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Simultaneous Mass Detection for Direct Inlet Mass Spectrometry

R. L. Gordon

May 1979

**Prepared for the U.S. Department of Energy
under Contract EY-76-C-06-1830**

**Pacific Northwest Laboratory
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CONTENTS

1. INTRODUCTION	1
2. DEVELOPMENT EXPERIMENTS	2
3. GAIN MEASUREMENTS	7
4. READING AND RECORDING OPTICAL SIGNAL	13
5. DATA ACQUISITION AND PEAK SHAPE	16
6. DETECTION SENSITIVITY	25
7. CONCLUSIONS AND RECOMMENDATIONS	29
ACKNOWLEDGEMENTS	32
REFERENCES	33
APPENDIX - RT11 FORTRAN-IV SOFTWARE; CCD DATA ACQUISITION AND ANALYSIS	A-1

FIGURES

1	Schematic of Mass Analyzer and Vacuum System	3
2	Detail of Detector Housing	5
3	Schematic of TDA Biasing Arrangement	6
4	Photograph of Operating TDA-Phosphor Screen	6
5	Observed TDA Gain for 3000-eV H ₂ Ions for Indicated Currents	8
6	TDA Current Transfer Characteristics for 3000-eV H ₂ Ions	9
7	Observed TDA Gain for Krypton Isotopes at Indicated Currents	10
8	Output Current as a Function of Position of the Incident Beam on the Face of the TDA, H ₂ Ions at the Indicated Energies	12
9	Comparison of Video (a) Sample-and-Hold (b) Output of CCD	15
10	Schematic Indicating Connections Between Charge-Coupled Device and Minicomputer	18
11	CCD Dark Signal at -40°C and a Data Rate of 1785 s ⁻¹	19
12	CCD Output Signal Range	20
13	H ₂ Spectrum	21
14	Central 256 Points of the Spectrum of Figure 13	22
15	Gaussian Analysis of Figure 14	23
16	Krypton Spectrum: Masses 78, 80, 82, 83, 84, and 86	24
17	CCD Output Versus Incident Ion Current of Kr Isotopes	26
18	CCD Output Versus Integrated Ion Current for Kr Isotopes 82, 84, and 86	28

SIMULTANEOUS MASS DETECTION FOR DIRECT INLET MASS SPECTROMETRY

1. INTRODUCTION

The evolution of analytical techniques for application in trace analysis has led to interest in practical methods for real-time monitoring. Direct inlet mass spectrometry (DIMS) has been the subject of considerable activity in recent years. In applications for the monitoring of particulate content of the atmosphere, a DIMS instrument consists of an inlet system designed to permit particles entrained in the inlet air stream to strike a hot, oxidized rhenium filament which serves as a surface ionization source. A mass analyzer and detection system then permits identification of the elemental composition of particulates which strike the filament.

Several approaches to DIMS instrumentation have been discussed. The original work was performed by Davis using a sector instrument.⁽¹⁾ Meyers and Fite,⁽²⁾ as well as Lassiter and Moen,⁽³⁾ used a quadrupole mass filter as the analyzer. Stoffels and Lagergren have developed a magnetic sector instrument for monitoring particulates in the atmosphere.⁽⁴⁾ These instruments are all configured for single mass detection. The quadrupole mass filter is capable of rapid scanning but still detects masses one-at-a-time. Magnetic sector instruments provide dispersion necessary for simultaneous observation of masses produced by the ionization of individual particles, but are usually arranged with slits in the detector end to improve resolution and hence are commonly thought of and used for single mass detection.

Single mass detection is not adequate for unambiguous identification of the elements contained in a single particle striking the filament. A particle striking the hot filament will dissociate, producing products, some of which will be ionized by surface ionization. Ions produced by one particle will appear at the detector essentially simultaneously. Consequently a means for simultaneous detection of ions produced by individual particulate impacts is

required to establish a definite time correlation between ionic signals at different masses.

The Pacific Northwest Laboratory (PNL) has evaluated an approach to simultaneous mass detection for application in a DIMS analyzer. The chosen concept, first suggested by Beottger,⁽⁵⁾ and by Giffen, Boettger, and Norris,⁽⁶⁾ has also been discussed by others.⁽⁷⁾ A phosphor-backed multiplier channel plate (MCP) is positioned at the focal plane of the mass spectrometer to serve as the ion detector. This device serves as a transducer to convert the ion image of the entrance slit at each mass position on the focal plane into individual bars of light on the phosphor screen. In previous work this optical signal was recorded numerically using a vidicon camera. In our experiments, a specially designed lens system was used to focus the light from the phosphor onto a charge-coupled-device (CCD), consisting of a linear array of photodetectors and supporting circuitry on the same single-crystal silicon chip. In eventual application a fiber optics arrangement will be used to bring the optical signal to the CCD. This method of mass detection permits simultaneous detection of all masses with sequential read-out of stored signals via the electronics of the CCD.

This paper describes work sponsored by the Department of Energy's Division of Chemical Sciences and conducted by PNL to evaluate this electro-optical detector concept. Section 2 describes the mass spectrometer assembled for these experiments. Section 3 reports results of measurements of MCP gain. The optical system and the operation of the CCD is described in Section 4, and data acquisition techniques and observations on peak shape are reported in Section 5. Section 6 describes results of sensitivity measurements using krypton gas and Section 7 presents conclusions and recommendations, while software developed for computerized data acquisition and analysis is presented in the Appendix.

2. DEVELOPMENT EXPERIMENTS

A mass analyzer was assembled for the specific purpose of evaluating different approaches to simultaneous detection. The analyzer and vacuum system, shown schematically in Figure 1, is constructed primarily of commercially

FIGURE 1. Schematic of Mass Analyzer and Vacuum System 1) Valve to Diffusion Pump and Liquid Nitrogen Trap; 2) Source Volume and Electrical Feedthroughs; 3) Gas Manifold; 4) Analyzer Drift Space; 5) Magnet; 6) Detector Housing; 7) Sorption Pump; 8) Vacuum Viewport; 9) Tubulation to Ion Pump; G) Bayard-Alpert Ionization Gauges.

available components. Only four components are of special design. These include the mass tube, two feedthrough collars for supplying potentials in the source region, and a special detector housing with appropriate feedthroughs to support electrical requirements of the MCP. The mass tube has inside dimensions of 5 cm x 0.95 cm to permit transmission of several masses. All components bolt together on demountable, bakeable ultra-high-vacuum flanges for ease in changing configurations. A 800-liter/s oil diffusion pump with a liquid nitrogen trap is used at the source end of the system, while a 26-liter/s ion pump operates continuously at the detector end. Sources of reagent-grade krypton and xenon gas were provided as mass standards for the

work. One-liter flasks of each gas mounted on independent leak valves communicate with the source region via a simple manifold. The entire vacuum system can be baked to 400°C should a need arise for performing experiments in ultra-high vacuum.

Ionization is accomplished by a simple electron bombardment source consisting of two helical tungsten filaments mounted on either side of a cage of 95%-transparent tungsten mesh positioned over the entrance aperture of the ion lens. The ion lens is a Nier-type thick lens⁽⁸⁾ used in other mass spectrometers in our laboratory. The instrument uses a 15-cm-radius, 60°-sector electromagnet capable of producing 6,000 gauss at 510 mA of magnet current.

Experiments reported here were conducted with a 40-mm-diameter tandem dual array (TDA) MCP available from LSE Division of Varian Associates, (Varian No. VUW 8998). The MCP consists of a close-packed array of 12.5- μ m-dia tubes placed at 15- μ m centers. The TDA, or "chevron" device used here consists of two MCPs stacked together. An individual array has a quoted resolution of 28 line pairs per millimeter while that for the TDA is 14 line pairs per millimeter. The MCP is backed by a phosphor screen with P-20 (green) response. The combination of high efficiency of the P-20 phosphor and significant sensitivity for the green 5682-Å emission possessed by the silicon photodiodes used for light detection determined the choice of the P-20 phosphor. Ions striking the face of the MCP generate electrons which undergo multiplication in the small tubes of the MCP. The electron output of the array is therefore in registry with the positions at which ions struck the front face. Electrons resulting from localized gain in the MCP are then accelerated a short distance (proximity focused) to the phosphor so the light distribution on the phosphor is essentially an image of the number and positions of ions which struck the front face of the MCP. The entrance slit images which are formed at the focal plane of the mass spectrometer are re-imaged by the phosphor screen.

The MCP-Phosphor assembly is mounted on a compression ring which slips into the inside diameter of the detector housing as shown in Figure 2. The system is held firmly so that the front face of the MCP lies in the focal plane of the mass analyzer by three set screws in the compression ring. The position was established by carefully constructed stand-off rods which bottom

FIGURE 2. Detail of Detector Housing (The front face of the TDA-MCP lies on the focal plane, as shown.)

on the back side of the detector housing. A grounded grid of 95%-transparent tungsten mesh, mounted on its own compression ring, serves to define the ground potential for ion accelerating voltage and sits about 1/2 mm in front of the theoretical focal plane of the instrument.

The presence of the grounded grid permits two possible methods of biasing the MCP-Phosphor system. In the first method, the front face of the MCP is held at ground potential and the rear face at the MCP operating voltage, V_c . The second method puts the front face of the MCP at $-V_c$ with the rear face at ground potential. With the second method there exists post-acceleration of the mass-analyzed ions into the face of the MCP. This method, however, introduced considerable distortion in slit images near the edge of the MCP because of the non-uniform post-accelerating field which was due to the finite extent of the grid. Though the second biasing method produced noticeably

brighter images on the phosphor, the distortion forced a choice of the first biasing method for subsequent work. A schematic of the MCP-Phosphor biasing arrangement is shown in Figure 3. Slightly better performance of the phosphor could be expected if the phosphor bias supply were floatable. Such a supply was not available for these experiments.

A closeup of the phosphor screen is shown in Figure 4. The photo shows the mass spectrum produced by residual gas in the mass 44 region. Six masses are visible in the photo. The brightest image is for mass 44.

FIGURE 3. Schematic of TDA Biasing Arrangement

FIGURE 4. Photograph of Operating TDA-Phosphor Screen (Mass Range covered is from 40 to 45 AMU).

3. GAIN MEASUREMENTS

Incident ion current was measured by steering the ion beam to a Faraday cup collector placed in the beam access port of the detector housing, as shown schematically in Figure 2. An electron trap was added after noting that unwanted secondary electrons, due to collisions of the ions with the tube walls, could enter the Faraday cup with adverse effects on current readings. Since the cup entrance aperture does not lie on the focal plane of the instrument, its width was set at 2 mm to insure collection of all ions at a particular mass. The electron current from the MCP was measured using the phosphor screen as the electron collector. Initial gain measurements were made using the hydrogen present as residual gas in the vacuum system so that only one mass would be incident when the beam was directed back to the center of the MCP. Current measurements were made with Kiethly 610-B electrometers. Current densities were estimated by measuring the area of photographed slit images produced on the phosphor screen. The slit image dimensions were controlled by tuning of the ion source of the instrument. It is important to note that maximum current transfer to the Faraday cup did not correspond to the finest slit image. Tuning was done entirely by visual observation of the shape of the slit image, adjusting ion lens potentials for maximum sharpness on the phosphor screen. Slit dimensions were nominally 14 mm x 0.72 mm; the current for a particular mass was therefore confined to an area of about 0.1 cm².

Typical results for gain measurements using 3000-eV H₂⁺ ions are shown in Figures 5 and 6. Figure 5 is a plot of the natural logarithm of the observed gain versus the TDA-MCP operating voltage for incident current densities which differ by about two orders of magnitude (1.29×10^{-13} A/cm² and 1.18×10^{-11} A/cm²). Saturation is evident in the curve for the higher current density. The saturation effect is more noticeable in Figure 6, the current transfer characteristics observed for 3000-eV H₂⁺ ions. Also shown on Figure 6 are lines of constant gain; marked deviation from constant-gain response occurs for currents above 10^{-12} A/cm² and voltages above 1400 V (700 V per MCP).

FIGURE 5. Observed TDA Gain for 3000-eV H_2^+ Ions for Indicated Currents (Left Ordinate: Natural Logarithm of the Gain, Right Ordinate: Gain Value. Abscissa: TDA Voltage; the voltage per MCP is one-half the indicated value.)

FIGURE 6. TDA Current Transfer Characteristics for 3000-eV H_2^+ Ions

Saturation appears to be more severe for 4000-eV Kr^+ ions, as shown in the curves of Figure 7. The total current delivered to the MCP was estimated by measuring the ^{84}Kr signal in the Faraday cup and assuming the standard Kr isotopic distribution to calculate the current contribution by the other isotopes allowed to reach the MCP. The total electron current delivered to the phosphor screen was then measured to determine the gain. Figure 7 compares the gain observed at 2.2×10^{-14} A/cm² incident current density to that for 2.1×10^{-11} A/cm². Saturation to the extent of gain reduction by two orders of magnitude is evident.

