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UCRL-77504
PREPRINT
Conf-751125--16

LAWRENCE LIVERMORE LABORATORY
University of California/Livermore, California

2XIIB COMPUTER DATA ACQUISITION SYSTEM

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November 18, 1975

Sixth Symposium on Engineering Problems in Fusion Research
San Diego, California, November 18-21, 1975

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Abstract**

All major plasma diagnostic measurements from the 2XIIB experiment are recorded, digitized, and stored by the computer data acquisition system. The raw data is then examined, correlated, reduced, and useful portions are quickly retrieved which direct the future conduct of the plasma experiment. This is done in real time and on line while the data is current. The immediate availability of this pertinent data has accelerated the rate at which the 2XII personnel have been able to gain knowledge in the study of plasma containment and fusion interaction. The up time of the experiment is being used much more effectively than ever before.

This paper will describe the hardware configuration of our data system in relation to various plasma parameters measured, the advantages of powerful software routines to reduce and correlate the data, the present plans for expansion of the system, and the problems we have had to overcome in certain areas to meet our original goals.

Hardware Configuration

The 2XIIB Computer Diagnostics System has undergone major growth since it was first announced.[1] Originally the system was basically a data collection system designed around a sixteen channel analog disc. It provided a ten microsecond resolution over a thirty millisecond range. This was a significant improvement over the use of oscilloscopes. The computer system also gave improved accuracy and digital magnetic tape storage for later retrieval and reduction of data using the services of a large remote computer center.

Both the physicists and engineers on the project recognized the need for on line rapid data reduction and retrieval. Direct links to a classified computer center were not allowed and the only large unclassified computer we could tie to was not reliable enough for our needs. Hence we set our goals on the development of a local minicomputer system which would provide us with the reliability and computing power we desired while working within a very limited budget.

The present system is the result of this preplanning, the use of knowledge we gained by developing and working with the system, and the development of new equipment.

The first goal in developing a more useful system was to add additional memory so we could write our programs in higher level languages such as Fortran IV. Trying to develop useful programs in eight thousand words of memory had limited us to assembly type programming which is a very slow form of programming. The addition of digital cartridge disc memory and thirty-two thousand words of core memory freed us to rapidly develop sophisticated programs which not only retrieved the raw data but which could examine the data, reduce it in real time and correlate data from various distinct diagnostic probes. This capability was used to clearly show what was happening to the meaningful plasma parameters such as density, energy, losses, etc. A low cost printer was then added allowing the physicists to examine reduced data in tabular format. This was a great help in making real time decisions as how to change the plasma experimental parameters to maximize useful results.

The next step in our plan was to add graphical output. Physicists can work with tabular data and it serves its purpose especially if one wants accuracy near twelve bits of resolution but good clear graphical output fulfills the old saying that one picture is worth a thousand words. One clear graphical output is worth a stack of computer printout. Details which were being missed before became clearly visible. Next, we added a graphical terminal with hardcopy. The hardcopy unit was for the rapid display of data which did not require the great resolution of our slower digital plotter. There is an experimental shot every three minutes when the machine is running which means data must be collected, stored, reduced, and output to the staff within minutes if we are to effectively use the plasma experimental machine. When running we often use two eight hour shifts and then make minor alterations to the experiment during the off time. This procedure often goes on for weeks without break.

Two types of equipment which have been developed that we did not originally plan into the computer system but which we now make great use of are very fast transcient recorders and the addition of a fast fortran hardware processor and arithmetic hardware to our computer mainframe. We now use this capability to record radio frequency probe data and microwave scattering data. We are able to reduce this data using fourier transforms to develop power spectrums and other useful output.

The system as of October 1975 is shown in Figure 1. It may be noted that the 2XIIB Computer Diagnostics System is also the master mainframe of the CTR experimental computer network. Currently two other computers, an H.P. 21MX mainframe which is dedicated to neutral beam source measurements (under the direction of George Pollock) and an H.P. 2115A mainframe which is dedicated to 2XIIB experiment control (under the direction of myself), are connected to the 2XIIB Diagnostic Computer via Hewlett Packard's distributed system network. This is a cable serial link which allows all computers to communicate via the host computer (H.P. 2100 mainframe) under our Real Time Executive system.

