UILU-ENG 84-3603

Report No. 103

SPECTROSCOPIC MEASUREMENT OF HYDROGEN CONTAMINATION IN WELD ARC PLASMAS

by

J. E. Shea* and C. S. Gardner

Radio Research Laboratory
Department of Electrical Engineering, UIUC

*Presently with National Security Company, Baltimore, MD

A Report of the

MATERIALS ENGINEERING - MECHANICAL BEHAVIOR

College of Engineering, University of Illinois at Urbana-Champaign

February 1984

ABSTRACT

The introduction of hydrogen into metals during welding is known to cause hydrogen assisted cracking and embrittlement in certain situations. It has been shown that the weld metal hydrogen content is directly related to hydrogen concentration in the weld arc plasma. In this paper we describe a simple spectroscopic technique for measuring the arc plasma hydrogen concentration in real time when an argon shield gas is used. This technique is based on the fact that the intensity ratio of the hydrogen Balmer Alpha emission line at 6563Å and an argon emission line at 6965Å was observed to an approximately linear function of hydrogen concentration in the weld arc plasma. This technique was experimentally verified under a variety of welding conditions for gas metal arc welding and found to have an error of less than 10% when measuring hydrogen concentrations in the arc plasma as low as 0.25% by volume. This method of hydrogen measurement is also applicable when welding with shield gases not containing argon so long as a suitable ratioing line is available.

PACS numbers: 52.70.Kz, 07.65.EH, 52.80.Mg, 81.40Np

ACKNOWLEDGEMENTS

The authors would like to acknowledge F. Kearney, D. Blackmon, F. Kisters and V. Hock of the U.S. Army Construction Engineering Research Laboratory for developing the gas mixing system and for their help in collecting the arc spectral data. This work was supported by the U.S. Army Corps of Engineers under contracts DACA88-81-C-0003, DACA88-81-C-0016 and DACA88-82-M-0269.

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I. INTRODUCTION

Hydrogen assisted cracking and embrittlement are often responsible for weld failure in high strength steels. During welding, hydrogen may be introduced into the weldment because molten metal will absorb hydrogen in proportion to its concentration in the arc atmosphere [1]. The most common sources of hydrogen in the weld arc plasma are the disassociation of hydrogen bearing compounds such as water vapor, lubricants, and electrode coatings. Once hydrogen has been introduced into the metal, cracking may occur as a result of interactions between the dissolved hydrogen and the metal [2], [3]. Savage, Nippes, and Husa [1] have analyzed the transfer of hydrogen from the weld arc plasma to the weldment when an AX-140 electrode is deposited on HY-130 plate. In their experiments, hydrogen was introduced into the arc plasma by either adding water vapor or hydrogen gas to the shield gas. They concluded that hydrogen induced cracking occurs when the volume of dissolved hydrogen exceeds 1 ppm in the weldment. This corresponds to a hydrogen concentration of approximately 0.25% of the shield gas.

To minimize hydrogen assisted cracking and embrittlement in critical welds, low moisture electrodes and special welding procedures have been developed. However, in practice, it is not always possible to guarantee strict adherence to the proper welding procedures. Consequently, in many cases, the welds must be carefully inspected to insure their integrity. The cost of locating and repairing defective welds is high. For the past few years, we have been developing a real-time weld quality monitor to detect defects as they occur [4]. In this paper, we discuss the development of an electro-optic based system to monitor in real time the concentration of hydrogen in the weld arc plasma.

This system is based on the fact that the intensity of light emitted by the arc plasma at wavelengths corresponding to the atomic transitions of hydrogen is proportional to the hydrogen concentration in the plasma. By monitoring the hydrogen emission wavelengths in arc welding, it is possible to measure hydrogen in concentrations as low as 0.25% of the shield gas with an error of less than 10%. Similar accuracies have also been obtained in limited experiments with tungsten inert gas welding and laser welding.

II. THEORETICAL BACKGROUND

The optical emissions of the weld arc result from atoms radiating energy after having been excited by electron collisions. The wavelength of light emitted by a particular atom will depend on the excitation gained by the atom in its collision with an electron and the transition probability of a particular wavelength. If none of the optical energy is absorbed by the weld plasma, the intensity of a given spectral line will be proportional to the number of atoms radiating at that wavelength. This suggests that, if we measure the intensity of the spectral lines emitted by a particular element or compound, it should be possible to infer its concentration.

If we consider the weld plasma to be in local thermodynamic equilibrium, the excitation levels within the plasma take on a Boltzmann distribution. Thus, if N atoms of a particular element exist in the plasma, the number of atoms N_m which have an energy E_m is [5]

$$N_m = \frac{N\ g_m\ e^{-E_m/kT}}{B(T)} \tag{1}$$

where

T = °K

g_m = degeneracy factor

k = Boltzmann's constant

and $B(T)$ is the partition function

$$B(T) = \sum_{r=\text{all states}} g_r\ e^{-E_r/kT} \tag{2}$$

The optical energy, corresponding to an atomic transition from state m to n, emitted by the plasma from a small volume element Δv, is equal to $N_m\ A_{mn}\ \Delta v$ where A_{mn} is the transition probability from state m to n. Recalling that the energy of a photon is $h\nu = E_m - E_n$, the intensity of the m-to-n transition per unit solid angle may be expressed as

$$I_{mn} = \frac{h\nu\ \Delta v\ Ng_m\ A_{mn}\ e^{-E_m/kT}}{4\pi B(T)} \tag{3}$$

The total intensity of light emitted at a given wavelength may be found by integrating Eq. (3) over all volume elements (Δv) of the plasma. Unfortunately, random variations in factors such as temperature and volume of excited gas severely limit the accuracy of this method. Changes in temperature may be caused by variations in the arc length and current. Furthermore, the temperature inside of the arc is not uniform, but decreases radially from the center of the plasma. The volume of excited gas will change with any instability in the arc, which has the effect of changing the parameter N in the intensity equation.

Not all of the light radiated from the plasma will reach the detector. A portion will be absorbed by smoke and particulate matter in the air. But more importantly, the amount of light actually received by the detector will critically depend on the alignment of the optical system used to collect the light. Any small pointing or focusing error will cause a significant change in the observed intensity.

Obviously, if the intensity measurements are to be of any value in determining concentrations, the variations due to random factors must somehow be removed by a normalization procedure. Probably the best way to normalize is to take a ratio of the spectral line intensities of two elements which have similar excitation energies, E_{m_i}. By choosing spectral lines with approximately equal excitation levels, temperature dependence is reduced. Furthermore, if the wavelengths of the two transitions are relatively close, scattering and other wavelength dependent factors will affect each spectral line intensity in the same manner so that the ratio will be approximately constant for a given concentration of the two elements. The intensity ratio of spectral lines resulting from two different elements is

$$\frac{I_{m_1n_1}}{I_{m_2n_2}} = \frac{\nu_1}{\nu_2}\frac{N_1}{N_2}\frac{g_{m_1}}{g_{m_2}}\frac{A_{m_1n_1}}{A_{m_2n_2}}\frac{\exp(-E_{m_1}/kT)}{\exp(-E_{m_2}/kT)}\frac{B_1(T)}{B_2(T)} \tag{4}$$

If $E_{m_1} \simeq E_{m_2}$

$$\frac{I_{m_1n_1}}{I_{m_2n_2}} \cong \frac{\nu_1}{\nu_2}\frac{N_1}{N_2}\frac{g_{m_1}}{g_{m_2}}\frac{A_{m_1n_1}}{A_{m_2n_2}}\frac{B_1(T)}{B_2(T)} \tag{5}$$

In general, the transition probabilities $A_{m_in_i}$ are not well-known (typical errors for argon are ± 25%). But if the intensity ratios are found experimentally using plasmas of known compositions, it is possible to develop an empirical curve, relating observed intensity ratio to atomic concentration ratio $\frac{N_1}{N_2}$. This empirical curve may then be used to determine the concentration ratio of two elements from an observed intensity ratio.

Although, as we have just stated that $A_{m_1n_1}$ and $A_{m_2n_2}$ are generally not well-known, the ratio $A_{m_1n_1}/A_{m_2n_2}$ is well-known for the special case when both transitions are produced by the same element, and have the same lower state (i.e., $n = n_1 = n_2$). The intensity ratio may then be written as

$$\frac{I_{m_1n}}{I_{m_2n_2}} = \frac{\nu_1}{\nu_2}\frac{g_{m_1}}{g_{m_2}}\frac{A_{m_1n}}{A_{m_2n}}\frac{\exp(-E_{m_1}/kT)}{\exp(-E_{m_2}/kT)} \tag{6}$$

From this equation, it is evident that if the two transitions are chosen so that $E_{m_1} - E_{m_2}$ is large, the ratio may be solved for the plasma temperature

$$T = \frac{E_{m_1} - E_{m_2}}{k} \left[\ell n \left(\frac{\nu_1}{\nu_2} \frac{g_{m_1}}{g_{m_2}} \frac{A_{m_1 n}}{A_{m_2 n}} \frac{I_{m_2 n}}{I_{m_1 n}} \right) \right]^{-1} \tag{7}$$

Thus far, we have considered the spectrum to be composed of discrete lines of negligible width, but in fact all spectral emissions have a non-zero width due to the finite lifetime of an atomic state. In a plasma, the lineshape will be even broader than that of the natural line width because processes such as Doppler broadening, pressure broadening and the Stark effect will increase the line width. If we again assume local thermodynamic equilibrium, the Doppler broadening may be calculated from [6]

$$\Delta\lambda = \left(\frac{8kT \ell n 2}{mc^2}\right)^{1/2} \lambda_o \tag{8}$$

m = atomic mass

c = speed of light .

In our welding work, the lines of primary interest are argon at 6965 Å, iron in the region of 6500 Å, and the hydrogen Balmer alpha line at 6563 Å. At 20,000 °K, these lines have the following Doppler line widths:

Argon: $\Delta\lambda_d = 0.110$ Å

Iron: $\Delta\lambda_d = 0.087$ Å

Hydrogen: $\Delta\lambda_d = 0.662$ Å .

