BNL-104620-2014-TECH

AGS/AD/Tech Note No. 192;BNL-104620-2014-IR

H- SOURCE HANDBOOK

R. L. Witkover

December 1983

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

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Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York 11973

AGS Division Technical Note
No. 192

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Richard L. Witkover

December 22, 1983

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H^- SOURCE HANDBOOK

I. Introduction

The H^- ion source presently being used is very different from the previous H^+ sources. Many more parameters can affect is operation than for the old source. This report will attempt to provide at least a conceptual understanding of the physical processes involved. Information about support hardware is included. Other sections will discuss procedures for conditioning a new source, normal operation, and troubleshooting a sick source.

II. How the H^- Source Works

The negative hydrogen ion source used is of the magnetron type developed at BNL and made operational by FNAL.

H^+ ions are formed by producing a breakdown in hydrogen gas between electrodes embedded in a magnetic field, and are accelerated toward the cathode. At the cathode, reactions occur between the H^+ ions and the electrons of cesium atoms adhering to the molybdenum surface of the cathode. Some H^+ ions attach a pair of electrons and become H^- ions which are accelerated back through the gas toward the anode. A slit in the anode allows some H^- ions to leave the source. When an external potential is applied, as by the extractor pulse, there is a large current of H^- ions pulled through the slit and out of the source.

This very simple description assumes many conditions have been met. For example: the gas pressure in the gap must be high enough for a good discharge but not so high that the extra electrons of the H^- ion are stripped on the return path from the cathode to anode. The cesium layer on the cathode must be the correct thickness. If it is too thin or too thick, the work function is higher and less H^- is created because the electrons are not liberated from the cathode surface as easily. The layer thickness is the result of a balance between incoming cesium from the boiler, and outgoing cesium due to ionization and evaporation. The evaporation rate is set by the surface temperatures, which are determined by the discharge current and voltage, and the duty factor.

As can be seen, the H^- production process is quite complex with many factors affecting the same parameters. To further complicate matters, some time constants involved are many hours long, since they are thermal in nature, and what may seem to be an immediate improvement can lead to be a long-term deterioration.

III. Source and Support Hardware

The magnetron source is small, measuring less than 3" x 1-1/2" x 1". It requires quite an array of auxiliary equipment to function in an operational accelerator environment. The source and its support equipment will be discussed in this section.

The Magnetron. Figure I shows the basic magnetron source configuration. The arc is formed in the "racetrack" gap between the anode and cathode. A burst of hydrogen gas is admitted from the pulsed gas valve mounted directly above the rear of the source. Cesium vapor enters through a tiny hole in the anode side wall. The anode and cathode electrodes are made of arc-cast molybdenum. A 1 mm x 1 cm slit in the titanium anode cover plate allows the H^- beam to leave when the extractor is pulsed to ~ 20 kV.

The cathode is electrically and thermally insulated from the anode, which is at dome potential, by MACOR machinable ceramic insulators. Another piece of MACOR thermally insulates the stainless steel anode body from the source base plate. This is needed to keep the anode hot so that excessive cesium condensation does not occur.

The thermal balance of the source is critical since it is the temperature which determines the equilibrium cesium layer on the cathode.

The mounted source and its auxiliary equipment is shown schematically in Figure II. The source, cesium delivery system and gas valve are all mounted on the source flange, which allows them to be removed as a single unit. The magnet yoke is welded to and passes through the column back plate. A vacuum pumping port and a vacuum monitoring port are also on the back plate. Other penetrations are provided for electrical and cooling connections to the pulsed quadrupoles, beam transformer connections, and the cold box chiller coolant, which passes through the extractor HV insulators.

As seen in Figure II, the H^- source is mounted above the column beam line axis, facing downward. Beam leaves the source when the extractor is pulsed. The extractor is physically mounted on the cold box and in electrical contact with the funnel-shaped extraction tube. All these are raised in voltage by the extractor pulse. If they were not, the beam would see dome potential and be decelerated.

Because of the long distance between the exit of the cold box and the first column electrode, focusing elements are required to keep the beam size reasonable. A pulsed quadrupole doublet performs part of this function. The extraction tube, which is pulsed to ~ 20 kV, must pass through the quadrupoles. Since it is very desirable to refer these to dome potential, a quartz tube is used to provide the insulation.

The cold box provides cryopumping for the cesium which comes out of the source. The vapor pressure of the cesium at the cold box temperature is several orders of magnitude below the column vacuum.

A stainless steel shroud surrounds the source components, shielding them from the first column electrode and providing a vacuum baffle to enhance the removal of hydrogen gas by the turbo-molecular pump in the dome.

A brief description of some of this equipment follows. Figure III should be consulted for the timing sequence of the source.

Discharge Pulser: The electrical pulse which initiates and sustains the plasma in the source is provided by the discharge pulser. The pulser voltage is controlled by the discharge power supply (DISP) which charges a 600 μs PFN. The discharge begins when an SCR is fired (DISD) and ends with the firing of a second SCR (EDIS) (see Figure III).

Figures IV and V show the PFN voltage at time scales of 500 μs and 20 ms/div. The lowest part of the part of the trace shows the fully charged (negatively) PFN. The middle portion is the voltage during the discharge, which is brought to zero by the dumping SCR at the end of discharge. The longer time base photo shows the recharge of the PFN, which is inhibited for 20 ms to extinguish any short circuit breakdowns in the source.

Pulsed Gas Valve: To provide the high gas density required for discharge while preventing breakdown of the column, a pulsed gas valve is used. The valve action occurs when a voltage pulse of ~ 150 V is applied to a piezoelectric crystal. This flexes the crystal, lifting a Viton seal from the valve orifice, letting the gas into the source. The voltage pulse applied to the valve is shown in Figure VII. The pulse delay with respect to the dome trigger is adjustable (GASD) (see Figure III). The gas in the pulse is adjusted by changing the vacuum reference voltage (DVAC) to a servo controller which adjusts the valve pulse width. The actual vacuum signal used by the servo is the time average of the gas pulse added to the background gas.

Cesium Delivery System: A stainless steel boiler, mechanical valve and stainless steel feed tube comprise the cesium delivery system. The valve and feed tube have preset heaters with power supplies to prevent cesium condensation enroute to the source. The entire system is well insulated thermally. Figure VIII shows the source flange assembly and cesium delivery system.

A closed-loop temperature controller keeps the cesium boiler at the command temperature (CSTP) to within $\pm 0.1°C$. The temperatures of the valve (CSVT) and feed tube (CSFT) are normally at least 200°C greater than the boiler. A readback of the cesium boiler current (CSBI) is provided as a check on the servo control.

<u>Extraction Pulser</u>: Beam is pulled from the magnetron anode slit when the extractor is pulsed. The amplitude of this pulse is set by the extractor power supply (EXTV), which provides plate voltage to the tetrode pass tube. The actual applied voltage is less than that of the power supply due to tube drop but is normally within 400 V. Figure VI shows the extractor voltage pulse for 17.6 kV, 500 μs.

The timing of the extractor pulse is set by the delay (EXTD) and pulse width (EXTW) (see Figure III).

<u>90° Bending Magnet</u>: Three functions are provided by the 90° bending magnet:

1. source magnetic field
2. 90° bend
3. focusing

This gradient magnet is controlled by the magnet power supply (90DI). Since the beam is bent vertically, adjusting this supply provides vertical steering in the column.

The magnetic field for the source is provided by pole tip extensions. However, this setting must be critically matched to the extraction voltage for the H^- beam to enter the column on axis. At extraction voltages of 16 kV or higher, the field provided for the source by the pole tip extensions is satisfactory.

Pulsed Quadrupoles: The two pulsed quadrupoles used for beam transport between the source and first electrode act with the focusing of the 90° magnet to provide a double waist at the first electrode. The currents of the two quads are separately adjustable (DQAI), (DQBI). Figures IX and X show the currents for these quads at 200 A and 180 A, 500 μs/dw. Because of the long rise time the quads are the first item triggered in the dome. The pulse width (DQPW) must be at least 2.6 msec to provide a flat top for the beam (see Figure III).

