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Proposed Scyllac Computer System
for Data Acquisition and Treatment

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**Proposed Scyllac Computer System
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by

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PROPOSED SCYLLAC COMPUTER SYSTEM FOR DATA ACQUISITION AND TREATMENT

by

A. S. Rawcliffe, F. L. Ribe, and G. A. Sawyer

ABSTRACT

The Los Alamos theta-pinch program is outlined. The need for a small digital computer for acquiring and reducing experimental data is explained in the context of the Los Alamos Scyllac experiment.

INTRODUCTION

The Los Alamos plasma experiment, Scyllac, will come into operation about 1970. Scyllac will be first, a linear θ pinch of 15-m length and 10-cm bore and later, a toroidal device of 5-m diameter and 10-cm bore; each will be driven by a 15-MJ energy storage bank of capacitors. Details of Scyllac are given in the Los Alamos Scientific Laboratory report LA-3487-MS.¹ It will have a 15-times-longer coil than the largest θ -pinch experiment now in use at Los Alamos and roughly 12 times the capacitor bank. The present θ pinch, Scylla IV, has a 1-m-long coil and when operated with auxiliary bumpy field windings has 1.2-MJ energy storage. In studying the operation of Scyllac, it will be necessary to record and analyze much more data (about 15 times more) than is now done on Scylla IV. With approximately 20 oscilloscope traces in active use on Scylla IV, the limit of reduction of data from photographs has almost been reached. With Scyllac it will be far exceeded. In addition, there is an inexorable trend toward more sophisticated diagnostic measurements which require more and more mathematical analysis of waveforms to reduce the data to usable form.

These facts indicate the need for a small on-line computer to acquire a large quantity of data and to analyze it quickly so that the results can be used as a guide in setting up the next Scyllac

discharge, approximately 5 min later. A brief description of θ -pinch principles and of the present experimental program on Scylla IV and other θ pinches will provide useful background to the Scyllac requirements.

PRINCIPLES OF THE THETA PINCH

The principles of a θ pinch are illustrated in Fig. 1. A massive single-turn coil is rapidly filled with magnetic field as a capacitor bank is switched into it. The inrushing magnetic field surrounds deuterium plasma inside the coil but cannot penetrate it because of the plasma's high electrical conductivity. Therefore, a large magnetic pressure is built up between the outside of the plasma and the coil wall, driving the plasma rapidly inward (illustrated for a short coil in Fig. 1a). During this early dynamic phase, a shock wave runs into the plasma to convert inward plasma motion to heat, producing temperatures of a few hundred electron volts. This process occurs before the capacitor has lost a great deal of its energy; i.e., long before the energy of the magnetic field in the coil has built up its final value. As the magnetic field increases, it contains the heated plasma from the dynamic phase and compresses it adiabatically during the quiescent phase of the discharge (Fig. 1b). Finally, when all the electrostatic energy has left the capacitor

Fig. 1. Simplified schematic view of a θ pinch.

bank and has been converted to magnetic energy in the coil, the plasma has a long, ellipsoidal shape, and is held away from the wall by the magnetic field.

The 100,000-G magnetic field of Scylla IV is representative of those found in θ pinches. The magnetic field is furnished by 10,000,000 A of current spread over the inner surface of the coil and flowing in a circle around it. The initial voltage to which the Scylla IV capacitor bank is charged is 50,000 V, and the electrostatic and magnetic energy is about 600,000 J. For Scyllac these figures are 110,000 G, 150,000,000 A, 60,000 V, and 10,000,000 J, respectively.

Figure 1, while correctly illustrating principles, is greatly over-simplified. The plasma is contained inside an evacuated cylindrical discharge tube made of refractory alumina ceramic (99% Al_2O_3) or fused quartz. The tube is fitted closely inside the compression coil, and is evacuated to 5×10^{-7} torr before the admission of deuterium gas at a pressure of 0.01 to 0.1 torr for producing the plasma. The switch, S, that allows current to flow from the capacitor bank consists of many parallel spark gaps, each feeding many parallel cables that carry the millions of amperes which flow in the coil. The

current collector which feeds the coil slot is a pair of 3-in.-thick aluminum plates, bolted and clamped together to withstand the large magnetic forces from the currents flowing through them.

