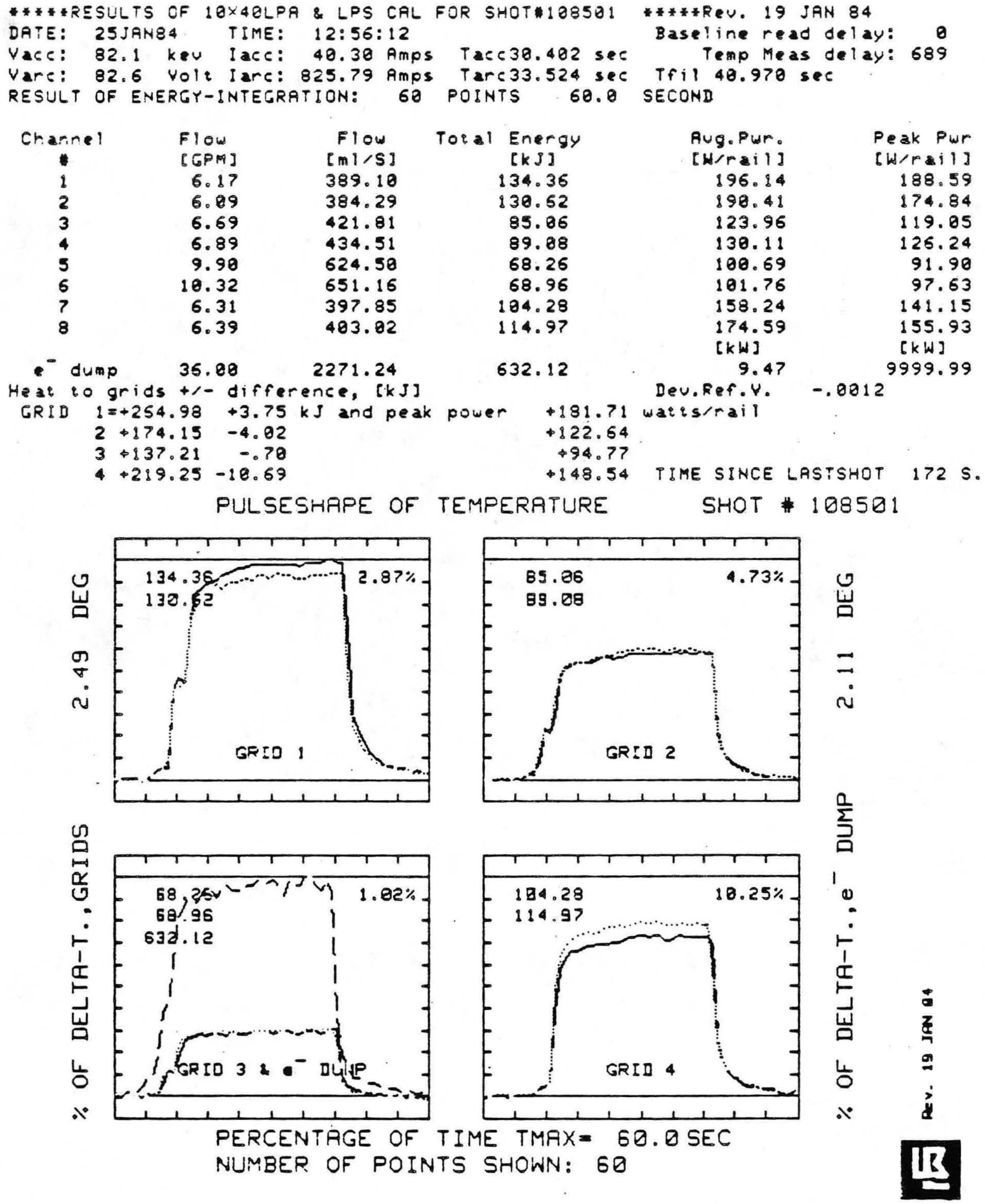
Figure 15. Illustration of water flow in the APIS Conceptual Design (long-side, cross-section). Water flow in the LPA is the same.



```
*****RESULTS OF 10×40LPA & LPS CAL FOR SHOT#108501   *****Rev. 19 JAN 84
DATE:  25JAN84    TIME:  12:56:12                      Baseline read delay:   0
Vacc:  82.1  kev  Iacc:  40.30 Amps  Tacc30.402 sec       Temp Meas delay: 689
Varc:  82.6  Volt Iarc: 825.79 Amps  Tarc33.524 sec  Tfil 40.970 sec
RESULT OF ENERGY-INTEGRATION:   60  POINTS   60.0  SECOND

 Channel       Flow          Flow    Total Energy           Avg.Pwr.          Peak Pwr
    #          [GPM]        [ml/S]       [kJ]               [W/rail]          [W/rail]
    1           6.17        389.10      134.36               196.14            188.59
    2           6.09        384.29      130.62               190.41            174.84
    3           6.69        421.81       85.06               123.96            119.05
    4           6.89        434.51       89.08               130.11            126.24
    5           9.90        624.50       68.26               100.69             91.90
    6          10.32        651.16       68.96               101.76             97.63
    7           6.31        397.85      104.28               158.24            141.15
    8           6.39        403.02      114.97               174.59            155.93
                                                             [kW]              [kW]
   e⁻ dump     36.00       2271.24      632.12                 9.47           9999.99
Heat to grids +/- difference, [kJ]                      Dev.Ref.V.    -.0012
 GRID  1=+254.98  +3.75 kJ and peak power   +181.71 watts/rail
       2 +174.15  -4.02                     +122.64
       3 +137.21   -.70                      +94.77
       4 +219.25 -10.69                     +148.54  TIME SINCE LASTSHOT  172 S.
                    PULSESHAPE OF TEMPERATURE         SHOT # 108501
```

XBL 847-2988

Figure 16. Computer printout of the LPA grid water flow calorimetry. The vertical scale on the left is for all grid halves; the scale on the right is for the electron dump. Average power is from steady state water flow. Peak power is an estimate based on the rate of rise; peak power is usually used only on short shots.

6 (B) ELECTRICAL CONNECTIONS

On NBETF, the LPS/LPA was connected to the power supplies as shown in Figure 17. The ion source, on the beamline, with all the water lines and electrical connections made, is shown in Figure 2.

The arc power supply and filament power supply cables are connected to the source at the current sheets. Current sheets are used to uniformly distribute the current from the power supplies to the source. We have found that the wires supplying the arc and filament current must be dressed neatly and attached to the source in a distributed way, to eliminate magnetic fields which adversly affect plasma uniformity. If all the currents are supplied with one connector, the currents flowing in the walls of the source to the connector produce such undesirable magnetic fields. If numerous cables are used, it is advantageous to color code them according to polarity and power supply with the respective current sheets. The chances of misconnections are reduced with this method.

Three elements of the LPS should be protected against overvoltage. These elements are:

1) Probe Plate
2) Forward Copper Spacer
3) Rear Spacer

To provide overvoltage protection for these elements, Metal Oxide Varistor (M.O.V.) - Diode Circuits, as shown in Figure 18, and Figure 9, item 13, are used on the LPS. The M.O.V. keeps potential differences from exceeding the voltage limit set by the size and number of M.O.V.'s in series. The M.O.V. that we use is a General Electric V33ZA70, which is rated at 33 volts. For the probe plate, two M.O.V.'s in series keeps the potential difference from exceeding 67 volts. For the forward spacer and the rear spacer, three M.O.V.'s are used to keep the potential difference from exceeding 100 volts. The diode (1N4732) restricts it even more. It provides a voltage clamp so that the spacer plate can never get more positive than the anode nor more negative than the cathode.

The gradient grid and suppressor grid cables are connected directly on their respective accelerator corona rings. Individual supply and monitor leads should be used so that loss of supply voltage to these grids is detected immediately. Care should be taken to dress these cables so as to avoid spark over to the water lines.

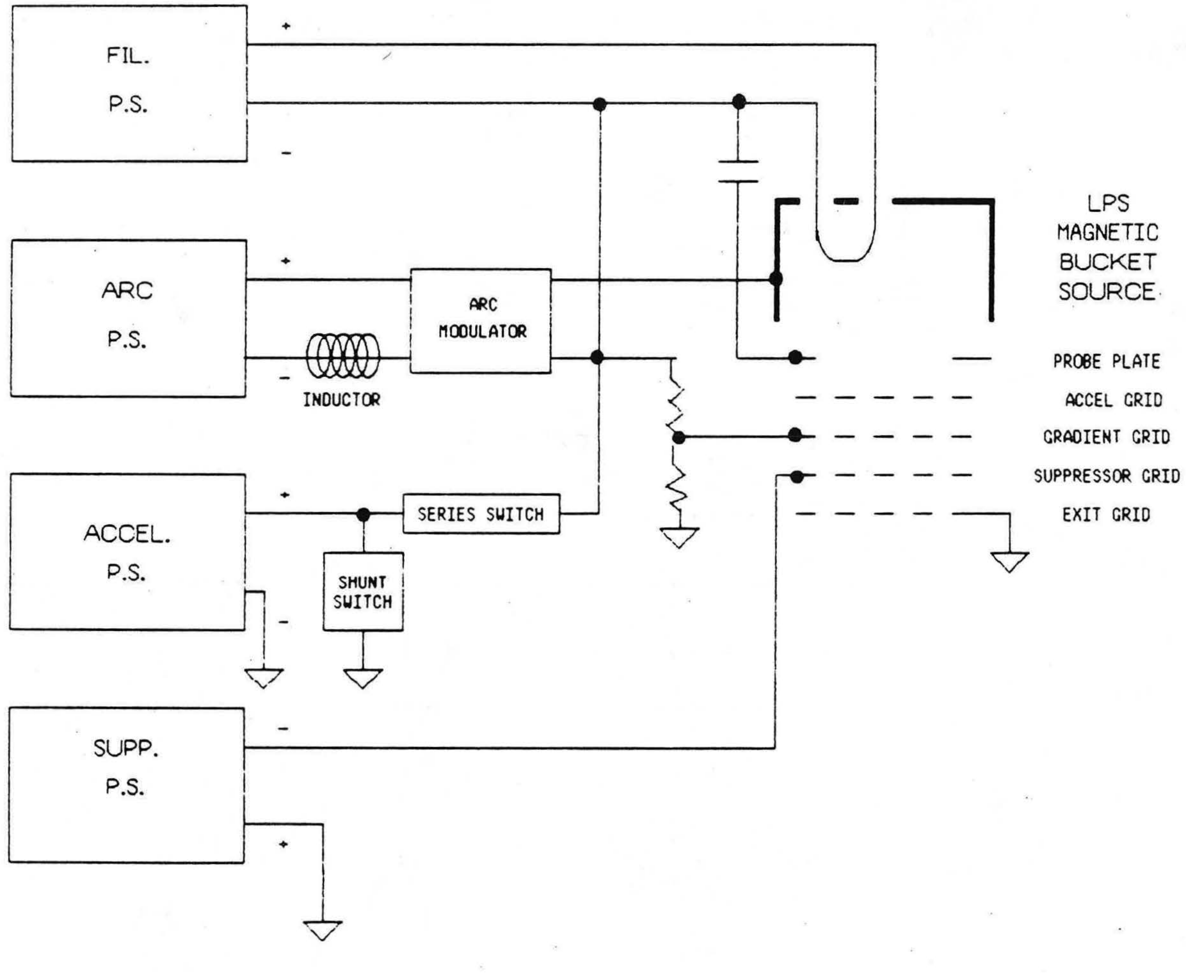
The appropriate signal monitor (see Section 7) wires are attached with spade lugs (for ease of connection and removal) on the source and go to a multi-pin connector which is situated on the rear bucket flange. Each of the signal wires should be clearly identified and labled. From the multi-pin connector, the signals go to the appropriate calibrator (Appendix 2) and telemetry channels for monitoring.

All cables connected to the source should pass through a magnetic core stack. This magnetic core acts as a series resistance to limit accelerator "spark down" current from that capacitance which is on the power supply side of the core[7].

LPS/LPA

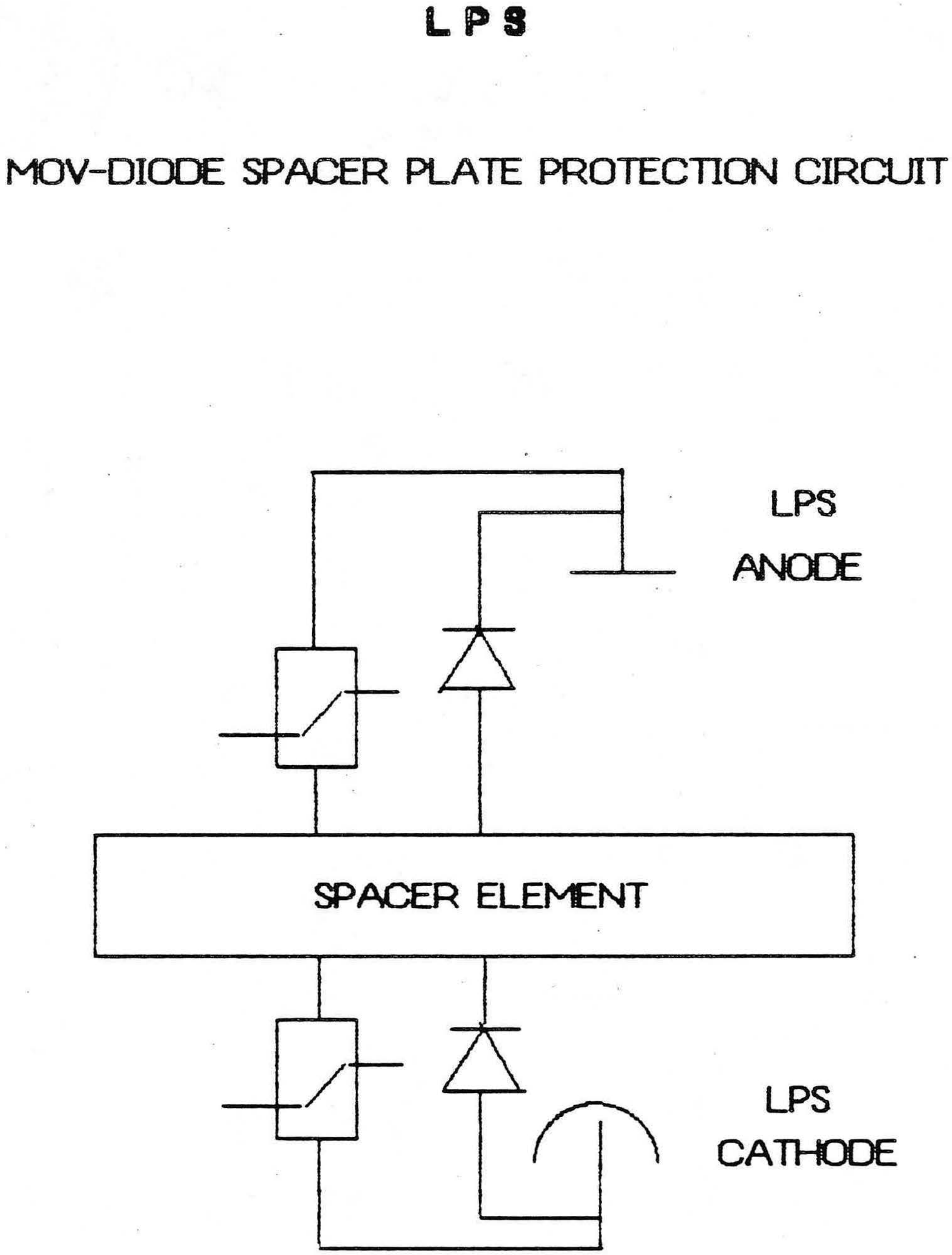
POWER SUPPLY CONNECTIONS

ON NBETF



XBL 847-2990

Figure 17. Schematic of the NBETF power supply connections, as used for testing the LPS/LPA.



XBL 847-2989

Figure 18. Schematic of a MOV-diode circuit used for spacer plate protection on the LPS.

7. LPS/LPA SIGNAL MONITORS

The following signals are monitored during LPS/LPA operation on NBETF. All signals which are telemetered (using analog telemetry) to ground are calibrated with a built-in calibrator system which is described in Appendix 2. These signals go to the computer, the oscilloscopes, and some of the signals go to the fault detector. The Fault Detector Signals are discussed in Section 8.

$I_{\text{accelerator}}$ (I_{accel} or $I_{\text{hot box}}$)

This monitor is a coaxial shunt located in the hot box. The signal (shunt + amplifiers) has a sensitivity of 20 A/V, and is telemetered to ground.

$I_{\text{gradient grid}}$ (I_{gg})

Two types of monitors are used to look at the gradient grid current. To observe the gradient grid during the fast turn-on, a toroidal current transformer is monitored. For long pulse, a 100 mA/V Hall-effect current probe is monitored. Both monitors are mounted in the hot box, and insulated wires (good for 20 kV) are looped through them to provide the insulation to gradient grid potential. These signals are telemetered to ground.

$I_{\text{suppressor}}$ (I_{supp})

For monitoring typical operation a 1 A/V sensitivity (shunt + amplifiers) in the power supply is adequate, but, for breakdown information, and/or fault detection, a toroidal current transformer, at or near the source connection is used which is referenced to ground.

I_{filament} (I_{fil})

1000 A/V Sensitivity (shunt + amplifiers), telemetered to ground.

I_{arc}

500 A/V Sensitivity (shunt + amplifiers), telemetered to ground.

$V_{\text{accel H.B.}}$

20 kV/V Resistive Compensated Divider, referenced to ground.

V_{arc}

20 V/V Divider, telemetered to ground.

V_{gg}

20 kV/V Resistive Compensated Divider, referenced to ground.

V_{fil}

2 V/V Divider, telemetered to ground.

V_{supp}

1 kV/V Resistive Divider, referenced to ground.

$V_{\text{grid 1}}$

20 V/V Resistive Divider between accel. grid (grid 1) and cathode, telemetered to ground.

$V_{\text{forward spacer}}$

20 V/V Resistive Divider between forward spacer and cathode, telemetered to ground.

$V_{\text{rear spacer}}$

20 V/V Resistive Divider between rear spacer and cathode, telemetered to ground.

V_{1-2}

5 kV/V Resistive Divider, located on the source, and telemetered to ground.

All voltage dividers should be well compensated to provide reliable frequency response up to about 1 MHz.

8. LPS/LPA FAULT PROTECTION

8 (A) FAULT DETECTOR SET-UP PROCEDURE

Neutral beam sources and power supply systems are intimately linked, and a fault protection system should cover both systems. The power supply systems should be protected against such conditions as overvoltage, over/under current, excessive pulse length, improper settings, and open interlocks. The source should be protected against sparkdown, over current, voltage collapse in the grids, and open interlocks.

The fault detector used on NBETF is described in Appendix 3, and shown in Figure 19. A list of the signals monitored with this detector during the operation of the LPS/LPA on NBETF is shown below.

MONITORED SIGNAL	TYPES OF FAULTS	TYPICAL SETTING
V_{accel} dV/dt	Accelerator Sparkdown	≈ 15% of V_{accel}
V_{1-2} / V_{accel}	Grid 1&2 Collapse	≈ 5% over
Igg DC	Gradient Grid (Grid 2) Overcurrent	250 mA MAX!!
Vgg / V_{accel}	Grid 1&2 Collapse	≈ 3-5% over
I_{supp} P.S.	Suppressor Power Supply Overcurrent	15 Amps MAX
V_{accel}-$\overline{\text{Strobe}}$	Accelerator Voltage but No Strobe (Accel On Gate) Present	
I_{accel} Source	Accelerator Overcurrent	≈ 10% over
I_{accel} P.S.	Accelerator Power Supply Overcurrent	≈ 15% over
$\overline{V_{accel}}$-Strobe	No Accelerator Voltage but Strobe Present	
G.G. dV/dt	Accelerator Sparkdown	

V_{arc} Overvoltage	Arc P.S. Overvoltage - protects arc modulator	150 Volts MAX.
Arc Modulator Overload	Protects arc modulator from latching up in divert mode	
Spot Detector	Arc &/or Filament Metal Arc Spot	Refer to Section 8 (B) for setting
Interlock Chain	Any of the Beam Operation Interlocks Open	
Interrupt Limit	More Interrupts than Set on Interrupt Counter	

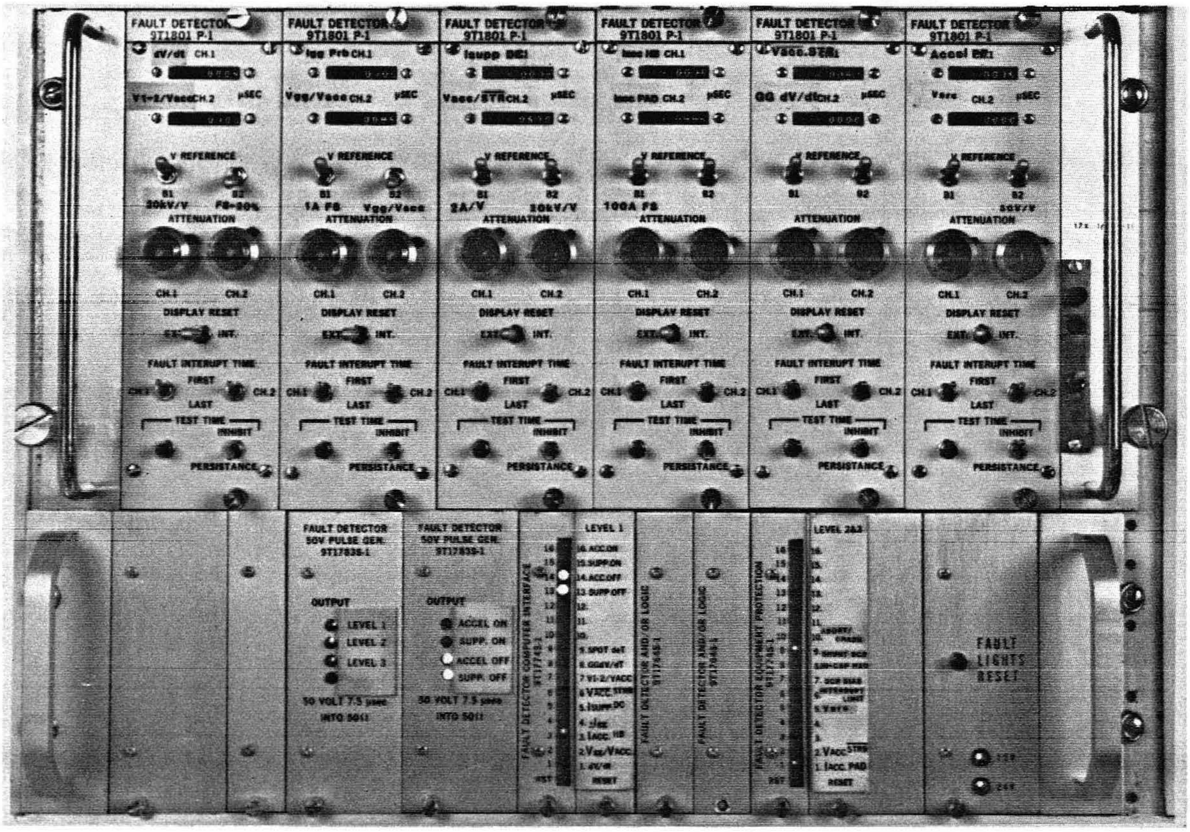


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Figure 19. A picture of the fault detector modules used on NBETF.

8 (B) SPOT DETECTOR SET-UP PROCEDURE

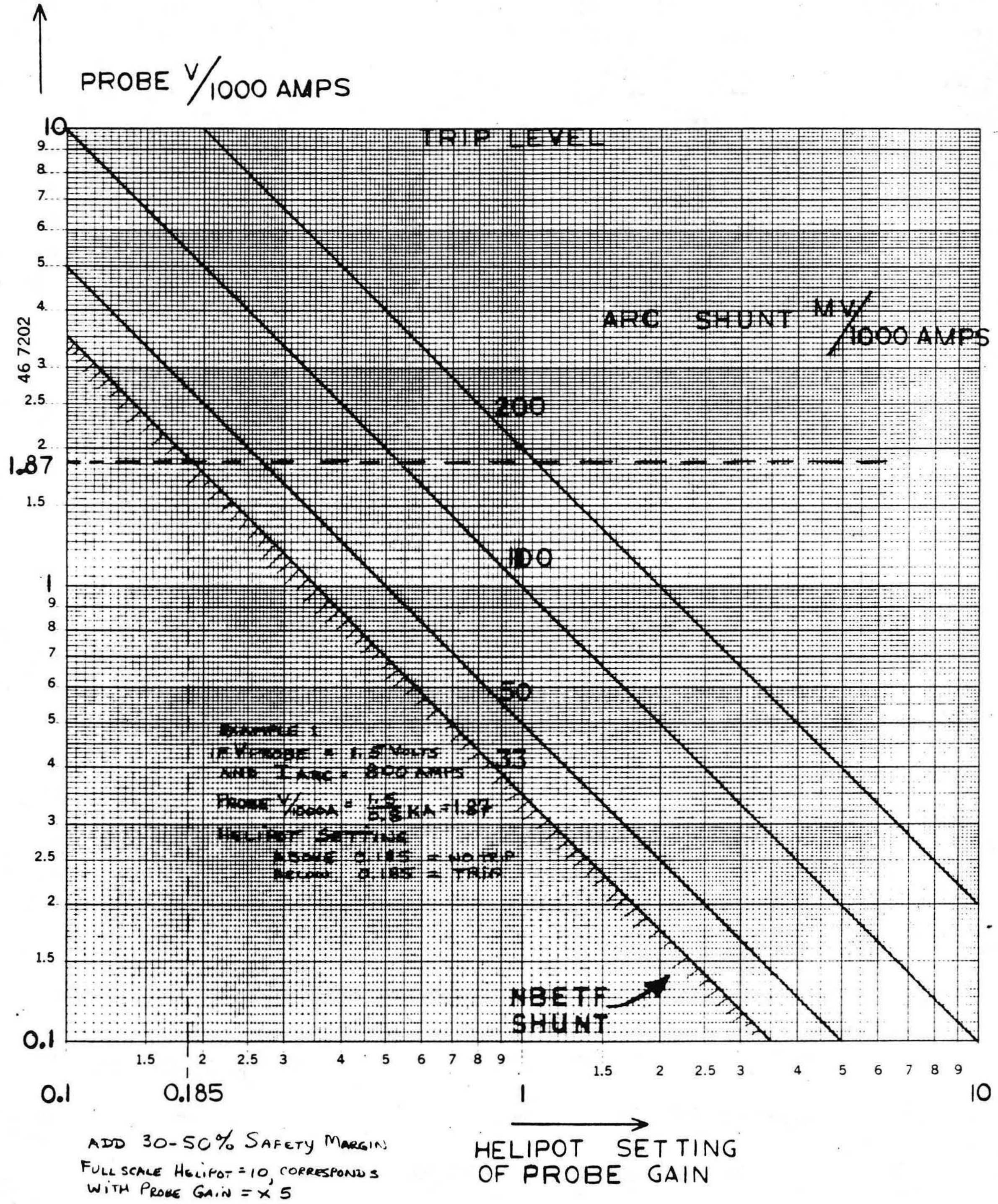
The spot detector (Appendix 4) should be set up to just allow operation, i.e., as close to the trip levels as possible. If the levels are too low, the arc will trip off at the persist time preventing arc operation. If the levels are too high, an arc spot will probably not be caught soon enough to prevent damage in the plasma source. With experience, the spot detector levels can be set close to the operational levels before conditioning the arc, and the final adjustments made during arc conditioning (Section 10 (B)) and beam operation.

The following procedure is used to set up the spot detector:

1. Set the pulse duration of the arc to ≈ 50 msec to minimize chances of spotting damage before the spot detector is set up properly. See Section 11 (B) for timing set up. Set arc power level to ≈ 20 kW. Be sure the source is operating in the efficient mode. See Section 14 (A) for details of the operational modes.
2. On the trip level graph, as shown in Figure 20, find the line that corresponds to the arc current shunt value in use. Determine the probe voltage expected (source efficiency determines the probe level) for the 20 kW arc power operating level. Calculate the trip level value and set the ratio threshold potentiometer to slightly below that value to ensure an arc crowbar, then increase the setting until no crowbar occurs and leave the ratio threshold set about 10% above this point. See the Spot Detector Trip Level graph for an example of how to set the ratio threshold level.
3. Set the probe noise threshold potentiometer to slightly above the maximum

peak-to-peak noise of the probe.

4. Set the persistence potentiometer to a short time (≈5msec).



EXAMPLE 1
IF V PROBE = 1.5 VOLTS
AND I ARC = 800 AMPS
PROBE V/1000A = 1.5/0.8 KA = 1.87
HELIPOT SETTING
ABOVE 0.185 = NO TRIP
BELOW 0.185 = TRIP

ADD 30-50% SAFETY MARGIN
FULL SCALE HELIPOT = 10, CORRESPONDS
WITH PROBE GAIN = × 5

XBL 847-2995

Figure 20. Graph of the Spot Detector Trip Levels for various arc current shunt values, including an example showing how the settings used on NBETF were determined.

9. FILAMENT OPERATION

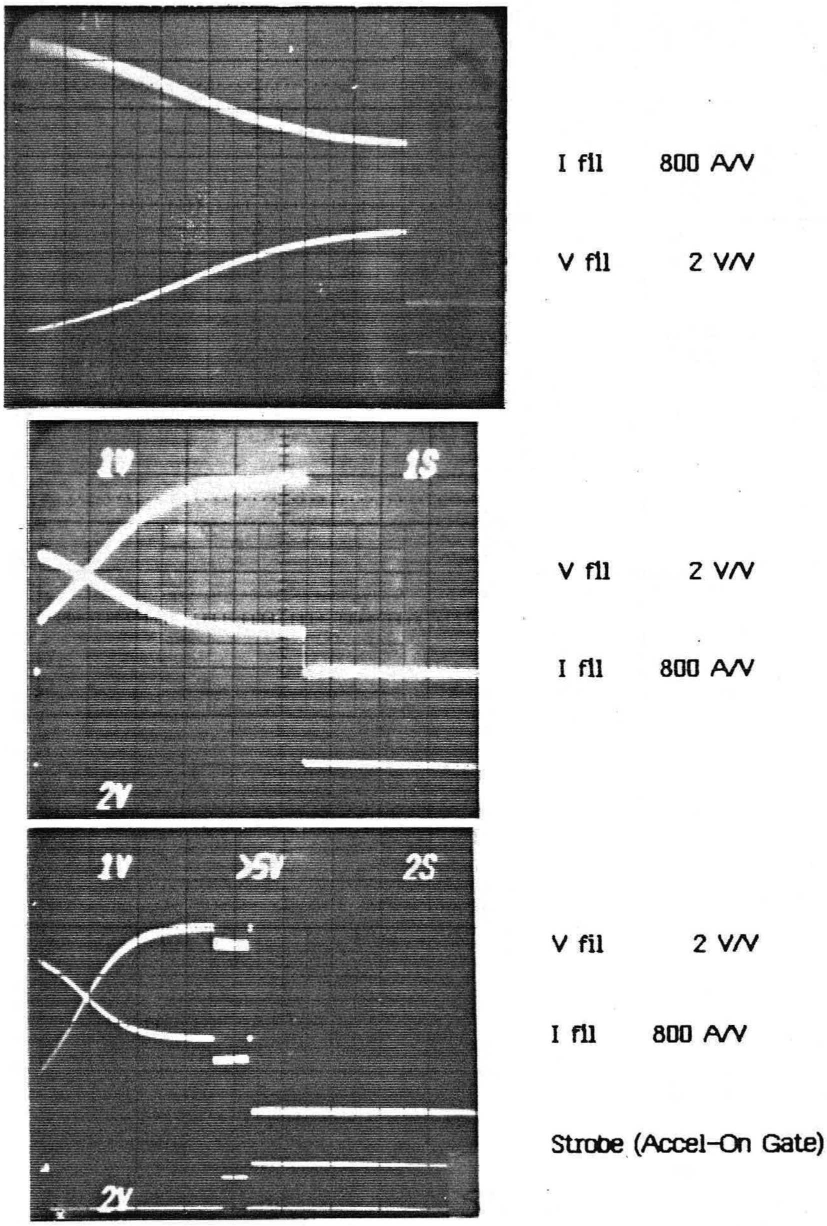
9 (A) FILAMENT CONDITIONING

When new filaments are installed in the LPS/LPA , a "filament sweep" should be done before turning on the arc. The filament sweep is primarily a check of the filament power supply system from low power up to the full operating level of the filaments, which also gives the operator power supply settings for the different filament powers. These settings will be useful later when conditioning the arc and running beam. A timing sequence should be set up prior to filament operation. See Section 11 (B) for a typical timing sequence. A filament on-time of ten seconds is adequate for the filaments to reach equilibrium provided the power is not too low. Filament scope waveforms for low power, high power, and "stepped" (Section 9 (B)) filament shots are shown in Figure 21. Begin with a low filament power and take a shot, checking the voltage and current to make sure that everything looks satisfactory. Slowly raise the power level, recording the current and voltage, at equilibrium, for each shot. When full unstepped power level (typically ≈ 118 amps/filament or ≈ 4000 amps total current for 34 filaments) is reached the filaments should be conditioned there for a few shots. If the filament stepper is not used during the sweep, a plot of the filament current vs. filament voltage should be nearly linear at the higher power levels. An example of a filament sweep from the LPS/LPA operation on NBETF is shown in Figure 22.

After completing the filament sweep, the operator should become familiar with the filament stepper settings in conjunction with the filament power supply settings, i.e., how much the filament heater current is reduced for the different stepper settings.

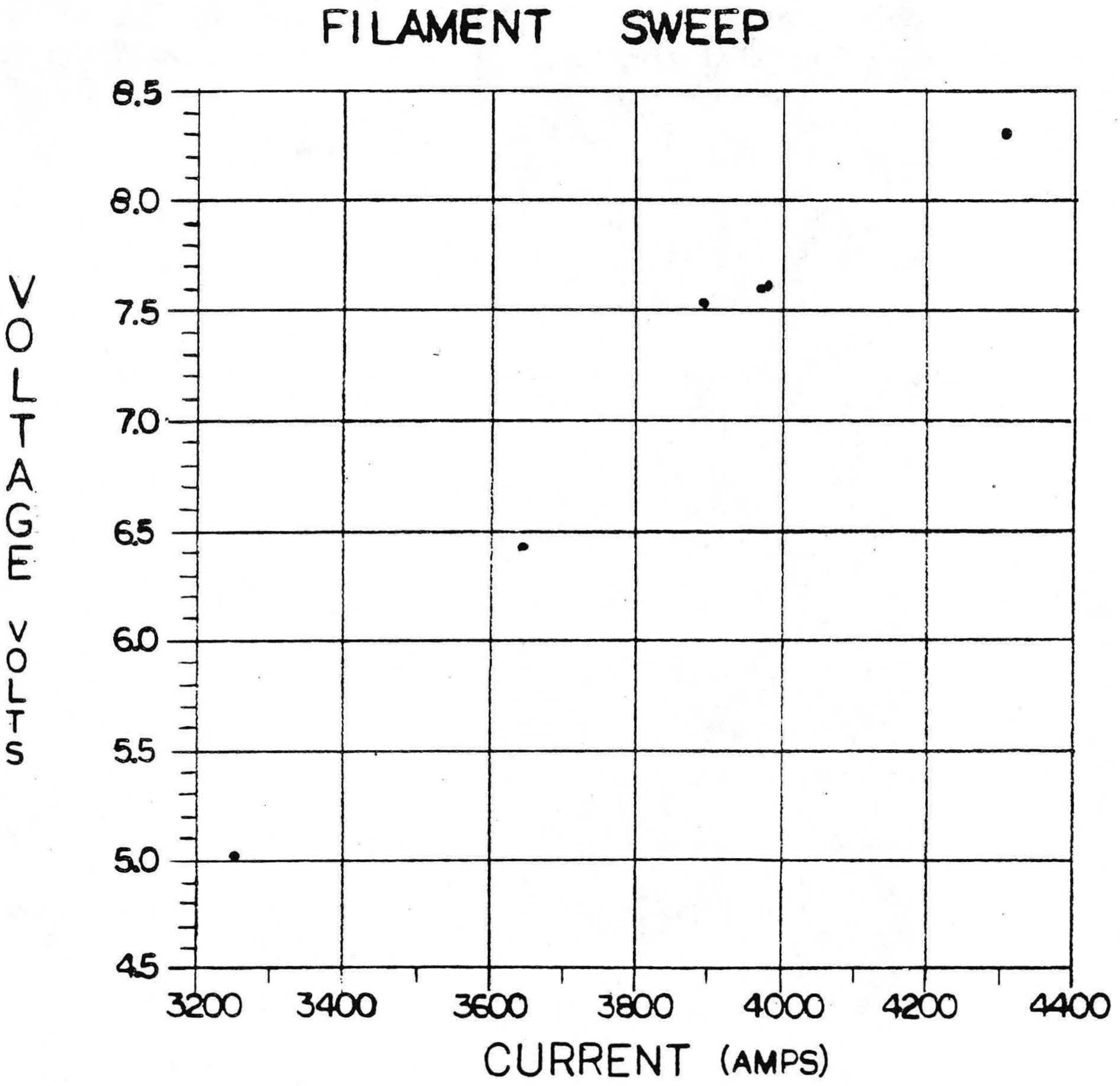
LPS/LPA

SCOPE SIGNALS OF THE FILAMENT,
AT LOW POWER, HIGH POWER, AND
STEPPED OPERATING POWER LEVELS



XBB 844-2875

Figure 21. Filament scope pictures. From top to bottom, low power, high power, and stepped filament voltage and current traces are shown. Note that the filaments have not reached thermal equilibrium in the first two pictures. Strobe is a logic signal for accel voltage.



XBL 847-2991

Figure 22. Filament sweep graph showing filament voltage vs current during conditioning.

9 (B) FILAMENT STEPPING

Operationally, the major difference between the LPS and previous LBL field-free plasma sources is that the LPS filaments are emission limited, i.e., electron emission (arc current) depends on the filament temperature (Ref. page 2). The arc current and arc voltage are determined by the filament heater current. Previous LBL field-free sources were space charge limited and did not have this characteristic. In steady state, emission limited operation means that, for a given arc IVR setting, the arc voltage is directly controlled by the filament heater current: more heater current gives a lower arc voltage (provided the source is in the "efficient" mode, Ref. Section 14 (A)). Conversely, (in the efficient mode) less filament heater current means higher arc voltage. Unfortunately, the arc does not turn-on in steady state, and the observed thermal time constant of the arc current in the LPS exceeded eight seconds. A technique for sidestepping the arc thermal time constant called "filament stepping" is described here. An associated advantage of stepping is that, by avoiding the thermal transient, it is much easier to keep the arc in the desired range of 70 - 100 volts.

If the LPS is turned-on with a constant heater current, as is normal with the field-free sources, the arc current rises as the filaments and chucks heat up, due to ohmic heating associated with the arc current passing through the negative filament leg. Unfortunately, the time constant observed in the LPS was more than eight seconds, and the effect on the arc was substantial. With unstepped filaments, the arc voltage fell as much as 20 - 30 volts as the filaments heated; the arc current rose; and the plasma level rose as much as 20%.

A technique to achieve a steady state arc discharge current is to "step", i.e., reduce, the filament heater current when the arc is turned on. (A waveform of the filament stepping effect is included in Section 12 Figure 39). Stepping the filament supply compensates for the additional ohmic power associated with the arc current. In this way, the total power heating the filaments is unchanged, and thermal equilibrium is sustained. Section 12 contains a discussion of the waveforms of the filaments on NBETF.

Stepping was developed by E. Thompson at Culham, who had an electronic contactor for the filament power supply, which was phased back at the time the arc was turned-on. The phase-back level is determined empirically. It is not sufficient to simply reduce the filament heater current by an amount equal to the arc current, since the arc current changes the temperature distribution of the filament. The temperature distribution of the filaments, at the beginning of arc turn-on, depends on the pre-stepped filament temperature. About 3 seconds after arc turn-on, the arc settles to voltage and current values which are directly determined by the filament current. To obtain the desired operating arc voltage, either the pre-stepped or stepped filament current should be adjusted -- increased filament current gives lower arc voltage, and decreased filament current gives higher arc voltage. In LBL jargon, the larger the step, the greater the reduction in filament current, which means that a larger step gives a higher arc voltage.

An additional thermal transient is associated with beam operation, due to back electron heat. For up to ≈ 10 seconds of beam, fine tuning the filament heater and step is sufficient to give a constant accel current. For longer pulses, arc feedback is required; this is discussed in Appendix 5. With feedback, the accel current could be held constant to the precision of the arc and filament power supplies, which was ± 2% on NBETF. Arc feedback has the additional advantage that, once operating points have been established, a given plasma level (and, therefore, accel current) can be dialed in reproducibly, without "ranging shots". The only disadvantage to feedback is that it adds another level of complexity to the system.

10. ARC OPERATION

10 (A) ARC CONDITIONING

The preferred procedure for conditioning a new plasma source and new filaments is to remove the Back Plate Magnets so that the arc can be run at low voltage to reduce spotting damage. When the Back Plate Magnets have been removed, the inefficient mode disappears, and initial operation can be at lower voltage.

Start at low arc power and short arc pulse length, ≈50 msec, (See Section 11 (B) for Timing). To prevent source damage, the spot detector ratio threshold and noise threshold should be set just above the trip levels at which the spot detector turns off the arc. Also, the spot detector persistence time should be set for a short duration, (see "Spot Detector Set Up Procedure"). These steps will minimize spot damage during conditioning.

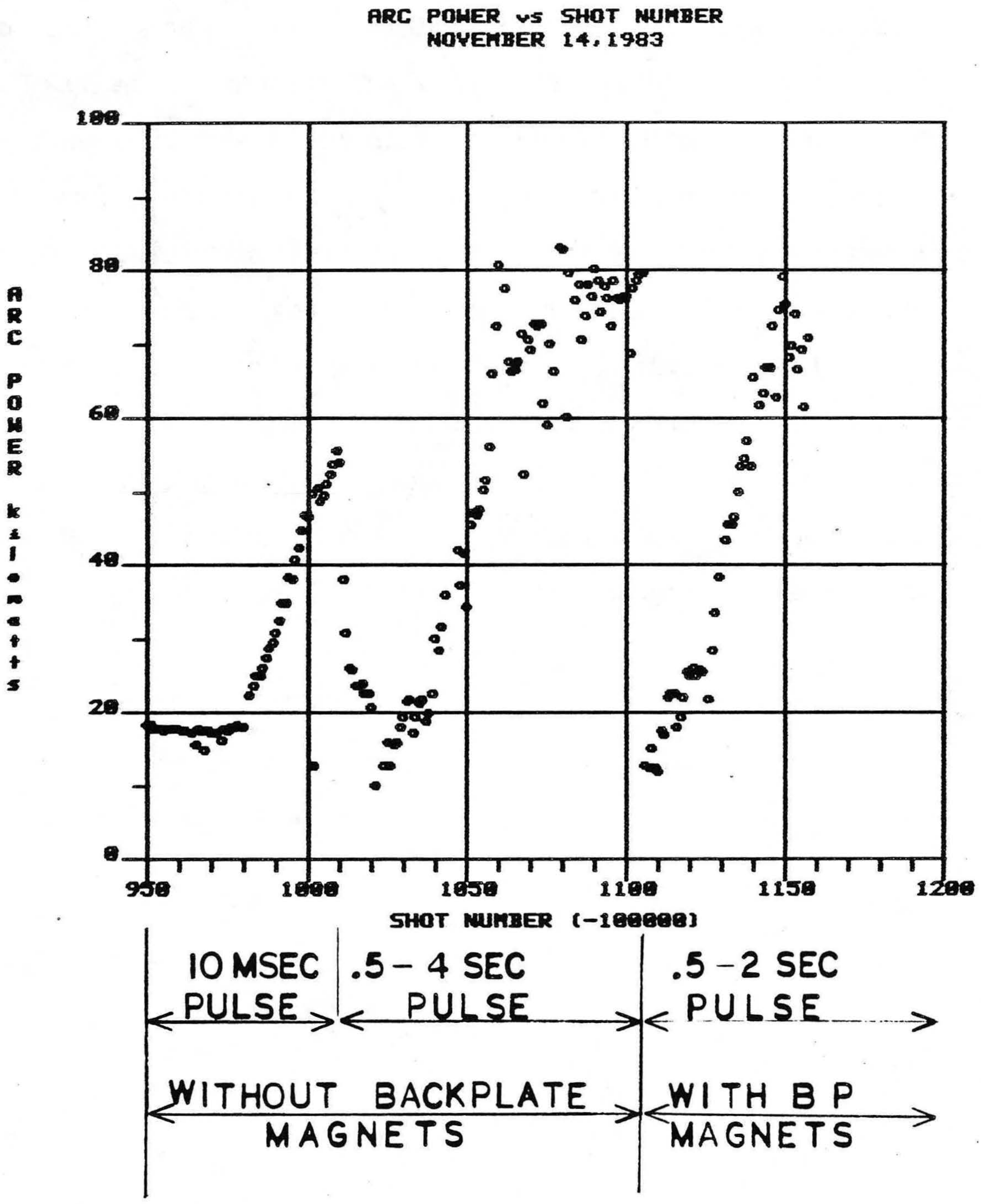
While conditioning at low arc powers, the voltage should be raised beyond the desired maximum anticipated operating voltage. Gradually work up in arc power and out in pulse length to full power and duration, at some arc voltage between low and maximum. (For the LPS/LPA, as set up for MFTF-B on NBETF, ≈ 80 kWatts was full power, 35 seconds was full duration, and arc voltage was 60 to 90 volts.) Then lower the arc power to a low value for short pulse, and install the Back Plate Magnets. Again work up to full arc power and duration. The LPS conditioning history on NBETF is illustrated in Figures 23 and 24.

During arc conditioning, the arc notch shape should be set up (Section 10 (B)), and the probe profile should be optimized (Section 10 (C)).

Provided vacuum has been maintained, once the LPS has been conditioned, it can be routinely started at full power for a few shots before turning on the accelerator voltage for beam. If the LPS has been up to atmosphere, it is best to start at a lower arc power and work up to the operating level for beam.

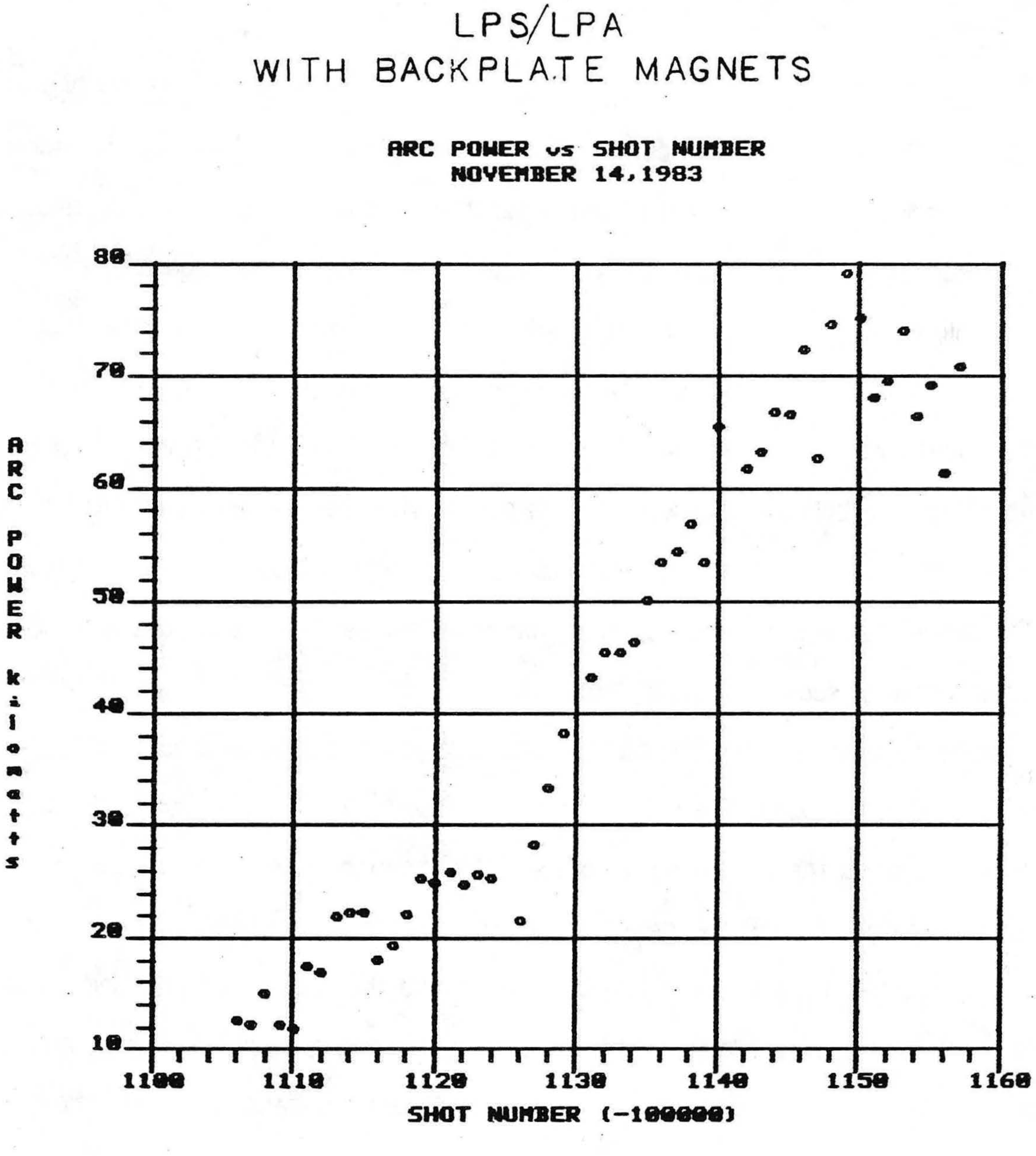
If the LPS chamber has once been conditioned, when new filaments are installed, it is possible to work up from low arc power to high arc power with the Back Plate Magnets in place. When conditioning this way, care must be taken to be sure the turn-on mode is not the inefficient one. Conversely, it is undesirable to come on with cold filaments and and the associated high arc voltages. Thus, an operator must have some prior experience to condition with the Back Plate Magnets in place.

Normally, with no systems problems which affect arc operation, almost all filament spot damage occurs during arc conditioning of the new filaments. Two common causes of spot damage are: improper spot detector settings; and increasing the arc power too rapidly during initial conditioning. With a conditioned arc chamber, arc conditioning of new filaments usually takes about four to eight hours.



XBL 847-2983

Figure 23. LPS arc conditioning history overview. Initial conditioning is without backplate magnets, at low power, from low voltage to normal operating voltage, with 10 msec shots. The next conditioning is from low power to high power, with up to 4 second shots. The final conditioning goes to full power, with the backplate magnets installed.



XBL 847-2984

Figure 24. LPS arc conditioning with the backplate magnets.

10 (B) ARC NOTCHING

Since the arc is turned-on before beam, beam turn-on must sweep out the low density plasma initially in the grid region. When the accelerator voltage is applied, it tries to set up an electric field in the grid region. This produces a large current transient which tends to load down the gradient grid, or even the accel, power supply. The transient may trip the overcurrent fault detectors, and limit the beam to very short shots. To avoid this turn-on transient the arc is "notched", i.e., the arc current is diverted for ≈100 μseconds to reduce the plasma density (See Appendix 6 "Arc Notcher"). The arc is then restarted at a rate that maintains good perveance match during turn-on. Good perveance match is determined from minimum gradient grid and suppressor grid currents on the fast scopes (See Section 14 (C)).

Severe perveance mismatch during accel turn-on can lead to a potentially disasterous operating mode. The most sensitive indicator for judging a good match in turn-on conditions is the gradient grid current (the gradient grid intercepts electrons produced at the suppressor). The next best indicator is the suppressor current. If the turn-on is extremely underdense, beam ions can strike the suppressor grid and produce secondary electrons which travel back into the source, and are read as accelerator current. As a result, the beam optics can be significantly underdense, while the accelerator current value is overdense.

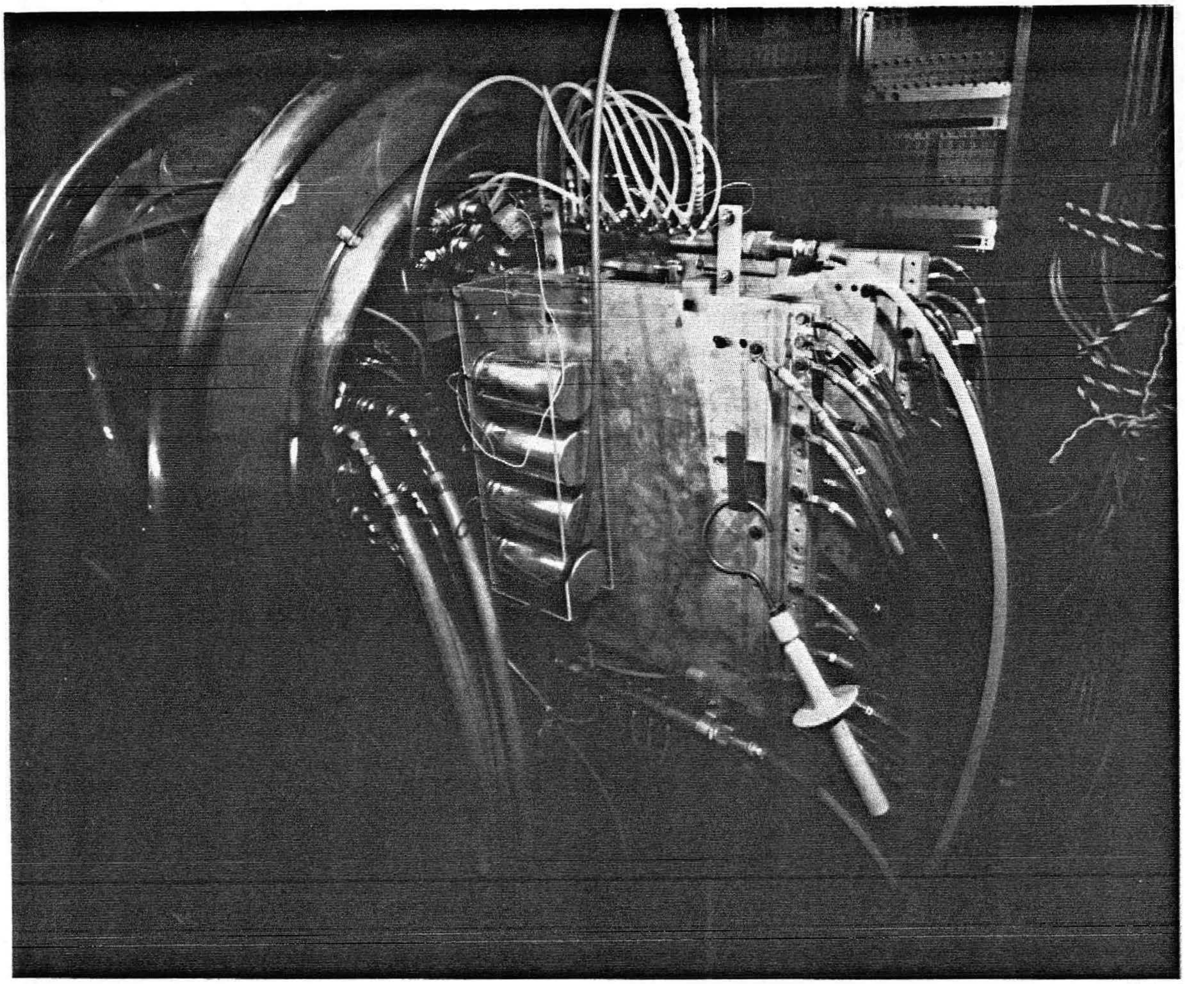
If the plasma notch is too shallow, if the notch shape is wrong, or if the accel turn-on is too late with respect to the notch, large current spikes and fluctuations appear on the gradient grid and suppressor. These spikes can be, and often are, large enough and last long enough to prevent beam operation. If either the gradient grid or suppressor show excessive currents during turn-on, the match between plasma density and accelerator voltage is incorrect and should be remedied immediately.

It is a good idea to set up the notch shape first, then set the notch depth according to the accel voltage level to be run. The notch shape is usually set up during arc conditioning, with arc only shots. With experience, the shape can be set close to that needed for accel operation. When the notch shape is set properly, the depth should be set. For low accel voltage (40kV) operation, a shallow notch (≈ 40% plasma density reduction) is sufficient; for higher accel voltage, a deeper notch (≈60% - 100%) is required. The maximum notch depth for the LPS/LPA with the Dynamic Anode (described below) is ≈ 70%. This was sufficient for this accelerator. Once the notch shape and depth are set, the timing for the accel turn-on should be determined. This is discussed later in the beam section.

On NBETF the LPS/LPA was run in two supplementary anode configurations. First, a "Dynamic Anode" [7] was used. During arc notching, the effective anode area is increased by connecting capacitance between the probe plate and the cathode. The notching capacitors, shown mounted on the current sheets in Figure 25, charge up to the floating potential of the probe plate during the initial arc turn-on. This potential is about 15 volts below anode potential. During a notch, the arc is shunted, lowering the total impedance seen by the power supply circuit. The inductance of the power supplies does not permit an increase in total current, so the voltage across the source drops to between 30 and 40 volts. The notching capacitors hold the probe plate at its previous potential, which is now above anode, and the probe plate temporarily acts like anode, thus increasing the anode area. This additional anode area is required to prevent a mode flip during the notch. As long as capacitors keep the potential of the probe plate high enough to collect a net electron current, the source remains in the efficient mode. The dynamic anode on the LPS is required because the LPS was designed with minimum anode area, in order to maximize atomic species and power efficiency.