Cold Box: The cesium which leaves the source must be trapped to prevent plating on the column walls. This is done by cryo-pumping the cesium on the cold box. This unit is cooled by a Freon-12 chiller located in the dome. The temperature (CBXT) is normally between -20°C and -40°C.

Toroid: Following the pulsed quadrupoles in the dome transport line is a beam intensity toroid. This allows monitoring the current from the source just prior to entrance into the column electrodes. When the Cockcroft-Walton generator is off, the beam intercepts the column and charges the electrodes. Sufficient voltage is soon built up to repell any further H^- beam. The effect is to produce no net current through the toroid and hence no signal. Thus, the Cockcroft-Walton must be on (> 50 kV) before beam can be observed on this toroid. The signal is displayed on the lower left-hand oscilloscope trace and is recorded by means of a sample-and-hold circuit fired at MSP-B. The name is DMBI.

IV. Conditioning The Source

When the source is first turned on after major maintenance, there is no cesium present. The start-up procedure begins by establishing a hydrogen-mode dicharge. This requires high gas pressure 5 x 10^{-5} Torr - 1 x 10^{-4} Torr (average reading), high discharge power supply voltage (~ 450 V), high 90° magnet current (~ 8 A) and very long pulse width (2-3 msec).

With these conditions the source will develop a hydrogen discharge with currents in the range of 1 to 3 amps. The purpose of the long pulse width is to heat the cathode and anode in preparation for the arrival of the cesium in the racetrack. If the anode is too cold, the cesium will condense and plug the entry hole.

Under normal conditions, about three hours are required to heat the source enough for cesium to enter. The anode temperature at this time is typically 115°C. The arrival of the cesium vapor causes a dramatic increase in discharge current, rising from 1 amp to more than 10 amps in a few minutes. For this reason limiting resistors built into the discharge pulser are normally put in series with the source. These prevent overheating if the source is left unattended when the cesium enters the discharge.

The discharge current may rise and fall several times as bursts of cesium enter and are depleted. This is followed by a period of steady increase to about 10 amps. The current limiting resistors can now be removed. During this period the gas should be reduced gradually by lowering it a small amount (5 counts), waiting several minutes and observing whether the discharge current rises or falls. It if remains low, then return the gas to its original setting. If it rises, wait a few minutes and lower it another 5 counts.

During this same period, the pulse width should be lowered to a value in the range from 300 to 500 μsec; just enough to keep the discharge current rising. The discharge power supply voltage must be reduced upon the entrance of the cesium gradually until it reaches ~ 350 V as required to keep the cathode temperature ~ 350°C. The voltage should be "tested" frequently by lowering it 5 V and observing if the discharge current rises after a few minutes. If so, then it must be left at the lower value.

Within about three hours of the arrival of the cesium, the gas should have been lowered to 2-3 x 10^{-5} Torr. The discharge current should be approximately 30 amps at this time.

This process of reducing the gas pressure and the voltage must continue until the source arrives at the "3 Ohm" discharge stage. This may take 12-24 hours to reach, with most changes being required in the first 2-3 hours. Throughout the conditioning period the pulse width must be adjusted to prevent the cathode temperature from going too high (over 400°C) or too low (below ~ 320°C).

V. Normal Operation

Once a source has been conditioned it can operate for as long as five months without maintenance. During this period, performance might drop by 10-20% as "discharge debris" obstructs the anode or extractor apertures.

This performance is possible because of the normal stability of the source. If, however, conditions are changed too drastically or too many at one time, the stability may be overcome and the performance deteriorates. If the source becomes contaminated due to improper handling, or leakage of air, water, oil, or freon into the vacuum, the stability as well as performance may suffer.

Table I is a listing of source parameters showing the nominal setting as well as the observed range of operation. It is seen that reasonable ranges exist around the nominal parameters. These cannot be expected to hold if multiple departures are made from normal conditions. That is, since a number of parameters may be changed which each influence some aspect of the source, it is unreasonable to assume that each can be changed as much as when it alone is varied. For example, increasing the pulse width will result in higher source temperatures, but so will increasing the gas or the power supply voltage. Clearly doing all three at once will cause a larger rise than if only changing the pulse width.

For this reason it is generally not a good idea to change more than one parameter at a time. It is also necessary to allow sufficient time to see the full effects of the change before making additional ones. Since thermal time constants may take several hours, the changes must be made slowly. Changes to the cesium boiler, which affect the equilibrium thickness of the surface layer may take even longer to see.

The recommended procedure for optimizing source performance, under normal operating conditions, is to make small perturbations around the existing set point. For example, raise the gas pulse 5 counts and observe the effects over a period of one hour. This should be sufficient time for transient heating to die out and the long-term trend to be observed. If the beam conditions show improvement, then further change upward would be indicated. If the beam deteriorates, then an opposite adjustment must be made.

Using this technique, small changes may be made in the discharge power supply voltage, dome vacuum, or beam pulse width (end of discharge), to optimize the beam. The cesium temperature should not be changed unless there is strong evidence of too much cesium (breakdown) or too little cesium. A good way of observing these changes would be through the use of the IAGP program which allows the plotting of multiple parameters over many AGS beam pulses. Another program which has the capability of displaying data taken over several days is SRCPLT. See Section VIII for more detailed information.

Figures XI and XII show normal scope waveforms for the various pulsed signals. Some deviation from unit to unit may exist but the general character will be the same.

Table I

Source Parameters

Function	Name	Readback Nominal	Readback Range	Units
Discharge PS Voltage	DISP	265	250→270	V
Extractor PS Voltage	EXTV	17.5	17→18	kV
Dome Vacuum	DVAC	8	7→10	μTorr
Cesium Boiler Temp.	CSTP	99	96→100	°C
Cesium Boiler Current	CSBI	480	450→520	mA
90° Magnet Current*	90DI	7.50	7.00→8.00	A
Discharge Current	DISI	40	38→45	A
Discharge Voltage	DISV	135	125→140	V
Cesium Valve Temp.	CSVT	300	280→330	°C
Cesium Feedtube Temp.	CSFT	330	300→340	°C
Source Anode Temp.**	SANT	200	180→220	°C
Source Cathode Temp.**	SCAT	380	350→400	°C
Cold Box Temp.	CBXT	-30°C	-40→-15	°C
Extractor Delay Time	EXTD	1830	1830	μsec
Extractor Pulse Width	EXTW	400	300→500	μsec
Gas Delay Time***	GASD	930	700→1130	μsec
Discharge Delay Time***	DISD	900	1130→700	μsec
End of Discharge	EDIS	500	400→550	μsec
Dome Beam Current	DMBI	45	35→60	mA

*Current shown for Pit I. Magnet in Pit II ~ 1 A less.

**Depends on many conditions, especially EDIS.

***Sum of these must equal EXTD.

VI. Troubleshooting the Source

People who work on ion sources are commonly called "sorcerors" because of the "magic" they must possess to make the sources work. While this is not true, it often seems to be. Because of the large number of interacting variables, the parameter space for an ion source is very complex, making it difficult to formulate hard rules for operation or for diagnosis of faults.

A few "rules of thumb" have been developed to assess if the operation is proper.

Rule of Thumb #1: The source operates best at about a 3 Ω discharge impedance (DISV/DISI). Actually 2.5 to 3.5 Ω is acceptable. If it is too low, check cesium temperature (CSTP) and dome vacuum (DVAC). If it is too high, check both plus the discharge power supply voltage.

Rule of Thumb #2: The dome beam current (DMBI) in mA should be roughly equal to the discharge current (DISI) in Amperes. This can differ by perhaps 25% and still be acceptable. If the beam current is too high, the vacuum will be found to be too low (DVAC). If it is too low the vacuum may be too high, but this condition could also be due to discharge power supply voltage (DISP) too high or improper cesium setpoint.