FIGURE 7. Observed TDA Gain for Krypton Isotopes at Indicated Currents

The origin of the saturation is to be found in the magnitudes of the observed output currents. The upper limit of the dynamic range of the MCP is determined by the standing current on the wall of each channel, referred to as the strip current for the device. The maximum strip current is the same for a single-stage device as for a TDA. The strip current limitation becomes important when the voltage per MCP exceeds about 700 V. Above that voltage, secondary electrons emerging from the channels raise the potential of the channel wall, thus reducing the local electric field and preventing increased gain. The TDA used in these experiments has a strip current of about one microampere per square centimeter of active surface area. The output current must not exceed 5% of this value if linear gain is to be maintained.⁽⁹⁾

For the TDA the output of the first MCP serves as the input for the second, so that saturation effects will occur at smaller input current densities for TDAs than for single-stage MCPs. Assuming a gain of 10^3 per MCP at a bias of 700 V per MCP ($V_c = 1400$ V for a TDA), the maximum output current density for linear gain in a TDA would be about 5×10^{-8} A/cm². Thus saturation is to be expected at an input current density above 5×10^{-14} A/cm². This is clearly evidenced in Figures 5, 6 and 7. For an image area of 0.1 cm² typical of the present mass spectrometer, the maximum ion current at one mass for linear gain is therefore only about 5×10^{-15} A. The upper curves in both Figures 5 and 7 are for input currents near the limit for linear gain. The difficulty of measuring currents below that level prevented extension of data to lower values of input current.

Uniform gain distribution across the entire area of a distributed detector is important to its satisfactory operation. A plot of output current as a function of peak position on the TDA for two different levels of H_2^+ incident current and at 6000 eV and 8000 eV is shown in Figure 8. A marked deviation from uniformity is noted. The nonuniformity is thought to be due to the fact that this TDA was used primarily for learning purposes and had already suffered significant damage prior to these measurements. Familiarization with the operation of the TDA as well as fine tuning of the image to determine magnet location for the mass spectrometer required a significant amount of operation time. Greatest damage was probably introduced by

FIGURE 8. Output Current as a Function of Position of the Incident Beam on the Face of the TDA, H_2^+ Ions at the Indicated Energies [Incident current for the 6000-eV (8000-eV) curve was 9.7×10^{-14} A (5.6×10^{-14} A)]

experiments in post-acceleration of ions which produced significant sputtering of the front face of the MCP. A reduction in gain by as much as a factor of two has been reported for operation times as low as 1500 hours with a V_c of 1000 V and an input current density of 3×10^{-12} A/cm² of low energy electron current.⁽⁹⁾ No accurate record of total exposure for the TDA used in these experiments was kept, so total exposure data are not available. It is likely that deterioration would be accelerated by exposure to high-energy ions.

From results of gain measurements it is obvious that care must be exercised in the use of TDA-MCPs for focal plane detection. TDAs will always be useful qualitative tools for distributed detection of ions. Saturation at low incident current levels limits their linear dynamic range so that reliance on them for accurate numerical analysis over extended current ranges is not warranted. A problem to be subsequently discussed is the non-linear gain distribution across a single mass peak due to saturation phenomena. Since the gain for incident currents below 5×10^{-14} A/cm² can be several orders of magnitude greater than that for incident currents above about 10^{-12} A/cm², an artificial peak broadening on the phosphor screen can result. This would have deleterious effects on mass resolution and abundance sensitivity. One other factor, the relatively strong dependence of MCP gain on ion mass as reported by Tuithoff et al.,⁽¹⁰⁾ must also be considered when using these devices for accurate numerical measurements.

4. READING AND RECORDING OPTICAL SIGNAL

The problem of recording the signal produced by the phosphor was approached by employing a Fairchild Charge Coupled Device (CCD). The device chosen for evaluation was the CCD 121H, an array consisting of 1×1728 photodiodes, each of which is $13 \mu\text{m}$ (0.51 mils) by $17 \mu\text{m}$ (0.67 mils) on $13\text{-}\mu\text{m}$ centers. There is no dead area throughout the 2.2-cm (0.88-in.) active length of the device. The image sensor elements are separated on the single crystal silicon chip by diffused channel stops and covered by a polycrystalline silicon photogate. Photons pass through the photogate and are absorbed in the single crystal silicon by hole-electron pair production. Electrons thus generated are accumulated in the photosites. The amount of charge accumulated is proportional to the illumination intensity and the total time of exposure, or the integration period. The background level in the device is determined by thermally generated noise, and the saturation exposure of nominally $0.5 \mu\text{J}/\text{cm}^2$ determines maximum output. The CCD is mounted on a vacuum-enclosed thermoelectric cooling system capable of operating temperatures to -50°C . (Marlowe Industries SP1056 in the Marlowe ST1018 vacuum enclosure. Marlowe Industries, Garland, Texas.)

On-chip circuitry permitting read-out of the stored charge includes two transfer gates, two 866-bit analog shift registers, and a gated charge detector/preamplifier. The transfer gate structures are adjacent to the row of image sensor elements and serve to transfer the accumulated charge to the shift registers, with alternate charge packets transferred to the right or left shift registers. The two shift registers are used to move the image-generated charge packets serially from the sensor elements to the charge detector/preamplifier. The phase relationships of the two shift registers provide for alternate delivery of charge packets to re-establish the serial sequence of the photosites. The charge detector/preamplifier is a precharged diode whose potential changes linearly in response to the quantity of signal charge delivered. This potential is applied to the gate of an n-channel MOS transistor which produces the final output signal. The charge detector diode capacitance is recharged by a reset transistor driven by a reset clock operating at the frequency with which packets are delivered to the detector so that the original charge state is established prior to the arrival of each new signal charge packet.

The various voltages and clock waveforms required for operation of the CCD were obtained with the CCD Design Development Board, Fairchild part no. SL62912. The board is driven by an external power supply providing a logic voltage of 5 V at 0.5 A, +15-V bias at 150 mA, and -15-V bias at 40 mA. A Hewlett-Packard model 222A pulse generator was used to provide the clock frequency so that a range in operating rates and integration times could be investigated. Also, in experiments reported here, the video output of the device was fed to a sample and hold amplifier so that only peak values during the measurement of each charge packet could be recorded. This greatly improved the qualitative nature of the output trace on the oscilloscope, as shown in Figure 9, where the video and sample and hold output are compared. Total time available for digital sampling of each signal was also increased by use of the sample and hold circuit. Positive spikes seen in the video output are due to feed-through from the reset pulse applied to the charge detector/preamp. The reader is referred to Fairchild Semiconductor product descriptions for further detail on the operation of the CCD 121H.

FIGURE 9. Comparison of Video (a) and Sample-and-Hold (b) Output of CCD. Sweep Speed for Lower Traces: 50 ms/cm. Upper Traces; 0.5 ms/cm. Vertical Sensitivity: 0.2 V/cm. (Zero for the upper traces of both photos is 1 cm down from the top graticule line, while that for the lower traces is 2 cm up from the bottom graticule line. Pulses showing above the graticule in (a) are due to feed-through from the clocking pulse to the on-chip amplifier. Signals are for dark current at room temperature and an operating frequency of 3.84 kHz.)

A special optical system to image the 40-mm active diameter of the distributed detector onto a 25-mm strip was designed and constructed. The lens system consists of three elements. The required reduction of 0.625 is accomplished using a negative lens of -150-mm focal length. The virtual image of that lens is then imaged on the CCD with a magnification of unity in the horizontal direction by a cylindrical lens of 90-mm focal length. Additional vertical reduction of 0.2 is provided by a second cylindrical lens of 50-mm focal length. The lenses are mounted in a brass tube with provision for adjustments which permit superposition of the images from the two cylindrical lenses on the CCD. The system has a F-number of about $f/7$. Estimates of collection efficiency based on entrance apertures determined by working distances indicate that approximately 0.24% of the light emitted by the phosphor is collected by the optical system. The 10 uncoated glass-air interfaces between the phosphor and the CCD each have a transmission of about 80%, so that 9.5% of the collected light reaches the CCD. At the combined horizontal and vertical magnification of 0.125, the intensity in the focal plane is about 0.18% of that on the phosphor.

5. DATA ACQUISITION AND PEAK SHAPE

Although suitable for qualitative observation, oscilloscopic records do not provide sufficient accuracy for quantitative measurements. Numerical data in the form of the voltage output of each photosensor in the CCD are required. For the purposes of this investigation, quantitative data were obtained with a Digital Equipment Corporation (DEC) PDP11/10 minicomputer equipped with a Laboratory Peripheral System (LPS11). The LPS11 is a general-purpose system with sufficient flexibility for application to a wide variety of laboratory data acquisition and experimental control problems. Data acquisition features include a real-time clock, an A/D converter multiplexed to accept up to 16 channels of input, a D/A converter with 4 channels for output, two Schmitt triggers for synchronization of sampling with external events, and a light-emitting-diode display. The reader is referred to product literature available from DEC for more detailed descriptions of the components of the LPS11. Software available for support of the system includes MACRO, BASIC,

and FORTRAN IV. Thus, the problem of collecting numerical data from the CCD was reduced to development of FORTRAN programs utilizing subroutine calls to LPS11 support elements.

Three programs were written for data acquisition, display and production of hard copy on a Gould 5000 printer/plotter. Program DIODE takes data and writes the results on a file on the RK0-5 disk. Program PKREAD retrieves data from the file, displays it on a Tektronix 4010 graphics terminal, and uses the cross-hairs on the terminal to define endpoints for numerical integration over mass peaks as well as a determination of the maximum signal level between the two endpoints. Both sets of values, i.e., the integrated and maximum values, are then used to calculate isotopic distributions for the spectrum displayed. Program GLDPLT reads data from the disk file and prints out all 1728 values corresponding to the voltage levels produced on each photosite and produces a hard-copy plot of the signal height versus diode number. Listings of the programs and brief descriptions of them are given in the Appendix.

Pertinent elements of the sampling program deserve discussion here. The dark signal on the CCD was always recorded prior to turning on the ion beam. The program was designed so that the average of as many as thirty scans of the CCD could be recorded. This required that each scan be synchronous with both the recorded dark signal and successive scans. The recorded average dark signal was then subtracted from the data prior to storing the data on the disk. Synchronization of successive sweeps is accomplished using the Schmitt triggers on the LPS11. The LPS11 real-time clock is started by feeding the transfer gate signal into Schmitt trigger #2. The rate of the clock is determined by the frequency of the oscillator driving the CCD circuitry via Schmitt trigger #1. The clock is stopped after one pulse of the driving signal and that event is sensed by the computer. The next transfer gate pulse to arrive restarts the clock and the sampling circuitry is enabled in a mode which samples after each clock pulse. In order to start sampling simultaneously with the start of the CCD output, a preset value is counted off prior to enabling the sampling circuitry. This allows for time required by the computer to reset flags and to accumulate successive samples in a buffer prior to taking the average of several scans. This technique guarantees synchronization between recorded samples but only records every other sweep of the CCD. A schematic

diagram illustrating the pertinent connections to the computer system is shown in Figure 10.

At the operating temperature of -40°C the dark signal in individual photosensors of the CCD was always in the neighborhood of 46 to 60 mV for a total integration time of 1 s. The output signal at saturation was 0.966 V. Signals due to light on the phosphor were apparently simply added to the dark signal. The difference between the dark signal and the signal from the phosphor was independent of the dark signal as long as the total was less than the saturation level. The observed dark signal was within the range of the 5 mV/ms specified at 25°C when the "rule of thumb" reduction of a factor of 2

FIGURE 10. Schematic Indicating Connections Between Charge-Coupled Device and Minicomputer

in leakage current for each 7°C drop in temperature for silicon devices was applied.

A typical record of the dark signal produced by the array at -40°C with an integration time of 1 s is shown in Figure 11 whereas Figure 12 shows the output signal range. The output signal range is defined as the difference between the leakage current, or dark signal, and the saturation output. The output signal range for the device tested here is approximately 0.87 V. Experience with numerical output of the data has shown that a difference of only 2 in output (decimal) from a 12-bit ADC (range of -1.0 to +1.0 volts) can be consistently related to the presence of a signal. The dynamic range of this device is therefore $0.87/0.00098 = 890$.

FIGURE 11. CCD Dark Signal at -40°C and a Data Rate of 1785 s^{-1} (The integration time was 1 s.)

FIGURE 12. CCD Output Signal Range (i.e., the saturation output with dark signal removed)

Standard operating conditions for the TDA-Phosphor detector and the CCD were adopted for subsequent experiments. The TDA was biased at 1360 V with the front face at ground potential. This value is slightly below the maximum of 700 V per MCP which permits constant gain of a single MCP. The phosphor voltage was always set at 5000 V above ground. Electrons therefore reached the phosphor with an energy of 3640 eV. Integration time on the CCD was nominally 1.0 s^{-1} . The corresponding rate of data accumulation was 1785 s^{-1} .