The compressed plasma (Fig. 1b) is made up of equal numbers of deuterium ions and electrons. The pressure of the plasma is balanced by that of the containing magnetic field, and both are about 400 atm. The plasma density is about $3 \times 10^{16} \text{ cm}^{-3}$ (about 1/1000 of atmospheric air density). Plasma ion temperature is about 5000 eV (55,000,000 $^\circ\text{K}$), and the electron temperature is about 300 eV (3,300,000 $^\circ\text{K}$). The two temperatures are different because the ions obtain more energy during the initial dynamic phase of the discharge and are unable to transfer it to the electrons during the few microseconds that the plasma exists. The present limiting factor on plasma containment is plasma streaming out of the ends of the discharge along magnetic field lines as indicated by the arrow in Fig. 1b. This is an inevitable effect of the present open-ended geometry and clearly indicates the need for the closed geometry planned in Scyllac.

THE SCYLLA IV PROGRAM AND TYPICAL EXPERIMENTAL DATA

The Scylla IV θ pinch has a 1-m-long coil of 10-cm bore, and its compression magnetic field rises to 100 kG during its 7.4- μsec half-period. An additional power crowbar capacitor bank (3.0 MJ at 20 kV) has been used to provide further compression to 160 kG with a 55- μsec half-period. During a run, the device may be fired every 2 to 5 min.

Magnetic Waveforms and Neutron Signals

Figure 2 shows typical oscilloscope waveforms of Scylla IV. The upper trace of both oscillograms is the magnetic field detected by a pickup loop near the compression coil; the lower trace is the neutron emission detected by a fast scintillation counter. These traces are for a power-crowbarred case in Scylla and are traces of the same machine discharge at two different oscilloscope sweep speeds. The traces of magnetic field and neutron emission are recorded for each discharge as routine monitors of performance. Other data are recorded on oscilloscopes simultaneously with the magnetic field and neutron data just mentioned. These additional data vary from week to week, depending on the diagnostic experiment being performed. As many as 20 oscilloscope traces

Fig. 2. Oscilloscope waveforms of Scylla IV magnetic field (upper traces) and neutron emission (lower traces). Both oscillograms are of the same machine discharge at sweep speeds of 2 $\mu\text{sec}/\text{cm}$ and 5 $\mu\text{sec}/\text{cm}$.

(10 dual beam scopes) may be used simultaneously on Scylla IV at the present time.

Differential Magnetic Loop Measurements

Figure 3 shows oscilloscope traces of a differential magnetic loop detector which measures magnetic flux excluded by the plasma. The actual data pictured are from Scylla III, a 20-cm-long θ pinch. This experiment requires two oscilloscope beams: one, for a single magnetic pickup, which produces a trace similar to that of Fig. 1, and a second producing a trace which measures the difference of two nearly-equal loop signals. In analyzing the data to obtain flux excluded and, consequently, an effective cross-sectional area of the plasma, the difference signal (lower trace) is divided by the magnetic loop signal (upper trace) and multiplied by a constant. This work is now done by reading the oscillograms at

Fig. 3. Oscilloscope traces of Scylla III differential magnetic probe signals.

each 0.1 μsec along the trace and performing hand calculation. Figure 4 shows the reduced data plotted as effective plasma area vs time.

This differential loop experiment yields much more information about the plasma than does the simple pickup loop of Fig. 1 now used, and it should replace the simple loop as a routine monitor of performance. But since the analysis of a single oscillogram to get the additional information shown in Fig. 4 requires about 2 man-hours of manual work, we cannot now adopt it as routine monitoring because we lack sufficient manpower. Even for occasional sampling with the present system, the feedback of answers is too slow to influence decisions about the next machine operations.

The differential magnetic loop results just described are a typical example of the data to be recorded many times over on Scyllac which should be acquired without an oscilloscope and analyzed by a computer to produce a graph like Fig. 4 during the 5 minutes before the next shot.

Interferometer Signals

Gas-laser interferometry is another technique which has been developed and should be adopted as a routine monitor. A gas-laser interferometer measures absolute integrated electron density along a diameter (transverse to the plane of the feed-slot) through the geometrical coil center using a He-Ne gas laser operating at 3.39 μ . Figure 5 shows the apparatus. The rotating corner reflector (which may also be a mirror mounted on a moving speaker coil) changes the optical path length of the light fed back into the

Fig. 4. Effective cross-sectional area of the plasma as a function of time determined from the differential magnetic probe experiment.

laser and modulates the laser output at 4 MHz. The plasma introduces additional phase shift, and its effects are superposed as period distortions on the regular oscillation. A comparison of the cumulative time history of fringes on a plasma trace with the time history of a background trace obtained in the absence of gas filling (Fig. 6) leads to absolute line-integrated density plots, such as are illustrated in Fig. 7.