Rule of Thumb #3: The beam current in the first LEBT transformer should be 90% of that in the dome. If it is less, then too much beam is being intercepted by the column. If Rule of Thumb #2 is not true, particularly when the beam current is significantly greater than the discharge current, one will find that less than 90% of the dome beam current will reach LEBT. This is because the extra current in the dome corresponds to beam with an emittance larger than the acceptance of the column. Thus, even though the dome current might reach 60-80 mA, only 45 mA may reach LEBT. This is not a good way to run since the lost beam "loads" the column voltage divider and upsets the column gradient. Column breakdown may occur in this case.

If the dome current is not too high and transmission is below 90%, the cause is due to poor adjustment of the dome transport [the quad doublet (DQAI, DQBI), the 90° magnet (90DI) and the extractor voltage (EXTV)]. The extractor voltage must be matched to the 90° magnet current or a vertical steering error will result.

Unfortunately, if the beam enters the quadrupoles off-axis, it will be steered by them too. One way to check if the quads are steering is to vary them and see if the beam changes position. This can be done with an emittance device in LEBT, but it is a destructive measurement.

There are several malfunction modes which can be easily diagnosed. These will be discussed in the following paragraphs.

Malfunction 1: Extractor Breakdown. When the microprocessor announces an extractor malfunction or the TV display shows a partial or no extractor voltage pulse (upper left hand trace) then arcing between the extractor and the source anode must be suspected. This can be caused by either the vacuum being too high or the cesium having coated the extractor. The vacuum is easily checked since it can be directly read. The cesium temperature too can be observed but it is not always sufficient to determine cesium excess. Since the only way for cesium to leave the source is through the anode slit, it is not surprising that eventually this might produce a sufficient coverage of the cold surface of the extractor electrode to result in breakdown. Since there is partial intercept of the beam current by the extractor, some cleaning action also takes place. Under normal conditions, up to five months may pass before buildup produces breakdown. If, however, the cesium temperature is set very high, even for short periods of time, arcing can begin.

The cure is to completely shut off the cesium flow (CSTP) for a few minutes to reduce the surface plating. Lower the extractor voltage to the point where arcing stops. Then in 1 kV increments, raise the extractor voltage until breakdown occurs midway in the pulse. This discharge is necessary to clean the surface of cesium.

This procedure must be continued past the desired operating voltage. The level is then reduced for normal running. At this point, the cesium boiler can be turned on again to its normal setpoint.

Malfunction 2: Irregular Beam Envelope. When the discharge current and beam curent develop holes or gaps in the time structure the cause is most likely insufficient gas in the gas pulse. This can be caused by several factors: (1) the gas command has been mis-set to too low a value, (2) the timing of the discharge with respect to the gas pulse has been mis-set so that insufficient gas is present when the discharge voltage is applied, (3) the background vacuum pressure has risen.

The most likely cause is the last one. The servo system which regulates the gas pulse reads the average vacuum in the column. Since this is the sum of the background level and the time average of the gas burst, an increase in background will cause the gas pulse to shrink to keep the total a constant. The source, however, ignores the background gas (within a reasonable range) but requires a specific pulsed pressure. When the gas pulse is reduced, the source current develops holes and may extinguish completely.

A new gas servo is being designed, which separately monitors the background and pulsed gas components. When installed, this should eliminate the problem (#3 above). Until then, the cure is:

1. find why the pressure in the column or LEBT rose and fix it
2. if not practical to fix it, raise the gas reference until the holes in the beam disappear.

Local Interlocks

Source Logic. To protect the ion source from operating when critical parameters exceed preset levels, local interlocks were installed. These circuits provide hard-wired real-time monitoring which will stop operation before the offending parameter can cause damage, or merely enunciate the condition when the results would be less severe. These faults are displayed on the dome malfunction panel and are telemetered to the ground microprocessor. The signals are also fed into the dome FBI (Fast Beam Interrupt) circuits.

The fault conditions which stop operation are:

1. Cathode temperature high. When the cathode thermocouple senses a temperature greater than 500°C, the gas valve trigger is inhibited.

2. Vacuum high. Also, inhibits the gas valve trigger when vacuum $> 1 \times 10^{-4}$ Torr.

3. Cold box temperature high. Shuts off the cesium feedtube, valve and boiler heaters when the cold box temperature exceeds 0°C.

4. Cesium temperature high. Shuts off the cesium system heaters when the boiler temperature exceeds 130°C.

5. 90° magnet temperature high. Shuts off the 90° magnet pwer supply when the magnet coil case exceeds 140°F.

The source faults which produce only warnings are listed below. They too are shown on the dome malfunction panel and are interfaced to the microprocessor.

1. Quad freon temperature high. Trips at 0°C.

2. Cesium valve temperature low. Set for 200°C.

3. Cesium feedtube temperature low. Set for 250°C.

Dome FBI Logic

There are several parameters beyond those of the source which affect performance and beam quality. These are monitored with window comparators which can be set for a narrow range. Operation outside of this range will produce a fast beam interrupt. These signals are:

1. Dome pulsed quad A current.

2. Dome pulsed quad B current.

3. 90° magnet current.

4. Extractor voltage.

These signals are displayed on the malfunction panel and are put into the microprocessor.

The extractor pulse width is set by the AGS and Linac timing systems. This pulse width forms an envelope within which the microprocessor timing can be set. See Figure III. This net pulse is passed through the dome FBI logic which can inhibit it should a malfunction occur in the dome.

VII. JEFF Displays of Pit Alarms

The alarm monitoring program, JEFF, and its parameter support program, MUTT, allow a number of Pit I and Pit II alarms to be displayed. The alarms are identified by parameter and condition as well as which pit was at fault. Either pit can be in one of four modes at any given time:

Mode	Status	Function
1	Off	Off
2	Standby	Discharge on, No extracted beam CW, LEBT off
3	Studies	As in 2, but CW on
4	Operations	All systems on

The various alarm names and modes in which each is monitored is shown in Table II. Any action to be taken is also shown.

It is the responsibility of Linac personnel to notify MCR when a change in status is made. The MCR operators will then make the appropriate constants changes in MUTT to allow JEFF to monitor the pit. Adherence to this procedure will mean that only real alarms will be displayed by JEFF and they must not be ignored.

Table II

Pit I	Pit II	Action
CBXT1 HI	CBXT2 HI	Freon-12 recharge required.
CSTP1 HI	CSTP2 HI	Lower CSTP CMD, if no change after 15 min., investigate.
90DG1T HI	90DG2T HI	If 90DI is normal, check Freon-113 (Pit 2); investigate.
SCAT1 HI	SCAT2 HI	Lower DISI (set DISP lower); Lower EDIS (shorten width.
CSFT1 LO	CSFT2 LO	PS problem; short circuit, investigate.
CSVT1 LO	CSVT2 LO	PS problem; short circuit, investigate.
DVAC1 HI	DVAC2 HI	Lower DVAC CMD, if no change, call Vacuum Group.
DQAI1 MAL	DQAI2 MAL	If CMD is normal, investigate; if not, set to normal
DQBI1 MAL	DQBI2 MAL	
90DI1 MAL	90DI2 MAL	
EXTV1 MAL	EXTV2 MAL	If EXTI > 3 mA, it is arcing; lower EXTV, DVAC, investigate.
PIT1 QUADT HI	PIT2 QUADT HI	Check Freon-113 cooling!!
PIT1 N-PRESS LO	PIT2 N-PRESS LO	Not critical; notify Linac.
	CW MALF	CW down, bouncer down; investigate.
	LEBT W MALF	A catch-all; needs further check of LEBT 2 magnets, security.

VIII. Source Data Plot Program: SRCPLT

A program is available which will plot the ten most used readbacks and ten most important command values for the H^- ion sources. The program uses data taken every 20 minutes by a batch job on System-C. It is very useful for looking back on the prior performance of the source (the file is moved from disk to tape weekly) to see if some trend in its behavior may exist. In this way, slowly varying phenomena can be observed. It is also useful for seeing the result of an earlier parameter change.