The calculation of pressure broadening is more complicated because we must know the collision frequency between the atoms in the plasma. To calculate the collision frequency, the collision cross section of the species in the plasma must be known, and, in general, can only be found experimentally. If we consider a plasma composed only of hydrogen and argon, the collision frequency can be approximated using gas kinetic theory [7]. With argon as the background gas, the collision frequency of a hydrogen atom with argon is

$$\nu_{col} = \pi(r_A + r_B)^2 \left[\frac{8kT}{\pi}\left(\frac{1}{M_A} + \frac{1}{M_B}\right)\right]^{1/2} N_B \qquad (9)$$

where

r_A, r_B = atomic radii

M_A, M_B = masses

N_B = number density of the background gas.

To find the collision frequency of argon, we use the rate at which an argon atom collides with the argon background gas.

$$\nu_{col} = \pi\sqrt{2}\, r_B^2 \left(\frac{8kT}{\pi M_B}\right)^{1/2} N_B \qquad (10)$$

The pressure broadening is then found from [6]

$$\Delta\lambda = \frac{\lambda_o^2}{c}\left(\tau_n + \frac{\nu_{col}}{\pi}\right) \qquad (11)$$

where τ_n is the natural lifetime. By substituting the collision frequencies in the above and assuming that the natural lifetime is small, we obtain

Argon: $\Delta\lambda = 0.003$ Å

Hydrogen: $\Delta\lambda = 0.006$ Å .

Obviously at welding temperatures and pressures, the effects of pressure broadening are insignificant when compared with the effects of Doppler broadening.

The final broadening mechanism to be considered, the Stark effect, may prove to be of particular importance in future work because the electron density of the plasma can be determined from the width of a Stark broadened hydrogen line. If we assume a quasistatic situation as set forth by Griem [8], the Stark broadening may be calculated as follows [9]:

$$\Delta\lambda = \frac{3\lambda_o^2 \ \varepsilon_o \ \hbar(n_1^2 - n_2^2)E}{mecZ_e} \tag{12}$$

$$= C(\lambda_o) \ E \text{Å}$$

where

$$E \simeq 3.4 \ E_o$$

and

$$E_o = \frac{2.603 \ eN^{2/3}}{4\pi\varepsilon_o}$$ is the Holtsmark normal field.

ε_o = dielectric constant of free space

$\hbar = h/2\pi$

h = Planck's constant

n_i = principal quantum number

m = electron mass

Z_e = particle charge

N = electron density

e = electron charge

c = speed of light

Bekefi [9] has tabulated values of $C(\lambda_o)$ for the prominent hydrogen lines. Typical electron densities for weld arc plasmas are on the order of 10^{16} cm^{-3}. By substituting this electron density into the above equation, we obtain

$\Delta\lambda \simeq 10$ Å for the hydrogen linewidth at 6563 Å. At these electron densities, Stark broadening is only significant for hydrogen and helium.

In addition to spectral lines, optical spectra contain background emissions which are slowly varying functions of wavelength. These background emissions are the result of blackbody radiation. Since blackbody radiation is a function of temperature, the primary sources of blackbody radiation in a welding environment are the weld arc plasma and the base metal.

In the preceding discussion, we have assumed that all of the optical radiation generated by the plasma is emitted. Often times, this condition does not hold and some of the optical radiation emitted from the inside of the plasma is absorbed in a process known as radiation trapping [10]. Radiation trapping can have two effects on the observed spectrum. It may change the line shape of a spectral line, or it may redistribute the energy within the spectrum. Radiation trapping effects are most prevalent in so-called resonance transitions where an atomic transition occurs between an upper state and the ground state. Fortunately, most of the transitions which generate spectral lines of interest in arc welding are not resonance transitions. Therefore, radiation trapping is minimal, and can be neglected.

III. INSTRUMENTATION

Figure 1 is a block diagram of the hydrogen monitoring system. A lens, which is mounted on the weld head, focuses light from the weld arc onto a metal-clad, optical-fiber bundle. This fiber bundle guides the light to the entrance slit of a monochromator. In our application, the monochromator is operated as a spectrograph where the exit slit has been replaced by a linear photodiode array consisting of 1024 photodiodes. The photodiode array converts the spectrum to a series of analog voltages which are proportional to the light intensity. The spectrum along with the signals from the current, voltage, and travel speed transducers are digitized by an A/D converter, processed, and then stored on a floppy disk.

The lens used for focusing the light from the weld arc is a 25 mm convex lens with a focal length of 50 mm. Since the lens is mounted on the weld head, it always points at the arc as the welder traverses the work piece. Even though the lens is about two feet from the arc, metal splatter occasionally strikes it. Pitting is avoided by placing a disk of pyrex glass over the lens so that any metal splatter will strike the disk. When the glass disk is pitted to the extent that it affects light collection efficiency, it is replaced. The two-meter fiber optic cable that is used to guide the light from the lens to the monochrometer is composed of glass fibers in a metal sheath. The metal protects the fibers from excessive bending, while at the same time adding mechanical strength. A graph of the transmittance of the fiber versus wavelength is shown in Figure 2. Because of absorption in the glass, ultraviolet (UV) radiation below 3500 Å is heavily attenuated.

A 0.32 meter Czerny-Turner type diffraction grating monochromator disperses the light from the weld arc into its spectral components. In this type of

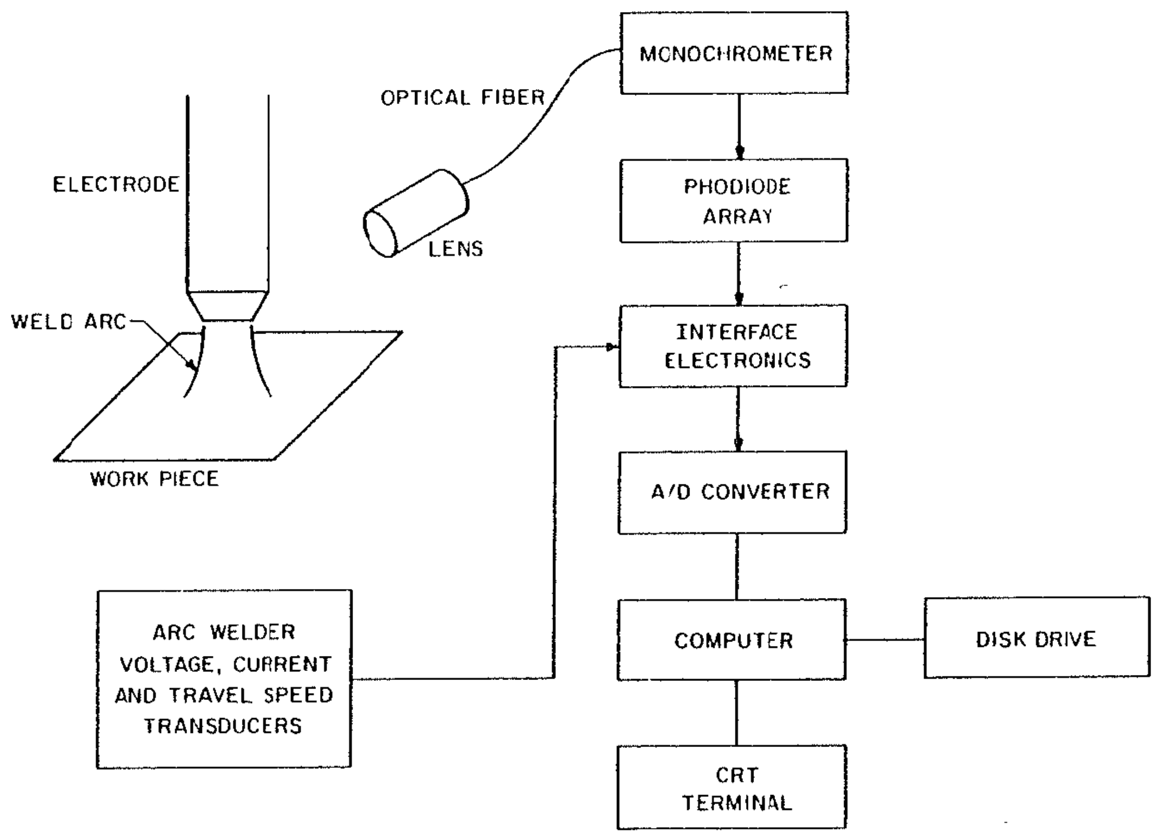

Figure 1. Block diagram of hydrogen monitor.

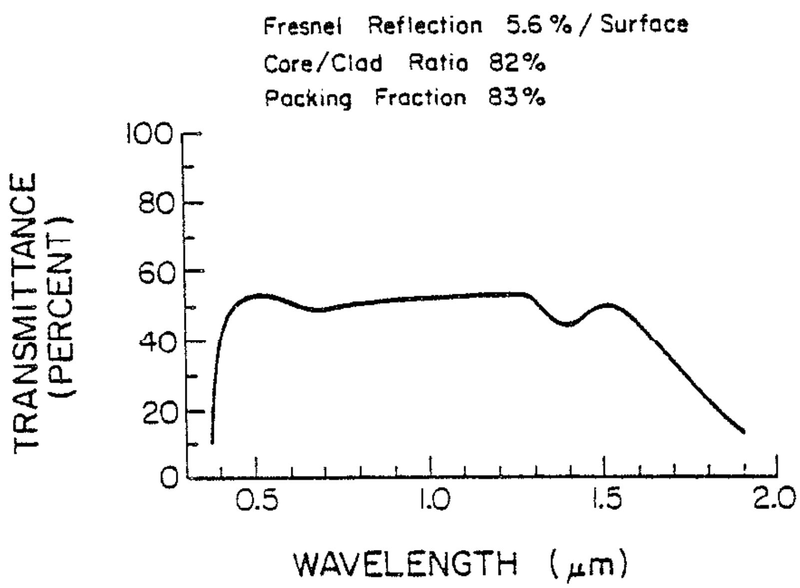

Figure 2. Optical fiber transmittance curve.

monochrometer, light is focused from the entrance slit onto the grating by a parabolic mirror. After the grating has dispersed the light, a second mirror focuses the spectrum onto the exit focal plane where a photodiode array is positioned. The angle of the diffraction grating with respect to the optical axis of the input mirror determines which portion of the spectrum is projected onto the photodiode array. This angle may be changed by rotating the grating, allowing the entire spectrum from the near infrared (IR) to the UV to be observed. Presently, a 1200 line/mm holographic grating is used for hydrogen detection, while a 2400 line/mm grating is used when higher resolution spectra are required. When the 1200 line/mm grating is used, a 500 Å band of the spectrum is focused onto the photodiode array. The monochromator optics and photodiode array impose a theoretical resolution limit of approximately 0.4 Å [11]. This resolution is comparable to the Doppler linewidths of argon and hydrogen.