The total capacitance required to keep the source in the efficient mode depends upon the source plasma impedance, the duration of the requested notch, and the notch depth. After the notch recovery, the probe plate returns to the floating potential on a time scale dependent upon the capacitor recharge time. For the LPS, with a 200 µsec notch, 12,000 µf of capacitance was sufficient for over 10 successive beam tries, spaced at 5 msec between tries. Too many successive tries discharge the capacitors, making them ineffective. For the eight (1500uf) capacitors used, the recharge time after the notch was about 25 msec. The plasma production efficiency is very slightly reduced during the recharge, but without significant effect upon the accelerator operation or beam current.

A second supplementary anode configuration was to connect the probe plate to anode with series resistance. With the series resistance adjusted to reduce the current to the probe plate to 15% of the total arc current, arc efficiency and species were only slightly reduced, and mode flip was eliminated.



CBB 846-5630

Figure 25. Picture of the arc notching capacitors installed on the LPS. Eight 1500 µfd capacitors were used; four mounted on the current sheets on each side of the source.

10 (C) PLASMA UNIFORMITY USING PROBE "PROFILE"

Plasma uniformity is critical for good beam optics. The LPS probe plate was designed to accept up to 6 water-cooled Langmuir probes, as shown in Figure 10. They are located near the plane of the grid, around the periphery of the 10 x 40 cm grid array. The probes are on the periphery to keep them from shadowing the grid, and to keep them out of the path of backstreaming electrons from the accelerator.

The probe tip, which is exposed to the plasma, collects any ions and electrons that happen to strike it. If it is left floating electrically, it will charge up to "floating potential" at which the net electric current (ions + electrons) is zero. If it is biased highly positive with respect to the plasma it will collect electrons and repel ions; with highly negative bias, it will repel electrons and collect ions - this is called "saturated ion current". At LBL, probes are biased -22.5 volts with respect to the negative filament, i.e., cathode. This is sufficient to measure saturated ion current and gives reproducible results.

The area of each probe tip should be known to within 2% (measured with a micrometer) before the probe is installed in the probe plate. The areas of the six probes should be within 2%, otherwise, a calibration factor is needed for probe "profile" evaluation. The area of the probes used in the LPS/LPA on NBETF was 0.113 cm^2 (0.10 cm diameter, 0.32 cm long).

Saturated ion current density as measured by the probe is essentially the ion flux that is accelerated when it falls into the opening between grid rails in the accelerator structure. Hence, a probe "profile" obtained by checking the probes in all 6 locations, shown in Figure 26, gives an <u>indication</u> of the ion current density uniformity at the accelerator. It is only an indication - because the probes are fixed at the periphery, and do not see the center of the extraction plane.

The probe profile should have a maximum value divided by a minimum value (max/min) of less than 1.15 for beam operation. If the max/min exceeds 1.15, the profile should be improved before proceeding with beam. Sometimes changing the gas flow, or arc voltage helps the uniformity. Check for external magnetic fields and materials which disturb flux lines i.e., steel bolts around magnets. Check the polarity of the backplate magnets. One or two magnets with reversed polarity can adversely affect the profile.

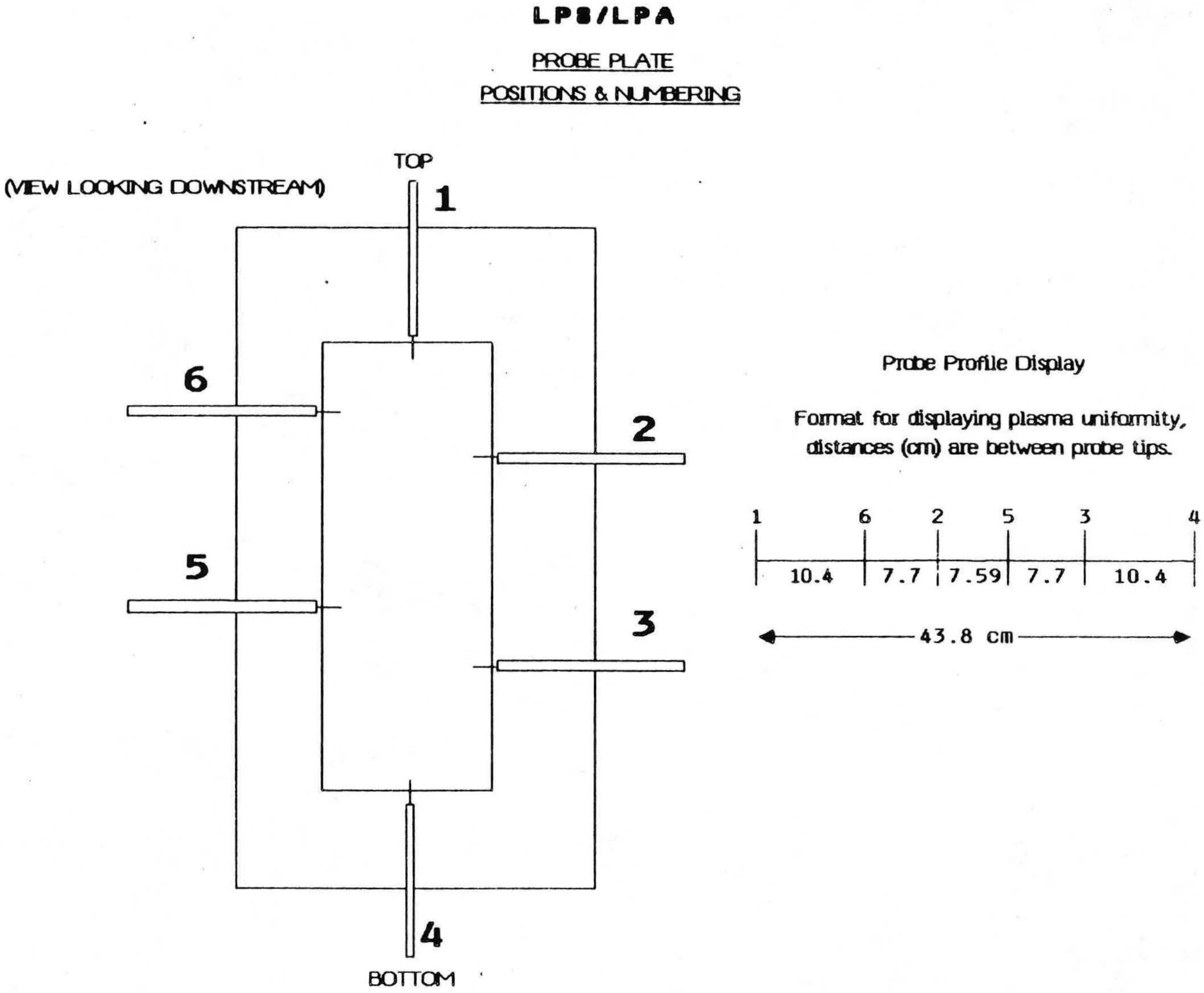


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Figure 26. Illustration of the LPS probe plate positions and profile display format.

11. ACCELERATOR CONDITIONING

11 (A) LPS/LPA 40 kV BEAM PARAMETERS

The initial start up for beam requires that the operating parameters be set up close to the expected values for the plasma source and accelerator. Typical **40 kV Initial Parameters** for the LPS/LPA operation on NBETF were as follows:

Stepped Filament Voltage	6-7 Volts
Stepped Filament Current	3-3.5 kAmps
Gas	12-16 TL/S Deuterium
Arc Voltage	65-70 Volts
Arc Current	340-400 Amps
Arc Power	22-26 kWatts
Probe Level	≈ 57-63 mAmps/cm^2
Probe Profile	Max/Min < 1.15
Accel Voltage	≈ 40 kVolts
Accel Current	≈ 12-14 Amps
Perveance	1.6-1.8 μpervs
Gradient Grid Voltage	≈ 33 kV (V_{gg}/V_{accel} = 83%)
Gradient Grid Current	< 250 mAmps
Suppressor Grid Voltage	1.0-1.2 kV
Suppressor Grid Current	< 2 Amps
Timing	Set up for < 15 ms (See Section 11 (B))
Fault Detector (F.D.)	Each of the appropriate fault trip levels should be set for the expected value. (See Sections 8 (A) and 11 (C))

11 (B) LPS/LPA TIMING

A general discussion of neutral beam timing[8] follows. The timing details are largely a result of the power system, but the general sequence of events is due to the source and is independent of the particular power system.

It is convenient to view the entire neutral beam system as having a single timing diagram which applies to all shots, then accomodate different operating modes by enabling or disabling various components of the hardware and software. For example, the timing for an arc-only shot is identical to the timing of a beam shot but the accel primary is disabled for arc-only.

All of the neutral beam power supplies are pulsed and, thus, "on" and "off" are always used to refer to the leading and trailing edges of a supply's gate pulse. The words "on" and "off" in the following description should not be construed as the sequence of actions necessary to bring a power supply to the armed and ready state.

There are actually 3 independent timing sequences for a neutral beam:

(1) The Shot Sequence covers the overall timing of a shot (power supply pulsing, data acquisition, etc.). This sequence is initiated by the Fire button. All of the timing in this sequence has fairly gross resolution of ±1 ms.

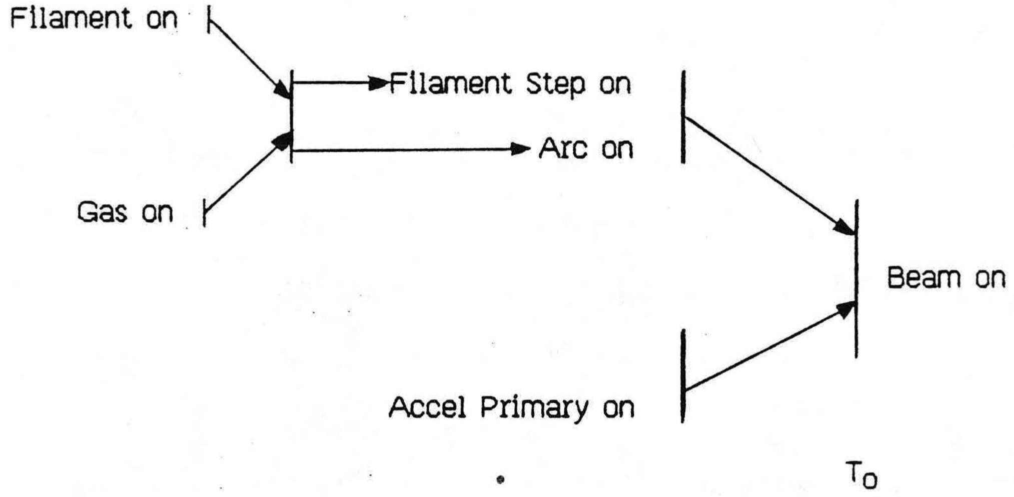
(2) The Interrupt Sequence concerns actions which must be performed during a fault. This sequence is initiated by the Fault Detector and things must happen on a micro-second scale (see below).

(3) The Turn-On Sequence concerns actions which must be performed when

applying high voltage to the source. This sequence is initiated either by the Shot Sequence, when everything is ready to make beam, or by the Interrupt Sequence, at the end of the interrupt. Everything in this sequence must happen on a micro-second scale (see below).

1. Shot Sequence Timing

The overall timing sequence can be derived by the following thought process: Assume you are going to turn on the beam at some time and call this time zero, T_0. Working backwards from zero, to fill in the prerequisites for beam, we see that we need arc and accel. To get accel, we only need to turn on the accel primary. To get arc, we must have gas and filament, and the filament should be "stepped" to be in the emission-limited mode of operation. Thus, the sequence of events must look like:



Given this sequence, the following intervals help to determine the relative times for turning on the power supplies:

- The accel primary has to be turned on early enough for its contactor to make up (20-60ms), and to allow any turn-on transients to dissipate (100-200ms). Thus, accel primary should be turned on about -120 to -260 ms relative to Beam On.

- The arc contactor takes 20-60 ms to make up, and the arc takes about 200 ms to strike and settle. Thus, the arc should be turned on at least -220 to -260 ms relative to Beam On.

- The gas valve takes 20-50 ms to open, then the gas takes another 100 -150 ms to fill the gas line and arc chamber. Thus, the gas should be turned on about -120 to -200 ms relative to arc on.

- The filaments take about 6 seconds to reach thermal equilibrium. Thus, the filaments need to be turned on about -8 sec relative to arc on, and the filament stepper turned on at arc on.

The timing at Beam Off is essentially the mirror image of the Beam On timing: turn off the accel; turn off the accel primary, arc, and filament stepper; then turn off the gas and filament. It takes about 100ms for the Arc contactor to open and the arc to go out. Thus, if the Arc is turned off at Beam Off, Gas and Filament can be turned off 100ms later.

The discussion above has covered the power supply timing. There also needs to be some computer data acquisition timing as part of the same sequence: Before Beam On:

- Read the pre-shot vacuum. Since the tank is being continuously pumped, this should be read as close to Gas On as possible but, again, not so close that there's any possibility of the read overlapping with the gas.

- Set up the transient digitizers' clock rates and start them scanning. The slow (≈ 1 kHz) digitizers should be set to 'cover' everything from Arc On to Beam Off. Thus they need to be set up before Arc On. To keep the window for a spurious digitizer trigger small, they should not be set up much before Arc On.

After Beam Off:

- Read the digitizers, scalars, fault detector, etc. This can be done anytime after Beam Off since the data is captured in local storage.

A shot sequence timing diagram much like Figure 27 results from the above logic. Time zero could be moved to the 'Fire' command to make the negative times disappear but one should keep the relationships in mind. For example, the operator may have to give the arc more time to stabilize. During 30 second operation, it was useful to have 1 to 2 seconds of arc before Beam On. Conceptually, one is simply moving Arc On earlier relative to Beam On. Since Filament and Gas are relative to Arc On, their timing need not change. Operationally, unless your timing software is similar to LBL's, the operator would probably have to lengthen Filament, Filament Stepper, Gas and Arc, then delay Beam On to give the arc more warmup time.

2. The Interrupt Sequence

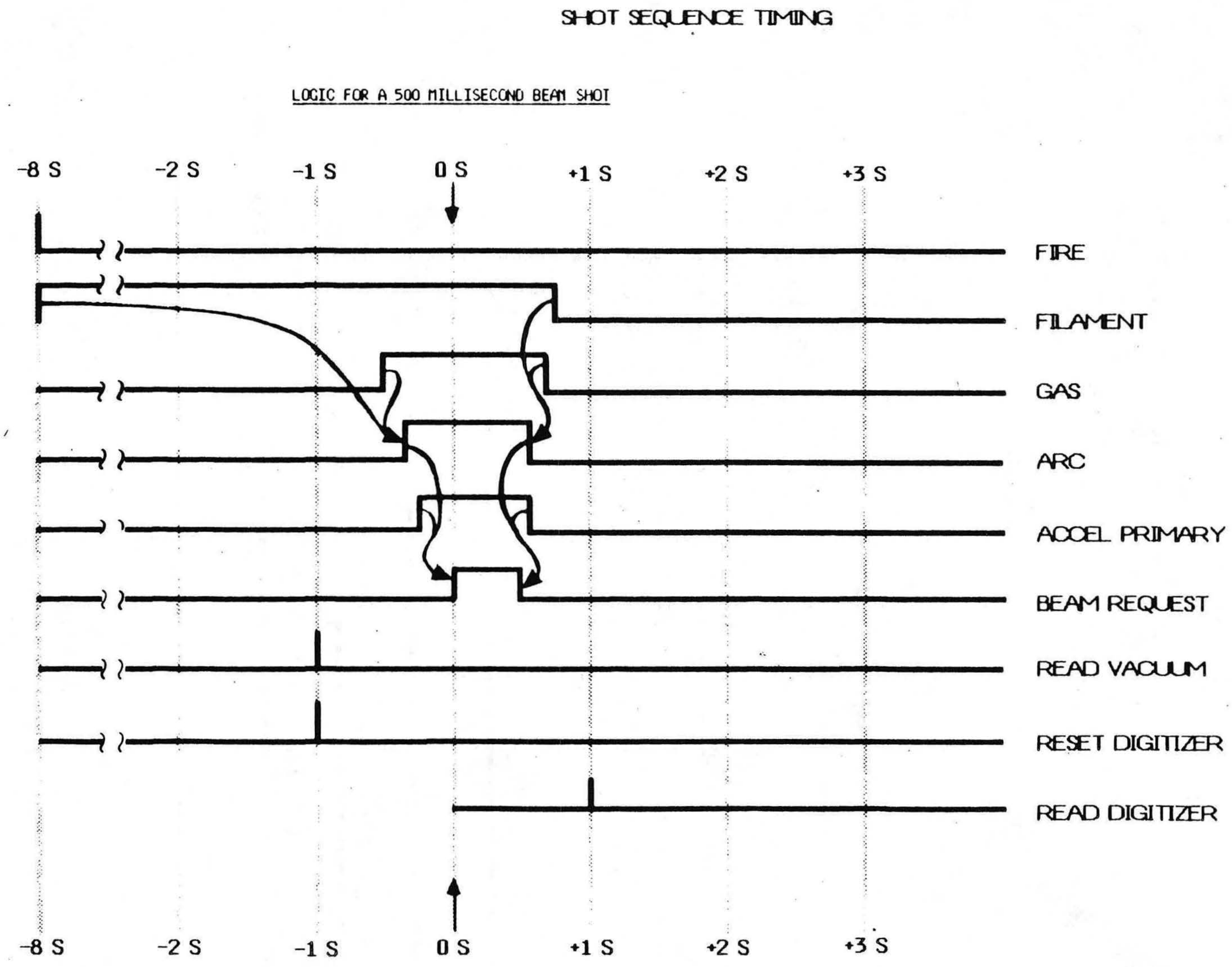
The interrupt sequence consists of 2 timers triggered by the Fault Detector. One timer controls the interrupt duration. It inhibits the "Strobe" for 5 ms, then triggers a 'turn-on' sequence at its end of time. This timer must turn on within 5 micro-seconds of the trigger. The interrupt sequence is shown in Figure 28.

3. The Turn-On Sequence

The turn-on sequence consists of 3 or 4 timers triggered by a 'turn-on' command (which is generated by either the shot sequence or the interrupt sequence). One timer is a fast digitizer (the 1 Mhz digitizer) or scope trigger (to allow the operator to view the turn-on so that the arc and accel can be matched). Another timer triggers the arc notch. Another timer triggers the accel turn on. The timing between the arc notch and accel turn on is probably the most crucial. The time between these two events is typically 100-300 micro-seconds and must be stable and repeatable to 1-5 micro-seconds. The turn-on sequence used on NBETF is illustrated in Figure 28.

The LBL software takes into account various minimum time constraints (like contactor delays or warm-up times) via "imaginary" timers, i.e., timing signals with no associated hardware timer whose function is to enforce a non-adjustable minimum time for some operation.

A diagram of the timing logic used on NBETF with the typical times is shown in Figure 29.



XBL 847-2986

Figure 27. Diagram of the timing for a 500 ms beam shot, illustrating the logic used for the overall timing sequence, for a beam shot with data acquisition.

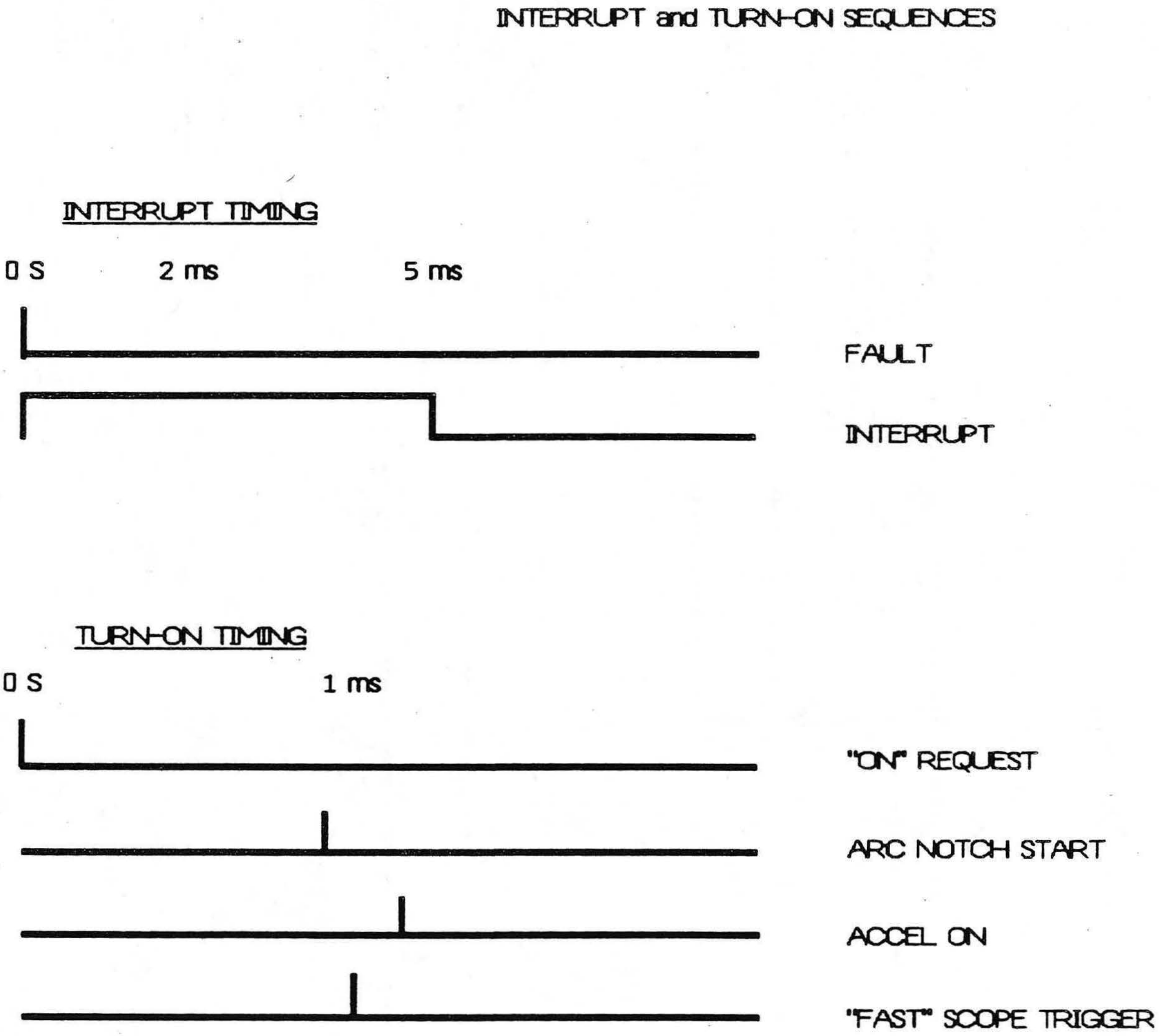


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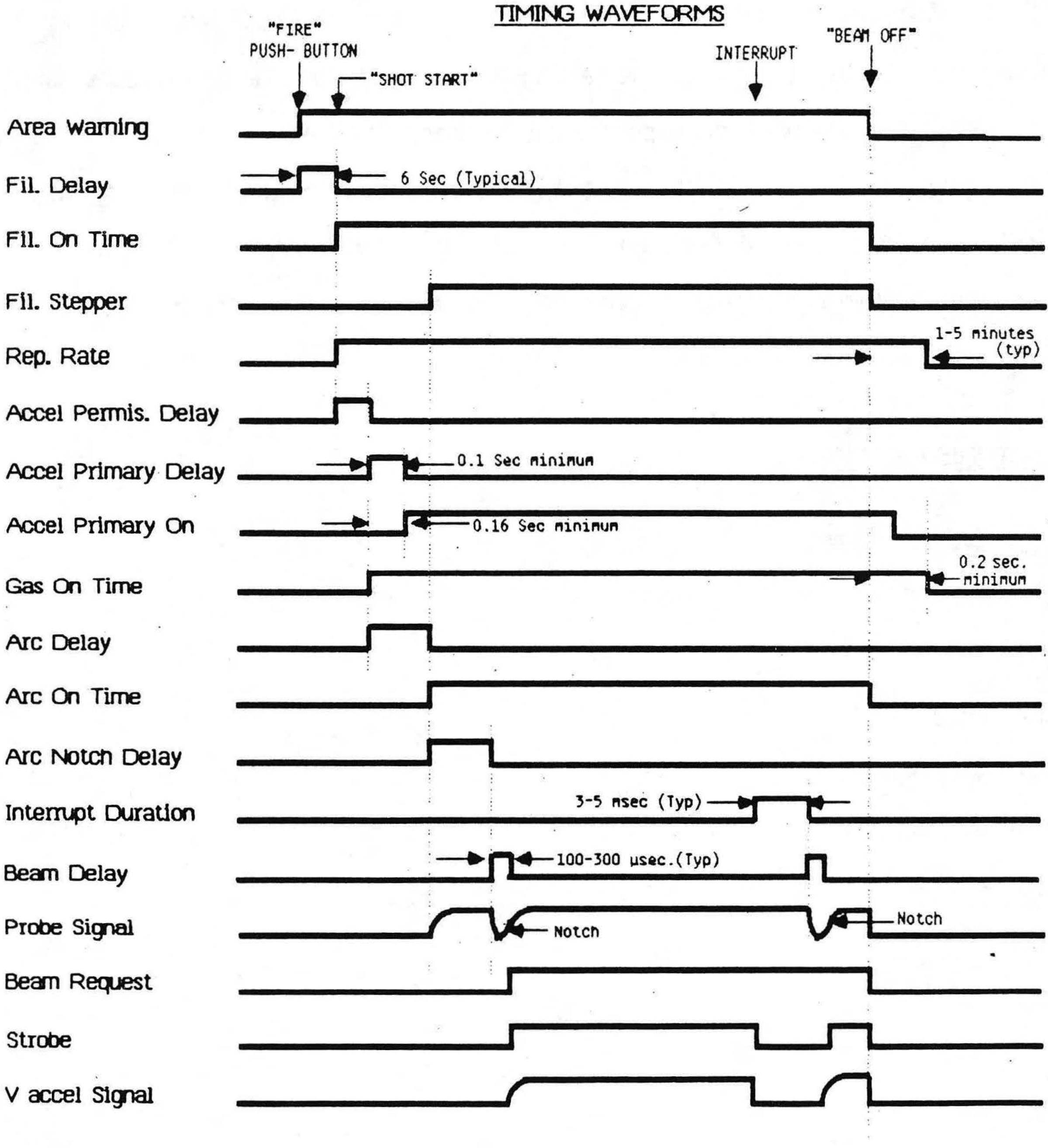
Figure 28. Diagram of interrupt and beam turn-on timing sequences.

LPS/LPA

TIMING LOGIC DIAGRAM



XBL 847-2982

Figure 29. Diagram of the overall timing logic for a beam shot on NBETF.

11 (C) SETTING THE FAULT DETECTOR FOR 40 KV ON NBETF

The following are typical settings of the fault detector which were used on NBETF for initial beam start up. The settings are derived from the percentages listed in Section 8 (A). For example, the expected accelerator current for the LPS/LPA at 40 kV deuterium was ≈ 13-14 Amps. Therefore, the fault detector threshold for I_{accel} was set to indicate a fault at ≈ 10% over the expected value, or ≈ 15 Amps. Most of the other levels were derived in a similar manner, however, several of the settings are determined by the power supply system.

MONITORED SIGNAL	POTENTIOMETER SETTING
V_{accel} dV/dt	≈ 1.7
V_{1-2} / V_{accel}	
I_{gg} DC	≈ 1.5
V_{gg} / V_{accel}	
I_{supp} P.S.	≈ 1.0
V_{accel}-Strobe	
I_{accel} Source	≈ 1.5
I_{accel} P.S.	≈ 1.6
V_{accel}-Strobe	
G.G. dV/dt	
V_{arc} Overvoltage	≤ 3.0
Spot Detector	(See Section 8 B)

11 (D) HIPOTTING THE LPA WITH THE POWER SUPPLIES

Hipotting is the initial step in grid conditioning. The method at LBL is to first use a D.C. hipotter (see Section 5), then to use the power supplies to hipot the grids. For hipotting with the power supplies, begin with a few millisecond pulse length and as low an accel voltage as possible. Arm the Filament, Suppressor, and Accel power supplies (leave the Arc power supply unarmed). Fire a shot, looking at the accel, gradient grid and suppressor waveforms. Measure the accel and gradient grid voltages to assure that the proper V_{1-2} ratio is set; the LPA V_{1-2} ratio is ≈17% of V_{accel}. Measure the suppressor voltage to see that the correct voltage is being applied to the suppressor grid; the LPA V_{supp} is ≈ -1.0 kV at 40 kV accel. If all the voltages are satisfactory, the pulse length can be increased for subsequent shots out to ≈ 1 second. Initially, a new set of grids will spark down repeatedly, but will progressively hold voltage for longer periods of time. The usual fault is Accel dv/dt. Once the grids hold voltage at the 40 kV accel level for full pulses, slowly increase the accel voltage. The suppressor voltage should be increased proportionally (≈-2.5% of V_{accel}) during hipotting to check out the suppressor power supply up to full operating potential. Good documentation of the power supply settings as the voltages are increased will be useful later for beam operation. Continue hipotting in this manner until close to full accelerator design voltage. For operation above 80 kV, a sulfurhexaflouride enviornment is required around the accelerator to prevent external break-overs on the air side of the ceramic insulator.

Hipotting with the power supplies to full accel voltage may take several hours, but is valuable in grid conditioning. It also provides a check-out for the power supplies, and control systems prior to trying for beam.

11 (E) INITIAL BEAM

Once the grids have been hipotted to full design voltage with the power supplies (Section 11 (D)), and the arc has been conditioned to full arc power with good plasma uniformity (Section 10), it is time to put the two together for beam. The following method is used at LBL to set up for initial beam.

Begin by setting the Accel power supply controls to deliver ≈ 40 kV to the accel grid. This can be determined from the settings used during hipotting with the power supplies. Since hipotting involves a no-load condition on the grids, it is necessary to use the accel power supply setting for a slightly higher accel voltage, i.e., ≈43 or 44 kV hipot accel power supply setting.

Set the Suppressor power supply controls to deliver the proper voltage to the suppressor grid. Again this setting can be determined from the settings used during hipotting, i.e., the Suppressor power supply setting for ≈ -2.5% of accel voltage.

Set correct gas flow, Filament power supply (including stepper), and Arc power supply settings. These can be determined from the settings used during the filament and arc conditioning. The probe level and/or the arc power are used to set up the proper plasma density for beam operation. It is best to try for beam with an underdense set up. For example, the LPS/LPA required a probe level of ≈ 60 mAmps/cm^2 and an arc power of ≈ 24 kW (V_{arc} = 70Volts) to be underdense at 40 kV accel, so the power supply settings that gave these values during arc conditioning were used. (See Section 12, Fig. 56 "Arc Power vs Vaccel" Graph)

Check the levels and thresholds of both the fault detector and spot detector to be sure they are set up for 40 kV beam operation (Section 8).

Two oscilloscopes should be set up with the following signals to look at the beam turn-on. These scopes should be triggered at accel turn-on or the beginning of arc notch, and the time base should be set at 100 μsecs/cm:

V_{accel} and V_{gg} -- to observe changes in the first gap or V_{1-2} voltage

Probe -- to compare magnitudes & rise times of plasma and accel voltages

I_{gg} and I_{supp} -- to watch for runaway currents as an indication of poor perveance match

I_{accel} -- to monitor the accelerator current level

Various combinations of these signals on fast scopes are illustrated in Figure 30. The rest of the monitor signals can be observed on oscilloscopes or on the computer printouts.

Before trying for beam, check that the power supply settings selected give the expected values. This is done by taking a filament only shot, an arc only shot, and a hipot shot, measuring the voltages and currents for each. If the power supplies, the plasma source and accelerator all give the expected values, trying for beam is next.

The timing should be set for a short pulse length i.e., ≤ 15 msec (Section 11(B)). At LBL, the timer for turning on the accel, with respect to the notch, is called "beam delay". Set beam delay to a value that will be at a point on the arc notch recovery ≈ 10% - 20% above the bottom of the notch. This is usually a good place for initial evaluation of beam turn-on characteristics. Matching the perveance for beam turn-on is discussed in greater detail in Section 14 (C). Occasionally a mismatched plasma density with accelerator voltage can be evaluated to be overdense or underdense by moving beam delay several μsec to the right or left on the notch recovery. This is helpful only when the mismatch is not too large.

Once 40 or 50 µsec of beam is obtained, it becomes more apparent how to adjust the plasma density or notch shape for matched perveance.

The first beam try may only last for a few microseconds because the grids of a new accelerator have to be conditioned with beam before reliable operation takes place. Careful observation of the voltage and current levels is necessary before requesting longer pulse lengths. It may take 20 shots, or more, to get 50-100 µsec. of beam-on-time. This is usually enough to determine, on the fast scopes, whether all the signals look satisfactory. Some minor adjustments of the arc and/or beam delay timing might be necessary to get a good beam turn-on perveance match. If the signals look reasonable, the beam request time can be increased to condition the grids with multiple retries.

The grid-conditioning process is not well understood, but over the years conditioning techniques have been developed. There seem to be two distinct phases in conditioning a new set of grids. Initially, the source sparks down repetitively after a few microseconds of beam; the time-to-sparkdown (beam-on-time) gradually increases, after a sufficient number of sparks. It may take an hour of 20 interrupts per half second pulse at a one minute firing rate to increase the average beam-on-time from 100 to 500 µsec. During this phase the number of sparks seems to determine the conditioning rate; therefore, it is desirable to use the maximum number of interrupts, the longest pulse length, and the fastest firing rate allowed by the power system. When one or two milliseconds of beam is achieved, check the accel current and voltage. Adjust the plasma density, if necessary, so that the accelerator current is ≈ 10% underdense. Since it is possible for the beam to stay lit with a mismatched perveance after turn-on, causing excessive gradient grid and suppressor currents in the accelerator, the perveance should be checked routinely throughout the grid conditioning process.

Once beam pulses of 10-20 milliseconds duration are achieved, the second phase begins. The rate of progress now appears to be determined by the total beam-on-time, rather than the number of sparks. During this phase, it is desirable to use the longest pulse length and fastest firing rate allowed by the power system. When beam-on-time of 100-200 msec is reached, the voltages and currents can be gradually increased.

LPS/LPA

SCOPE SIGNALS OF THE ARC NOTCH AND BEAM TURN-ON DURING OPERATION ON NBETF

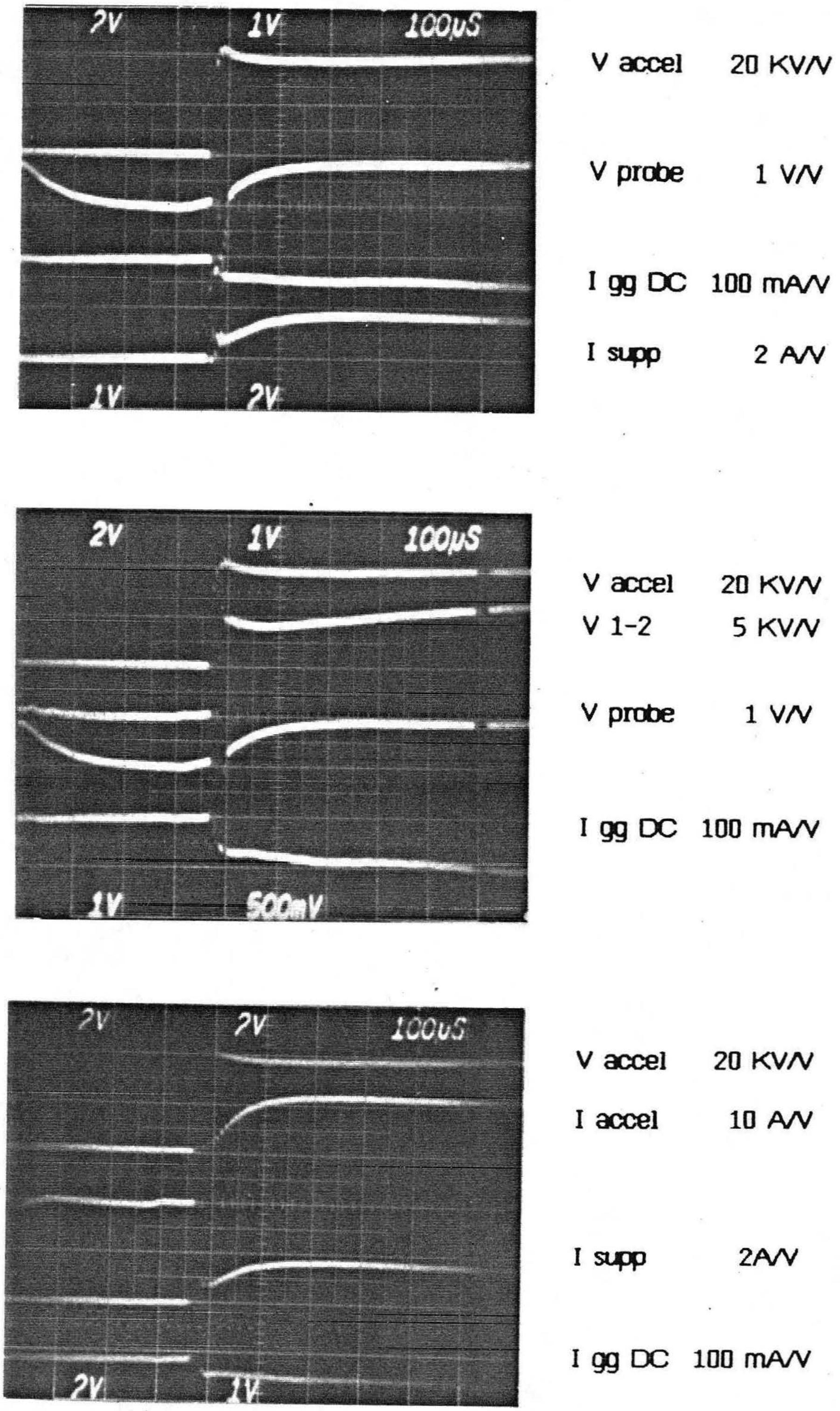


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Figure 30. Picture of fast scope waveforms showing various combinations of signals monitored during arc notching and beam turn-on during LPS/LPA operation on NBETF.

11 (F) INCREASING VOLTAGE AND TUNING

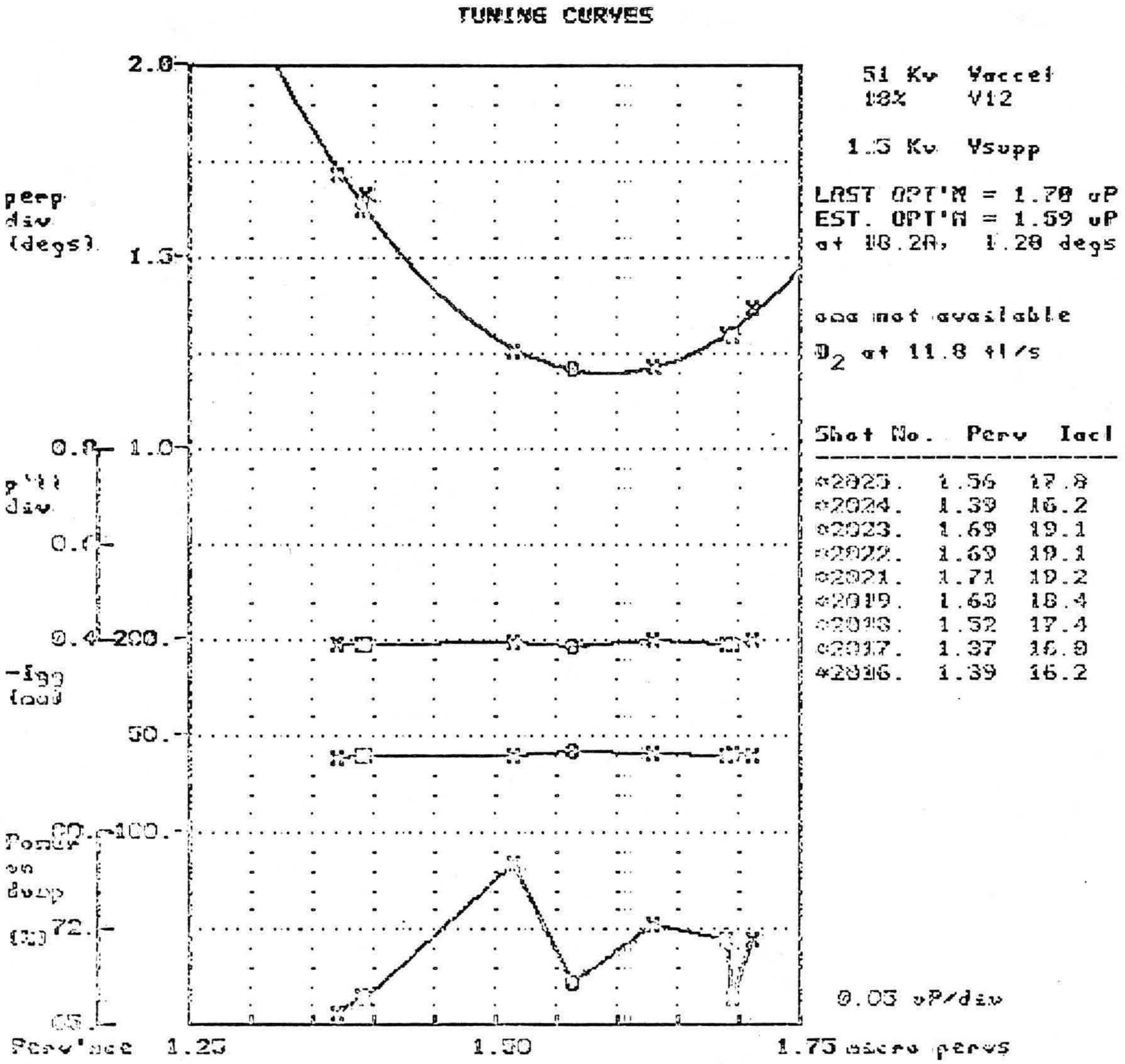
Voltage holding gets more difficult with increased current as well as increased voltage, but the grids seem to condition faster at higher accel power. So the guideline for the second phase of grid conditioning is "nudge but don't push". Gradually increase the accel current (by increasing the arc power) or the accel voltage, to stay roughly near perveance match, somewhere between 15% underdense and optimum. With each increase in either parameter, the average beam-on-time will decrease. Take small enough steps so that the beam-on-time during a pulse is at least half of the beam request time. If the cumulative beam time drops to less than 50% of the request time, lower the voltage or current; if it exceeds 75% nudge up either parameter. Remember to track the increased accel, gradient grid, and suppressor voltages and currents with the fault detector. When enough heat or light from the beam is achieved, 1/2 to 1 second pulses with only a few interrupts at 50 kV, go back to 40 kV and do a fine tune.[9]

Examples of tunes at two different accel voltage levels are shown in Figures 31 and 32. During conditioning, the perveance changes as the accel voltage is increased, and it is necessary to update the perveance after each tune to establish a new perveance line to follow while increasing the accel voltage and current. On NBETF tunes are done on a beam dump, using thermocouple calorimetry,[10] to establish optimum perveance (See Key Definitions, page 2). The pulse length required for enough heat to do a tune decreases as the accel voltage increases, from 500 msec at 40 kV to 75 msec at 80 kV. If dump calorimetry is unavailable, an Optical Mass Analyzer divergence plot can be used for an indication of optimum perveance (See Section 12). A fine tune consists of a series of several shots, with the same pulse duration, alternating between progressively higher and lower densities. This yields a fairly smooth curve. Along with the divergences (perpendicular and parallel), it is wise to plot suppressor current, gradient grid current, and arc power against the accel current as the arc is varied. Watch for possible current runaways at either end of the tune. Runaway currents may indicate an improper V_{gg}/V_{accel} ratio, grid misalignment, or other problems. The most consistent results can be found in this manner. The perveance line in Figure 33 was generated from a tune done on the LPS/LPA during operation on NBETF. The points above the line are on the overdense side, while those below the line are underdense. An updated perveance line is shown in Figure 34; this was used as a guide to increase the voltage and current from 68-83 kV. (These models are small sections of the overall perveance graph shown in Section 12 Figure 55.) After establishing a perveance line for the 40 kV level, follow it on the underdense side to above 50 kV. Continue conditioning the source up to 60 kV, lower to 50 kV, do a fine tune, and update the perveance line. Repeat this sequence of conditioning to the full design accel voltage and current for full pulse lengths. Be sure to increase the suppressor voltage appropriately at ≈ 10 kV accel voltage steps along the way up.

Grid heat loading should be monitored routinely during grid conditioning and tuning, to detect any grid heat imbalances.

A part of the LPS/LPA conditioning history is illustrated in Figures 35 through 38. The average on-time between interrupts is shown in Figure 35, and total on-time per shot in Figure 36. At a given accel voltage, the average on-time shows a reasonable rate of improvement with successive shots. The breaks in the graphs were due to water leaks in the facility, not source problems. Graphs of the Gradient Grid current, Figure 37, and the Suppressor Grid current, Figure 38, are included to show their levels during grid conditioning.

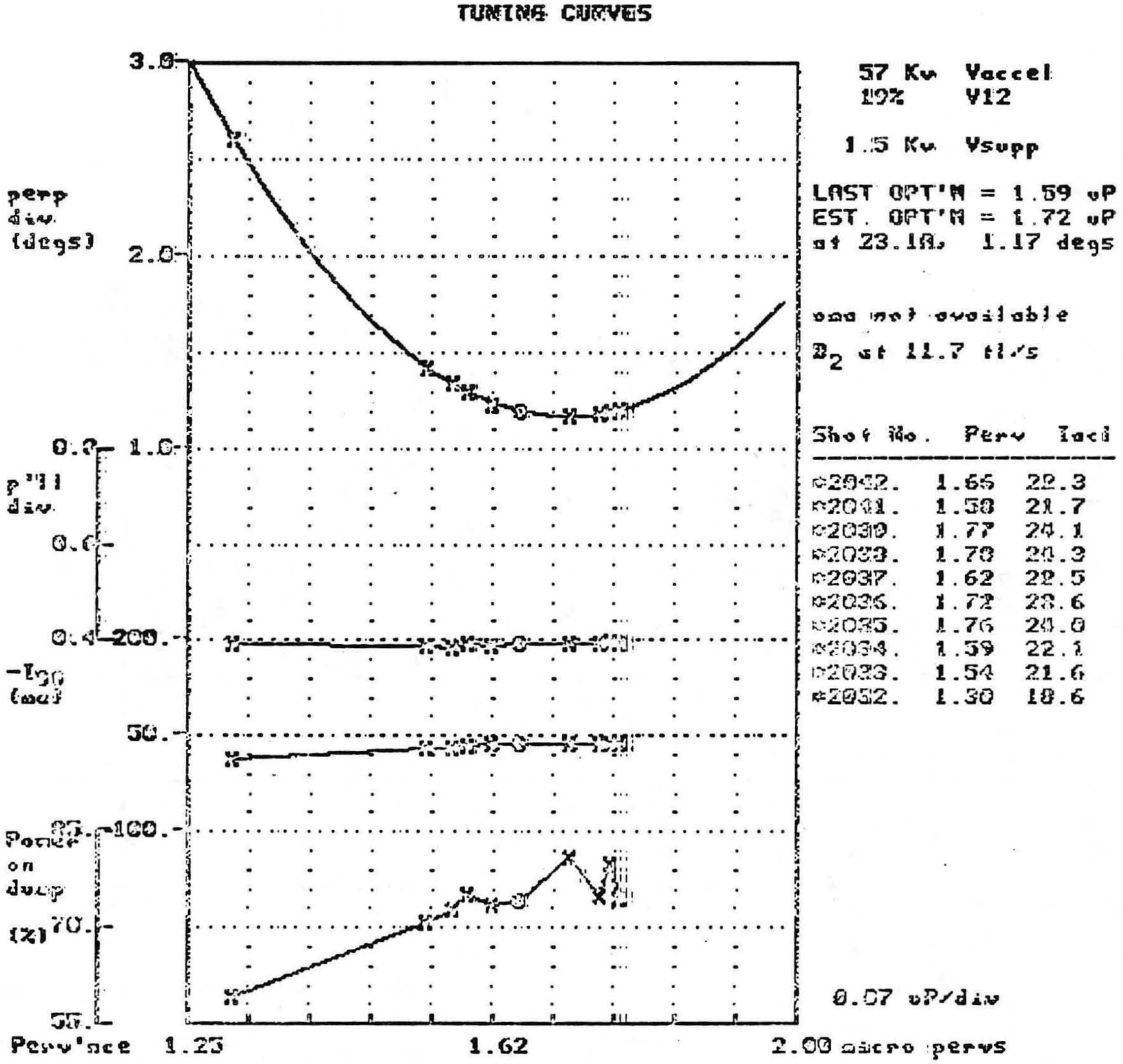
Grid conditioning is a slow process and can take several weeks, or more, to achieve full pulses at full power. However, once the grids are conditioned, they stay fairly well conditioned unless they become contaminated. Contamination can occur with an air leak, water leak, or from material deposited on the grids from severe arc spotting. The grids can be reconditioned by lowering the accel voltage and current to 1/2 or 2/3 full power and gradually increasing the accel voltage and current again. Reconditioning generally proceeds much faster than initial conditioning.



Shot No.	Perv	Iacl
#2025.	1.56	17.8
#2024.	1.39	16.2
#2023.	1.69	19.1
#2022.	1.69	19.1
#2021.	1.71	19.2
#2019.	1.63	18.4
#2018.	1.52	17.4
#2017.	1.37	16.9
#2016.	1.39	16.2

XBL 847-2959

Figure 31. LPA tune taken during conditioning. Once the accelerator reached 60 kV, the accelerator operated reliably at lower voltage, and a tune was done at 51 kV to determine the optimum perveance.



57 Kv Vaccel
19% V12

1.5 Kv Vsupp

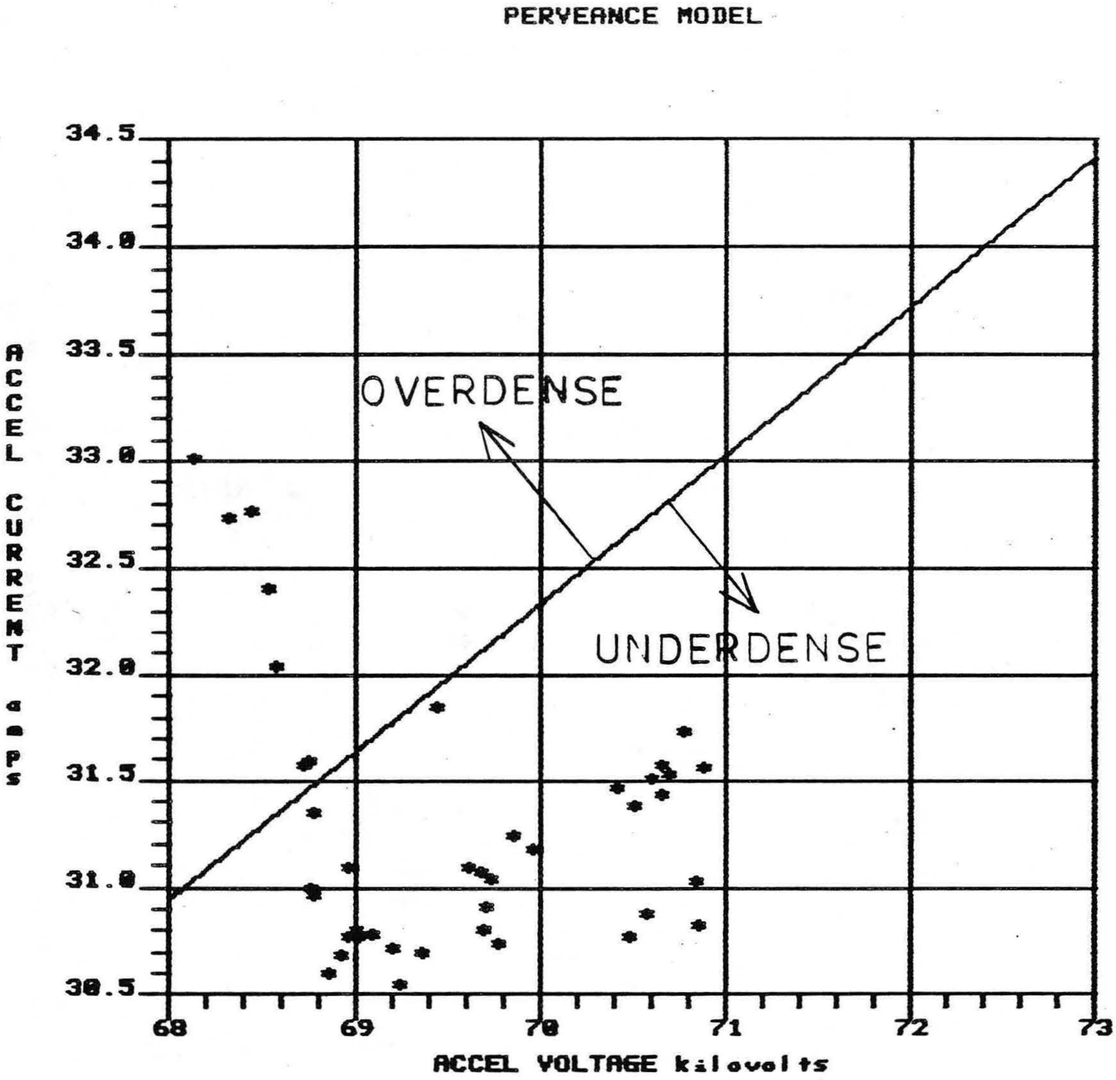
LAST OPT'M = 1.59 uP
EST. OPT'M = 1.72 uP
at 23.1A, 1.17 degs

emu not available
D_2 at 11.7 tl/s

Shot No.	Perv	Iacc
#2042.	1.65	22.3
#2041.	1.58	21.7
#2039.	1.77	24.1
#2038.	1.78	24.3
#2037.	1.62	22.5
#2036.	1.72	23.6
#2035.	1.76	24.0
#2034.	1.59	22.1
#2033.	1.54	21.6
#2032.	1.30	18.6

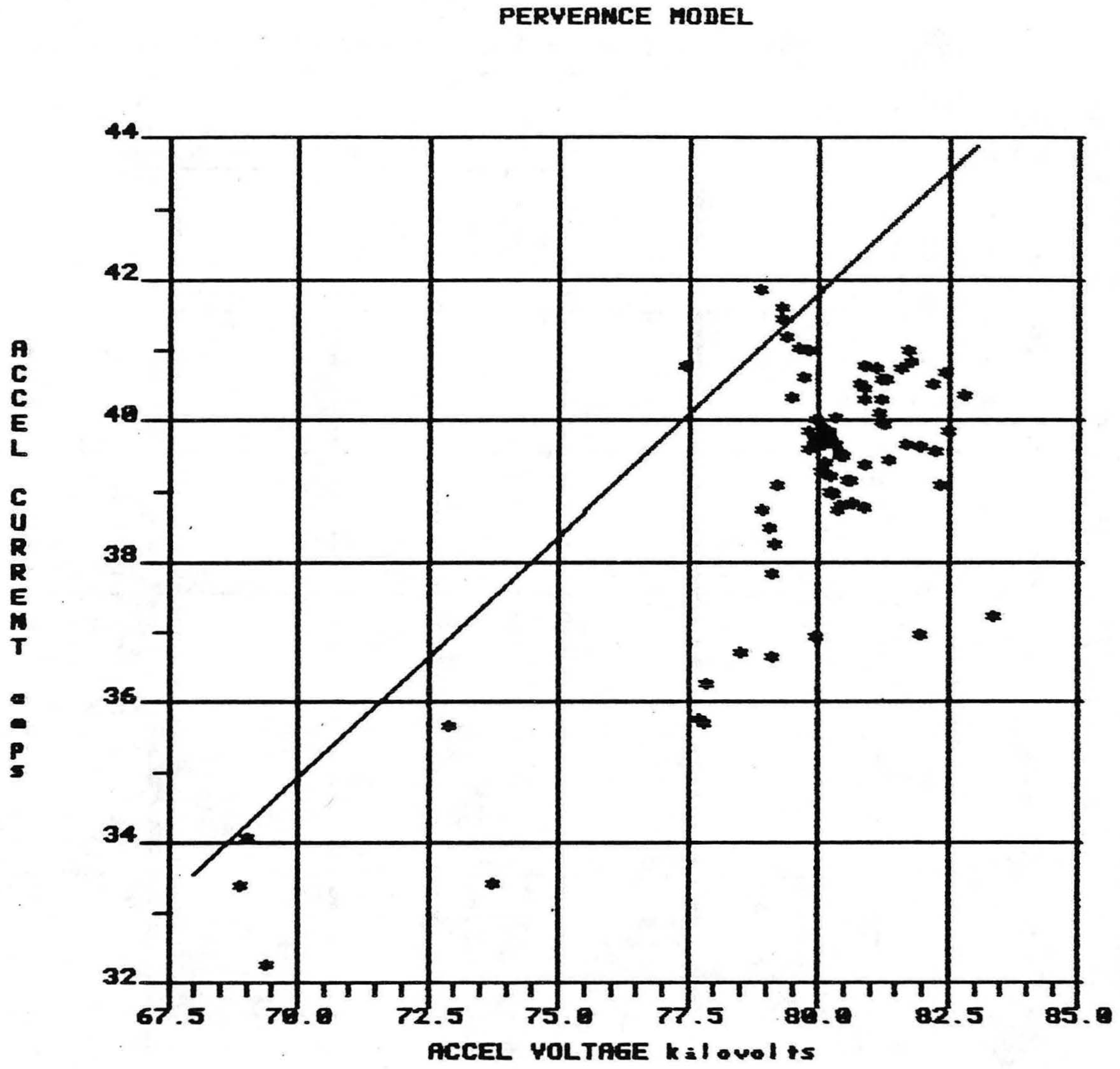
XBL 847-2960

Figure 32. LPA tune taken during conditioning. This tune is at 57 kV, after conditioning up to 70 kV.