The program is available in "R R". A sample dialog is shown below. After specifying which source is desired, the output medium must be stated. The hardcopy option may be exercised by entering a "2" if CRT display is also desired, or "3" if not. The CRT only mode requires a "1" entry.

The date and time range over which the plot is desired must be provided as shown. Note that a two-digit entry is always required for the date.

The program requires considerable time to process a large file. The CRT plot of the readbacks is displayed, if this mode was selected. The program then waits for a carriage return, <CR>, before building a Versatek file (if selected). The second CRT plot (command values) is then prepared and displayed. Another <CR> is required to end the display and prepare the Versatek file or exit the program. The hardcopy graphs are automatically made at exit. The user should delete the VECTOR.DAT file after the hardcopy has been made.

A typical plot is shown in Figure XIII. A sample dialog is shown below.

```
R R
*SRCPLT
DO YOU WANT LINAC PIT 1 (1), OR LINAC PIT 2 (2) DATA?
     (GIVE 1 OR 2) 1
OUTPUT DEVICE? (1=CRT, 2=CRT AND LPS, 3=LPS): 2
ENTER DAY/TIME RANGE IN FORMAT:  DA-MON-YR HR:MM
BEG:  28-NOV-83 08:00
END:  01-DEC-83 13:00
```

IV. Controls

Because of the large number of controlled parameters and readbacks, a microprocessor is used as the heart of the control system. There are actually three microprocessors involved. One controls the parameters of the source and its support equipment in the dome, and processes the data for transmission to the ground. A second unit controls any ground parameters and processes communications to the dome. It also services a local terminal for input and display. The third microprocessor is on the same signal bus as the ground unit. It handles requests from Datacon for changes or readbacks by using the bus protocols to access the memory used by the control CPU to store commands and readbacks. In this way each microprocessor has specific tasks which can be efficiently performed on a non-interference basis.

A block diagram of the microprocessor system is shown in Figure XIV.

All functions are handled by the microprocessor system. Timing, analog references, analog readbacks and status bits are processed by various cards within the crates. The communication between the dome and ground microprocessors is via commercial UARTS (Universal Asynchronous Receiver/Transmitters). These signals are sent over fiber optic links at a rate of 19.2 kiloband, allowing complete system refresh in the interpulse period of 200 msec. Three light links are used: one each for transmissions up and down, and one for the timing envelope sent from the ground. Software error detection is used to determine if the data received is reasonable. If several consecutive errors are found, the communication link will self-initialize and send a reset code to its partner.

The microprocessor systems have "heartbeat" circuits to sense when they are running properly. If not, a hardware reset is performed within 8 beam pulses at the linac repetition rate of 5 pps.

The dome microprocessor is isolated from the hardware it controls by local light links. These handle dc analog signals by converting them to pulse trains by means of voltage-to-frequency converters (VFC's) and back again on the receiving end. The tuning and status signals are sent as digital pulses. Receiver and transmitter circuits are packed eight per single-width NIM module.

Analog command signals are taken from the optical receivers and scaled as required for presentation to the suppply being controlled. These scaling amplifers are packaged in double width NIM modules. Front panel multi-turn pots on these units allow local control when a switch is set for this mode. In this way, a faulty optical link can be bypassed to continue operation. Readbacks also pass through a scaling amplifier in the microprocessor rack.

Further protection of the signals into or out of the microprocessor crate is provided by diode-clamping all signals. The overall history of the system has been exceptionally good, even in the face of severe Cockcroft-Walton arcing problems.

On rare occasions communication with the dome has been seen to stop. The reason for this has not been found since it happens so rarely. In the event it does, the ground station micrprocessor should be inintialized by pressing its reset button. The software is designed to retain the last reference value except in the event of a power up, or if the memory is scrambled. In this case, it restarts with values previously burned into ROM.

One caution: At the present time commands entered directly from the local terminal are not passed on to the AGAST program. When a change in AGAST is later made, undesirable values may result.

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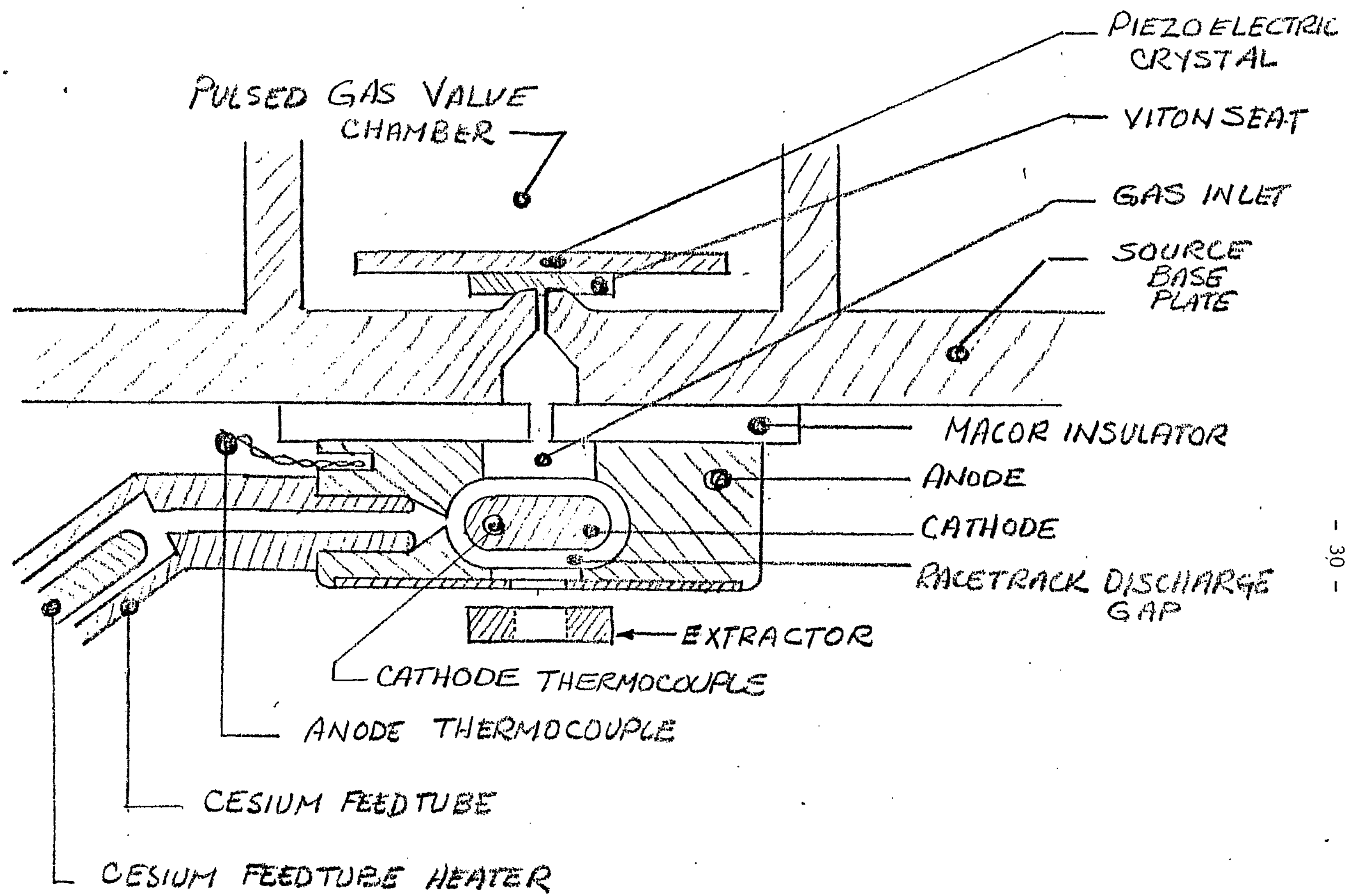