The photodiode array consists of a linear array of 1024 photodiodes on a silicon bar one-inch long. The length of time that light is integrated by the array may be varied from 500 microseconds to several seconds. An integration time of 50 milliseconds was selected to minimize the effects of dark current. The voltages representing the optical energy integrated by the array are outputted in a serial staircase form suitable for A/D conversion. The spectral response of the photodiode array is illustrated in Figure 3. Notice the significant drop-off in the near IR region of the spectrum. The UV transmittance of the optical fiber and the near IR response of the photodiode array limit the overall spectral response of the system to the region from 3500 Å to 9000Å.

System control and data acquisition are implemented by a 16-bit LSI-11/23 microcomputer. The computer contains a parallel input output port and an analog-to-digital converter. The parallel I/O port is used to send commands

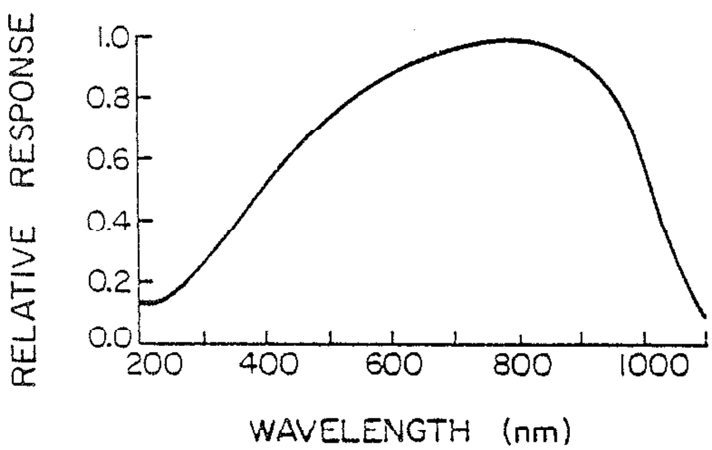

Figure 3. Photodiode array optical response.

to the interface electronics which enable the data acquisition. The analog-to-digital converter converts the analog staircase array voltages and the transducer outputs from the voltage, current and travel speed transducers to a signed 12-bit format. The minimum conversion time of the A/D converter is 10 microseconds or 100,000 voltage samples per second. With an array integration time of 50 milliseconds, the maximum data acquisition rate is 20 complete spectra per second. Each spectrum consists of 1024 samples uniformly distributed over a 500 Å band. If the spectra are stored on a floppy disk, the access time of the disk limits the data acquisition to approximately two spectra per second.

Table 1 gives a summary of the performance specifications of the data acquisition system. It should be noted that with the high resolution grating, the Doppler profile of the spectral lines is not quite resolvable. In choosing the 1200 line/mm grating and the 0.32 meter monochromator, a trade-off was made between the desire to observe as much of the spectrum as possible while at the same time preserving spectral resolution. In making this trade-off, we have designed the system resolution so that the atomic emission lines can be easily resolved, and so that significant effects such as Stark broadening are measurable. As shown in Table 1, the time resolution of the system is limited to 0.5 seconds when the data are stored on the disk. Even at this slow data acquisition rate, a considerable amount of data is generated on each welding run. If greater temporal resolution is desired, processing can be minimized by only recording the spectra near a few important wavelengths.

In this experiment, hydrogen was introduced into the weld arc plasma through the shield gas by mixing gas containing 98% argon and 2% oxygen with gas

TABLE 1

SYSTEM SPECIFICATIONS

Optical Resolution:	0.5 Å (1200 line/mm)	0.24 Å (2400 line/mm)
Bandwidth:	500 Å (1200 line/mm)	250 Å (2400 line/mm)
Time Resolution:	50 msec (0.5 sec when stored in disk)	
Current Transducer:	Hall Effect Transducer	
Voltage Transducer:	Voltage Divider	
Speed Transducer:	Tachometer	

containing 90% argon and 10% hydrogen. By regulating the flow rates of these two gases, the volume concentration of hydrogen in the shield gas can be varied from 0.00% to 3.00%. Table 2 lists the error in setting the hydrogen content of the shield gas which occur when reading the hydrogen flow rate meter.

TABLE 2

ERROR IN SETTING HYDROGEN CONTENT OF SHIELD GAS

%H	ERROR
0.00	± 0.0%
0.25	±17.0%
0.50	±10.0%
0.75	± 6.7%
1.00	± 5.0%
1.25	± 3.8%
1.50	± 3.1%
1.75	± 2.6%
2.00	± 2.2%
2.25	± 2.0%
2.50	± 1.8%
2.75	± 1.6%
3.00	± 1.4%

IV. EXPERIMENTAL RESULTS

A. Procedure

The materials used for welding were ASTM-242 low-alloy, high-strength steel, and E70S-3 electrode wire. The nominal composition of these materials can be found in Table 3. In an effort to remove surface contaminants from the base metal, a small amount of the welding plate was ground away before welding.

All welding was performed on a semi-automatic Gas Metal Arc welder. This welder consisted of a welding head mounted to a carriage which was motorized on one axis. Generally, an arc length of 20 mm was used except when welding at hydrogen concentrations above 1.5%. At these higher concentrations, it was necessary to lengthen the arc to establish stable operation. The nominal values for welder voltage and current were 30 V and 300 A, respectively. Travel speed was varied from 10 cm/min (4 ipm) to 60 cm/min (24 ipm).

The first step when recording data was to adjust the welder for the proper current, voltage, and travel speed. The gas mixture was then adjusted for the desired hydrogen concentration, and the gas lines bled to remove any residual gases. After all preparations were completed, the welder was started. A single pass of the metal plate lasted approximately 25 seconds during which fifty spectra were acquired and stored on the floppy disk. In all of the welding performed in this experiment, a bead of metal was deposited on the base metal plate.

B. Sample Spectra

There are two prominent hydrogen lines in the visible region of the spectrum which can be used for monitoring hydrogen concentration. One is the Balmer series alpha line at 6563 Å, and the other is the Balmer series Beta line at 4861 Å. The 4861 Å line was not used because several emission lines of the

TABLE 3

E70S-3 WELDING WIRE COMPOSITON (%)

C	0.06-0.15
Mn	0.9-1.4
Si	0.45-0.70
P_{max}	0.025
S_{max}	0.035

ASTM 242 LOW ALLOY STEEL COMPOSITION (%)

C	0.12%
Mn	0.25
P	0.07-0.15
S	0.05 max
Si	0.25-0.55
Cu	0.25-0.40
Cr	0.4%-0.65
Va	0.02%-0.10%
Fe	Remainder

base metal interfered with the hydrogen spectrum. In addition, the 6563 Å line is near several strong argon emission lines which can be used for normalization.

Figure 4 is a spectral sample taken with the monochrometer set at a center wavelength of 6725 Å and a hydrogen shield gas concentration of 2.0% by volume. Notice that most of the spectral lines are due to either hydrogen, argon, or iron. The hydrogen line is by far the broadest line in the spectrum. An expanded plot of the hydrogen line is shown in Figure 5. The large width of the hydrogen line relative to the other emission lines is due to the Stark broadening mechanism mentioned earlier.

C. Signal Processing

Both line broadening mechanisms and variations in the spectral background level will affect the peak intensity of a spectral line. When a line is broadened, the optical energy generated in an atomic transition is spread over a larger bandwidth. The effects of line broadening may be significantly reduced if the intensity is integrated over a substantial portion of the linewidth. Since an integral provides a measure of total energy, it should remain relatively constant regardless of linewidth.

The background level of the spectrum is due to two sources. The first source is the bias level of the photodiode array. The bias level may be set by adjusting a potentiometer in the interface electronics, but in time it will change due to drift in the electronic circuitry. The second source is blackbody emissions from the weld arc plasma and hot base metal. Because only a small portion of the spectrum is examined at any one time (i.e., 500 Å), the blackbody radiation can be considered to be uniform over the bandwidth of the monochrometer. Since the bias level is also uniform, a region free of spectral lines can be used to determine the background level. To minimize the effects of noise, the background level was determined by averaging over a 10 Å bandwidth