The Impact of Powerful Software

Most of the software routines developed for the 2XIIB computers were done by Bill Cummins, Harry Chow

[1]George C. Tyler, UCRL 73030 (April 5, 1971), "The Automatic Data Processing System For 2XII." Also presented at the 4th Symposium on Engineering Problems of Fusion Research, Naval Research Lab, 1971

*Work performed under the auspices of the United States Energy Research and Development Administration, W-7405 ENG-48

**Abstract prepared for Sixth Symposium on Engineering Problems in Fusion Research, San Diego, CA, Nov. 18-21, 1975.

and Tom Haratani. It is thru the efforts of these men using the hardware provided that we now have data available in real time which is used to direct the immediate future conduct of the plasma experiment. There is no question that the immediate availability of this pertinent data has accelerated the rate at which the 2XIIB personnel have been able to gain knowledge in the study of plasma containment and fusion interaction.

I am not going to list in this paper what these software programs are but I am going to try to clearly show the effects these powerful routines have had on reducing and correlating the data and how the results are displayed.

Figure 2 is a drawing of the major plasma diagnostics installed on the 2XIIB plasma experiment and Figure 3 is a list of the thirty-two analog channels showing the mix of diagnostics as they existed in October of this year.

As a typical example of the effect of software on the experiment I am going to discuss the ion mass-energy analyzer. This particular diagnostic is a prime method used to measure ion energy which some people prefer to call ion temperature. Figure 4 is a sketch of the plasma showing an ion reacting with the background gas in the chamber. Charge exchange takes place in the plasma and a small portion of the hot deterium ions react with the background gas forming deterium atoms and other neutral atoms which being neutral are not contained by our magnetic field. Some of these atoms are then stripped by a nitrogen stripping cell which produces positive ions outside the mirror field. These ions are then first passed by a bending magnetic field which sorts the ions according to their energy levels and then they are electrostaticly selected to provide only the species of ions that we are interested in. These selected ions are then counted by 11 detectors which among other things give us an energy distribution. Figure 5 is typical of the raw data from one of these detectors. Each of the eleven channels provides us with charged ion current changing with time.

One of our software routines takes these eleven channels and for each ten microseconds produces eleven points for each time slice selected. Figure 6 shows the typical results at larger time intervals to stress the changing waveshape. The data in this format is displayed as the energy distribution (dN)/(dE) for a particular time. Other software routines using this data and appropriate factors gained from other probes calculate the ion density (N) by integrating the energy distribution for each energy level ($N = \int \frac{dN}{dE} dE$) (Figure 7). By further correlating this information with data from other inputs another software routine produces a graph showing mean energy ($\bar{E} = \frac{\int E \frac{dN}{dE} dE}{\int \frac{dN}{dE}}$), see Figure 8. Yet another routine uses this data to produce a plot of the fast atom flux.

There is not space to adequately show how all information from the various channels are correlated to produce the data in clear formats but I am going to site one more example.

A four millimeter microwave beam is directed toward the plasma and split so that part is sent thru the plasma and part around the plasma. When the two portions of the beam are recombined there is a phase shift which is proportional to the average density and the plasma radius. One of our other probes measures plasma radius versus time. By correlating these inputs with software routines we have yet another method for calculating density.

The output format of data is often as important as the data itself. Figure 9 shows data from channel 1 of the Biomation transient recorder. Using the computer we take 2,048 points of this data which is the capacity of the Biomation unit. Then this data is taken from a form which is frankly quite difficult to interpret and a fourier transform is performed to develop a power spectrum (Figure 10) which clearly shows where the power peaks are. The five megacycles are the cyclotron frequency often referred to by plasma physicists.

Without going into the details of our software routines I have attempted to develop an appreciation of how powerful software coupled with the right hardware can produce much more than a stack of printout. It can produce clear, concise, easy to understand output which is already fully reduced and it can be done in less than a few minutes using a modest minicomputer.

Expansion Plans

The shortrange plans for expansion of the system described in this paper include the addition of a very fast Gould 5000 line printer and plotter, a twelve channel transient recorder designed to our specifications with four thousand words of remote memory in each channel, the addition of Thomson Scattering measurements to the computer system, and an additional thirty-two channels of high grade analog disc.

We are switching from a single user disc operating system to a real time executive multiterminal (up to 8 users) system. My objective is to let each physicist on the staff communicate directly with the computer to output his data in whatever format he is most at ease with and to use the software language (Fortran, Algol, Basic) of his choice. Our total diagnostics is increasing so much (soon we will have over sixty channels) the only apparent way we can output all our data within three minutes is to go to a multiuser system with rapid response. I am looking into the concept of smart terminals connected to a host minicomputer which acts more or less like a smart dispatching center. The results of our efforts within the next year should have great bearing on our next step of system architecture. I am currently pleased with our new operating system. It runs the hardware much faster (more efficiently) than the disc operating system did.