The data reduction is exacting and tedious at present, even with partially automated analysis. An operator, using a large magnification comparator, digitizes some 80 pairs of coordinates directly onto punch cards; a computer program is used to reduce the data. In effect, the coordinate of each maximum

Fig. 5. Gas-laser interferometer apparatus for measuring integrated density through the plasma.

of the plasma trace is compared to the corresponding maximum without plasma. The difference in coordinates or phase shift is directly proportional to plasma density. If a linearly translated mirror is used for measuring small densities between the plasma column and the wall, there is no 4-MHz modulation and fractional-fringe density variations appear as signals requiring similar band width for their display.

Fig. 6. Oscilloscope traces from the gas-laser interferometer experiment showing the 4 MHz modulation of laser output. The upper trace is the Scylla magnetic field, showing the preionization discharge followed by main capacitor bank discharge. The sweep is 2 $\mu\text{sec}/\text{cm}$.

If the gas-laser interferometer data were acquired directly by the computer without the oscilloscope as an intermediary, they too could provide valuable routine monitoring of operations. These data become very important in Scyllac, since one of the basic purposes is to observe the build up of

tenuous plasma outside the plasma column due to diffusion and instability.

Photographic Interferometry

So far, only electrical data have been discussed. However, a large part of Scylla data is recorded photographically. Figure 8 shows Mach-Zehnder interferograms typical of photographic data to be analyzed. These interferograms are analogous to topographic maps and show contours of constant plasma density integrated through the plasma. Comparison of the shift in fringe position with plasma (Fig. 8b) from the undisturbed position (Fig. 8a) yields profiles of integrated plasma density. Figure 9 shows typical density profiles derived from this type of interferometric picture.

Large quantities of such data were analyzed by hand in the past. Now photographs are being read on the comparator described above and digitized onto punch cards so that the data can be reduced by a computer program. As a next stage of development it would be desirable to record the photograph electrically and to process the photograph completely by computer.

Experience with Scylla IV shows that data

Fig. 7. Integrated density through the plasma side-on measured with the gas-laser interferometer. The data are partially computer-analyzed.

Fig. 8. Mach-Zehnder interferogram of the Scylla IV discharge.

reduction is time-consuming; newer experiments require more complete analysis, and greater quantities of data are being generated. Physicists spend much time in data manipulation and the data reduction process is so slow that results are not available for days. Thus, experimental results are not available to guide the experimenters in the next machine operations. It seems that for Scyllac, computer acquisition and reduction of data will be essential.

PROPOSED SCYLLAC COMPUTER SYSTEM

Computerized Monitoring of the Scyllac Discharge The monitoring function

We discuss first the treatment of data acquired for each discharge which provide a monitor of the electrical operation of Scyllac and of the gross plasma quality. We assume that the monitor signals are acquired at each coil sector, giving 15 signals

of each kind. The five kinds of monitor signals are as follows: (1) magnetic flux at each sector (15 signals, 0 to 20 μ sec); (2) differential magnetic loop signals (15 signals, 0 to 20 μ sec); (3) neutron signals (15 signals, 0 to 20 μ sec); (4) time derivative of magnetic flux $\dot{\phi}$ (15 signals, 0 to 5 μ sec); and (5) current waveform of the stabilizing field at each sector junction (15 signals, 0 to 20 μ sec).

These add up to 75 data channels.

Comparison of the monitor signals

We assume sampling of each signal at 256 time steps, irrespective of the total time duration of the signals. Methods of acquiring and temporarily storing the data are discussed later. Each stored-and-held waveform is a 256-component vector, $U = (U_1 U_2 \dots U_{256})$, in which each component consists of a computer word. Apparently the best way to compare two waveforms U^i and U^j is to take their correlation, which is the dot product $U^i \cdot U^j = \sum_k U_k^i \cdot U_k^j$. For each of N channels there are $N!/2! (N-2)!$ such products. Considering the monitor signals in order, we have:

- (1) magnetic flux $F^i (i = 1 \dots 15)$, 105 correlations $F^i \cdot F^j$.
- (2) differential magnetic loop signals $P^i (i = 1 \dots 15)$, 105 correlations, $P^i \cdot P^j$.
- (3) neutron signals $N^i (i = 1 \dots 15)$, 105 correlations.
- (4) Magnetic flux time derivative $E^i (i = 1 \dots 15)$, 105 correlations.
- (5) Stabilizing current $S^i (i = 1 \dots 15)$, 105 correlations.

It may be necessary to increase the total number of correlations given above, 525, by a factor of 3 to account for phase differences between waves; by slipping vector j back and forth with respect to vector i by a few time steps, the maximum value of the correlation may be found. One would also include the self-correlations, $U^i \cdot U^i$, of each signal, giving 75 of these.