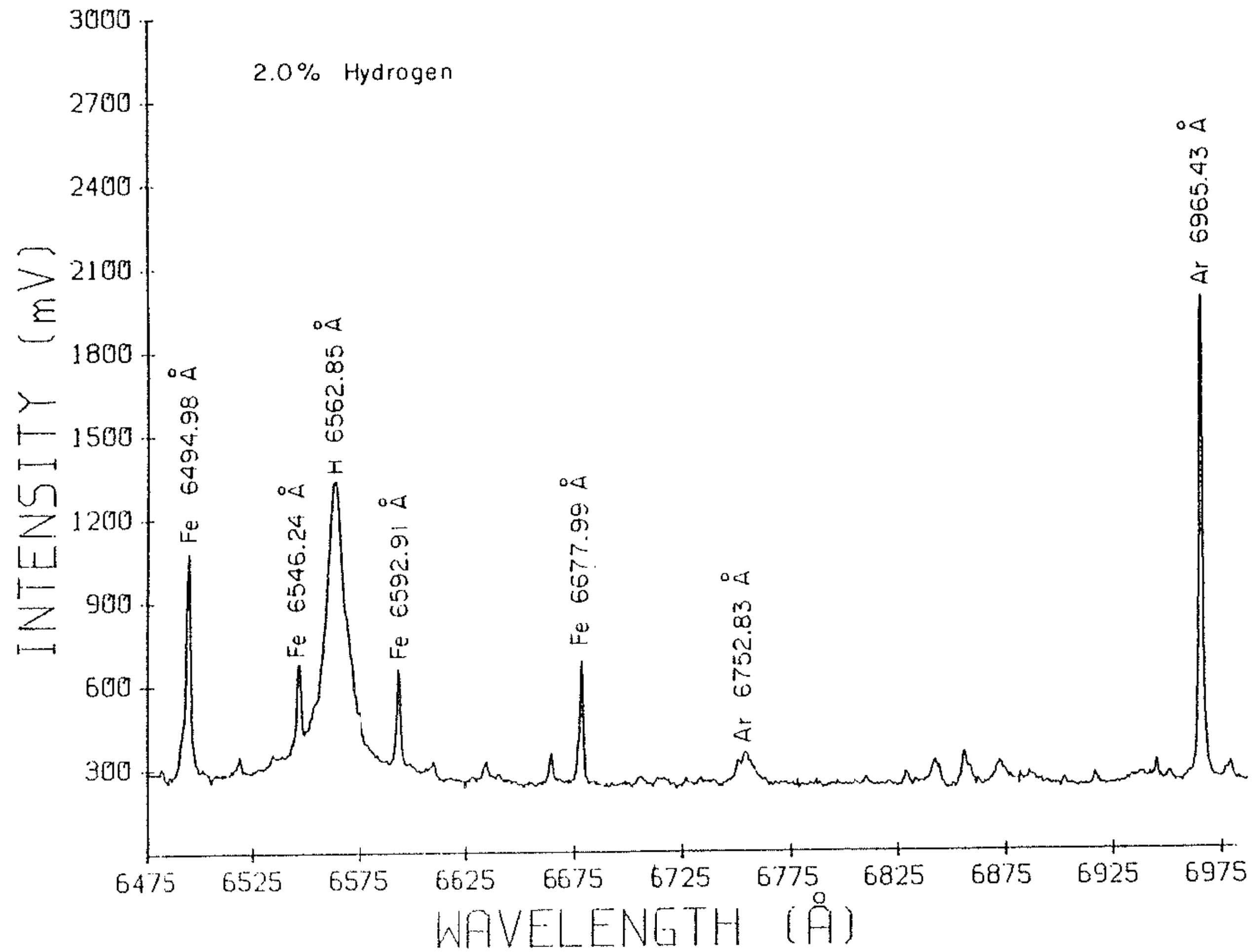

Figure 4. 6475 Å – 6975 Å spectral sample. Two percent hydrogen added to shield gas.

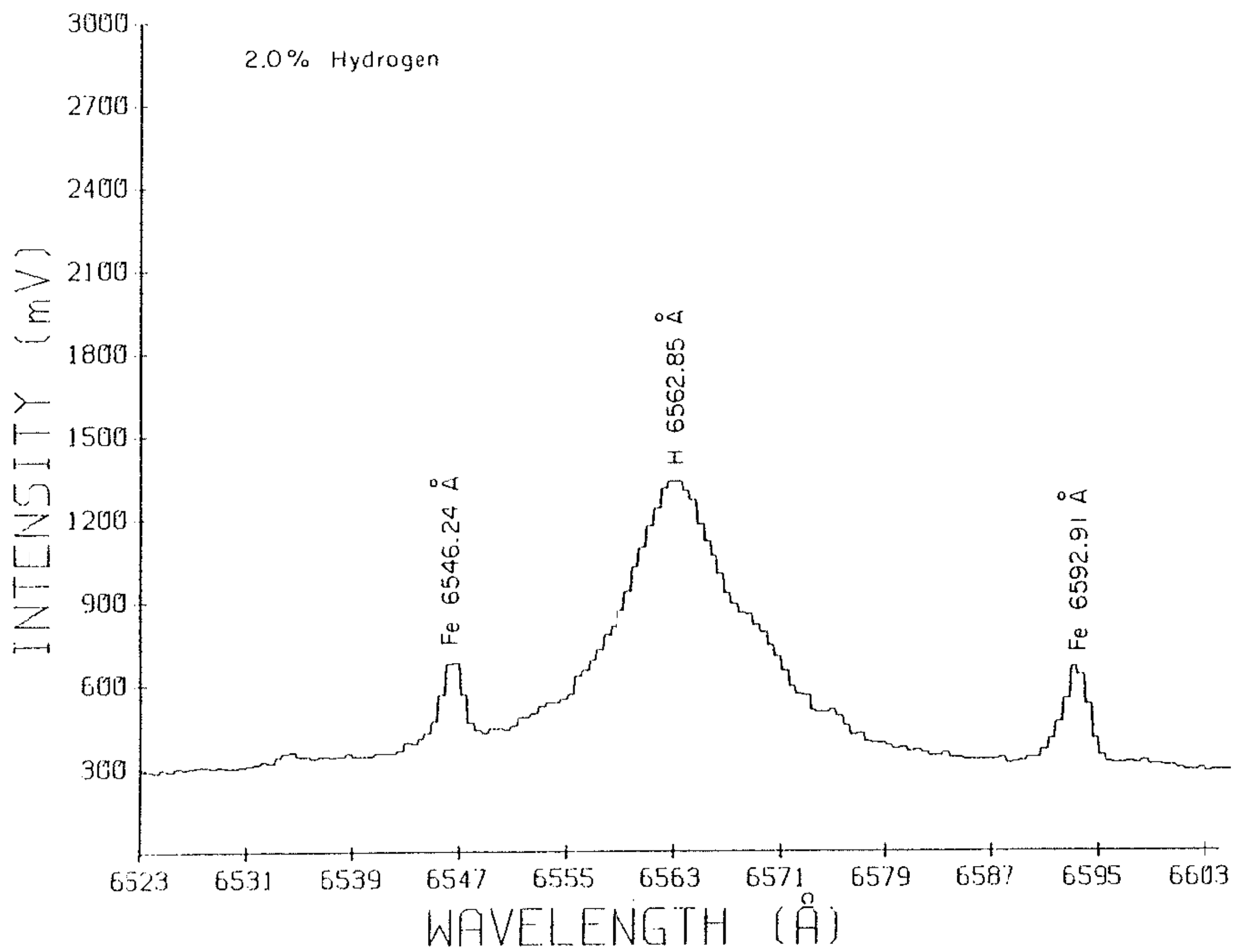

Figure 5. Expanded hydrogen spectra.

centered at 6800 Å. Before the integrated line intensities were computed, the background level was subtracted from the entire spectrum.

Figure 4 shows that the Stark broadened hydrogen line at 6563 Å extends over a bandwidth of more than 60 Å. To avoid interference from the iron lines at 6546 Å and 6592 Å and the zirconium line at 6569 Å, (see Fig. 8) the hydrogen line integration was limited to ± 3.5 Å about the line peak. Figure 6 is a plot of the integrated line intensity versus hydrogen concentration. Although a generally increasing trend is evident in this plot, it is obvious that good quantitative measurements of the hydrogen concentration cannot be made by measuring just the hydrogen intensity.

The graph of the intensity versus hydrogen concentration clearly shows the need for the normalization procedure discussed earlier. Recall that in this approach the hydrogen line intensity is divided by the intensity of a nearby spectral line. To be effective, intensity variations in the ratioing line should be highly correlated with intensity variations in the hydrogen line. This is extremely important if ratioing is to have the desired effect of removing random variations in the intensity of the hydrogen line.

Table 4 is a list of the correlation coefficients (ρ) between the intensity fluctuations of hydrogen and the major iron and argon lines in the spectrum plotted in Figure 4. The closer the correlation coefficient is to unity, the more highly correlated are variations in the intensity of the two lines. Clearly, the argon line at 6965 Å is the most highly correlated with the hydrogen line. This probably results from two factors. First, the excitation energy of the 6965 Å line is 13.3 eV, and the excitation energy of the 6563 Å hydrogen line is 12.0 eV. Since these values are quite close, the temperature dependence of the two lines is very similar. Second, the argon emissions are due to argon present in the shield gas, while the iron emissions are due to iron vapor from

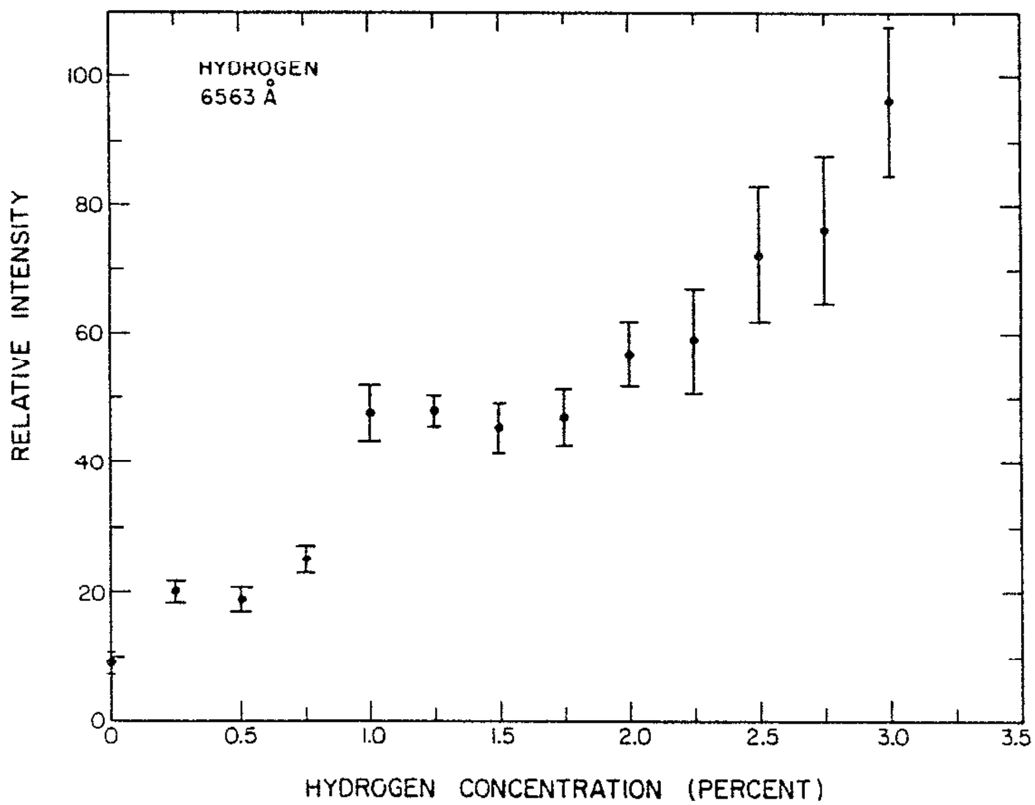

Figure 6. Hydrogen line intensity versus hydrogen concentration.