Problem Areas

I have experienced problems in both software and hardware areas. Many manufacturers are issuing software systems before they are fully debugged. It appears that every few months result in a new revision to provide a more efficient system. Actually the new revisions are not more efficient but they work where earlier versions did not. The only protection one really has is to not purchase a software system until it has been proven on the market for a year or to purchase a system with penalty clauses for non-performance and this is usually expensive for both the buyer and seller.

The main problem areas in hardware have been failure to meet advertized specifications and poor reliability once the equipment has been delivered. In our system the analog disc has shown very poor reliability while our transient recorders cannot meet vendor specifications.

Another problem I have noticed recently is the shipment of equipment which has not been tested or in some cases inspected at the seller's factory. I have received within the last few months equipment from more than one manufacturer which had meters miswired, power supplies connected to the wrong output terminals, and even units which were supposed to be precision equipment (±.01% specifications) where the manufacturer could not measure his own equipment to within ±3%. LLL incoming inspection found the equipment to be 7% off of published specifications. Most of these problems are caught during incoming inspection and the equipment is rejected. I have started demanding a minimum 1 year warranty from all manufacturers. It sometimes cost more initially but we have consistantly come out ahead as much of today's equipment is not designed to stay within specifications for one year.

Summary

I believe this paper has discussed the areas stated in the abstract. Besides those previously mentioned in the paper the following people: Fred Coensgen, Bill Nexsen, and George Vogtlin had a great deal to do with the original design of the system. The computer system is kept in good running order by Don Stiles, Frank Upper, and Gary Willett. A good functioning system is more than hardware and software components. It depends on the efforts of the people who designed it, use it, and maintain it.

DIGITAL DATA SYSTEM (DIAGNOSTIC ROOM)

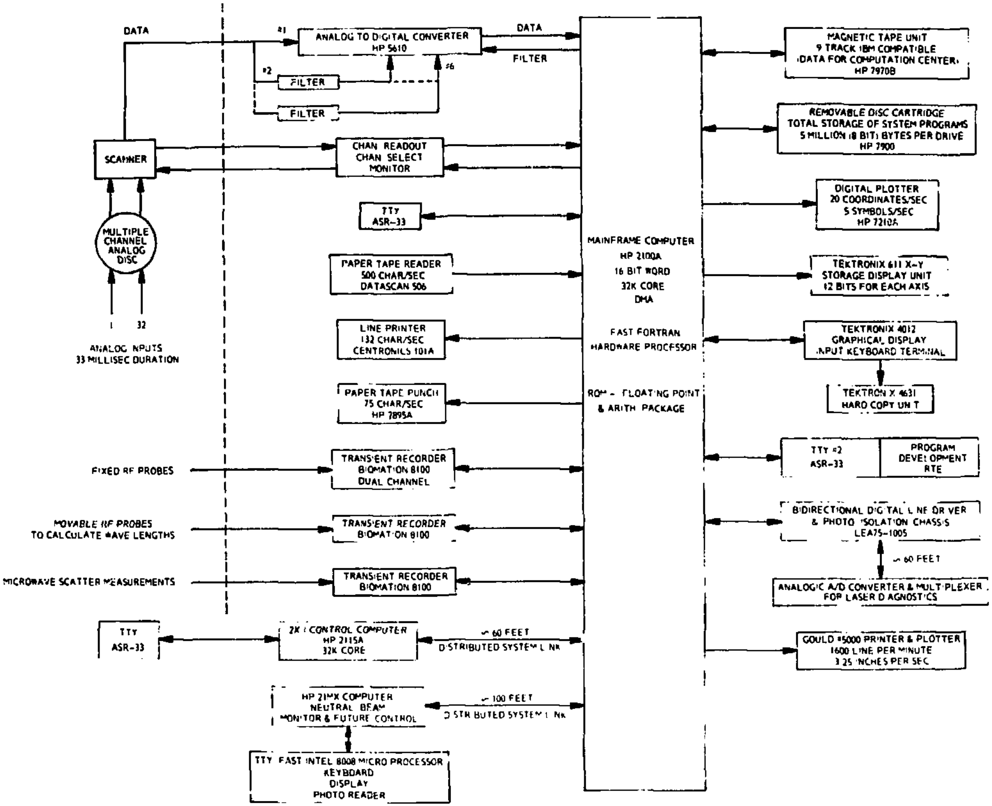


FIGURE 1.