The hydrogen spectrum due to residual gas in the vacuum system was used to determine the shape of an individual mass peak. Such a spectrum is shown in Figure 13 for 6000-eV H_2^+ ions at an incident current density of $1 \times 10^{-11} \text{ A/cm}^2$. The peak exhibits a sharp central portion with a

FIGURE 13. H_2^+ Spectrum (Ion Energy = 6000 eV; Current Density = 1×10^{-11} A/cm²)

maximum CCD output of 155 mV superimposed on a broad pedestal. The central 256 points of the normalized, smoothed spectrum of Figure 13 is shown in Figure 14 to permit better visualization of the peak shape. The sharp central region of the peak has a full width at half-maximum of 61 diodes, which corresponds to 0.79 mm on the CCD. Since the width of the peak on the phosphor screen is 0.72 mm, it is apparent that the optical system does not produce the expected 0.625 horizontal magnification of the image. Slight misplacement of the lenses is probably responsible for the increased width.

The central portion of the spectrum strongly resembles two superimposed Gaussian curves. A Gaussian analysis of the spectrum is shown in Figure 15, a plot of $\ln(F)$ versus $(N - N_0)^2$, where F , N , and N_0 represent signal height, diode number, and peak center, respectively. Two straight line portions are

FIGURE 14. Central 256 Points of the Spectrum of Figure 13

apparent. The sharp central region has a center at diode 774 and a standard deviation of 51 diodes, while the broad pedestal shows a satisfactory Gaussian character with a center at diode 772 and a standard deviation of 115 diodes. Using the diode separation of 0.013 mm, the full width at the 1/e point on the sharp portion is 0.937 mm, while that for the broad portion is 4.2 mm. The latter width cannot be explained solely on the basis of misplacement of optical components.

Comparison of normalized spectra obtained using 72-eV and 135-eV electrons in the ion source indicate that the shape of the broad pedestal is independent of electron energy. Further, an estimate of peak width made by sweeping the H_2^+ beam over the edge of the Faraday collector entrance aperture yielded 0.71 mm, a value in agreement with the 0.72 mm measured on the

FIGURE 15. Gaussian Analysis of Figure 14

face of the phosphor. The shape characteristics are most likely the result of nonuniform gain distribution across the mass peak. In the center of the spectrum the incident current density of 1×10^{-11} A/cm² exceeds the saturation limit for the TDA. The gain in that position is therefore in the neighborhood of 10^4 . Currents in the wings of the Gaussian pedestal are due to ions scattered from the walls of the system and are well below the limiting current for constant gain. The gain for these currents can therefore exceed 10^6 , with the consequence that the light produced by the phosphor per ion striking the TDA is two orders of magnitude greater in the wings of the peak than it is in the center.

The effect of the broad peak shape on spectral quality is illustrated in the Kr spectrum of Figure 16. That spectrum was obtained at a pressure of 7.05×10^{-6} torr; the ion current for $^{84}\text{Kr}^+$ was 6.92×10^{-12} A so that the incident current density of 6.92×10^{-11} A/cm² was well above the limit for constant gain. Integration time on the CCD was 1.033 s. This pressure was approximately two orders of magnitude above the background, so that effects due to residual gases would be minimized. The broad contribution to the spectrum due to scattering prevents the signal from reaching the background leakage level at any position on the CCD, and is most noticeable in the 82, 83, and 84 mass peaks. Superposition of the wings of these peaks produces a valley between them with an amplitude greater than the total height of the mass 80 signal. The TDA saturation effects in the sharp portions of the peaks are such that neither peak height nor area measurements produce the correct isotopic distribution for Kr.

FIGURE 16. Krypton Spectrum: Masses 78, 80, 82, 83, 84, and 86 (Contributions due to residual gases at intermediate mass positions are evident.)

The known isotopic distribution can be used to estimate the relative gain at different mass positions. Let R_{ij} denote the known isotopic abundance ratio, S_i the CCD voltage, and G_i the gain for mass i . Then the relative gain can be defined as

$$\frac{G_i}{G_j} = \frac{1}{R_{ij}} \frac{S_i}{S_j}$$

Results for the spectrum of Figure 16 are shown in Table 1.

In substantial agreement with the current transfer characteristics of Figure 6, the appropriate gain for mass 78 with an incident current density of $4.3 \times 10^{-13} \text{ A/cm}^2$ is more than one order of magnitude greater than that for mass 84.

TABLE 1. Gain Relative to Mass 84

<u>Mass</u>	<u>r1,84</u>	<u>S_i, Volts</u>	<u>G_i/G₈₄</u>
78	0.00615	0.081	34.54
80	0.0399	0.114	7.52
82	0.203	0.200	2.58
83	0.203	0.229	2.96
84	1.000	0.381	1.00
86	0.305	0.371	3.19

6. DETECTION SENSITIVITY

The object of experiments conducted was to determine the sensitivity of the total detector system. This required measurement of the output of the CCD as a function of the ion current striking the TDA. Incident ion current was measured by steering the beam to the Faraday cup, and the output of the CCD was measured using the developed sampling program. Numerical measurements of the CCD output as a function of ion current were made using Kr gas. The relationship between gas pressure and cup current with constant emission parameters in the electron gun was first determined. The ^{84}Kr peak was monitored while the leak valve to the Kr gas bottle was cracked slightly open and the main valve to

the diffusion pump was throttled down. Ion currents at other Kr isotopes were inferred using the established isotopic abundance of Kr. A series of records of CCD output as a function of pressure were then recorded by leaving the leak valve slightly open and adjusting the main valve to the diffusion pump so that a dynamic equilibrium could establish the desired pressure in the chamber. A sample consisting of 10 successive scans was then recorded and the average, with dark signal removed, filed on the disk.

A plot showing the CCD output in volts versus ion current with atomic mass as a parameter is shown in Figure 17. Apparent saturation effects are due to large incident current densities on the TDA so that the output current exceeds the strip current for the device. No saturation of the CCD was observed. This is not surprising because of the poor optical coupling between phosphor and CCD used in these experiments.

FIGURE 17. CCD Output Versus Incident Ion Current for Kr Isotopes

It is seen from Figure 17 that plots of CCD output versus ion current show considerable inconsistency. This is partly due to the saturation of the MCP, previously mentioned, and partly due to assuming the current at a particular mass is due only to Kr. This is particularly true of mass 78, which corresponds to the minor isotope of Kr (abundance of 0.35 %) as well as to benzene (C_6H_6). Since pressure control was achieved by throttling of the pump valve, the impurity level in the system rose along with the Kr pressure. Since current for each mass was not measured, corrections for background gas contributions cannot be made. Data for masses 80, 82, and 84 show similar slopes on the plot but exhibit displacement. The data for mass 86 can be explained by pointing out that the ion beam for that mass was incident on the edge of the TDA, a region which had not been exposed as much as the central portion of the TDA, and produced a brighter signal on the phosphor. (See Figure 8.)

In order to minimize questions raised by partial pressures of impurities, the determination of the ultimate sensitivity of this detection arrangement was accomplished by analysis of the 82, 84, and 86 peaks of Kr. Figure 18 is a plot of the CCD output voltage as a function of total number of ions delivered to the front face of the MCP during the nominal 1-s integration time used in these experiments (1.033 s was the actual measured value of the integration time). The relative abundances of these isotopes are 11.56%, 56.9%, and 17.37%, respectively. Saturation of the MCP is evident in all three curves. An estimate of the minimum detectable number of ions was made by making a quadratic extrapolation of the 84 signal to the baseline, or zero level of the plot. The extrapolation intersects the axis at a value corresponding to about 2.2×10^5 ions. The other two plots do not extrapolate to zero because of the contribution of the wings of adjacent signals to their total height.

In another independent test, straight-line fits of V_{CCD} versus pressure and ion current to the Faraday cup versus pressure were compared. The ratio of the two slopes thus derived corresponds to an average sensitivity in terms of CCD output voltage per ampere striking the front face of the TDA. The pressure range for this experiment was between 1×10^{-6} torr to 8.6×10^{-6} torr.

FIGURE 18. CCD Output Versus Integrated Ion Current for Kr Isotopes 82, 84, and 86 (A quadratic extrapolation of the ^{84}Kr curve yields a sensitivity value of 2.2×10^5 ions.)

The following two relations resulted:

$$I^+ = 1.732 \times 10^{-13} + 7.14 \times 10^{-8} P$$

and

$$V_{\text{CCD}} = 1.805 \times 10^{-2} + 1.436 \times 10^{-4} P,$$

with the pressure P in torr for both equations. Correlation coefficients for the current and voltage lines were 0.998 and 0.982, respectively. The ratio $(dV/dP)/(dI/dP) = dV/dI$ yields a value of 2.011×10^{11} V/A. The integration time employed in this experiment was 1.122 s, so the sensitivity per ion striking the MCP derived for this case is 2.872×10^{-8} V/ion. The sensitivity of the array is determined by the variations naturally present in the leakage signal. As can be seen from Figure 11 this varies as a function of position on the CCD. The standard deviation of the leakage signal over the entire array at the operating temperature of -35°C is 2.8 mV, while the value for separate 200 element sections of the array varies between 0.8 mV and 4.5 mV. If the value of 4.5 mV is used as the threshold for significant signal, the sensitivity of the detection arrangement under discussion is nominally $0.0045 / (2.872 \times 10^{-8}) = 1.56 \times 10^5$ ions. This estimate agrees with that obtained by extrapolation in the previously discussed example.

7. CONCLUSIONS AND RECOMMENDATIONS

The most severe problem encountered in this work is that due to saturation in the TDA. It becomes important therefore to estimate the contribution of the second stage MCP to the total gain of the TDA. Published current transfer characteristics for single MCPs⁽⁹⁾ indicate that under the present operating conditions (680 V/MCP) a gain of 1.08×10^3 can be expected in the first stage. Gain measurements made in this work can therefore be used as a basis for estimating the gain of the second stage. Representative data and results for H_2^+ ions at 8000 V are shown in Table 2 with the total MCP voltage at 1360 V.

TABLE 2. TDA Second Stage Gain for 2000-eV H₂ Ions. Single Stage Gain = 1.08×10^3 ($V_C = 80$ V/MCP)

$J_{in}, \text{ A/cm}^2$	$J_{out}, \text{ A/cm}^2$	TDA Gain	2nd Stage Gain
1.04×10^{-13}	3.3×10^{-9}	3.27×10^4	29
1.71×10^{-13}	6.09×10^{-8}	3.46×10^4	33
3.62×10^{-13}	1.42×10^{-8}	3.75×10^4	36
5.97×10^{-13}	2.34×10^{-8}	3.95×10^4	36
1.19×10^{-12}	5.01×10^{-8}	4.21×10^4	39

The average for the five values of Table 2 indicate that the second stage gain in this current range is only 35 ± 4 . A single MCP has a linear gain of 10^4 with a bias of 900 V up to an input current density of 10^{-11} A/cm². The TDA is therefore not necessary since the increase gain is not required and can lead to excessive saturation effects.

The use of fiber optic reducers in place of a lens system for optically coupling the phosphor image to the CCD can increase the transmission to a value near 90% from the 0.18% used in these experiments. The light intensity at the CCD should be a factor of 500 higher than in the present study if efficient transmission is used. If the MCP gain is adjusted to 10^4 , an over-all increase in sensitivity of about 143 can be expected by using efficient optical coupling with a single MCP.

With 90%-efficient optical coupling, the upper limit of detectability will be determined by saturation in the CCD. To demonstrate this, assume that the sensitivity figure of 2.872×10^8 V/ion derived in this work is correct and adjust it for anticipated improvements due to better optical coupling. We also assume that the sensitivity of the CCD is $0.4 \text{ V} \cdot \mu\text{J}^{-1} \cdot \text{cm}^{-2}$, as quoted in product literature. Combining these estimates yields a value for light reaching the CCD per ion striking the MCP of $L = 1.026 \times 10^{-5} \mu\text{J}/\text{cm}^2$ ion. The output signal range for the CCD used in these experiments was shown to be 0.86 V. This corresponds to a light intensity on the CCD of $2.15 \mu\text{J}/\text{cm}^2$.

The maximum total number of ions which can be seen is therefore the ratio of the last two numbers, namely 2.1×10^5 . This value is close to the minimum detected in these experiments and would therefore seem to pose a difficult quandary. However, the great flexibility in integration times for the CCD allows it to operate with variable sensitivity and maintain its linearity. The minimum detectable signal is, as previously stated, (2/2048) volts. This would correspond to 238 ions striking the single-stage MCP. The dynamic range of the system with fixed integration period of 1 s would therefore be 881. The potential for dynamic adjustment of integration time on the CCD under computer control can extend its dynamic range considerably. The combination: single-stage MCP - Fiber Optics - CCD should prove flexible enough for a broad range of analytical situations.

For ion currents densities below about 10^{-14} A/cm² the TDA remains an attractive candidate for focal plane detection. However, due to saturation effects, care must be taken to design mass analyzer systems to minimize scattering in the source region and from analyzer tube walls. These conditions should be met with surface ionization sources in direct inlet systems. More experience with DIMS instruments is required to determine adequate sensitivity levels for distributed focal plane detectors. Work discussed here supports the recommendation that single-stage MCPs be used to avoid non-linearities found in TDA-MCPs.