The average of all 600 correlation functions must then be formed, as well as the variance about the average. Those correlations C^{ij} falling outside 2, 4, or 8 times the variance from the mean must then be tabulated. The number of times each index occurs in each interval would be counted and evaluated as a fraction of the total number of times all indices occur. Each index would be listed with

Fig. 9. Scylla IV density profiles determined from analysis of interferograms.

this fraction. Thus the bad units would be identified with respect both to machine operation and plasma quality.

As a measure of how each channel looks, one would search for the first maximum of all signals and give its time and magnitude.

In addition, one would calculate the average value of each signal (sum of components of the vector). For the correlations, each of these 75 quantities would be averaged, the variance found, and the channels rated in terms of deviation from the mean.

Cathode-ray tube

A main object of the computer is to reduce the essentials of signal behavior to tabular form or graphs displayed on a cathode-ray tube. This does not preclude examining selected signals; e.g., those that have bad correlations or waveforms. Each signal vector will be in storage, and we visualize being able to call selected ones out to the display where they can be examined and photographed. It is likely that the cathode-ray tube will be the preferred output format for routine examination of data.

Data Treatment

When the monitoring assures that the discharge has been satisfactory, the treatment of data from specialized diagnostic experiments such as laser light-scattering, Faraday rotation, and the Mach-Zehnder interferometer, can be considered. These experiments will be done at only one station and will use one or two data channels each, for a total of 10 to 20 channels, in addition to the 75 required for monitoring.

Abel inversion

In one typical plasma experiment, the density profile of the plasma is determined by measuring the plasma continuum radiation along nine chords through the plasma. The light intensities in the nine chords are detected by photomultipliers and appear as voltages varying with time.

The data give the intensity as a function of the transverse dimension y . In terms of the plasma emission coefficient $\epsilon(r)$,

$$I(y) = 2 \int_y^{r_0} \frac{\epsilon(r) r dr}{(r^2 - y^2)^{1/2}}$$

The desired emission coefficient is then obtained by performing an Abel inversion:

$$\epsilon(r) = -\frac{1}{\pi} \int_{r_0}^{\infty} \frac{I'(y) dy}{(y^2 - r^2)^{3/2}}$$

where $I'(y)$ is the derivative of $I(y)$.

In the present partially computerized data reduction, the values of $I(y)$ are hand-read from oscillograms and fed into a computer program as a table of values. In a fully computerized system, the values of $I(y)$ would be acquired directly from a scan converter tube or some other data storage system. The Fortran IV program presently used for performing the Abel inversion is given in Appendix A; the program also normalizes the data and takes a square root to make the output proportional to the density. The output appears as a single graphical display and/or as approximately 27 lines of line printer output.

Gas-laser interferometer data

Analysis of the gas-laser interferometer data (Fig. 6) is simple in principle. Changes in plasma density are directly proportional to changes in period of laser oscillation. Therefore the time of each maximum and minimum of the oscillation is read from the oscilloscope trace and compared to the time of the corresponding oscillation on a background trace. The time difference is then multiplied by the appropriate constant to give the density of the plasma.

A Fortran IV program is now used to analyze the data after they are tabulated on punch cards. This particular program (Appendix B) has been considerably embellished over a year or so of use to allow for experimental difficulties. The data analyst often mistakes a false wiggle in the trace for a true fringe; the program compensates for this fault by automatically skipping a fringe whenever the density reaches a predetermined value, and by calculating both with and without the additional fringe. The data must be examined after computer processing to select the correct solution. Fortunately, the selection of the correct solution is easy because the density must return to its starting value after the θ -pinch discharge is over.

In fully computerized analysis of the data, the oscillation waveform must be read off a store-and-hold unit (scan converter) in fine enough steps

so that the computer can find the positions of the maxima and minima. It is necessary to follow the oscillation for at least 50 μ sec or 200 cycles. It will probably be necessary to read at least 8 points per cycle to reproduce the wave and find the maxima and minima, which would require 1600 words of data to be handled. Since the scan converter resolution is about 1/1000 of the tube face diameter, it will be necessary to use two or more scan converters, or two or more traces on a single scan converter to get the necessary resolution. However, as mentioned before, this type of data will be taken at only a few stations. The output appears as a single graphical display and/or 200 lines of line printer output.