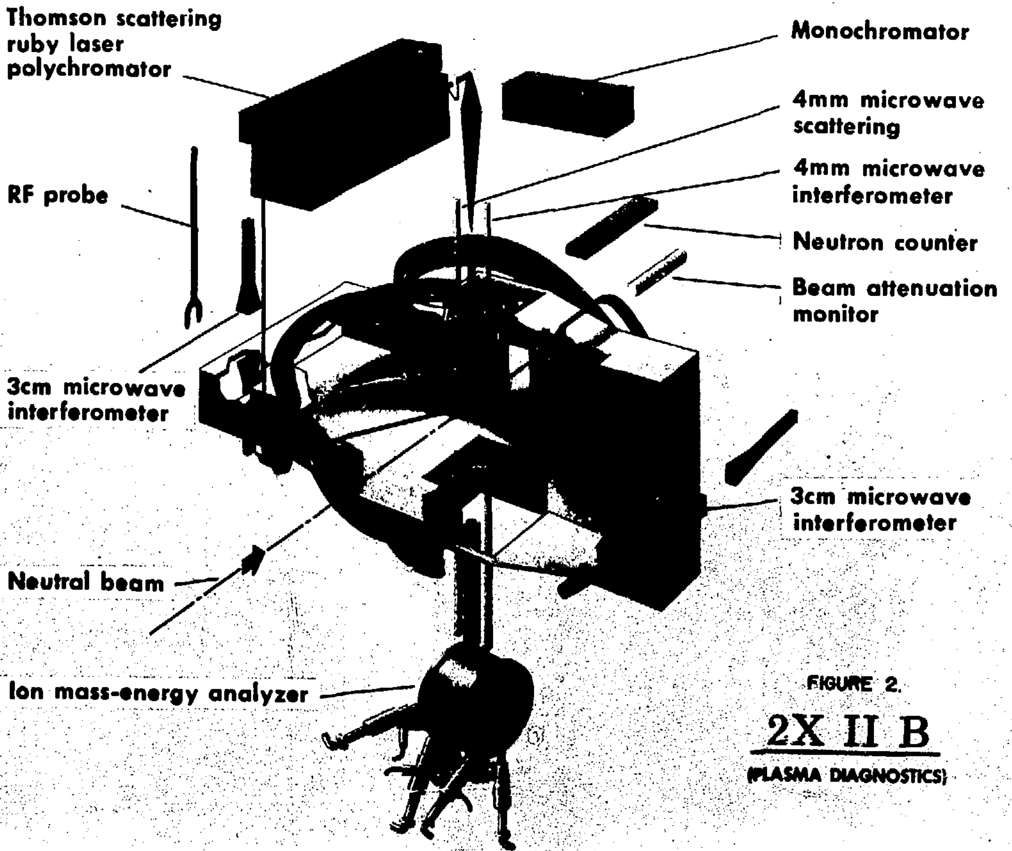


FIGURE 2.

2X II B

(PLASMA DIAGNOSTICS)

REVISED DATA DISC LAYOUT

1.–11. N.A — MEASURE IN ENERGY "ION TEMPERATURE" 13 Kev

12. 4 MM 2 PHASE INTEROMETER
13. 4 MM LINE DENSITY
14. RF AT Wce
15. MOVEABLE MICRO WAVE
16. DIA LOOP
17. NEUTRONS
18. RF ENVELOPE
19. MICROWAVE SCATTERING ENVELOPE
20. NEUTRAL BEAM CURRENT
21. END LOSS
22. SWINGING ANALYZER
23. SWINGING ANALYZER
24. BEAM ATTENUATION
25.
26.
27.
28.
29.
30.
31.

(24.–31.: LINE DENSITY)

32. RF AT Wci

FIGURE 3.