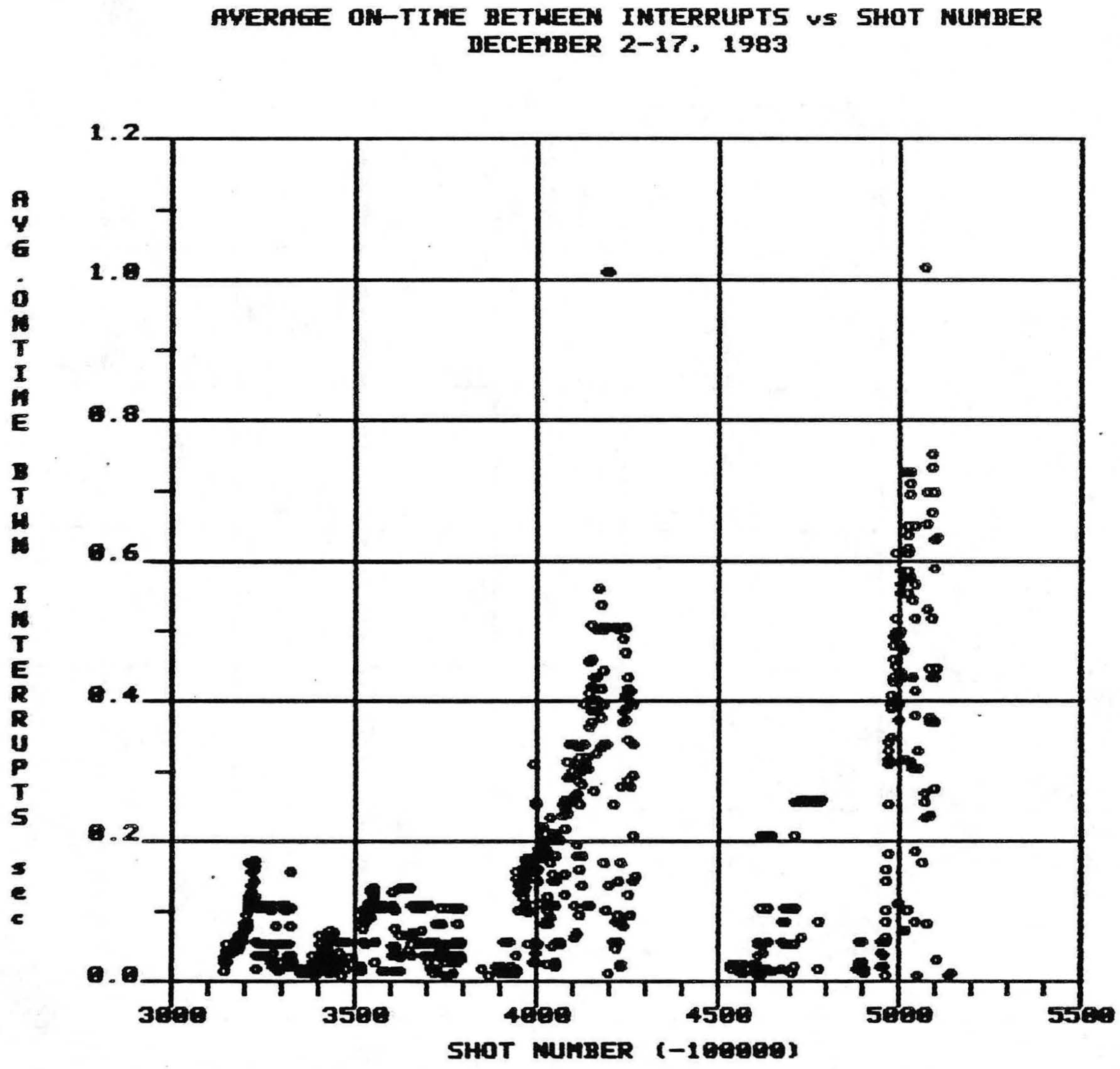
XBL 847-2978

Figure 33. Perveance plot, 68 - 73 kV. Based on a recent tune, this model is used as a guide while increasing accelerator voltage and current.



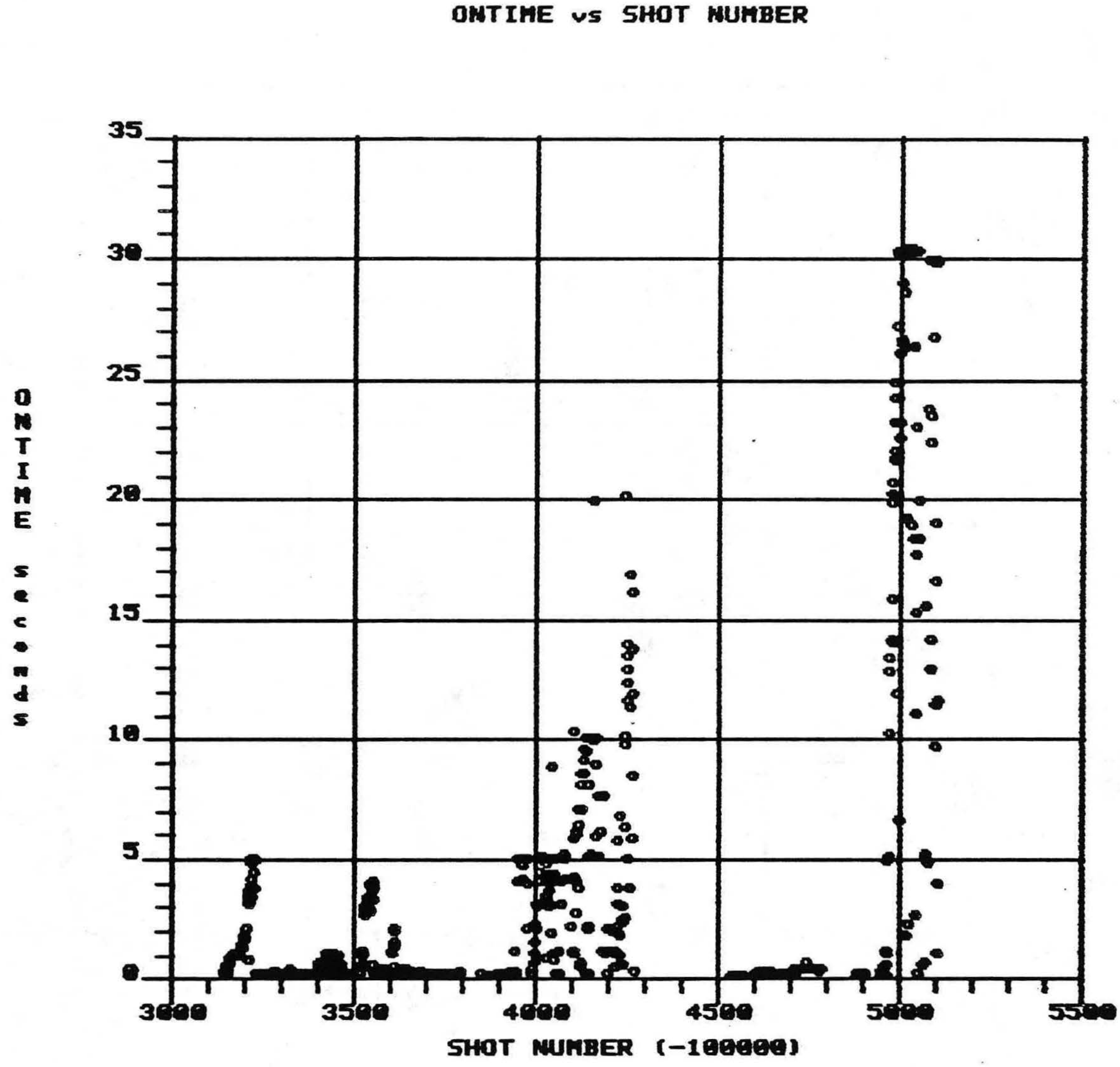
XBL 847-2979

Figure 34. Perveance plot, 67.5 - 85 kV. Based on a recent tune, this model is used as a guide while increasing accelerator voltage and current.



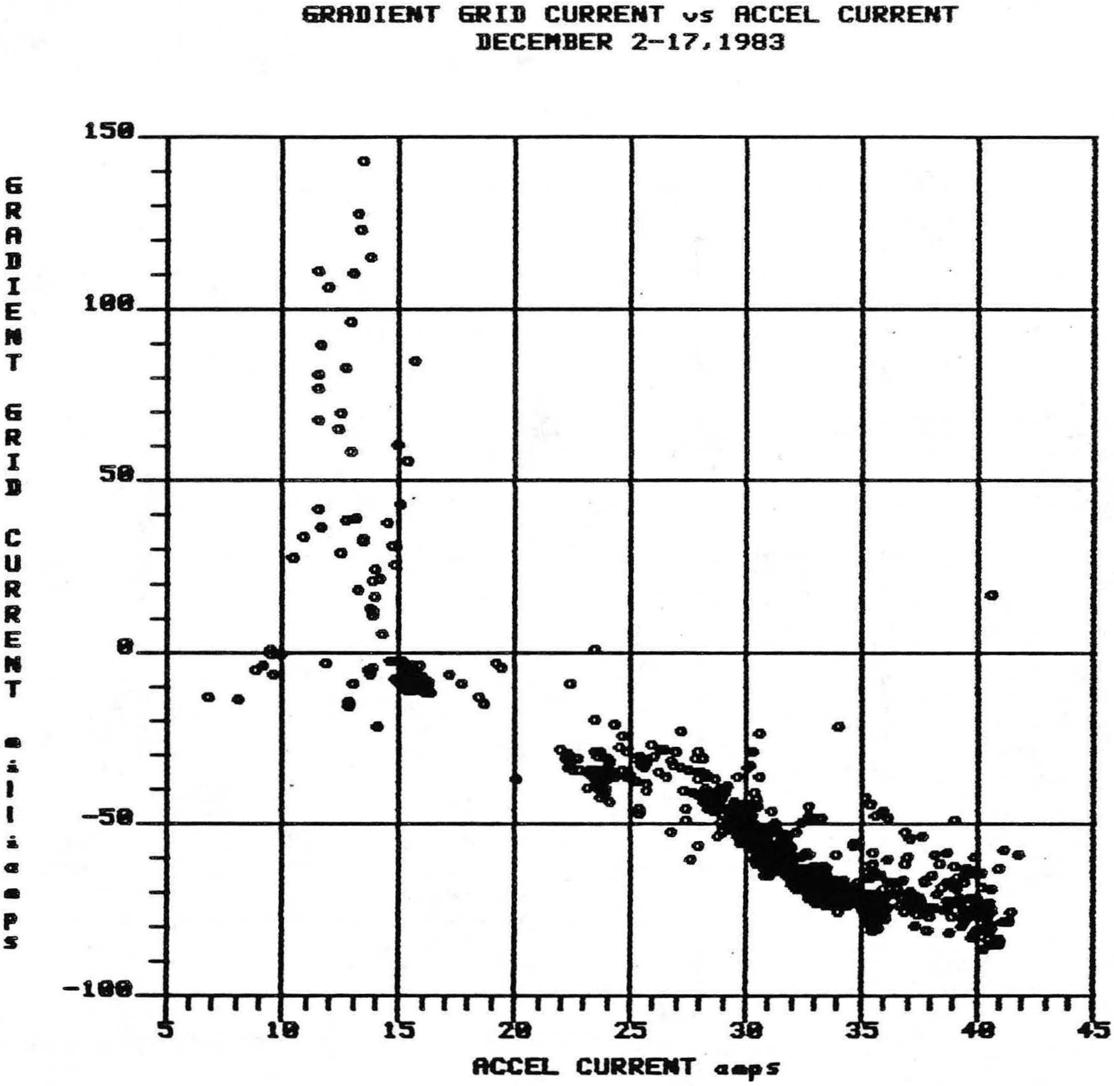
XBL 847-2980

Figure 35. LPA conditioning history. The average on-time between interrupts is plotted vs shot number. Conditioning at a fixed accelerator voltage is illustrated; the breaks are due to test stand problems.



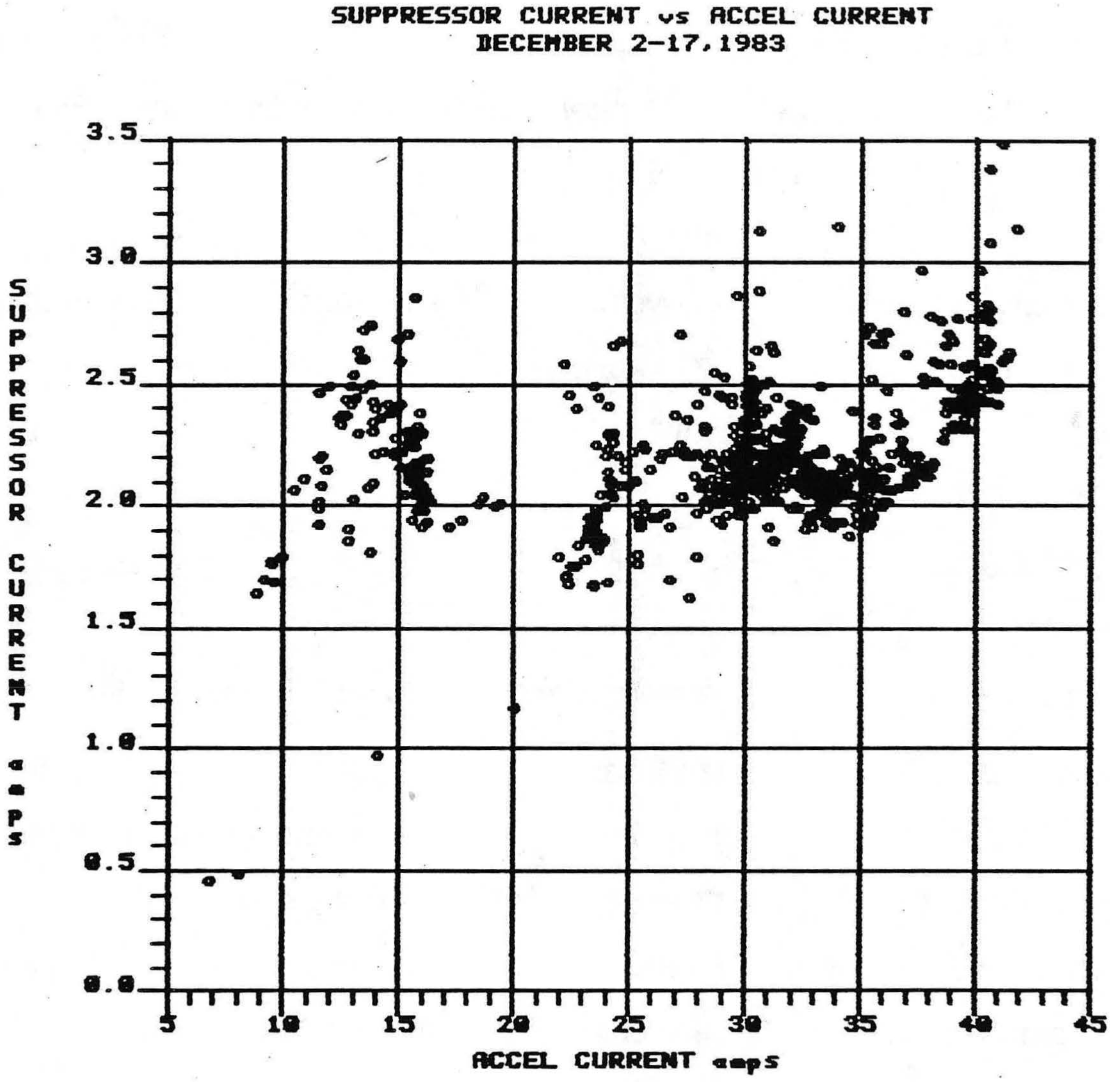
XBL 847-2981

Figure 36. LPA conditioning history. The total on-time per shot is plotted vs shot number to illustrate behavior during grid conditioning.



XBL 847-2977

Figure 37. Gradient grid current history. The gradient grid current is plotted vs accel current. Note that the gradient grid current can be relatively high during initial conditioning, although the accel current is relatively low. The decline in gradient grid current at higher accel current is due to accelerator conditioning. Once the grids are conditioned the gradient grid current remains relatively low over the entire accel current range.



XBL 847-2976

Figure 38. Suppressor grid current history. The suppressor grid current is plotted vs accel current. Note that suppressor current is relatively insensitive to accel current or conditioning.

12. LPS/LPA OPERATION PARAMETERS ON NBETF

Long pulse testing of the LPS/LPA was carried out on NBETF. Data were taken to characterize the source and accelerator performance and to measure the beam characteristics. Typical summary data are presented and waveforms are discussed to illustrate the important aspects required for a functional neutral beam injector.

The following is a list of typical operating parameters for the LPS/LPA at optimum for different accelerator voltages:

	40 kV	60 kV	80 kV
Filament Voltage*	6.65 Volts	6.69 Volts	6.66 Volts
Filament Current*	3.35 kAmps	3.30 kAmps	3.10 kAmps
Gas	12.0 TL/S	11.7 TL/S	12.3 TL/S
Arc Voltage	70.0 Volts	68.9 Volts	80.8 Volts
Arc Current	340 Amps	615 Amps	859 Amps
Arc Power	24.0 kWatts	42.4 kWatts	69.4 kWatts
Probe Level	60 mAmps/cm2	110 mAmps/cm2	170 mAmps/cm2
Probe Profile††	<1.15 max/min	<1.15 max/min	<1.15 max/min
Accel Voltage	40 kVolts	59.1 kVolts	79 kVolts
Accel Current	13 Amps	25.4 Amps	40.5 Amps
Perveance	1.7 μpervs	1.77 μpervs	1.81 μpervs
Gradient Grid Voltage	34 kVolts	48.1 kVolts	65.7 kVolts
Gradient Grid Current	50 mAmps	31 mAmps	75 mAmps
Suppressor Voltage	-1.0 kV	-1.5 kV	-2.0 kV
Suppressor Current	2.0 Amps	2.4 Amps	2.5 Amps

* Stepped Filament Values (See Section 9 (B))

†† The LPS/LPA Probe Profile was not measured on NBETF, but was previously taken on another test stand. See Section 10 (C) for additional profile information.

As mentioned previously, 18 Tl/s would be an equilbrium gas flow on NBETF, but 12 Tl/s corresponded to the source pressure anticipated for equilibrium flow with a "pure beam" neutralizer.

The source operating conditions are monitored with a mini computer, and also on oscilloscopes. Waveforms[11] of these signals from both will be discussed. All diagnostics are monitored with the mini computer; the water flow calorimetry of the accelerator grids, is also monitored on a Hewlett-Packard 9845-B desktop computer. During the requested beam, an average value of monitored signals for each shot is computed and archived by the computer, and later transferred to tapes. Thus, a permanent record of the data for each shot is available for analysis at any time. The very important signals, e.g., arc current, accel current and voltage, gradient grid current, suppressor voltage, and others, are monitored by oscilloscopes, to give an instantaneous record to the operator. These signals and others are digitized to be retrievable on a request basis for the current shot.

The first scope picture in Figure 39 shows the filament voltage and current as thermal equilibrium is being reached, then the filament power is stepped to retain filament thermal equilibrium during arc on-time. The computer waveforms of the filament are shown in Figure 40.

Typical arc voltage and current waveforms are shown in the arc scope picture in Figure 39; the arc computer waveforms are shown in Figure 41. The water-cooled probe signal is included on the arc scope picture, with the computer printout shown in Figure 42. Since the filaments take ≈ 7.5 seconds to reach thermal equilibrium, the arc turn-on is timed to start at ≈ 7.5 seconds after filament on. The arc is unregulated for 1.5 seconds; then arc regulation takes place at ≈ 9 seconds after filament-on. The 1.5 second delay allows the operator to view the arc voltage and current levels before arc regulation begins. Adjustment of the filament power (i.e., filament temperature) may be indicated if the unregulated arc voltage is outside the 70 to 100 volts operating range. The regulated arc is run an additional 1.5 seconds for stabilization before turning on accel power supply for beam. Other plasma source voltages monitored (to indicate shorts) during the arc pulse are, 1st grid, probe plate, and rear spacer, as shown in Figure 43.

In Figure 39, the third scope picture is a fast time base scope; arc voltage and current, the probe, and the 1st grid voltage behavior during an arc turn-on are shown. Monitoring these signals is important at the beginning of arc conditioning to identify the discharge mode. The arc always begins in the inefficient mode, then in a few msec, normally makes a transition to the normal mode. See Section 14 (A) for additional information on mode changes.

The accelerator current and voltage signals are shown in Figures 44 and 45. The gradient grid current, V_{1-2} voltage, and the suppressor current and voltage are shown in Figure 44. Monitoring these signals is essential for safe operation of the LPS/LPA.

On NBETF, other data were taken to evaluate backstreaming electron power. Computer printouts of waterflow calorimetry of the LPS Bucket are shown in Figrues 46 and 47. The Bucket walls reach thermal equilibrium in approximately 20 seconds at 80 kV accel voltage, with a ΔT of ≈ 14°C. The rest of the LPS (excluding the Electron Dump) doesn't reach thermal equilibrium, as shown in Figure 46. The Electron Dump waterflow calorimetry is included on the Accelerator grid waterflow calorimetry printout, Figure 16. The Electron Dump reaches thermal equilibrium after ≈ 2 seconds of arc, with a ΔT of ≈ 2°C.

Beam species and divergence are measured with the Optical Mass Analyzer (OMA), which is based on Doppler shifted spectroscopy of hydrogen or deuterium. The data, shown in Figure 48, are presented in two views. Beam properties in the direction parallel to the slots are presented in the parallel view, which is based on up-shifted light looking through the beam, perpendicular to the slots. Beam properties perpendicular to the slots are shown in the perpendicular view, which is based on down-shifted light, looking parallel to the slots. The full energy peak is on the left for the parallel plane and on the right for the perpendicular plane. The other two peaks in each view are the 1/2 and 1/3 energy species. The first column on the display gives the percentage of full, 1/2, and 1/3 energy particles. The second column gives the 'root mean square' (RMS) divergence of the species fractions, obtained by folding in a shape factor 'a' with the 1/e point. The third column shows the divergence angle for each peak. The divergence of each species is determined by a least squares fit of the peaks to the function:

$$e^{-[\, x-x_0 \,/\, w \,]^{2a}}$$

where w is the 1/e point, x_0 is the peak center, and a is the shape factor (fourth column). For a=1, the function is a Gaussian; for a<1, the function is more peaked. The weighted divergence is a single beam divergence angle, obtained as a weighted average of the three 'RMS DIV' values in the second column. This weighted divergence value is comparable to the beam divergence from calorimetry. The last column contains the relative percentage of light collected under each peak. Finally, the relative quantity of water in the beam is also fit, and compared to the total beam species light. The water fraction is obtained from doppler shifted spectral lines of hydrogen (or deuterium) atoms bound to oxygen, i.e., hydroxides. In Figure 48, the water peaks are barely perceptible bumps, below the third energy peaks.

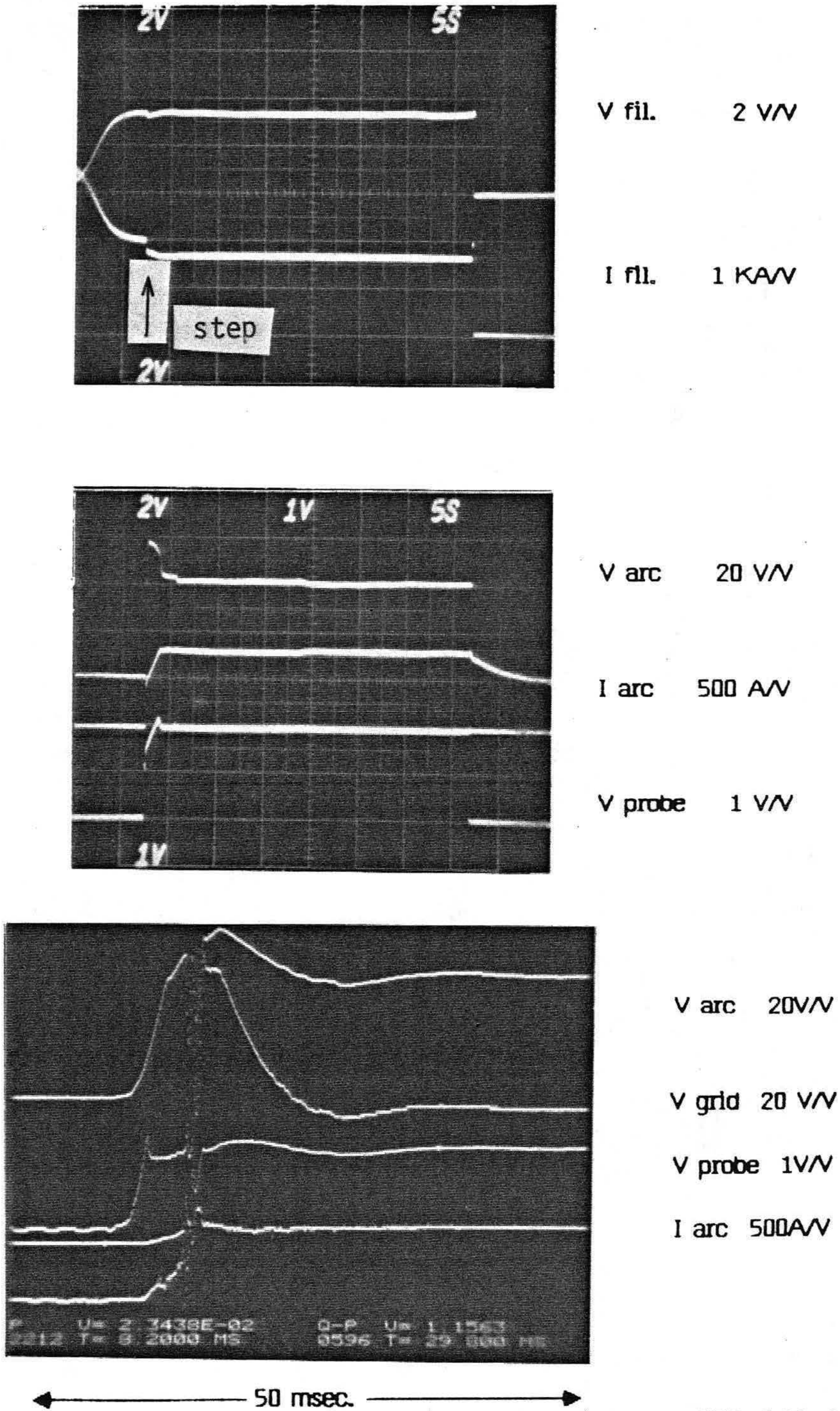
An 80 kV tune, using the inertial dump thermocouple array, is shown in Figure 49. The inertial dump measures the beam profile, shown in Figure 50. This dump depends on the copper material mass to absorb the beam energy. Some 100 thermocouples give the energy distribution deposited by the beam. At optimum perveance, the beam divergence is 0.95° perpendicular to the slots and 0.41° parallel to the slots (1/e half width). Figure 51 is the shot summary for the optimum point on the tune. The computer averaged values of the Filament, Arc, Accel, Gradient Grid, Suppressor Grid, and Probe waveforms are printed on the shot summary. In addition, the shot summary shows the gas flow, the vacuum status of the injector and target tanks, the requested pulse length, beam on-time, and dump calorimetry.

For calorimetry diagnostics of the beam during long pulses, the active dump was used. Forty high pressure water cooled panels gave a time history, shown in Figures 52 and 53, of the rise in temperature through the panels. These signals along with the flows gave the measured power distribution on the active dump panels. In Figure 54, isotherms are shown in the left display (Beam Profile); calculated beam power density is shown on the right. Target beam divergence is calculated from the power densities.

Perveance graphs ($V^{3/2}$) of accel voltage vs. accel current and accel voltage vs. arc power are shown in Figures 55 and 56. These graphs are useful for determining operation parameters for accel voltages not listed at the beginning of this section.

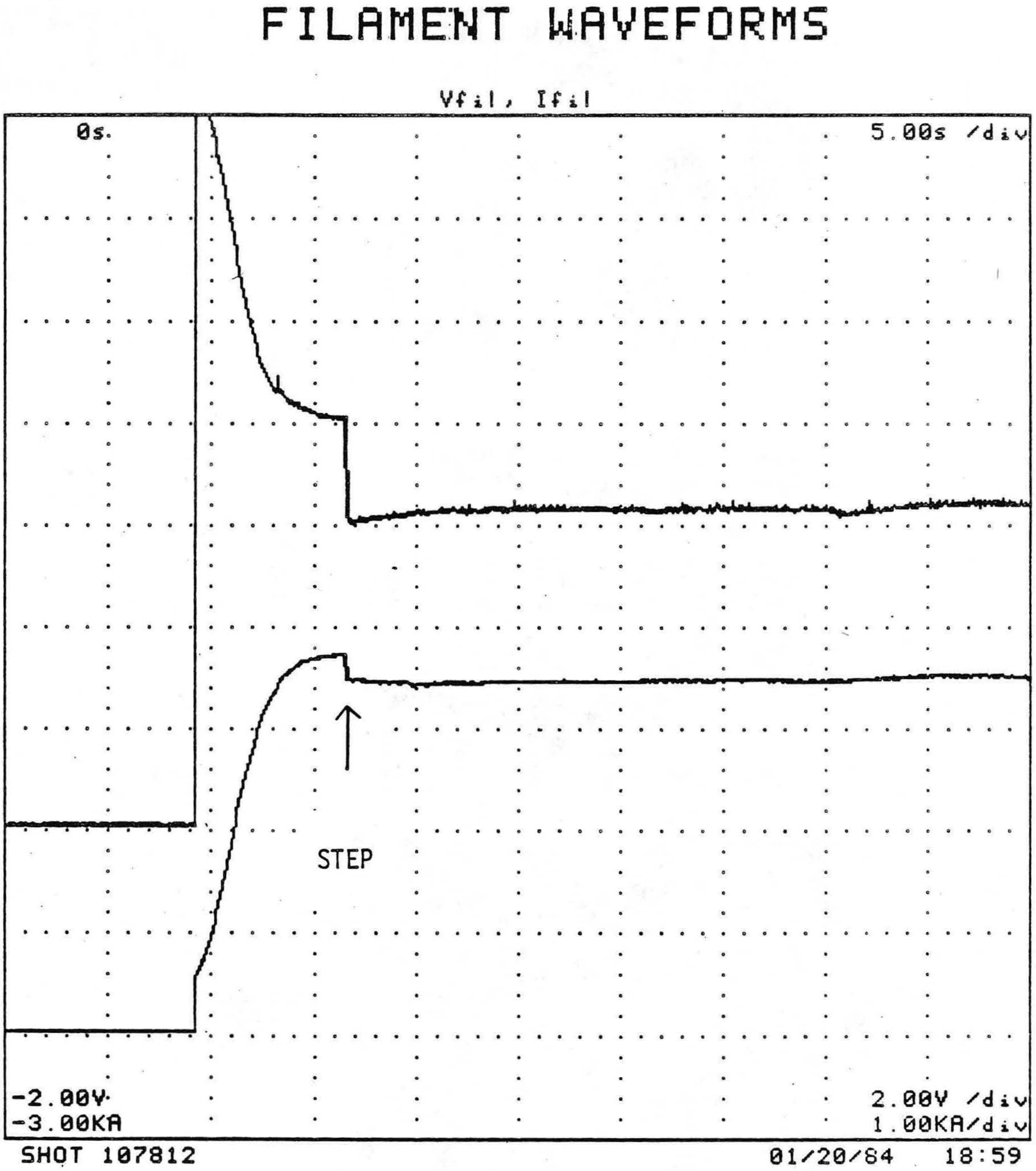
LPS/LPA

SCOPE SIGNALS OF THE FILAMENT,
ARC, AND A MODE CHANGE
DURING OPERATION ON NBETF



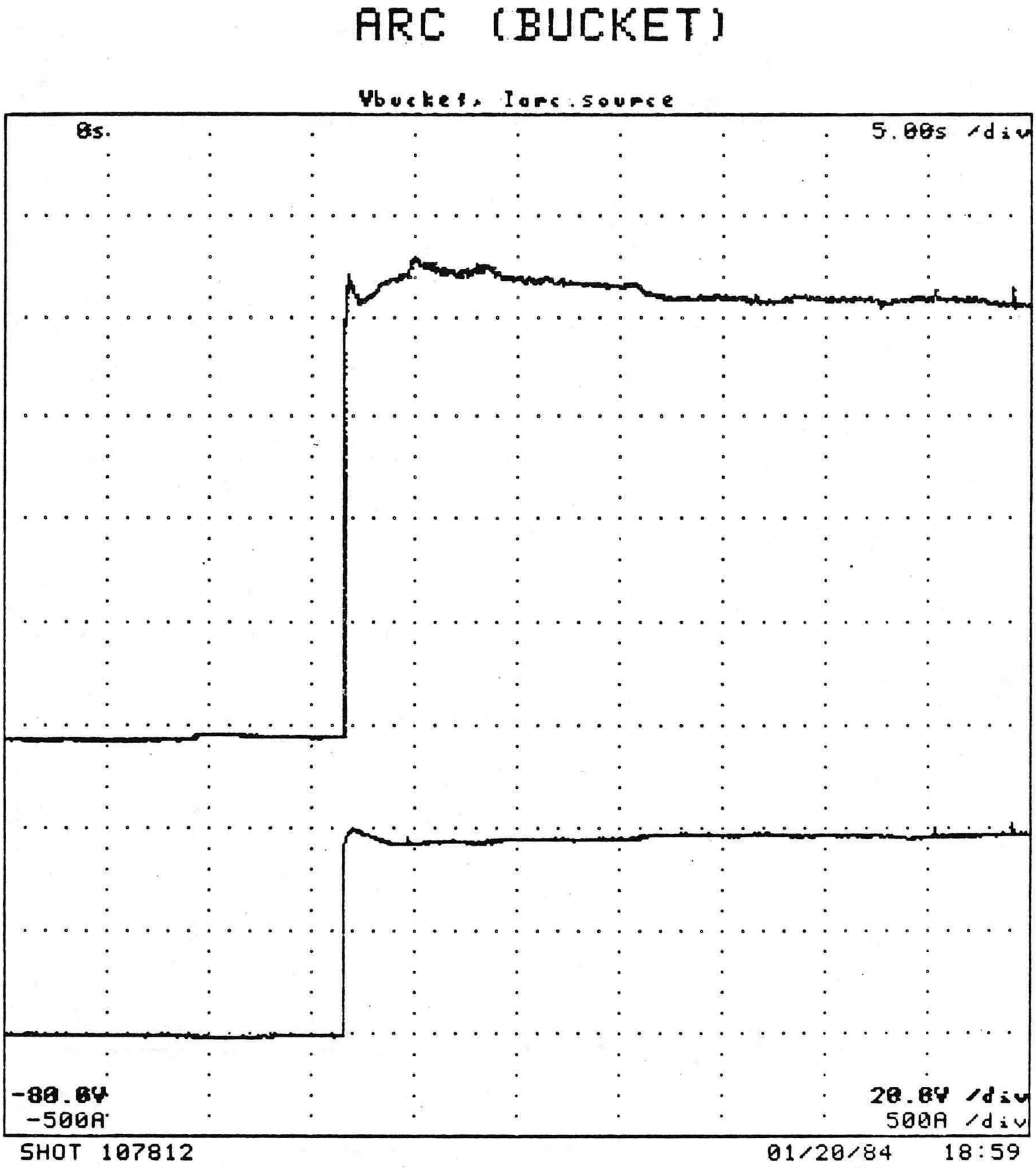
XBB 842-1391

Figure 39. Picture of the scope signals monitored during arc operation. The top scope waveforms show the filament voltage and current before and after the filament power supply is stepped. The middle scope waveforms show typical arc voltage and current traces, with a probe signal included. The bottom "fast" scope illustrates the arc behavior during the transition between the inefficient and efficient mode.



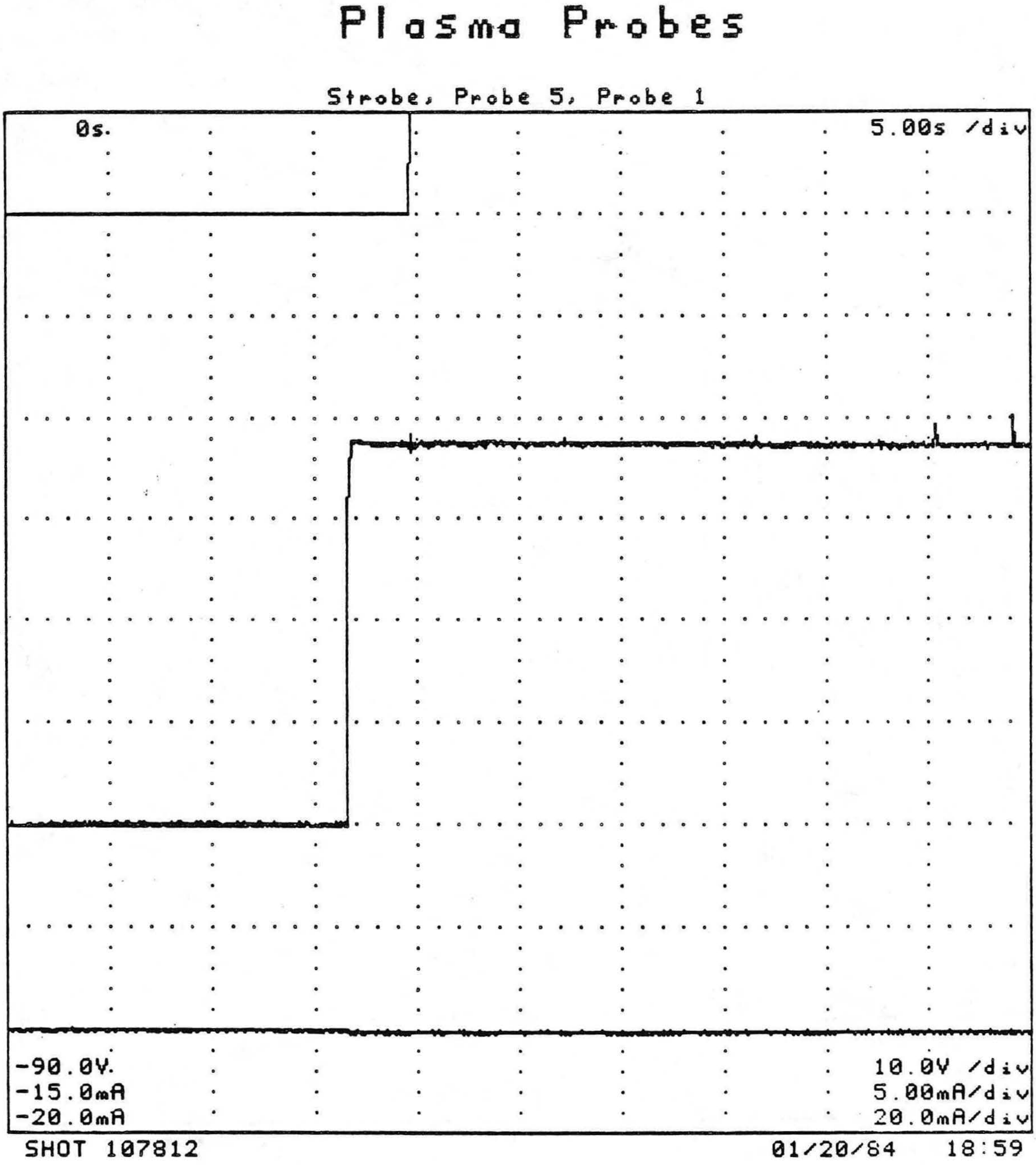
XBL 847-2975

Figure 40. Computer printout of filament voltage and current during a 30 second shot.



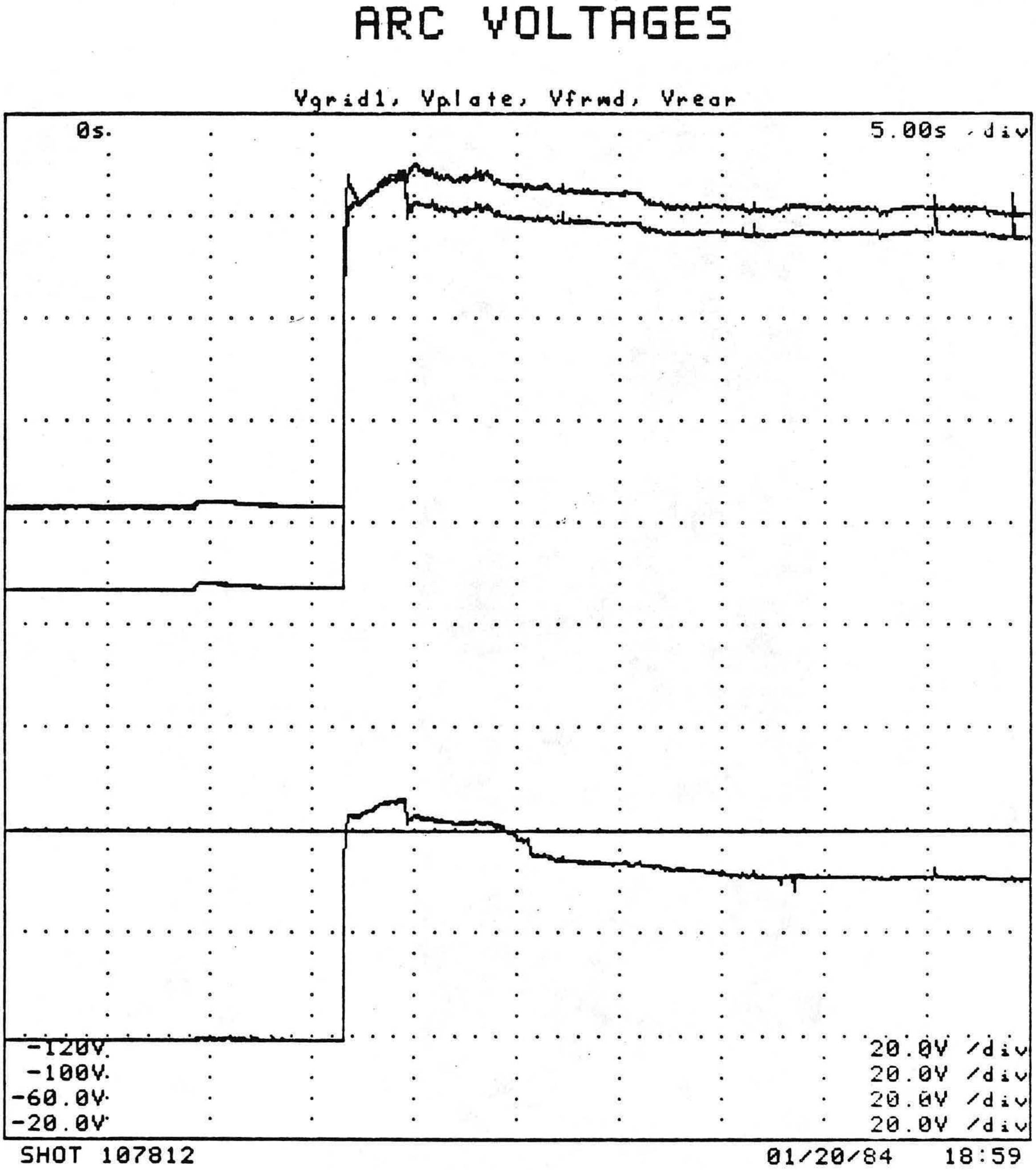
XBL 847-2974

Figure 41. Computer printout of arc voltage and current during a 30 second shot.



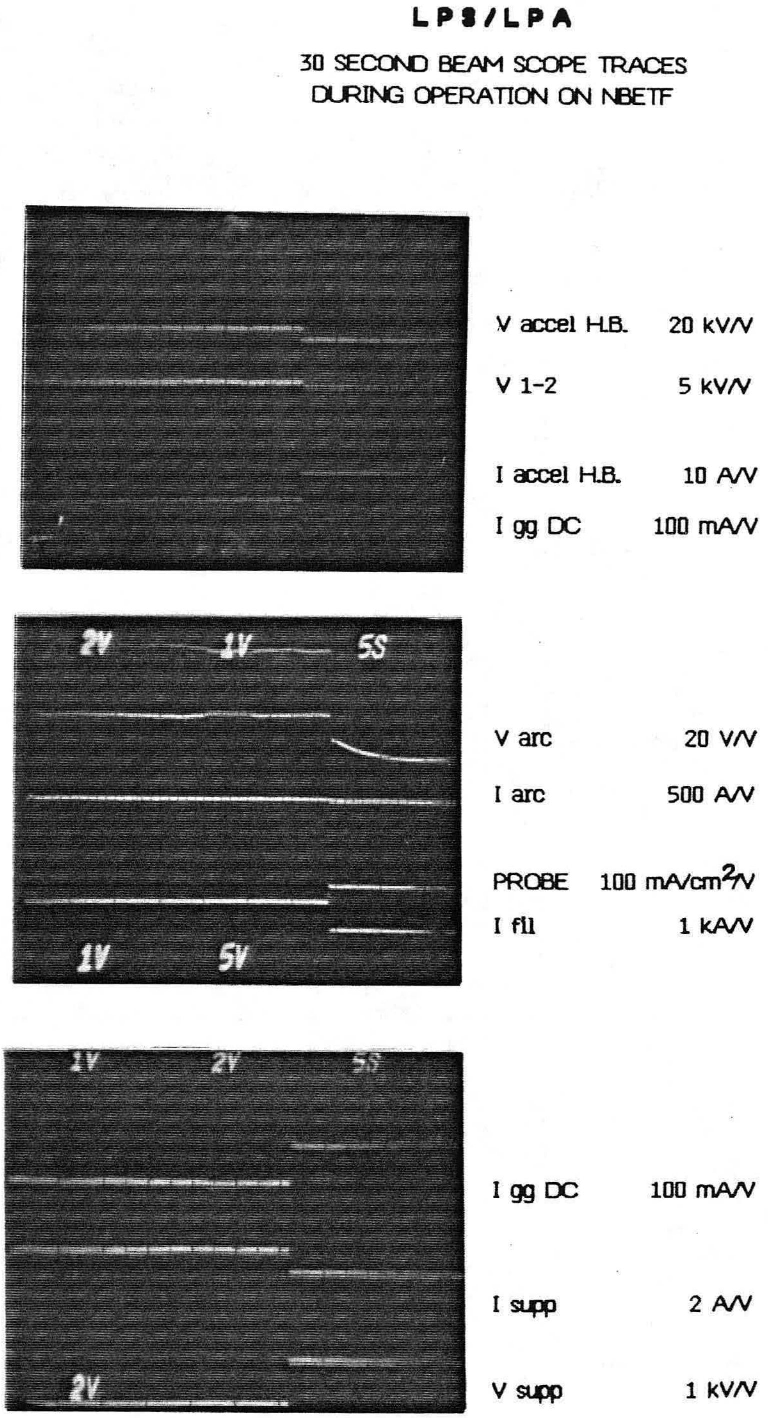
XBL 847-2973

Figure 42. Computer printout of saturated ion current as read by a water cooled plasma probe during a 30 second shot. The strobe is the logic signal for accel voltage.



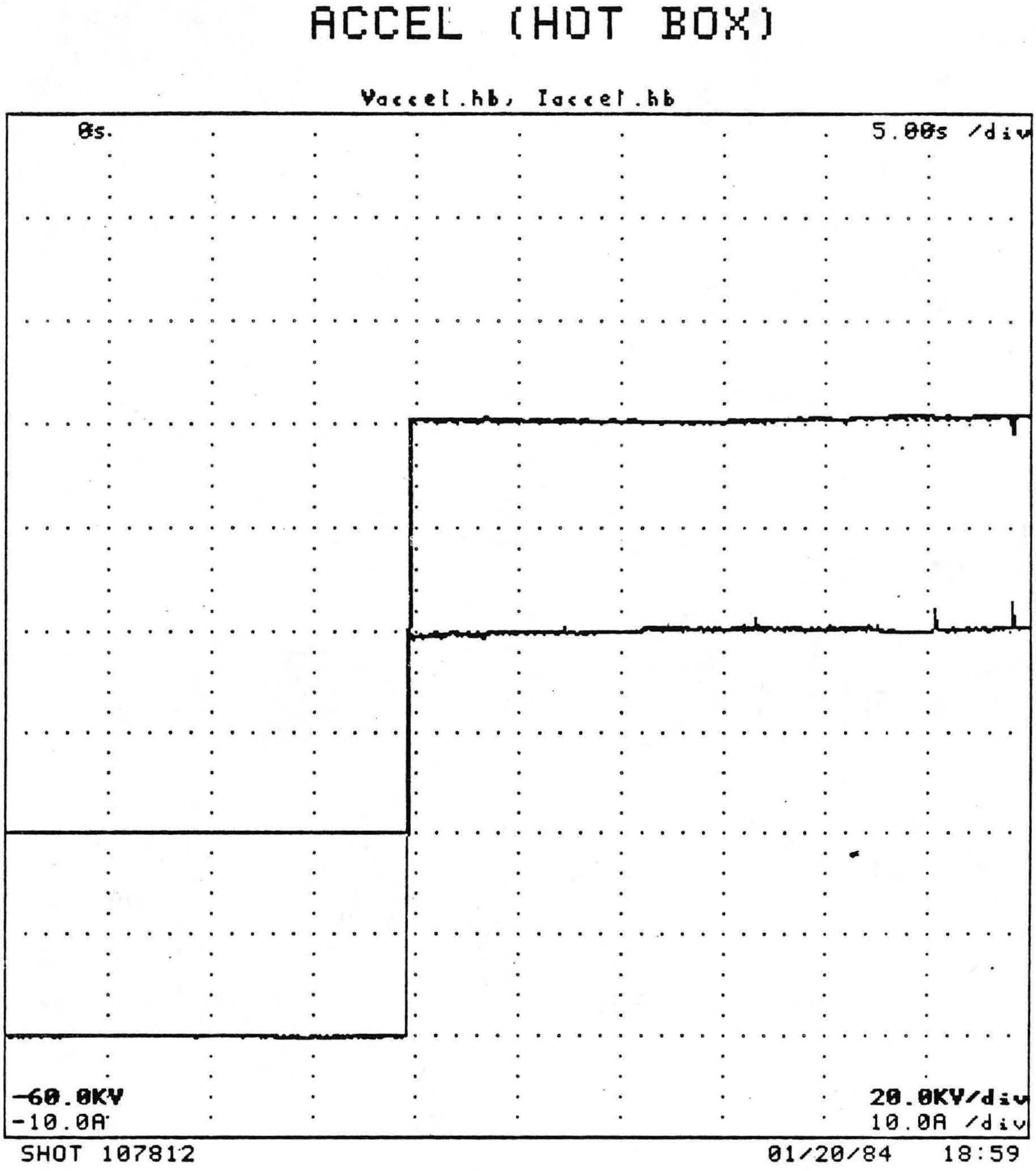
XBL 847-2972

Figure 43. Computer printout of floating plate voltages during a 30 second shot. The voltage of grid 1, the probe plate, and the rear spacer plate are shown; the foward spacer plate channel was not functional on this shot.



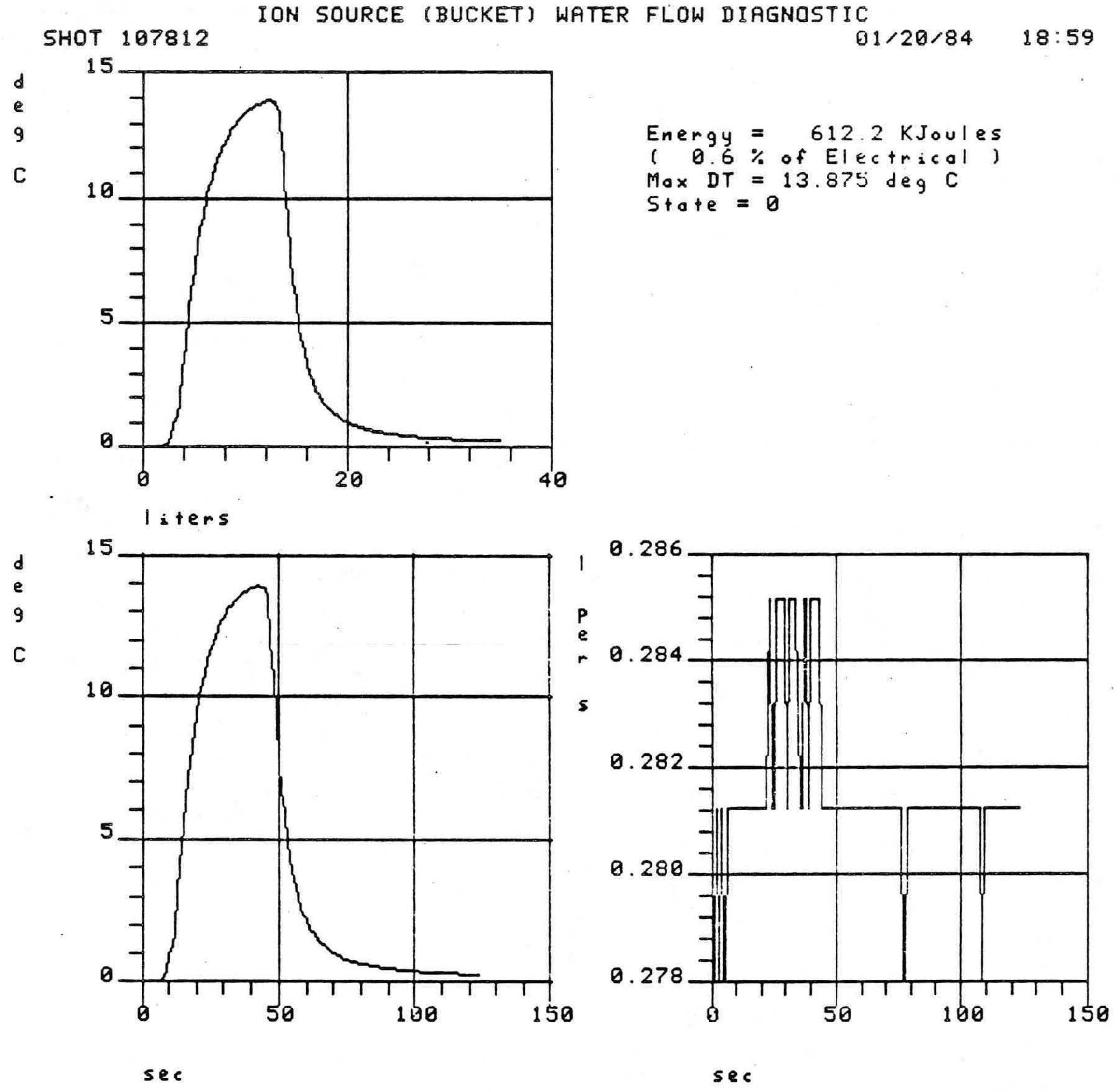
XBB 843-1704

Figure 44. Scope traces showing plasma source and accelerator voltages and currents monitored during a 30 second beam shot.



XBL 847-2962

Figure 45. Computer printout of accelerator voltage and current during a 30 second shot.