FIG I. MAGNETRON H^- SOURCE

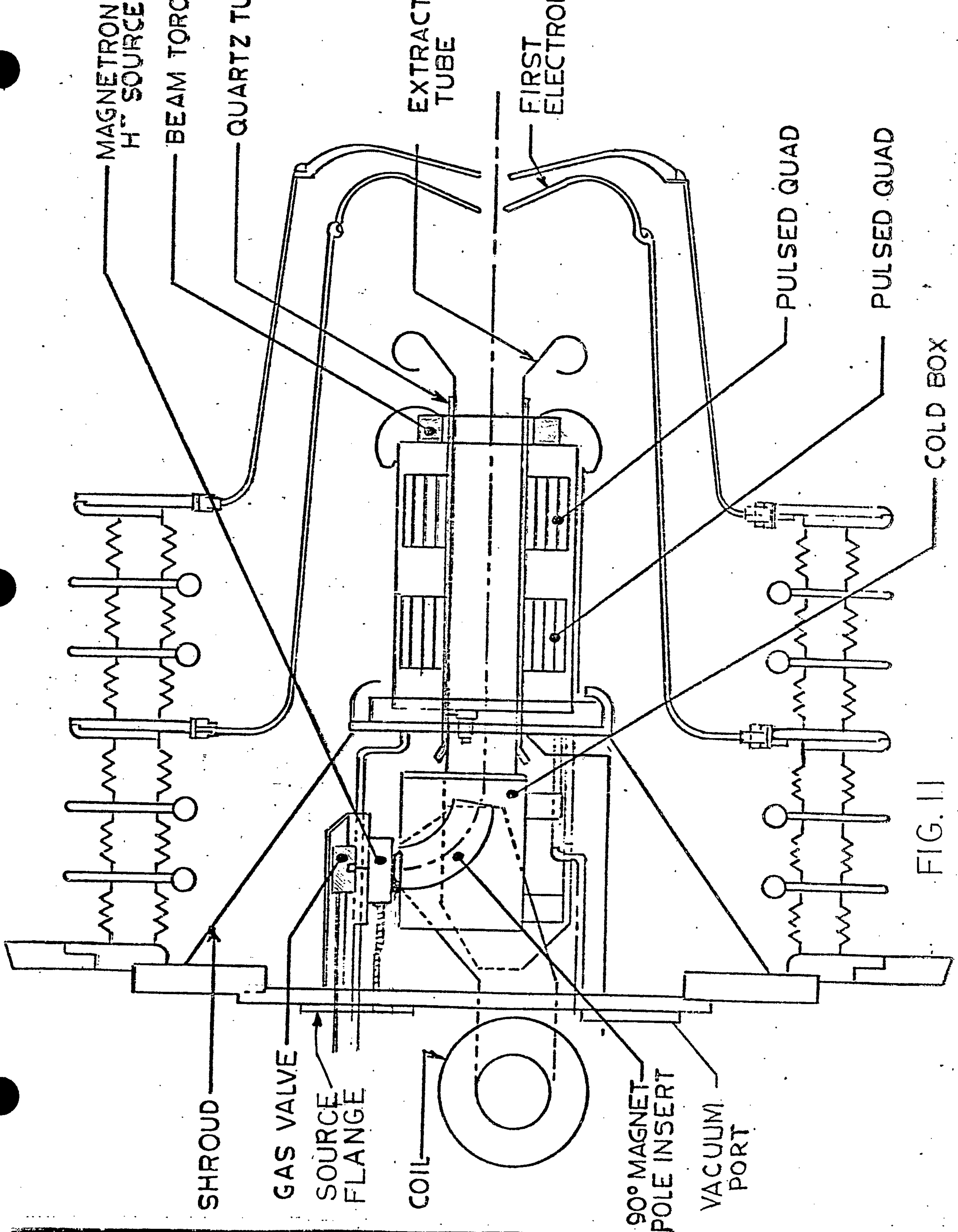
MAGNETRON
H⁻ SOURCE
BEAM TOROID
QUARTZ TUBE
EXTRACTION
TUBE
FIRST
ELECTRODE
PULSED QUAD
PULSED QUAD
COLD BOX
SHROUD
GAS VALVE
SOURCE
FLANGE
COIL
90° MAGNET
POLE INSERT
VACUUM
PORT

FIG. 11

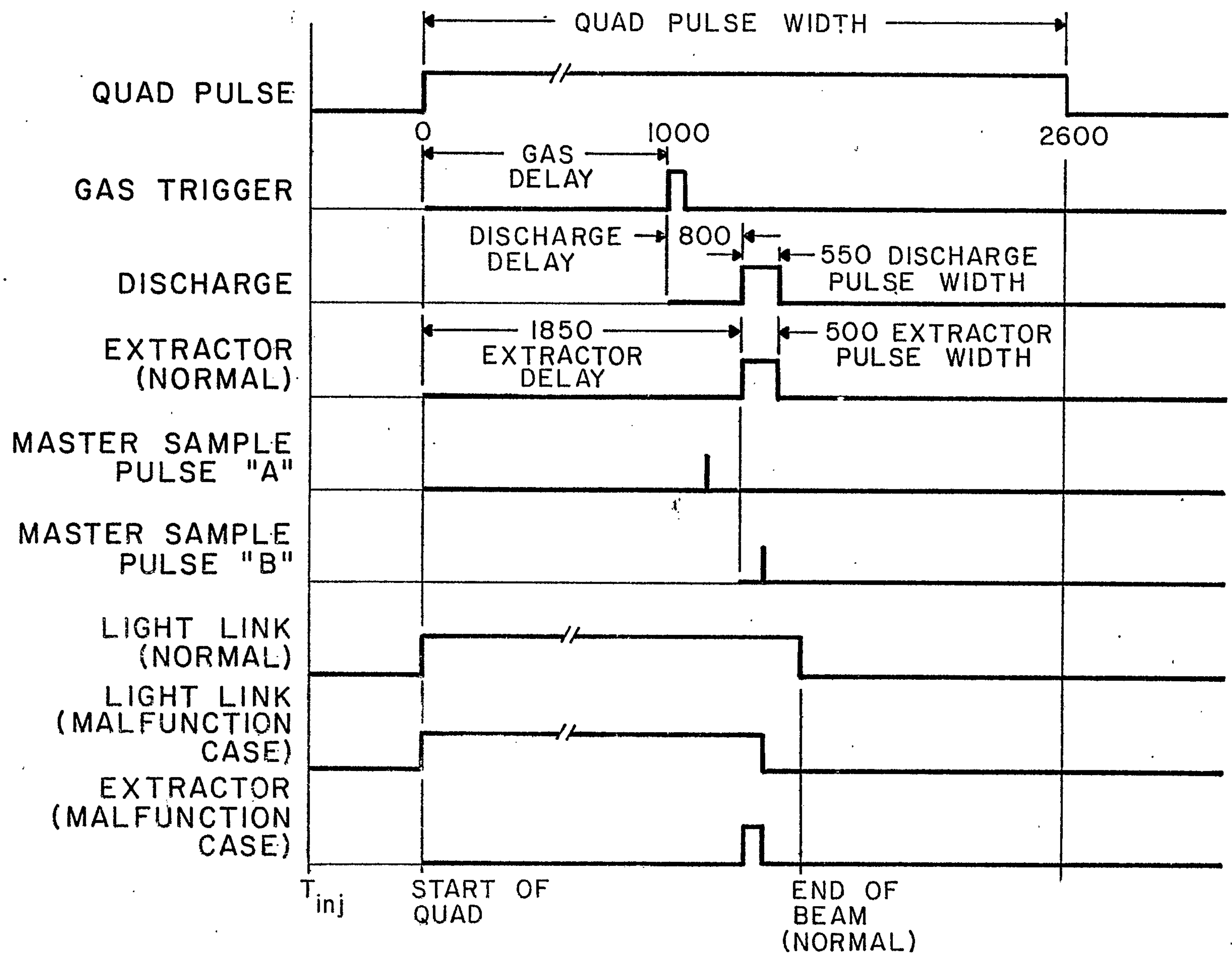

FIG. III H^- SOURCE TIMING (μs)