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APPENDIX

RT11 FORTRAN-IV SOFTWARE;
CCD DATA ACQUISITION AND ANALYSIS

APPENDIX

RT11 FORTRAN-IV SOFTWARE; CCD DATA ACQUISITION AND ANALYSIS

Software development represents a significant portion of the effort expended to perform the evaluation of the approach to simultaneous mass detection described in this report. This section serves to document the results of that effort. In addition to programs required for taking data from the CCD, several were written to perform special analyses and to draw plots. The three programs most essential to the conduct of this work will be described here: Program DIODE, the routine for recording CCD output and creating a data file on the disk; Program PKREAD which retrieves the data from the disk file, draws a plot on the Tektronix 4010 graphics terminal, and uses the cross-hairs on the terminal to define the end points for integration over mass peaks so that relative abundances can be determined; and program GLDPLT which generates a printout of the stored values for each element of the diode array and a hard-copy plot using a Gould 5000 printer-plotter. In the following a general description of each program will be followed by a FORTRAN listing and a sample of the output from each program.

A.1 PROGRAM DIODE

Program DIODE is the routine used for sampling the CCD array. The program is written in the MAIN program-SUBROUTINE structure for greater flexibility, and is designed to operate on a PDP 11/10 equipped with a Laboratory Peripheral System (LPS) and 16K-word core. The COMMON element includes IBUF, dimensioned at 1785, for receiving data acquired by the LPS, and IY, also dimensioned at 1785, for accumulating successive scans prior to signal averaging. Other variables in COMMON are IDUR, dimensioned at 30, for storing the results of the HISTogram sampling element of LPS support for up to 30

consecutive scans, and ISIZ, NCALL, ISTCHN, MODE, PRESET, and LIM which represent the total number of data points to be taken per scan, a counter for recording the number of scans taken, the input channel on the LPS used for receiving data from the CCD, the sampling mode used in the Real Time Sampling (RTS) subrouting in LPS support software, the number of received pulses to count prior to initiating the RTS routine, and the total number of scans to be taken, respectively. Definitions and uses of the COMMON variables are summarized in Table A.1.

The main program first calls SUBROUTINE DURATE which uses the LPS real time clock operating at 1kHz to measure the duration of 20 successive scans of the CCD. Each scan requires 1785 cycles of the external oscillator driving the CCD Design Development board. The time between scans is measured by sensing the CCD transfer-gate pulse from the Design Development Board with Schmitt Trigger #2 on the LPS. The average scan duration and its standard deviation are then calculated and the results typed on the terminal. since there is no way to control the start of sampling synchronously with the oscillator, the first number recorded is excluded from the average.

TABLE A.1. Common Element in Program Diode

<u>Variable</u>	<u>Dimension</u>	<u>Function</u>
IBUF	1785	Data receiver
IY	1785	Data accumulator
IDUR	30	Storage of Histogram data
ISIZ	1	Number of points in IBUF
NCALL	1	Counter
ISTCHN	1	LPS ADC channel number
MODE	1	Sampling mode of LPS
PRESET	1	Number of cycles delay between scan starts
LIM	1	Total number of scans to be taken

Program DIODE next calls SUBROUTINE SETUP. This is a simple initialization routine which zeroes all buffers and prompts the user with messages to the terminal. Necessary run parameters, such as the number of points to be recorded, the sampling mode, the LPS ADC channel number to be used, the number of pulses to be counted prior to the start of sampling, and the total number of scans to be recorded, are established in SETUP.

The background or dark signal from the CCD is next recorded with SUBROUTINE BKGRND. BKGRND calls SUBROUTINE DATAKE and SUBROUTINE PUTBKG. SUBROUTINE PUTBKG creates a file on the RK0-5 disk which contains the results of sampling in unformatted binary using routines in the DEC System Subroutine Library. SUBROUTINE DATAKE is the basic sampling element of the program and is used for all data-taking activity of the program. A detailed description of DATAKE will be given here.

For effective signal averaging, each successive scan must be in synchronization. Synchronization is established in the loop "DO 40 I=1, LIM" in the listing for SUBROUTINE DATAKE. All event flags are first initialized to 0 in the loop. The histogram routine, HIST, is then called to sense the arrival of the next CCD transfer gate pulse via Schmitt Trigger #2 by calling the real-time clock routine, SETR such that it is driven by the external oscillator via Schmitt Trigger #1 (rate 6) and in the inter stimulus mode (3), with the clock preset value set at 0.0. The next firing of ST #2 then fills the variable ITRIG, the first argument of the call to HIST, and sets the histogram event flag. The progress of the routine is delayed by the call to LWAIT until the histogram event flag has been set. The clock must then be turned off [CALL SETR(-1,,)] and started again at the externally driven frequency and in single interval mode and counts off the value entered for PRESET in SUBROUTINE SETUP. After the clock flag has been set, sensed by the next call to LWAIT, the Real Time Sampling (RTS) routine is called.

The argument list for the call to RTS contains 10 elements. Data are stored in IBUF, ISIZ words are to be stored, and no subbuffers are required as indicated by the unity value of the next argument. Data are entering via channel ISTCHN, and only one channel is used. The gain has previously been

set to 1 in the subroutine, and the MODE normally used is mode 0, sample when ST #1 fires. The variables ICMF and IBEF are the completion/error flag and the buffer event flag, respectively. After the setting of the completion flag, sensed by the next call to LWAIT, the current value of ITRIG is stored in the array IDUR and the values read into the buffer IBUF are accumulated in the array IY by the call to subroutine FILL. The progress of sampling is monitored in real time by displaying the current value of NCALL on the light emitting diode display of the LPS with the call to LED. The clock is then turned off and the process repeated LIM times. The current values for ITRIG and the histogram and clock flags are then typed on the terminal, as are the values stored in IDUR, representing the number of oscillator cycles between clock start and the next transfer gate pulse for each successive scan. Finally, the array IY is averaged.

SUBROUTINE FILL simply accumulates data in the array IY and increments the variables NCALL and IBEF. The latter is necessary so that the RTS routine can start with a value of 1 for the buffer event flag.

SUBROUTINE SAMPLE uses DATAKE to acquire data and calls SUBROUTINE GETBKG which retrieves the dark signal data from the disk and subtracts it from the current contents of IY. The listing for GETBKG contains several statements with a "D" in column one. These can be included in the compilation by using the /D switch when running the RT-11 FORTRAN compiler. These statements call the display routines in the LPS supporting software so that the effects of subtracting the background from the averaged signal can be observed on the digital oscilloscope. The output of the sample and hold amplifier is negative, as is the output of the CCD. In order to display positive-going peaks the contents of IY are subtracted from the data in file BKG.DAT. This is done merely for the sake of convenience in subsequent display and plotting routines.

PROGRAM DIODE next calls SUBROUTINE SHOW which uses the display routines to display the contents of the buffer on the digital oscilloscope. This subroutine also has facilities for isolating portions of the nominally 1728-word buffer and displaying a smaller number of points so that detail can be

investigated. If the number of points displayed is less than or equal to 30, SUBROUTINE PARSE is called and values of the displayed points are typed on the terminal.

The final routine called in the program is SUBROUTINE DATRIT. This routine creates a file on the RK05 disk which contains the current contents of the array IY, which is the element-by-element average of the results of LIM successive scans. The file can then be accessed by analysis programs at a future time.

All subroutines which write and read data to and from the disk use subroutines in the DEC System Subroutine Library SYSLIB. Thus, the subroutines PUTBKG, GETBKG, and DATRIT use SYSLIB elements to convert file names in ASCII to the Radix-50 format required for the file allocation routines IENTER and LOOKUP. SYSLIB calls are also used for identifying the RT-11 channel number to use for data transfers, to write or read data to or from specified files, and close and free input/output channels for later use. The number of words specified in the IWRITE and IREADW routines are transferred in one operation, making this technique the most efficient and rapid method for writing and reading data from mass storage. The 1728 elements which result from sampling the entire CCD array are written to 7 blocks on the disk in one operation.

The RT-11 LINK procedure for program DIODE is as follows:

```
.R LINK
*DIODE=DIODE,DATAKE,FILL,LDPNEW,SYSLIB/F/C
*DURATE,SETUP/O:1/C
*BKGRND,PUTBKG/O:1/C
*SAMPLE,GETBKG/O:1/C
*SHOW,PARSE,DATRIT/O:1
```

* Use of the overlay switch, /O:1, guarantees adequate room for operation of the program on a 16K-core machine, since only the subroutines necessary for operation are resident at any one time. Note that DATAKE and FILL are in the root segment of the link since they are accessed by subroutines in the overlay region.

A listing of PROGRAM DIODE follows.

Program DIODE

```
PROGRAM DIODE.FOR
RLG 6-JAN-77, SAMPLES PHOTODIODE ARRAY, FILES AND PLOTS DATA

C
C
C   COMMON /PFG
C   COMMON ELEMENT FOR DIODE ARRAY SAMPLING
C   RLG 6-JAN-77
C
C   COMMON /BUF(1286), /Y(1286), /DUR(20), /C1Z, /NCALL, /STCHN, /MODE,
C   /PRESET, /LIM
C
C   Q=0.
100  IF(Q.EQ.1.) GO TO 200
      CALL DURATE
      CALL SETUP
200  CALL BKGRND
      CALL SAMPLE
      CALL SHOW
      CALL DATRIT
C      CALL TXPLOT
      TYPE 10
10   FORMAT('E TYPE 1.0 FOR ANOTHER RUN ')
      ACCEPT 20,0
20   FORMAT(F6.2)
      IF(Q.EQ.1.0) GO TO 100
      STOP 'RUN COMPLETED'
      END
```

SUBROUTINE DURATE

```
C
C---MEASURES TOTAL DURATION OF SCAN, 1785 PULSES FROM SAMPLE CLOCK
C      USES 1 KHZ CLOCK FREQUENCY.  FOR USE IN PHOTODIODE ARRAY
C      SAMPLING.  RLG 19-JAN-77 DURATE

C      COMMON.PRG
C      COMMON ELEMENT FOR DIODE ARRAY SAMPLING
C      RLG 5-JAN-77
C
      COMMON IBUF(1786),IY(1786),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
      1PRESET,LIM

C      PROGRAM INTRVL.FOR      RLG, 7-DEC-76
C
C      USES HISTOGRAM SAMPLING TO MEASURE TIME INTERVALS BETWEEN
C      EVENTS.  OPTIONAL CLOCK RATE, MODE, AND PRESET.  MAX 20
C      SAMPLES.  OUTPUTS RESULTS TO TT:.
C
      DIMENSION ITRIG(20)

C      INITIALIZE FLAGS, GET CLOCK PARAMETERS.
C
      TYPE 9010
9010  FORMAT(' DURATION MEASUREMENTS UNDER WAY',//)
      DO 100 I=1,20
      ITRIG(I)=0
100   CONTINUE
      LIM=20
      ICHF=0
      ICCF=0
      IRATE=4
      MODE=3
      PRESET=0.0
      CALL HIST(ITRIG,LIM,LIM,ICHF,IBHF)
      CALL SETR(IRATE,MODE,PRESET,ICCF)

C
C      WAIT FOR THE DATA
C
      CALL LWAIT(ICHF,0)

C      OUTPUT RESULTS
C
      TYPE 9030
9030  FORMAT(' HISTOGRAM SAMPLING RESULTS')
      D  TYPE 9040, (ITRIG(I),I=1,LIM)
D9040  FORMAT(10I7)
      CALL SETR(-1,.,.)
      S=0.
      SQ=0.0
      DO 200 I=2,LIM
      S=S+FLOAT(ITRIG(I))
200   CONTINUE
      S=S/FLOAT(LIM-1)
      DO 250 I=2,LIM
      SQ=SQ+(FLOAT(ITRIG(I))-S)**2
250   CONTINUE
```


SUBROUTINE DURATE (contd)

```
      SQ=SQ/FLUHT(LIM-3)
      SQ=SQRT(SQ)/1000.
      S=S/1000.
      RATE=1785.0/S
      TYPE 9000, S, SQ, RATE
9000  FORMAT(' DURATION   ',F8.3,' +/-',E12.3,' SECONDS'//,
           1' SAMPLING RATE= ',F8.3, '//)
      RETURN
      END
```

SUBROUTINE SETUP

```
C
C      SETUP.PRG
C      INITIALIZATION ROUTINE FOR DIODE ARRAY SAMPLING
C      RLG 5-JAN-77
C
      COMMON IBUF(1786),IY(1786),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
      1PRESET,LIM
C
      DO 150 I=1,1786
      IBUF(I)=0
      IY(I)=0
150    CONTINUE
      DO 200 I=1,30
      IDUR(I)=0
200    CONTINUE
      NCALL=0
      TYPE 9020
9020   FORMAT(' $ SELECT SIZE,MODE,      ')
      ACCEPT 9030, ISIZ,MODE,
9030   FORMAT(2I5)
      TYPE 9050
9050   FORMAT(' $ CHANNEL $,PRESET, NUMBER OF SCANS? ')
      ACCEPT 9060,ISTCHN,PRESET,LIM
9060   FORMAT(I6,F7.1,I6)
      RETURN
      END
```