ION ENERGY 'ION TEMP'
NEUTRAL ANALYZER

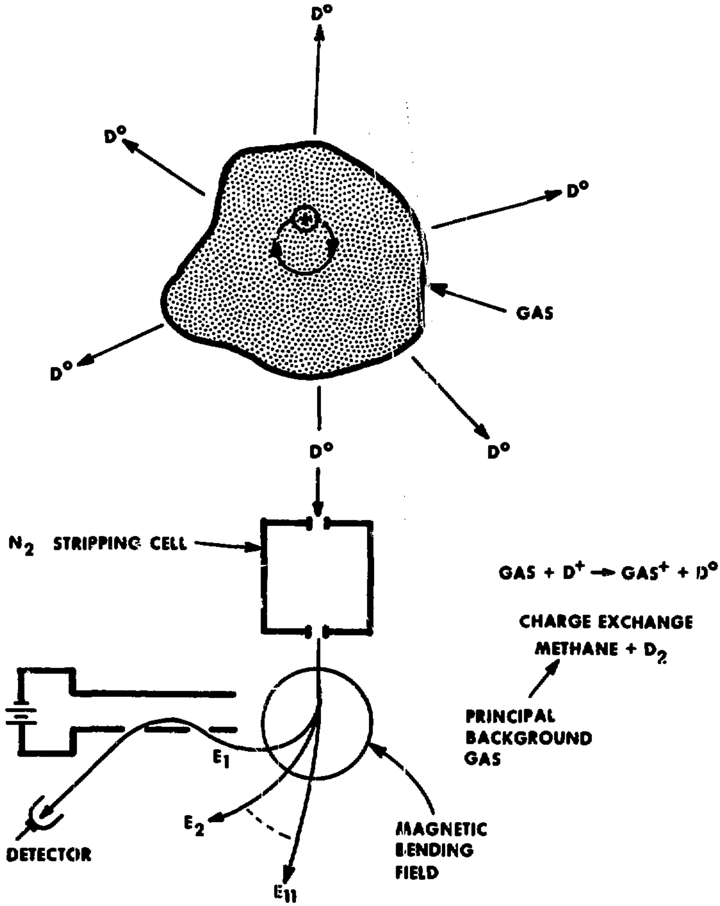


FIGURE 4.