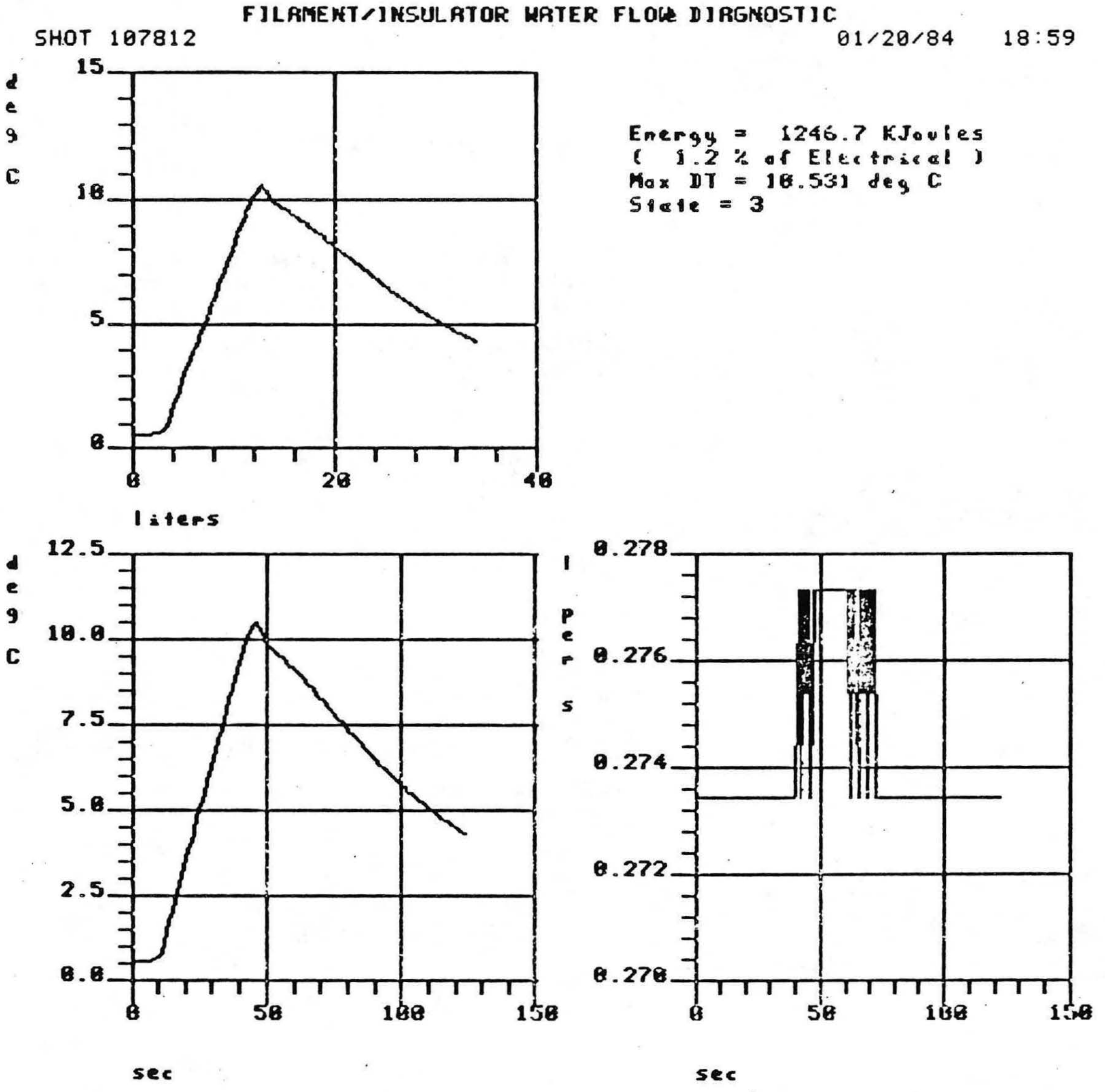


```
ION SOURCE (BUCKET) WATER FLOW DIAGNOSTIC
SHOT 107812                                    01/20/84    18:59

Energy =    612.2 KJoules
(  0.6 % of Electrical  )
Max DT = 13.875 deg C
State = 0
```

XBL 847-2964

Figure 46. Computer printout of water flow calorimetry from the bucket section of the LPS. The digitized data are plotted on top, below that the extrapolated fit to the digitized data, and the water flow rate in the lower right.



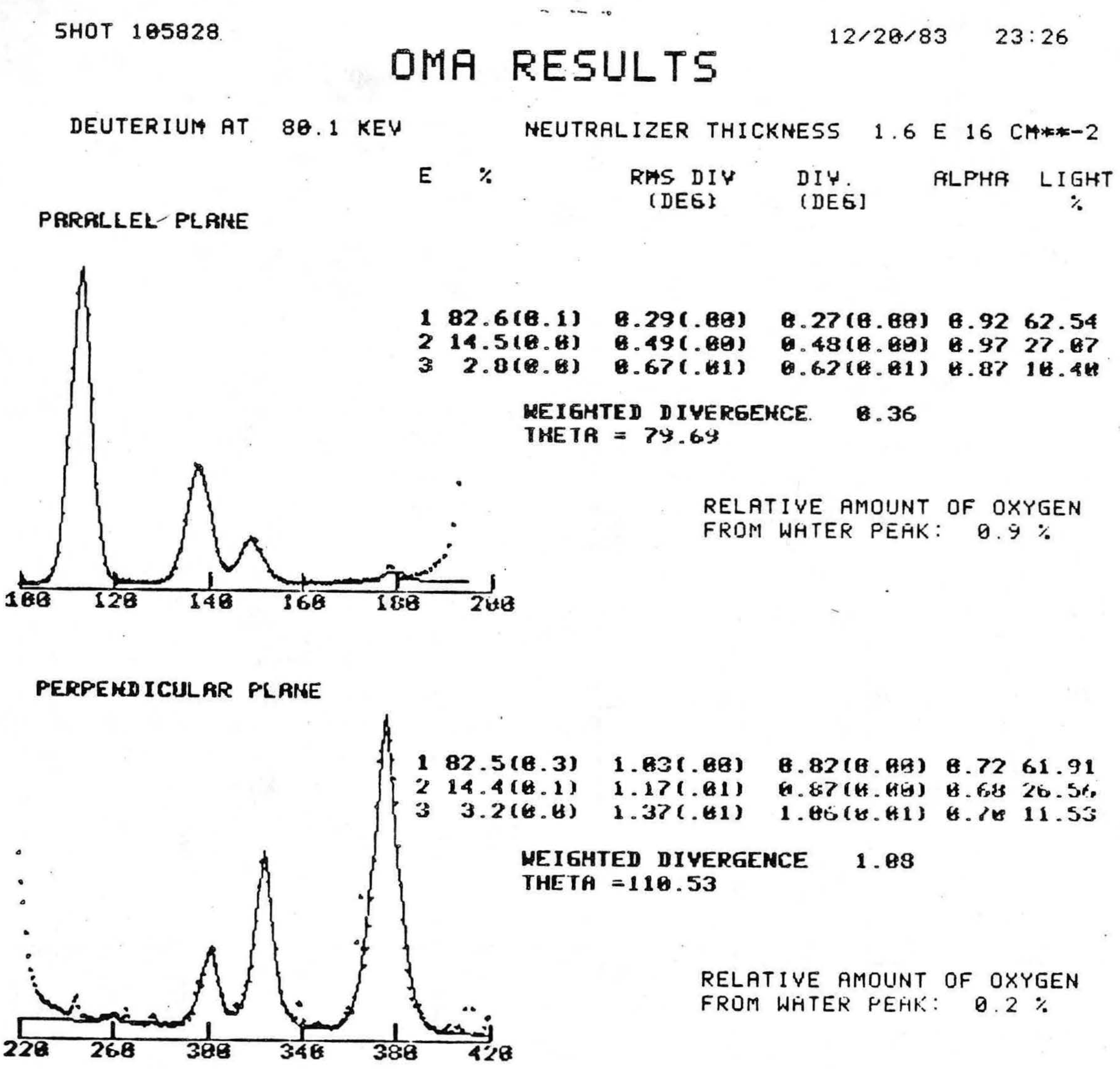
FILAMENT/INSULATOR WATER FLOW DIAGNOSTIC

SHOT 107812 01/20/84 18:59

Energy = 1246.7 KJoules
(1.2 % of Electrical)
Max DT = 10.531 deg C
State = 3

XBL 847-2963

Figure 47. Computer printout of filament sandwich water flow calorimetry. Common manifolds provide water for the two filament plates and the two spacer plates (foward and rear). Note that steady state is not achieved, even in a 30 second shot. The digitized data are plotted above, and the water flow rate in the lower right.



```
SHOT 105828                                         12/20/83    23:26
                          OMA RESULTS

 DEUTERIUM AT  80.1 KEV        NEUTRALIZER THICKNESS  1.6 E 16 CM**-2

                          E   %        RMS DIV      DIV.      ALPHA  LIGHT
                                        (DEG)       (DEG)              %
PARALLEL PLANE

                        1 82.6(0.1)  0.29(.00)   0.27(0.00) 0.92 62.54
                        2 14.5(0.0)  0.49(.00)   0.48(0.00) 0.97 27.07
                        3  2.0(0.0)  0.67(.01)   0.62(0.01) 0.87 10.40

                              WEIGHTED DIVERGENCE   0.36
                              THETA = 79.69

                                           RELATIVE AMOUNT OF OXYGEN
                                           FROM WATER PEAK:   0.9 %

PERPENDICULAR PLANE

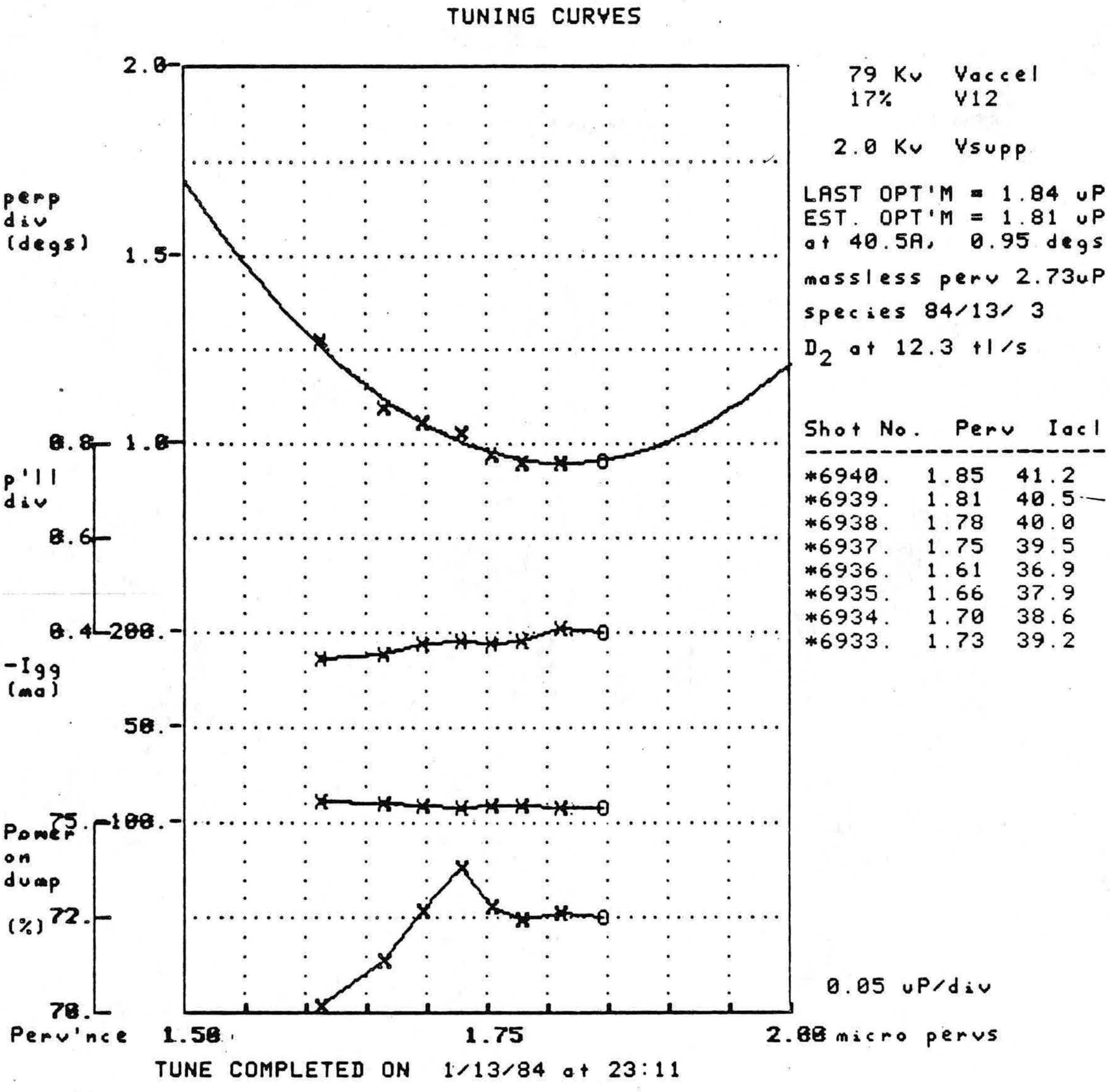
                        1 82.5(0.3)  1.03(.00)   0.82(0.00) 0.72 61.91
                        2 14.4(0.1)  1.17(.01)   0.87(0.00) 0.68 26.56
                        3  3.2(0.0)  1.37(.01)   1.06(0.01) 0.70 11.53

                              WEIGHTED DIVERGENCE   1.08
                              THETA =110.53

                                           RELATIVE AMOUNT OF OXYGEN
                                           FROM WATER PEAK:   0.2 %
```

XBL 847-2965

Figure 48. Computer printout of Optical Mass Analyzer (OMA) data at 80 kV. The parallel and perpendicular views measure beam properties in the directions parallel and perpendicular to the accelerator slots. The deuterium species are tabulated in the second column from the left for full (1), half (2), and third (3) energy components. The divergence properties are explained in the text.



TUNING CURVES

79 Kv Vaccel
17% V12

2.0 Kv Vsupp

LAST OPT'M = 1.84 uP
EST. OPT'M = 1.81 uP
at 40.5A, 0.95 degs
massless perv 2.73uP
species 84/13/ 3
D_2 at 12.3 tl/s

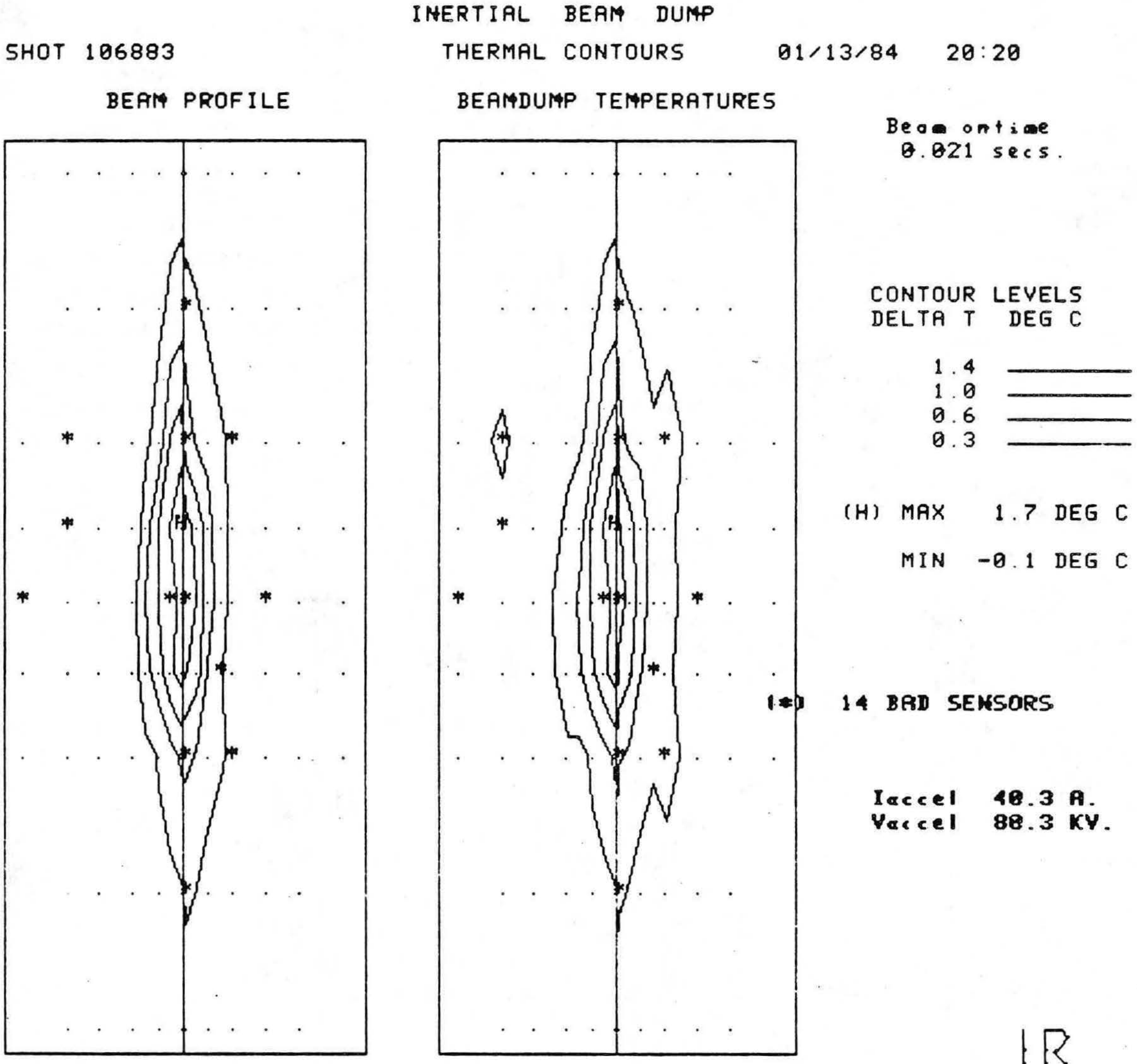
Shot No.	Perv	Iacl
*6940.	1.85	41.2
*6939.	1.81	40.5
*6938.	1.78	40.0
*6937.	1.75	39.5
*6936.	1.61	36.9
*6935.	1.66	37.9
*6934.	1.70	38.6
*6933.	1.73	39.2

0.05 uP/div

TUNE COMPLETED ON 1/13/84 at 23:11

XBL 847-2966

Figure 49. Computer printout of a 79 kV tune during LPS/LPA operation on NBETF.



```
                         INERTIAL  BEAM  DUMP
SHOT 106883                THERMAL CONTOURS       01/13/84   20:20

      BEAM PROFILE          BEAMDUMP TEMPERATURES
                                                    Beam ontime
                                                     0.021 secs.

                                                   CONTOUR LEVELS
                                                   DELTA T  DEG C

                                                        1.4
                                                        1.0
                                                        0.6
                                                        0.3

                                                 (H) MAX    1.7 DEG C

                                                     MIN   -0.1 DEG C

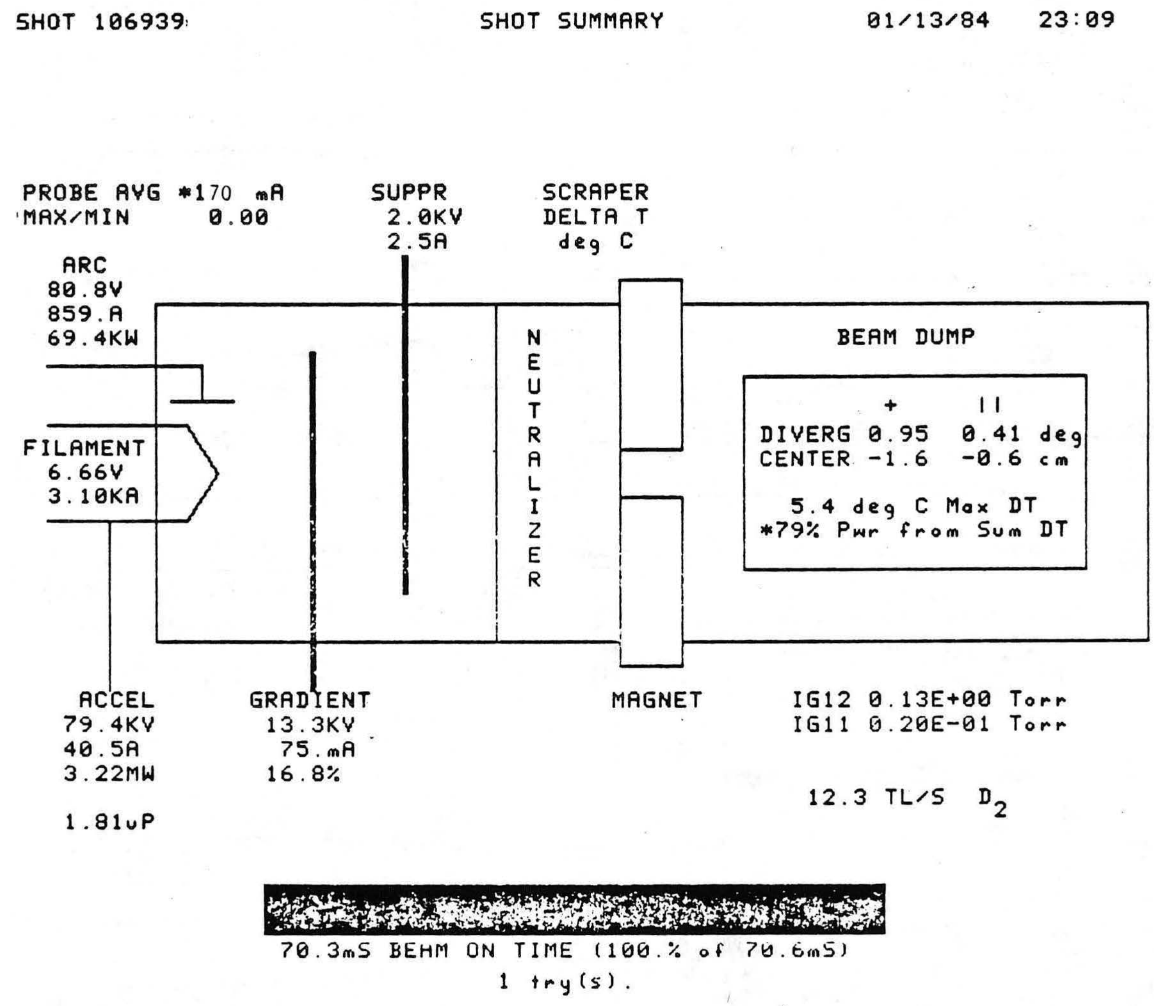
                                              (*)  14 BAD SENSORS

                                                   Iaccel  40.3 A.
                                                   Vaccel  80.3 KV.
```

XBL 847-2967

Figure 50. Computer printout of inertial dump contours. Thermocouple isotherms are plotted on the left, and calculated beam power profile is on the right.

[redacted]



SHOT 106939 SHOT SUMMARY 01/13/84 23:09

PROBE AVG *170 mA
MAX/MIN 0.00

SUPPR
2.0KV
2.5A

SCRAPER
DELTA T
deg C

ARC
80.8V
859.A
69.4KW

FILAMENT
6.66V
3.10KA

\+ ||
DIVERG 0.95 0.41 deg
CENTER -1.6 -0.6 cm

5.4 deg C Max DT
*79% Pwr from Sum DT

ACCEL
79.4KV
40.5A
3.22MW

1.81uP

GRADIENT
13.3KV
75.mA
16.8%

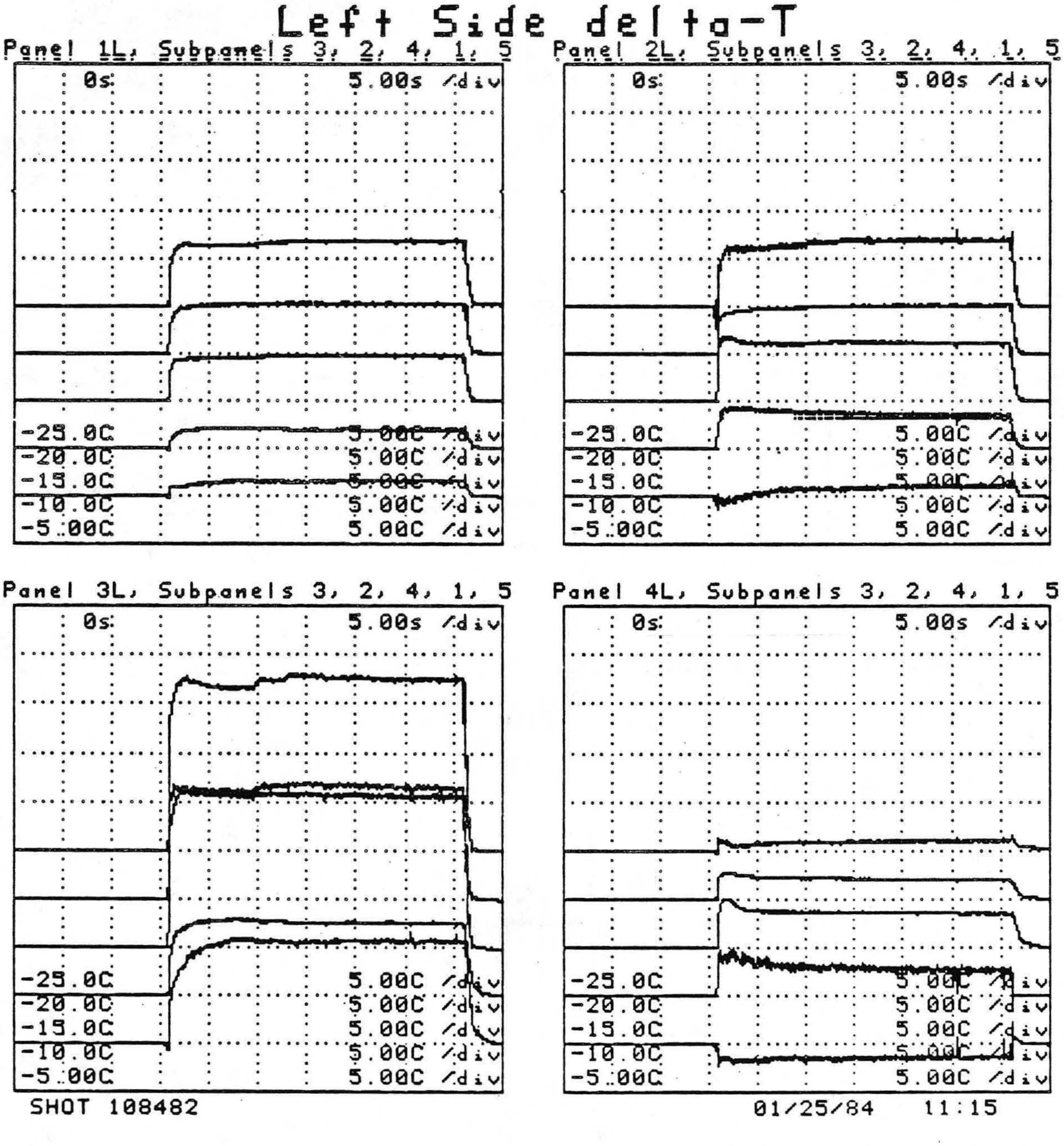
IG12 0.13E+00 Torr
IG11 0.20E-01 Torr

12.3 TL/S D_2

70.3mS BEAM ON TIME (100.% of 70.6mS)
1 try(s).

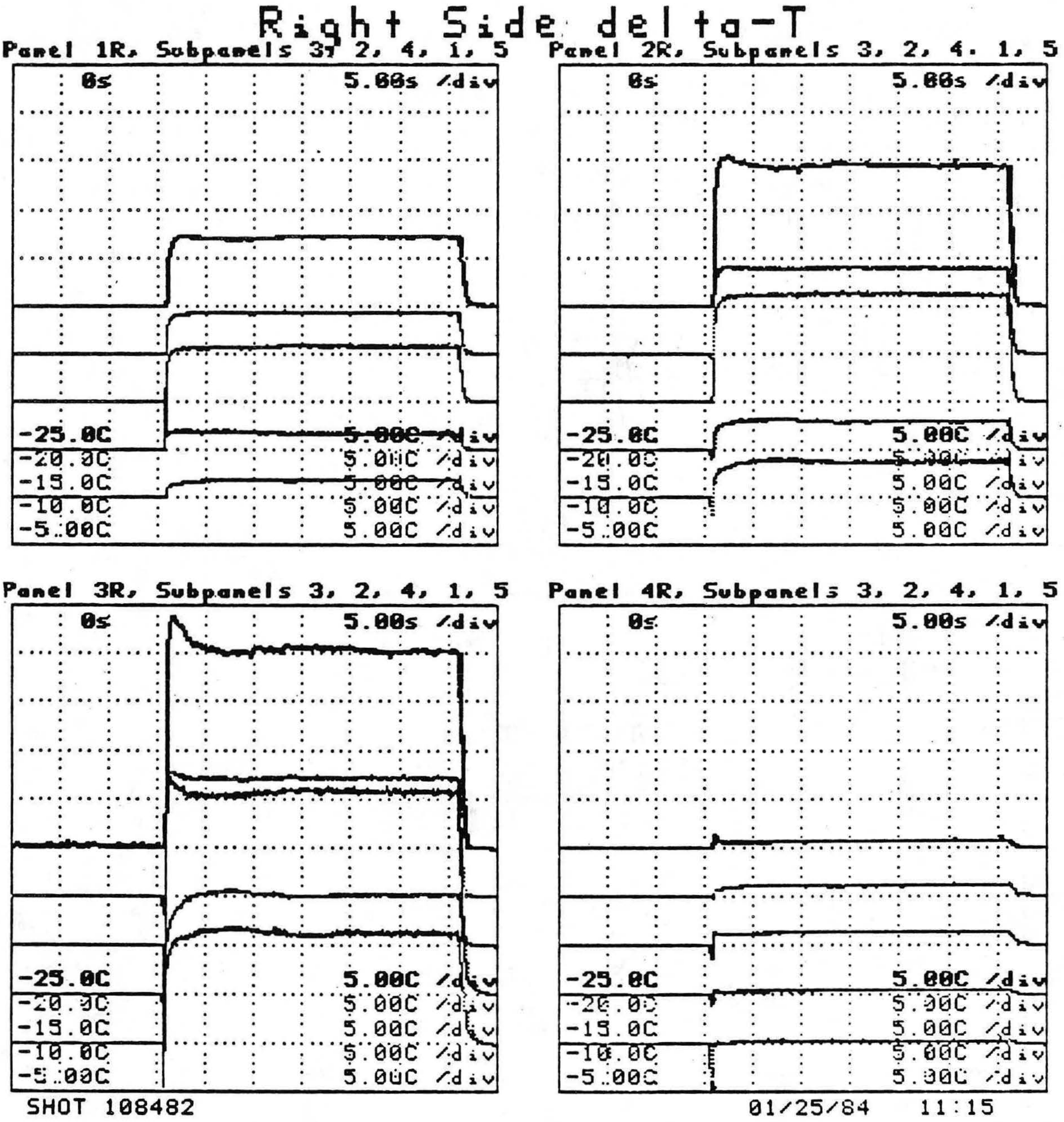
XBL 847-2968

Figure 51. Typical beam shot summary computer printout.



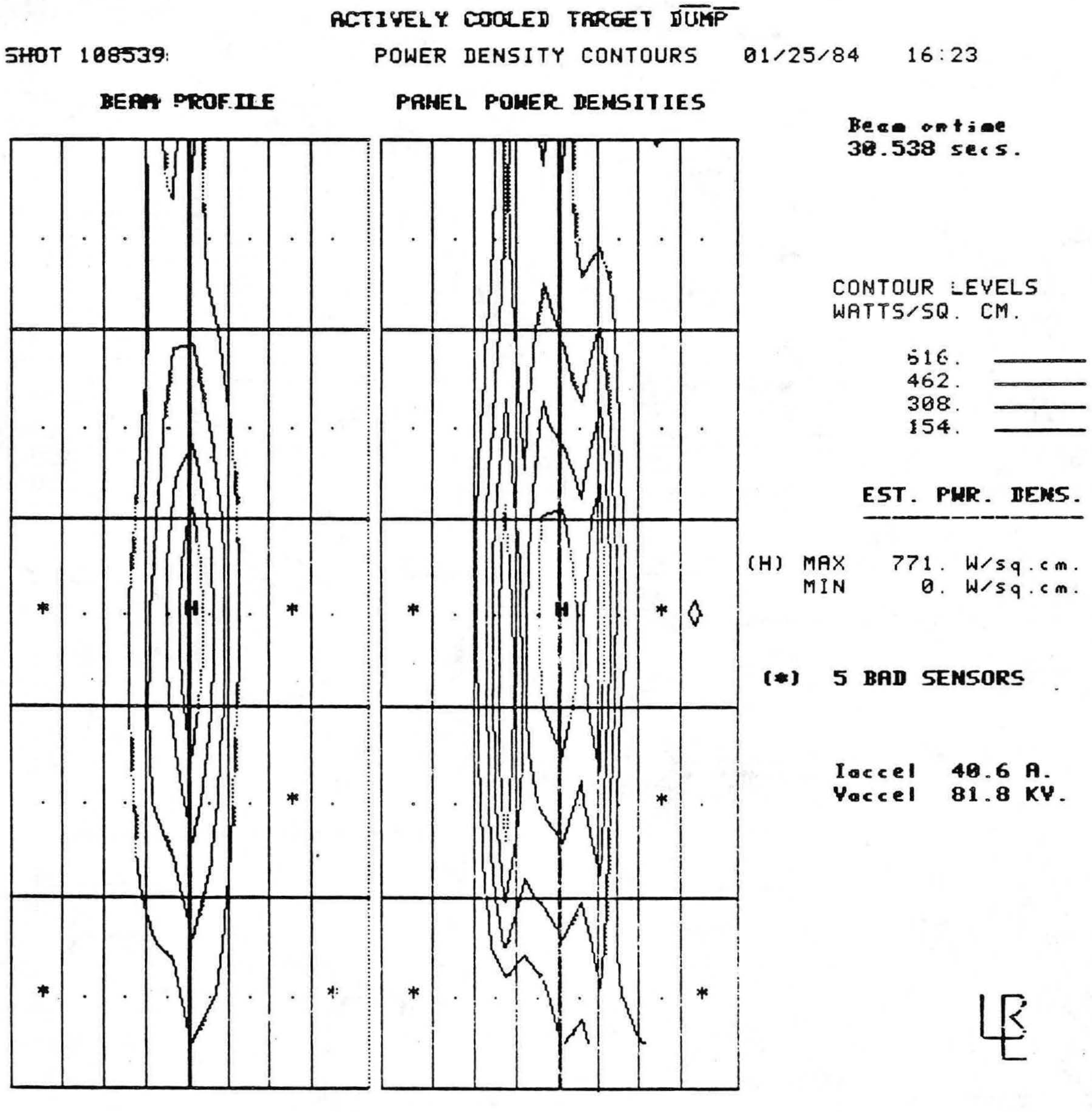
XBL 847-2969

Figure 52. Computer printout of active dump water flow waveforms for a 30 second shot at 80 kV. These data are from the plates on the left side of the target.



XBL 847-2970

Figure 53. Computer printout of active dump water flow waveforms for a 30 second shot at 80 kV. These data are from the plates on the right side of the target.



ACTIVELY COOLED TARGET DUMP

SHOT 108539 POWER DENSITY CONTOURS 01/25/84 16:23

BEAM PROFILE

PANEL POWER DENSITIES

Beam ontime
30.538 secs.

CONTOUR LEVELS
WATTS/SQ. CM.

616.
462.
308.
154.

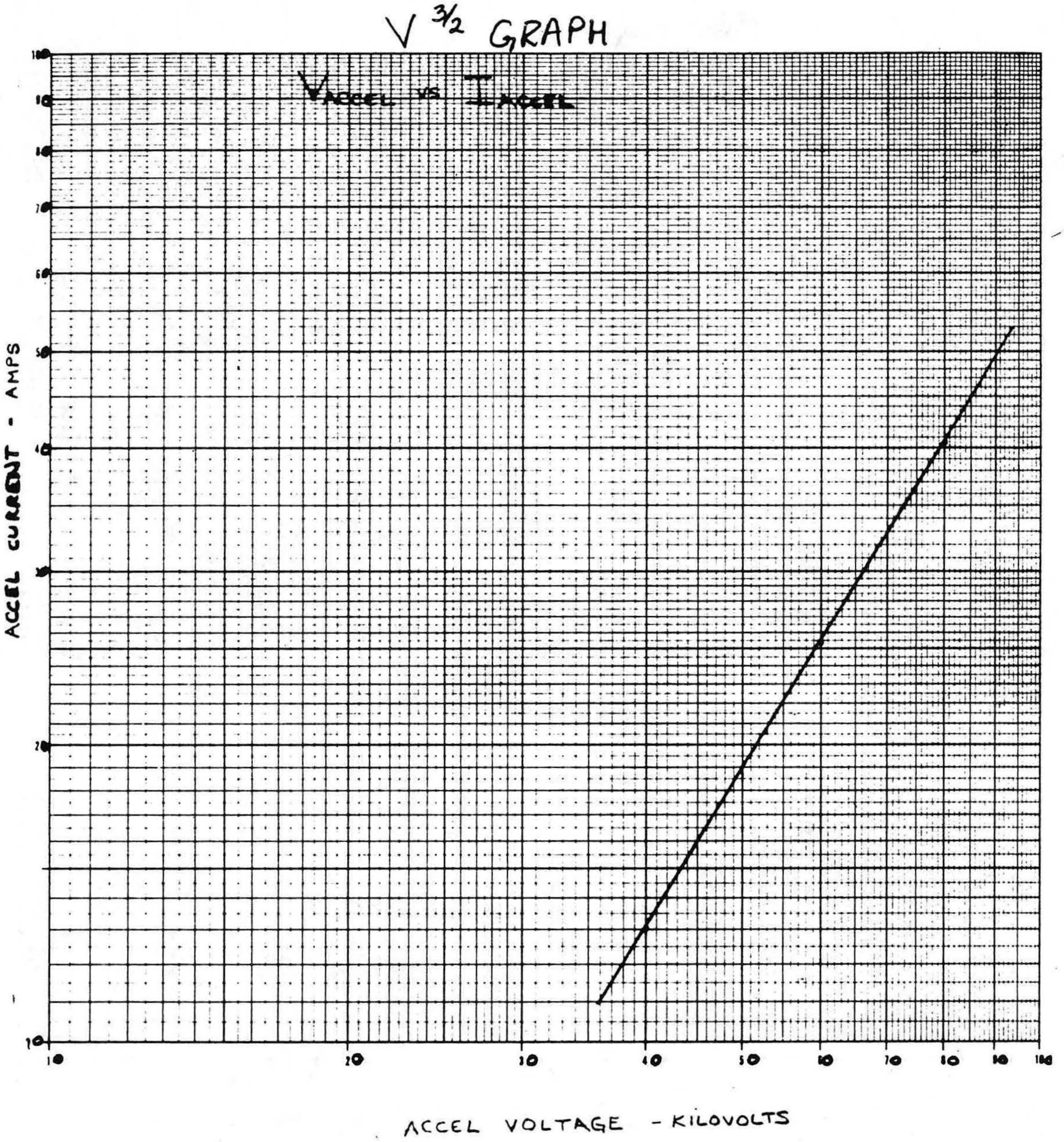
EST. PWR. DENS.

(H) MAX 771. W/sq.cm.
MIN 0. W/sq.cm.

(*) 5 BAD SENSORS

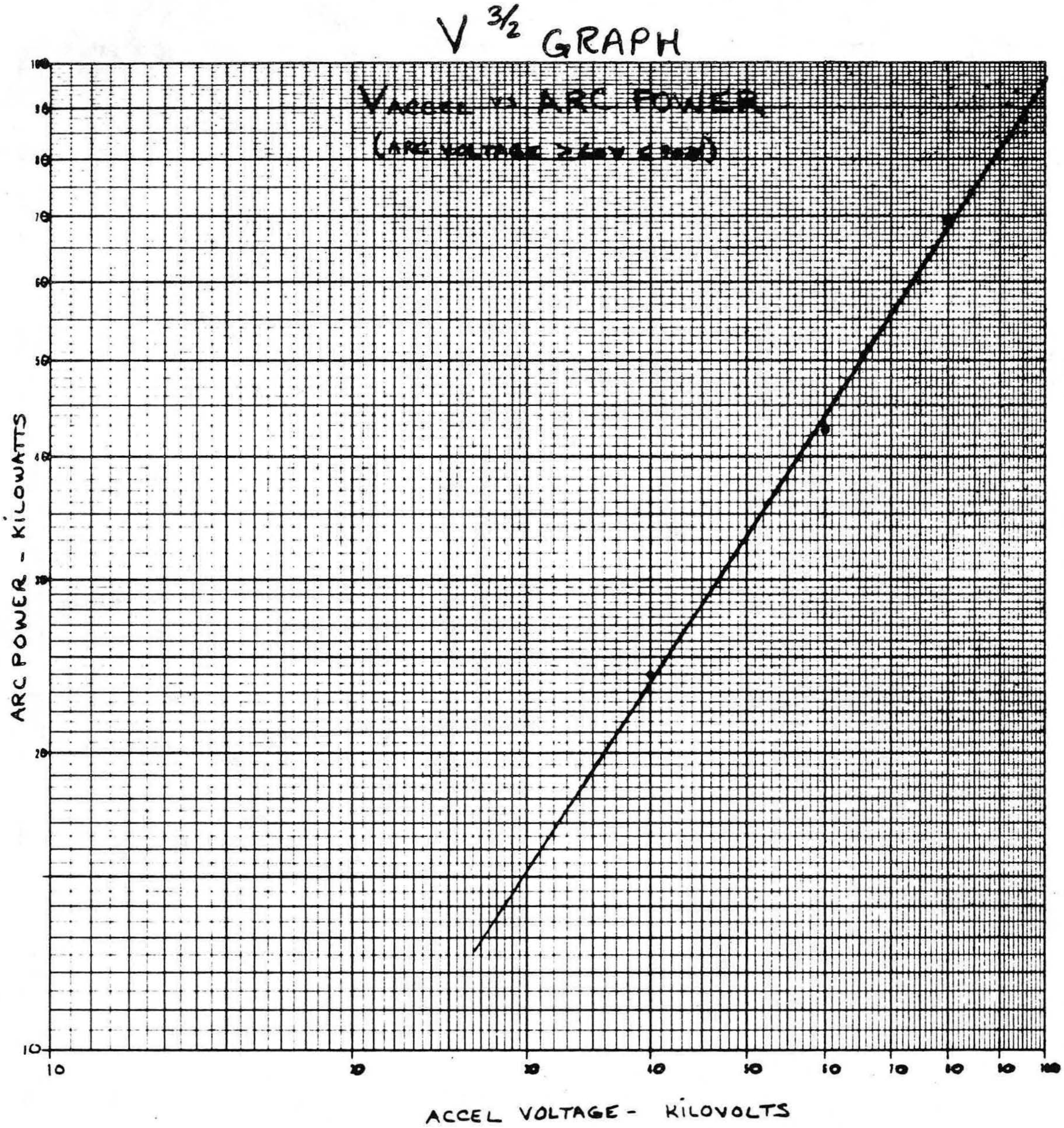
Iaccel 40.6 A.
Vaccel 81.8 KV.

Figure 54. Computer printout of active target contours for a 30 second shot. Thermocouple isotherms are plotted on the left, and calculated beam power densities are plotted on the right.



XBL 847-2996

Figure 55. Log-log plot of accel current vs accel voltage. The $V^{3/2}$ slope of accel current is shown.



XBL 847-2997

Figure 56. Log-log plot of arc power vs accel voltage. Since arc power and accel current are directly proportional, arc power also has the typical $V^{3/2}$ slope.

13. LPS/LPA REMOVAL PROCEDURE

When the plasma source and accelerator have to be removed from the Beamline, use extreme caution that no stresses are placed on the accelerator during the removal procedure. On NBETF, we use the following method:

1. With LPS/LPA still under vacuum, remove all water & electrical connections.
2. Flush the water lines on the accelerator with alcohol, then pump out the lines to insure they are completely dry, to prevent oxidation in the tubes.*
3. With the unit still under vacuum, install the LPS lifting fixture. Connect the crane to the LPS lifting fixture. Adjust the tension of the crane so it is taut, but not exerting any force on the LPS/LPA.
4. Place the LPA support under the accelerator flange that the LPS is bolted to. Adjust the support under the accelerator so it is touching the flange, but not exerting any upward force.
5. After securing the proper valves, the system is ready to be let up to air.
6. The LPS can be unbolted, as a unit, and removed to another area. Disconnect the crane from the LPS.
7. Install the lifting fixture on the LPA. Place the dynamometer between the LPA and the crane. Set the dynamometer to 300 pounds, or to the weight the dynamometer registered when installing the LPA (See Section 4), by adjusting the tension with the crane.
8. When the dynamometer is adjusted properly, the support under the LPA can be removed, along with the bolts that hold the LPA to the

beamline. The crane now has the load, and the LPA can be moved away from the beamline.

*Necessary only if the accelerator is disconnected for a long period of time.

14. TROUBLESHOOTING GUIDE

14 (A) LPS OPERATIONAL MODES

One difficulty with the LPS is the occurrence of at least two operational modes, one of which is inefficient for the production of plasma. The difference between the efficient and inefficient operational modes is illustrated in Figure 57, which shows arc and probe traces. In the first 50 msec, arc voltage is 72 volts, with ≈ 35 amps of current, and very little plasma density. The arc is interrupted for 40 msec, and the good mode comes on with the arc at 64 volts, 750 amps, and higher plasma density. The inefficient mode is externally characterized by higher voltage, much lower current, decreased plasma density, and lower 1st grid potential. In the inefficient mode, the net charge, or plasma potential, of the source plasma is negative with respect to the anode. In effect, the cathode sheath becomes extended, and primary electrons don't have enough energy for efficient ionization in the chamber volume. Only a fraction of the primary electron power goes into ionization; most goes to the anode. If the power supply permits a higher impedance coupling and the LPS is operated with marginal anode area, the inefficient mode occurs spontaneously. The discharge current is low because the extended cathode sheath makes the cathode space charge limited at a very low current level.

In normal operation, the source turns on in the inefficient mode because the initial low density plasma limits the extraction current to the space charge limit, as illustrated in the fast scope picture shown in Figure 58. Note that the discharge current and the plasma probe signal are low, as for the inefficient mode. In addition, the grid voltage is closer to cathode than it is in the normal operating mode. A very rapid transition occurs, and the grid potential goes high, just below arc potential. The overshoot is a power supply system oscillation. If the anode area is large enough and the allowed emission current is low enough, the discharge eventually pops into the efficient mode, where it is stable. If not, the source remains in the inefficient mode. In Figure 57, the efficient mode is marginally stable. For the LPS with 34 filaments, the allowed emission current is kept low enough for efficient mode operation by reducing the filament heater current so that the filaments are emission limited.

When operation is in the efficient mode, raising the filament temperature lowers the arc voltage, and will eventually result in the inefficient mode. However, if the LPS is already in the inefficient mode, an attempt by the operator to lower the voltage by reducing the filament heater current only drives the source more firmly into the inefficient mode. This is a common error at low plasma levels. Therefore, it is very important to determine the LPS operating mode before changing the filament temperature (i.e., the filament heater current).

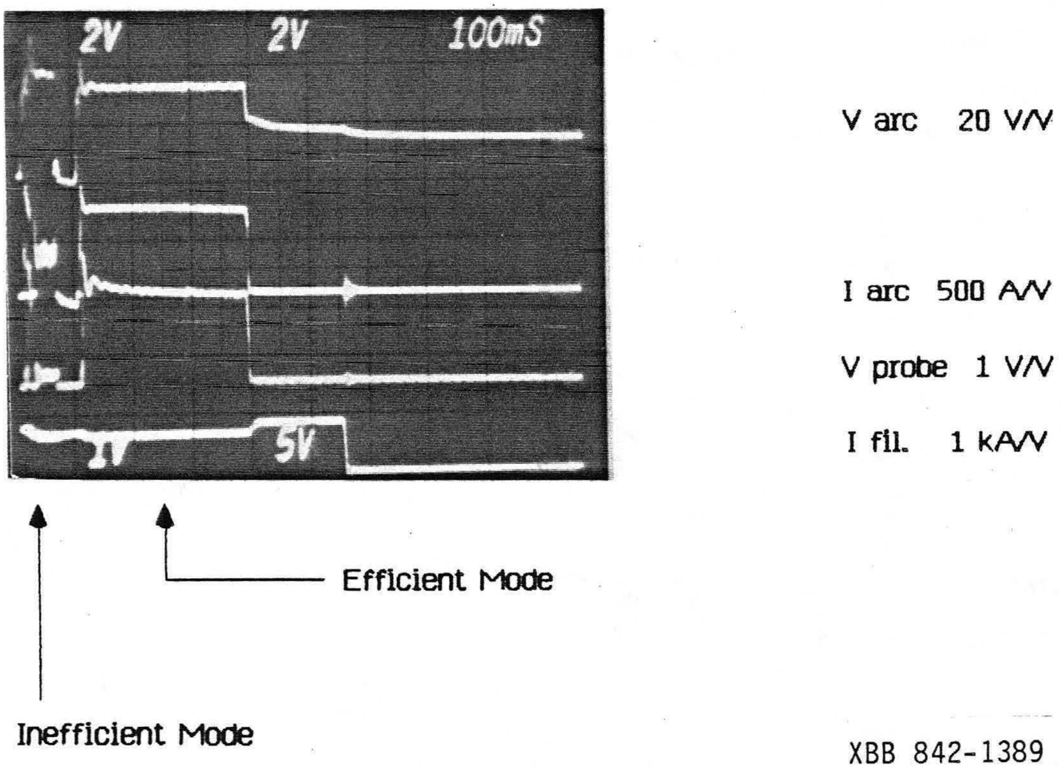
Ultimately, the inefficient mode is due to a design decision to minimize the anode area in order to obtain the maximum power efficiency and atomic fraction. The inefficient mode can be completely eliminated in the LPS by removing the Back Plate Magnets, which gives a field-free anode area. This configuration results in lower atomic species fraction, and greatly reduced efficiency.

A second possibility is to increase the anode area during arc turn on by connecting the probe plate (or first grid) to cathode, i.e., the "dynamic anode" discussed in Section 10 (B). This causes the probe plate to effectively increase the anode area during a notch, but preserves the maximum efficiency and species during steady state source operation.

A third possibility is to resistively tie the probe plate to anode. If the resistance is such that 10 - 20% of the arc current goes to the probe plate, efficiency and species are slightly reduced, but operating reliability is improved. On the LPS, the current to the probe plate was reduced to 15% of the total arc current by connecting the probe plate to anode with an 80 mΩ water cooled resistor.

By itself, the inefficient mode is no danger to the plasma generator. Proper fault protection (Refer to Section 8 (A)) should ensure that an accel fault occurs if the arc flips into the inefficient mode during beam. However, if a mode flip occurs during beam without an accel fault, the accelerator would be extremely underdense, and could sustain serious damage. With suppplementary anode, as described above, mode flips can usually be avoided by operating the arc at 70-100 volts. If mode flipping persists, the operator should consider the possibility that the bucket wall may have become contaminated with an insulator, which reduces anode.

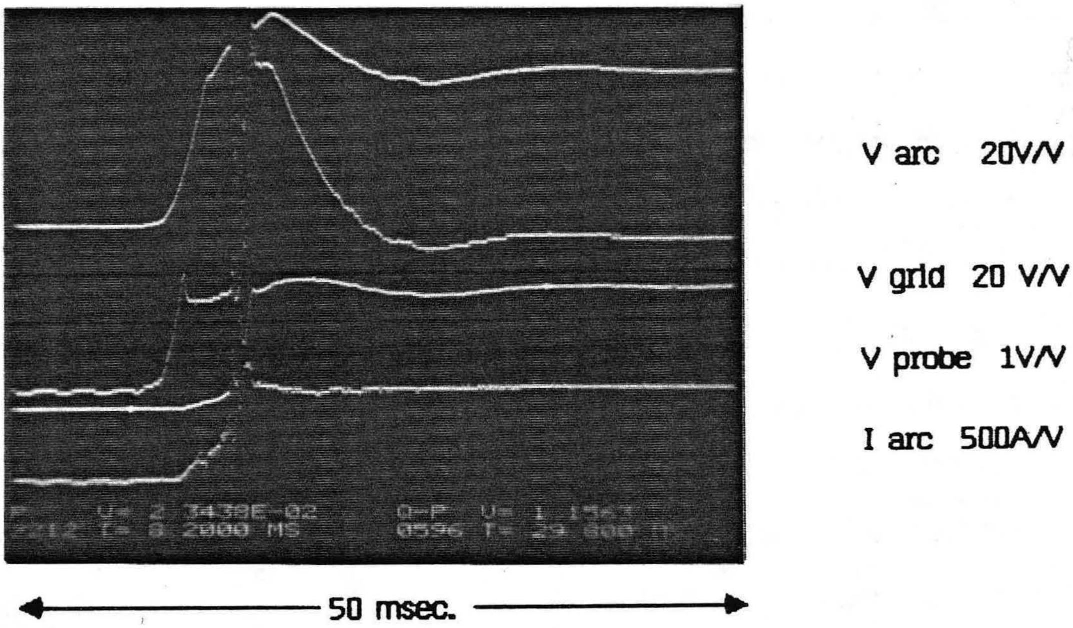
MODE CHANGE



XBB 842-1389

Figure 57. "Fast" scope illustrating the behavior of the arc voltage and current, probe voltage, and grid 1 voltage during the transition between the inefficient and efficient mode.

SCOPE SIGNALS OF A TURN-ON TRANSIENT (MODE FLIP) DURING OPERATION ON NBETF



XBB 843-1391A

Figure 58. Norland scope picture illustrating the behavior of the arc voltage and current, probe voltage, and filament current during the transition between the inefficient and efficient mode.

14 (B) ARC SPOTTING

High power arcs, like the LPS, draw one to two thousand ampers of arc current, and are susceptible to "spot" damage in areas at, or near, cathode potential. Arc spotting occurs when some surface other than the filaments becomes an emitter, or when a hot spot develops on a filament. The new emitter can be a wall at cathode potential, or an electrically floating wall (unipolar arcing). The potential damage from a unipolar arc is limited by the available capacitively stored energy. The potential damage from a cathode spot is unlimited, since a spot is effectively a localized short of the arc power supply. Electrical waveforms showing a spot in the LPS are shown in Figure 59.

Although normal arc voltages are relatively low (50 to 100 volts), the electric fields at the walls can be quite high, since the sheath distances are small. This can lead to field emission, especially from low work function materials on the wall. Once a spot is initiated, wall material is vaporized. This results in a high local plasma density which produces smaller sheaths and higher electric fields, i.e., a metal vapor arc. With spot protection, the tell-tale sign of an arc spotting in the arc chamber is called "chicken tracks" or "dendridic tracks", -- which look like frost marks on a window pane.

Spotting is most frequent when a source is dirty (e.g., a new source), especially with fingerprints, or when there is a small vacuum or water leak. Spotting can be reduced by conditioning an arc chamber (Section 10 (B)). After the source is conditioned, spotting tends to occur at high arc power, due to either high density or high arc voltage. At high power levels, a spark in the grids can sometimes trigger an arc spot promptly, or as much as several milliseconds later.

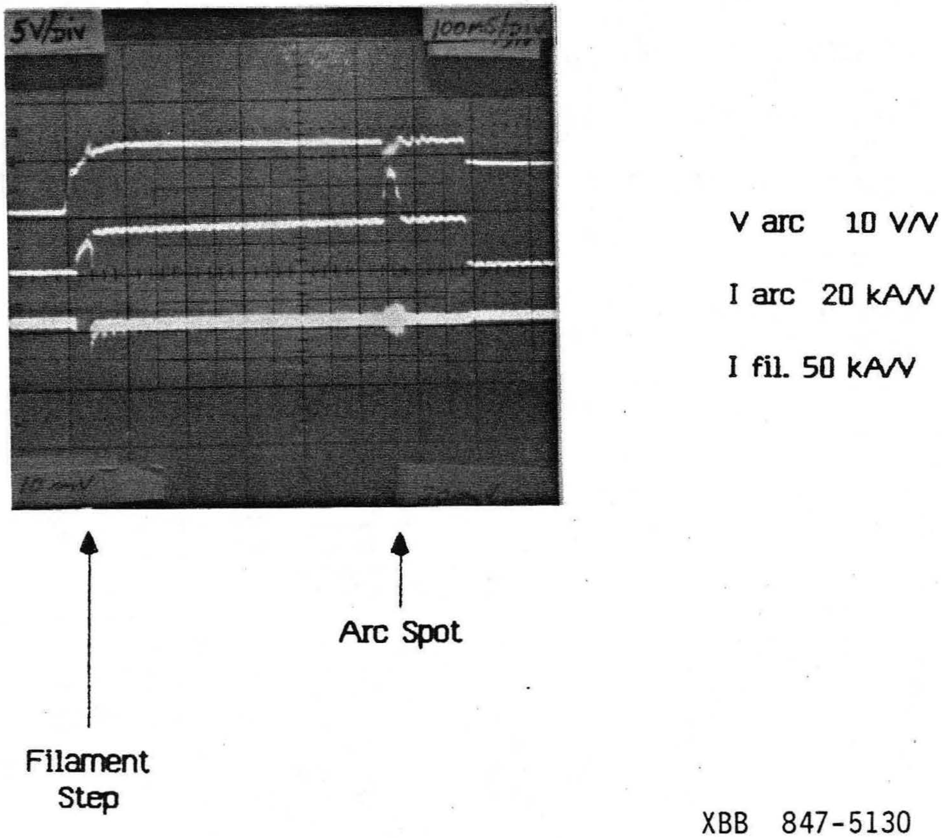
The electrical characteristics of arc spotting are: lower arc voltage, higher arc current, very noisy discharge (white noise in the tens of kHz range), and lower plasma probe signal, with similar noise. The electrical waveforms shown in Figures 59 illustrate these characterisitcs. Fast, digital scope traces are shown in Figure 60. Note that the electrical characteristics of a spot are the opposite of the inefficient mode characteristics described in Section 14 (A).

An arc spot should be extinguished by turning off the discharge power as soon as possible; this is best done by crowbarring the arc supply. If a spot persists for more than a few milliseconds, serious damage can be done to the arc chamber. (If a spot persists for a few hundred milliseconds, vacuum integrity can be lost!) In addition, the grids may become contaminated and need to be reconditioned before they hold voltage. A spot detector circuit that senses arc spotting is described in Appendix 4.

The operator should learn to quickly distinguish between an arc spot and a mode flip. With proper protection, both can be made harmless. Spots are common during arc conditioning, but should be infrequent after conditioning. If spotting persists, a shorted spacer element, a contaminated gas bottle, or a vacuum leak should be suspected.