Autocorrelation, crosscorrelation, and Fourier analysis of selected signals

Correlations provide a basic means of determining the nature of instabilities, oscillations, or fluctuating turbulence. For example, the power frequency spectrum of a signal is given by the time Fourier transform of its autocorrelation:

$$\varphi_{ii} = \frac{1}{2T} \int_{-T}^T T^i(t) U^i(t + \Delta t) dt.$$

The scale of the instability or turbulence is given by the space Fourier transform of the crosscorrelation as a function of separation Δx of the signals:

$$\varphi_{ij} = \frac{1}{2T} \int_{-T}^T U^i(t, x) U^j(t, x + \Delta x) dt.$$

The autocorrelation is the collection of dot products $U(U_1, U_2, \dots, U_{256}) \cdot U(U_m, U_{m+1}, \dots, U_{256}, U_1, \dots, U_{m-1})$ for different values of the slippage index m .

Storage and Digitizing of Signals

Since the electrical data must be sampled once during every 0.1 μ sec, it will be necessary to store the data temporarily, presumably in analog form. The data can then be digitized, multiplexed, and fed to the computer at a suitable rate. Conventional computer sampling circuits appear to be prohibitively expensive for the number of data words contemplated, but at least two possible solutions have already appeared:

Magnetic storage

Signals could be recorded in analog form on magnetic material. A television video tape recorder can record at approximately 5 MHz, fast enough for

our intermediate and slower speed signals. Commercial tape recorders could probably be used with minimum modification. Still better, a magnetic drum or disc with a number of recording channels would probably be compact and simple, although it is not known to be commercially available. Slow playback to the computer could be done by slowing down the tape, drum, or disc. But it may be better to run the recorder at constant speed and pick off one data point at each revolution of the recorder.

Electrostatic storage

A second possible method, amenable to larger bandwidth, uses the scan converter tube developed by Group J-16 at LASL in conjunction with Sandia Corporation and various commercial firms. The scan converter tube is basically an oscilloscope storage tube and a television camera tube or orthicon in a single envelope. An electrical signal is written on a zinc sulfide screen as in any oscilloscope. A scanning electron beam then picks off the recorded image by detecting the location of charge on the zinc sulfide. The system has been highly developed by J-16 and demonstrated to be practical. Circuitry for sweep and timing circuits is available. Performance exceeds our most difficult requirements; signal rise times of a few nanoseconds are possible, spatial resolution is better than 1/1000 of the tube face diameter, and signals may be stored for hours. Furthermore, digitizing of the signals is elementary. At each x coordinate, successively, a clock steps the reading, or scanning, beam in the y direction until it finds the recorded trace. The clock reading then provides the required digital coordinate. This scan converter system looks very promising and will be tested during the next fiscal year on Scylla IV.

Storage of photographic data

Storage of photographic data has already been mentioned in connection with interferometers. Other data, such as spectrographic information, lend themselves best to photographic recording. A television camera tube could perhaps be used directly for storing a picture and converting it to electrical signals for digitizing. J-16 is developing a version of their scan converter for photographic recording.

Computer size

The problem of data acquisition, temporary storage, and digitizing has been briefly outlined in the

preceding sections.

It is assumed that the data will be fed into the computer serially from the various channels over a fairly long time (seconds). If we assume 90 data channels, each to be sampled at 256 time steps, 23,000 words of memory will be required to store the data. The data can probably be held on a magnetic disc. Related data to be processed together might involve up to 30 data channels or 7700 words.

One percent accuracy in recording is probably sufficient for most purposes, but it may also be necessary to retain sign information. An eight-bit word is probably not sufficient to record the desired information. A ten-bit word is minimum to achieve the necessary accuracy and there may be need for even larger word size.

Peripheral equipment

Cathode-ray tube - To examine computer results promptly and efficiently, a scope presentation of the data from memory will be desirable. Processed data can then be graphed in format so that the operator can visualize the results quickly and make necessary adjustments for the next operation. Alpha-numeric display can also be used for listings of data and for program debugging.

Magnetic disc - A magnetic-disc unit or an equivalent slow-access storage will be needed to provide sufficient capacity for combined data and program storage. It will be desirable to have sufficient storage capacity to hold data from an entire day's run so that they can be recalled for comparison with the latest data. This would mean 100 discharges times 23,000 words, or 2,300,000 words for storage of the raw data, plus additional words for storage of reduced data.

Paper tape - Paper-tape equipment seems the most efficient and economical way to keep permanent records of programs for handling the data.

Magnetic tape - Magnetic tape is probably the most economical method for permanent bulk storage of data.