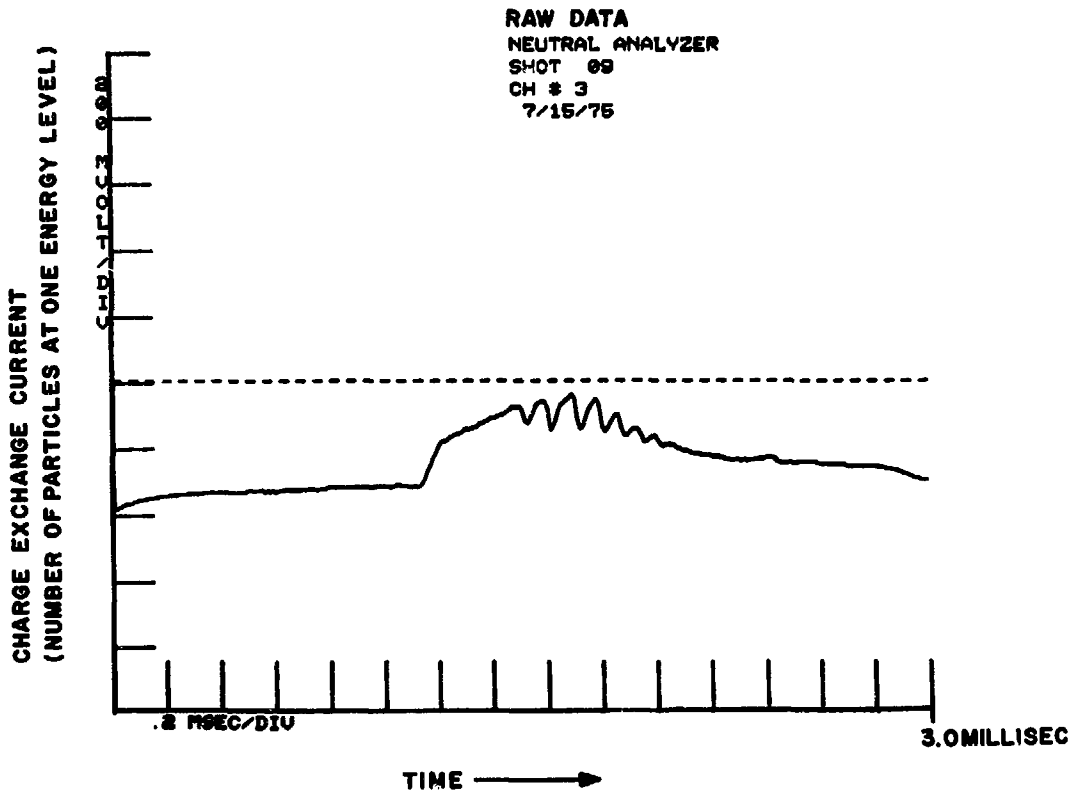
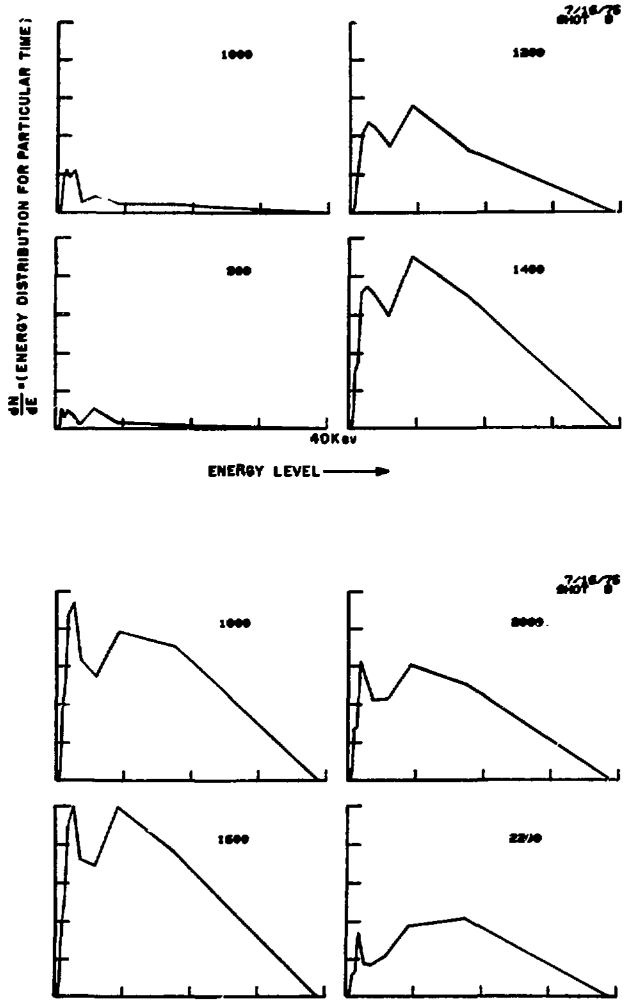
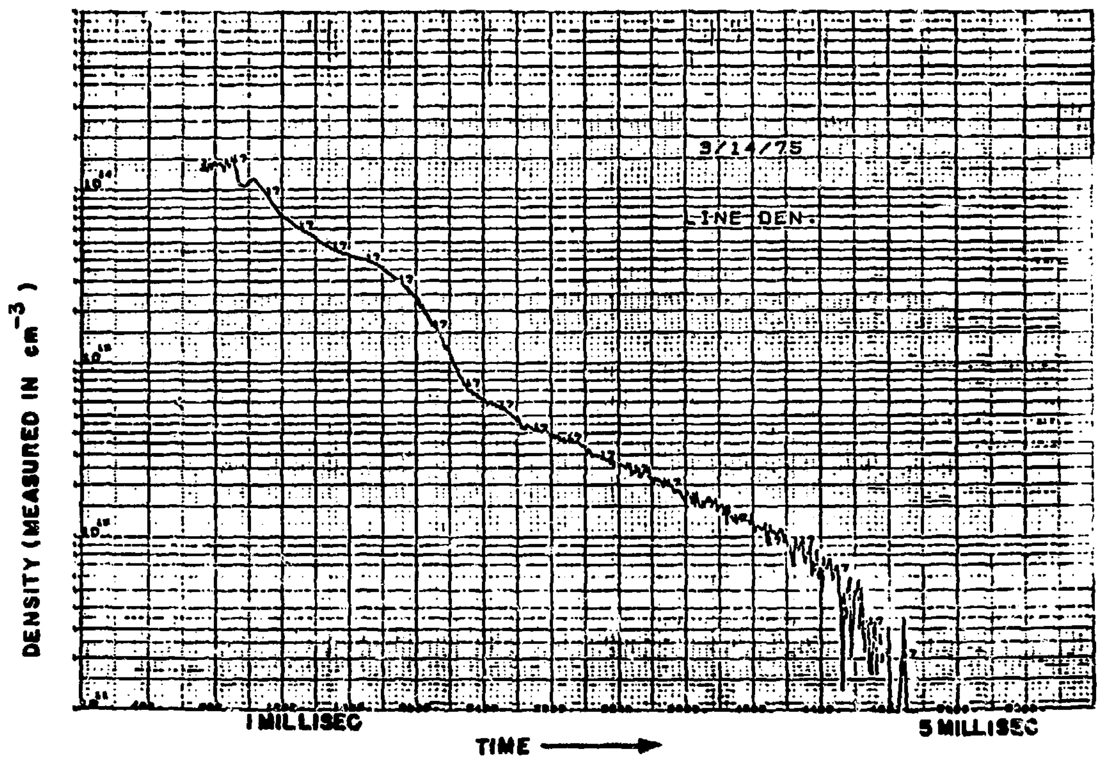

RAW DATA
NEUTRAL ANALYZER
SHOT 09
CH # 3
7/15/75
CHARGE EXCHANGE CURRENT
(NUMBER OF PARTICLES AT ONE ENERGY LEVEL)
.2 MSEC/DIV
3.0MILLISEC
TIME

FIGURE 5.