LPS/LPA

ARC SPOT

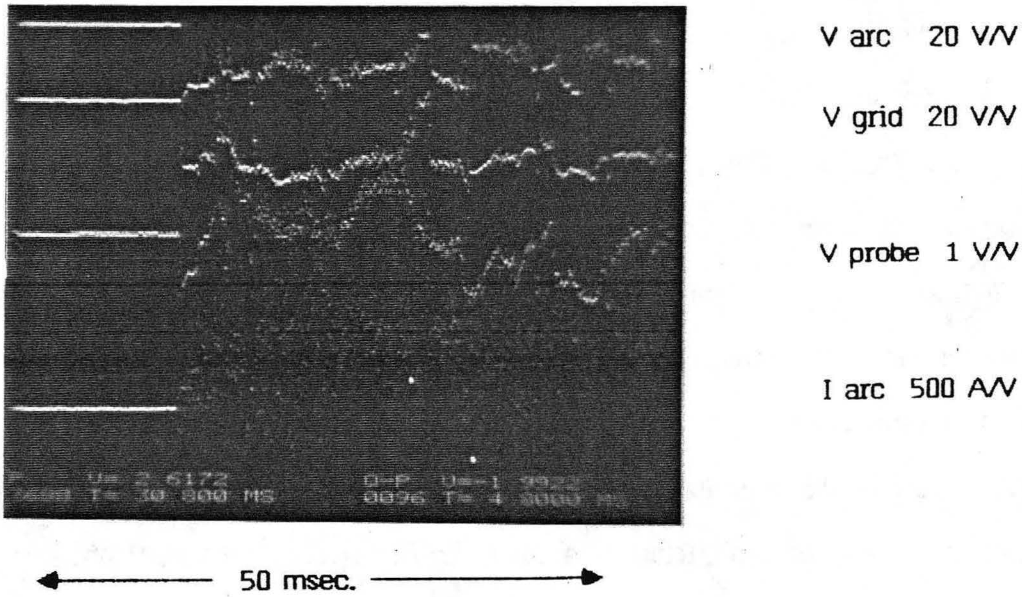


XBB 847-5130

Figure 59. Scope picture illustrating the behavior of the arc voltage and current, and filament current during an arc spot.

LPS/LPA

ARC SPOT



XBB 842-1390

Figure 60. Norland scope picture illustrating the behavior of the arc voltage and current, and filament current during an arc spot.

14 (C) PERVEANCE MATCHING FOR BEAM TURN-ON

Matching the plasma density with acceleration voltage at beam turn-on can be critical to reliable accelerator performance. Three examples are presented here. First, a good perveance match is illustrated. Next, the effects of beam delay with respect to the arc notch for two different V_{1-2}/V_{accel} ratios is shown. The third example depicts an overdense beam turn-on.

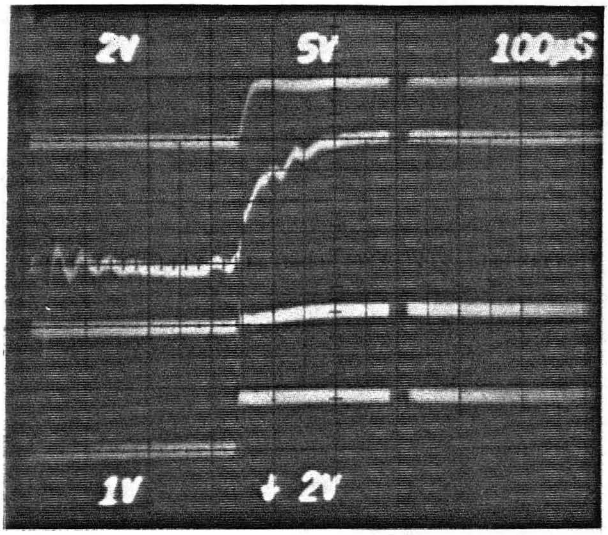
The waveforms in Figure 61 were taken during operation of the LPS/LPA on NBETF prior to Dynamic Anode (Section 10 (B)) installation. A good match between plasma density and accelerator voltage for beam turn-on at 40 kV is illustrated. The beam-delay is set for 330 µsec, i.e., the accelerator voltage is applied 330 µsec after the beginning of the arc notch. The arc notch is ≈ 500 µsec wide and the plasma is reduced by 75% at the deepest part of the notch. The negative spike on the gradient grid at accel-on shows that the source is underdense for ≈ 30 µsec, then is near optimum for the remainder of the turn-on. There are no significant variations on the gradient grid which would indicate a large perveance mismatch. The dip in accel voltage at ≈ 425 µsec is usually an indication of a very slightly overdense condition, and corresponds with the oscillation on the accel current trace.

The oscilloscope pictures in Figure 62 were taken during 80 kV operation of the LPS/LPA on NBETF. A dynamic anode (Section 10 (B)) was connected to the LPS at this time. The V_{1-2}/V_{accel} ratio was 19.6% for the top and middle picture; 18.1% for the bottom picture. The arc notch depth is ≈ 60% and notch width is ≈ 700 µsec. The first 40 µsec after accel-on is power supply related and for this discussion can be ignored. The top picture shows an attempt for beam at an extremely underdense condition. The fluctuations in the gradient grid current are high enough and last long enough to trip the fault detector which turns off the high voltage. The beam delay is 315 µsec for this try. The middle picture was taken after moving the beam delay out to 320 µsec. This 5 µsec change allows the accelerator voltage to come on at a higher plasma density and the beam stays on, but there is still a definite perveance mismatch, as indicated by the gradient grid and suppressor currents. The type of behavior on the grid currents is indicative of an extremely underdense condition and, in this case, an improper V_{1-2}/V_{accel} ratio. The voltage drop across the 1st gap is too large for the plasma density. For the LPS/LPA, at this ratio, the window for changing beam delay was very narrow and beam operation was extremely erratic at best. The bottom scope picture illustrates the effects of lowering the V_{1-2}/V_{accel} ratio to 18.1% while keeping all other parameters the same as they were for the middle picture. Now the match between the accel voltage and plasma density is close to optimum.

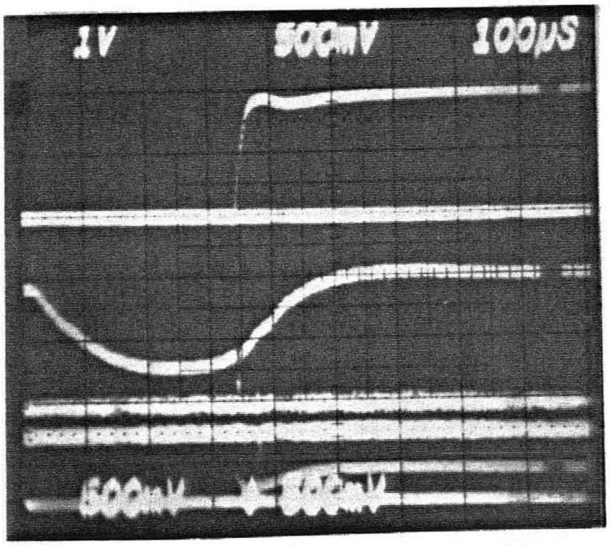
Keep in mind that the beam turn-on is one of the most difficult aspects of running neutral beams and should be monitored carefully.

In order to further illustrate beam turn-on parameters, an example using a field free plasma source and accelerator (called the PPPL Diagnostic Source) is shown in Figure 63. The PPPL was not operated on NBETF so the power supply characteristics are different for this example. The accelerator voltage rise time is considerably slower than on NBETF, and since there was no probe in the plasma source, the floating potential of the source wall and Grid 1 combination, was used as a guide for setting up the notch shape. The notch shape and timing are adjusted to give the minimum perturbations on the acceleration voltage and gradient grid voltage and current. The top picture shows a near optimum match between acceleration voltage and plasma density. The slight rise in gradient grid current and corresponding dip in voltages, seen ≈ 400 µsec after accel-on, is due to a slight overshoot of the arc when coming out of the notch before settling down to the proper density. The bottom scope picture is an example of mismatched plasma density and accel voltage. In this case, the plasma density is too high for the applied voltage. Again, the prime indicator of the mismatch is the gradient grid current.

PERVEANCE MATCHING FOR BEAM TURN-ON



V accel	20 kV/V
I accel	10 A/V
I supp	2 A/V
V Grid 3	1kV/V

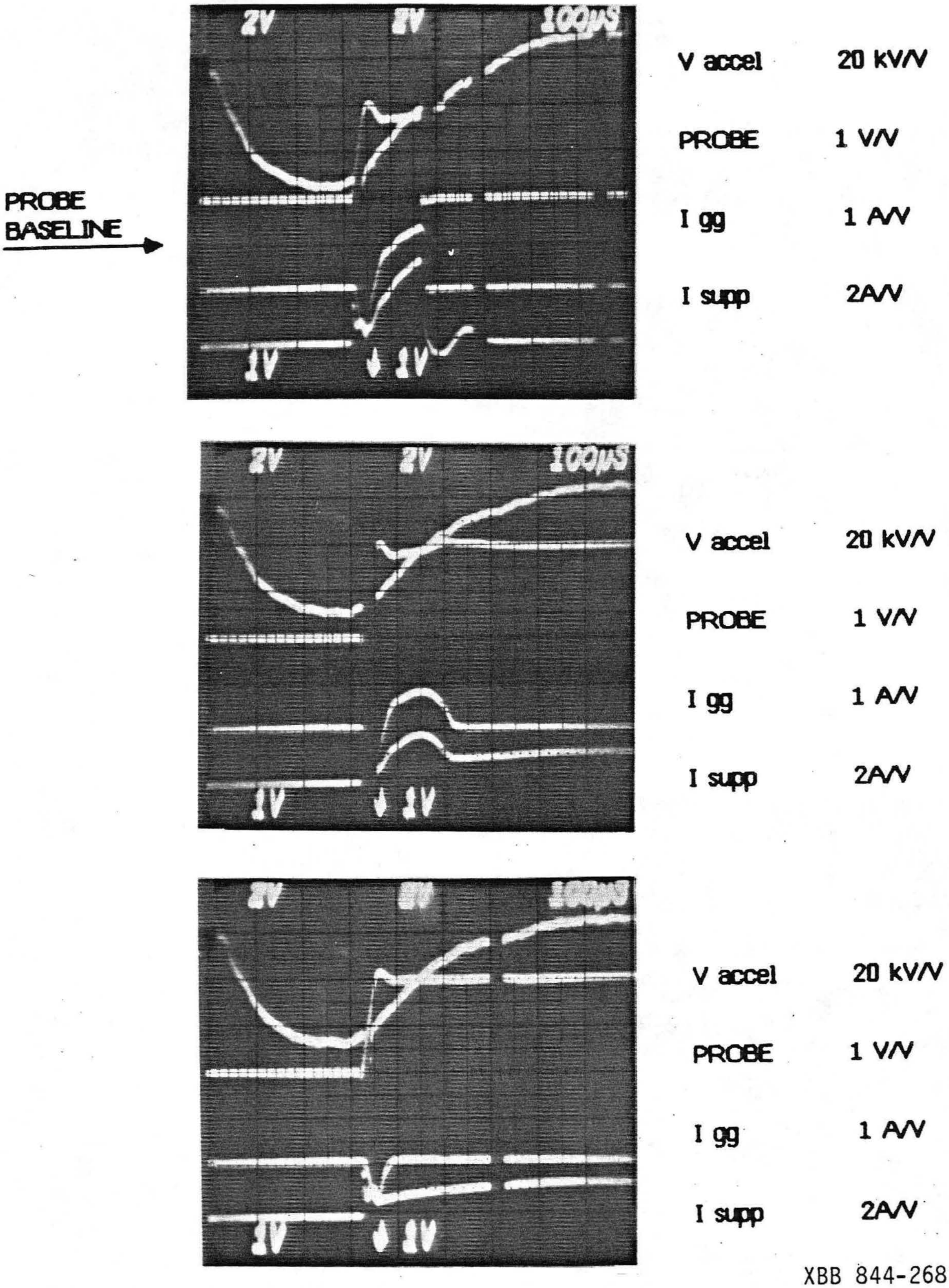


V accel	20 kV/V
PROBE	1 V/V
I gg	1 A/V
I supp	2 A/V

XBB 844-2683

Figure 61. "Fast" scope picture of a matched perveance beam turn-on. The top scope traces show the accel and suppressor voltages and currents. The bottom scope shows the accel and probe voltages, gradient grid current, and suppressor current. Note that all the signals are relatively smooth during the turn-on.

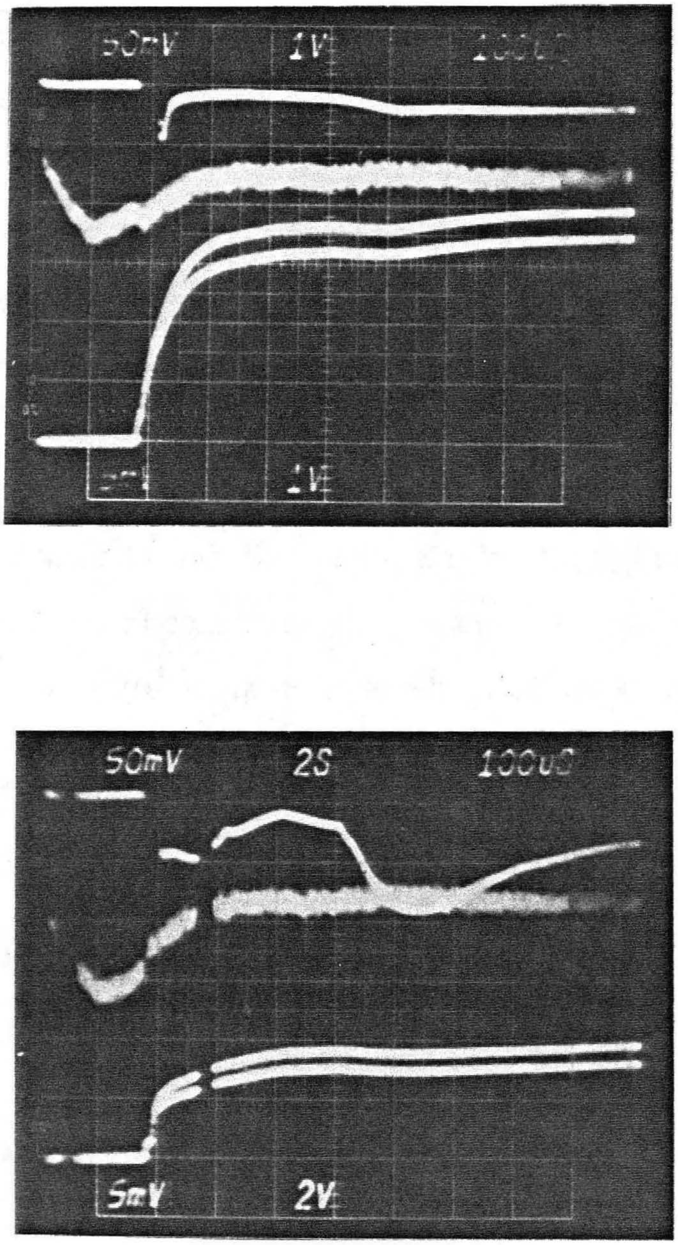
PERVEANCE MATCHING FOR BEAM TURN-ON



XBB 844-2681

Figure 62. "Fast scope picture of an underdense perveance beam turn-on. From top to bottom, an example of an extremely underdense beam try, one that is significantly underdense, and one that has a reasonably well matched perveance.

PERVEANCE MATCHING FOR BEAM TURN-ON



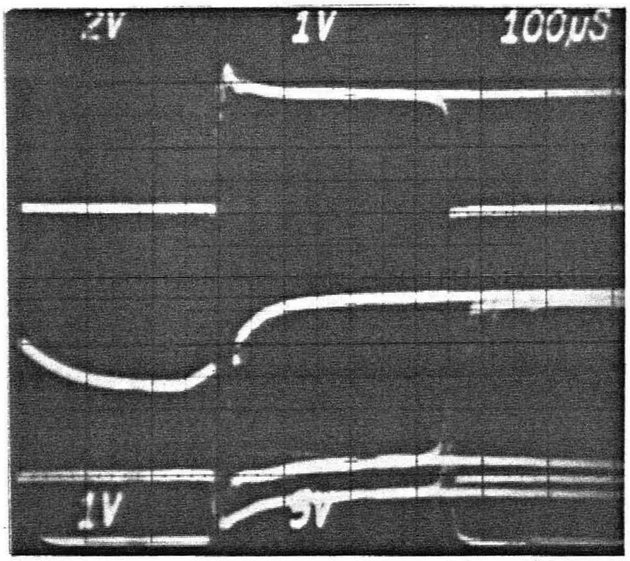
XBB 844-2682

Figure 63. "Fast scope picture of an overdense perveance beam turn-on. Note that the gradient grid current in the top scope trace is relatively smooth for a near optimum perveance turn-on. The bottom scope trace shows an erratic gradient grid current during an overdense beam turn-on.

14 (D) ACCEL SPARKDOWN

An oscilloscope picture of the accelerator voltage, probe voltage, gradient grid and suppressor currents showing an accel sparkdown is illustrated in Figure 64. The scope is set up for multiple triggers, so the picture also shows a beam try that did not spark off. The accel voltage is turned on at 300 µsec, and one beam try sparks off 350 µsec later. This breakdown is characterized by the rapid accel voltage fall, and a sharp rise in both gradient grid and suppressor currents. There is no indication that the source is either overdense or underdense, as there are no other fluctuations on the grid currents. Also, the probe level is essentially the same value at 350 µsec for both beam tries, as evaluated by the trace intensity at this point. This type of sparkdown is usually associated with new or dirty accelerator grids, and the occurrences tend to diminish after conditioning with beam, unless the grids are recontaminated.

ACCELERATOR SPARKDOWN



V accel	20 kV/V
PROBE	1 V/V
I gg CT	1 A/V
I supp DC	2 A/V

XBB 844-2874

Figure 64. "Fast" scope picture illustrating a normal accel sparkdown during grid conditioning.

14 (E) GRADIENT GRID

The purpose of the gradient grid, i.e., the second grid of the accelerator, is to improve beam optics, e.g., in comparison with a three grid accelerator. Operationally, the gradient grid is the most sensitive indicator of accelerator performance. In particular, the gradient grid current can provide important clues about beam turn-on and perveance match.

The voltage applied to the gradient is normally expressed as a ratio of gradient grid voltage to the accelerator voltage, i.e., V_{gg} = gradient grid voltage/accel voltage. Alternatively, it is sometimes useful to use the ratio of the difference of the accelerator and the gradient grid voltage to the accelerator voltage, i.e., V_{1-2} = (accel voltage - gg voltage)/accel voltage. The LPA was typically run with a V_{gg} of 80 to 85% (or, equivalently, a V_{1-2} ratio of 15 to 20%).

During the initial start-up of a new or "dirty" source, problems can occur which will not be present once the source is "cleaned up". Initially, the plasma generator tends to have a high percentage of heavy impurities, which become accelerated ions. It is impossible for the accelerator optics to be properly tuned for all ions, light and heavy. Thus, a larger than normal percentage of the beam particles will strike the grid structures when impurities are present. This puts a higher current load on the gradient grid due to both beam ions and secondary electrons from the suppressor grid. Depending on the stiffness of the gradient grid power supply, this loading can drastically change V_{1-2}. Even though the gradient grid supply has been set for the proper value, V_{1-2} may run at drastically reduced value if the gradient grid current is too high. The value of V_{1-2} is itself the best signal to check for this condition, since the change in V_{1-2} is proportionally much larger than the change in V_{gg}. However, it is quite easy to miss this problem, since the beam may turn-on and all electrical traces will be smooth. A check of the various parameters, perveance, divergence, etc., will show that the values are not as expected. The best cure is to provide a stiffer gradient grid supply during initial conditioning. If a resitor divider is used, go to a lower string resistance value. After conditioning and "cleaning up" the source, this problem should not re-occur, but during start-up it can be a headache.

At optimum perveance, the gradient grid current is generally quite small, $\leq$ 100 mA in a well conditioned accelerator. The level of the gradient grid current is very sensitive to source tuning, and is typically used as the primary indicator of a mis-match of plasma level and accelerator voltage. Refer to Section 14 (C) for a discussion of the effect of perveance mismatch on the gradient grid current during turn-on..

Although it would be desirable for all production accelerators to function identically, this is generally not the case. At start-up, a gradient grid ratio (V_{gg}) of 82% should be used. However, when reliable operation is attained in the 50 to 60 KV range, the optimum perveance of a particular accelerator can be found by lowering the accel voltage to 40 KV and doing tunes for various values of V_{gg} within ± 1.5% of 82%. At the accelerator optimum, the gradient grid current will stay relatively flat through the tune. Below optimum V_{gg} the gradient grid current has a tendency to run away on the under-dense side of the tune. Conversely, if V_{gg} is too high, the gradient grid current runs away on the over-dense side of the tune (usually much more drastically), and makes operation at optimum more difficult. Selection of an operating value for V_{gg} for a particular source is based on a combination of divergence, accelerator current, stable gradient grid current over a wide tuning range, and ease of operation. Higher perveance and tighter divergence is desirable but sporatic operation is not.

The gradient grid current should be monitored by the operator at all times. An abnormally high or noisy signal should be investigated immediately. The gradient grid current should also be monitored in the fault detector system, and a current in excess of 250 mA should trip off the beam. It will probably be necessary to inhibit the fault detector for several hundred microseconds during beam turn-on, since there may be high current transients present. Most of the transients can be removed with proper matching of beam and arc turn-ons, however one must observe these transients in order to make the proper adjustments.

Systems which bias the gradient grid by means of a resistive divider are susceptible to current overload. A given divider has a maximum current which it can provide while maintaining the desired voltage. If the gradient grid current fault level allows the gradient grid current to be too high, the gradient grid potential will approach the full accel potential, i.e., the gradient grid will go to the potential of the source grid. Unfortunately, this condition is electrically stable, but self-destructive for the accelerator. This situation sometimes occurs when fault levels have been raised in order to get an unconditioned accelerator into operation, and beam turn-on is mismatched. In order to avoid disaster, the operator must notice that the gradient grid ratio is wrong, or that the gradient grid currents are too high, before requesting more than a few milliseconds of beam. The source will not provide an obvious clue. Unlike the case of overdense operation (where the source is very difficult to operate), the source may run very well with the gradient grid "locked" to source grid potential.

Again, never assume that all accelerators will run optimally at the same gradient grid ratio. Each accelerator should be checked to find its optimum.

14 (F) SUPPRESSOR GRID

The purpose of the suppressor grid is to prevent electrons in the downstream plasma from being accelerated back into the plasma source. The suppressor grid potential is negative with respect to ground, typically 1.5% to 2.5% of the acceleration potential. Operation with too high a voltage increases wear of the suppressor grid, but is not immediately damaging. Too low a suppressor voltage is dangerous and must be avoided. A common problem is that during conditioning the operator gets involved with gradient grid currents, divergences, arc operation, etc., and forgets to raise the suppressor voltage as the accelerator voltage is raised. This usually leads to accel faults, or operation problems which do not point directly at the suppressor voltage.

Beam ions and back-streaming electrons produce the same signal on the accel current monitor, but optics and perveance depend on mass. If the suppressor voltage is too low, back-streaming electrons add to the indicated accel current, but the ion optics are correspongingly underdense. High back electron current can damage the ion source, and grossly underdense ion optics can damage the accelerator.

Conditions which may indicate that the suppressor voltage is too low:

1. High perveance.

   The indicated beam perveance may be higher than expected for a given arc power.

2. High Apparent Arc Efficiency.

   An increase in accelerator voltage may be accompanied by an unusually large increase in indicated accelerator current, although arc power has not been increased. Under normal conditions, an increase of accelerator voltage with no increase of arc power gives a minimal increase in accelerated current. (Typically, measured perveance in this case will go down.) If the accel current increases enough to increase the perveance, insufficient suppressor voltage is the most likely cause.

3. Ramping Gradient Grid Current

If the accelerator is running properly, the gradient grid current should be stable, particularly when running underdense. With insufficient suppressor voltage, a significant number of back-streaming electrons strike the gradient grid. The lower the suppressor voltage, the worse this condition will be. The beam may turn-on, but is the gradient grid current will be rising throughout the shot.

Typically, no significant effect will appear in the suppressor current or voltage signals which would indicate that the suppressor is at fault. The symptoms first appear in accelerator and gradient grid currents. If allowed to go uncorrected, low supressor voltage can cause significant damage to both the plasma generator and the accelerator.

ACKNOWLEDGEMENTS

This manual represents the hard work and special efforts of numerous individuals in the MFE Group, including scientific, technical, mechanical, electrical, and administrative staff members. The authors especially wish to thank K. H. Berkner, L. A. Biagi, V. L. Jacobson, A. F. Lietzke, H. M. Owren, J. A. Paterson, J. W. Roberts, E. H. Theil, B. O. Yant, and the entire NBETF operation, mechanical, and electrical crew.

This work was supported by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division of the U. S. Department of Energy under Contract No. DE-AC03-76SF00098.

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APPENDIX 1

HP-9845B Software for Grid Heat Loads

```
10                                                          Version$="19 JAN 84"
20   GOTO Begin
30 !
40 ! REMEMBER: To continue printing, after running out of paper, do READY #0
50 !
60 !
70 !                                 40 LPA
80 !                                [AUTOST]
90 !
100 !
110 !
120 !
130 !
140 !  ZERO FLO OFFSETS AND FLO CALIB.:  8DEC81 - LOG, LPA DATA (BINDER) #1
150 !
160 !  ZERO FLO OFFSETS AND FLO CAL UPDATED :  1. 07 JAN 82 - LOG, LPA DATA #1
170 !                                          2.
180 !
190 ! ******************PROGRAM FOR GRID-CALORIMETRY*************************
200 !
210 !    40 LPA :  10X40 LPA GRID HEAT DEPOSITION MONITORING FOR BLG.6 AND LLNL
220 ! OPERATION; PROGRAM TO READ DATA FROM  8 FLOWMETERS AND 8 DELTA-T BLOCKS,
230 ! TO STORE THE DATA ON TAPE AND TO INTEGRATE THE PRODUCT FLOW*DELTA-T OVER
240 ! AN ARBITRARY PERIOD OF TIME. DATA INPUT FROM A TAPE IS ALSO POSSIBLE.
250 ! TO BE SYNCHRONIZED WITH A SHOT OF THE ION SOURCE, ONE NEEDS AN EXTERNAL
260 ! TRIGGER APPROXIMATELY 8 SECONDS PREVIOUS TO FIRING AND ANOTHER EXTERNAL
270 ! TRIGGER PRIOR TO BEAM ON, THIS ALLOWS FOR TAKING A BASE-LINE MEASUREMENT.
280  !                                            APRIL 1st, 1980. Jost Feist
290  !  MODIFICATIONS:
300  !
310  !  30. Use SRQ on data ready to stop Rover measurement period timer.
320  !      SRQ is handled in SUB Srqon7. Rnmeas and VW in Rovtempsus$ can
330  !      be changed and the measurement time will be correct.-LLS-13MAY82
340  !  31. Added a "GOTO" to a few conditional branches scattered thru the
350  !      code. No other alterations.                           DJM 15SEP82
360  !  32. Alphabetized subroutines and subprograms.      lls 3-5-83
370  !  33. Changed code to get shot sequencing interrupts via option 50
380  !      digital input board. Added key #11 to simulate interrupt from
390  !      Modcomp. Redefined key #1 to simulate filament on interrupt.
400  !      Changed 3497a command strings to put hold(VT4) on voltmeter
410  !      before closing channel. Removed some superfluous software
420  !      triggers after AIxx commands since AI triggers voltmeter after
430  !      closing channel. Changed Appr for anodes to merely subtract
440  !      effects of arc and filament outside of beam on window.
450  !      SRQ is kept enabled throughout shot for purpose of getting
460  !      fire, filament on, Vacceletc and Rover data ready interrupts.
470  !      Interrupt handler(Srqhandler) merely fields interrupts and sets
480  !      program flags corresponding to the interrupts, except that it
490  !      does stop the clock timing Rover data aquisition. Deleted common
500  !      since all interrupts are fielded in main program segment. lls-5May83
510  !  34. Made flow/conductivity error messages < 80 characters. Went to
520  !      serial mode while waiting for fire interrupt so taking base line
530  !      message comes up immediately. Changed graphics storage to use
540  !      2 arrays to accomodate 45C. Add calibrate mode which reads
550  !      LPA heater volts and current and calculates total power to LPA
560  !      channel and prints it with total measured energy. lls 16May83
570  !  34a.Change calibrations back to those of 2/20/82.  lls-5Ma
580  !      Bugger out flow and conductivity tests. lls-31May83
590  !      Forbid Tfil=0 in Appr for filament only shots.lls-31May83
600  !  34b.Change to interrupt on transition from low to high. lls-1Jun83
610  !  34c.Get interface status in Srqhandler. Take absolute value of Vacc
620  !      and Iacc from Modcomp. Count Srqs from digital interrupts and
630  !      save digital interrupt status for current shot. lls 03Jun83
640  !  34d.Change anode to and add electron dump. Flow Technology type
650  !      flowmeter is used. Changed to key Getflow on reference voltage=0.
660  !      Made electron dump readout the default option. lls-13JUN83
```

```
670  !
680  !  NOTE. ELECTRON DUMP FLOW IS FORCED TO BE 36GPM. SEE CONSTANTS.   13JUN83
690  !  35a.Add reading data from, sending data to Modcomp. lls - 14JUN83
700  !  36a.Added a 3495 to the HPIB at 708 for passing control. Added checks
710  !      to flows,energy, etc. so they cannot overflow the fixed formats.
720  !      Fixed bug in the parsing of data received from Modcomp. Added
730  !      serial poll and interface status queries after interrupt to
740  !      Modcomp to drop the SRQ line. Increased number of bytes sent to
750  !      Modcomp to accomodate e- dump variables. lls - 15Jun83
760  !  37a.Added checks to Rover and grid heat variables so they cannot
770  !      overflow the fixed formats. lls 16Jun83
780  !  38a.Set Modcomponhpib=False.  Pulled Vref2=5 from Getflow. lls 17Jun83
790  !  38b.Nmeas=60. Set Ovtmp$="Y" only if accel ontime > .15 sec.lls-21Jun83
800  !  39a.Switched to RS232 communications with Modcomp. lls-14Jul83
810  !  39b.Check for overflow of Mi$ in Readchr. Define total characters
820  !      expected from modcomp in Milen. Fix printout of Vacc and Iacc
830  !      so not truncated to integer part. Nop key #7 so rewind of mag
840  !      tape will not be accidentally attempted during TOPEN. lls-20Jul83
841  !  39c.Dump TBUF$ into M$[532] , not Mi$[100] at shot start. lls-29jul83
842  !  40a.Program hanging up with Mi$ overflows. Dim Mj$[320] and always
843  !      dump TBUF$ into Mj$ first. Never let Mi$ get longer than Milen.
844  !      Do not really understand why the overflows were coming. lls-29Nov83
845  !  40b.Read Tacc,Tarc,Tfil after getting parameters from Modcomp in
846  !      order to avoid simultaneous RS232 inputs. lls-05Dec83
847  !  41a.Change Year to 84. lls-19Jan84
848  !  41b.By default calculate delay(tdelay) between temp measurements to
849  !      produce total integration time(Tmax)=Tfil of previous shot + time
850  !      for heat to disipate(Tmpostfil).  Allow operator to override
851  !      default by specifying total integration time(Tmtot) or delay
852  !      between measurement sets(Tmdelay).  Tmtot supercedes default;
853  !      Tmdelay supercedes both default and Tmtot. Switch to SERIAL in
854  !      subr. Read3497a so that total time increases linearly with
855  !      Tdelay. lls - 19Jan84
859  !  ***********************************************************************
860  !  ***********************************************************************
870   !       3497A DATA ACQUISTION/CONTROL UNIT CHANNEL ASSIGNMENTS
880   !
890   ! *N.B.:
900   !        Connect a BNC cable from "EXT. INC." to "DVM COMPLETE" to run.
910   !
920   !                        CH. 0       ABS. TEMP.
930   !                            1-8     GRID FLOW METERS
940   !                            9       ELECTRON DUMP FLOW METER
950   !                            10      avaliable for Anz=2 operation
960   !                            11-18   GRID DELTA T BLOCKS
970   !                            19      ELECTRON DUMP DELTA T
980   !                            20      avaliable for Anz=2 operation.
990   !                            21      SYSTEM TOTAL WATER FLOW
1000  !                            22      WATER CONDUCTIVITY
1010  !                            23      FLOW METER REF. VOLTAGE
1020  !                   Parameter data input from MODCOMP              25JAN82
1030  !                   [ Scale factors in SUB Rdparam ]
1040  !
1050  !                            24      Vacc
1060  !                            25      Iacc
1070  !                            26      Varc
1080  !                            27      Iarc
1090  !
1100  !  ***********************************************************************
1110  !
1120  !                     TEST STAND TIMER INPUTS
1130  !                        used as triggers
1140  !
1150  !                        1.  FIRE COMMAND
1160  !
1170  !                        2.  FILAMENT ON
```

```
1180  !                                                                   16FEB82
1190  !                          3.  MOD COMP Rdparam TRIGGER              16FEB82
1200  !                                                                   16FEB82
1210  ! Note: The interval between these two is a variable (Area Warning Time
1220  !          is used in Berkeley, i.e.- approx. 8.5 Sec.)
1230  ! ************************************************************************
1240  !     Paper for the HP-45 is ordered from stock:
1250  !            Perforated          xxxx-xxxxx
1260  !            Un-perforated       7530-66227
1270  !     Tapes                      7544-64758
1280  ! ************************************************************************
1290  !
1300  !
1310 Begin: OVERLAP                      ! PROVIDES SIMULTANEOUS I/O AND CALCULATIONS
1320 OPTION BASE 1
1330 FIXED 2
1340 READ True,False
1350  DATA   1,    0
1360 !
1370 ! INITIALIZATION OF PARAMETERS
1380 !
1390 DIM Fbuffer$(14)[30],Tbuffer$(100)[30] ! Raw data from 3497A buffers06MAY82
1400 DIM Tbbuffer$(14)[30],Im$[100]                                       !14JUN83
1410 DIM Rfbuffer$(14)[3],Rtbbuffer$(14)[3],Rtbuffer$(200)[3]!Rover raw   06MAY82
1420 INTEGER I,Spoll,Srqclr,Spoll(0:10)     ! Loop index,serial poll      03JUN83
1430 !
1440 DIM M$[532],V(5),Mi$[100],Mj$[320] !HP/MODCOMP COMMUNICATIONS        29NOV83
1450 READ Messmax,Nvin,Nbytesper,Rs                                       !14JUL83
1460  DATA    532,    5,         14,11                                    !14JUL83
1470 !
1480 ! *********************************************************************
1490 !                            MAGNETIC TAPE
1500 !
1510 INTEGER Blockid(6),B
1520 !
1530 DIM Stape$[1],Tapes$[1],Ms14$[4],Ms15$[4],Keyentry$[1]               !06MAY82
1540 READ Stape$,Tapes$,Ms14$,Ms15$,Keyentry$[1]                          !06MAY82
1550  DATA "N","N",":T14",":T15","Y"              !TAPE FLAG/MASS STORAGE 06MAY82
1560 !
1570 SHORT Snrs,Months,Days,Years,Hours,Minutes,Seconds
1580 !
1590 DIM Blocksize(6)                                  !BYTES/TAPE BLOCK     06MAY82
1600 DIM Blockformat(6)
1610 READ Blockformat(*)                               !TAPE BLOCK FORMAT NO.
1620  DATA  1,  1,    1,    0,  1,    0                !0 MEANS DO NOT WRITE BLOCK
1630  !
1640  ! **********************************************************************
1650  !                 FILAMENT AND ARC CORRECTIONS TO AVERAGE POWER
1660  !
1670 DIM Slope(8),Fil(8)
1680 READ Slope(*)                                     ! kW/ch per kW Arc    28JAN82
1690  DATA  .019,.019,.014,.014,.0080,.0080,.004,.004! for Arc and Fil    12MAY82
1700 READ Fil(*)                                       ! kW/channel for      22FEB82
1710  DATA  .200,.200,.10,.10,.07,.07,.00,.00                ! filament      12MAY82
1720 DIM Aslope(2),Afil(2)                             !                     18MAR82
1730 READ Aslope(*)
1740  DATA   .137,.137
1750 READ Afil(*)
1760  DATA  2.930,2.930
1770  !
1780  ! ***********************************************************************
1790  !                           WORKING ARRAYS
1800  !
1810 DIM Flowb(8,14),Aflowb(2,14)                 !PRESHOT FLOW READINGS    !06MAY82
1820 DIM Rflowb(1,14)                                                       !06MAY82
1830 DIM Tempb(8,14),Atempb(2,14)                 !PRESHOT TEMP READINGS    !06MAY82
```

```
1840 DIM Rtempb(1,14)                                                     !06MAY82
1850 DIM Tempm(8,100),Atempm(2,100)            !SHOT TEMP READINGS
1860 DIM Rtempm(1,100)
1870 DIM Tempmt(8,100),Atempmt(2,100)          ! ARRAY FOR PERCENTAGES
1880 DIM Rtempmt(1,100)
1890 DIM Timem(100),Rtimem(100)                ! STORAGE ARRAY FOR TIME(plot only)
1900 DIM Sf(8),Asf(2)                          ! FLOW
1910 DIM Rsf(1)
1920 DIM St(8),Ast(2)                          ! ARRAYS FOR TEMP.DATA BASELINE
1930 DIM Rst(1)
1940 DIM Rese(8),Arese(2),Resecf(8),Aresecf(2) ! INTEGRATED ENERGY & CORRECTION
1950 DIM Rrese(1),Rresecf(1)                     ! FACTORS                29APR82
1960 DIM Appr(8),Aappr(2)                      ! CORRECTED AVG PWR/RAIL
1970 DIM Xm(8),Axm(2)                          ! SCALE FOR PLOTTING
1980 DIM Rxm(1)
1990 DIM Peak_pwr(8),Apeak_pwr(2)              ! PEAK POWER
2000 !
2010 ! **********************************************************************
2020 !                         YEAR AND MONTHS
2030 !
2040 DIM Mensis$(12)[3]                        ! Months of the year       22JAN82
2050  READ Mensis$(*)
2060  DATA "JAN","FEB","MAR","APR","MAY","JUN","JUL","AUG","SEP","OCT","NOV","DE
C"
2070  READ Year
2080  DATA 84                                                             !19Jan84
2090 !
2100 ! **********************************************************************
2110 !                  ENERGY CORRECTION FACTORS FOR SUB INTG
2120  READ Resecf(*),Aresecf(*),Rresecf(*)                                !29APR82
2130  DATA 1.030, 1.080, 1.050, 1.040, 1.120, 1.070, 1.110, 1.120 !GRIDS 31MAY83
2140  DATA 1.000, 1.000                                          !ANODES 29APR82
2150  DATA 1.276                                                 !ROVER  06MAY82
2160 !
2170 ! **********************************************************************
2180 !                        3497A CHANNEL ASSIGNMENTS
2190 !
2200  DIM Flowfc$[2],Flowlc$[2],Aflowlc$[2]   ! FLOWMETER CHANNELS
2210  DIM Tempfc$[2],Templc$[2],Atemplc$[2]   ! TEMPERATURE CHANNELS
2220  DIM Tfl$[2],Cond$[2],Fmrv$[2]           ! TOTALFLOW,CONDUCTIVITY,FM REF V.
2230  DIM Vacc$[2],Iacc$[2],Varc$[2],Iarc$[2]! SOURCE PARAMETERS
2240  READ Flowfc$,Flowlc$,Aflowlc$
2250   DATA    "1",     "8",     "9"   !FLOW GRID FC, LC, ANODE LC          13JUN83
2260  READ Tempfc$,Templc$,Atemplc$
2270   DATA   "11",    "18",    "19"   !GRID FC, GRID LC, ANODE LC          13JUN83
2280  READ Tfl$,Cond$,Fmrv$
2290   DATA "21","22","23"             !TOTALFLOW, CONDUCTIVITY, FM REF VOLTAGE
2300  READ Vacc$,Iacc$,Varc$,Iarc$
2310   DATA "24", "25", "26", "27"    !ACCEL V,I  ARC V,I
2320 !
2330  DIM Flowsus$[40],Tempsus$[40]  !3497A COMMAND STRINGS FOR READ3497A
2340 !
2350  DIM Rovflowsus$[41],Rovtempbsus$[41],Rovtempsus$[49]                !13MAY82
2360 ! ********************************************************************
2370 !                       PROGRAM FLAGS/OPTIONS
2380 !
2390  DIM Ano$[1],Opt$[1],Offref$[1],Rover$[1]  !PROGRAM FLAGS
2400  DIM Outmp$[1],Offflo$[1],Offcond$[1]
2410  DIM Basel$[1],Spike$[1],Clock$[1]
2420  DIM Counter$[1],Rdparam$[1],Redotd$[1]
2430  DIM Outp$[1],Plot$[1],Perf$[1]
2440 !
2450 ! ********************************************************************
2460 !                       GRAPHICS
2470 !
2480  ! INTEGER Aa(23835),Aaa(23835)     ! 45C !Make room for GRAPHICS image16May
```

```
2490  INTEGER Aa(16381)                 ! 45B !Make room for GRAPHICS image16May83
2500 !
2510 DIM Frame1(4),Frame2(4),Frame3(4),Frame4(4) !GRID FRAME BOUNDARIES
2520 READ Frame1(*)                     !GRID 1      Lx,Ux,Ly,Uy
2530  DATA 20,80,90,140
2540 READ Frame2(*)                     !GRID 2
2550  DATA 90,150,90,140
2560 READ Frame3(*)                     !GRID 3
2570  DATA 20,80,30,80
2580 READ Frame4(*)                     !GRID 4
2590  DATA 90,150,30,80
2600 !
2610 DIM Anode(4),Rover(4)              !ANODE/ROVER GIVES ANODE/ROVER CHANNEL
2620 !                                  !WHICH GOES ON THE ITH GRID      !20APR82
2630 ! *****************************************************************
2640 !
2650  Nmeas=60          ! Number of read passes during pulse,<100          21JUN83
2660  Tmdelay=0         ! Operator requested delay between readings(sec). 19Jan84
2661  Tmtot=0           ! Operator requested total integration time        19Jan84
2662  Tmpostfil=20      ! Operator requested time to add to Tfil to get    19Jan84
2663                    ! default integration time.                        19Jan84
2670  Bldelay=0         ! Baseline reading delay                           27JAN82
2680  Anmeas=Nmeas                                                        !18MAR82
2690 !
2700  Nbase=14                            ! NUMBER OF BASE-LINE MEASUREMENTS. 06MAY82
2710  Anbase=Nbase
2720 !
2730  Rnbase=14         !See Rovflowsus$                                  !06MAY82
2740  Rnz=1             !See Rovtempbsus$
2750  Rnmeas=90         !See Rovtempsus$                                  !11MAY82
2760 !
2770 ! ********************************************************************
2780 !           TOTAL WATER FLOW AND WATER CONDUCTIVITY
2790 !
2800  Tflo1=-.064                        ! TOTAL SYSTEM FLOW REF.     read 14DEC81
2810  !                                 flagged for 2% discrepancy: Offflo$
2820  Tflo2=0                           ! FLOW level to be read on-line    (Ch.23)
2830  !
2840  Cond1=.053        ! Water Conductivity [ie:0.053=0.175E-6 mhos] read 15DEC81
2850  Cond2=0                           ! level to be read                (Ch.24)
2860  !
2870  Vref1=5.0446                      ! FLOW METER REFERENCE VOLTAGE,read 4DEC81
2880  !                                 flagged for 2% discrepancy: Offref$
2890  Vref2=0                           !  REF VOLTAGE to be read on-line.(Ch.25)
2900  !
2910  ! *******************************************************************
*
2920  !                     FLOWMETER CALIBRATIONS
2930  !
2940 READ Mlpstogpm                           ! ML/SEC TO GPM              13JUN83
2950  DATA 63.09019667
2960 DIM Voff(8)                              ! GRIDS FLOWMETER OFF-SETS  18MAR82
2970 READ Voff(*)                             ! INPUT DATA: VOLTAGE OFFSETS
2980 DATA  .032,.109,.063,.038,.004,.015,.150,-.017   ! In mV.            23APR82
2990  DIM Avoff(2)                            ! ANODE FLOWMETER OFF-SETS  18MAR82
3000  READ Avoff(*)
3010   DATA 0.0,0.0                                                       !18MAR82
3020  DIM Rvoff(1)                            ! ROVER FLOWMETER OFFSET    20APR82
3030  READ Rvoff(*)
3040   DATA -.026                             ! mv                        23APR82
3050  !
3060 DIM Fmc1(8),Fmc2(8)                 !Grid flowmeter conversion coefficients
3070  !
3080 ! ********************************************************************
3090 !       ALL VALUES DERIVED FROM CALIBRATION CURVES SUPPLIED WITH UNITS
```

```
3100 !                 note:  FLOWMETERS ARE NOT LINEAR BELOW 2.0 GPM
3110 !
3120 READ Fmc1(*)                                                  !
3130 !                                                     F.M.    !   TEMP.
3140 ! Fmc1= mlpS/mV/V  ! Fmc2=mlpS.  !  chan.     grid      ser # !   chan.
3150    DATA 592.15   !   -64.03     !    1    SOURCE A      7694  !    12
3160    DATA 615.13   !   -87.32     !    2             B    7702  !    13
3170    DATA 598.11   !   -54.52     !    3    GRADIENT A    7698  !    14
3180    DATA 592.15   !   -51.98     !    4             B    7695  !    15
3190    DATA 603.82   !   -71.00     !    5    SUPPRESSOR A  7699  !    16
3200    DATA 584.35   !   -66.37     !    6               B  7697  !    17
3210    DATA 577.95   !   -61.24     !    7    EXIT A        7693  !    18
3220    DATA 595.32   !   -77.98     !    8         B        7696  !    19
3230 !
3240 READ Fmc2(*)
3250    DATA -64.03
3260    DATA -87.32
3270    DATA -54.52
3280    DATA -51.98         !   N.B.-  ALL DATA is in ml/S.
3290    DATA -71.00
3300    DATA -66.37
3310    DATA -61.24
3320    DATA -77.98
3330 !
3340 DIM Afmc1(2),Afmc2(2)          !Anode flowmeter conversion coefficients
3350 READ Afmc1(*)
3360    DATA 0      !4851.322668           !FLOW TECHNOLOGY #240496      13JUN83
3370    DATA 926.16                        !#8687                        29APR82
3380 READ Afmc2(*)
3390    DATA 2271.24   !-6.20852                                        !13JUN83
3400    DATA -237.22                                                    !29APR82
3410 DIM Rfmc1(1),Rfmc2(1)          !Rover flowmeter conversion coefficients
3420 READ Rfmc1(*)
3430    DATA 256.71062
3440 READ Rfmc2(*)
3450    DATA   -19.33900
3460 !
3470 ! ************************************************************************
3480 !
3490  Vacc=Iacc=Varc=Iarc           !    Defaults                       !19Jan84
3491  !
3500  Tdelay=0    ! delay(msec) between temp measurements for Read3497a. !19Jan84
3505  Tmax=0      ! total integration time(sec) from subr. Read3497a     !19Jan84
3506  !
3510  Tmax0=0     ! total temp measurement time with tdelay = 0.          !19Jan84
3515  Tdinc=0     ! increase in Tmax(sec) produced by every msec increase!19Jan84
3516              ! in Tdelay. Calculated it initialization.              !19Jan84
3520  !
3550  Tacc=.002                     !    Defaults                       !19Jan84
3560  Tarc=.002                                                         !19Jan84
3570  Tfil=3.5                                                          !19Jan84
3571  !
3590  !
3600 ! ********  SET FLAG  OPTIONS ******
3610 !
3620 !                 Data Handling
3630 Dumdat$="N"                           ! USE DUMMY DATA FLAG      !18MAR82
3640 Opt$="N"                              ! OPTION LIST CHANGE
3650 Offref$="N"                           ! F.M. Volt. Ref. deviation
3660 Ovtmp$="N"                            ! Overtemperature Limit
3670 Offflo$="N"                           ! TOTAL SYSTEM FLOW O.L. FLAG
3680 Offcond$="N"                          ! WATER CONDUCTIVITY O.L. FLAG
3690 Calibrate=False                       ! CALIBRATION MODE
3700 Rs232=True                            ! MODCOMP ACCESSIBLE ON RS232 14JUL
3710 !
3720 Basel$="Y"                            ! BASELINE CORRECTION
```

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3730 Spike$="Y"                                  ! FOR NUM. SPIKE SUPRESSION
3740 !                 Accessory Devices
3750 Clock$="Y"                                  ! REALTIME CLOCK              9FEB82
3760 Countr$="Y"                                 ! ARC/ACCEL COUNTERS         18JAN82
3770 Rdparam$="Y"             ! Read Vacc,Iacc,Varc,& Iarc from MODCOMP       16FEB82
3780 Redotd$="N"              ! Set 3497A clock Flag default                  28JAN82
3790  !                                                                        9FEB82
3800  ! ************* Operator Option List ************
3810  !
3820 Ano$="Y"                                    ! ELECTON DUMP FLAG          13JUN83
3830 Rover$="N"
3840 Outp$="Y"                                   ! OPTION FOR HARDCOPY OUTPUT
3850 !                                           CRT PLOT only IF ="N"
3860 Plot$="Y"                                   ! AUTOMATIC HARDCOPY PLOT OPTION :
3870 !                                           when OUTP$="Y". Calculations only
3880 !                                           if Plot$="N"
3890 Perf$="Y"                                   ! PERFORATED PAPER OPTION
3900 !
3910 ! ***************   PROGRAMMED  KEY  FUNCTIONS  *************************
3920 !
3930 !
3940 ON KEY #0 GOSUB Fire                        ! SIMULATE FIRE INTERRUPT  05MAY83
3950 ON KEY #1 GOSUB Filon                       ! SIMULATE FILAMENT ON "   05MAY83
3960 ON KEY #2 GOSUB Vacceletc                   ! SIMULATE VACCELETC INT   16MAY83
3970 ON KEY #3 CALL Dump                         ! DUMP GRAPHICS
3980 ON KEY #4 GOSUB Tapeini                     ! INITIALIZE TAPE          18MAR82
3990 ON KEY #5 GOSUB Tapestop                    ! STOP TAPE WRITING        18MAR82
4000 ON KEY #6 GOSUB Calibrate                   ! TOGGLE CALIBRATE FLAG    16MAY83
4010 ON KEY #7 GOSUB Nop                         ! DISABLE REWIND           20JUL83
4020 ON KEY #8 GOSUB Tapeskip                    ! SKIP SHOT ON TAPE        06MAY82
4030 ON KEY #9 GOTO Reset                        ! RESET OF THE MEASUREMENT 05MAY83
4040 ON KEY #11 GOTO Calc                       ! (RE) CALUCLATE           16MAY83
4050 !
4060 IF Countr$="Y" THEN CALL Countr(Dummy,Dummy,Dummy)                     ! 28JAN82
4070 !
4080 ! *********************************************************************
4090 !
4100 ! BEGINNING OF THE PROGRAM
4110 !
4120 ! **********************************************************************
4130 !
4140  PRINTER IS 16
4150 IF Clock$="N" THEN CALL Daytime(Month,Day,Hour,Minute,Second)      !  9FEB82
4160 IF Clock$="Y" THEN CALL Hpclock(Month,Day,Hour,Minute,Second)      !  9FEB82
4170 !
4180  PRINT PAGE
4190  PRINT "*************************************************************"
4200  PRINT
4210  PRINT " WATER-FLOW CALORIMETRY PROGRAM FOR 10X40 L.P.A. GRIDS AND LPS"
4220  PRINT "                         Rev. ";Version$
4230  PRINT "*************************************************************"
4240  PRINT
4250  PRINT USING 4260;Day;Mensis$(Month);Year;Hour;":";Minute;":";Second!18MAR
4260  IMAGE 28X,DD,3A,DD,4X,DD,A,DD,A,DD                                  !18MAR82
4270  PRINT                                                              ! 22JAN82
4280  PRINT                                                              ! 22JAN82
4290  PRINT " THE OPTIONS ARE:"
4300  PRINT "ANO$=    ",Ano$,"ELECTRON DUMP DATA OPTION"                  ! 13JUN83
4310  PRINT "ROVER$=  ",Rover$,"ROVER DATA OPTION"                        ! 20APR82
4320  PRINT "PLOT$=   ",Plot$,"PLOT OF OUTPUT DATA"
4330  PRINT "OUTP$=   ",Outp$,"PRINT OUT  OUTPUT DATA"
4340  PRINT "PERF$=   ",Perf$,"PERFORATED PAPER IS USED"
4350 !
4360  INPUT "DO YOU WANT TO CHANGE THE DATE OR TIME ?(Y/N)",Redotd$   ! 22JAN82
4370  IF Redotd$="Y" THEN CALL Newtime(Clock$)                        !  9FEB82
4380 !
```

```
4390  INPUT "DO YOU WANT TO CHANGE OPTIONS (Y/N) ?",Opt$
4400 !
4410  IF Opt$="N" THEN GOTO 4520
4420 !
4430 !           ******  OPERATOR CHANGE OPTIONS  **********
4440 !
4450 INPUT "DO YOU WANT ELECTRON DUMP DATA ?(Y/N)",Ano$
4460 INPUT "DO YOU WANT ROVER DATA ?(Y/N)",Rover$
4470 INPUT "DO YOU WANT THE PLOT BE PREPARED AFTER EACH SHOT (Y/N) ?",Plot$
4480 INPUT "DO YOU WANT THE RESULT PRINTED OUT AFTER EACH SHOT (Y/N) ?",Outp$
4490 !
4500 IF Outp$="Y" THEN INPUT "ARE YOU USING PERFORATED PAPER ?(Y/N)",Perf$
4510 !
4520 FIXED 0                                                          !23APR82
4530 Rovflowsus$="VT4AC1AF1AL1VW10VR1VD5VN"&VAL$(Rnbase)&"AE0VS2VF2"     !05MAY83
4540 Rovtempbsus$="VT4AC2AF2AL2VW10VR1VD5VN"&VAL$(Rnbase)&"AE0VS2VF2"    !05MAY83
4550 Rovtempsus$="VT4AC2AF2AL2VW20000VR1VD5VN'&VAL$(Rnmeas)&"AE0VS2VF2" !05MAY83
4560 !
4570 CALL Mcset3497a(Flowfc$,Flowlc$,Aflowlc$,Ano$,NcK,Nz,Anz,Flowsus$) !18MAR82
4580 CALL Mcset3497a(Tempfc$,Templc$,Atemplc$,Ano$,L,J,K,Tempsus$)      !18MAR82
4590 IF (Nch=L) AND (Nz=J) AND (Anz=K) THEN B100                        !14JUN83
4600 DISP "NOT SAME NUMBER OF FLOWMETER AND TEMPERATURE CHANNELS"       !18MAR82
4610 PAUSE
4620 B100:IF Anz=1 THEN B110                                            !14JUN83
4630 DISP "ANZ>1. CHANEL SCREWUP. BYTE COUNT TO MODCOMP WILL BE WRONG." !14JUN83
4640 I=1/0                            !FORCE AN ERROR                    14JUN83
4650  ! *************************************************************
4660  !
4670  ! DIMENSION ARRAYS ACCORDING TO NUMBER OF CHANNELS ACTUALLY BEING
4680  ! USED AND NUMBER OF MEASUREMENTS BEING TAKEN
4690  !
4700 B110: REDIM Flowb(Nz,Nbase),Tempb(Nz,Nbase)                         !14JUN83
4710  REDIM Sf(Nz),St(Nz),Tempm(Nz,Nmeas)
4720  REDIM Rese(Nz),Appr(Nz),Xm(Nz),Peak_pwr(Nz)                      !18MAR82
4730  !
4740  REDIM Aflowb(Anz,Anbase),Atempb(Anz,Anbase)                      !18MAR82
4750  REDIM Asf(Anz),Ast(Anz),Atempm(Anz,Anmeas)                       !18MAR82
4760  REDIM Arese(Anz),Axm(Anz),Apeak_pwr(Anz)
4770  !
4780  REDIM Rfbuffer$(Rnbase),Rtbbuffer$(Rnbase),Rtbuffer$(Rnmeas)
4790  REDIM Rflowb(Rnz,Rnbase),Rtempb(Rnz,Rnbase)                      !20APR82
4800  REDIM Rsf(Rnz),Rst(Rnz),Rtempm(Rnz,Rnmeas)
4810  REDIM Rrese(Rnz),Rxm(Rnz)
4820  MAT Asf=(1E30)
4830  MAT Ast=(1E30)
4840  MAT Aappr=(1E30)
4850  MAT Apeak_pwr=(1E30)
4860  MAT Anode=ZER                      ! SPECIFY GRIDFRAMES ON WHICH    !18MAR82
4870  IF Ano$="N" THEN GOTO 4890         ! THE ANODES ARE TO BE PLOTTED.
4880  Anode(3)=1                                                       !13JUN83
4890  MAT Rover=ZER                                                    !20APR82
4900  IF Rover$="Y" THEN Rover(4)=1
4910  PRINT PAGE
4920 PLOTTER IS 13,"GRAPHICS"           !  PREPARATION OF BASIC PLOT   18MAR82
4930 GRAPHICS                                                         !18MAR82
4940 CALL Pictlabel(Version$,Ano$,Rover$)                             !20APR823
4950 CALL Logo
4960 CALL Gridframe(Frame1(*),1,Anode(1),Rover(1))
4970 CALL Gridframe(Frame2(*),2,Anode(2),Rover(2))
4980 CALL Gridframe(Frame3(*),3,Anode(3),Rover(3))
4990 CALL Gridframe(Frame4(*),4,Anode(4),Rover(4))
5000  GSTORE Aa(*)                 !45B & C !STORAGE OF BASIC PLOT       16MAY83
5010  ! GSTORE Aaa(*),0,227        !45C      STORAGE OF 2ND HALF OF PLOT 16MAY83
5020 EXIT GRAPHICS
5021  !
5022  DISP "TIMING MEASUREMENTS FOR SUBSEQUENT CALCULATIONS OF TDELAY"  !19Jan84
```