Computer Monitoring of Scyllac

Engineering Performance

The performance of the Scyllac θ pinch depends on the simultaneous firing of 4000 to 5000 spark gaps. Some method has to be used for checking the simultaneity of the various groups of gaps. Limits would be set on the time of firing and the location

of gaps. The feasibility of monitoring the 50 power supplies during the charge will also be investigated. Discrepancies would be printed out for diagnosis and the charge cycle stopped when trouble occurs.

Many of the monitoring functions of Scyllac will be done by means of control indicators similar to those presently in use. However, we shall actively investigate a voltage divider system that would present on-off signals indicating the firing of the spark gaps. As experience with the actual control system accumulates, we expect to add some analog, direct current voltage signals to the computer input to indicate the accurate performance of certain crucial capacitor voltages and currents.

REFERENCE

1. Sherwood Personnel, "Proposal for a Toroidal Theta-Pinch (Scyllac)," Los Alamos Scientific Laboratory Report LA-3487-MS, (1966).

APPENDIX A
ABEL INVERSION PROGRAM

SPEC - EFN SOURCE STATEMENT - IFN(S) -

07/06/66

DIMENSIONX(50),S(50),A(50),Y(50),F(50),DS(50),DF(50)	1	
DIMENSION SN(50), AN(50)	1A	
DIMENSIONTRACE(12)	1B	
DIMENSIONANSR(50)	1C	
5 L=1	2	
READ(10,11) TRACE	2A	2
11 FORMAT(12A6)	2B	
6 READ(10,10)X(L),S(L)	3	4
10 FORMAT(2F12.6)	4	
IF(X(L)-0.0)14,12,12	5	
12 L=L+1	6	
GOTO6	7	
14 M=L-2	7A	
DO100K=1,M	8	
DO20I=1,K	9	
Y(I)=X(I)/X(K+1)	10	
R=SQRT(Y(I)**2-1.)	10A	23
F(I)=ALOG(Y(I)+R)/3.1416	11	25
20 DS(I)=(S(I+1)-S(I))/(X(I+1)-X(I))	12	
F(K+1)=0.	13	
DO25I=1,K	14	
25 DF(I)=F(I+1)-F(I)	15	
SUM=0.	16	
DO30I=1,K	17	
30 SUM=SUM+DS(I)*DF(I)	18	
100 A(K+1)=SUM	19	
A(1)=0.	20	
WRITE(9,40)	21	52
40 FORMAT(1H1,60H POSITION INTENSITY	122	
INVERSION)	23	
N=L-1	23A	
WRITE(9,41)(X(J),S(J),A(J),J=1,N)	24	53
41 FORMAT(2F20.2,20.4)	25	
DO50I=1,N	25A	
50 SN(I)=S(I)/S(N-2)		
DO51I=2,N	25D	
51 AN(I)=A(I)/A(N-2)		
DO52I=2,N	25E1	
52 ANSR(I)=SQRT(AN(I))	25E2	85
WRITE(9,55)TRACE	25E3	88
55 FORMAT(1H0,12A6)	25E4	
WRITE(9,56)(SN(J),AN(J),ANSR(J),J=2,N)	25E5	90
56 FORMAT(3F20.3)	25E6	
CALLADV(2)	25F	99
CALLDGA(120,980,50,910,0.,18.,1.2*0.)	25G	101

CALLDLNLN(9,12)	25H	103
CALLSLLIN(12,1)	25I	105
CALLSRLIN(9,1)	25J	107
CALLPLOT(N,X ,1,SN,1.44,0)	25K	109
CALLPLOT(N-1,X (2),1,AN(2),1,16,1)	25L	111
CALLPLOT(N-1,X (2),1,ANSR(2),1,0,1)	25L1	113
CALLWLCH(0,0,72,TRACE,1)	25M,N,U	115
CALLWLCH(700,1000,14,14HDISTANCE IN MM,1)	25P	117
CALLWLCV(0,980,53,53HRELATIVE SMOOTHED DATA*,ABEL INVERSION*,AND DENSITY 0,1)	25Q	119
	25Q1	119
CALLADV(1)	25T	121
GOTO5	252	
END	26	

SPEC

STORAGE MAP

07/06/66

MAIN PROGRAM

DIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
X	00001	R	S	00063	R	A	00145	R
Y	00227	R	F	00311	R	DS	00373	R
DF	00455	R	SN	00537	R	AN	00621	R
TRACE	00703	R	ANSR	00717	R			

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
L	01001	I	M	01002	I	K	01003	I
R	01004	R	SUM	01005	R	N	01006	I