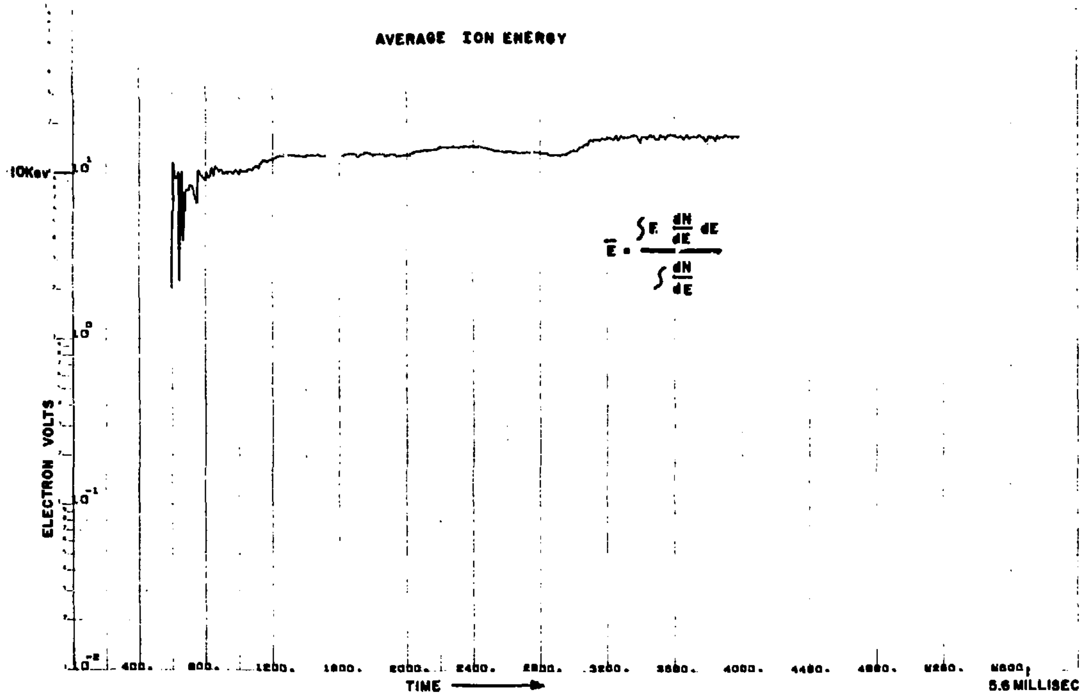
NOTE. EVERY POINT IS NORMALIZED TO LARGEST VALUE TO PREVENT LOSS OF NUETRAL ANALYZER DATA

FIGURE 6.



PROCESSED DATA FROM TWO PHASE MICROWAVE DENSITY MEASUREMENT

FIGURE 7.



AVERAGE ION ENERGY
10Kev
ELECTRON VOLTS
10^1
10^0
10^{-1}
10^{-2}
$\bar{E} = \frac{\int E \frac{dN}{dE} dE}{\int \frac{dN}{dE}}$
400.
800.
1200.
1600.
2000.
2400.
2800.
3200.
3600.
4000.
4400.
4800.
5200.
5600.
TIME
5.6 MILLISEC

FIGURE 8.