```
5023  CALL Read3497a(Clock$,Nmeas,1,0,Tempsus$,Tbuffer$(*),Tmax0)         !19Jan84
5024  CALL Read3497a(Clock$,Nmeas,0,100,Tempsus$,Tbuffer$(*),Tmax)        !19Jan84
5025  Tdinc=(Tmax-Tmax0)/100  ! change in Tmax/msec of delay               !19Jan84
5026  !
5030  IF NOT Rs232 THEN Snr                                                !14JUL83
5040  Milen=Nvin*Nbytesper         !CHARACTERS FROM MODCOMP                !20JUL83
5050  RESET Rs                  !SETUP COMMUNICATIONS LINK WITH MODCOMP
5060  CONTROL MASK Rs;128+4
5070  WAIT READ Rs,4;Rsdummy
5080  WRITE IO Rs,7;0
5090  CARD ENABLE Rs
5100  TOPEN Rs GOSUB Readchr
5110 ! ****************************************************************
5120 !
5130 !                PREPARE FOR ON-LINE DATA ACQUISITION
5140 !
5150 Snr: ON ERROR GOTO 5160                                              !14JUL83
5160 INPUT " ENTER CURRENT SHOT NUMBER",Snr                              !18MAR82
5170 Snr=INT(Snr)+1                                                       !18MAR82
5180 Reset: OFF ERROR                                                     !05MAY83
5190 Snr=Snr-1                                                            !18MAR82
5200 !
5210 ! ****************************************************************
5220 !
5230 !                WAIT FOR FIRE COMMAND INTERRUPT
5240 !
5250 ! *****************************************************************
5260 !
5270                                    ! ********************************
5280 Reentry:Stape$=Tapes$              !  RE-ENTRY POINT      *********14JUN83
5290 GOSUB Srqsetup                     ! ***************************05MAY83
5300 EXIT GRAPHICS
5310 PRINTER IS 16
5320 PRINT PAGE
5330 Ki=0
5340 !
5350 Waitforfire:  Ki30=Ki/30                                             !05MAY83
5360   FIXED 0
5370   Next_shot=Snr+1                                                    !29APR82
5380   IF (Outmp$="Y") AND (Ki MOD 2=0) THEN DISP " WAITING FOR TRIGGER ..shot #
 ";Next_shot;"TIMER=";Ki30;"      OVERTEMP ON shot: ";Snr
5390   IF Outmp$="Y" THEN BEEP
5400   IF (Outmp$="Y") AND (Ki MOD 2=1) THEN DISP " WAITING FOR TRIGGER ..shot #
 ";Next_shot;"TIMER=";Ki30;"      OVERTEMP ON shot: ";Snr
5410   !
5420   IF Outmp$="N" THEN DISP " WAITING FOR FIRE INTERRUPT ..shot # ";Next_shot
;"TIMER=";Ki30
5430   !
5440   Ki=Ki+1                                               !(2JUL81)
5450   IF NOT Fire THEN Waitforfire                                       !05MAY83
5460   !
5470   !                          HAVE FIRE COMMAND INTERRUPT
5480  EXIT GRAPHICS
5490  BEEP
5500  !                                                                   !18MAR82
5510  Snr=INT(Snr)+1              ! INCREMENT SHOT NUMBER                 !18MAR82
5520  Mi$=""                      !CLEAR RS232 COMMUNICATIONS BUFFER      !14JUL83
5525  Mj$=TBUF$                                                           !29NOV83
5526  !
5528  IF Tmdelay>0 THEN Fire10  !Tmdelay overrides default and Tmtot  19Jan84
5533  IF Tmtot>0 THEN Fire15    !Tmtot overrides default              19Jan84
5534  IF Tfil<4 THEN Fire20     !Base Tdelay calc only on good Tfil   19Jan84
5535  Tdelay=MAX(Tfil+Tmpostfil-Tmax0,0)/Tdinc ! sec/(sec/msec)=msec  19Jan84
5536  GOTO Fire20                                                        !19Jan84
5537 Fire10:  Tdelay=Tmdelay                                             !19Jan84
5538  GOTO Fire20                                                        !19Jan84
```

```
5550 Fire15: Tdelay=MAX(Tmtot-Tmax0,0)/Tdinc                        !19Jan84
5557 Fire20:  FIXED 0                                                 !19Jan84
5558  !
5560  DISP "READ BASE LINE, TO RESET PRESS KEY #9 ..SHOT ";Snr
5570 !
5580 Filon=Vacceletc=Roverdataready=False      ! Reset interrupt flags   !05MAY83
5590 Outmp$="N"                                ! Reset  OVER TEMPERATURE flag
5600 Offref$="N"                               ! Reset OFF REF.VOLT. FLOWMETER
5610 Offflo$="N"                               ! Reset TOTAL SYSTEM FLOW flag
5620 Offcond$="N"                              ! Reset WATER CONDUCTIVITY flag
5630  !
5640  FIXED 5
5650  CALL Sysstat(Tfl$,Tflo1,Tflo2,Offflo$,Cond$,Cond1,Cond2,Offcond$,Bflo)
5660  IF Dumdat$="Y" THEN GOSUB Dumsystat                              !18MAR82
5670  IF (Offflo$="N") AND (Offcond$="N") THEN GOTO 5750
5680  IF (Offflo$="Y") AND (Offcond$="Y") THEN PRINT "FLOW ERR";Tflo2;" vs ";Tfl
o1;"=";Bflo;"GPM err. COND ERR";Cond2;" vs";Cond1
5690  IF (Offflo$="Y") AND (Offcond$="Y") THEN GOTO 5720
5700  IF Offflo$="Y" THEN PRINT "SYS TOTAL FLOW ERR";Tflo2;"should be:";Tflo1;"(
";Bflo;"GPM)err."
5710  IF Offcond$="Y" THEN PRINT "COND ERR ";Cond2;"should be:";Cond1
5720  BEEP                                                             !30APR82
5730  BEEP                                                             !30APR82
5740  !
5750  CALL Rdfmr(Fmrv$,Vref1,Vref2,Offref$)      ! Read Flow Meter Voltage Ref.
5760  IF Dumdat$="Y" THEN GOSUB Dumrdfmr                               !18MAR82
5770  !
5780  IF Offref$="N" THEN GOTO 5840
5790  !
5800  DISP "FLOWMETER REF. V. OFF RANGE,Set @:";Vref1;"Read value:";Vref2;"Devia
tion >2%"
5810  BEEP
5820 !
5830  GOTO 5750
5840                                       !   ********************************
5850                                       !   WAIT interval is for:
5860         WAIT 0                        !                             27JAN82
5870                                       !   Area Warning, Pre-filament-on Time.
5880                                       !   ********************************
5890 !          **** TAKE TEMPERATURE BASE-LINES *****                   06MAY82
5900 !
5910  IF Rover$="N" THEN 5950                                          !05MAY83
5920  CALL Roverstart(Rovtempbsus$)                                    !20APR82
5930  CALL Roverfinish(Rtbbuffer$(*),Dummy)                            !20APR82
5940 !
5950 CALL Read3497a(Clock$,Nbase,1,Bldelay,Tempsus$,Tbbuffer$(*),Dummy) !06MAY82
5960 FIXED 0
5970 IF Dumdat$="Y" THEN GOSUB Dumbase                                 !18MAR82
5980   !
5990   ! *****************************************************************
*
6000   !
6010   !      WAIT FOR FILAMENT ON INTERRUPT
6020   !
6030   ! *****************************************************************
*
6040   DISP "WAITING FOR FILAMENT ON INTERRUPT.  TO RESET PRESS KEY #9 ..SHOT #
";Snr !05MAY83
6050 Waitforfilon:  IF NOT Filon THEN Waitforfilon                     !05MAY83
6060  DISP "READING DELTA T's FOR SHOT #";Snr                          !05MAY83
6070  BEEP
6080 !
6090 !
6100 ! ***********  TAKE THERMOCOUPLE READINGS HERE    ******************
6110 !                       THEN GET FLOW                             !06MAY82
6120  IF Rover$="Y" THEN CALL Roverstart(Rovtempsus$)!START ROVER DATA   05MAY83
```

```
6130  CALL Read3497a(Clock$,Nmeas,0,Tdelay,Tempsus$,Tbuffer$(*),Tmax)   !19Jan84
6140  CALL Read3497a(Clock$,Nbase,1,Bldelay,Flowsus$,Fbuffer$(*),Dummy) !06MAY82
6150  IF NOT Calibrate THEN Unpak                                        !16MAY83
6160  PRINT "READING HEATER VOLTAGE"
6170  Cevolts=Ceav=0
6180  FOR I=1 TO 5                  !GET LPA HEATER VOLTS AND AMPS
6190  ENTER Vdevice;Cev
6200  WAIT 100
6210  Cevolts=Cevolts+Cev
6220  ENTER Adevice;Cea
6230  WAIT 100
6240  Ceav=Ceav+Cea                 !SEE GOSUB CALIBRATE
6250  NEXT I
6260  Cevolts=Cevolts/5
6270  Ceav=Ceav/5
6280  Ceamps=Ceav*Toamps
6290  Cenergy=Cevolts*Ceamps*.001*Tmax !GET TOTAL ENERGY FROM HEATER IN KJ
6300  Cenergy=MAX(Cenergy,.00001)
6310  !
6320 Unpak:  Atmax=Tmax                                                  !18MAR82
6330  !
6340  DISP "UNPACK GRID DATA, SHOT";Snr
6350 CALL Unpack(Nz,Nbase,1,Fbuffer$(*),Flowb(*))        !GRID FLOWS      18MAR82
6360 CALL Unpack(Nz,Nbase,1,Tbbuffer$(*),Tempb(*))      !GRID TEMP BASE   18MAR82
6370 CALL Unpack(Nz,Nmeas,1,Tbuffer$(*),Tempm(*))       !GRID TEMP MEAS   18MAR82
6380 IF Ano$="N" THEN GOTO 6430
6390  DISP "UNPACK ELECTRON DUMP DATA, SHOT";Snr                         !13JUN83
6400 CALL Unpack(Anz,Anbase,Nz+1,Fbuffer$(*),Aflowb(*))!ANODE FLOWS      18MAR82
6410 CALL Unpack(Anz,Anbase,Nz+1,Tbbuffer$(*),Atempb(*))!ANODE TEMP BASE 18MAR82
6420 CALL Unpack(Anz,Anmeas,Nz+1,Tbuffer$(*),Atempm(*)) !ANODE TEMP MEAS 20APR82
6430 IF Dumdat$="Y" THEN GOSUB Dumbase                                   !18MAR82
6440 IF Dumdat$="Y" THEN GOSUB Dumdat                                    !18MAR82
6450  !
6460  !
6470  ! ************************************************************************
6480  !
6490  DISP "END OF GRID DATA ACQUISITION    ";Snr                         !13MAY82
6500  WAIT 200
6510  BEEP
6520  WAIT 200
6530  BEEP
6540  ! ************************************************************************
6550  ! ******************  END  OF  ON-LINE  DATA  ACQUISITION ***************
6560  ! ************************************************************************
6580  !
6650  IF Clock$="N" THEN CALL Daytime(Month,Day,Hour,Minute,Second)    !  22JAN82
6660  IF Clock$="N" THEN GOTO 6750
6670 !
6680 CALL Hpclock(Month,Day,Hour,Minute,Second)                        !  9FEB82
6690                                                                   !  9FEB82
6700 ! **************************************************************** 27JAN82
6710 !
6720 !    GET VACCEL FROM MODCOMP EITHER VIA RS232 OR DACS                14JUL83
6730 !
6740 ! *****************************************************************
6750  IF Rdparam$="N" THEN Param10                                     ! 14JUN83
6760  IF Calibrate THEN Calc                                           ! 14JUN83
6770 !                                                                 ! 27JAN82
6780  IF Rs232 THEN GOSUB Readfrommodcomp                              ! 14JUL83
6790  IF NOT Rs232 THEN GOSUB Readfromdacs                             ! 14JUL83
6800  IF Dumdat$="Y" THEN GOSUB Dumrdparam
6810 ! **************************************************************** 27JAN82
6820 Param10: PRINTER IS 16
6825  IF Countr$="Y" THEN CALL Countr(Tarc,Tacc,Tfil)! Read times      ! 05Dec83
6826  IF Dumdat$="Y" THEN GOSUB Dumcountr                              ! 05Dec83
6830  FIXED 3
```

```
6840  PRINT             !LET'S  SHOW WHAT WE HAVE FOR SOURCE PARAMETERS
6850  PRINT "Vacc IS ";Vacc
6860  PRINT "Iacc IS ";Iacc
6870  PRINT "Varc IS ";Varc
6880  PRINT "Iarc IS ";Iarc
6890  PRINT "Tacc IS ";Tacc
6900  PRINT "Tarc IS ";Tarc
6910  PRINT "Tfil IS ";Tfil
6920  PRINT "Eacc IS ";Vacc*Iacc*Tacc;"   Earc IS ";Varc*Iarc*Tarc
6930  !
6940  DISP "TO CHANGE THE ABOVE DATA PRESS KEY #15"
6950  !
6960  !
6970  Fbeep=5                                 ! Set up times to wait    25JAN82
6980  IF Countr$="N" THEN Fbeep=Fbeep+5       ! enough to recognize &   25JAN82
6990  IF Rdparam$="N" THEN Fbeep=Fbeep+5      ! get parameter changes. 25JAN82
7000  !
7010  ON KEY #15 GOTO Param60                 !
7020  FOR Beep=1 TO Fbeep                     !
7030  BEEP                                    !
7040  WAIT 1000.0                             ! THIS IS THE BASE WAIT TIME
7050  NEXT Beep
7060  BEEP
7070  GOTO Param80
7080  ! ******************** ACCEPT CHANGE DATA HERE ********************
7090 Param60: INPUT "Vacc = ?",Vacc           ! ACCEL VOLTAGE
7100  INPUT "Iacc = ?",Iacc                   ! ACCEL CURRENT
7110  INPUT "Varc = ?",Varc                   ! ARC VOLTAGE
7120  INPUT "Iarc = ?",Iarc                   ! ARC CURRENT
7130  INPUT "Tacc = ?",Tacc                   ! ACCEL ON-TIME
7140  INPUT "Tarc = ?",Tarc                   ! ARC ON-TIME
7150  INPUT "Tfil = ?",Tfil                   ! FIL ON-TIME
7160  !
7170 Param80: FIXED 0
7180  OFF KEY #15                             ! SPEC FUNC, SHOT DATA KEY OFF
7190 !
7200 ! ****************************************************************
7210 ! ****************************************************************
7220 !
7230 !                     CALCULATION OF CALORIMETRY DATA
7240 !
7250 Calc:  Istart=1                          !FIRST MEASUREMENT         05MAY83
7260  Iend=Nmeas                        !LAST MEASUREMENT              !18MAR82
7270  Idelt=Iend-Istart+1               !NUMBER OF MEASUREMENTS        !18MAR82
7280  !
7290  DISP " CALCULATION OF BASIC GRID DATA  SHOT NUMBER ";Snr
7300  CALL Getflow(Nz,Nbase,Fmc1(*),Fmc2(*),Voff(*),Vref2,Flowb(*),Sf(*)) !18M
7310  CALL Gettempbase(Basel$,Nz,Nbase,Tempb(*),St(*))                 !18MAR82
7320  CALL Gettemp(Nz,Nmeas,St(*),Tempm(*))                            !18MAR82
7330  CALL Spike(Spike$,Nz,Nmeas,Tempm(*))                             !18MAR82
7340  !
7350  DISP " CALCULATION OF THE ENERGY TO THE GRIDS, SHOT NUMBER  ";Snr
7360  CALL Intg(Rese(*),Istart,Iend,1,Nz,Tmax,Tempm(*),Sf(*),Idelt,Resecf(*))!29
APR82
7370  CALL Getmax(Nz,Nmeas,Tempm(*),Xm(*),Tempmax)                     !18MAR82
7380  CALL Getpkpwr(Nz,Xm(*),Sf(*),Peak_pwr(*))                        !18MAR82
7390  CALL Appr(Tacc,Tarc,Tfil,Varc,Iarc,Nz,Rese(*),Slope(*),Fil(*),Appr(*))
7400  IF Ano$="N" THEN GOTO 7560
7410  Astart=1                                                         !18MAR82
7420  Aend=Anmeas                                                      !18MAR82
7430  Adelt=Aend-Astart+1
7440  ! DISP "CALCULATION OF BASIC ANODE DATA, SHOT NUMBER ";SNR        !18MAR82
7450  CALL Getflow(Anz,Anbase,Afmc1(*),Afmc2(*),Avoff(*),0,Aflowb(*),Asf(*))!13J
7460  CALL Gettempbase(Basel$,Anz,Anbase,Atempb(*),Ast(*))             !18MAR82
7470  CALL Gettemp(Anz,Anmeas,Ast(*),Atempm(*))                        !18MAR82
7480  CALL Spike(Spike$,Anz,Anmeas,Atempm(*))                          !18MAR82
```

```
7490  !
7500  DISP "CALCULATION OF ENERGY TO THE ELECTRON DUMP, SHOT NUMBER";Snr!13JUN83
7510  CALL Intg(Arese(*),Astart,Aend,1,Anz,Atmax,Atempm(*),Asf(*),Adelt,Aresecf(
*))!29APR82
7520  CALL Getmax(Anz,Anmeas,Atempm(*),Axm(*),Atempmax)                  !18MAR82
7530  CALL Agetpkpwr(Anz,Axm(*),Asf(*),Apeak_pwr(*))                     !18MAR82
7540  CALL Aappr(Tacc,Tarc,Tfil,Varc,Iarc,Anz,Arese(*),Aslope(*),Afil(*),Aappr(*
))!18MAR82
7550  !
7560  IF Rover$="N" THEN GOTO 7830                                       !20APR82
7570  DISP "WAITING FOR ROVER DELTA T MEASUREMENTS TO FINISH, SHOT";Snr !05MAY83
7580 Waitforrover:  IF NOT Roverdataready THEN Waitforrover              !05MAY83
7590  DISP "READING ROVER DATA, SHOT";Snr
7600  CALL Roverfinish(Rtbuffer$(*),Rtmax)                               !20APR82
7610  Roverdataready=False                                               !05MAY83
7620  CALL Roverstart(Rovflowsus$)           !GET FLOW                   !06MAY82
7630  DISP "WAITING FOR ROVER FLOW MEASUREMENTS TO FINISH,SHOT";Snr      !05MAY83
7640 Waitforflow:  IF NOT Roverdataready THEN Waitforflow                !05MAY83
7650  CALL Roverfinish(Rfbuffer$(*),Dummy)                               !06MAY82
7660  DISP "UNPACKING ROVER DATA, SHOT";Snr
7670  IF Dumdat$="Y" THEN GOTO 7710
7680  CALL Unpack(Rnz,Rnbase,1,Rfbuffer$(*),Rflowb(*)) !UNPACK FLOW      !20APR82
7690  CALL Unpack(Rnz,Rnbase,1,Rtbbuffer$(*),Rtempb(*))!UNPACK TEMP BASE!20APR82
7700  CALL Unpack(Rnz,Rnmeas,1,Rtbuffer$(*),Rtempm(*)) !UNPACK TEMP MEAS 20APR82
7710  Rstart=1                                                           !20APR82
7720  Rend=Rnmeas                                                        !20APR82
7730  Rdelt=Rend-Rstart+1
7740  ! DISP "CALCULATION OF BASIC ROVER DATA, SHOT NUMBER ";SNR          !20APR82
7750  CALL Getflow(Rnz,Rnbase,Rfmc1(*),Rfmc2(*),Rvoff(*),Vref2,Rflowb(*),Rsf(*))
7760  CALL Gettempbase(Basel$,Rnz,Rnbase,Rtempb(*),Rst(*))               !20APR82
7770  CALL Gettemp(Rnz,Rnmeas,Rst(*),Rtempm(*))                          !20APR82
7780  CALL Spike(Spike$,Rnz,Rnmeas,Rtempm(*))                            !20APR82
7790  !
7800  DISP " CALCULATION OF ENERGY TO THE ROVER, SHOT NUMBER";Snr        !20APR82
7810  CALL Intg(Rrese(*),Rstart,Rend,1,Rnz,Rtmax,Rtempm(*),Rsf(*),Rdelt,Rresecf(
*))!29APR82
7820  CALL Getmax(Rnz,Rnmeas,Rtempm(*),Rxm(*),Rtempmax)                  !18MAR82
7830  !
7840  ! *****************************************************************
7850  !       OUTPUT SUMMARIZED RESULTS
7860  ! ******************************************************************
7870  !
7880  PRINTER IS 16
7890  IF Outp$="Y" THEN PRINTER IS 0
7900  IF (Perf$="Y") AND (Plot$="N") AND (Snr MOD 2=0) THEN PRINT PAGE  !18MAR82
7910  !
7920  IF Ano$="N" THEN GOTO 7960                                         !18MAR82
7930  PRINT USING 7940;"*****RESULTS OF 10X40LPA & LPS CAL FOR SHOT#";Snr;"*****
Rev.";Version$
7940  IMAGE 44A,6D,2X,9A,1X,9A
7950  GOTO 7980
7960  PRINT USING 7970;"*****RESULTS OF 10X40LPA GRID CAL FOR SHOT #";Snr;"*****
Rev.";Version$
7970  IMAGE 44A,6D,5X,9A,1X,9A
7980  PRINT USING 7990;"DATE:";Day;Mensis$(Month);Year;"TIME:";Hour;":";Minute;"
:";Second;"Baseline read delay:";Bldelay                                 !18MAR82
7990  IMAGE 5A,2X,2D,3A,DD,4X,5A,2X,2D,A,2D,A,2D,20X,20A,4D              !18MAR82
8000  !
8010  A=MIN(999.9,MAX(Vacc,-99.9))
8020  C=MIN(9999.99,MAX(Iacc,-999.99))
8030 PRINT USING 8040;"Vacc:";A;" kev  Iacc:";C;"Amps  Tacc";Tacc;"sec";"Temp Me
as delay:";Tdelay                                                        !19Jan84
8040 IMAGE 5A,X,DDD.D,X,11A,DDDD.DD,X,10A,DD.DDD,X,3A,6X,16A,4D
8050  !
8060  A=MIN(999.9,MAX(Varc,-99.9))
8070  C=MIN(9999.99,MAX(Iarc,-999.99))
```

```
8080 IF NOT Calibrate THEN PRINT USING 8090;"Varc:";A;" Volt Iarc:";C;"Amps  Tar
c";Tarc;"sec  Tfil";Tfil;" sec"
8090 IMAGE 5A,X,DDD.D,X,11A,DDDD.DD,X,10A,DD.DDD,X,10A,DD.DDD,4A              ! 1FEB82
8100 IF Calibrate THEN PRINT USING 8110;Cevolts,Ceamps,Ceav                   !17MAY83
8110  IMAGE "HEATER:",DDDD.D," Volts   ",DDDD.D," Amps(from ",DDD.DD," Volts)"
8120 PRINT USING 8130;"RESULT OF ENERGY-INTEGRATION:";Idelt;"POINTS";Tmax;"SECON
DS"
8130 IMAGE 29A,2X,DDD,2X,6A,3X,DDD.D,2X,6A
8140 PRINT
8150 PRINT " Channel      Flow          Flow    Total Energy";
8160 IF NOT Calibrate THEN PRINT "              Avg.Pwr.        Peak Pwr"    !16MAY83
8170 IF Calibrate THEN PRINT "    Calibration Energy     diff"               !16MAY83
8180 PRINT "    #          [GPM]        [ml/S]          [kJ]";                 !16MAY83
8190 IF NOT Calibrate THEN PRINT "               [W/rail]        [W/rail]"   !16MAY83
8200 IF Calibrate THEN PRINT "                [kJ]              %"           !16MAY83
8210  !
8220  Tacc$=" "
8230  IF Tacc<.15 THEN Tacc$="?"                                             !15JUN83
8240  !
8250  Im$="4X,D,9X,DD.DD,6X,4D.DD,8X,3D.DD,10X,1A,4D.DD,8X,4D.DD"      !  14JUN83
8260  !
8270  FOR I=1 TO Nz
8280  Sfgpm=Sf(I)/Mlpstogpm                     !Flow in GPM                  13JUN83
8290  Sfgpm=MIN(99.99,MAX(Sfgpm,-9.99))
8300  F=MIN(9999.99,MAX(Sf(I),-999.99))
8310  R=MIN(999.99,MAX(Rese(I),-99.99))
8320  A=MIN(9999.99,MAX(Appr(I),-999.99))
8330  C=MIN(9999.99,MAX(Peak_pwr(I),-999.99))
8340  IF NOT Calibrate THEN Nocal                                            !16MAY83
8350  Ediff=(Cenergy-Rese(I))/Cenergy*100
8360  A=MIN(9999.99,MAX(Ediff,-999.99))
8370  C=MIN(9999.99,MAX(Cenergy,-999.99))
8380 !                                                                        9FEB82
8390 Nocal: IF (Appr(I)>=600) AND (Tacc$=" ") THEN Ovtmp$="Y"!     Flag  14JUN83
8400 !                                                                        9FEB82
8410  PRINT USING Im$;I,Sfgpm,F,R,Tacc$,A,C                                  ! 14JUN83
8420  NEXT I
8430  !
8440  IF Ano$="N" THEN Rov1
8450  PRINT USING 8460;"  [kW] ","[kW]"                                      !13JUN83
8460  IMAGE 56X,7A,10X,4A                                                   !13JUN83
8470  FOR I=1 TO Anz
8480  Sfgpm=Asf(I)/Mlpstogpm                                                 !13JUN83
8490  Sfgpm=MIN(99.99,MAX(Sfgpm,-9.99))
8500  F=MIN(9999.99,MAX(Asf(I),-999.99))
8510  R=MIN(999.99,MAX(Arese(I),-99.99))
8520  A=MIN(9999.99,MAX(Aappr(I),-999.99))
8530  C=MIN(9999.99,MAX(Apeak_pwr(I),-999.99))
8540  Im$="1X,8A,5X,DD.DD,6X,4D.DD,8X,3D.DD,10X,1A,4D.DD,8X,4D.DD"     !  14JUN83
8550  PRINT USING Im$;" e"&CHR$(176)&" dump",Sfgpm,F,R,Tacc$,A,C
8560  NEXT I
8570  !
8580 Rov1: IF Rover$="N" THEN Grid1
8590  Sfgpm=Rsf(1)/Mlpstogpm
8600  Sfgpm=MIN(99.99,MAX(Sfgpm,-9.99))
8610  F=MIN(9999.99,MAX(Rsf(1),-999.99))
8620  R=MIN(999.99,MAX(Rrese(1),-99.99))
8630  PRINT USING 8640;"ROVER",Sfgpm,F,R
8640  IMAGE 2X,5A,7X,DD.DD,6X,DDDD.DD,8X,DDD.DD
8650  !
8660 Grid1: PRINT USING 8670;"Heat to grids +/- difference, [kJ]";"
     Dev.Ref.V.";Vref1-Vref2
8670  IMAGE 35A,30A,SD.DDDD
8680   FOR I=2 TO Nz STEP 2
8690   Gridno=I/2                                                            !18MAR82
8700   Gridegy=MIN(999.99,MAX(Rese(I-1)+Rese(I),-999.99))
```

```
8710   Gridegydif=MIN(999.99,MAX(Rese(I-1)-Rese(I),-999.99))
8720   Gridpkpwr=MIN(99999.99,MAX((Peak_pwr(I-1)+Peak_pwr(I))/2,-99999.99))
8730   !
8740  IF I=2 THEN PRINT USING 8750;Gridno,Gridegy,Gridegydif,Gridpkpwr !18MAR82
8750  IMAGE  " GRID ",DD,"=",SDDD.DD,SDDD.DD," kJ and peak power ",SDDDDD.DD," w
atts/rail"
8760  !
8770  IF (I>2) AND (I<8) THEN PRINT USING 8780;Gridno,Gridegy,Gridegydif,Gridpkp
wr                                                                      !18MAR82
8780  IMAGE 6X,DD,X,SDDD.DD,SDDD.DD,19X,SDDDDD.DD
8790  !
8800  IF I=8 THEN PRINT USING 8810;Gridno,Gridegy,Gridegydif,Gridpkpwr,"TIME SIN
CE LASTSHOT",Ki/30," S."                                                !18MAR82
8810  IMAGE 6X,DD,X,SDDD.DD,SDDD.DD,19X,SDDDDD.DD,2X,20A,DDDD,3A
8820   NEXT I
8830  !
8840  !
8850   IF Plot$="Y" THEN GOTO 8880                                   !   18JAN82
8860   PRINT
8870   PRINT
8880  IF Ovtmp$="Y" THEN PRINT "*********WARNING rail heat OVER 600 W. LIMIT ***
***********"
8890 PRINTER IS 16
8900  IF Ovtmp$="N" THEN S10
8910  PRINT "WARNING  RAIL  HEAT  OVER  600 WATT LIMIT"
8920  FOR Beep=1 TO 30
8930  WAIT 100
8940  BEEP
8950  WAIT 200
8960  BEEP
8970  NEXT Beep
8980  !
8990  !
9000 S10:IF NOT Calibrate AND Rs232 THEN GOSUB Sendtomodcomp            !14JUL83
9010 !
9020 ! *******************************************************************
9030 !                MAKE THE DATA PLOTS
9040 ! ********************************************************************
9050   IF Plot$="N" THEN P500
9060   DISP "PREPARATION OF PLOT DATA, SHOT NUMBER  ";Snr
9070 !
9080   CALL Getpercent(Nz,Nmeas,Tempmax,Tempm(*),Tempmt(*))!Temps to %  18MAR82
9090   CALL Getxtime(Idelt,Istart,Iend,Tmax,Nmeas,Timem(*),Tmes)        !20APR82
9100   IF Ano$="N" THEN GOTO 9130
9110   Atmes=Tmes
9120   CALL Getpercent(Anz,Anmeas,Atempmax,Atempm(*),Atempmt(*))        !18MAR82
9130   IF Rover$="N" THEN GOTO 9160                                     !20APR82
9140   CALL Getpercent(Rnz,Rnmeas,Rtempmax,Rtempm(*),Rtempmt(*))        !20APR82
9150   CALL Getxtime(Rdelt,Rstart,Rend,Rtmax,Rnmeas,Rtimem(*),Rtmes)    !20APR82
9160   PRINTER IS 16
9170   PRINT PAGE
9180   DISP ""
9190  GLOAD Aa(*)                                     !CLEAR  & RE-LOAD GRAPHICS
9200  ! GLOAD Aaa(*),0,227            !45C  !LOAD REST OF GRAPHICS          16MAY8
3
9210  GRAPHICS
9220  CALL Plot1(Tmes,Tempmax,Idelt,Snr,Atempmax,Ano$,Rtmes,Rtempmax,Rdelt,Rover
$)
9230  CALL Plot2(Frame1(*),Timem(*),Tempmt(*),Rese(*),1,Istart,Iend,Timem(*),Are
se(*),Atempmt(*),Anode(*),Astart,Aend,Ano$)
9240  CALL Plot2(Frame2(*),Timem(*),Tempmt(*),Rese(*),2,Istart,Iend,Timem(*),Are
se(*),Atempmt(*),Anode(*),Astart,Aend,Ano$)
9250  CALL Plot2(Frame3(*),Timem(*),Tempmt(*),Rese(*),3,Istart,Iend,Timem(*),Are
se(*),Atempmt(*),Anode(*),Astart,Aend,Ano$)
9260  CALL Plot2(Frame4(*),Timem(*),Tempmt(*),Rese(*),4,Istart,Iend,Rtimem(*),Rr
ese(*),Rtempmt(*),Rover(*),Rstart,Rend,Rover$)
```

```
9270  !
9280  IF Plot$="N" THEN GOTO 9330
9290  IF Outp$="Y" THEN CALL Dump
9300  PRINTER IS 0
9310  IF (Outp$="Y") AND (Perf$="Y") THEN PRINT PAGE
9320  PRINTER IS 16
9330  EXIT GRAPHICS
9340  !
9350  GOSUB Tapewrite                   ! SAVE DATA ON TAPE IF REQUESTED 06MAY82
9360  !
9370  GOTO Reentry
9380  !
9390  ! **************************************************************
9400  !              BEGINNING OF GOSUB TYPE SUBROUTINES
9410  !
9420  !
9430  ! *******************************************************************
9440  !
9450  !                    CALIBRATION MODE SUBROUTINE                 !16MAY83
9460  !
9470  ! LPA HEATER VOLTS AND AMPS ARE ACQUIRED VIA 2 HP 3438A DVMS.
9480  ! LPA HEATER CURRENT IS DVM VOLTS * 66.67
9490  !
9500 Calibrate:  Calibrate=NOT Calibrate      !TOGGLE CALIBRATION MODE FLAG
9510  IF Calibrate THEN PRINT "ENTERED CALIBRATE MODE"
9520  IF NOT Calibrate THEN PRINT "LEFT CALIBRATE MODE"
9530  Vdevice=725                        !DVM HPIB ADDRESS FOR HEATER VOLTS
9540  Adevice=724                        !DVM HPIB ADDRESS FOR HEATER AMPS
9550  Toamps=66.67                       !CONVERSION FROM VOLTS TO HEATER
9560  RETURN                             !AMPS.
9570  !
9580  !                    DUMMY DATA GOSUB ROUTINES
9590  !
9600 Dumsystat:  Tflo2=Tflo1
9610  Cond2=Cond1
9620  Dumcnt=Dumcnt+1
9630  RETURN
9640 Dumrdfmr: Vref2=Vref1-.005
9650  Offref$="N"
9660  RETURN
9670 Dumrdparam: Vacc=80
9680  Iacc=25+Dumcnt*5
9690  Varc=36
9700  Iarc=1250
9710  RETURN
9720 Dumcountr: Tacc=.5
9730  Tarc=.8
9740  Tfil=3
9750  RETURN
9760 Dumbase: I=0
9770  FOR I=1 TO Nz                   !FLOW
9780  FOR J=1 TO Nbase
9790  Flowb(I,J)=4.961E-3
9800  Tempb(I,J)=0
9810  IF I>2 THEN GOTO 9870
9820  Aflowb(I,J)=4.961E-3
9830  Atempb(I,J)=0
9840  IF I>1 THEN GOTO 9870
9850  Rflowb(I,J)=4.961E-3
9860  Rtempb(I,J)=0
9870  NEXT J
9880  NEXT I
9890  RETURN
9900 Dumdat: F2pi=2*3.14
9910  Inc=2/Nmeas
9920  Sqrt2pi=1/SQR(F2pi)
```

```
9930  Mean=0
9940  Fac=Dumcnt MOD 2
9950  IF Fac=0 THEN Fac=.5
9960  X=-1
9970  FOR J=1 TO Nmeas
9980  Sigma=.2
9990  Tempm(1,J)=-Sqrt2pi/Sigma*EXP(-(X-Mean)^2/(2*Sigma*Sigma))*15*1E-6*Fac
10000 Tempm(3,J)=Tempm(1,J)
10010 Tempm(5,J)=Tempm(1,J)
10020 Tempm(7,J)=Tempm(1,J)
10030 Sigma=.3
10040 Tempm(2,J)=-Sqrt2pi/Sigma*EXP(-(X-Mean)^2/(2*Sigma*Sigma))*15*1E-6*Fac
10050 Tempm(4,J)=Tempm(2,J)
10060 Tempm(6,J)=Tempm(2,J)
10070 Tempm(8,J)=Tempm(2,J)
10080 Sigma=.5
10090 Atempm(1,J)=-Sqrt2pi/Sigma*EXP(-(X-Mean)^2/(2*Sigma*Sigma))*15*1E-6*Fac
10100 Atempm(2,J)=Atempm(1,J)
10110 Rtempm(1,J)=Atempm(1,J)
10120 X=X+Inc
10130 NEXT J
10140 RETURN
10150 ! *************************************************************
10160 !                   GOSUB ROUTINE FILON                       05MAY83
10170 ! Filon is gives function key simulation of filament on interrupt
10180 !
10190 Filon: Filon=True
10200 Nop:RETURN
10210 ! *************************************************************
10220 !                   GOSUB ROUTINE FIRE                       05MAY83
10230 ! Fire gives function key simulation of fire interrupt
10240 !
10250 Fire: Fire=True
10260 RETURN
10270 ! *************************************************************
10280 !                   GOSUB ROUTINE VACCELETC                  05MAY83
10290 ! Vacceletc gives function key simulation of Vacceletc interrupt from
10300 !                                                          Modcomp.
10310 Vacceletc:Vacceletc=True
10320 RETURN
10330 ! **************************************************************
10340 !                   GOSUB ROUTINE READCHR
10350 ! Readchr fetches characters from TOPEN's circular buffer in     14Jul83
10360 ! in response to interrupts.
10370 !
10380 Readchr: Mj$=TBUF$
10381 Lenmi=LEN(Mi$)                                            ! 29NOV83
10390 IF Lenmi=Milen THEN RETURN                                ! 29NOV83
10391 IF Lenmi+LEN(Mj$)>Milen THEN Mj$=Mj$[1,Milen-Lenmi]       ! 29NOV83
10392 Mi$=Mi$&Mj$                                               ! 29NOV83
10400 RETURN
10410 ! **************************************************************
10420 !                   GOSUB ROUTINE READFROMDACS
10430 ! Readfromdacs gets vaccel, etc. from dacs setup by Hpsend in Modcomp
10440 ! after an interrupt is received from the Modcomp. The usual and
10450 ! preferred method is to get vaccel, etc. from the Modcomp via the
10460 ! Hpib. See Readfromhpib.
10470 !
10480 Readfromdacs: DISP "WAITING FOR INTERRUPT FROM MODCOMP...shot #";Snr
10490 !
10500 Waitformodcomp: IF NOT Vacceletc THEN Waitformodcomp
10510 DISP "READING PARAMETERS FROM DACS SETUP BY MODCOMP"
10520 CALL Rdparam(Vacc$,Iacc$,Varc$,Iarc$,Vacc,Iacc,Varc,Iarc)
10530 RETURN
10540 ! ****************************************************************
10550 !                       GOSUB ROUTINE READFROMMODCOMP
```

```
10560 ! Readfrommodcomp waits for the message from HPSEND in the Modcomp
10570 ! which contains shot number, vaccel, iaccel, varc, and iarc. Then it
10580 ! extracts the values from the message.
10590 !
10600 Readfrommodcomp: DISP "READING VACCEL, ETC. FROM MODCOMP VIA RS232 shot #:
";Snr
10610 !                                                              ! 27JAN82
10620 FIXED 0
10630 FOR J=1 TO 120             !WAIT FOR MESSAGE FROM HPSEND BUT NOT ! 14JUL83
10640 IF LEN(Mi$)>=Milen THEN Rfm40 !MORE THAN ABOUT 2 MINUTES        ! 20JUL83
10650 WAIT 1000.0
10660 NEXT J
10670 Nodata=True                !TIMED OUT. DATA FROM MODCOMP MISSING
10680 GOTO Rfm50
10690 Rfm40: Nodata=(Mi$[1;2]="NO")
10700 !
10710 Rfm50: J=1                !GET VALUES FROM MESSAGE
10720 FOR I=1 TO Nvin           !VALUES ARE DELIMITED BY COMMA
10730 V(I)=1E30
10740 IF Nodata THEN Pr100
10750 V(I)=VAL(Mi$[J])
10760 K=J
10770 J=POS(Mi$[K],",")+K
10780 Pr100: NEXT I
10790 !
10800 IF V(1)<>1E30 THEN Snr=V(1)
10810 Vacc=V(2)                 !CONVERT VACCEL TO Kv
10820 IF Vacc<>1E30 THEN Vacc=Vacc*.001
10830 Iacc=V(3)
10840 Varc=V(4)
10850 Iarc=V(5)
10860 RETURN
10870 ! ****************************************************************
10880 !                     GOSUB ROUTINE SENDTOMODCOMP
10890 ! Sendtomodcomp transfers the LPA, LPS calorimetry results to the  14JUL83
10900 ! Modcomp via the RS232.
10910 !
10920 Sendtomodcomp: DISP "SENDING LPA RESULTS TO MODCOMP"
10930 M$=""                     !FORMAT LPA RESULTS INTO MESSAGE
10940 FLOAT 6                   !FOR MODCOMP.
10950 M$=M$&VAL$(Tmax)&" "      !INTEGRATION TIME
10960 FIXED 0
10970 M$=M$&VAL$(Nmeas)&" "              !NO. OF POINTS IN INTEGRATION
10980 CALL Varadd(Nz,Sf(*),M$)           !FLOWRATES
10990 CALL Varadd(Anz,Asf(*),M$)
11000 CALL Varadd(Nz,Rese(*),M$)         !TOTAL ENERGY
11010 CALL Varadd(Anz,Arese(*),M$)
11020 CALL Varadd(Nz,Appr(*),M$)         !AVERAGE POWER PER RAIL
11030 CALL Varadd(Anz,Aappr(*),M$)
11040 CALL Varadd(Nz,Peak_pwr(*),M$)     !PEAK POWER PER RAIL
11050 CALL Varadd(Anz,Apeak_pwr(*),M$)
11060 FIXED 0
11070 L=LEN(M$)
11080 IF L<Messmax THEN M$=M$&RPT$(" ",Messmax-L)
11090 !
11100 Im$="#,"&VAL$(Messmax)&"A"
11110 OUTPUT Rs USING Im$;M$
11120 RETURN
11130 ! *************************************************************
11140 !                   GOSUB ROUTINE SRQSETUP                    05MAY83
11150 ! Srqsetup resets Hpib, setups acquisition units to give SRQ
11160 ! on Fire, Filament on[, Modcompready] or Rover data ready.
11170 !
11180 Srqsetup:OFF INT #7
11190 CLEAR 7
11200 STATUS 709;Spstatus
```

```
11210 OUTPUT 709;"SD0SIS01VA0"              !ENABLE FIRE,...ON LO TO HI  !14JUL83
11220 IF Rs232 THEN OUTPUT 709;"DE2,3DS2,3SE2"     !RS232 IN USE
11230 IF NOT Rs232 THEN OUTPUT 709;"DE2,7DS2,7SE2" !DAC's IN USE
11240 Isp=0
11250 IF Rover$="N" THEN Srq100
11260 STATUS 710;Spstatus
11270 OUTPUT 710;"SD0SIS01VA0"
11280 OUTPUT 710;"SE1"                     !ENABLE DATA READY FOR ROVER
11290 Srq100: ON INT #7,4 GOSUB Srqhandler!ENABLE SRQ
11300 CONTROL MASK 7;128
11310 CARD ENABLE 7
11320 Fire=Filon=Vacceletc=False           !RESET FLAGS
11330 RETURN
11340 ! ********************************************************************
11350 !                GOSUB ROUTINE SRQHANDLER
11360 ! Srqhandler fields interrupts and sets the corresponding
11370 ! program flags.
11380 !
11390 Srqhandler: STATUS 709;Spoll             !SERIAL POLL 709
11400 IF BIT(Spoll,1)=0 THEN Srq710            !IGNORE IF NOT DIG INT
11410 STATUS 7;Srqclr                                                    !03JUN83
11420 OUTPUT 709;"DI2"                         !GET OPTION 50 INT STATUS
11430 ENTER 709;Spoll
11440 Isp=Isp+1
11450 Spoll(Isp)=Spoll
11460 Spoll(0)=Isp
11470 IF BIT(Spoll,0)=1 THEN Fire=True
11480 IF BIT(Spoll,1)=1 THEN Filon=True
11490 IF BIT(Spoll,2)=1 THEN Vacceletc=True
11500 Srq710:IF Rover$="N" THEN Srq900
11510 STATUS 710;Spoll                         !SERIAL POLL 710
11520 IF BIT(Spoll,0)=0 THEN Srq900            !TEST FOR DATA READY
11530 Roverdataready=True
11540 OUTPUT 9;"U3H"                           !STOP ROVER TIMER
11550 Srq900: CARD ENABLE 7                    !REENABLE FOR SRQ
11560 RETURN
11570 ! ********************************************************************
11580 !                GOSUB ROUTINE TAPEINI                          !18MAR82
11590 ! Tapeini creates a new file on mag tape with name = the next shot
11600 ! and sets the save data on tape flag.
11610 ! There are a possible 6 blocks of data
11620 ! which can be written to mag tape for a shot. The array Blockformat
11630 ! gives the current format number for each block. Blocksize gives
11640 ! the number of bytes in each block for the current format. Blockid
11650 ! is made up from block number and block format:
11660 !          Blockid = blocknumber + 100*blockformat
11670 ! Blockid is integer and is the 1st word of each block.
11680 !
11690 Tapeini: IF NOT Rs232 THEN Ti10                                !14JUL83
11700 PRINT "TAPE REQUEST DENIED. GET DATA FROM MODCOMP."
11710 BEEP
11720 RETURN
11730 Ti10: MASS STORAGE IS Ms14$
11740 !
11750 IF Tapes$="N" THEN GOTO 11860
11760 PRINTER IS 16                      !SORRY, FILE IS ALREADY OPEN
11770 PRINT PAGE
11780 PRINT "KEY 4 DATA FILE CREATION REQUEST DENIED"
11790 BEEP
11800 PRINT "THERE IS ALREADY A DATA FILE OPEN"
11810 BEEP
11820 PRINT "HIT KEY 5 TO CLOSE FILE. THEN HIT KEY 4 AGAIN"
11830 BEEP
11840 RETURN
11850 !                           OK. LETS DO IT.
11860 Nbytes=4                   !4 BYTES FOR TRAILING INTEGER
```

```
11870 Blocksize(1)=4+7*4         !4 BYTES PER INTEGER                  !06MAY82
11880 Blocksize(2)=4+7*8         !4 BYTES PER SHORT                    !06MAY82
11890 Blocksize(3)=4+(2*Nz+2)*8  !8 BYTES PER FULL PRECISION           !06MAY82
11900 Blocksize(4)=4+(Nz+Nz*Nmeas+3)*8                                !06MAY82
11910 Blocksize(5)=4+(2*Anz+2)*8                                       !06MAY82
11920 Blocksize(6)=4+(Anz+Anz*Anmeas+3)*8                             !06MAY82
11930 FOR I=1 TO 6               !SETUP BLOCK IDS AND CALCULATE RECORD SIZE
11940 Blockid(I)=0
11950 IF Blockformat(I)=0 THEN GOTO 11990
11960 IF (Ano$="N") AND ((I=5) OR (I=6)) THEN GOTO 11990               !06MAY82
11970 Blockid(I)=I+Blockformat(I)*100
11980 Nbytes=Nbytes+Blocksize(I)
11990 NEXT I
12000 !
12010 FIXED 0
12020 Nr=Snr                            !KEYENTRY="Y" MEANS CALLED FROM !06MAY82
12030 IF Keyentry$="Y" THEN Nr=Nr+1     !"ON KEY". ="N" MEANS CALLED   !06MAY82
12040 Fnam$=VAL$(Nr)                    !FROM TAPEWRITE. FILE NAME IS  !06MAY82
12050 Keyentry$="Y"                     !CURRENT SHOT IF FROM TAPEWRITE !06MAY82
12060 Nr=INT((Nbytes+255)/256)*30 !***** SETUP FOR 30 SHOTS            !06MAY82
12070 ON ERROR GOTO 12150
12080 CREATE Fnam$,Nr                   !CREATE FILE                   !06MAY82
12090 OFF ERROR
12100 ASSIGN #1 TO Fnam$          !OPEN FILE
12110 MASS STORAGE IS Ms15$
12120 Tapes$="Y"                  !SET SAVE DATA FLAGS
12130 Stape$="Y"                                                       !06MAY82
12140 RETURN
12150 OFF ERROR                   !ERROR. REPORT PROBLEM AND TRY AGAIN  !06MAY82
12160 PRINTER IS 16               !WHEN OPERATOR GIVES GO AHEAD        !06MAY82
12170 PRINT "ERROR CREATING MAG TAPE FILE FOR DATA SAVE"               !06MAY82
12180 PRINT "CORRECT PROBLEM AND HIT CONTINUE TO TRY AGAIN"            !06MAY82
12190 PRINT ERRM$
12200 BEEP
12210 PAUSE                                                            !06MAY82
12220 GOTO 12070                                                       !06MAY82
12230 !
12240 ! *************************************************************************
*
12250 !                     GOSUB ROUTINE TAPESKIP                     !06MAY82
12260 !
12270 ! Tapeskip sets Stape$ = "N" so that current shot will not be stored
12280 ! on tape.
12290 Tapeskip: Stape$="N"
12300 RETURN
12310 ! *******************************************************************
12320 !                  GOSUB ROUTINE TAPESTOP
12330 !
12340 ! Tapestop resets the save data on tape flag and closes the mag tape
12350 ! data file.
12360 Tapestop: IF Tapes$="N" THEN RETURN
12370 MASS STORAGE IS Ms14$
12380 ASSIGN #1 TO *           !CLOSE THE FILE
12390 Tapes$="N"               !RESET THE FLAGS
12400 Stape$="N"                                                       !06MAY82
12410 MASS STORAGE IS Ms15$
12420 RETURN
12430 ! ******************************************************************
12440 !                  GOSUB ROUTINE TAPEWRITE                      !18MAR82
12450 !
12460 ! Tapewrite outputs data to the mag tape. Up to 6 blocks
12470 ! of data may be written to tape. Tapewrite writes all blocks for which
12480 ! their block id number in Blockid is not 0. Twrite has built into
12490 ! it knowledge of which variables get written for a particular
12500 ! format of a data block.
12510 !
```

```
12520 Tapewrite: IF Stape$="N" THEN RETURN                              !06MAY82
12530 MASS STORAGE IS Ms14$
12540 ON END #1 GOTO 12870                                              !06MAY82
12550 !                                                        !BLOCK 1
12560 Snrs=Snr                    !CONVERT TO SHORT PRECISION
12570 Months=Month
12580 Days=Day
12590 Years=Year
12600 Hours=Hour
12610 Minutes=Minute
12620 Seconds=Second
12630 PRINT #1;Blockid(1),Snrs,Months,Days,Years,Hours,Minutes,Seconds
12640 !
12650 IF Blockid(2)=0 THEN GOTO 12680                          !BLOCK 2
12660 PRINT #1;Blockid(2),Vacc,Iacc,Tacc,Varc,Iarc,Tarc,Tfil
12670 !
12680 IF Blockid(3)=0 THEN GOTO 12710                          !BLOCK 3
12690 PRINT #1;Blockid(3),Nz,Rese(*),Appr(*),Tmes
12700 !
12710 IF Blockid(4)=0 THEN GOTO 12740                          !BLOCK 4
12720 PRINT #1;Blockid(4),Nz,Nmeas,Tmax,Sf(*),Tempm(*)
12730 !
12740 IF Blockid(5)=0 THEN GOTO 12770                          !BLOCK 5
12750 PRINT #1;Blockid(5),Anz,Arese(*),Apeak_pwr(*),Atmes
12760 !
12770 IF Blockid(6)=0 THEN GOTO 12800                          !BLOCK 6
12780 PRINT #1;Blockid(6),Anz,Anmeas,Atmax,Asf(*),Atempm(*)
12790 !
12800 CHECK READ #1               !FLUSH THE BUFFER
12810 B=0
12820 PRINT #1;B
12830 CHECK READ OFF #1
12840 OFF END #1                                                        !06MAY82
12850 MASS STORAGE IS Ms15$
12860 RETURN
12870 OFF END #1                  !END OF FILE RECOVERY                  06MAY82
12880 CHECK READ OFF #1                                                 !06MAY82
12890 PRINT "HIT END OF FILE ON MAG TAPE. CREATING NEW FILE."           !06MAY82
12900 BEEP
12910 GOSUB Tapestop              !CLOSE CURRENT FILE                    06MAY82
12920 Keyentry$="N"
12930 GOSUB Tapeini               !CREATE A NEW FILE                     06MAY82
12940 GOTO 12530                  !GO BACK AND WRITE SHOT DATA           06MAY82
12950 !
12960 ! ************************************************************************
12970 END  !END OF MAIN PROGRAM  END OF MAIN PROGRAM  END OF MAIN PROGRAM
12980 !
12990 ! ************************************************************************
13000 !                    SUBROUTINE AAPPR                              17JUN82
13010 !          To adjust Anode channel heat deposition for             05NOV82
13020 !       Fil heat load & Arc heat load at given Power level         05MAY83
13030 SUB Aappr(Tac,Tar,Tfil,Var,Iar,Nz,Rese(*),Slope(*),Fil(*),Appr(*))!17JUN82
13040 OPTION BASE 1                                                    ! 17JUN82
13050 INTEGER I                                                        ! 17JUN82
13060 !                                                                  17JUN82
13070 IF Tfil=0 THEN Tfil=.001                                          !16JUN83
13080 IF (Tac<.002) AND (Var=0) THEN Filonly        ! Branch on FIL only 16JUN83
13090 IF Tac=0 THEN Tac=.001                                           ! 17JUN82
13100 IF Tar=0 THEN Tar=.002             ! Let's not have anything       17JUN82
13110 !                                  ! calculated using zero,        16JUN83
13120 IF Var=0 THEN Var=1                ! to avoid ERRM$ on trigger     17JUN82
13130 IF Iar=0 THEN Iar=1                ! shots etc.                    17JUN82
13140 !                                                                  17JUN82
13150 Var1=Var*Iar/1000*Tar               ! Var1[kJ] is:                 17JUN82
13160                                     ! Arc Volts times Arc Amps [kW]17JUN82
13170                                     ! times Arc on-time.           17JUN82
```

```
13180 !                                                               17JUN82
13190 FOR I=1 TO Nz                      !                            17JUN82
13200 !                                                               17JUN82
13210 Var2=Rese(I)-(Slope(I)*Var1+Fil(I)*(Tfil-Tac))             !  05MAY83
13220                                    ! Var2[kJ] is:               17JUN82
13230                                    ! Total kJ/Ch. minus the sum  17JUN82
13240                                    ! of %Parc times Var1[kJ] &   17JUN82
13250                                    ! normalized Fil heat[kJ].    17JUN82
13260 !                                                               17JUN82
13270 Appr(I)=Var2/Tac                   ! Appr[kW] is:               17JUN82
13280                                    ! Var2[kJ] divided by Beam on-17JUN82
13290                                    ! time .                     17JUN82
13300 NEXT I                                                        ! 17JUN82
13310 SUBEXIT
13320 !                                                               17JUN82
13330 !                   FILAMENT ONLY SHOT PROCESSING               17JUN82
13340 !                                                               17JUN82
13350 Filonly: FOR I=1 TO Nz
13360 Appr(I)=Rese(I)/Tfil                                          ! 17JUN82
13370 NEXT I                                                        ! 17JUN82
13380 !                                                               17JUN82
13390 SUBEND                                                        ! 17JUN82
13400 !
13410 ! *****************************************************************
13420 !                     SUBROUTINE AGETPKPWR                     !18MAR82
13430 !
13440 ! Agetpkpwr calculates the peak power dissipated by the anodes in
13450 ! watts through each cooling channel.
13460 !
13470 ! CALL Agetpkpwr(Anz,Axm(*),Asf(*),Apeak_pwr(*))
13480 !
13490 ! Anz is number of anode cooling channels
13500 ! Axm(Anz) contains largest temperature sensed in each channel
13510 ! Asf(Anz) contains the flow through each channel
13520 ! Apeak_pwr(Anz) returns the peak power dissipated in each channel
13530 !
13540 !   DEG C * ML   *  JOULES   = JOULES/SEC = WATTS
13550 !           SEC    ML*DEG C
13560 !
13570 SUB Agetpkpwr(Anz,Axm(*),Asf(*),Apeak_pwr(*))
13580 OPTION BASE 1
13590 INTEGER J
13600 FOR J=1 TO Anz
13610 Apeak_pwr(J)=Axm(J)*Asf(J)*4.18
13620 NEXT J
13630 SUBEND
13640 !                                                             ! 22JAN82
13650 ! ********************************************************************
13660 !                   SUBROUTINE APPR                           ! 28JAN82
13670 !          To adjust each channels heat deposition for        ! 28JAN82
13680 !       Fil heat load & Arc heat load at given Power level.   ! 28JAN82
13690 !                                                             ! 28JAN82
13700 SUB Appr(Tacc,Tarc,Tfil,Varc,Iarc,Nz,Rese(*),Slope(*),Fil(*),Appr(*))!18MA
13710 OPTION BASE 1                                               ! 28JAN82
13720 INTEGER I                                                   ! 18MAR82
13730 !                                                           ! 28JAN82
13740 IF Tfil=0 THEN Tfil=.001          !                           31May83
13750 IF (Tacc<.002) AND (Varc=0) THEN Filonly      ! Branch on FIL only
13760 IF Tacc=0 THEN Tacc=.001                                    ! 28JAN82
13770 IF Tarc=0 THEN Tarc=.002         ! Let's not have anything     1FEB82
13780 !                                ! calculated using zero,      1FEB82
13790 IF Varc=0 THEN Varc=1            ! to avoid ERRM$ on trigger   1FEB82
13800 IF Iarc=0 THEN Iarc=1            ! shots etc.                  1FEB82
13810 !                                                           ! 28JAN82
13820 Var1=Varc*Iarc/1000*(Tarc-Tacc)   ! Var1[kJ] is:              28JAN82
```