TABLE 4

CORRELATION COEFFICIENTS

		1% H	2% H
Element	λ	ρ	ρ
Argon	6965 Å	0.8380	0.900
Argon	6752 Å	0.8264	0.831
Iron	6495 Å	0.0500	0.0183
Iron	6546 Å	0.3451	0.4319
Iron	6593 Å	0.0702	-0.6754
Iron	6678 Å	0.0308	-0.2468

the electrode and base metal. During welding, the shield gas flow rate remains essentially constant which implies that the volume of argon in the weld plasma remains nearly constant. Conversely, metal transfer processes and arc instabilities can vary the volume of iron vapor in the weld plasma considerably. Since argon is a more stable component of the weld plasma than iron vapor, its optical emissions will be more highly correlated with the optical emissions of other plasma components. If we let R denote the ratio of the hydrogen line intensity with the argon line intensity, and $I(\lambda)$ denote the intensity profile of the spectra, the ratio can be expressed as

$$R = \frac{\frac{1}{\Delta h}\int_{\lambda_H-\Delta h/2}^{\lambda_H+\Delta h/2} I(\lambda)d\lambda - \frac{1}{\Delta b}\int_{\lambda_B-\Delta b/2}^{\lambda_B+\Delta b/2} I(\lambda)d\lambda}{\frac{1}{\Delta a}\int_{\lambda_{Ar}-\Delta a/2}^{\lambda_{Ar}+\Delta a/2} I(\lambda)d\lambda - \frac{1}{\Delta b}\int_{\lambda_B-\Delta b/2}^{\lambda_B+\Delta b/2} I(\lambda)d\lambda} \qquad (13)$$

where

$\Delta h = 7.0$ Å

$\lambda_H = 6563$ Å

$\Delta a = 7.0$ Å

$\lambda_{Ar} = 6965$ Å

$\Delta b = 10.0$ Å

$\lambda_B = 6800$ Å

A more generalized form of this equation is obtained by multiplying the intensity profile, $I(\lambda)$, by a filter function and integrating over the entire spectra. Equation (13) then becomes

$$R = \frac{\int_{-\infty}^{\infty} I(\lambda)\, f_H(\lambda)d\lambda - \int_{-\infty}^{\infty} I(\lambda)\, f_B(\lambda)d\lambda}{\int_{-\infty}^{\infty} I(\lambda)\, f_{Ar}(\lambda)d\lambda - \int_{-\infty}^{\infty} I(\lambda)\, f_B(\lambda)d\lambda} \qquad (14)$$

where in this case

$$f_H(\lambda) = \begin{cases} \frac{1}{\Delta h} & |\lambda - 6563\ \text{Å}| \leq \Delta h/2 \\ 0 & \text{elsewhere} \end{cases}$$

$$f_B(\lambda) = \begin{cases} \frac{1}{\Delta b} & |\lambda - 6800\ \text{Å}| \leq \Delta b/2 \\ 0 & \text{elsewhere} \end{cases}$$

$$f_{Ar}(\lambda) = \begin{cases} \frac{1}{\Delta a} & |\lambda - 6965\ \text{Å}| \leq \Delta a/2 \\ 0 & \text{elsewhere} \end{cases}$$

D. Results

The intensity ratio given by Equation (14) is plotted versus hydrogen concentration for three separate data sets in Figure 7. It is evident from this plot that the intensity ratio is very nearly a linear function of the hydrogen concentration. A linear regression was used to determine a best-fit line for each data set. The best-fit lines and the coefficients of determination for the three data sets are listed in Table 5. Notice that the regression lines of Table 5 do not pass through the origin. The reason for the offset from zero at the origin can be found by examining the spectrum, plotted in Figure 8, taken with no hydrogen added to the shield gas. The occurrence of a hydrogen emission line clearly indicates that hydrogen exists in the weld plasma. The source of this hydrogen has not been positively identified but is thought to be due to moisture in the gas feed system and hydrogen in the base metal.

The coefficients of determination of the regression lines indicate that the linear fit is quite good, but a definite nonlinear region exists at the lower hydrogen concentrations. This nonlinearity could be attributed to several sources, but the most likely is error in setting the gas flow rates. For

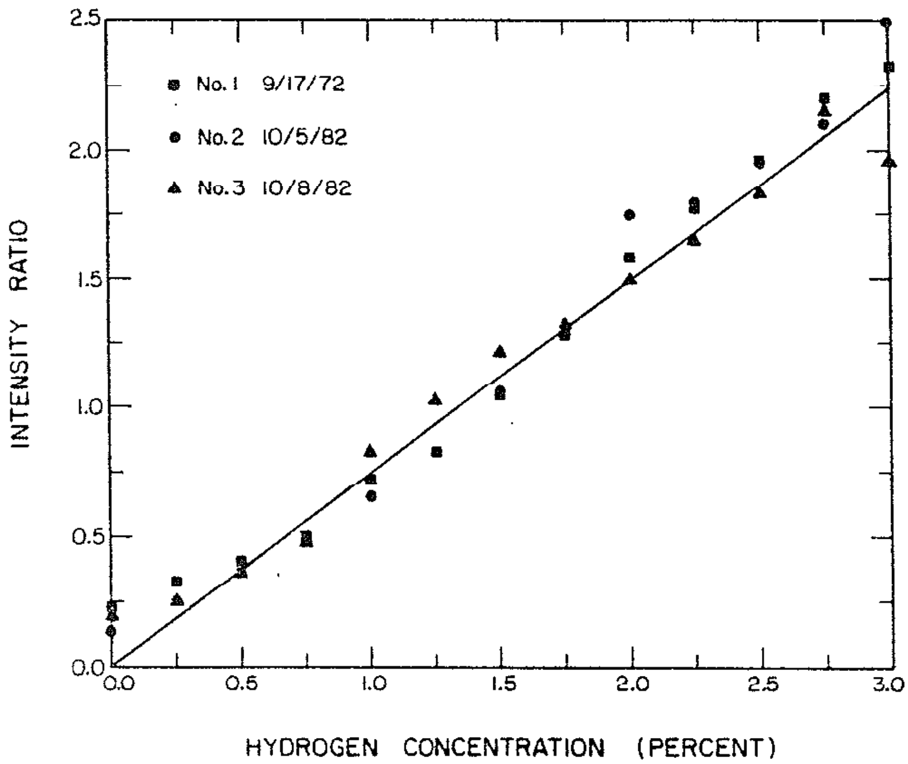

Figure 7. Intensity ratio versus hydrogen concentration.

TABLE 5

LINEAR REGRESSION

DATA SET	SLOPE	INTERCEPT	COEFFICIENT OF DETERMINATION
1	0.7974	0.0283	0.98
2	0.7548	0.0363	0.97
3	0.6819	0.1156	0.97
Combined	0.7501	0.0010	0.97