RADIO FREQUENCY VOLTAGE

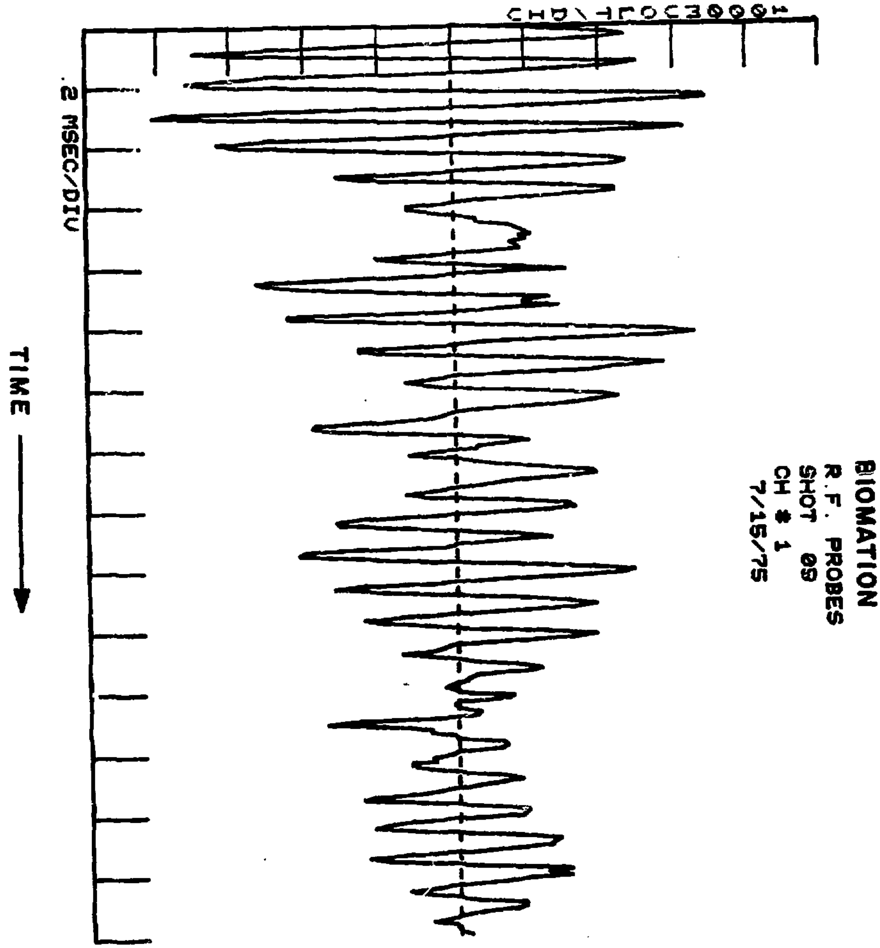


FIGURE 9.

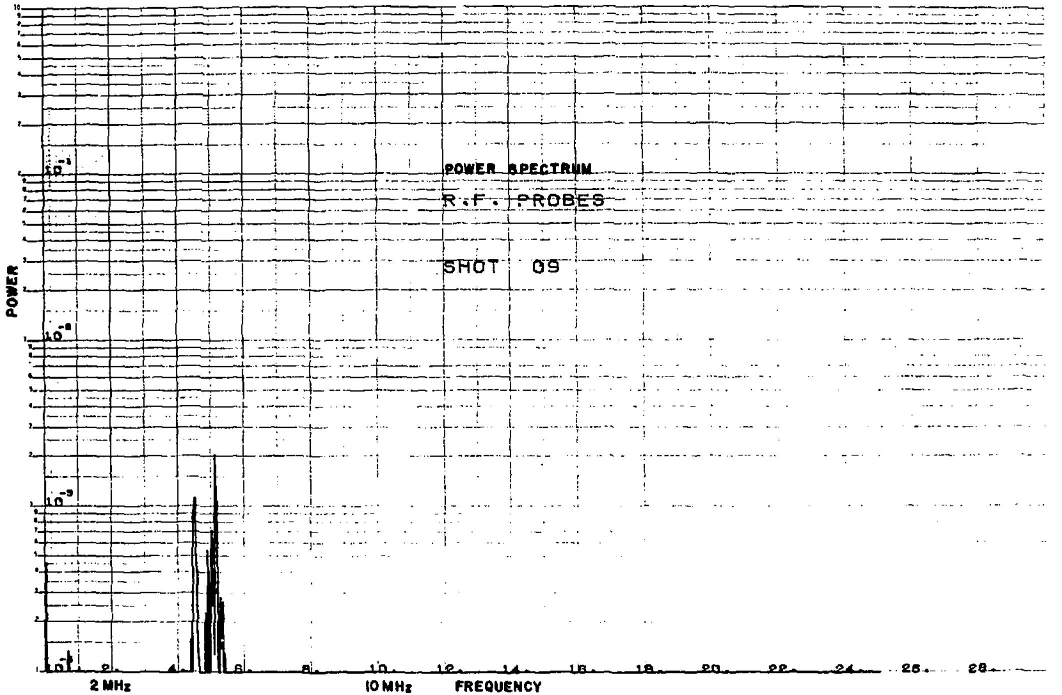

POWER SPECTRUM
R.F. PROBES
SHOT 09
POWER
FREQUENCY
2 MHz
10 MHz

FIGURE 10.