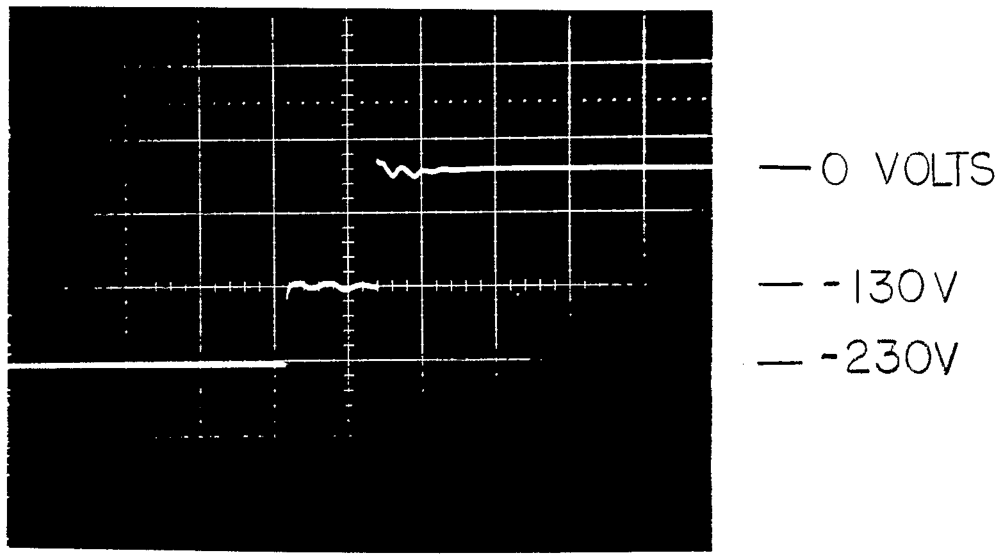

FIG. IV. PFN VOLTAGE (500μSEC/DIV)

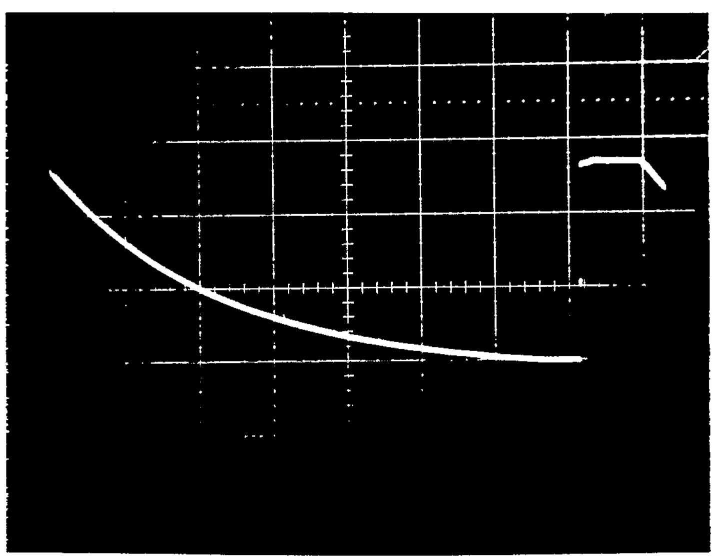

FIG. V. PFN VOLTAGE (20 MSEC/DIV)