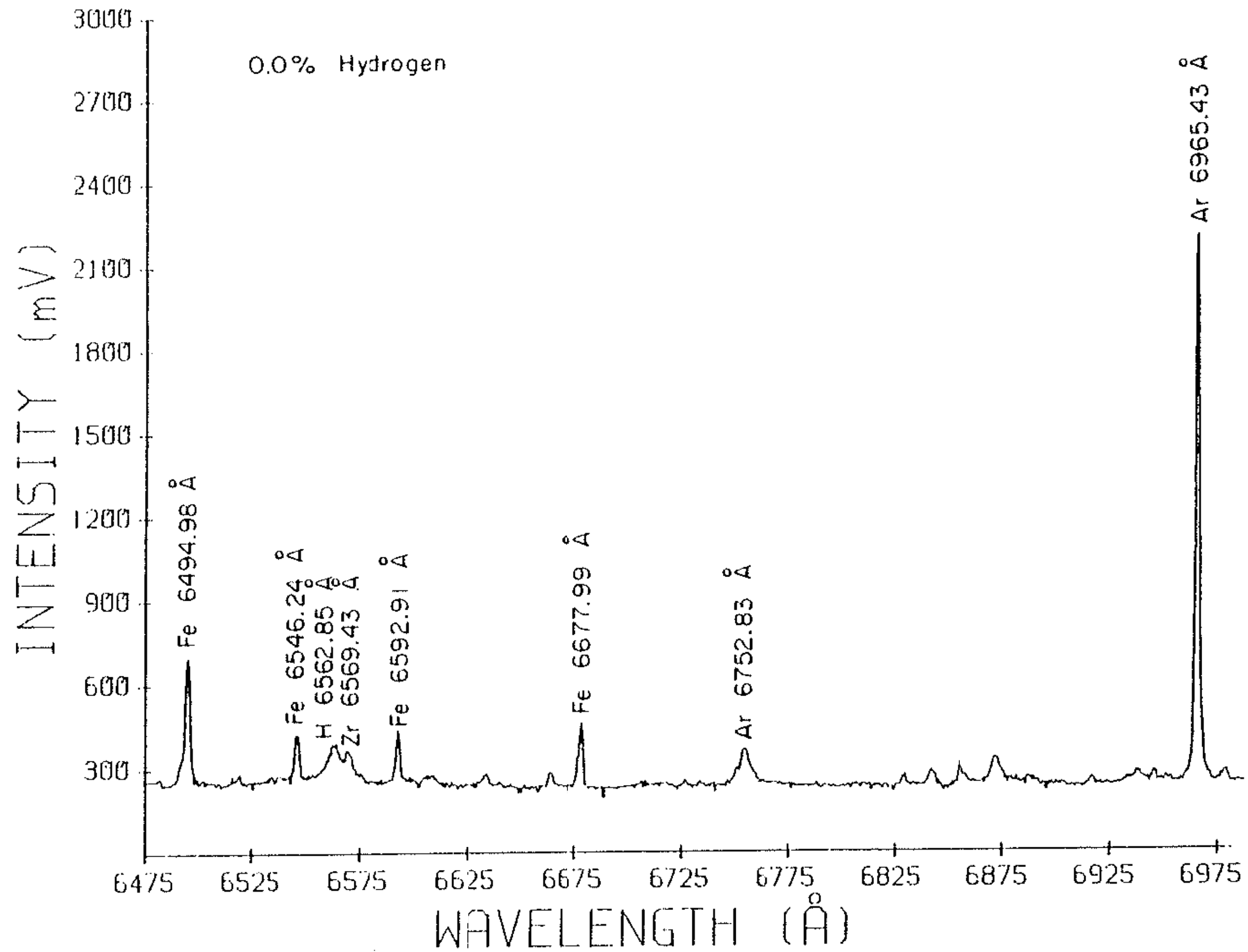

Figure 8. 6475 Å – 6975 Å spectral sample. No hydrogen added to shield gas.

example, when setting the flow rate for the 0.25% hydrogen mixture, an error of 17% occurs when reading the hydrogen flow rate meter. Other possible sources of nonlinearities are interference from adjacent emission lines and errors in determining the background level.

If the standard deviation of a data set is divided by its mean, the resulting normalized standard deviation provides a measure of the percent error in the data set. Figure 9 is a plot of the normalized standard deviation of the hydrogen ratio versus the hydrogen content of the shield gas. Except for the second data set, the error is well below 10% for most values of hydrogen. The error in the second data set exceeds 10% when the hydrogen concentration exceeds 1.5% of the shield gas. We believe this occurred because a stable arc could not be maintained on this data set at the higher hydrogen levels. Because all of the other data had less than 10% error for hydrogen contents below 1.5%, it appears that the measurement error is on the order of 10%, or less, when measuring the intensity ratio. It may be possible to reduce this error by optimizing the integration time, or by using a more sophisticated filter function.

The stability of the intensity ratio with respect to travel-speed variations is also important if the hydrogen detector is to be used in practical applications. Figure 10 is a plot of the variation of the ratio about the mean versus travel speed for two different hydrogen concentrations. From this plot, it is seen that the error in measuring the ratio is on the order of ±10%. It should be noted that from Figure 9 this error is approximately the same error that is expected if travel speed is not varied.

From the preceding analysis it appears that there is a linear relationship between the intensity ratio and the concentration of hydrogen gas in the shield gas mixture. Thus once the best-fit line to a series of test data points has

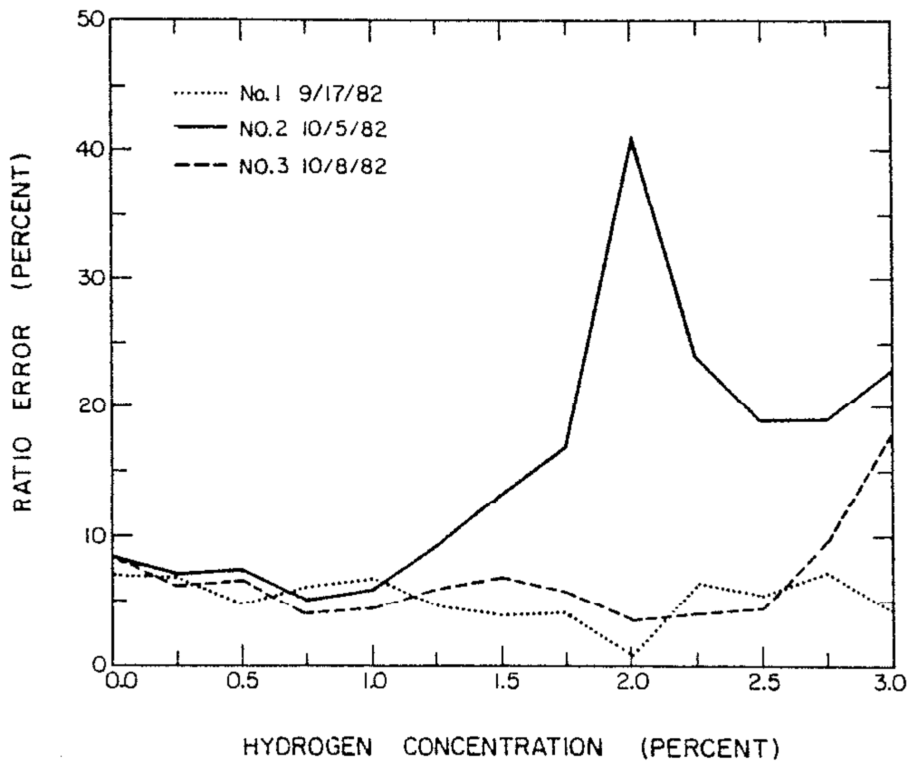

Figure 9. Ratio error versus hydrogen concentration.

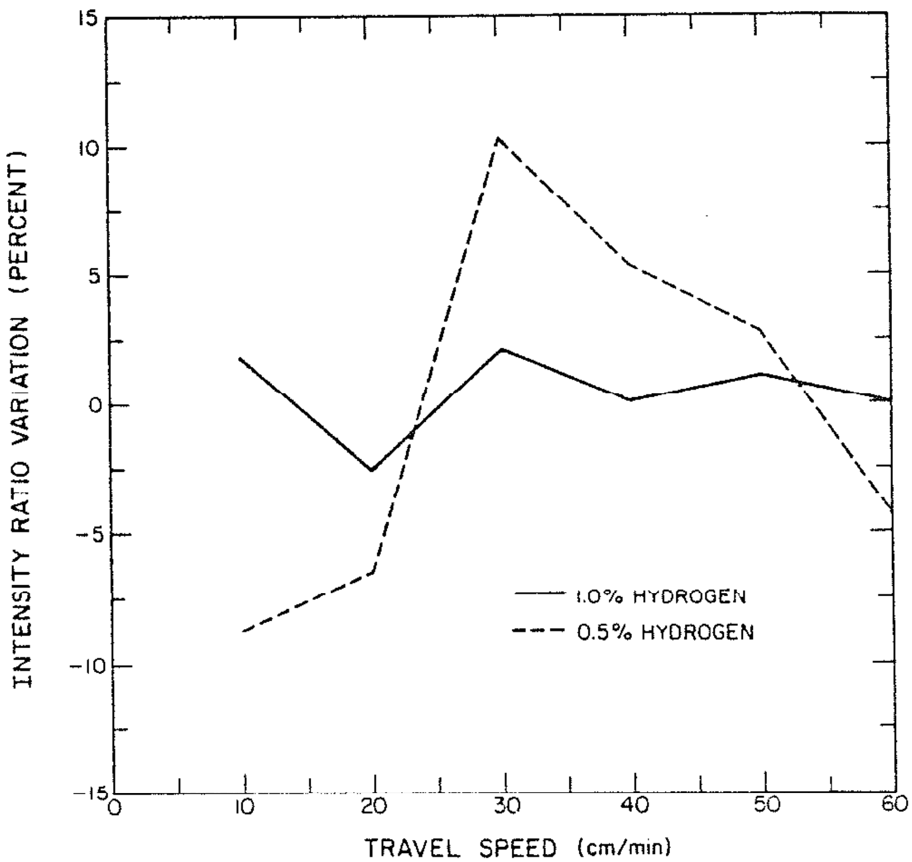

Figure 10. Intensity ratio variation versus travel speed.

been found, the actual hydrogen concentration of an unknown shield gas mixture can be found by substituting the observed intensity ratio into the best-fit line equation. It should be noted that hydrogen introduced from sources other than the shield gas will also be detected and measured by this system.

E. Interference Filter Based H Monitor

The monochromator based hydrogen monitor is an excellent research tool. However, the monochromator, detector array, and computer are expensive. As an alternative, optical interference filters and photodetectors can be used to measure the appropriate line intensities. In an interference filter based system, light from the weld plasma would be passed through each of three filters centered at 6563 Å, 6965 Å, and 6800 Å, respectively, corresponding to the three regions of the spectrum required for hydrogen monitoring. A photodetector positioned behind each interference filter would convert the light intensity to an analog voltage which could then be processed by either simple analog electronics, or a small microprocessor, to compute the hydrogen concentration in the weld plasma.