SUBROUTINE BKGRND

```
      SUBROUTINE BKGRND
C
C      FOR GETTING BACKGROUND OUTPUT OF DIODE ARRAY
C      RLG 5-JAN-77
C
C      COMMON.PRG
C      COMMON ELEMENT FOR DIODE ARRAY SAMPLING
C      RLG 5-JAN-77
C
      COMMON IBUF(1786),IY(1786),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
      1PRESET,LIM
C
      TYPE 9000
9000   FORMAT(' TURN OFF ION BEAM ')
      PAUSE 'CARRIAGE RETURN TO SAMPLE'
      CALL DATAKE
      CALL PUTBKG
      RETURN
      END
```

SUBROUTINE DATAKE

```
C
C      COMMON.PRG
C      COMMON ELEMENT FOR DIODE ARRAY SAMPLING
C      RLG 5-JAN-77
C
C      COMMON IBUF(1786),IY(1786),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
C      1PRESET,LIM
C
C      DATA TAKING ELEMENT FOR DIODE ARRAY PROGRAM
C      RLG 5-JAN-77 DATAKE.PRG
C
C      IGAIN=1
C      NCALL=0
C      DO 100 I=1,ISIZ
C      IY(I)=0
100  CONTINUE
C      DO 40 L=1,LIM
C      ICCF=0
C      ICCF1=0
C      ICMF=0
C      ITRIG=0
C      ICHF=0
C      IBHF=0
C      CALL HIST(ITRIG,1,1,ICHF,IBHF)
C      CALL SETR(6,3,0,0,ICCF)
C      CALL LWAIT(ICHF,0)
C      CALL SETR(-1,,,)
C      CALL SETR(6,0,PRESET,ICCF1)
C      CALL LWAIT(ICCF1,0)
C      CALL RTS(IBUF,ISIZ,1,ISIZ,ISTCHN,1,IGAIN,MODE,ICMF,IBEF)
C      IF(ICMF.LT.0) STOP 'ERROR ICMF'
C      CALL LWAIT(ICMF,0)
C      IDUR(L)=ITRIG
C      CALL FILL
C      CALL LED(NCALL,'I6')
C      CALL SETR(-1,,,)
40   CONTINUE
C      TYPE 9040,ITRIG,ICHF,ICCF
9040  FORMAT(' ITRIG,HFLAG,CFLAG= ',3I7)
C      TYPE 9120
9120  FORMAT(' PULSES BETWEEN START AND STOP OF CLOCK ')
C      TYPE 9130,(IDUR(I),I=1,LIM)
9130  FORMAT(10I7)
C      IF(NCALL.EQ.0) GO TO 50
C      DO 45 I=1,ISIZ
C      IY(I)=IY(I)/NCALL
45   CONTINUE
50   RETURN
C      END
```

SUBROUTINE PUTBG

```
C
C      COMMON PRG
C      COMMON ELEMENT FOR DIODE ARRAY SAMPLING
C      RLG 5-JAN-77
C
C      COMMON IBUF(1786),IY(1786),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
C      1PRESET,LIM
C
C      PUTBG.PRG   RLG 5-JAN-77
C      STORES BACKGROUND DATA ON RK1 WITH SYSLIB CALLS
C
C      REAL*8 FLBK
C      CALL IRAD50(12,'RK1BG   DAT',FLBK)
C      IBLK=0
C      ICHAN=IGETC()
C      CALL IENTER(ICCHAN,FLBK,0)
C      CALL IWRTW(ISIZ,IY,IBLK,ICCHAN)
C      CALL CLOSEC(ICCHAN)
C      CALL IFREEC(ICCHAN)
C      RETURN
C      END
```

SUBROUTINE FILL

```
C
C      ADDS IBUF TO IY TO GET AVERAGE
C
C      COMMON IBUF(1786),IY(1786),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
C      1PRESET,LIM
C
C      DO 10 I=1,ISIZ
C      IY(I)=IY(I)+IBUF(I)
10  CONTINUE
C      NCALL=NCALL+1
C      IBEF=IBEF+1
C      RETURN
C      END
```

SUBROUTINE SAMPLE

```
      SUBROUTINE SAMPLE
C
C      COMMON.PRG
C      COMMON ELEMENT FOR DIODE ARRAY SAMPLING
C      RLG 5-JAN-77
C
      COMMON IBUF(1786),IY(1786),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
      1PRESET,LIM
C
      TYPE 9000
9000  FORMAT(' TURN ON ION BEAM AND PREPARE TO TAKE DATA  ')
      PAUSE 'CARRIAGE RETURN TO CONTINUE'
      CALL DATAKE
      CALL GETBKG
      RETURN
      END
```

SUBROUTINE GETBKG

```
      SUBROUTINE GETBKG
C
C      COMMON.PRG
C      COMMON ELEMENT FOR DIODE ARRAY SAMPLING
C      RLG 5-JAN-77
C
      COMMON IBUF(1786),IY(1786),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
      1PRESET,LIM
C
C      GETBKG.PRG RLG 5-JAN-77
C      READS BACKGROUND DATA FROM DISC, SUBTRACTS FROM IY
C      FOR USE IN DIODE ARRAY SAMPLING
C
      REAL*8 FLBK
      CALL IRAD50(12,'RK1BKG  DAT',FLBK)
      IBLK=0
      ICHAN=IGETC()
      CALL LOOKUP(ICHAN,FLBK)
      CALL IREADW(ISIZ,IBUF,IBLK,ICHAN)
      CALL CLOSEC(ICHAN)
      CALL IFREEC(ICHAN)
D      CALL CLRD(IBUF,ISIZ,IDEL,1,1)
D      CALL DIS(IBUF,IDEL,ISIZ,1,1)
D      PAUSE 'BKG.DAT ON SCOPE'
D      TYPE100,(IBUF(I),I=1,10)
D100  FORMAT(' ', 'FIRST 10 POINTS OF IBUF',/,10I7)
D      CALL SDIS
D      CALL DIS(IY,IDEL,ISIZ,1,1)
D      PAUSE 'CURRENT CONTENTS OF IY ON SCOPE'
D      TYPE 200,(IY(I),I=1,10)
D200  FORMAT(' ', 'FIRST 10 POINTS OF IY',/,10I7)
D      CALL SDIS
D      DO 250 I=1,ISIZ
      IY(I)=IBUF(I)-IY(I)
250   CONTINUE
D      CALL DIS(IY,IDEL,ISIZ,1,1)
D      PAUSE 'IBUF-IY ON SCOPE'
D      TYPE 300,(IY(I),I=1,10)
D300  FORMAT(' ', 'FIRST 10 POINTS OF DIFFERENCE',/,10I7)
D      CALL SDIS
      RETURN
      END
```

SUBROUTINE SHOW

```
C
C      COMMON.PRG
C      COMMON ELEMENT FOR DIODE ARRAY SAMPLING
C      RLG 5-JAN-77
C
C      COMMON IBUF(1786),IY(1786),IDUR(30),ISIZ,NCALL,ISTCHN,MODE
C      1PRESET,LIM
C
C      SHOW.PRG  RLG 5-JAN-77
C      DISPLAY ROUTINE FOR DIODE ARRAY SAMPLING
C
C      SCL=1.0
60      TYPE 9200
9200      FORMAT('$ INPUT NSTART,NPNTS')
ACCEPT 9070,NSTART,NPNTS
9070      FORMAT(2I6)
      IF(NSTART.EQ.0.AND.NPNTS.EQ.0) GO TO 3000
      GO TO 3010
3000      NSTART=1
      NPNTS=ISIZ
3010      CALL CLRD(IY,NPNTS,IDEL,SCL)
      TYPE 3020,NSTART,NPNTS,IDEL
3020      FORMAT(' DISPLAY START ',I4,' # SHOWN ',I4,' IDEL= ',I4)
      CALL DIS(IY,IDEL,NPNTS,NSTART,1)
      IF(NPNTS.LE.30) CALL PARSE(NSTART,NPNTS)
      PAUSE
      NSTART=0
      NPNTS=0
      CALL SDIS
      CALL LED(0,'IG')
      TYPE 9080
9080      FORMAT('$ TYPE 1. FOR DISPLAY CHANGE ')
ACCEPT 9090,Q
9090      FORMAT(F4.1)
      CALL SDIS
      IF(Q.EQ.1.) GO TO 60
      RETURN
      END
```

SUBROUTINE PARSE

```
      SUBROUTINE PARSE(NST,NPT)
C
C      TYPES OUT VALUES OF POINTS DISPLAYED.  MAX OF 30 POINTS.
C
      COMMON IBUF(1786),IY(1786),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
      1PRESET,LIM
C
      DIMENSION IX(30)
C
      DO 100 I=1,NPT
      L=(NST-1)+I
      IX(I)=IY(L)
100    CONTINUE
      TYPE 150, NST,L
150    FORMAT(' BUFFER CONTENTS FROM ',16,' TO ',16)
      TYPE 200, (IX(I),I=1,NPT)
200    FORMAT(10I7)
      RETURN
      END
```

SUBROUTINE DATRIT

```
      C
C      WRITES DATA ON SPECIFIED DEVICE FOR LATER USE.  OPTIONAL FILE NAME
C      RLG 6-JAN-77
C
      COMMON IBUF(1786),IY(1786),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
      1PRESET,LIM
C
      REAL*8 FLMS
      DIMENSION FLNAME(3)
      TYPE 10
10     FORMAT('$ ENTER FILE NAME,DEVNAM,___EXT ')
      ACCEPT 20, FLNAME
20     FORMAT(3A4)
      CALL IRADS0(12,FLNAME,FLMS)
      IBLK=0
      ICHAN=IGETC()
      CALL IENTER(ICCHAN,FLMS,0)
      CALL IWRTW(ISIZ,IY,IBLK,ICCHAN)
      CALL CLOSEC(ICCHAN)
      CALL IFREEC(ICCHAN)
      RETURN
      END
```

Program DIODE - Console Device Record

.R DIODE

DURATION MEASUREMENTS UNDER WAY

HISTOGRAM SAMPLING RESULTS.

DURATION 1.006 +/- 0.431E-03 SECONDS
SAMPLING RATE= 1774.725

SELECT SIZE,MODE, 1728,0

CHANNEL #,PRESET, NUMBER OF SCANS? 0,1755.0,10

TURN OFF ION BEAM
PAUSE -- CARRIAGE RETURN TO SAMPLE

ITRIG,HFLAG,CFLAG= 1280 -1 1
PULSES BETWEEN START AND STOP OF CLOCK
221 1279 1280 1280 1280 1279 1279 1280 1280 1280
TURN ON ION BEAM AND PREPARE TO TAKE DATA
PAUSE -- CARRIAGE RETURN TO CONTINUE

ITRIG,HFLAG,CFLAG= 1279 -1 1
PULSES BETWEEN START AND STOP OF CLOCK
1644 1280 1280 1280 1280 1280 1280 1280 1279 1279
INPT NSTART,NPTS

DISPLAY START 1 # SHOWN 1728 IDEL= 10
PAUSE --

TYPE 1. FOR DISPLAY CHANGE

ENTER FILE NAME,DEVNAM,EXT RK12BK629A01

TYPE 1.0 FOR ANOTHER RUN

STOP -- RUN COMPLETED

A.2 PROGRAM PKREAD

Program PKREAD retrieves data from the disk, draws a plot of the data on the Tektronix 4010 graphics terminal (TX), and uses the cross hairs on the terminal for reading the position of each side of a mass peak. These positions are then used as endpoints for finding the average maximum of each peak and performing a numerical integration between the limits defined by the endpoints. Computed values are then used to calculate abundance ratios and isotopic abundance of the recorded spectrum. Subroutine TXPLOT draws the plot of amplitude versus diode number on the Tektronix 4010. Subroutine AVMAX finds the maximum of each peak and calculates the average value of the maximum 5 points in the peak. Subroutine SUMIT performs the numerical integration using Simpson's one-third rule. Both AVMAX and SUMIT then calculate isotopic abundances and ratios and type results on the Console terminal.

TXPLOT is the first subroutine called by PKREAD. The routine first uses SYSLIB subroutines to fetch the TX handler and to identify and read the file to be plotted. The balance of the routine uses Device Independent Graphics (DIG) subroutines contained in the Battelle-Northwest library, BNWLIB.

After drawing and labeling the axes, a message from TXPLOT prompts the user to select the origin for the ordinate so that the data plot may be placed conveniently in the plotting field. After the plot has been drawn on the terminal the user is given the option of re-drawing the data at increased vertical expansion. This element was supplied to make extremely small peaks more visible on the plot and to permit better definition of the beginning and end points of the peak for cross-hair placement.

The next series of statements in PKREAD are required to read the positions of the cross-hair intersections of the Tektronix 4010 terminal. The FORTRAN direct read, established by the DEFINE FILE statement and the following READ statement, was found necessary for consistent reading of the cross-hair positions. Following the TX read, the received values are corrected

for offsets and scaling used in the plotting subroutine, TXPLOT, and pairs of limits are stored sequentially, the abscissa and ordinate value being stored in the arrays IDUR and IT, respectively.