```
13830                                     ! Arc Volts times Arc Amps [kW]28JAN82
13840                                     ! times Arc on-time less Accel 28JAN82
13850                                     ! on-time.                     28JAN82
13860 FOR I=1 TO Nz                                                    ! 18MAR82
13870 !                                                                ! 28JAN82
13880 Var2=Rese(I)-(Slope(I)*Var1+Fil(I)*(Tfil-Tacc))                  ! 28JAN82
13890                                     ! Var2[kJ] is:                 28JAN82
13900                                     ! Total kJ/Ch. minus the sum   28JAN82
13910                                     ! of %Parc times Var1[kJ] &    28JAN82
13920                                     ! normalized Fil heat[kJ].     28JAN82
13930 !
13940 Appr(I)=Var2/Tacc*(1000/21.5)     ! Appr[W/rail] is:               28JAN82
13950                                   ! Var2[kJ] divided by Beam on-   28JAN82
13960                                   ! time & adjusted for Watts/rail.28JAN82
13970 NEXT I                                                           ! 28JAN82
13980 SUBEXIT
13990 !
14000 !                    FIL ONLY SHOT PROCESSING
14010 !
14020 Filonly:FOR I=1 TO Nz
14030 Appr(I)=Rese(I)/Tfil*(1000/21.5)
14040 NEXT I
14050 !
14060 SUBEND
14070 !
14080 ! *********************************************************************
14090 !                         SUBROUTINE COUNTR                    !28APR82
14100 !               Reading Arc and Accel Pulse Duration
14110 !                     and zero-ing the counters.
14120 !
14130 SUB Countr(Tarc,Tacc,Tfil)
14140 OPTION BASE 1
14150 DIM X(30),V(3)
14160 Eot=4
14170 Null=0
14180 Cr=13
14190 Sp=32
14200 Zero=48
14210 Nine=57
14220 Card=10                      !SELECT CODE
14230 Count=0
14240 MAT X=ZER
14250 !
14260 RESET Card                   !RESET INTERFACE
14270 WAIT WRITE Card,5;1          !R4 TO "CONTROL" USE
14280 WAIT WRITE Card,4;64         !RESET USART
14290 WAIT WRITE Card,4;79         !USART MODE-1/64,8 BITS,1 STOP BIT
14300 WAIT WRITE Card,4;55         !USART CONTROL-ENABLE XMITTER,RECEIVER,
14310                              !             -RESET STATUS,SET DSR,CTS
14320 WAIT WRITE Card,5;0          !R4 TO "DATA" USE
14330 !
14340 ON INT #Card,15 GOSUB Isr    !SETUP FOR RECEIVER INTERRUPT SERVICE
14350 CONTROL MASK Card;132
14360 WAIT WRITE Card,7;0          !DECLARE INPUT REGISTER EMPTY
14370 CARD ENABLE Card             !ENABLE INTERRUPTS
14380 !
14390 WAIT WRITE Card,4;18         !SEND DC2 TO RESET 779
14400 WAIT WRITE Card,4;20         !SEND DC4 TO START 779
14410 !
14420 FOR Iwait=1 TO 3000          !WAIT FOR COMPLETION OF INPUT
14430 IF Y=Eot THEN GOTO 14460
14440 NEXT Iwait
14450 !
14460 OFF INT #10
14470 IF Iwait>3000 THEN GOTO Bad
14480 !
```

```
14490 I=1                          !SEARCH FOR 1ST COUNTER DIGITS
14500 IF (X(I)>=Zero) AND (X(I)<=Nine) THEN GOTO Getval
14510 IF X(I)<>Null THEN GOTO Bad  !IGNORE LEADING NULLS
14520 I=I+1
14530 IF I<=30 THEN GOTO 14500
14540 !
14550 Bad: Tacc=.002               !ERROR DETECTED
14560 Tarc=.002
14570 Tfil=3.5
14580 SUBEXIT
14590 !
14600 Getval:FOR J=1 TO 3          !GET VALUES FROM COUNTER INPUT
14610 V(J)=0
14620 FOR K=1 TO 6
14630 IF I>30 THEN GOTO Bad        !TEST FOR END OF STRING
14640 IF (X(I)<Zero) OR (X(I)>Nine) THEN GOTO Bad!TEST FOR A DIGIT
14650 V(J)=V(J)*10+X(I)-Zero       !ADD IN THIS DECADE
14660 I=I+1
14670 NEXT K                       !GOTO NEXT CHARACTER
14680 IF (X(I)<>Sp) AND (X(I)<>Cr) THEN Bad !DEMAND SPACE/CR AFTER VALUE
14690 I=I+1
14700 NEXT J                       !GOTO NEXT VALUE
14710 !
14720 Tacc=V(1)*1E-4               !CONVERT TO SEC
14730 Tarc=V(2)*1E-4
14740 Tfil=V(3)*1E-4
14750 SUBEXIT
14760 Isr:WAIT READ Card,4;Y
14770 IF Y=Eot THEN RETURN
14780 Count=Count+1
14790 X(Count)=Y
14800 IF Count=30 THEN GOTO 14840
14810 WAIT WRITE Card,7;0
14820 CARD ENABLE Card
14830 RETURN
14840 Y=Eot
14850 RETURN
14860 SUBEND
14870  ! ***********************************************************************
14880  !                         SUBROUTINE DAYTIME                        ! 22JAN82
14890  !                 Get the time and date from the 3497A              ! 22JAN82
14900  !                                                                  ! 22JAN82
14910  SUB Daytime(Month,Day,Hour,Minute,Second)                         ! 22JAN82
14920  OPTION BASE 1
14930  DIM A$(1)                                                         ! 22JAN82
14940  !                                                                ! 25JAN82
14950  OUTPUT 709;"TD"                                                   ! 22JAN82
14960  ENTER 709;A$                                                      ! 22JAN82
14970  !                                                                ! 25JAN82
14980  Month=VAL(A$[1,2])                                                ! 22JAN82
14990  Day=VAL(A$[4,5])                                                  ! 22JAN82
15000  Hour=VAL(A$[7,8])                                                 ! 22JAN82
15010  Minute=VAL(A$[10,11])                                             ! 22JAN82
15020  Second=VAL(A$[13,14])                                             ! 22JAN82
15030  !                                                                ! 25JAN82
15040 SUBEND
15050 !
15060 ! **********************************************************************
15070 !                           SUBROUTINE DUMP
15080 SUB Dump
15090 DUMP GRAPHICS
15100 SUBEND
15110 !
15120 ! *********************************************************************
15130 !                        SUBROUTINE GETFLOW                           !18MAR82
15140 !
```

```
15150 ! Getflow converts the flowmeter digitizings to milliliters/sec.
15160 ! The flow returned in Sf(*) is the average of the baseline readings
15170 ! in Flowb(*) by channel(flowmeter). For Ramapo type call with vref2
15180 ! = reference voltage. For Flow Technology type call with vref2 = 0.
15190 ! CALL Getflow(Nz,Nbase,Fmc1(*),Fmc2(*),Voff(*),Vref2,Flowb(*),Sf(*))
15200 !
15210 ! Nz is number of flowmeters
15220 ! Nbase is number of readings taken for determining flow
15230 ! Fmc1(Nz) is array of slopes for flow conversion
15240 ! Fmc2(Nz) is array of intercepts for flow conversion
15250 ! Voff(Nz) is array of flowmeter offsets
15260 ! Vref2 is flowmeter reference voltage or zero for Flow Technology type.
15270 ! Flowb(Nz,Nbase) is array of flowmeter digitizings which get
15280 !                converted to ml/sec.
15290 ! Sf(Nz) is array of averaged flowmeter readings.
15300 !
15310 SUB Getflow(Nz,Nbase,Fmc1(*),Fmc2(*),Voff(*),Vref2,Flowb(*),Sf(*))
15320 OPTION BASE 1
15330 INTEGER I,J
15340 Ref=Vref2                                                        !13JUN83
15350 IF Ref=0 THEN Ref=1000.0!FLOW TECHNOLOGY TYPE CALIBRATIONS ARE IN MLPS
15360                         ! PER VOLT. 1000 UNDOES CONVERSION TO MV BELOW.
15370 FOR I=1 TO Nz
15380 Sf(I)=0
15390 FOR J=1 TO Nbase
15400 Flowb(I,J)=(Flowb(I,J)*1000.0-Voff(I))/Ref*Fmc1(I)+Fmc2(I)    !V TO milli v
15410 Sf(I)=Sf(I)+Flowb(I,J)/Nbase
15420 NEXT J
15430 NEXT I
15440 SUBEND
15450 !
15460 ! ***********************************************************************
15470 !                       SUBROUTINE GETMAX
15480 !
15490 ! Getmax determines the maximum value for each channel in the
15500 ! data array Tempm and also the overall maximum value.
15510 !
15520 ! CALL Getmax(Nz,Nmeas,Tempm(*),Xm(*),Tempmax)
15530 !
15540 ! Nz is the number of data channels
15550 ! Nmeas is the number of measurements
15560 ! Tempm(Nz,Nmeas) is temperature array
15570 ! Xm(Nz)  returns the maximum value for each of the Nz data channels
15580 ! Tempmax returns the overall maximum value in Tempm.
15590 !
15600 SUB Getmax(Nz,Nmeas,Tempm(*),Xm(*),Tempmax)
15610 OPTION BASE 1
15620 INTEGER I,J
15630 Tempmax=0
15640 FOR I=1 TO Nz                            !Get maximum by channel    18MAR82
15650 K=0
15660 FOR J=1 TO Nmeas
15670 K=MAX(K,Tempm(I,J))
15680 NEXT J
15690 Xm(I)=K
15700 Tempmax=MAX(Tempmax,K)
15710 NEXT I
15720 SUBEND
15730 !
15740 ! **********************************************************************
15750 !                    SUBROUTINE GETPERCENT                     18MAR82
15760 !
15770 ! Getpercent converts the values in Tempm to a percent of the
15780 ! largest value in Tempm and returns these percentages in Tempmt.
15790 !
15800 ! CALL Getpercent(Nz,Nmeas,Tempmax,Tempm(*),Tempmt(*))
```

```
15810 !
15820 ! Nz is the number of channels of data in Tempm
15830 ! Nmeas is the number of values for each channel
15840 ! Tempmax is largest value in Tempm
15850 ! Tempm(Nz,Nmeas) contains the data to be converted to percent
15860 ! Tempmt(Nz,Nmeas) returns the data converted to percentages of Tempmax
15870 !
15880 SUB Getpercent(Nz,Nmeas,Tempmax,Tempm(*),Tempmt(*))
15890 OPTION BASE 1
15900 INTEGER I,J
15910 Xplot=Tempmax
15920 IF Xplot=0 THEN Xplot=1
15930 Xplot=100/Xplot
15940 FOR J=1 TO Nz                     !Convert values to percent
15950 FOR I=1 TO Nmeas
15960 Tempmt(J,I)=Tempm(J,I)*Xplot
15970 NEXT I
15980 NEXT J
15990 SUBEND
16000 !
16010 ! ****************************************************************
16020 !                   SUBROUTINE GETPKPWR                         !18MAR82
16030 ! Getpkpwr calculates the peak power dissipation on each grid half.
16040 !
16050 ! CALL Getpkpwr(Nz,Xm(*),Sf(*),Peak_pwr(*))
16060 !
16070 ! Nz is number of data channels(no. of grid halves)
16080 ! Xm(Nz) contains the maximum temperature sensed for each grid half.
16090 ! Sf(nz) contains the flow through each grid half.
16100 ! Peak-pwr(Nz) returns the power peak-power dissipated in each grid half.
16110 !
16120 !  DEG C * ML  *   1   *  JOULES   = JOULES/SEC  = WATTS
16130 !          SEC   RAILS   ML*DEG C       RAIL         RAIL
16140 !
16150 SUB Getpkpwr(Nz,Xm(*),Sf(*),Peak_pwr(*))!
16160 OPTION BASE 1
16170 INTEGER J
16180 I=4.18/21.5             !ml/sec   !division by number of rails per half grid
16190 FOR J=1 TO Nz
16200 Peak_pwr(J)=Xm(J)*Sf(J)*I
16210 NEXT J
16220 SUBEND
16230 !
16240 ! ****************************************************************
16250 !                    SUBROUTINE GETTEMP                   18MAR82
16260 !
16270 ! Gettemp converts temperature sensor digitizings to temperture
16280 !
16290 ! CALL Gettemp(Nz,Nmeas,St(*),Tempm(*))
16300 !
16310 ! Nz is number of data channels to be converted
16320 ! Nmeas is number of measurements in each channel
16330 ! St is array of baseline values for each channel to be
16340 !     subtracted from each value in that channel. If operator
16350 !     suppresses the baseline subtraction, St will contain
16360 !     all zeros.
16370 ! Tempm(Nz,Nmeas) is array of digitizings to be converted to temperature
16380 !
16390 SUB Gettemp(Nz,Nmeas,St(*),Tempm(*))
16400 OPTION BASE 1
16410 INTEGER I,J
16420 FOR J=1 TO Nz
16430 Stj=St(J)
16440 FOR I=1 TO Nmeas
16450    !  Includes conversion: micro-V/degC. and sign inversion.
```

```
16460 Tempm(J,I)=-((Tempm(J,I)-St(j)/4.0199E-5)
16470 NEXT I
16480 NEXT J
16490 SUBEND
16500 !
16510 ! ********************************************************************
16520 !                     SUBROUTINE GETTEMPBASE                   !18MAR82
16530 !
16540 ! Gettempbase determines the temperature baseline by averaging
16550 ! the temperature baseline readings for each channel. No conversion
16560 ! to temperature is done. If baseline subtraction is suppressed,
16570 ! Basel$="N" and Gettempbase will return all zeros in ST(*).
16580 !
16590 ! CALL Gettempbase(Basel$,Nz,Nbase,Tempb(*),St(*))
16600 !
16610 ! Basel$ is baseline subtraction flag.
16620 ! Nz is number of temperature sensors
16630 ! Nbase is number of baseline readings
16640 ! Tempb(Nz,Nbase) is array of baseline readings
16650 ! ST(Nz) returns averaged baseline values
16660 !
16670 SUB Gettempbase(Basel$,Nz,Nbase,Tempb(*),St(*))
16680 OPTION BASE 1
16690 INTEGER I,J
16700 MAT St=ZER
16710 IF Basel$="N" THEN SUBEXIT
16720 FOR I=1 TO Nz
16730 FOR J=1 TO Nbase
16740 St(I)=St(I)+Tempb(I,J)/Nbase
16750 NEXT J
16760 NEXT I
16770 SUBEND
16780 ! ***********************************************************************
*
16790 !                     SUBROUTINE GETXTIME
16800 !
16810 ! Getxtime detemines the x coordinates for a plot as percentage of
16820 ! total time.
16830 !
16840 ! CALL Getxtime(Idelt,Istart,Iend,Tmax,Nmeas,Tmax,Timem,Tmes)
16850 !
16860 ! Idelt is number of channels used
16870 ! Istart is first channel used
16880 ! Iend is last channel used
16890 ! Tmax is total time
16900 ! Nmeas is total number of measurements during Tmax
16910 ! Timem returns times as percent of time between Istart and Iend
16920 ! Tmes returns time between Istart and Iend
16930 !
16940 SUB Getxtime(Idelt,Istart,Iend,Tmax,Nmeas,Timem(*),Tmes)
16950 OPTION BASE 1
16960 INTEGER I
16970 Jdelt=100/Idelt
16980 J=.5*Jdelt
16990 FOR I=Istart TO Iend
17000 Timem(I)=J
17010 J=J+Jdelt
17020 NEXT I
17030 Tmes=Tmax*Idelt/Nmeas
17040 SUBEND
17050 !
17060 ! ******************************************************************
17070 !                       SUBROUTINE GRIDFRAME                  18MAR82
17080 !
17090 !  Gridframe plots the frame for a grid, puts tick marks on the
17100 !  frame, draws horizontal lines at 0 and 100 percent, and plots
```

```
17110 !  the grid id.
17120 !
17130 !  CALL Gridframe(Lxuxlyuy(*),I,Anode,Rover)                         !20APR82
17140 !
17150 !  Lxuslyuy(*) is lower and upper bounds of horizontal axis and
17160 !              plus lower and upper bounds of vertical axis in mm
17170 !  I           is the grid number
17180 !  Anode       is anode channel which gets plotted on this grid
17190 !              and is 0 if there is none.
17200 !  Rover       is the rover channel which gets plotted on this grid!20APR8
17210 !              and is zero if there is none.
17220 SUB Gridframe(Lxuxlyuy(*),I,Anode,Rover)
17230 !
17240 OPTION BASE 1
17250 LIMIT Lxuxlyuy(1),Lxuxlyuy(2),Lxuxlyuy(3),Lxuxlyuy(4)
17260 SCALE 0,100,-10,110
17270 CSIZE 7.5
17280 AXES 10,10,100,110,1,1,6
17290 AXES 10,10,0,-10,1,1,6
17300 MOVE 0,0
17310 DRAW 100,0
17320 MOVE 0,100
17330 DRAW 100,100
17340 MOVE 50,10
17350 LORG 4
17360 IF Anode=0 THEN GOTO 17400
17370 LABEL USING 17380;"GRID";I;" & e"&CHR$(176)&" DUMP"                !13JUN83
17380 IMAGE 4A,X,D,10A
17390 GOTO 17450
17400 IF Rover=0 THEN 17430                                              !20APR82
17410 LABEL USING 17380;"GRID";I;" & ROVER "                             !20APR82
17420 GOTO 17450                                                         !20APR82
17430 LABEL USING 17440;"GRID";I
17440 IMAGE 4A,X,D
17450 LORG 1
17460 SUBEND
17470 ! *********************************************************************
17480 !                         SUBROUTINE HPCLOCK                        !  9FEB82
17490 !                      To get the most accurate time                !  9FEB82
17500 !                       for pulse temp measurement.                 !  9FEB82
17510 !                                                                      9FEB82
17520 SUB Hpclock(Month,Day,Hour,Minute,Second)                         !  9FEB82
17530 !                                                                      9FEB82
17540 OUTPUT 9;"U2C"                          ! RESET  CLOCK                 9FEB82
17550 OUTPUT 9;"R"                            ! Request Time and Date        9FEB82
17560 ENTER 9;Month,Day,Hour,Minute,Second    ! Input  Time and Date         9FEB82
17570 !                                                                      9FEB82
17580 SUBEND                                                            !  9FEB82
17590 !
17600 ! ********************************************************************
17610 !                             SUBROUTINE INTG
17620 !                         Heat Deposition Integration
17630 !
17640 !    DEG C *  ML   * SEC *    KJ     = KJ             (constant flow)
17650 !            SEC           ML*DEG C
17660 !
17670 SUB Intg(Rese(*),Istart,Iend,Nsi,Nsf,Tmax,Tempm(*),Sf(*),Nmeas,Cf(*))!29AP
17680 OPTION BASE 1
17690 INTEGER Ix,Jx
17700 FOR Ix=Nsi TO Nsf                                                !18MAR82
17710 R=0                                                              !18MAR82
17720 FOR Jx=Istart TO Iend                                            !18MAR82
17730 R=R+Tempm(Ix,Jx)                                                 !18MAR82
17740 NEXT Jx                                                          !18MAR82
17750 Rese(Ix)=R*Sf(Ix)*(Tmax/Nmeas)*.00418*Cf(Ix)                     !29APR82
```

```
17760 NEXT Ix                                                          !18MAR82
17770 SUBEND
17780 ! *************************************************************************
17790 !                     SUBROUTINE LOGO
17800 !            THIS SUBROUTINE DRAWS THE LBL LOGO
17810 !
17820 SUB Logo
17830 !
17840 !
17850 X=113                !  X,Y ARE THE COORDINATES OF THE POSITION OF THE LOGO
17860 Y=10
17870 LOCATE X,X+40/5.59,Y,Y+40/5.59
17880 SCALE 0,39,0,39
17890 PEN 1
17900 MOVE 0,0
17910 FOR I=0 TO 39     ! BLACK OUT
17920 DRAW 39,I
17930 MOVE 0,I+1
17940 NEXT I
17950 PEN -1
17960 MOVE 16,7
17970 FOR I=7 TO 10
17980 DRAW 31,I
17990 MOVE 16,I+1
18000 NEXT I
18010 MOVE 16,11
18020 FOR I=11 TO 12
18030 DRAW 19,I
18040 MOVE 16,I+1
18050 NEXT I
18060 MOVE 8,14
18070 FOR I=14 TO 17 STEP 3
18080 DRAW 30,I
18090 MOVE 8,I+3
18100 NEXT I
18110 MOVE 8,15
18120 FOR I=15 TO 16
18130 DRAW 31,I
18140 MOVE 8,I+1
18150 NEXT I
18160 MOVE 8,14
18170 FOR I=8 TO 11
18180 DRAW I,34
18190 MOVE I+1,14
18200 NEXT I
18210 MOVE 16,19
18220 FOR I=16 TO 19
18230 DRAW I,34
18240 MOVE I+1,19
18250 NEXT I
18260 MOVE 20,31
18270 FOR I=20 TO 28
18280 DRAW I,34
18290 MOVE I+1,31
18300 NEXT I
18310 MOVE 29,32
18320 DRAW 29,33
18330 MOVE 22,24
18340 FOR I=22 TO 25
18350 DRAW I+3,31
18360 MOVE I+1,24
18370 NEXT I
18380 MOVE 22,24
18390 FOR I=22 TO 25
18400 DRAW I+5,18
18410 MOVE I+1,24
```

```
18420 NEXT I
18430 SUBEND
18440 !
18450 ! *****************************************************************
18460 !                          SUBROUTINE MCSET3497A                     18MAR82
18470 !
18480 ! Mcset3497a sets up the string which is sent to the HP 3497A
18490 ! before the flowmeter and temperature multichannel reads.
18500 !
18510 ! Call Mcset3497a(Fc$,Lc$,ALc$,Ano$,Nch,Nz,Anz,Sus$)
18520 !
18530 ! Fc$ is the first channel of a sequence of channels
18540 ! Lc$ is the last channel of a sequence of channels without anode
18550 ! Alc$ is the last channel of a sequence with anode
18560 ! Ano$ is the anode present flag
18570 ! Nch returns the number of channels in the sequence
18580 ! Nz returns number of grid calorimetry channels
18590 ! Anz returns number of anode calorimetry channels
18600 ! Sus$ returns the HP 3497A setup string
18610 !
18620 !  AC_   CLOSE CHANNEL             VN_      NUMBER OF CHANNELS
18630 !  AF_   FIRST CHANNEL             AE1      EXTERNAL INCREMENT ON
18640 !  AL_   LAST CHANNEL              S01      SYSTEM WAIT
18650 !  VT4   TRIGGER HOLD              VS2      STORE PACKED DIGITIZINGS
18660 !  VR1   .1 V RANGE                VF2      PACKED FORMAT
18670 !  VA0   AUTOZERO OFF                        ______
18680 !  VD5   5 DIGITS/CONVERSION
18690 SUB Mcset3497a(Fc$,Lc$,Alc$,Ano$,Nch,Nz,Anz,Sus$)
18700 DIM A$[2],Nc$[2]
18710 FIXED 0
18720 A$=Lc$
18730 IF Ano$="Y" THEN A$=Alc$
18740 Nch=VAL(A$)-VAL(Fc$)+1
18750 Nz=VAL(Lc$)-VAL(Fc$)+1
18760 Anz=VAL(Alc$)-VAL(Lc$)
18770 Nc$=VAL$(INT(Nch))
18780 Sus$="VT4AC"&Fc$&"AF"&Fc$&"AL"&A$&"VR1VA0VD5VN"&Nc$&"AE1S01VS2VF2"!05MAY83
18790 SUBEND
18800 ! *******************************************************************
18810 !                        SUBROUTINE NEWTIME                     ! 22JAN82
18820 !      Set the time and date in the 3497A or real time clock    ! 18MAR82
18830 !                                                               ! 22JAN82
18840 SUB Newtime(Clock$)                                           !  9FEB82
18850 OPTION BASE 1                                                ! 25JAN82
18860 DIM B$[13]                                                    !18MAR82
18870 !                                                            25JAN82
18880 IF Clock$="N" THEN LET B$[1,2]="TD" ! Set first part for the 3497A.18MAR82
18890 IF Clock$="Y" THEN LET B$[1,2]="S " ! Set first part/ HP clock     18MAR82
18900 !                                                                  9FEB82
18910 !          ask for the next bits:                            25JAN82
18920 !                                                            25JAN82
18930 INPUT "Enter two digits for the Month",B$[3,4]                ! 18MAR82
18940 INPUT "Enter two digits for the Day  ",B$[5,6]                ! 18MAR82
18950 INPUT "Enter two digits for the Hour ",B$[7,8]                ! 18MAR82
18960 INPUT "Enter two digits for the Minute",B$[9,10]              ! 18MAR82
18970 B$[11,13]="00/"              ! Let's make the seconds 0          22JAN82
18980 !                                                             ! 22JAN82
18990 IF Clock$="Y" THEN GOTO 19040                                 !  9FEB82
19000 CLEAR 709                                                     ! 22JAN82
19010 OUTPUT 709;B$                  ! Stuff new Date/Time in 3497A.   18MAR82
19020 GOTO 19050                                                    !  9FEB82
19030 !                                                                  9FEB82
19040 OUTPUT 9;B$                    ! Stuff new Date/Time in HP clock. 18MAR82
19050 SUBEND                                                        ! 22JAN82
19060 !
19070 ! *****************************************************************
```

```
19080 !                       SUBROUTINE PICTLABEL              18MAR82
19090 !
19100 ! Pictlabel plots the labels on the display without any current
19110 ! values so that the image can be saved for recall on each shot.
19120 !
19130 ! CALL Pictlabel(Version$,Ano$,Rover$)                            !20APR82
19140 !
19150 ! Version$ is the program revision number.
19160 ! Ano$ is anode data flag
19170 ! Rover$ is rover data flag                                       !20APR82
19180 !
19190 SUB Pictlabel(Version$,Ano$,Rover$)
19200 OPTION BASE 1
19210 DEG
19220 MSCALE 0,0
19230 MOVE 40,145
19240 LABEL USING 19250;"PULSESHAPE OF TEMPERATURE ";"SHOT #"
19250 IMAGE 27A,4X,6A,1X
19260 IF Rover$="N" THEN GOTO 19340
19270 MOVE 20,25                                                        !20APR82
19280 LABEL USING 19290;"GRID TMAX=","SEC","ROVER TMAX=","SEC"
19290 IMAGE 10A,6X,3A,3X,11A,6X,3A                                      !20APR82
19300 MOVE 20,20                                                        !20APR82
19310 LABEL USING 19320;"GRID PTS =","ROVER PTS ="                      !20APR82
19320 IMAGE 10A,12X,11A                                                 !20APR82
19330 GOTO 19400                                                        !20APR82
19340 MOVE 40,25
19350 LABEL USING 19360;"PERCENTAGE OF TIME TMAX=";"SEC"
19360 IMAGE 24A,6X,3A
19370 MOVE 40,20
19380 LABEL USING 19390;"NUMBER OF POINTS SHOWN:"
19390 IMAGE 23A,X
19400 LDIR 90
19410 MOVE 15,30
19420 LABEL USING 19430;"% OF DELTA-T.,GRIDS ";"DEG"
19430 IMAGE 26A,6X,4A
19440 MOVE 160,30                                                       !20APR82
19450 IF Ano$="N" THEN 19490                                            !20APR82
19460 LABEL USING 19470;"% OF DELTA-T.,"&"e"&CHR$(176)&" DUMP ";"DEG"   !13JUN83
19470 IMAGE 28A,4X,4A                                                   !13JUN83
19480 MOVE 165,30                                                       !20APR82
19490 IF Rover$="N" THEN GOTO 19510                                     !20APR82
19500 LABEL USING 19470;"% OF DELTA-T.,ROVER ";"DEG"                    !20APE82
19510 CSIZE 2
19520 MOVE 175,30
19530 LABEL USING 19540;"Rev. ";Version$
19540 IMAGE 5A,9A
19550 SUBEND
19560 !
19570 ! ************************************************************************
19580 !                         SUBROUTINE PLOT1
19590 !                 Plotting of Labels and Titles
19600 !
19610 SUB Plot1(Tmes,Tempmax,Idelt,Snr,Atempmax,Ano$,Rtmes,Rtempmax,Rdelt,Rover$
)!20APR82
19620 OPTION BASE 1
19630 DEG
19640 LIMIT 0,184,0,149.8
19650 MSCALE 0,0
19660 MOVE 152,145
19670 LABEL USING 19680;Snr
19680 IMAGE DDDDDD
19690 IF Rover$="N" THEN GOTO 19790                                     !20APR82
19700 MOVE 49,25                                                        !20APR82
19710 LABEL USING 19810;Tmes                                            !20APR82
19720 MOVE 117,25                                                       !20APR82
```

```
19730 LABEL USING 19810;Rtmes                                             !20APR82
19740 MOVE 49,20                                                          !20APR82
19750 LABEL USING 19840;Idelt                                             !20APR82
19760 MOVE 117,20                                                         !20APR82
19770 LABEL USING 19840;Rdelt                                             !20APR82
19780 GOTO 19850                                                          !20APR82
19790 MOVE 110,25
19800 LABEL USING 19810;Tmes
19810 IMAGE DDDD.D
19820 MOVE 109,20
19830 LABEL USING 19840;Idelt
19840 IMAGE DDD
19850 LDIR 90
19860 MOVE 15,105
19870 LABEL USING 19880;Tempmax                                         !18MAR82
19880 IMAGE DD.DD
19890 MOVE 160,105                                                      !20APR82
19900 IF Ano$="N" THEN GOTO 19930                                       !20APR82
19910 LABEL USING 19880;Atempmax                                        !20APR82
19920 MOVE 165,105                                                      !20APR82
19930 IF Rover$="N" THEN SUBEXIT                                        !20APR82
19940 LABEL USING 19880;Rtempmax                                        !20APR82
19950 SUBEND
19960 !
19970 ! ***********************************************************************
19980 !                          SUBROUTINE PLOT2
19990 !                       Plotting of Graphs and Data
20000 !
20010 SUB Plot2(F(*),Timem(*),Tempmt(*),Rese(*),I,Istart,Iend,Atimem(*),Arese(*)
,Atempmt(*),Anode(*),Astart,Aend,Ano$)
20020 OPTION BASE 1
20030 Firsthalf=2*I-1
20040 Secondhalf=2*I
20050 Rese1=Rese(Firsthalf)                                            ! 18MAR82
20060 Rese2=Rese(Secondhalf)                                           ! 18MAR82
20070 Ts1=(Rese1-Rese2)*100                                             ! 18MAR82
20080 Prcntkj=0                                                        ! 18MAR82
20090 P=0                                                    !         18MAR82
20100 !                                                                 1FEB82
20110 IF Rese1<>0 THEN Prcntkj=ABS(Ts1/Rese1)                          ! 18MAR82
20120 IF Rese2<>0 THEN P=ABS(Ts1/Rese2)                                ! 18MAR82
20130 Prcntkj=MAX(Prcntkj,P)                                            ! 18MAR82
20140 !                                                                19JAN82
20150 LIMIT F(1),F(2),F(3),F(4)
20160 SCALE 0,100,-10,110
20170 CSIZE 7.5
20180 CALL Plotdata(1,Firsthalf,Timem(*),Tempmt(*),Istart,Iend)
20190 CALL Plotdata(3,Secondhalf,Timem(*),Tempmt(*),Istart,Iend)
20200 MOVE 10,90
20210 LABEL USING 20270;Rese1                                    !   18MAR82
20220 MOVE 70,90                                                 !   19JAN82
20230 LABEL USING 20240;Prcntkj;"%"                              !   19JAN82
20240 IMAGE DDD.DD,A                                             !   19JAN82
20250 MOVE 10,80
20260 LABEL USING 20270;Rese2                                    !   18MAR82
20270 IMAGE DDD.DD
20280 IF Ano$="N" THEN SUBEXIT
20290 IF Anode(I)=0 THEN SUBEXIT
20300 CALL Plotdata(5,Anode(I),Atimem(*),Atempmt(*),Astart,Aend)!   20APR82
20310 MOVE 10,70
20320 LABEL USING 20270;Arese(Anode(I))
20330 SUBEND
20340 !
20350 ! ******************************************************************
20360 !                        SUBROUTINE PLOTDATA                     !18MAR82
20370 !
```

```
20380 ! Plotdata plots the data for a temperature channel
20390 !
20400 ! CALL Plotdata(Linetype,Channel,Timem(*),Tempmt(*),Istart,Iend)
20410 !
20420 ! Linetype is line structure number
20430 ! Channel is data channel to be plotted
20440 ! Timem(*) contains the time scale(x-axis)
20450 ! Tempmt(*) contains the temperature percents(y-axis)
20460 ! Istart is first data value to be plotted
20470 ! Iend is last data value to be plotted
20480 !
20490 SUB Plotdata(Linetype,Channel,Timem(*),Tempmt(*),Istart,Iend)
20500 OPTION BASE 1
20510 INTEGER I
20520 LINE TYPE Linetype
20530 MOVE Timem(Istart),Tempmt(Channel,Istart)
20540 FOR I=Istart TO Iend
20550 DRAW Timem(I),Tempmt(Channel,I)
20560 NEXT I
20570 LINE TYPE 1
20580 SUBEND
20590 !
20600 ! **************************************************************************
20610 !                       SUBROUTINE RDFMR
20620 !                Read Flow Meter Reference Voltage
20630 !
20640 SUB Rdfmr(Fmrv$,Vref1,Vref2,Offref$)                              !18MAR82
20650 OPTION BASE 1      ! READ FLOW METER REFERENCE VOLTAGE
20660 DIM Sus$[30]                                                      !18MAR82
20670 !
20680 CALL Scset3497a(Fmrv$,Sus$)
20690 OUTPUT 709;Sus$
20700 ENTER 709;Vref2
20710 !
20720 !
20730 IF (Vref2>Vref1+.1) OR (Vref2<Vref1-.1) THEN Offref$="Y"
20740 !
20750 !
20760 SUBEND
20770 !
20780 ! ***********************************************************************
20790 !                       SUBROUTINE RDPARAM                       ! 25JAN82
20800 !              Reading Accel and Arc Volts and Amps                25JAN82
20810 !            from MODCOMP ports, read thru the 3497A.              16FEB82
20820 !                                                                  25JAN82
20830 SUB Rdparam(Vacc$,Iacc$,Varc$,Iarc$,Vacc,Iacc,Varc,Iarc)         ! 18MAR82
20840 OPTION BASE 1                                                    ! 25JAN82
20850 DIM Sus$[30]                                                     ! 18MAR82
20860 Vacmult=10                                ! Scale factors          16FEB82
20870 Iacmult=10                                ! of MODCOMP output      25JAN82
20880 Varmult=20                                ! needed @ Berkeley     16FEB82
20890 Iarmult=300                               ! N.B.: May not apply    16FEB8
2
20900                                           ! for LLL application.  16FEB82
20910 !                                                                  25JAN82
20920 ! Read Vacc in:                                                    25JAN82
20930 CALL Scset3497a(Vacc$,Sus$)
20940 OUTPUT 709;Sus$                                                  ! 18MAR82
20950 ENTER 709;Vacci                                                  ! 25JAN82
20960 Vacci=ABS(Vacci)                                                 ! 03JUN83
20970 IF Vacci<0 THEN LET Vacci=0                                      ! 16FEB82
20980 Vacc=Vacci*Vacmult                                               ! 25JAN82
20990 !                                                                ! 25JAN82
21000 ! Read Iacc in:                                                    25JAN82
21010 CALL Scset3497a(Iacc$,Sus$)                                      !18MAR82
21020 OUTPUT 709;Sus$                                                  ! 18MAR82
```

```
21030 ENTER 709;Iacci                                                 ! 25JAN82
21040 Iacci=ABS(Iacci)                                                ! 03JUN83
21050 IF Iacci<0 THEN LET Iacci=0                                     ! 16FEB82
21060 Iacc=Iacci*Iacmult                                              ! 25JAN82
21070 !                                                               ! 25JAN82
21080 ! Read Varc in:                                                   25JAN82
21090 CALL Scset3497a(Varc$,Sus$)                                     ! 18MAR82
21100 OUTPUT 709;Sus$                                                 ! 18MAR82
21110 ENTER 709;Varci                                                 ! 25JAN82
21120 IF Varci<0 THEN LET Varci=0                                     ! 16FEB82
21130 Varc=Varci*Varmult                                              ! 25JAN82
21140 !                                                               ! 25JAN82
21150 ! Read Iarc in:                                                   25JAN82
21160 CALL Scset3497a(Iarc$,Sus$)                                     ! 18MAR82
21170 OUTPUT 709;Sus$                                                 ! 18MAR82
21180 ENTER 709;Iarci                                                 ! 25JAN82
21190 IF Iarci<0 THEN LET Iarci=0                                     ! 16FEB82
21200 Iarc=Iarci*Iarmult                                              ! 25JAN82
21210 !                                                               ! 25JAN82
21220 SUBEND                                                          ! 25JAN82
21230 !
21240 ! ************************************************************************
21250 !
21260 !                       SUBROUTINE READ3497A             !18MAR82
21270 !
21280 ! Read3497A reads data from the HP 3497A in ascii.  Nrdgs reads
21290 ! are done with a delay of Tdelay between reads.  The 3497A is
21300 ! setup using the command string in SUS$.  The readings
21310 ! are returned in string array Buffer$(Nrdgs)[]. Ndrop readings are done
21320 ! and discarded before the Nrdgs readings are taken. The total time to
21330 ! the readings is returned via Tmax. The clock to use is given by Clock$
21340 !
21350 SUB Read3497a(Clock$,Nrdgs,Ndrop,Tdelay,Sus$,Buffer$(*),Tmax)
21360 OPTION BASE 1
21370 INTEGER I
21380 !
21390 OUTPUT 709;Sus$
21400 IF Ndrop<=0 THEN GOTO R5                                          !19Jan84
21410 !
21420 FOR I=1 TO Ndrop
21430 OUTPUT 709;"VT3"                  !  Do a
21440 OUTPUT 709;"VT4VS"                ! read and
21450 ENTER 709;Buffer$(1)              ! throw away.
21460 NEXT I
21470 !
21471 R5: SERIAL                                                       !19Jan84
21480 IF Clock$="Y" THEN GOTO R10       !                               05MAY83
21490 OUTPUT 709;"TE0TE2"             !USE 3497A ELAPSED TIMER          05MAY83
21500 GOTO R20                                                         !05MAY83
21510 !
21520 R10:OUTPUT 9;"U2=I1"            !USE 98035A REAL TIME CLOCK UNIT 2 05MAY83
21530 OUTPUT 9;"U2C"                     !CLEAR UNIT 2
21540 OUTPUT 9;"U2G"                     !START UNIT 2
21550 !
21560 R20:FOR I=1 TO Nrdgs               !  Loop to get data into Buffer
21570 OUTPUT 709;"VT3"                   !VT3 - Software trigger
21580 OUTPUT 709;"VT4VS"                 !VT4 - Trigger HOLD
21590 ENTER 709;Buffer$(I)               !VS  - Enable buffer readout
21600 WAIT Tdelay
21610 NEXT I
21620 IF Clock$="N" THEN R30                                           !05MAY83
21630 OUTPUT 9;"U2H"                     !STOP REAL TIME CLOCK
21640 OUTPUT 9;"U2V"                     !REQUEST VALUE
21650 ENTER 9;Tmax                       !GET TIME IN MILLISEC
21660 Tmax=Tmax/1000                     !CONVERT TO SEC
```

```
21670 GOTO R40                                                        !05MAY83
21680 !
21690 R30:OUTPUT 709;"TE1TE"           !STOP 3497A TIMER                05MAY83
21700 ENTER 709;Tmax                   !GET ELAPSED TIME
21710 !
21720 R40:OUTPUT 709;"AE0"             !AE0 - External increment OFF    05MAY83
21721 OVERLAP                                                         !19Jan84
21730 SUBEND
21740 ! **********************************************************************
21750 !
21760 !                      SUBROUTINE ROVERFINISH         !20apr82
21770 !
21780 ! Roverfinsih reads digitizings from the 3497a buffer. The
21790 ! digitizing must have been started by a call to Roverstart.
21800 ! For the nonbaseline readings, the timer will have already been
21810 ! stopped by Srqon7.
21820 !
21830 ! CALL Roverfinish(Buffer$(*),Tmax)
21840 !
21850 ! Buffer$(*) returns the digitizings read from the 3497A.
21860 ! Tmax returns the digitizing interval
21870 !
21880 SUB Roverfinish(Buffer$(*),Tmax)
21890 OPTION BASE 1                                                   !13MAY82
21900 OUTPUT 710;"VT4VS"               !VT4 - Trigger HOLD              05MAY83
21910 ENTER 710;Buffer$(*)             !VS  - Enable buffer readout
21920 OUTPUT 9;"U3V"                   !GET TIME. CLOCK STOPPED BY SRQHANDLER
21930 ENTER 9;Tmax                     !GET TIME IN MILLISEC
21940 Tmax=Tmax/1000                   !CONVERT TO SEC
21950 SUBEND
21960 ! **********************************************************************
21970 !
21980 !                      SUBROUTINE ROVERSTART          !20APR82
21990 !
22000 ! Roverstart starts up a set of digitizings in the 3497A which
22010 ! is device 10 on bus 7. The digitizings are stored the the 3497A
22020 ! buffer and read out later by a call to Roverfinish.
22030 !
22040 ! CALL Roverstart(Sus$)
22050 !
22060 ! Sus$ is the command string to send to the 3497A.
22070 !
22080 SUB Roverstart(Sus$)
22090 OPTION BASE 1
22100 !
22110 OUTPUT 710;Sus$                  !SETUP FOR DIGITIZIG
22120 OUTPUT 9;"U3=I2"                 !USE 98035A REAL TIME CLOCK UNIT 3
22130 OUTPUT 9;"U3C"                   !CLEAR UNIT 3
22140 OUTPUT 9;"U3G"                   !START UNIT 3
22150 OUTPUT 710;"VT3"                 !VT3 - Software trigger
22160 SUBEND
22170 !
22180 ! *******************************************************************
22190 !                    SUBROUTINE SCSET3497A                     !18MAR82
22200 !
22210 ! Scset3497a makes the string sent to the HP 3497A before single
22220 ! channel reads which do not return the result in ascii.
22230 !
22240 ! Call Scset3497a(Channel$,Sus$)
22250 !
22260 ! Channel$ is the channel number in ascii.
22270 ! Sus$ returns the channel number concatinated with the rest
22280 !       of the string to go to the HP 3497A.
22290 !
22300 SUB Scset3497a(Channel$,Sus$)
22310 Sus$="VT4VR5VD5VF1VS0AI"&Channel$                               !05MAY83
```

```
22320 SUBEND
22330 !
22340 ! ************************************************************
22350 !                    SUBROUTINE SPIKE                    !18MAR82
22360 !
22370 ! Spike reduces noise spikes in the data.
22380 !
22390 ! CALL Spike(Spike$,Nz,Nmeas,Tempm(*))
22400 !
22410 ! Spike$ is "Y" if spike suppression to be done;otherwise, "N"
22420 ! Nz is the number of data channels in Tempm
22430 ! Nmeas is the number of data points for each channel
22440 ! Tempm(Nz,Nmeas) contains the data for noise suppression
22450 !
22460 SUB Spike(Spike$,Nz,Nmeas,Tempm(*))
22470 OPTION BASE 1
22480 INTEGER J
22490 IF Spike$="N" THEN SUBEXIT
22500 FOR J=1 TO Nz
22510 FOR I=2 TO Nmeas-1             ! LOOP TO REDUCE NOISE SPIKES
22520 IF (ABS(Tempm(J,I-1)-Tempm(J,I))>=1) AND ABS(Tempm(J,I)-Tempm(J,I+1))>=1) T
HEN Tempm(J,I)=(Tempm(J,I-1)+Tempm(J,I+1))*.5
22530 NEXT I
22540 NEXT J
22550 SUBEND
22560 ! *************************************************************
22570 !                       SUBROUTINE SYSSTAT                     14DEC81
22580 !         READ SYSTEM TOTAL WATER FLOW and WATER CONDUCTIVITY   14DEC81
22590 !                                                              14DEC81
22600 SUB Sysstat(Tfl$,Tflo1,Tflo2,Offflo$,Cond$,Cond1,Cond2,Offcond$,Bflo)
  ! 14DEC81
22610 !                                                              18MAR82
22620 OPTION BASE 1                                                ! 14DEC81
22630 DIM Sus$[30]                                                 !18MAR82
22640 !                                                              14DEC81
22650 CALL Scset3497a(Tfl$,Sus$)                                   ! 18MAR82
22660 OUTPUT 709;Sus$                                              ! 18MAR82
22670 ENTER 709;Tflo2                                              ! 14DEC81
22680 !                                                              14DEC81
22690 IF (ABS(Tflo2)<ABS(Tflo1)+.0013) AND (ABS(Tflo2)>ABS(Tflo1)-.0013) THEN GO
TO 22750                                                           ! 29APR82
22700 Bflo1=ABS((Tflo1+.012)*1667)          ! Includes  conversion to GPM 14DEC81
22710 Bflo2=ABS((Tflo2+.012)*1667)                                 ! 14DEC81
22720 Bflo=Bflo1-Bflo2                                             ! 14DEC81
22730 ! Offflo$="Y"                         ! 2% deviation flagged        14DEC
81
22740 !                                                              14DEC81
22750 CALL Scset3497a(Cond$,Sus$)                                  ! 18MAR82
22760 OUTPUT 709;Sus$                                              ! 18MAR82
22770 ENTER 709;Cond2                                              ! 14DEC81
22780 Cond2=ABS(Cond2)                                             ! 14DEC81
22790 IF (Cond2>Cond1+.008) OR (Cond2<Cond1-.008) THEN Offcond$="Y"    ! 30APR82
22800 !                                                              14DEC81
22810 SUBEND                                                       ! 14DEC81
22820 !
22830 ! *************************************************************
22840 !                     SUBROUTINE UNPACK                 !18MAR82
22850 ! Unpack extracts values from the packed data obtained from
22860 ! the HP 3497A by Read3497a.
22870 !
22880 ! CALL Unpack(Nz,Nmeas,First,Buffer$(*),Values(*))
22890 !
22900 !  Nz        is number of values to be extracted from each element
22910 !               of Buffer$(*)
22920 !  Nmeas     is number of elements of Buffer$(*) from which values
22930 !               are to be extracted.
```