Optical interference filters are composed of layers of dielectric materials with differing indices of refraction. An interference filter is essentially a series of Fabry Perot interferometers stacked end to end [12]. By controlling the thickness and index of refraction of each layer, it is possible to tailor the transmittance function of the filter. If the bandwidth of the filter is very narrow (less than 10 Å), the filter must be temperature stabilized to prevent drift in the passband. In addition, narrow band filters require the input light to be collimated. These inconveniences can be avoided by working with filters having full width at half maximum (FWHM) bandwidths that are greater than 10 Å. The transmittance characteristics of an optical interference filter can be modeled as a Gaussian function.

$$f(\lambda) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(\lambda-\lambda_c)/2\sigma^2} \quad (15)$$

where

$\sigma = \frac{B}{2\sqrt{2\,\ell n 2}}$

λ_c = center wavelength

σ = RMS bandwidth

B = FWHM bandwidth

If the uniform filter functions in Equation (14) are replaced with Gaussian filter functions, the operation of the interference filter based hydrogen monitor can be simulated with the spectra used earlier. We assume that the three filters all have the same bandwidth. Systems using filters with bandwidths of 10 Å, 20 Å, 50 Å, and 100 Å FWHM were simulated using data set #1. The intensity ratio, R, is plotted versus hydrogen concentration in Figure 11. Notice that as the filter width is increased, the ratio increases, and nonlinearities become more apparent. These effects occur because as the filter bandwidth increases, interfering lines near the desired hydrogen and argon lines have a greater effect on the ratio. More importantly, from the plot of the normalized standard deviation shown in Figure 12, we see that the error increases significantly as the filter FWHM width is increased. From Figures 11 and 12 it appears that filter bandwidths of between 10 Å and 20 Å FWHM should result in a hydrogen monitor which performs almost as well as the monochrometer based hydrogen system.

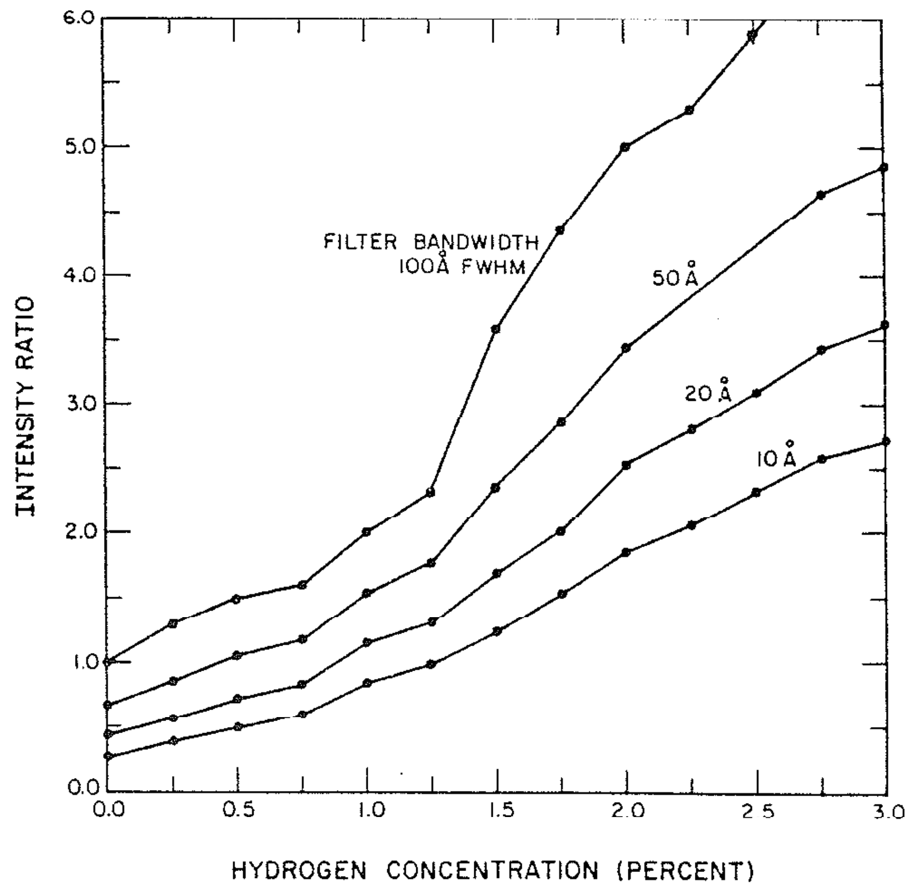

Figure 11. Intensity ratio versus hydrogen concentration.

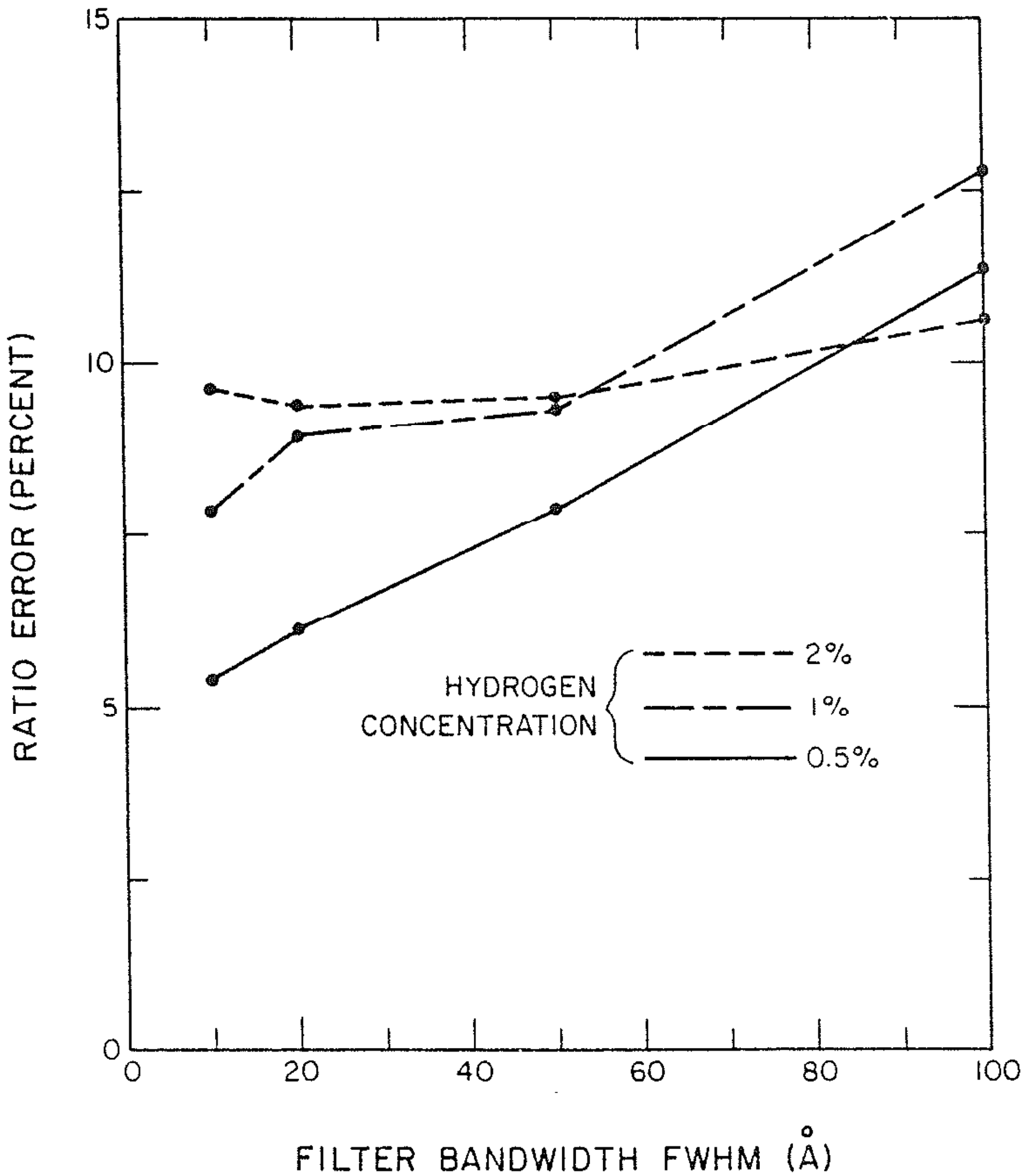

Figure 12. Ratio error versus filter bandwidth.

V. CONCLUSIONS

The spectroscopic technique described in this paper is capable of measuring the absolute hydrogen concentration in weld arc plasmas at concentration levels which have been shown to cause weld failure (0.1 - 0.2% of the shield gas). The measurement accuracy is approximately 10%. Since the method is a real-time technique, hydrogen contamination problems can be spotted and corrected as the weld is being made, thus reducing costly rework. The cost of the interference filter based hydrogen monitor should be low enough to allow its general use when welding steels which are susceptible to hydrogen embrittlement.

Although our experiments were conducted by mixing known concentrations of hydrogen gas with the shield gas, this spectroscopic technique will measure the hydrogen from all sources including water and lubricants. It should also be possible to adapt the technique to other welding configurations which use different shield gasses or flux bearing electrodes. If argon is not present in the shield gas, an emission line from a different element will have to be used to normalize the hydrogen line intensity. This will result in a different relation between the intensity ratio and hydrogen concentration. However, by properly choosing the normalizing line, it should be possible to obtain a nearly linear variation of the line ratio with respect to hydrogen concentration.

The same spectroscopic techniques developed for detecting hydrogen can also be used for detecting many other impurities which affect weld quality. For example, by tuning the monochrometer to a prominent oxygen spectral line, we have detected oxygen contamination in titanium welding. The system has also been used to detect loss of shield gas [4] and to detect flux voids while welding with flux core electrodes.

In summary, the optical techniques described in this paper provide an effective research tool for studying the physics and chemistry of welding, while at the same time offer the prospect of improved weld quality and, hence, reduced cost in commercial welding.