Subsequent programming assumes that abscissa values for limits increase monotonically, with the last upper limit read the largest. Meaningless results are produced if this condition is not satisfied. Limits for up to 15 mass peaks can be stored for analysis in subroutines AVMAX and SUMIT.

Subroutine AVMAX is a straightforward FORTRAN routine using standard techniques and functions for finding the maximum of each mass peak. Lower and upper limits for the DO loops in the individual searches through segments of the buffer IBUF are passed to AVMAX via the array IDUR. The first loop finds the maximum and the second identifies the index of the maximum value and stores it in the array M1. The average value of 5 points at the peak, including the maximum, is then computed and stored in array Y. Next, the standard deviation of the 5 points is determined and placed in array STD. After writing these results on the console terminal the routine finds the largest peak and computes and prints the ratios with respect to that peak. Abundance values are calculated and printed prior to the RETURN to the main program.

Subroutine SUMIT differs from AVMAX in that numerical integration over peak heights is used to determine isotopic ratios and abundances. The integration uses Simpson's rule in the form:

$$f(x)dx = (h/3) f_0 + 4 (f_1 + f_3 + \dots + f_{n-1}) + 2(f_2 + f_4 + \dots + f_{n-2}) + f_n , \quad (1)$$

where the notation $f(x_i) = f_i$ has been used. The uniform interval has the value unity. The integral over the base line is calculated in closed form and stored in the variable BINT. After integrating is completed, the integral with respect to the origin is stored in array X, the base line integral is

subtracted and the result stored in array BX. The results of the integration are typed on the console, and calculation of ratios and abundances proceeds as in AVMAX.

In both routines the variable LUP is used to sense completion of initial operations. For example, in SUMIT, after the integration is completed the result is stored in array X and LUP is incremented by 2. This is compared to the last upper limit contained in IDUR, and if it exceeds that value, the integration results are typed and the remaining calculations performed. The index L is incremented prior to the test and once more at the start of the test so that the variable LO will always correspond to the lower integration limit.

A listing of the program and an example of the output produced are shown in the following.

Program PKREAD

```
C--PROGRAM PKREAD.FOR, PLACES TX READ IN MAIN PROGRAM.
C RLG 26-APR-77, PROGRAM INTEGRATES, FINDS AVERAGE PEAK HEIGHT.
C      COMMON PRG
C      COMMON ELEMENT FOR DIODE ARRAY SAMPLING
C      RLG 5-JAN-77
C
C      COMMON IPUF(1786),IY(30),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
C      1PRESET,LIM,ORG
C
C--READ COORDINATES OFF OF PLOT USING TX CROSS HAIRS
C
1000  CALL TXPLOT
      I=0
      LIM=0
      TYPE 313
313   FORMAT(' TYPE A ON TX FOR LAST POINT OF FINAL PAIR',//)
310   CONTINUE
      I=I+1
      LIM=I/2
      CALL ASSIGN(S,'TX:',0,'OLD','NC',0)
      DEFINE FILE 8 (1,10,U,MODE)
      READ(8'1,ERR=1200) ICHAR,U,V
      CALL CLOSE(8)
      TYPE 315,ICHAR,U,V
315   FORMAT(' ICHAR,FLOAT(U,V) ',17,2F8.4)
C
C--CONVERT COORDINATES TO INTEGERS
C
      FCT=10./FLOAT(ISIZ)
      IU=IDIX((U-0.5)/FCT)
      IV=IFIX(2048.*(V-ORG)/(PRESET*7.))
      IDUR(I)=IU
      IY(I)=IV
      TYPE 320,IU,IV
320   FORMAT(' DIODE #= ',17,' VALUE= ',17,//)
      IF(ICHAR.EQ.65) GO TO 330
      GO TO 310
C--OPTION.PR.G.  OPTION FOR SWITCHING BACK TO START OF PROGRAM
C      RLG 13-JAN-77
330   CONTINUE
      CALL AVMAX
      CALL SUMIT
      TYPE 10
10    FORMAT('$ TYPE 1.0 FOR A DIFFERENT PLOT ')
      ACCEPT 20,Q
20    FORMAT(F6.2)
      IF(Q.EQ.1.0)GO TO 1000
      GO TO 1300
1200  WRITE(6,1250)
1250  FORMAT(' CANNOT READ THIS WAY')
1300  STOP 'PLOTING COMPLETED'
      END
```

SUBROUTINE TXPLOT

```
      SUBROUTINE TXPLOT
C      COMMON.PRG
C      COMMON ELEMENT FOR DIODE ARRAY SAMPLING
C      RLG 5-JAN-77
C
      COMMON IBUF(1786),IY(30),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
      1PRESET,LIM,ORG
C
C      TXPLOT.PRG, BASIC PLOTTING ELEMENT FOR PLOTTING ON TX
C      RLG 6-JAN-77
C      SLIGHT CHANGES IN STATEMENTS PERMIT PLOTTING ON GP
C
      REAL*8 FLTXX              !TX=CGP FOR GP PLOT
      REAL*8 DATFL              !DATA FILE NAME RECEIVER
      REAL*4 IDNAM
      DIMENSION FLNAME(3)
      DATA IDNAM/3RTX0/
      CALL IFETCH(IDNAM)
      GO TO 1000
1110  TYPE 1111,FLNAME
1111  FORMAT(' BAD LOOKUP, NAME= ',3A4)
1000  TYPE 1000
100  FORMAT('$ INPUT FILE NAME,DEVNAM___EXT ')
      ACCEPT 150,FLNAME
150  FORMAT(3A4)
      TYPE 200
200  FORMAT('$ INPUT ISIZ ')
      ACCEPT 225, ISIZ
225  FORMAT(I6)
      CALL IRADS0(12,FLNAME,DATFL)
      ICHAN=IGETC()
      LOK=LOOKUP(ICHAN,DATFL)
      IF(LOK.LT.0) GO TO 1110
      IBLK=0
      CALL IREADW(ISIZ,IBUF,IBLK,ICHAN)
      CALL 'CLOSEC(ICHAN)
      CALL IFREEC(ICHAN)
      CALL IRADS0(12,'TX0',FLTXX)
      CALL IENTER(10,FLTXX,0)
      CALL PLOTS(0,0,10)
      CALL NEWPAG
C
C      DRAW AXES
C
      CALL PLOT(0.5,0.5,3)
      CALL PLOT(0.5,7.5,2)
      CALL PLOT(10.5,7.5,2)
      CALL PLOT(10.5,0.5,2)
      CALL PLOT(0.5,0.5,2)
      CALL PLOT(0.5,4.0,3)
      CALL PLOT(10.5,4.0,2)
      CALL PLOT(0.5,0.5,3)
C
C      GO TO ORIGIN
C
C---DRAW TIC MARKS
C
      Z=0.7
      DO 2000 I=1,9
```

SUBROUTINE TXPLOT (contd)

```

      Y=0.5+Z*FLOAT(I)
      CALL PLOT(0.5,Y,3)
      CALL PLOT(0.9,Y,2)
      CALL PLOT(10.1,Y,3)
      CALL PLOT(10.5,Y,2)
2000  CONTINUE
      Z=10./16.
      DO 2100 I=1,15
      X=0.5+Z*FLOAT(I)
      CALL PLOT(X,0.5,3)
      CALL PLOT(X,0.9,2)
      CALL PLOT(X,7.1,3)
      CALL PLOT(X,7.5,2)
2100  CONTINUE
C
      CALL SYMBOL(6.4,1.5,0.3,FLNAME)
      CALL PLOT(0.5,4.0,3)          !GO TO ORIGIN
C
C--LABEL TICS
C
      Y=1.
      X=0.5
      DO 2200 I=1,17,2
      CALL NUMBER(X,0.2,0.15,Y,0.0,-1)
      X=0.43+Z*FLOAT(I)
      Y=108.*FLOAT(I)
2200  CONTINUE
      Z=0.7
      X=-1.0
      Y=0.5
      DO 2300 I=1,11
      CALL NUMBER(0.05,Y,0.15,X,0.0,1)
      X=-1.+0.2*FLOAT(I)
      Y=0.5+Z*FLOAT(I)
2300  CONTINUE
C
C  PLOT DATA, NORMALIZE ABSCISSA TO ISIZ
C
      TYPE 8100
8100  FORMAT(' $ ORIGIN FOR ORDINATE? ')
      ACCEPT 8150, ORG
8150  FORMAT(F8.0)
C
C
      Q=1.0
      GO TO 3200
3100  CALL PLOTS(0.,0.,10)
3200  CALL PLOT(0.5,4.0,3)
      JY=0
      FCT=10./FLOAT(ISIZ)
      DO 300 I=1,ISIZ
      JY=JY+1
      X=FLOAT(JY)*FCT+0.5
      Y= Q*(FLOAT(IBUF(I))/2048.0)*7.0 +ORG
      CALL PLOT(X,Y,2)
300  CONTINUE
      CALL PLOT(0.5,0.5,3)
      CALL PLOTND

```

SUBROUTINE TXPLOT (contd)

```
      PRESET=0  
      TYPE 2400  
2400    FORMAT('#VERTICAL EXPANSION?')  
      ACCEPT 2450, Q  
2450    FORMAT(FS 0)  
      IF(Q.EQ.0) GO TO 3000  
      GO TO 3100  
      CALL CLOSED(10)  
3000    RETURN  
      END
```

SUBROUTINE AVMAX

```
      SUBROUTINE AVMAX
      C
      C---FINDS AVERAGE MAX OF MASS PEAK FROM PHOTODIODE ARRAY. RLG 31-MAY-77
      C
      COMMON IBUF(1736),IY(30),IDUR(30),ISTD,NCALL,ISTCHN,MODE,
      1SFRESET,LIM,ORG
      C
      DIMENSION Y(15),STD(15),M1(15)
      CALL ASSIGNUS,'TT',1)
      L=0
      K=0
100    CONTINUE
      L=L+1
      K=K+1
      LO=IDUR(L)
      LUP=IDUR(L+1)
      C
      C---FIND MAX OF EACH PEAK
      C
      YMAX=FLOAT(IBUF(LO))
      DO 300 J=LO,LUP
      BUF=IBUF(J)
      Z=AMAX1(YMAX,BUF)
      YMAX=Z
300    CONTINUE
      DO 325 J=LO,LUP
      BUF=IBUF(J)
      IF(YMAX.EQ.BUF) M1(K)=J
325    CONTINUE
      SPK=0.0
      N1=M1(K)-2
      N2=M1(K)+2
      DO 650 J=N1,N2
      SPK=SPK+IBUF(J)
650    CONTINUE
      Y(K)=SPK/5.0
      SQA=0.0
      DO 675 J=N1,N2
      BUF=IBUF(J)
      SQA=SQA+(Y(K)-BUF)**2
675    CONTINUE
      STD(K)=SQRT(SQA/3.)
      L=L+1
      LUP=LUP+2
      NOP=2*K*LIM
      IF(LUP.GT.IDUR(NOP)) GO TO 685
      GO TO 100
685    WRITE(6,700)
700    FORMAT(' ',//,' *****MAXIMAX*****',//)
      WRITE(6,40) (M1(I),I=1,LIM)
40    FORMAT(5I14)
      WRITE(6,20) (Y(K),K=1,LIM)
      WRITE(6,710)
710    FORMAT(' ',//,' *****DEVIATIONS*****',//)
      WRITE(6,20) (STD(K),K=1,LIM)
      Z=Y(1)
      DO 725 I=1,LIM
```


SUBROUTINE AVMAX (contd)

```
      YMAX=HIGHAL(4) * 1.77
      Z=YMAX
725    CONTINUE
      DO 750 I=1,LIM
      Y(I)=Y(I)/YMAX
750    CONTINUE
      WRITE(6,30)
      WRITE(6,20)(Y(I),I=1,LIM)
      SUM=0.0
      DO 775 I=1,LIM
      SUM=SUM+Y(I)
775    CONTINUE
      DO 800 I=1,LIM
      Y(I)=Y(I)/SUM
800    CONTINUE
      WRITE(6,550)
      WRITE(6,20)(Y(I),I=1,LIM)
C
30    FORMAT(5G14.5)
30    FORMAT(' ',//,' *** RATIOS *** ',//)
550   FORMAT(' ',//,' **** ABUNDANCES ****',//)
      CALL CLOSE(6)
      RETURN
      END
```