```
22940 !  First     is the ordinal of the first value to be extracted -
22950 !            from each element of Buffer(*).
22960 !  Buffer$(Nmeas) is an array in which each element contains the
22970 !            packed readings from a sequence of 3497a channels.
22980 !  Values(Nz,Nmeas)returns the unpacked digitizings. There are 3
22990 !            bytes per digitizing, Nz digitizings per element
23000 !            of Buffer$.
23010 !
23020 SUB Unpack(Nz,Nmeas,First,Buffer$(*),Values(*))
23030 OPTION BASE 1
23040 DIM M(4)                                !RANGE MULTIPLIERS
23050 READ M(*)
23060 DATA 1E-6,1E-5,1E-4,1E-3
23070 INTEGER I,J,A,B,C
23080 L=(First-1)*3+1
23090 FOR I=1 TO Nz                            !LOOP OVER THE DATA CHANNELS
23100 FOR J=1 TO Nmeas                         !LOOP OVER THE MEASUREMENTS
23110 A=NUM(Buffer$(J)[L])                     !1ST BYTE OF DIGITIZING
23120 B=NUM(Buffer$(J)[L+1])                   !2ND BYTE OF DIGITIZING
23130 C=NUM(Buffer$(J)[L+2])                   !3RD BYTE OF DIGITIZING
23140 Sm=(1-2*ROTATE(BINAND(A,32),5))*M(ROTATE(BINAND(A,192),6)+1)
23150 Values(I,J)=(((((ROTATE(BINAND(A,16),4)*10+BINAND(A,15))*10+ROTATE(BINAND(
B,240),4))*10+BINAND(B,15))*10+ROTATE(BINAND(C,240),4))*10+BINAND(C,15))*Sm
23160 NEXT J
23170 L=L+3                                    !TO NEXT CHANNEL
23180 NEXT I
23190 SUBEND
23200 !
23210 ! *********************************************************************
23220 !                          SUBROUTINE VARADD
23230 ! Varadd converts values to ascii and adds them to the message string
23240 ! which sends the results to the Modcomp.
23250 !
23260 ! Nvars is the number of variables to add, no. in array(*).
23270 ! Array(*) contains the variables to add.
23280 ! M$ collects the converted variables.
23290 !
23300 SUB Varadd(Nvars,Array(*),M$)
23310 OPTION BASE 1
23320 INTEGER I
23330 FLOAT 6
23340 FOR I=1 TO Nvars
23350 M$=M$&VAL$(Array(I))&" "
23360 NEXT I
23370 SUBEND
```

APPENDIX 2

Signal Monitor Calibrators

ETF-0027

G.J. deVries
March 5, 1984

SIGNAL MONITOR CALIBRATORS

Purpose

The signal monitor calibrator in the Neutral Beam Engineering Test Facility (NBETF) calibrates each monitor signal with a voltage staircase, sequenced with a fixed frequency upon command via a relay. The calibrator unit has eight output channels and each channel output voltage is adjusted to a particular monitor impedance. In calibration mode, the voltage staircase produces a standard reference for the computer data acquisition unit and aids troubleshooting.

Description

The calibrator electronics is housed in a NIM module. Eight output channels are available on the rear panel with channel range adjustments accessible on the front panel. The voltage level staircase consists of seven voltage levels (Figure 1). The output voltage is adjusted for each monitor impedance to obtain a calibration voltage independent of the monitor impedance. In the case of a low impedance current monitor, a 51 ohm, 1% resistor is added to the shunt monitor signal because the output current of the calibrator is limited to about 200 mA/channel. On the front panel, the calibrator reference can be monitored, and zero and full scale adjustments are available.

In the "free run" mode, the internal frequencey of the calibrator voltage staircase is on the order of 1 kHz. In the "single step" mode, the voltage staircase can be advanced by activating a pushbutton located on the front panel.

Technical Notes

Drawing 8T3164 S-1 C shows a detailed schematic of the calibrator electronics. The voltage reference is obtained from a temperature compensated accurate voltage zener. The staircase is generated with a simple oscillator, a digital counter, a BCD to decimal decoder and analog switches. An operational amplifier amplifies the voltage across the resister, whose value is controlled by the analog switches. The amplifier output voltage swing is ±10 volts. A current amplifier provides the current drive capability of about 1.6 A total (200 mA/channel).

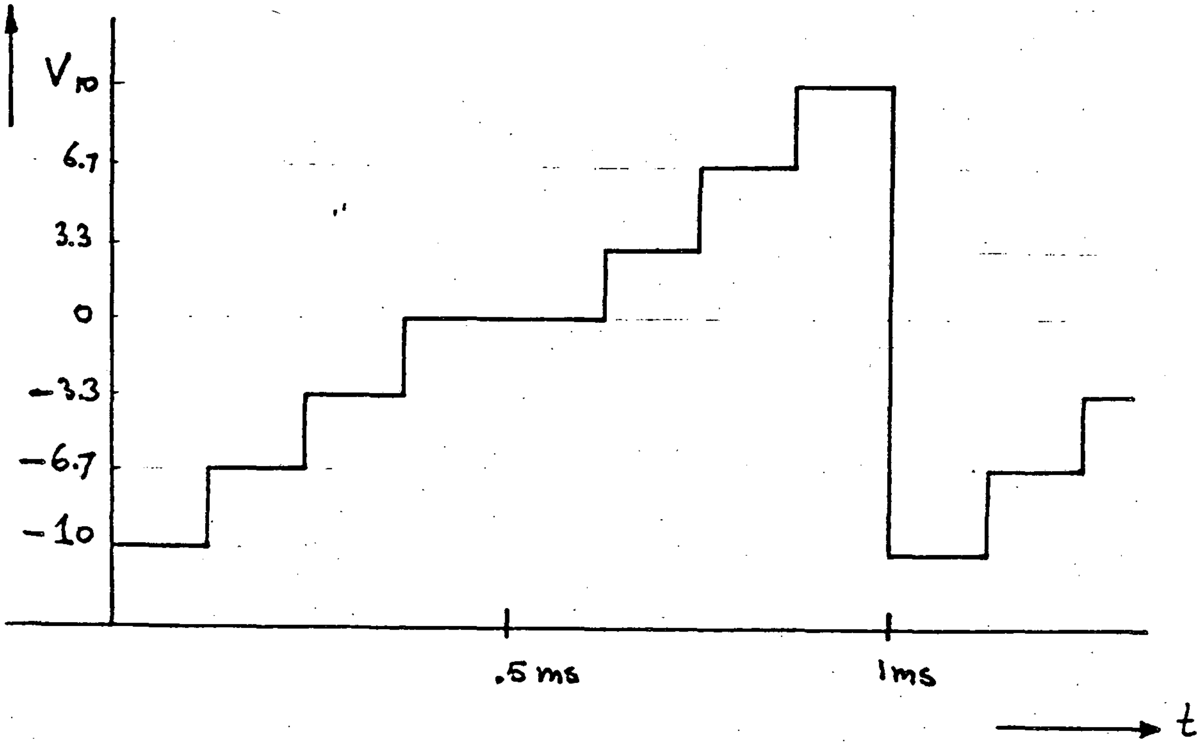

FIGURE 1

APPENDIX 3

Fault Detector

LBL-16142

FAULT DETECTION AND PROTECTION SYSTEM FOR NEUTRAL BEAM GENERATORS ON THE NEUTRAL BEAM ENGINEERING TEST FACILITY (NBETF)

G.J. deVries, K.L. Chesley and H.M. Owren

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

Summary

Neutral beam sources, their power supplies and instrumentation can be damaged from high voltage sparkdown or from overheating due to excessive currents. The Neutral Beam Engineering Test Facility (NBETF) in Berkeley has protective electronic hardware that senses a condition outside a safe operating range and generates a response to terminate such a fault condition. A description of this system is presented in this paper.

Introduction

High voltage sparkdown can cause deterioration or damage in a neutral beam injector. Deterioration in performance of the neutral beam source is influenced by the amount of energy that is stored in the capacitances associated with the accelerator.[1] Damaging effects can be diminished by slowing the discharge with a core snubber.[2]

Overheating the accelerator grids (due to excessive currents) can also cause damage to the neutral beam source. To prevent damage, it is required that certain voltages and currents are monitored closely and if their value exceeds their safe operating value (fault condition), the high voltage is quickly interrupted. The fault detection electronic hardware is designed to respond to a fault condition in microseconds. Three types of responses are possible and the type of response generated depends on the fault identified. The fault detector is an upgraded version of an earlier design, tested on the Neutral Beam System Test Facility (NBSTF).[4]

Fault Detector Input Signals

Various voltages and currents are monitored closely and compared to a preset safe operating threshold value during beam operation. If these signals exceed the preset operating thresholds, a response is generated by the fault detector.

The monitored signals, used in the NBETF, are listed in Table 1. The "inhibit time", listed in this table for each signal, is the time that the fault detector is disabled during the accel voltage turn-on. The "persistence time" is the time that the fault signal is allowed to continue before an action is taken. The fault detection input signals used in the NBETF are:

1. -dV/dt

"-dV/dt" senses a rapid decrease in accel voltage. The signal is generated by differentiating the accel sense voltage ($\tau = 20$ μsec) and provides the earliest information that a spark has occurred.

2. V_{1-2}/V_{Accel}

"V_{1-2}" senses the voltage difference between the first grid, which is at accel potential, and the second grid (gradient grid). This voltage is monitored on the neutral beam sources since its collapse can cause severe overheating in the accelerator grids. V_{1-2} is usually about 20% of V_{Accel}. The ratio V_{1-2}/V_{Accel} permits an operating threshold setting that is independent of the accel voltage.

3. V_{gg}/V_{Accel}

V_{gg} is the gradient grid (second grid) voltage measured to ground. The V_{gg}/V_{Accel} monitor can be used in addition to or as a substitute for the V_{1-2}/V_{Accel} monitor. V_{gg} is in the order of 80% of V_{Accel} and since it is measured to ground potential, no telemetry channel is required.

4. I_{gg} and I_{Supp}

The gradient grid current and the suppressor current are monitored by the fault detector because excessive currents in the grids can bend the grids and thus degrade or damage the source. The inhibit time (600 μsec) permits excessive currents to flow during the accel transient turn-on.

5. I_{Accel}

The beam related accel current is monitored at two places with shunts: near the source and near the accel power supply rectifiers. Both signals are used as fault detector inputs and their thresholds can be adjusted for operating conditions.

6. V_{Accel}-Strobe

The accel voltage is switched to the neutral beam source with a SCR switch,[5] after the accel power supply has been turned on. The command comes from the computer. A logic gate pulse (beam request time or "strobe") controls the duration of the "neutral beam pulse request." The V_{Accel}-strobe fault detector compares the presence (or absence) of the high voltage with the beam request duration. A fault condition exists if no accel voltage is measured during this request time or if accel voltage is present without the computer logic strobe pulse.

7. Metal Arc (Spot) Detector[6]

A persistent metal arc can cause severe damage to the plasma chamber and should be terminated within a few milliseconds. A metal arc usually decreases the efficiency of the plasma production. The ion output, measured with a Langmuir plasma probe, is compared to the arc current. The ratio of the plasma probe current and the arc current is a measurement of the source efficiency. If the ratio falls below a preset value (operator adjustable), the neutral beam is terminated (or interrupted depending on operating conditions). The spot detector also measures a "noise" component of the probe current since a metal arc also produces high frequency plasma fluctuations.

8. Gradient Grid Voltage

The gradient grid voltage also has a -dV/dt sparkdown sensor. It provides independent spark protection. Its status is displayed with a LED indicator.

Table 1 Type of Responses Versus Detected Faults

Fault Detector Monitor Signal	Calibration	Inhibit Time	Persistance Time	Type of Response		
				1	2	3
V_{Accel} dV/dt	20 kV/V	4 μs	4 μs	X		
V_{1-2}/V_{Accel}	Ratio FS = 20%	6 μs	100 μs	X		
$V_{Grad\ Grid}/V_{Accel}$	Ratio FS = 100%	200 μs	85 μs	X		
I_{Accel} Source	10 A/V	50 μs	10 μs	X		
I_{Accel} P.S.	10 A/V	-	500 μs		X	X
*$I_{Grad\ Grid}$	0.1 A/V	600 μs	100 μs	X		
I_{Supp} P.S.	1 A/V	50 μs	10 μs	X		
Spot Detector	Plasma Probe 0.5 V/V	-	~5 ms		X	
Grad Grid dV/dt	20 kV/V	-	<10 μs	X		
V_{Accel}-$\overline{\text{Strobe}}$	20 kV/V	20 μs	570 μs		X	X
$\overline{V_{Accel}}$-Strobe	20 kV/V	40 μs	7 μs	X		
V_{Arc} Overvoltage	20 V/V	-	-		X	
Arc Modulator Overload	Logic Signal	-	-		X	
Interlock Chain	Logic Signal	-	-		X	X
Maximum Number Interrupt	Logic Signal	-	-		X	

9. Interlock Chain

Safety requirements demand that high voltage areas and other potential health hazard areas are closed and interlocked during neutral beam operation. Any intervention of the interlock chain terminates the neutral beam operation. A few key elements of this chain, such as high pressure water flow, are displayed with LED indicators.

Fault Detector Output Signals

Three levels of responses have been designed as output commands of the fault detector. (Table 2). A level 1 response produces a temporary interruption in neutral beam operation. An interruption may occur frequently when an unconditioned neutral beam source has been installed. Contamination in the source requires a conditioning period under reduced operating power. During this period, the power to the source is interrupted for a short time (3-40 ms) when a fault has been detected. The high voltage is interrupted with a SCR switch. The plasma arc current is diverted by means of an arc modulator.[7]

A level 2 terminates the beam pulse by removing the power to the neutral beam. The level 2 responds to a more severe malfunction, such as overloading or overheating. A level 3 response terminates the beam in the same manner as a level 2 response and also turns off the power to the power supplies. This response will occur when a power supply current limit is exceeded or if the high voltage persists after a level 1 or a level 2 has been generated. From Table 1, it can be noted that whenever a level 3 response is generated, a level 2 response is also generated.

Table 2 Type of Response Causing Protective Actions

	Type of Response		
	1	2	3
Accel Voltage Off	X	X	X
Suppressor Voltage Off	X	X	X
Computer Timing Strobe Off	X	X	X
Accel P.S. SCR Control Off		X	X
Accel P.S. 12 kv Supply Off			X
Auxiliary P.S. 480 V Supply Off			X

Block Diagram (Fig. 1)

The inputs to the fault detector electronics are analog or digital fault monitor signals. The monitor signals, measured at high voltage levels, are transmitted via high frequency response telemetry fiber optic links[8]. The outputs of the fault detector are the commands to react to the specific fault(s).

The input signals are grouped with OR-gates to cause the desired output effect. The threshold detectors allow the neutral beam source operators to choose fault trip levels for the analog signals. The digital signals are obtained from on-off type inputs (such as high pressure water flow detector and maximum number of interrupts/beam pulse). Time of fault, measured from beam start, is indicated on a LED display and aids the neutral beam source operators to troubleshoot the cause of the fault. A computer interface has been designed for future fault display and analysis. The type of fault and the type of output response (level 1, 2 or 3) are also marked by a LED display. (Fig. 2) The output pulses (50 V, 10 μsec) are used to turn off the high voltage and suppressor supply; the logic level pulses (10 V) are used as input signals to the computer timing circuits.

Circuit Design Notes

Threshold Detector

The input voltages to the threshold detectors are in the range of 0 to +10 V. They can be filtered with a two pole bessel filter if noise rejection is required. The input signals are compared to reference voltages using signal comparators (LM311); their outputs are enabled with an external logic pulse. The enable pulse is usually synchronous with the beam request gate pulse (strobe) and can be delayed by means of an internal adjustable delay, thus disabling the fault detector output during accel turn-on transient time. The adjustability of the persistence time and inhibit delays is accomplished with an analog timer (LM555).

The time at which a threshold detector generates an output signal (level 1, 2 or 3) is referenced to the start of the "beam request" pulse. The elapsed time is registered with a seven segment display; its accuracy is a few microseconds (a 1 MHz crystal oscillator is used as the clock frequency). The display is driven with a digital counter (ICM7217A).

A "test" button located on the front panel of the threshold detector, when activated, causes the seven segment display to indicate the internal enable delay or the fault persistence duration of each detector. It also generates output signals for system test purposes.

OR-Gate Logic

The desired level of response (level 1, 2 or 3) to a fault signal is determined by diode connections between the input (fault) and output (level). The logic circuit is designed to accommodate any user defined choice of response to fault input signals.

Pulse Generator

The pulse generators are blocking oscillators. The output pulses are 50 V and about 10 μsec wide; their driving capability is 50 V into 50 Ohms. The output pulses are transformer coupled to eliminate ground loops. The 50 V level is chosen to obtain a high signal to noise ratio.

Packaging

Two fault detector discriminators are packaged in a NIM plug-in module (Fig. 2). The fault detector OR-gate logic, the 50 V pulse generators and the LED fault indication display are also constructed with plug-in modules, thus providing quick access to the electronic hardware if service is needed.

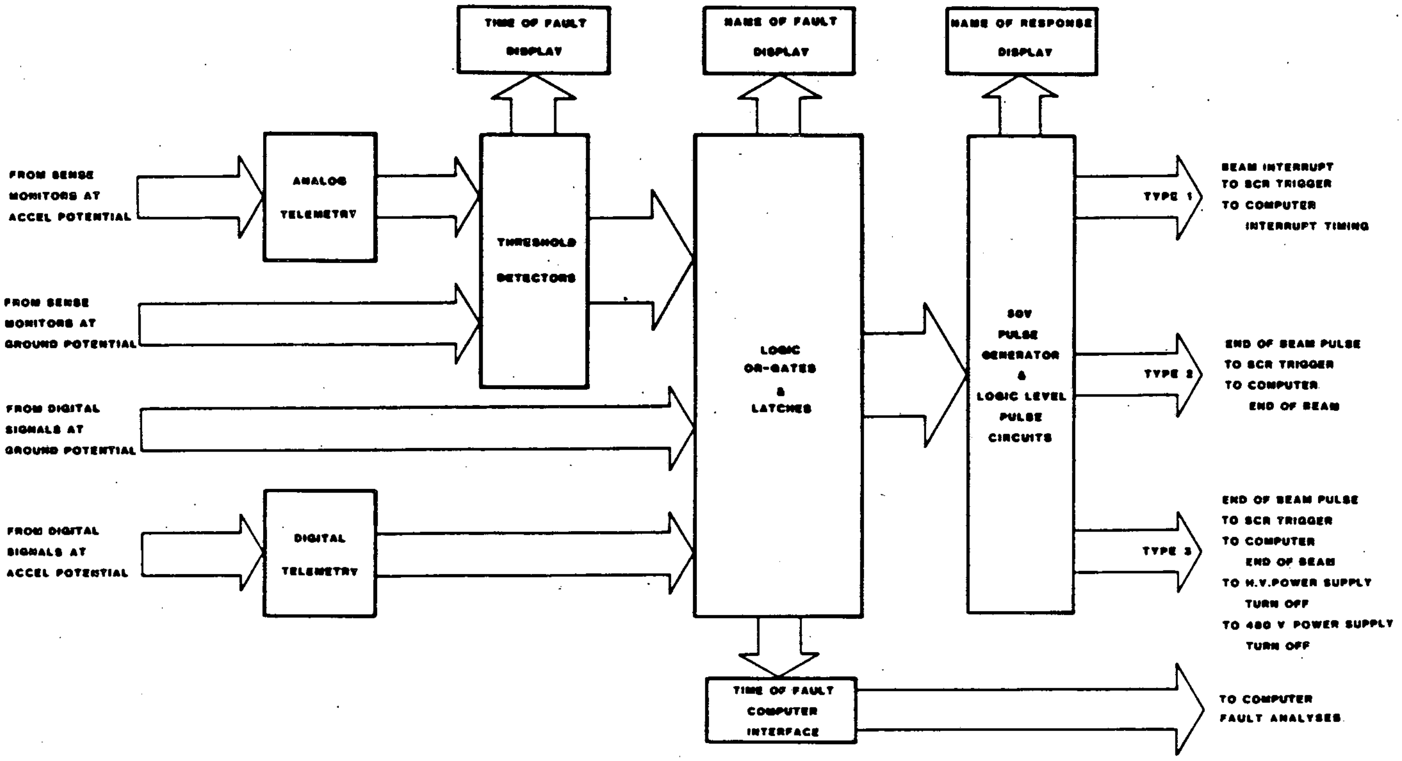

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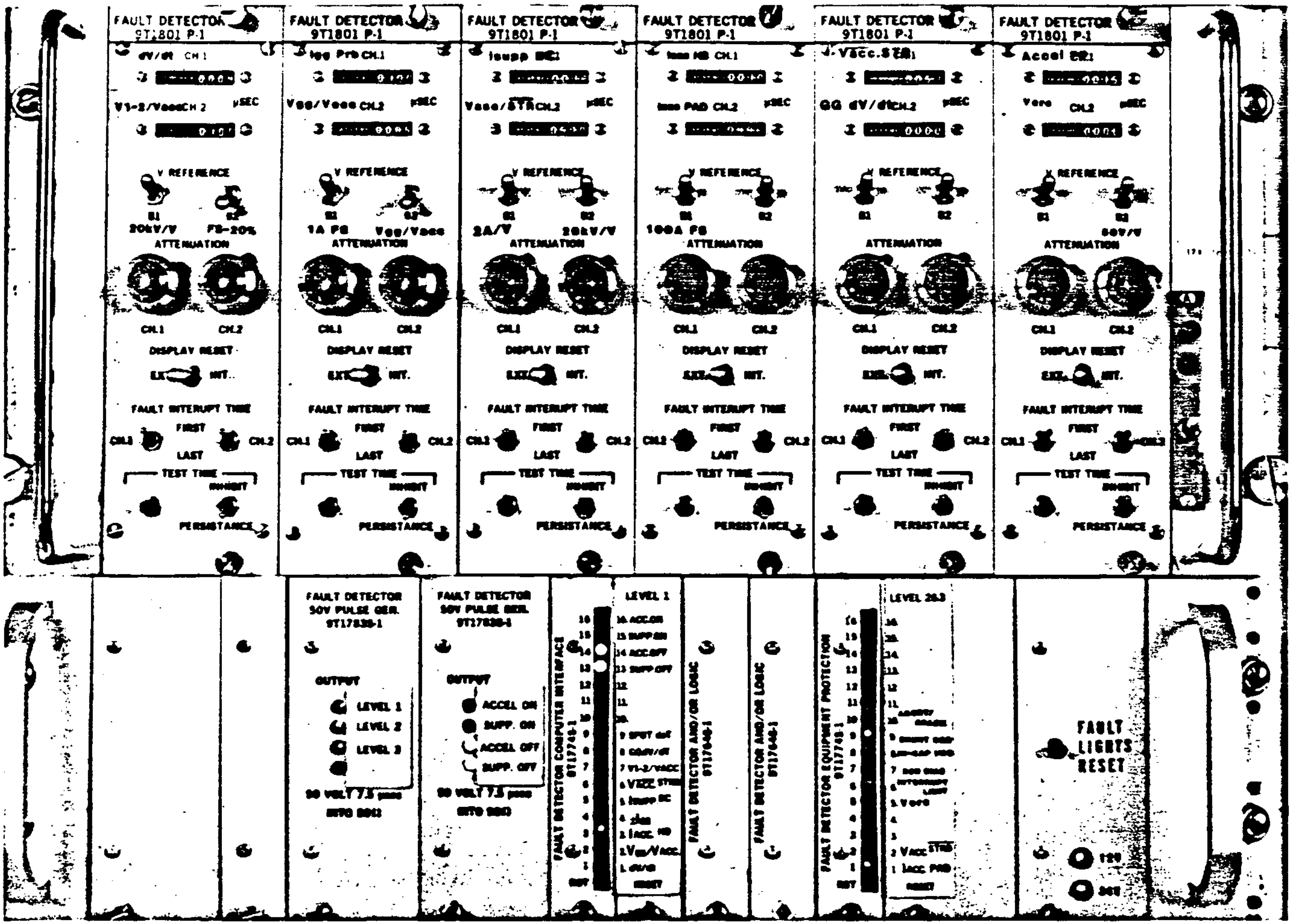
Figure 1 Block Diagram of Fault Detection and Protection System



CBB 8310-9611

Figure 2 Modular Fault Detector System With Time of Fault and Type of Fault Display

Performance Description

The fault detector system has been operating successfully at NBETF for the last 1-1/2 years. During this period, test sources, built in Berkeley, have been operated at a power range of 40 to 120 kV for 0.5 to 30 sec pulse lengths; the system has been operating well recently with the Oak Ridge neutral beam source. Its adaptability has been noteworthy.

Acknowledgement

The authors wish to thank the many people involved in manufacturing the fault detector system, A.F. Lietzke for reviewing this paper, Joe Perez for the preparation of the figures and Carolyn Wong for the preparation of this manuscript.

This work was supported by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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LBL-12721

NEUTRAL-BEAM PLASMA SOURCE METAL-ARC PROTECTION CIRCUIT*

G.J. deVries, D.B. Hopkins, A.F. Lietzke and H.M. Owren
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

SUMMARY

Neutral beam sources occasionally suffer from metal arcs inside the plasma chamber. This arcing can cause serious damage when it is sustained. Experience has shown that arcing for less than 10 msec is tolerable. This paper describes an electronic circuit designed to detect such an arc (or "cathode spot") and generate a signal which can be used to turn off the source arc current and the accel voltage.

One principle of spot recognition is based on the detection of abnormal, fast fluctuations in a Langmuir probe signal.

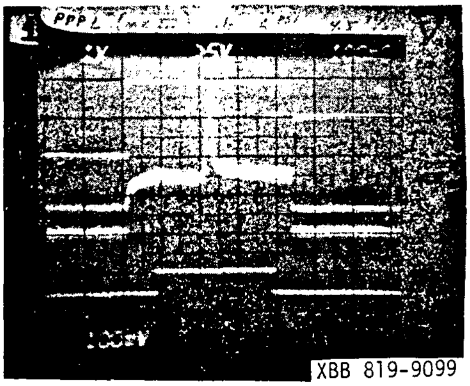
A second detection principle looks for an abnormally low plasma source efficiency by comparing the probe's saturated ion current to the arc current. Both of these principles are exploited in the circuit described in this paper.

METAL ARCS IN PLASMAS

Metal-arcs in plasma sources are frequently observed when the plasma source is operating under the conditions where electron density ≈6 x 10^{11}/cm^3, Debye length ≈20 μm, and average positive ion current density ≈200 mA/cm^2. The phenomenon represents a "punch-thru" of the voltage sheath which separates the plasma from all relatively-negative electrodes. It is frequently labeled by such names as "cathode-spot" and "unipolar-arc", depending on whether the electrode is "hard-wired" to the arc power supply negative terminal or floating, i.e., with zero net current. It is believed to be the vacuum analog of the common arc welder. The sheath's potential difference is generally a substantial fraction of the arc voltage (V_{anode} - $V_{cathode}$) and may be viewed as a measure of the relative difficulty which the plasma encounters in obtaining electron emission from the electrode surface. This interface can be ruptured with the formation of one or more tiny, high density metal-plasma plumes. These are believed to be maintained by very local, very intense electron emission through a dense metal-vapor cloud (resulting from intense cathode sublimation).

This electron emission reduces the sheath impedance. Hence, the spot causes the arc voltage to drop and/or the arc current to increase (Figure 1); the average ion output current then becomes reduced and noisy. For a unipolar-arc, the electron cooling effect of the spot is believed to be responsible for the slight increase in observed arc impedance; most noticeable is the noisy probe signal. Negative-electrode material coats surrounding surfaces in both cases. Variations of this general description have been observed.

Sustained operation of metal arcs have produced at least six bad effects:



XBB 819-9099

Figure 1 A metal arc usually causes the arc voltage to lower (top trace) and the arc current to increase (center trace) due to a lower arc impedance.

1. Melt-thru of the anode wall;
2. Insulator metallization, carbonization, or puncture;
3. Little balls or flakes of cathode material, transferred to the accelerator grids, interfere with voltage-holding and beam production;
4. Filament destruction by pitting or melt-thru;
5. Retrograde $(-\bar{J}X\bar{B})$ motion in a magnetic field can move a "spot" from a relatively innocuous location to one where a, b, c, or d occur;
6. Unipolar-arcs, usually relatively innocuous due to their small current, can trigger the formation of high-current cathode spots.

For these reasons, when a spot occurs, the arc current is terminated until the sheath's voltage-holding capability is restored.

DETECTION PRINCIPLE

The operation of a neutral beam plasma source includes power supply, plasma source and accelerating protection circuitry as standard equipment.[1] During the years of neutral beam operation in Berkeley, various methods of metal arc (spot) detection have been tried and found to be inconvenient because of neutral-beam source characteristic dependence. The detection principle described in this paper is relatively independent of source characteristic variations.

The detection principle is based on the following two techniques:

a. The unipolar-arc usually causes a fast fluctuating Langmuir probe signal. These fast fluctuations (in the range of 1 kHz to 40 kHz) are detected when the amplitude exceeds a preset threshold value of a signal comparator. The output of this comparator is linearly integrated by means of a charge pump and compared to a preset adjustable threshold. If this

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*This work was supported by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

threshold is exceeded, a fault signal is generated.

b. The plasma efficiency is measured by comparing the DC component of the probe current with the arc current. The ratio is approximately constant for varying operating conditions of a given source. A fault signal is generated when the ratio I_{probe}/I_{arc} drops below a preset value, thus indicating low-efficiency plasma production or a cathode spot.

SIMPLIFIED CIRCUIT DIAGRAM (FIGURE 2)

Plasma Fluctuation Detector

The probe signal is amplified via a high-pass filter with a corner frequency of 650 Hz. Probe signal fluctuations with frequencies above 650 Hz generate an error signal if they exceed the comparator's amplitude threshold. Each time an error signal is detected, the integrating capacitor is charged a fixed amount. For a repetitive error signal (with a frequency of 3 kHz and above), the capacitor will be charged continuously, thus causing the voltage to rise linearly. This voltage on the capacitor is compared with a preset reference voltage and an arc termination signal is generated if this reference voltage is exceeded.

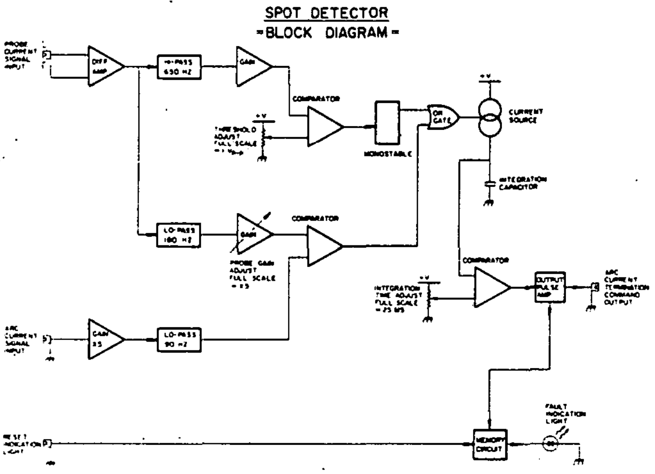

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Figure 2 Simplified Circuit Diagram of the Metal Arc Detector

Arc Efficiency Detector

The DC component of the probe signal is obtained from a low-pass filter with a corner frequency of 180 Hz. This signal is then compared to a signal proportional to the source arc current. The arc current signal is amplified via a low-pass filter with a corner frequency of 90 Hz. This filter delays the rise of the arc current signal, with reference to the probe signal, in order to maintain the I_{probe}/I_{arc} ratio above the preset fault trigger level during the turn-on of the source arc current, thus preventing an unwanted fault signal from being generated. The I_{probe}/I_{arc} ratio is measured with a signal comparator whose output controls the current source feeding the integration capacitor. A fault signal is generated by means of the same type of comparator described above for the repetitive fluctuating probe signal detection circuit.

OPERATIONAL CONTROLS OF THE DETECTOR

Operation of the detector requires only a few adjustments. These are:

a. "Noise threshold" adjustment (calibration range of 1 volt peak-to-peak, full-scale). This probe-signal noise threshold has been set empirically at 100 - 150 mV on the neutral-beam sources in Berkeley (a 100 current viewing resistor is used.)

b. "Persistence" adjustment (calibration range of 25 msec full-scale). This adjustment sets the time duration that a suspicious probe signal may persist before a command is generated to terminate the arc current. For clean-source operation, a few milliseconds usually suffices.

c. "Arc efficiency threshold" (calibration range of probe signal gain is x5 full-scale). This adjustment controls the gain of the DC component of the probe signal for comparison with the I_{arc} signal. The gain should be adjusted for the particular arc current shunt in use and the plasma source efficiency. Figure 3 indicates the exact trip level. An operational margin of 30 - 50% is usually added.

d. "Test". A circuit allows the user to quickly check the unit for proper performance. This is accomplished by means of a local oscillator (frequency is 6 kHz) with a variable amplitude. By activating the test circuit with a front panel push button, one injects a simulated "noisy probe" signal. By varying the amplitude, the noise-threshold trip level can be checked. The I_{probe}/I_{arc} ratio is checked by injecting a test signal (frequency approximately 30 Hz) into both input circuits.

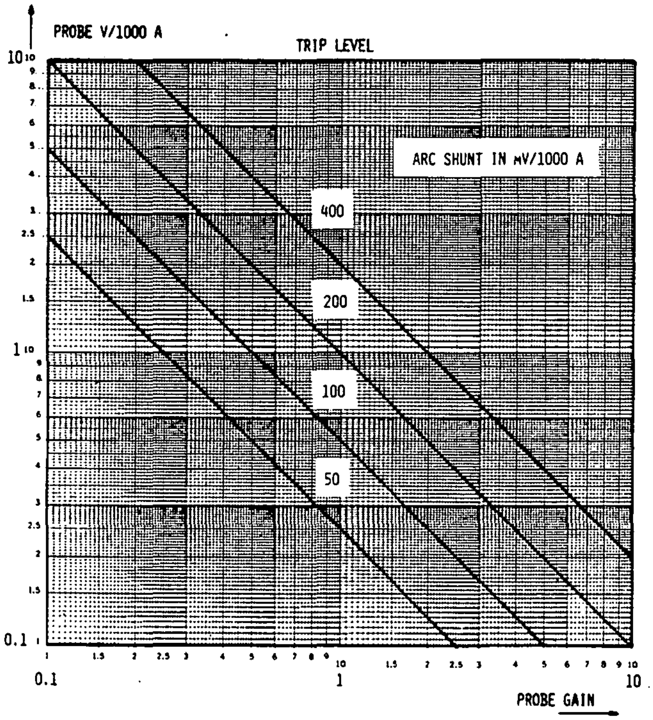

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Figure 3 This figure shows the arc efficiency detector trip threshold for various arc current shunt values. The probe signal amplitude for 1000 Amps arc current is graphed versus the probe gain.

SCHEMATIC AND CIRCUIT DESIGN NOTES

A detailed circuit diagram is given in Figure 4. A few functions are described below.

The Charge Rate Control

The charge rate is controlled by means of a retriggerable monostable which switches the current-source that charges the integrating capacitor. The capacitor discharges (time-constant is 0.5 sec) to an adjustable negative offset voltage in order to bias the comparator slightly negative, thus preventing spurious fault signals from being generated when no input signal is present.

The Frequency Filters

Two pole Bessel filters[2] are used. They do not suffer from overshoot in response to a step voltage on the input. The necessary delay difference mentioned earlier between I_{probe} and I_{arc} is accomplished by a difference in the corner frequencies of the filters. An active diode circuit in the arc signal filter removes the filter delay during arc turn-off time, thus preventing an unwanted fault signal from being generated. Figure 5 shows a photograph of the filtered signals of I_{probe} and I_{arc} when square-wave input signals are employed.

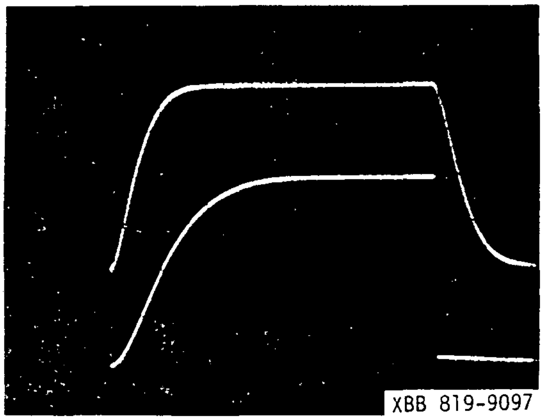

Figure 5 The square wave response of the two frequency filters are shown above. The top trace is the low-pass probe filter response; the bottom trace is the arc current filter response. Time scale is 1 msec/division. (F.S. = 10 ms)

Operational Amplifier

The operational amplifiers have been selected according to the gain bandwidth performance (20 MHz for the HA2525 and 100 MHz for the HA2625) needed for the amplifiers of the AC component of the probe signal. These op amps also offer a relatively small offset voltage (<5 mV) so that no external adjustments are required to obtain high threshold accuracy.

Indicator Light

A light-emitting diode has been added, for fault analysis purposes. It remains lit after a "termination command" has been generated . A reset pulse, for resetting the light-controlling flip-flop, is obtained from the next beam "turn-on" pulse.

CIRCUIT PACKAGE AND PERFORMANCE

Circuit Package

The detector circuit has been built on a printed circuit layout, one side of which is used as a ground plane. The circuit is housed in a NIM module.

Performance Results

The detector has been in service steadily this year on different plasma sources. In general, the unit has performed satisfactorily (Figure 6) provided that the operational adjustments have been set according to the specific source in use.

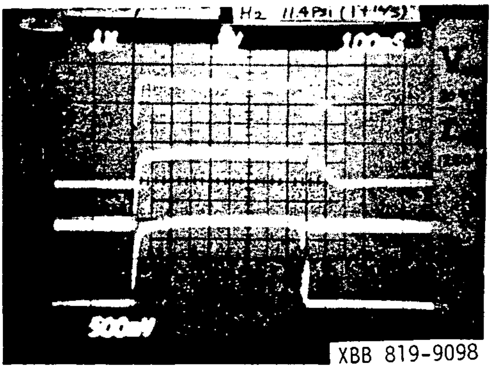

Figure 6 The photograph shows an increase in arc current (center trace) and a decrease in probe current (lower trace), indicating a spot and causing the arc efficiency detector to terminate the arc. The top trace shows the arc voltage.

Possible Improvement

Some consideration has been given to an automatic adjustment of the noise threshold in the fast fluctuating (AC) probe signal detection circuit. The idea is based on the fact that the ratio of the AC component of the probe signal to the low frequency component of the probe signal should be nearly independent of plasma source operating levels. To achieve this feature in practice, the DC component of the probe signal could function as the reference voltage for the noise threshold comparator. This function has not yet been implemented.

ACKNOWLEDGEMENTS

The authors wish to thank the many people involved in manufacturing the unit, and in particular, Horace Warnock for the printed circuit layout work, Joe Perez for the preparation of the figures and Carolyn Wong for the typing and layout of this paper.

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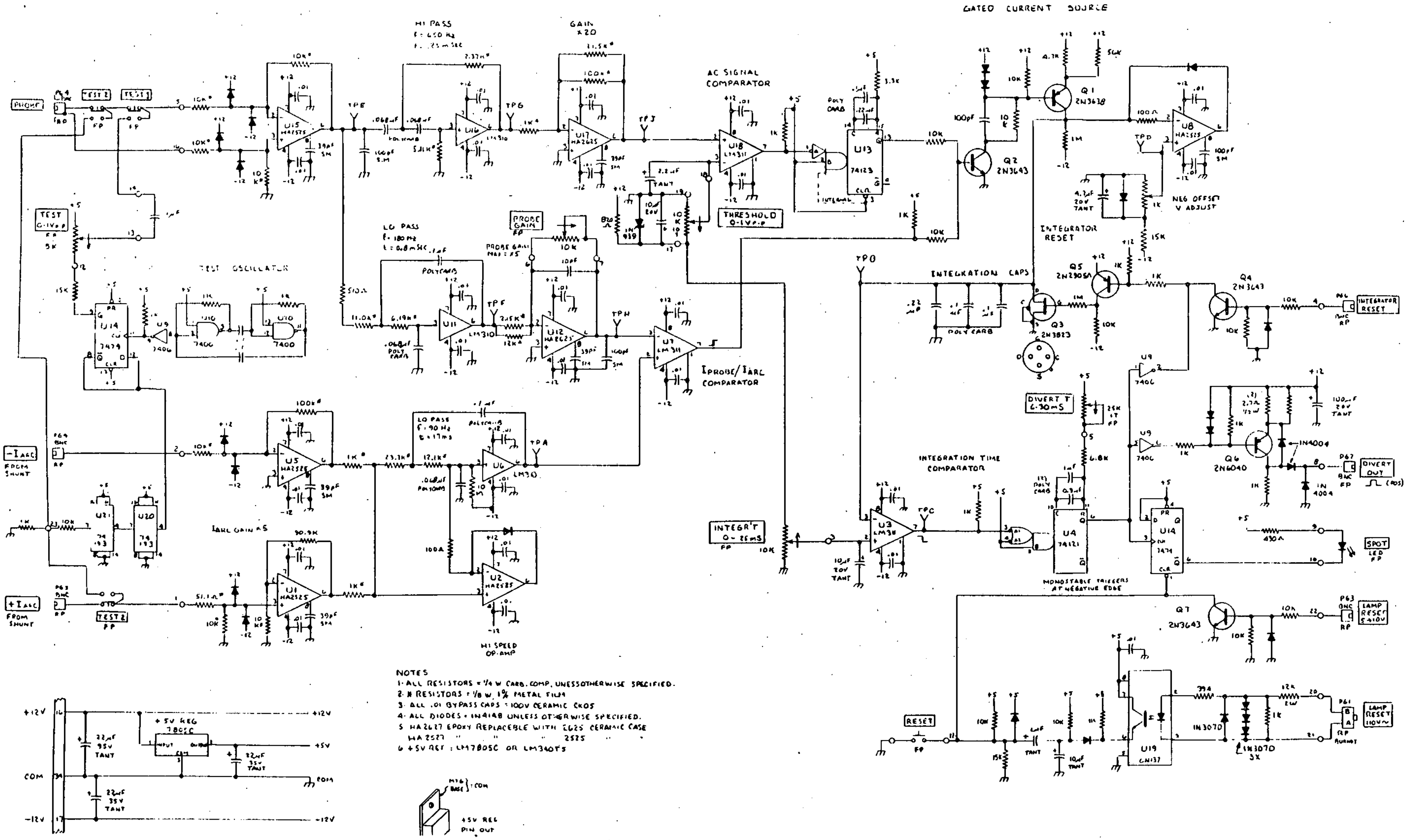

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Figure 4 Detailed Circuit Diagram of the Spot Detector

APPENDIX 5

Arc Power Supply Feedback Loop Electronics

G.J. deVries
February 16, 1984

ARC POWER FEEDBACK LOOP ELECTRONICS

Summary

The arc power supply output voltage is controlled by a SCR rectifier phase control unit. To obtain a constant arc power level, a feedback loop is formed with the application of an integrating differential amplifier housed in a NIM module. This module processes the measured arc voltage and/or arc current, compares it to a reference voltage, integrates the error signal, and controls the phase of the arc power supply SCR rectifier unit.

Description of the Feedback Loop

The feedback loop has been designed to accommodate for slow changes, during 30 sec neutral beam, in gas pressure or filament temperature. A simplified diagram of the electronics used is shown in Figure 1. Inputs A and B are the feedback signals, arc voltage and arc current monitor signals (the range of 0 to +10 volts). An analog multiplier is used to obtain a signal which is proportional to the product of A and B, thus proportional to the arc power. Its output is compared to a reference signal with a differential amp and the output error voltage is integrated and used as an input to the SCR phase control unit of the arc power supply. A given arc power level will be maintained with the feedback loop within the range of the SCR phase control unit. An adjustment of the arc power supply IVR might be necessary when the SCR phase control unit reaches its control limits. During the initial arc power supply turn, the feedback loop is closed internally (for about 50 msec) to prevent oscillations in the arc current, related to turn-on transients. The voltage reference is switched, after this initial turn-on time, from a second voltage reference to the feedback voltage reference to diminish the effect of the load change on the power supply when the neutral beam accel voltage is turned on.

Operating Notes

1. Feedback can be used with either one or two inputs (inputs, A and B). If one input is used as a feedback input, the other is internally connected to the +10 V. Inputs A and B have a gain adjust of 0 → x10.
2. A and B input-impedance is 1 MΩ.
3. Using A or B as feedback, input, then:
   a. measure input signal at the scope (for example, probe signal);
   b. set signal gain such that (input A or B) x Gain = Reference Signal, where (A or B) x Gain $\leq$10 Volts. (If Gain ≈ 1, the reference signal should be approximately equal to signal at input A or B.)
4. Using A x B input (for example, power of beam):
   a. input A and B in the 0 → 10 V range gives AB/10 as the feedback control input;
   b. set the feedback signal level according to:

$$V_{Ref} = \frac{(A \times G)(B \times G)}{10} \qquad (A \times \text{Gain} \leq 10\text{ V};\ B \times \text{Gain} \leq 10\text{ V})$$

5. The SCR voltage control (feedback module output) should be ∿5 V ±15%. Lower voltages seem to introduce excessive ripple on the arc power supply. The goal is to maintain the SCR voltage in the "right" operating range (5 V ±15%) during the long pulse. One should increase or decrease the SCR control voltage for a given fixed arc current by decreasing or increasing (respectively) the arc power supply IVR. Within the SCR range, the arc level can be adjusted by changing the reference voltage. A green/red LED indicates whether or not the output voltage is in range (green) or out of range (red).
6. Deactivate Feedback Loop

   The switch "Feedback In/Out" enables/disables the feedback function; in the "Out" position, the SCR voltage is controlled by the helipot "SCR Control" calibrated in 0 → +10 V.

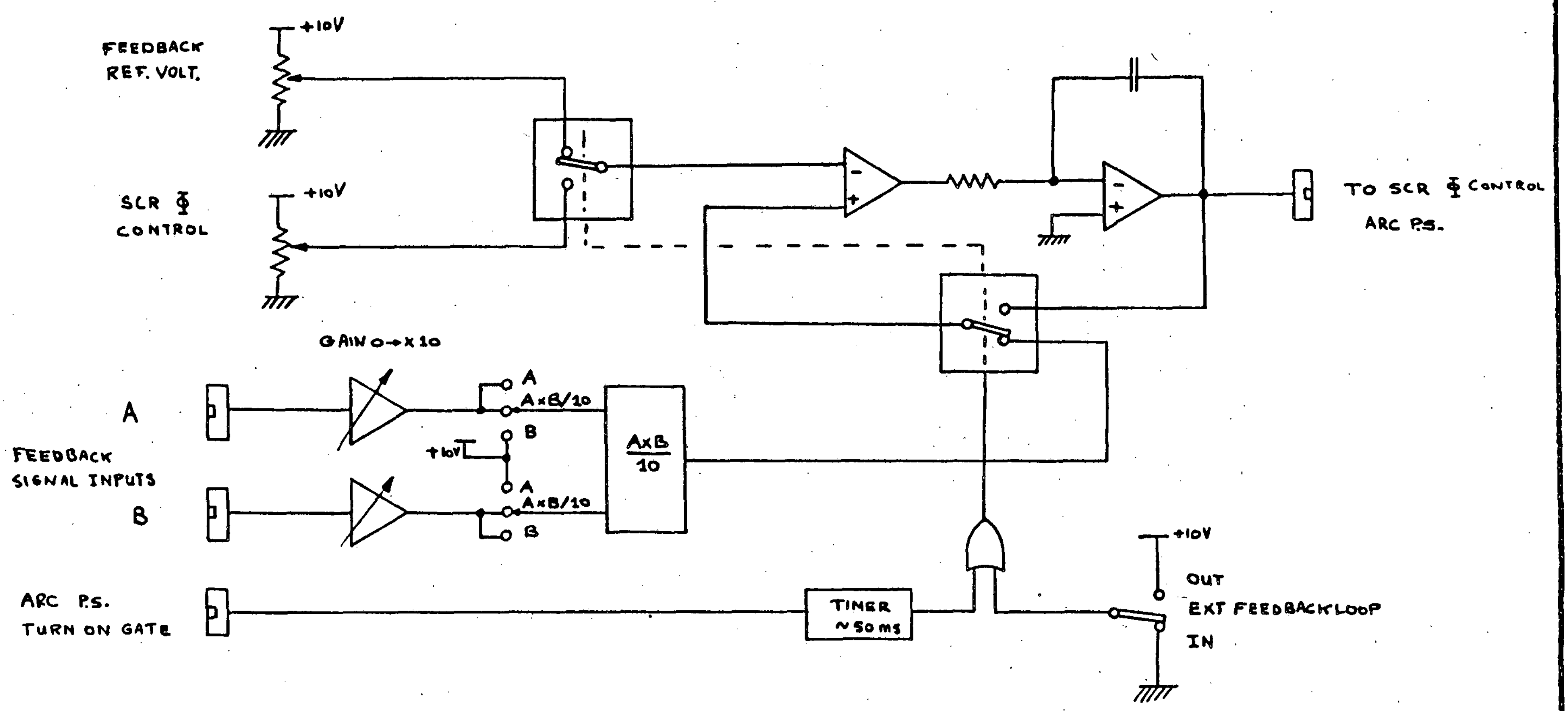

FIGURE 1

CHG LTR	DRAWN BY	CHECKED BY	DATE	CHANGES	I:	MFE NBETF	
					II:	ARC POWER SUPPLY SCR Φ CONTROL	
					III:	FEEDBACK SIMPLIFIED DIAGRAM	
					SHWN ON		
					ACCT. & SER.	DRWN. BY J dV	DATE 2-15-84
					DATE ISSUED / NO. REQD.	CHKD. BY	SCALE
					DATE RECD.	APPR.	
					DEL TO	ENG. J. de Vries	

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UNIVERSITY OF CALIFORNIA

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APPENDIX 6

Arc Notcher

Jan deVries
April 26, 1982

ARC NOTCHER

This note briefly describes the operation of the arc notcher, designed for the Neutral Beam Engineering Test Facility (NBETF).

The functions of the arc notcher are:

1. to match the arc current during beam turn-on with the shape of the accel voltage rise in order to maintain desired plasma density,
2. to divert the arc current from the plasma source into the arc notcher during a fault. (A fault can be generated by various sensors, such as V_{1-2}, spot detector, etc.)

Description

The arc notcher (consisting of two elements) is connected across the arc power supply (also two elements) and functions as a variable load to the power supply as shown in Figure 1.* Each arc notcher has been constructed from 64 transistor switches which can turn on and off in the order of μsec. Each transistor switch consists of one or more transistors with collector resistors. (A breakdown of the number of transistors per switch and the calculated current per switch is given in Tables 1 and 2.)

The transistor switches are controlled by an analog input voltage of 0 → +10 volts by means of 64 signal comparators. The input voltage is compared to a voltage divider with 64 voltage taps (10 volts/64 ≈ 155 mV/tap).

---

*The two power supplies with the two arc notchers can be switched in parallel or series mode. The two arc notchers are identical and are controlled from one electronics control unit.

The design approach has been to achieve a linear response of arc current when a linear varying input voltage is applied. Since the arc current depends on the source impedance and the power supply impedance, the design center is based on the following source characteristics:

Source Impedance	R_A = 50 milliOhms	Maximum Arc Voltage =	100 Volts
Arc Zener Voltage	V_B = 25 Volts	Maximum Arc Current =	1500 Amps

(For lower arc impedance and higher arc current sources, two arc notchers are switched in parallel mode.) The power supply output impedance is represented by a 300 μH inductor. Table 2 shows the calculated power supply current buildup for a divert time of 10 msec as a function of the number of switches turned on.

Figure 2 shows the calculated arc current versus the number of switches for a 10 msec and a 100 μsec divert.

Figure 3 shows the calculated arc current versus number of switches for various arc source impedances.

Input signals to the arc notcher can be:

1. START BEAM (Strobe): This digital signal initializes the protection maximum time circuit at the leading edge of the gate pulse.
2. ARC FULL-ON: This digital signal overrides the analog control voltage and turns all switches off during the presence of this gate pulse, thus allowing arc current to flow independently of the controlling analog voltage (V_{accel} input).
3. V_{ACCEL}: This analog input controls the arc notcher current and is obtained from the accel voltage divider. (-10 → 0 V)
4. V_{ACCEL} (Telemetry): The function of this input is the same as mentioned under #3. (0 → +10 V)

5. POWER SUPPLY CROWBAR: This digital signal turns the arc notcher switches on and can be used to divert the arc current as a spot protection input when connected to the output of the spot detector.
6. DIVERT: This digital signal turns the arc notcher on, to depress the arc current, to a preset level (notch depth). The notch depth keeps the arc alive during DIVERT and can be varied to accommodate different source characteristics.
7. NOTCH DEPTH: This is a 16 digital input connection which can be used to set the notch depth level. (The notch depth level can also be controlled with a switch on the rear panel.)

Output signals from the arc notcher are:

1. FAULT: This output generated a pulse (10 V, 7.5 μsec long) when the maximum divert time of 1 sec has been exceeded (100 interrupts), or generates a pulse when overvoltage has occurred. It can be used to turn off the arc power supply.
2. NOTCH SHAPE MONITOR: This analog signal monitors the arc notcher controlling input voltage, and can be used to monitor the accel voltage turn-on shape.
3. MAXIMUM TIME: This monitor signal indicates the maximum divert time has been exceeded, and is used simply as an indicator to distinguish between a fault caused by overvoltage or by maximum divert time.

<u>Limitations</u>

1. The divert time per interrupt is internally timed and set at a maximum of 10 msec to limit excessive power supply current buildup, causing overshoot in arc current after divert.
2. The maximum divert time per beam pulse is set at 1 sec in order to protect the power transistor collector-resistors from overheating.

Group	No. of Switch	Value R Switch	No. of R Transistor	No. of Transistor	R Value Transistor	Value of Each R
1	1 thru 8	0.4 Ω	3	3	1.2 Ω	3.6 Ω
2	9 thru 16	0.7 Ω	3	2	1.4 Ω	4.2 Ω
3	17 thru 24	1.0 Ω	3	2	2.0 Ω	6.0 Ω
4	25 thru 32	1.3 Ω	3	2	2.6 Ω	7.8 Ω
5	33 thru 40	1.6 Ω	3	2	3.2 Ω	9.6 Ω
6	41 thru 48	1.9 Ω	6	1	1.9 Ω	11.4 Ω
7	49 thru 56	2.2 Ω	6	1	2.2 Ω	13.2 Ω
8	57 thru 64	2.5 Ω	6	1	2.5 Ω	15.0 Ω

(Total Number of Transistors is 112)

TABLE 1

```
IA= 1500.000           N= 64.000           OAK-RIDGE REGUIREMENTS
                                          *************************
N                      RP

 57.000                 .312
 49.000                 .146
 41.000                 .091
 33.000                 .062
 25.000                 .045
 17.000                 .033
 9.000                  .024
 1.000                  .016


N                      IA                  VA                   IPS

 8.000                  309.396             40.470               2095.302
IP(N)= 1785.905
 16.000                 473.563             48.678               2013.219
IP(N)= 1539.656
 24.000                 627.804             56.390               1936.098
IP(N)= 1308.294
 32.000                 781.610             64.080               1859.195
IP(N)= 1077.586
 40.000                 939.819             71.991               1780.090
IP(N)= 840.271
 48.000                 1105.880            80.294               1697.060
IP(N)= 591.180
 56.000                 1282.820            89.141               1608.590
IP(N)= 325.771
 64.000                 1473.684            98.684               1513.158
IP(N)= 39.475


N                      R-SWITCH            I-SWITCH             WATTS
 8.000                  .400                101.149              4093.492
 16.000                 .700                69.530               3384.603
 24.000                 1.000               56.385               3179.535
 32.000                 1.300               49.289               3158.455
 40.000                 1.600               44.992               3238.984
 48.000                 1.900               42.258               3393.046
 56.000                 2.200               40.517               3611.706
 64.000                 2.500               39.472               3895.271

NON LINEARITY FROM STRAIGHT LINE I(N)-I(1)


N                      %ERROR              I-Diff

 8.000                  2.669               8.043
 16.000                 1.010               4.733
 24.000                -1.336              -8.501
 32.000                -2.758              -22.171
 40.000                -3.237              -31.437
 48.000                -2.885              -32.852
 56.000                -1.791              -23.388
 64.000•                0.000               0.000
```

<u>NOTE</u>

N - Number of Switches

RP - Arc Notcher Resistance

IA - Arc Current

VA - Arc Voltage

IPS - Power Supply Current

R-SWITCH - Resistance/Switch

I-SWITCH - Current/Switch

WATTS - Collector Resistor Power Dissipation

TABLE 2

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ENGINEERING NOTE

CODE	SERIAL	PAGE
ETF-0018		

AUTHOR	DEPARTMENT	LOCATION	DATE

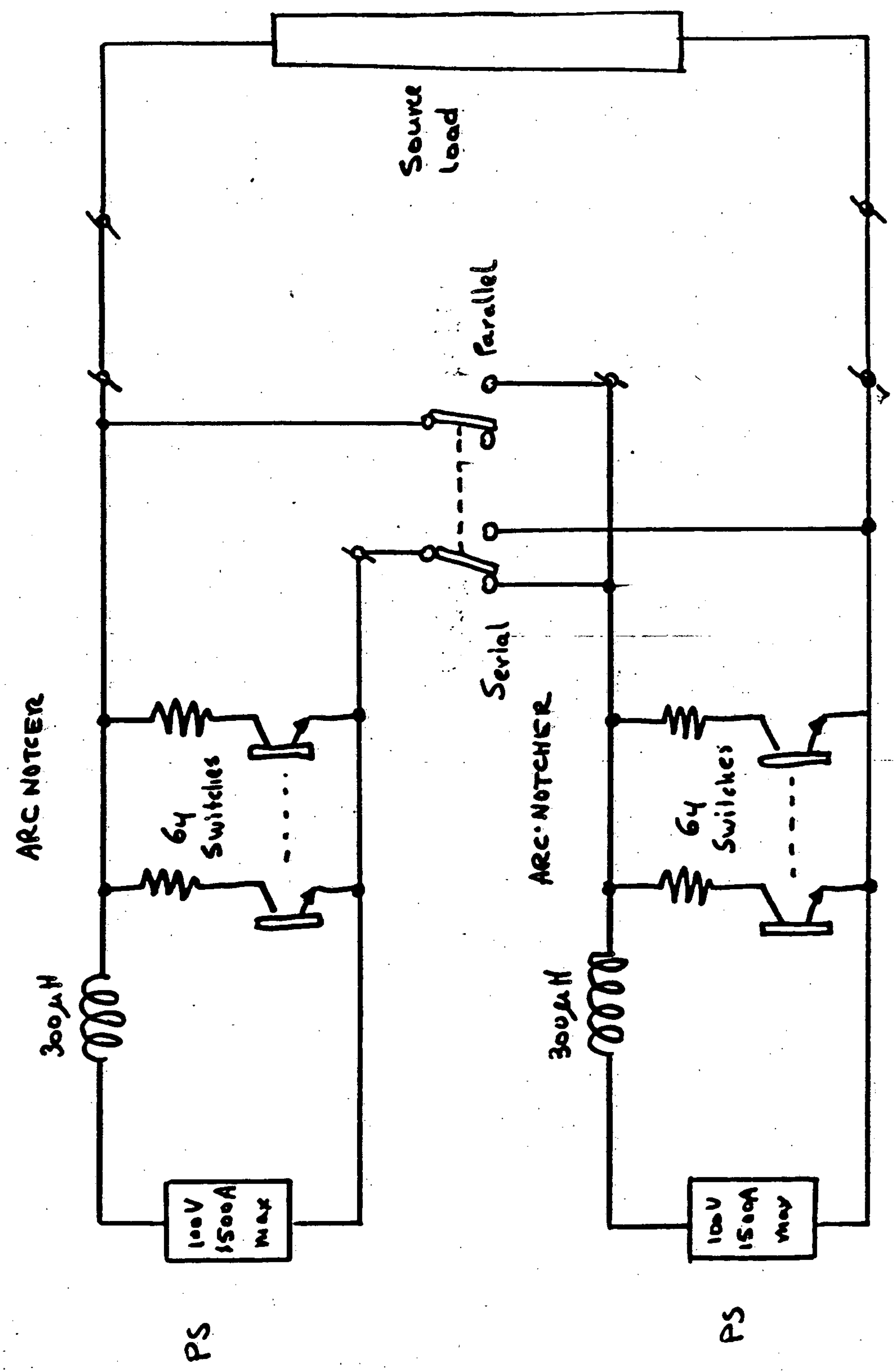

Fig 1

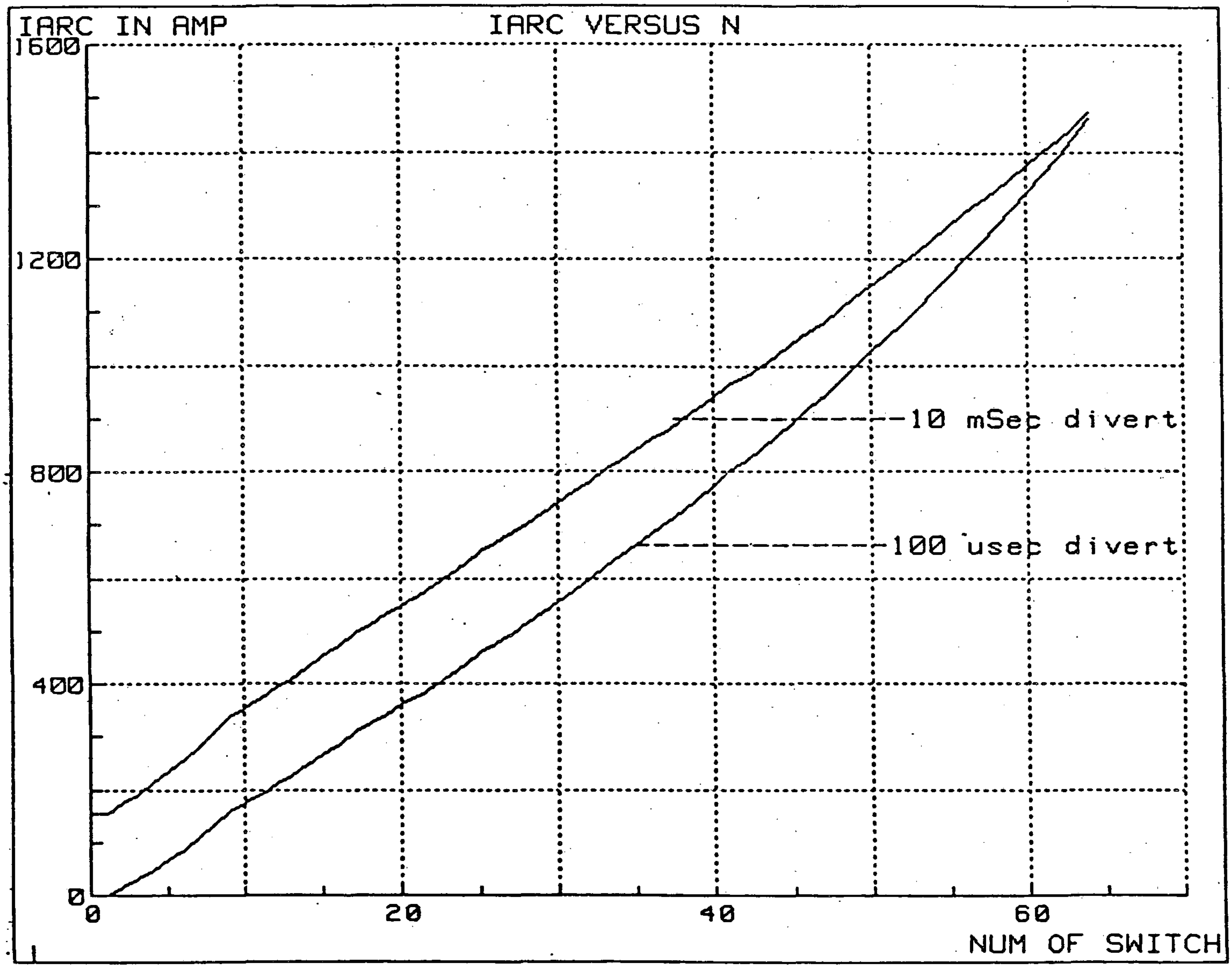
IARC IN AMP
IARC VERSUS N
1600
1200
800
400
0
0
20
40
60
NUM OF SWITCH
10 mSec divert
100 usec divert

FIGURE 2

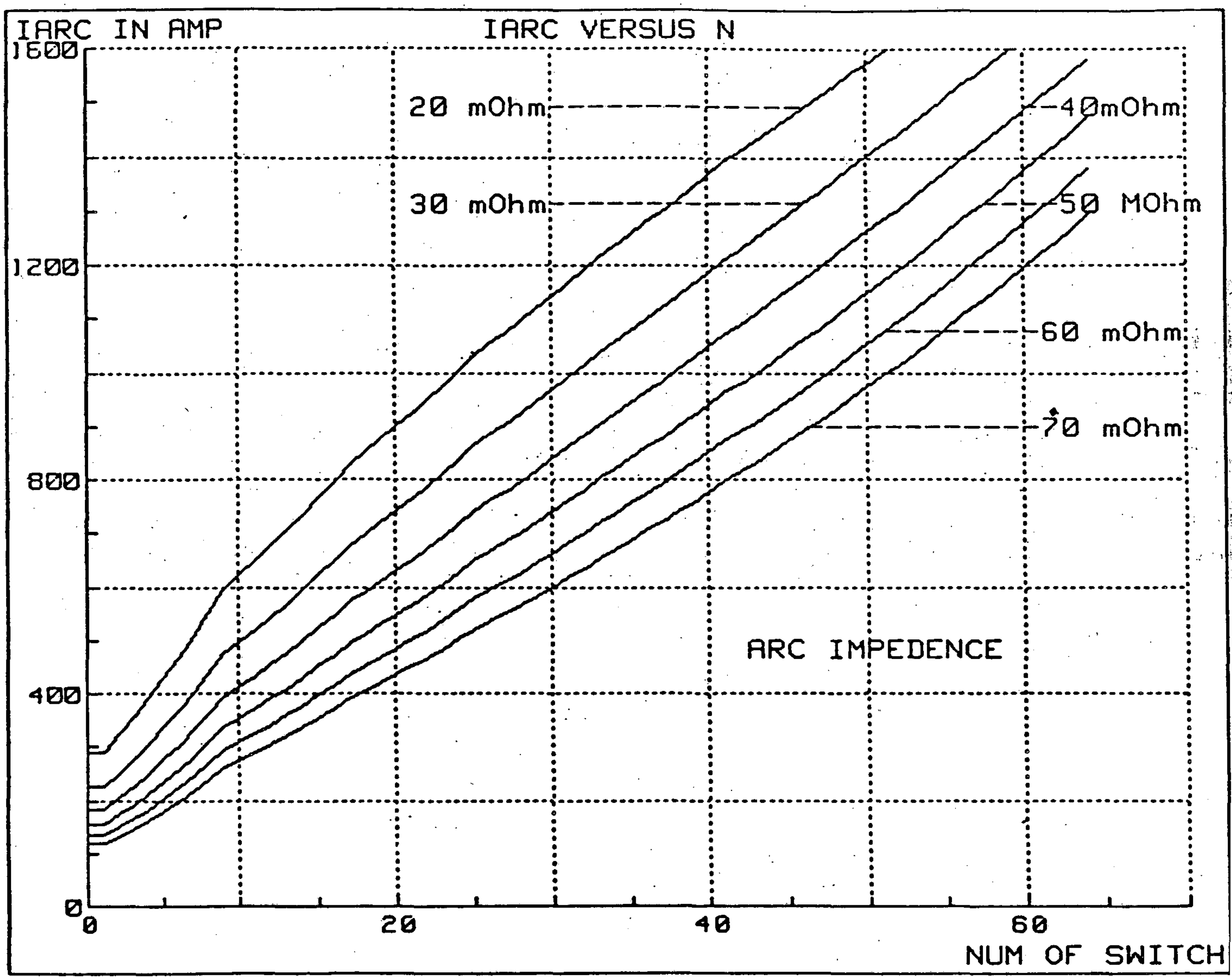
IARC IN AMP
IARC VERSUS N
1600
1200
800
400
0
0
20
40
60
NUM OF SWITCH
20 mOhm
30 mOhm
40mOhm
50 MOhm
60 mOhm
70 mOhm
ARC IMPEDENCE

FIGURE 3

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TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720