ENTRY POINTS

..... SECTION 3

SUBROUTINES CALLED

	SECTION		SECTION		SECTION
.FRDD.	4	.FSLI.	5	SORT	6
ALOG	7	.FWRD.	8	.FSLO.	9
ADV	10	DGA	11	DLNLN	12
SLLIN	13	SRLIN	14	PLOT	15
WLCH	16	WLCV	17	.UN10.	18
.FRTN.	19	.FCNV.	20	.UN09.	21
.FFIL.	22	SYSLOC	23		

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION
5	1A	01107	11	FORMAT	01061	6	4A	01124
10	FORMAT	01062	14	11A	01147	12	9A	01143
100	48A	01254	20	27A	01214	25	37A	01234
30	44A	01246	40	FORMAT	01064	41	FORMAT	01100
50	65A	01323	51	74A	01337	52	83A	01350
55	FORMAT	01103	55	FORMAT	01105			

THE FIRST LOCATION NOT USED BY THIS PROGRAM IS 01576.

APPENDIX B

GAS-LASER INTERFEROMETER DATA PROGRAM

HENE - EFN SOURCE STATEMENT - IFN(S) -

05/19/66

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DIMENSION A(6,3(400),P(400),D(400),I(400),D2(400),D4(400)
DIMENSION PTRACE(2),BTRACE(2)
DIMENSION D6(400),D8(400)
5 N=0
  D0321=1.400
32 B(1)=0.0
  6 READ(10,15)(A(I),I=1,6)
15 FORMAT(6F12.6)
  D0181=1.6
  IF(A(1)-0.0)21,16,16
16 N=N+1
18 B(N)=A(1)
  GOTO 6
21 READ(10,22)M
22 FORMAT(12)
  FACTOR=(B(12)-3(36))/(12.*3.285)
25 D0200J=1,M
  READ(10,26)PTRACE,BTRACE,SWEEP,ONECM,YLIM,12
26 FORMAT(2A6,2A6,3F12.0,11)
27 L=0
  D0201=1.400
  P(1)=0.0
  D(1)=0.0
  D2(1)=0.0
  D4(1)=0.0
  D6(1)=0.0
  D8(1)=0.0
20 I(1)=0.0
28 READ(10,15)(A(I),I=1,6)
  D0301=1.6
  IF(A(1)-0.0)31,29,29
29 IF(A(1)-1.0)30,24,24
24 L=L+1
  P(L)=A(1)
30 CONTINUE

```