SUBROUTINE SUMIT

```

C
C--INTEGRATES OVER MASS PEAK FROM PHOTODIODE ARRAY.  RLG 14-APR-78
C
C      BETTER TECHNIQUE FOR REMOVING BASELINE.  PRINTS BOTH INTEGRALS.
C      FOR USE WITH PROGRAM PKREAD.
C--STORED AS FILE BASINT.FOR
C
      COMMON IBUF(1786),IY(30),IDUR(30),ISIZ,NCALL,ISTCHN,MODE,
      IPRESET,LIM,ORG
C
      DIMENSION X(15),BX(15)
      CALL ASSIGN(6,'TT: ')
      L=0
      K=0
100    CONTINUE
      L=L+1
      K=K+1
      LO=IDUR(L)
      LUP=IDUR(L+1)
C
C--REMOVE BASELINE VARIATIONS FROM Ibuff
C
      A=FLOAT(IY(L)-IY(L+1))/FLOAT(LO-LUP)
      B=FLOAT(IY(L))-A*FLOAT(LO)
      BINT=FLOAT(LUP-LO)*(A*FLOAT(LUP+LO)/2.+B)
C
C--HAVE SET LIMITS.  NOW INTEGRATE
C
      SUM=FLOAT(IBUF(LO-1)+IBUF(LUP))/3.
      DO 150 I=LO,LUP,2.
      SUM=SUM+4.*FLOAT(IBUF(I))/3.
150    CONTINUE
      LOT=LO+1
      DO 200 I=LOT,LUP,2
      SUM=SUM+2.*FLOAT(IBUF(I))/3.
200    CONTINUE
C
C--INTEGRATION COMPLETED
C
      X(K)=SUM
      BX(K)=SUM-BINT
      L=L+1
      LUP=LUP+2
      NOP=2*KLIM
      IF(LUP.GT.IDUR(NOP)) GO TO 300
      GO TO 100
300    WRITE(6,10)
10     FORMAT(' ',//,' INTEGRAL VALUES, TOTAL THEN LESS BASE  ')
      WRITE(6,20) (X(I),I=1,LIM)
      WRITE(6,20) (BX(I),I=1,LIM)
20     FORMAT(5G14.5)
      S=X(1)
      Q=BX(1)
      DO 320 I=1,LIM
      PMAX=AMAX1(S,X(I))
      QMAX=AMAX1(Q,BX(I))
```

SUBROUTINE SUMIT (contd)

```
      S=PMAX
      Q=PMAX
      400  CONTINUE
            DO 350 I=1,LIM
              X(I)=X(I)/PMAX
              BX(I)=BX(I)/PMAX
      350  CONTINUE
            WRITE(6,20)
      20   FORMAT('  ',//,' *** RATIOS *** ',//)
            WRITE(6,20) (X(I),I=1,LIM)
            WRITE(6,20) (BX(I),I=1,LIM)
            S=0.0
            Q=0.0
            DO 500 I=1,LIM
              S=S+X(I)
              Q=Q+BX(I)
      500  CONTINUE
            DO 525 I=1,LIM
              NX(I)=X(I)/S
              BX(I)=BX(I)/Q
      525  CONTINUE
            WRITE(6,550)
      550  FORMAT('  ',//,' **** ABUNDANCES **** ',//)
            WRITE(6,20) (X(I),I=1,LIM)
            WRITE(6,20) (BX(I),I=1,LIM)
            CALL CLOSE(6)
            RETURN
            END
```

PKREAD Output

Some explanation of the output from program PKREAD is warranted. The first five messages come from TXPLOT and require user response. In this example file RG25A.003 from disk RKO was read. The file has 1728 words. The ordinate origin of 4.0 in. places the plotted data in the center of the plot field on the TX. After plotting the data as read, the data were re-plotted with twice the amplitude. A vertical expansion of 0. caused return to the main program. Upon return to the main program, the cross hairs are displayed on the TX terminal and adjusted by the user. A read is performed when any key on the TX is typed. Typing "A" terminates the reading session.

Two lines of output are produced for each read. The first line displays the variables ICHAR, U and V. The latter two variables represent the coordinates of the cross-hair intersection from the origin of the TX. The variable ICHAR is the decimal equivalent of the ASCII octal code for the character typed. The next line of output contains the integer values corresponding to the coordinates (U,V) adjusted for the origin of the plot axes. In the example shown, 5 peaks were read prior to analysis by AVMAX and SUMIT.

Results of analyses follow the record of the TX read. The first line of output displays the buffer position at which a maximum occurred and this is followed by the average maximum value. The balance of the output is self explanatory.

Program PKREAD - TX Read Record

5 PKREAD

INPUT FILE NAME,DEVNAM.....EXT RK00005A 003

INPUT ISIZ 1726

ORIGIN FOR ORDINATE? 4.

VERTICAL EXPANSION? 0.

TYPE A ON TX FOR LAST POINT OF FINAL PAIR

ICHA	R,FLOAT(U,V)	49	2.3472	4.1474
DIODE #=	319	VALUE=	43	

ICHA	R,FLOAT(U,V)	49	3.0000	4.1368
DIODE #=	432	VALUE=	40	

ICHA	R,FLOAT(U,V)	50	4.1789	4.1158
DIODE #=	635	VALUE=	33	

ICHA	R,FLOAT(U,V)	50	4.0526	4.1158
DIODE #=	752	VALUE=	33	

ICHA	R,FLOAT(U,V)	51	6.0313	4.1579
DIODE #=	955	VALUE=	46	

ICHA	R,FLOAT(U,V)	51	6.6313	4.1368
DIODE #=	1059	VALUE=	40	

ICHA	R,FLOAT(U,V)	52	7.6532	4.1695
DIODE #=	1237	VALUE=	55	

ICHA	R,FLOAT(U,V)	52	8.3368	4.1474
DIODE #=	1354	VALUE=	43	

ICHA	R,FLOAT(U,V)	53	9.4211	4.0526
DIODE #=	1541	VALUE=	15	

ICHA	R,FLOAT(U,V)	65	9.9265	4.0421
DIODE #=	1628	VALUE=	12	

Program - TX Read Record (contd)

*****MAXIMA*****

377	701	1021	1337	1593
246.00	93.400	153.00	235.40	33.000

*****DEVIATIONS*****

4.6904	3.3267	3.7417	3.8816	2.4495
--------	--------	--------	--------	--------

*** RATIOS ***

0.73345	0.27847	0.45617	1.0000	0.11330
---------	---------	---------	--------	---------

**** ABUNDANCES ****

0.28413	0.10788	0.17672	0.38739	0.43890E-01
---------	---------	---------	---------	-------------

INTEGRAL VALUES, TOTAL THEN LESS BASE

16850.	7522.7	11137.	22344.	2839.0
12161.	3661.7	6664.7	16611.	1664.5

*** RATIOS ***

0.75412	0.33667	0.49842	1.0000	0.12706
0.73208	0.22044	0.40122	1.0000	0.10020

**** ABUNDANCES ****

0.27763	0.12395	0.18349	0.36815	0.46777E-01
0.29833	0.89930E-01	0.16350	0.40751	0.40834E-01

TYPE 1.0 FOR A DIFFERENT PLOT

STOP -- PLOTTING COMPLETED

A.3 PROGRAM GLDPLT

Program GLDPLT uses a Gould 5000 printer/plotter (GP) to produce hard copy of data taken by program DIODE. The file specified in FLNAME containing ISIZ words is read using SYSLIB routines. The program then writes a plot file, PLOT00.DIG, on disk RK0, writes the contents of the input buffer IBUF on the GP in integer form, and finally chains to program DIDOT to translate the plot file on the disk to a hard copy plot on the GP. DIDOT then chains back to GLDPLT so that another file can be read and processed without returning to the monitor. To insure proper operation of the chain, the monitor command ".SET USR NO SWAP", must be issued prior to running GLDPLT.

Initialization for the program includes calls to IFETCH to load necessary device handlers. These calls are not required for program operation. They were inserted prior to learning that the SET USR NO SWAP command allowed correct operation of the chain procedure and were never removed. The same is true of the ASSIGN command which allocated channel 5 to the terminal.

The commands necessary to read the data are identical to those in TXPLOT except for the case when dark signal data are to be processed. The file containing that data is always named BKG.DAT and always contains values as recorded in program DIODE. Data are recorded on a +/- 1 volt ADC with the value 2048 being produced for zero input voltage. The plots of background data would therefore be nearly full-scale on the paper since the output of the CCD under dark conditions is always a small negative voltage. Consequently, in case the file name has the suffix DAT, that file is subtracted from 2048 before writing and plotting. The other files are only scaled in the plotting routine since they were sent to the disk file as positive numbers by program DIODE.

The plotting routine in GLDPLT is similar to that in TXPLOT, the major difference being that the axes drawn on GP are rotated 90° with respect to those on the TX. Both plotting routines draw a 9 in. x 6.5 in. frame for plotting.

Data are written in 16 columns, labeled 1 through 16. Sampling of a full array therefore causes 108 lines of numerical output for the 1728 diodes in the array.

Program DIODOT is an element of the Pacific Northwest Laboratory (PNL) Device Independent Graphics Package. This program converts the plot file written on the disk in floating point to dot mode and transfers the dot mode output to the electrostatic printer/plotter.

A listing of GLDPLT and an example of its output are shown in the following. In the example, two copies of the desired output are obtained. Only one is shown.

Program GLDPLT

```
C      PROGRAM GLDPLT.FOR
C--PLOTS ON GP, RLG, 20-JAN-77, PRINTS DATA ON GOULD
C      COMMON.PRG
C      COMMON ELEMENT FOR DIODE ARRAY SAMPLING
C      RLG 5-JAN-77
C
      COMMON IBUF(1786),IDUR(50),ISIZ,NCALL,ISTCHN,MODE,
      1PRESET,LIM,FLNAME(3)
      LOGICAL*1 DUR(100)
      EQUIVALENCE(IDUR,DUR)
C
C      TXPLOT.PRG, BASIC PLOTTING ELEMENT FOR PLOTTING ON TX
C--CHANGED TO PLOTTING ROUTINE FOR GP:, 20-JAN-77,RLG
C      RLG 6-JAN-77
C      SLIGHT CHANGES IN STATEMENTS PERMIT PLOTTING ON GP
C
      REAL*8 FLGP              !TX=CGP FOR GP PLOT
      REAL*8 DATFL
      REAL*8 BKGFL
      REAL*4 IDNAM
      REAL*4 IDTT
      DATA IDNAM/3RGPO/,FID//,DAT//,IDTT/3RTT0/
C      IF(ICDFN(18).NE.0) STOP 'CANNOT DEFINE CHANNELS'
      CALL IFETCH(IDNAM)
      CALL IFETCH(IDTT)
      CALL IRAD50(12,'RK0BKG  DAT',BKGFL)
      CALL ASSIGN(5,'TT: ')
      GO TO 90
50      WRITE(5,400) FLNAME
400      FORMAT(' BAD LOOKUP, NAME= ',4A3)
90      WRITE(5,100)          !DATA FILE NAME RECEIVER
100      FORMAT('$ INPUT FILE NAME,DEVNAM,____EXT ')
      ACCEPT 150,FLNAME
150      FORMAT(3A4)
      WRITE(5,200)
200      FORMAT('$ INPUT ISIZ ')
      ACCEPT 221, ISIZ
221      FORMAT(I6)
      CALL IRAD50(12,FLNAME,DATFL)
      ICHAN=IGETC()
      IF(LOOKUP(ICHAN,DATFL).LT.0) GO TO 50
      IBLK=0              !FOR 1728 POINTS
      CALL IREADW(ISIZ,IBUF,IBLK,ICHAN)
      CALL CLOSEC(ICHAN)
      CALL IFREEC(ICHAN)
D      WRITE(5,9000) FLNAME(3),FID
D9000      FORMAT(' FLNAME(3)= ',A4,' FID= ',A4)
      CALL CLOSE(5)
      IF(FLNAME(3).EQ.FID) GO TO 450
      GO TO 520
450      DO 500 I=1,ISIZ
      IBUF(I)=2048-IBUF(I)
500      CONTINUE
520      CONTINUE
      CALL IRAD50(12,'RK0PLOT00DIG',FLGP)
      ICHAN=IGETC()
```

Program GLDPLT (contd)

```
      CALL ENTER(ICHAN,FLGP,0)
      CALL PLOTS(0.,0.,ICHAN)
C
C   DRAW AXES
C
      CALL PLOT(0.5,1.0,3)
      CALL PLOT(7.0,1.0,2)
      CALL PLOT(7.0,10.0,2)
      CALL PLOT(0.5,10.0,2)
      CALL PLOT(0.5,1.0,2)
      CALL PLOT(7.0,1.0,3)                !GO TO ORIGIN
C
C   PLOT DATA, NORMALIZE ABSCISSA TO ISIZ
C
      JY=0
      FCT=9.0/FLOAT(ISIZ)
      DO 300 I=1,ISIZ
        JY=JY+1
        Y=FLOAT(JY)*FCT+1.0
        X=7.0-(FLOAT(IBUF(I))/2048.)*6.5
        CALL PLOT(X,Y,2)
300    CONTINUE
C
C--DRAW TICS
C
      Y1=1.0
      Z=0.65
      DO 2010 I=1,2
        DO 2000 J=1,9
          X=7.0-Z*FLOAT(J)
          Y=Y1+0.36
          CALL PLOT(X,Y1,3)
          CALL PLOT(X,Y,2)
2000    CONTINUE
          Y1=9.64
2010    CONTINUE
          Z=9./16.
          X1=0.5
          DO 2110 I=1,2
            DO 2100 J=1,15
              Y=1.0+Z*FLOAT(J)
              X=X1+0.36
              CALL PLOT(X1,Y,3)
              CALL PLOT(X,Y,2)
2100    CONTINUE
              X1=6.64
2110    CONTINUE
C
C--LABEL TICS
C
      Z=9./16.
      Y=1.
      X=1.
      DO 2200 I=1,17,2
        CALL NUMBER(7.3,X,0.15,Y,90.,-1)
        X=0.74+Z*FLOAT(I)
        Y=108.*FLOAT(I)
2200    CONTINUE
```