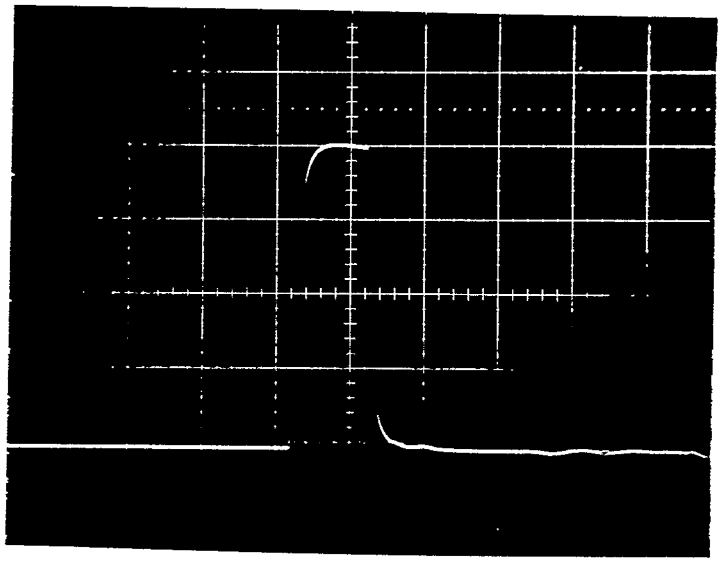

FIG. VI. PULSED GAS VALVE VOLTAGE
40 V/DIV 200 μSEC/DIV

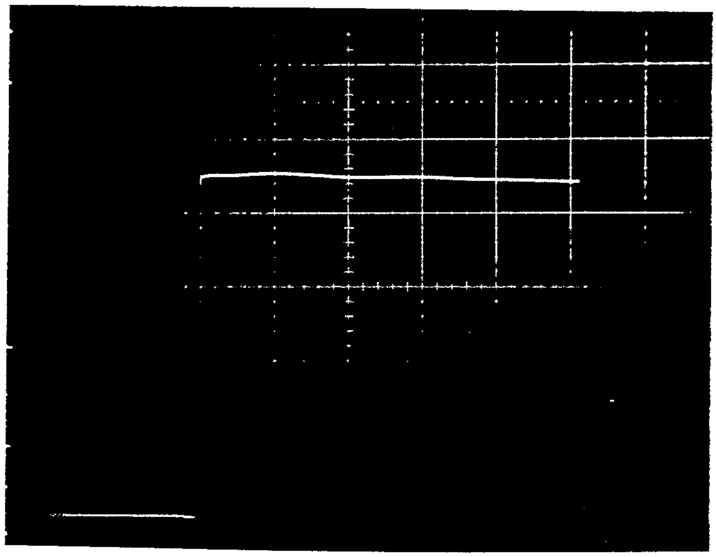

FIG. VII. EXTRACTOR PULSE VOLTAGE
400 VOLTS/DIV 100 μSEC/DIV

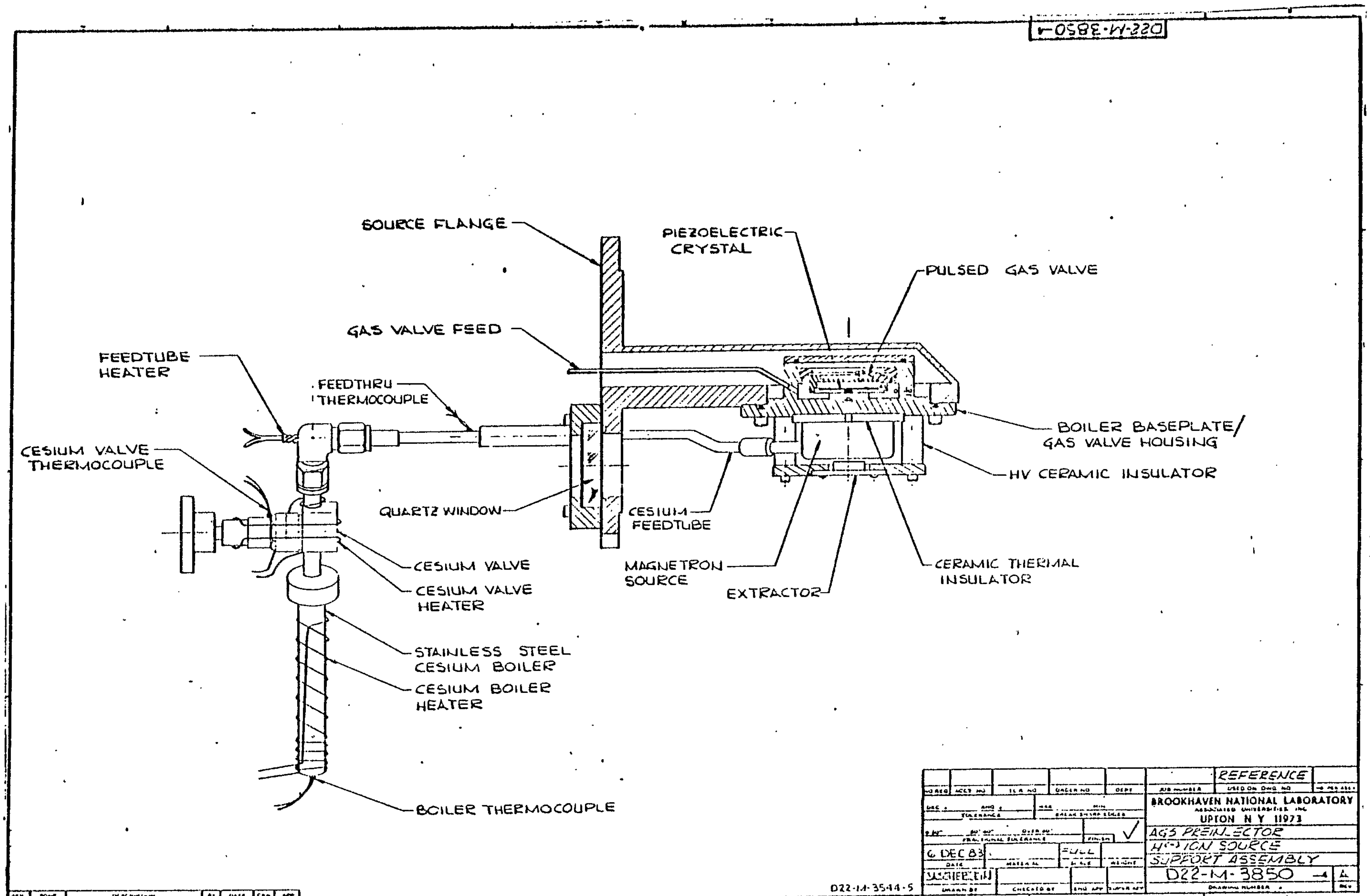

FIG. VIII. SOURCE ASSEMBLY-CESIUM SYSTEM

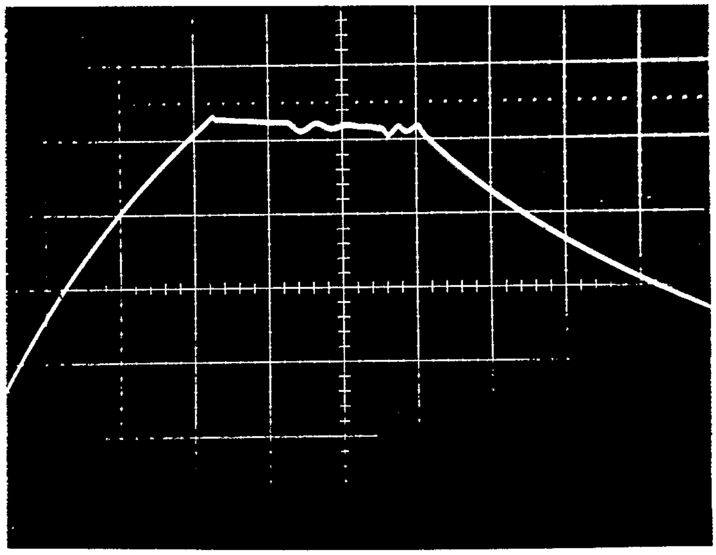

FIG. IX
QUAD A 200A

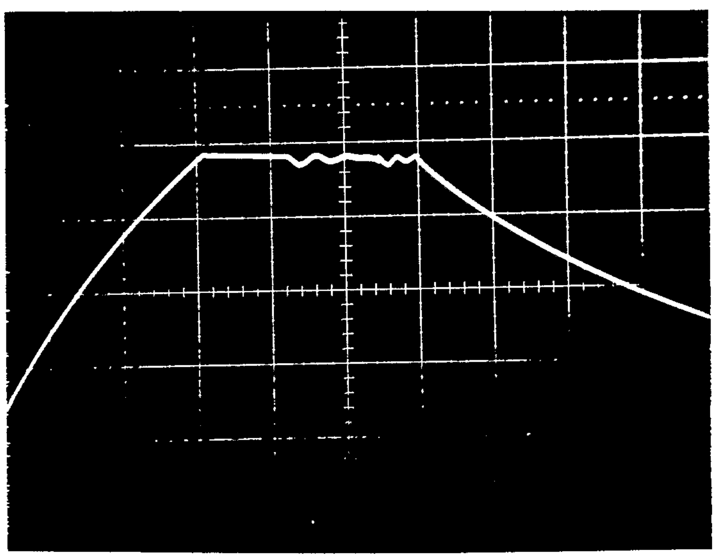

FIG. X