```

1
1A
1B
2
3
4
5
6
7
8
9
10
11
11A
12
13
14
15
15A
15C1
15C2
15C3
15C4
16
17
18
19
20
20A
20B
10
29
34
51

```

GOTO28	21	
31 IF(N-L)55,33,33	27	
33 K=N	28	
KP=L	29	
GOTO36	30	
35 K=L	31	
KP=N	32	
36 WRITE(9,38)PTRACE,BTRACE,SWEEP	33	77
38 FORMAT(1H1,64PLASMA,2A6,14H BACKGROUND,	34	
12A6,26H SWEEP(MICROSECONDS/CM),F5,1)	35	
WRITE(9,40)	36	80
40 FORMAT(110H PLASMA BACKGROUND NDL *E16	37	
TIME	37	
1P(I+2)-B(I) 3(I+4)-B(I) P(I+6)-B(I) P(I+8)-B(I)	38	
DO44 I=1,L	38A	
IF(P(I)-500000.)44,44,43	38B	
43 P(I)=P(I)-1000000.	38C	
44 CONTINUE	38D	
DO42 I=1,N	38E	
IF(B(I)-500000.)42,42,45	38F	
45 B(I)=B(I)-1000000.	38G	
42 CONTINUE	38H	
DO50 I=1,KP	39	
D(I)=P(I)-B(I)-P(9)+B(9)	40	
50 D(I)=D(I)/FACTOR	41	
CONV=ONECM/SWEEP	42	
DO80 I=1,L	42	
80 T(I)=(1.0E05-P(I))/CONV	42A	
DO51 I=1,KP	43A	
51 D2(I)=(P(I+2)-3(I)-P(9)+B(9))/FACTOR	43B	
DO53 I=1,KP	43C	
69 D6(I)=(P(I+6)-3(I)-P(9)+B(9))/FACTOR	43C1	
74 D8(I)=(P(I+8)-3(I)-P(9)+B(9))/FACTOR	43C2	
53 D4(I)=(P(I+4)-3(I)-P(9)+B(9))/FACTOR	43D	
WRITE(9,52)(P(I),B(I),D(I),T(I),D2(I-2),D4(I-4),D6(I-6),D8(I-8),	44	
1I=9,K)	44A	135
52 FORMAT(2F15.0,5F12.2)	45	
CALLADV(2)	45A	147
IF(I2-1) 54,54,56	45A2	
56 CALLADV(2)	45A3	151
CALLDGA(120,900,50,910,-5.,35.,2.,-12.)	45A4 INV	153
GOTO57	45A5	
54 CALLDGA(120,900,50,910,-35.,5.,2.,-12.)	45B INV	156
57 CALLDLNLN(8,14)	45C A	158
CALLSLLIN(14,0)	45D	160
CALLSBLIN(8,7)	45E	162
CALLPLO1((KP+1)/2,T,2,D,2,44.0)	45F	164
CALLWLCH(0.0,12,PTRACE,1)	45G	166
CALLWLCH(600,0,12,BTRACE,1)	45H	168
CALLWLCH(700,1000,18,18*TIME(MICROSECONDS),1)	45H2	170
CALLWLCV(0,450,7,7*HNDL*E16,1)	45H3	172
DO60 I=1,KP	45I	
55 IF(D(I)-YLM)60,60,62	45K	
60 CONTINUE	45L	
GOTO200	45L1	

62 CALLPLOT((KP+1-I)/2,T(I+2),2,D2(I),2,2,0)	45M	183
D064I=1,KP	45M2	
63 IF(D2(I)-YLIM)64,64,65	45M4	
64 CONTINUE	45M5	
GOTO200	45M5A	
65 CALLPLOT((KP+1-I)/2,T(I+4),2,D4(I),2,3,0)	45M6	196
D067I=1,KP	45M7	
66 IF(D4(I)-YLIM)67,67,68	45M9	
67 CONTINUE	45M10	
GOTO200	45L10A	
68 CALLPLOT((KP+1-I)/2,T(I+6),2,D6(I),2,4,0)	45M13	209
D072I=1,KP	45M14	
70 IF(D6(I)-YLIM)72,72,73	45M16	
72 CONTINUE	45M17	
GOTO200	45L107A	
73 CALLPLOT((KP+1-I)/2,T(I+8),2,D8(I),2,5,0)	45M20	222
200 CONTINUE	46	
CALLADV(1)	45N	228
GOTO5	47	
END	48	

HENE.

STORAGE MAP 05/19/66

MAIN PROGRAM

DIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
A	00001	R	B	00007	R	P	00627	R
D	01447	R	T	02267	R	D2	03107	R
D4	03727	R	Ptrace	04547	R	BTrace	04551	R
D6	04553	R	D8	05373	R			

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
N	06213	I	I	06214	I	M	06215	I
FACTOR	06216	R	J	06217	I	SWEEP	06220	R
ONECM	06221	R	YLIM	06222	R	I2	06223	I
L	06224	I	K	06225	I	KP	06226	I
CONV	06227	R						

ENTRY POINTS

..... SECTION 3

SUBROUTINES CALLED

.FRDD.	SECTION	4
.FSLO.	SECTION	7
ULNLN	SECTION	10
PLOT	SECTION	13
.UN10.	SECTION	16
.UN09.	SECTION	19

.FSLI.	SECTION	5
ADV	SECTION	8
SLLIN	SECTION	11
WLCH	SECTION	14
.FRIN.	SECTION	17
.FFIL.	SECTION	20

.FWRD.	SECTION	6
DGA	SECTION	9
SBLIN	SECTION	12
WLCV	SECTION	15
.FCNV.	SECTION	18
SYSLOC	SECTION	21

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION
5	1A	06364
15	FORMAT	06305
16	22A	06413
200	225A	07412
20	48A	06520
31	70A	06564
35	75A	06575
38	FORMAT	06314
43	85A	06641
50	104A	06671
53	131A	06747
52	FORMAT	06361
57	157A	07066
62	182A	07203
65	195A	07250
68	208A	07315

EFN	IFN	LOCATION
32	6A	06366
15	23A	06416
22	FORMAT	06307
25	FORMAT	06310
25	51A	06523
29	60A	06545
33	72A	06570
41	FORMAT	06335
42	97A	06656
83	110A	06705
69	123A	06733
54	155A	07047
60	179A	07200
64	192A	07245
67	205A	07312
72	218A	07357

EFN	IFN	LOCATION
6	10A	06371
21	29A	06420
25	31A	06447
27	38A	06510
30	67A	06561
24	63A	06551
36	77A	06601
44	88A	06644
45	94A	06650
51	116A	06717
74	127A	06741
56	150A	07020
55	176A	07174
63	189A	07241
66	202A	07300
70	215A	07350