Program GLDPLT (contd)

```

      Z=0.65
      X=0.0
      Y=7.0
      DO 2300 I=1,11
      CALL NUMBER(Y,0.56,0.15,X,90.,1)
      X=0.1*FLOAT(I)
      Y=7.0-Z*FLOAT(I)
2300  CONTINUE
C
C---IDENTIFY AXES, LABEL PLOT
C
      CALL SYMBOL(0.4,6.0,0.25,FLNAME,90.,12)      !PLOT ID
      CALL SYMBOL(7.7,4.21,0.25,'DIODE NUMBER',90.) !ABSCISSA
      CALL SYMBOL(5.04,0.48,0.25,'OUTPUT,VOLTS',180,0,12) !ORDINATE
C
      CALL PLOTND
      CALL CLOSEC(ICHAN)
      CALL IFREEC(ICHAN)
      CALL ASSIGN(6,'GP: ','0','NEW','CC')
      WRITE(6,305) (FLNAME(I),I=1,3)
305  FORMAT(' DATA FOR FILE ',3A4)
      WRITE(6,600) (I,I=1,16)
600  FORMAT(1X,'DIODE#',2X,16I6)
      LO=1
      LUP=16
1200  WRITE(6,650) LO,(1BUF(I),I=LO,LUP)
650  FORMAT(1X,16,3X,16I6)
      LO=LO+16
      LUP=LUP+16
      IF(161Z-LUP) 1300,1200,1200
1300  WRITE(6,700)
700  FORMAT(1H1)
      CALL CLOSE(6)
C
C---TRANSFER TO DIDOT TO PRINT PLOT ON GP:
C
      IDUR(1)=1
      J=(6*2)-1
      CALL STRING(DUR,J,'RK0:GLDPLT')
      CALL STRING(DUR,J,0)
      J=(16*2)-1
      CALL STRING(DUR,J,'GP:/P:15=RK0:PLOT00')
      CALL STRING(DUR,J,0)
      CALL BCHAIN('DIDOT.SAV',IDUR)
      STOP 'THIS JOB FINISHED'
      END

```

Program GLDPLT - Read Record

P. GLDPLT
INPUT FILE NAME,DEVNAM,EXT RKORGEA 003
INPUT ISIZ 1728
INPUT FILE NAME,DEVNAM,EXT RKORGEA 003
INPUT ISIZ 1728
INPUT FILE NAME,DEVNAM,EXT TC

DATA FOR FILE RKORG25A 003

DIODE#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	-1	-1	-1	-1	0	-1	0	0	-1	-1	0	0	-3	-4	20	18
17	16	15	14	16	17	17	21	18	24	18	17	19	19	20	17	18
33	17	15	18	18	17	16	19	16	20	15	17	18	15	17	18	20
49	18	18	22	16	19	21	16	19	19	15	17	21	16	19	14	21
65	15	17	17	18	18	17	18	15	21	22	13	18	20	21	20	18
81	19	17	17	19	20	21	18	15	18	20	21	19	19	19	22	18
97	18	19	19	20	16	19	16	18	17	18	20	17	21	17	18	16
113	21	21	18	19	23	21	24	23	22	20	22	17	18	22	22	20
129	22	20	19	22	23	25	20	20	24	19	22	14	18	17	22	22
145	23	22	24	26	21	20	26	25	26	24	25	24	22	22	22	22
161	22	18	22	27	26	25	26	27	28	29	29	18	27	31	25	25
177	24	26	24	27	28	24	30	29	25	30	27	28	29	29	28	31
193	29	28	29	26	28	28	26	28	30	31	24	25	31	29	28	27
209	29	26	30	25	30	28	28	30	28	32	31	33	32	30	33	28
225	26	29	32	29	34	33	30	33	31	32	30	27	26	29	31	31
241	35	30	29	31	31	32	31	31	29	31	33	31	31	30	30	30
257	31	29	28	30	30	30	32	32	30	31	28	33	31	31	34	31
273	36	33	33	29	33	34	30	33	32	36	33	33	34	33	35	34
289	36	37	40	33	37	36	37	37	40	37	41	40	38	40	39	38
305	40	42	40	44	43	42	43	46	46	45	45	42	46	47	44	45
321	51	46	52	49	53	54	61	65	68	66	77	75	80	83	89	87
337	101	103	107	111	123	125	133	133	143	146	158	154	167	172	177	176
353	192	189	195	197	209	207	212	210	224	221	233	229	237	231	239	234
369	243	239	245	241	250	233	249	242	251	242	246	242	246	235	238	224
385	231	221	224	213	218	213	212	202	205	192	195	184	183	175	171	164
401	160	151	152	143	135	129	129	122	118	115	110	99	99	92	87	81
417	76	71	72	66	67	66	59	57	57	50	48	46	45	43	42	43
433	46	44	43	39	40	39	38	38	38	43	36	39	39	38	38	36
449	34	33	35	37	38	39	35	36	42	38	36	36	39	34	35	36
465	36	33	37	37	36	35	32	34	36	36	36	33	35	31	36	34
481	32	35	35	35	33	32	33	36	34	32	35	36	35	35	36	35
497	30	31	33	31	34	33	33	30	35	35	30	34	32	33	31	33
513	31	35	36	38	34	35	34	37	38	38	37	33	32	31	33	37
529	36	35	28	33	34	33	34	33	34	37	33	33	34	35	33	33
545	34	38	35	36	31	32	32	30	39	32	32	31	30	34	29	32
561	36	34	31	30	29	32	33	31	31	33	36	36	33	36	32	31
577	35	34	32	32	31	32	32	28	31	31	32	33	33	34	37	31
593	35	33	29	32	31	30	29	27	35	31	32	33	35	33	35	34
609	35	28	31	31	36	32	34	34	32	34	36	32	34	31	36	35
625	38	39	36	32	36	32	37	36	33	38	37	37	39	37	34	34
641	37	34	33	37	37	34	33	36	37	39	39	47	42	42	43	44
657	49	50	47	47	52	52	57	58	58	64	61	66	70	67	69	68
673	72	75	74	75	79	76	81	78	83	87	89	94	89	90	95	88
689	91	89	91	92	95	93	92	91	90	91	94	93	98	91	91	91
705	89	85	93	86	90	84	89	85	85	77	83	78	75	72	80	74
721	74	71	71	63	69	65	64	57	58	56	58	51	52	52	53	46
737	46	42	46	42	38	39	37	37	36	39	34	37	39	37	34	34
753	36	36	35	32	34	35	34	31	33	30	35	35	33	30	32	31
769	34	30	30	33	32	36	35	30	35	30	31	31	36	33	37	36
785	36	29	27	30	33	35	32	31	33	32	36	33	36	31	32	30
801	33	29	35	30	30	34	30	30	34	29	33	36	37	34	34	31
817	37	35	32	35	39	38	33	32	35	33	29	32	33	32	37	38
833	30	31	36	29	31	28	38	38	31	30	35	36	35	35	34	32

Program GLDPLT - Data Output Example (contd)

865	39	37	36	37	40	41	42	35	36	39	38	36	34	37	43	36
881	40	41	37	38	36	39	41	39	37	40	40	43	40	40	41	41
897	42	39	36	40	35	38	38	44	39	37	41	40	39	41	40	43
913	42	43	40	40	42	45	38	42	42	39	39	41	39	39	41	41
929	38	39	46	42	40	42	40	40	41	39	39	42	44	46	48	43
945	46	46	41	43	46	44	45	45	46	44	44	49	46	53	51	47
961	48	49	53	53	57	57	60	56	58	61	59	65	70	68	74	73
977	79	78	84	86	90	93	95	101	99	104	106	109	115	112	117	121
993	126	127	134	129	136	136	140	141	141	140	146	145	154	148	156	151
1009	150	149	153	149	155	151	155	153	155	155	154	153	157	148	153	149
1025	155	146	148	138	138	137	137	131	132	124	126	120	120	114	116	110
1041	105	99	98	93	93	82	86	75	79	73	72	68	64	62	63	59
1057	53	48	54	50	53	46	49	48	48	44	46	47	40	46	46	44
1073	47	43	46	47	44	42	44	43	46	45	63	46	42	48	45	47
1089	42	45	47	45	45	47	51	45	49	45	42	48	46	44	44	48
1105	48	46	46	45	44	44	48	47	51	49	48	48	51	51	47	47
1121	48	48	50	50	50	50	50	52	49	52	52	47	41	48	49	48
1137	50	50	55	49	46	51	54	51	49	53	47	54	52	46	51	50
1153	55	48	50	56	51	50	52	54	52	54	53	52	52	48	55	50
1169	53	50	50	50	48	46	49	50	49	49	48	51	49	47	46	51
1185	51	50	51	45	45	48	49	53	49	51	55	48	48	48	47	47
1201	50	50	49	50	54	46	46	51	48	51	53	48	52	52	48	49
1217	49	53	55	53	52	54	55	59	55	53	55	57	53	54	56	58
1233	59	60	59	61	60	61	61	61	64	61	65	68	68	65	72	72
1249	77	80	82	86	91	92	99	104	115	112	124	125	134	137	143	147
1265	155	157	172	170	184	183	195	199	209	205	219	224	242	235	248	248
1281	261	258	271	265	285	281	293	286	301	296	311	306	316	310	326	321
1297	333	324	339	327	333	329	334	335	340	331	337	322	332	323	325	309
1313	311	305	306	290	287	269	272	256	254	236	240	220	216	198	198	183
1329	181	168	162	147	139	133	122	115	108	97	96	89	84	78	73	71
1345	68	63	61	59	56	54	53	52	51	45	46	45	47	48	43	39
1361	44	49	48	43	46	45	39	44	36	41	43	38	41	35	42	39
1377	39	39	38	38	42	37	36	37	40	37	36	35	36	39	35	31
1393	33	31	35	35	35	35	36	28	32	34	35	35	36	34	34	30
1409	34	32	32	31	33	31	33	34	27	33	36	31	34	33	31	29
1425	33	32	32	33	29	32	30	31	31	27	30	28	29	33	30	28
1441	31	28	29	31	29	27	32	29	27	32	33	29	31	29	26	28
1457	28	25	29	27	33	28	30	31	27	26	27	26	25	30	29	28
1473	23	26	27	29	27	27	24	27	25	27	26	27	25	25	27	25
1489	24	29	26	26	26	25	23	20	24	23	27	25	19	21	27	28
1505	23	21	25	24	26	25	23	28	22	25	21	24	22	24	20	22
1521	24	21	24	25	25	24	22	25	24	22	27	26	23	26	27	19
1537	22	24	25	25	27	27	26	28	22	24	29	27	25	26	27	24
1553	26	28	32	32	32	30	29	34	31	34	37	34	36	36	34	33
1569	37	36	34	35	33	36	37	35	36	38	38	38	38	40	41	39
1585	38	37	36	38	41	36	39	38	41	36	36	37	40	40	39	38
1601	35	36	39	34	31	33	33	33	31	28	30	29	30	26	29	24
1617	26	19	26	21	24	26	22	24	23	25	21	20	16	20	17	17
1633	16	19	20	17	15	16	15	15	16	18	18	14	18	19	14	16
1649	16	12	15	11	14	16	14	16	14	14	13	11	11	11	11	13
1665	15	14	12	11	12	15	12	9	9	12	14	13	14	8	10	7
1681	12	7	8	6	10	6	12	5	8	8	7	9	10	6	10	9
1697	8	10	6	12	8	11	12	10	6	7	8	11	9	10	8	5
1713	6	9	6	7	8	9	9	9	7	12	9	10	5	7	12	11

Program GLDPLT - Plotted Data

A.4 BIBLIOGRAPHY

Readers who are interested in the details of the programs discussed in this appendix are referred to the following documents. Definition and use of the software support for the DEC Laboratory Peripheral System can be found in the FORTRAN/RT-11 Extensions Manual, Order No. DEC-11-LRTEA-C-D, Chapter 3. The DEC System Subroutine Library, SYSLIB, is described in detail in Appendix O. of the DEC RT-11 System Reference Manual, Order No. DEC-11-ORUGA-C-D, DN1, DN2. These manuals are available from Digital Equipment Corporation, Maynard, Massachusetts.

The Pacific Northwest Laboratory (PNL) Device Independent Graphics subroutines were written by members of PNL Computers and Information Systems Section and are described in internally distributed documents. Information regarding operational and TX support can be obtained from Jim Thomas. Device independent graphics and BNWLIB were the responsibility of Vern Crow and Larry Gerhardstein.

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