QUADB 180A

PULSED QUAD CURRENT

500 μSEC/ DIV

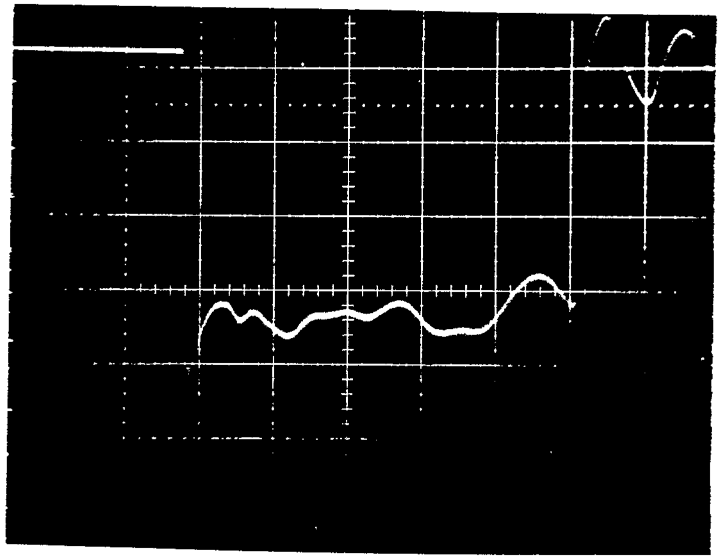

FIG. XI. SOURCE DISCHARGE CURRENT
10 A / DIV 100 μSEC / DIV

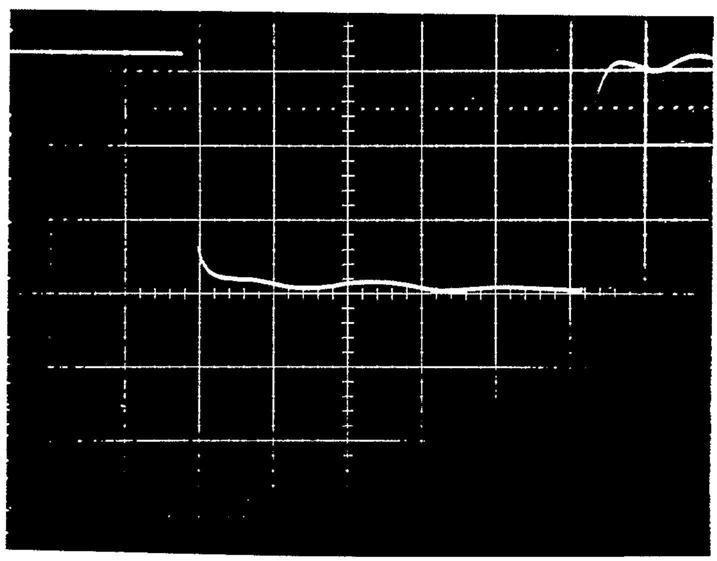

FIG. XII. SOURCE DISCHARGE VOLTAGE

40 V / DIV 100 μSEC / DIV

PIT 1 - RDBKS

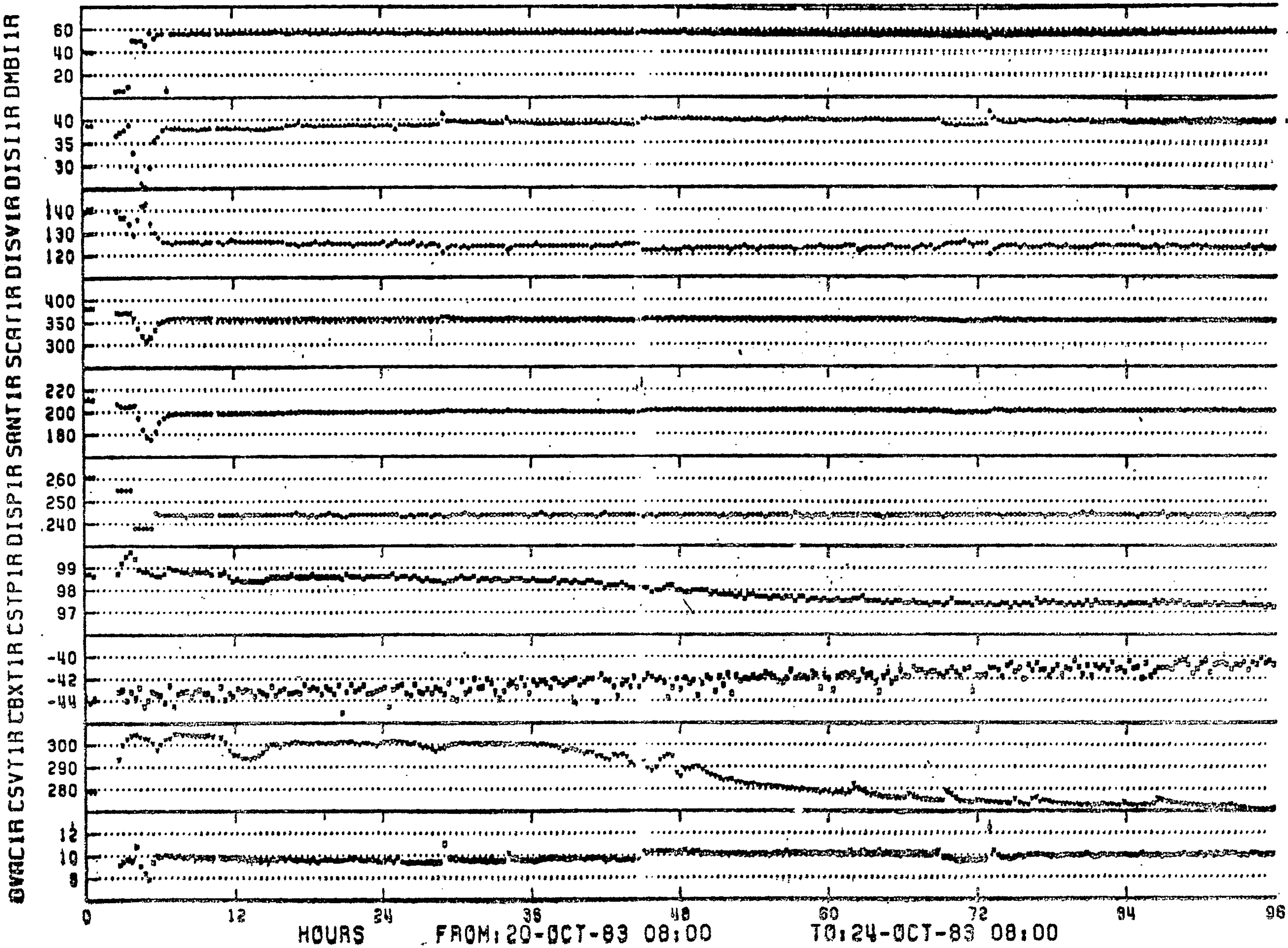

FIG XIII

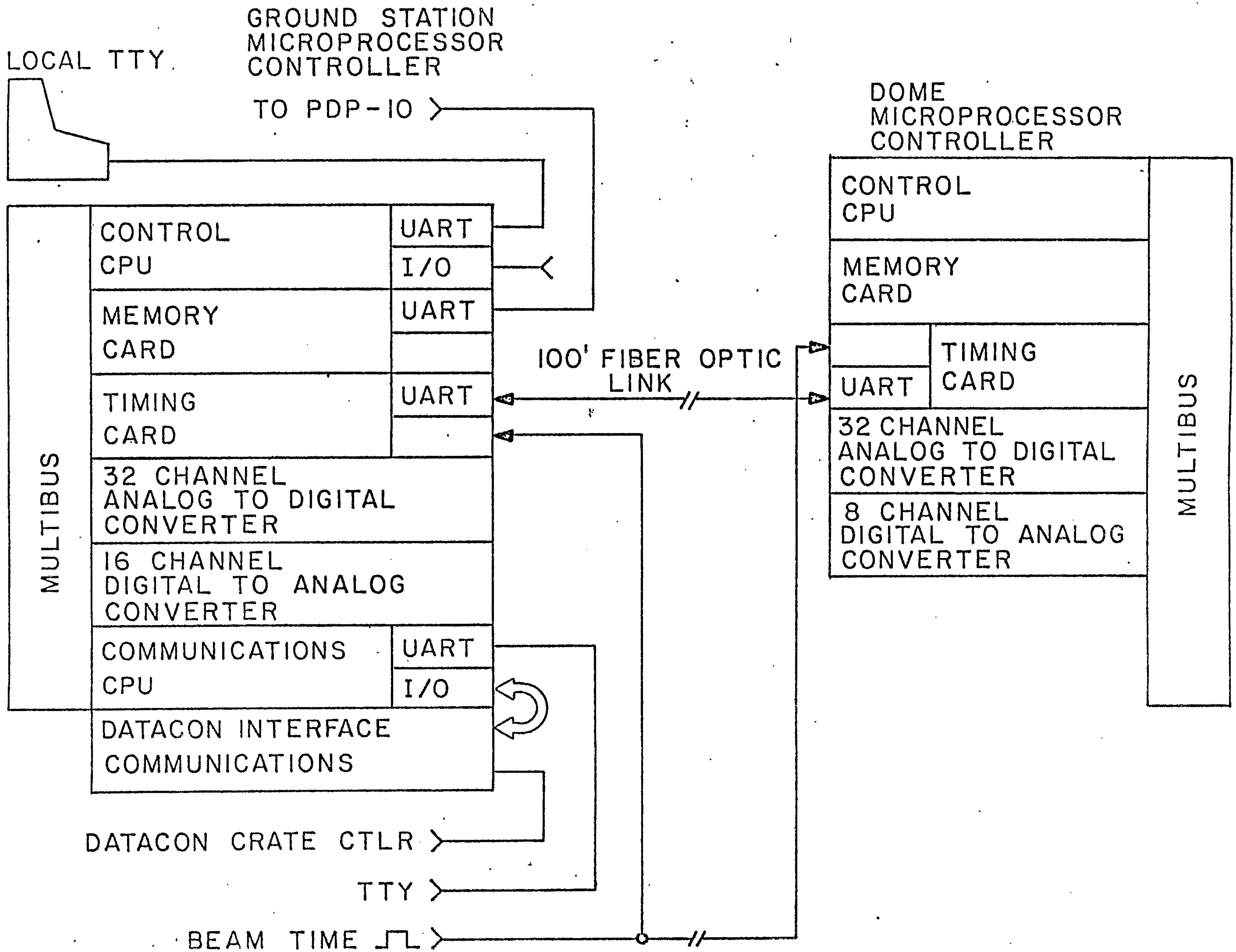

FIG. XIV MICROPROCESSOR SCHEMATIC