APPENDIX A

SIGNAL PROCESSING SOFTWARE

A.1. Main Program

```
C*****************************************************************************
C        PROGRAM SPSTAT                                                       *
C        BY JIM SHEA          AUGUST 3,1982                                   *
C                                                                             *
C      THIS PROGRAM CALCULATES THE STATISTICS AND RATIOS OF                   *
C      SPECTRAL DATA.  IT WILL RATIO ONE LINE WITH UP TO                      *
C      FOUR OTHER LINES                                                       *
C                                                                             *
C*****************************************************************************
C                                                                             *
C        VARIABLES:                                                           *
C                IDATA  INTEGER ARRAY USED TO HOLD A DATA SCAN.               *
C                                                                             *
C                BAKDIO: THE BACKGROUND DIODE NUMBER.                         *
C                INTBAK: NUMBER OF DIODES INTEGRATED ABOUT THE                *
C                BACKGROUND                                                   *
C                                                                             *
C                LINDIO: THE LINE DIODE NUMBER.                               *
C                INTLIN: NUMBER OF DIODES INTEGRATED ABOUT THE                *
C                LINE DIODE.                                                  *
C                                                                             *
C                RATDIO: ARRAY USED TO HOLD THE FOUR RATIO DIODES.            *
C                INTRAT: ARRAY USED TO HOLD THE NUMBER OF DIODES              *
C                INTEGRATED ABOUT THE RATIO DIODE.                            *
C                                                                             *
C*****************************************************************************
C
        COMMON/ARRAY/IDATA
        INTEGER INTDIO,INTLIN,INTRAT(4)
        INTEGER IDATA(1024),BAKDIO,LINDIO,RATDIO(4)
C
        BYTE LFILE(6)
C
        REAL INTEG,BACKGN(100),LINE(100),TEMP(100),RATIO(4,100)
        REAL MEAN1,MEAN2(4),STD1,STD2(4),RI(4),MEANL,MEANB
        REAL RMEAN(4),RSTD(4),MEAN,STD,MAXRAT(4),MINRAT(4)
C
C
C
C       SET THE REGION OF THE SPECTRUM TO BE USED FOR
C       THE BACKGROUND CALCULATION
C
        BAKDIO=920
        INTBAK=10
C
C       GET THE FILE NAME
C
        TYPE 100
100     FORMAT(/' ENTER THE FILE NAME: '$)
        ACCEPT 200,(LFILE(I),I=1,6)
200     FORMAT(6A1)
C
```

```
C       GET THE DIODE NUMBER OF THE WAVELENGTH OF INTEREST
C
        TYPE 101
101     FORMAT(/' ENTER THE DIODE NUMBER OF THE LINE OF INTEREST:'$)
        ACCEPT 201,LINDIO
201     FORMAT(I4)
        TYPE 102
102     FORMAT(' HOW MANY DIODES SHOULD BE INTEGRATED ON EITHER SIDE ',
     X   'OF THE LINE:'$)
        ACCEPT 202,INTLIN
202     FORMAT(I4)
C
C
C       GET THE LINES TO BE USED FOR AVERAGING.  UP TO FOUR
C       LINES MAY BE USED.  DATA ENTRY IS STOPPED WHEN A
C       RETURN IS ENTERED WITHOUT ANY DATA.
C
        TYPE 103
103     FORMAT(/' ENTER THE DIODE NUMBERS OF THE LINES TO BE',
     X   ' USED FOR AVERAGING.',/,' TO STOP DATA ENTRY ENTER',
     X   ' A RETURN')
        NUMRAT=0
10      NUMRAT=NUMRAT+1
        TYPE 104,NUMRAT
104     FORMAT('  RATIO DIODE NUMBER',I2,':'$)
        ACCEPT 203,RATDIO(NUMRAT)
203     FORMAT(I4)
        IF(RATDIO(NUMRAT).EQ.0) GO TO 22
        TYPE 300
300     FORMAT(' NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE',
     X   ' OF THE LINE :'$)
        ACCEPT 400,INTRAT(NUMRAT)
400     FORMAT(I4)
22      IF((NUMRAT.NE.4).AND.(RATDIO(NUMRAT).NE.0)) GO TO 10
        IF(NUMRAT.NE.4)NUMRAT=NUMRAT-1
        IF((NUMRAT.EQ.4).AND.(RATDIO(4).EQ.0)) NUMRAT=3
C
C
C       SEE IF THE BACKGROUND REGION SHOULD BE CHANGED
C
        TYPE 1000
1000    FORMAT(/,' DO YOU WANT TO USE A NON-DEFAULT BACKGROUND REGION :'$)
        ACCEPT 1001,IBAK
1001    FORMAT(A1)
        IF(IBAK.NE.'Y') GO TO 600
        TYPE 1002
1002    FORMAT(' ENTER THE BACKGROUND DIODE NUMBER:'$)
        ACCEPT 1003,BAKDIO
1003    FORMAT(I4)
        TYPE 1004
1004    FORMAT(' ENTER INTEGRATION RANGE:'$)
        ACCEPT 1003,INTBAK
```

```
C
C       EXTRACT THE DATA FROM THE FILE
C
600     ISCAN=1
20      CALL READIT(LFILE,ISCAN-1,IDATA,FILEND)
        IF(FILEND.EQ.0.) GO TO 30
        CALL CONV(IDATA)
        BACKGN(ISCAN)=INTEG(BAKDIO,INTBAK)
        LINE(ISCAN)=INTEG(LINDIO,INTLIN)
        DO 25 I=1,NUMRAT
           RATIO(I,ISCAN)=INTEG(RATDIO(I),INTRAT(I))
25      CONTINUE
        ISCAN=ISCAN+1
        GO TO 20
30      ISCAN=ISCAN-1
C
C
C******* SUBTRACT THE BIAS ********************
C
C
        DO 700 I=1,ISCAN
           LINE(I)=LINE(I)-BACKGN(I)
           IF(LINE(I).LT.0.) TYPE 701,I-1
701        FORMAT(' LINE WENT BELOW BACKGROUND ON SCAN',I3)
           DO 800 J=1,NUMRAT
              RATIO(J,I)=RATIO(J,I)-BACKGN(I)
              IF(RATIO(J,I).LT.0.) TYPE 702,J,I-1
702           FORMAT(' RATIO LINE DIODE NUM',I4,'WENT BELOW BACK',
     X        'GROUND ON SCAN',I3)
800        CONTINUE
700     CONTINUE
C
C       CALCULATE THE STATISTICS AND RATIOS
C
        DO 50 I=1,NUMRAT
           DO 70 J=1,ISCAN
              TEMP(J)=RATIO(I,J)
70         CONTINUE
           CALL CORREL(ISCAN,LINE,TEMP,MEAN1,MEAN2(I),STD1,STD2(I),RI(I))
50      CONTINUE
        CALL CORREL(ISCAN,LINE,BACKGN,MEANL,MEANB,STDL,STDB,R)
C
C
C       CALCULATE RATIOED MEANS AND STANDARD DEVIATIONS
C
        DO 80 I=1,NUMRAT
           DO 85 J=1,ISCAN
              RATIO(I,J)=LINE(J)/RATIO(I,J)
85         CONTINUE
           DO 900 K=1,ISCAN
              TEMP(K)=RATIO(I,K)
900        CONTINUE
```

```
          CALL CORREL(ISCAN,LINE,TEMP,MEAN,RMEAN(I),STD,RSTD(I),RJUNK)
80      CONTINUE
C
C       FIND THE MAXIMUM AND MINIMUM VALUE OF THE RATIOED DATA
C
        DO 601 I=1,NUMRAT
          MAXRAT(I)=0.
          MINRAT(I)=100000.
          DO 610 J=1,ISCAN
            IF(MAXRAT(I).LT.RATIO(I,J)) MAXRAT(I)=RATIO(I,J)
            IF(MINRAT(I).GT.RATIO(I,J)) MINRAT(I)=RATIO(I,J)
610       CONTINUE
601     CONTINUE
C
C
C       DISPLAY THIS WONDERFUL DATA
C
C
        TYPE 110
110     FORMAT(//'  ****** UNRATIOED STATISTICS *****')
        TYPE 111,MEANL
111     FORMAT('       MEAN OF LINE OF INTEREST :',F9.3)
        TYPE 112,STD1
112     FORMAT('       STANDARD DEVIATION OF LINE OF INTEREST :',F8.3)
        TYPE 412,STD1/MEANL
412     FORMAT('                   NORMALIZED STANDARD DEVIATION :',F8.4)
        TYPE 113
113     FORMAT('  STATISTICS OF LINES USED FOR RATIOING')
        TYPE 114,(RATDIO(I),I=1,NUMRAT)
114     FORMAT('         DIODE NUMBER OF RATIO LINE',I8,3I12)
        TYPE 115,(MEAN2(I),I=1,NUMRAT)
115     FORMAT(10X,'                         MEAN',F8.3,3F12.3)
        TYPE 116,(STD2(I),I=1,NUMRAT)
116     FORMAT(10X,'      STANDARD DEVIATION',F8.3,3F12.3)
        TYPE 416,(STD2(I)/MEAN2(I),I=1,NUMRAT)
416     FORMAT(3X,' NORMALIZED STANDARD DEVIATION',F8.4,3F12.4)
        TYPE 117,(RI(I),I=1,NUMRAT)
117     FORMAT(10X,'CORRELATION COEFFICIENT',F8.4,3F12.4)
        TYPE 118
118     FORMAT(/'  ***** RATIOED DATA *****')
        TYPE 119,(RATDIO(I),I=1,NUMRAT)
119     FORMAT(' DIODE NUMBER OF RATIO LINE:',I8,3I12)
        TYPE 620,(MAXRAT(I),I=1,NUMRAT)
620     FORMAT(4X,'  MAXIMUM OF THE RATIOS:',F8.4,3F12.4)
        TYPE 630,(MINRAT(I),I=1,NUMRAT)
630     FORMAT(4X,'  MINIMUM OF THE RATIOS:',F8.4,3F12.4)
        TYPE 120,(RMEAN(I),I=1,NUMRAT)
120     FORMAT(4X,'                        MEAN',F8.4,3F12.4)
        TYPE 121,(RSTD(I),I=1,NUMRAT)
121     FORMAT(4X,'        STANDARD DEVIATION',F8.4,3F12.4)
        TYPE 421,((RSTD(I)/RMEAN(I)),I=1,NUMRAT)
421     FORMAT(' NORMALIZED STANDARD DEVIATION',F6.4,3F12.4)
```

```
C
C
C       SEE IF THE DATA SHOULD BE GATHERED ON A DIFFERENT FILE
C
        TYPE 130
130     FORMAT(/' DO YOU WANT TO CALCULATE THESE STATISTICS FOR A ',
     X 'DIFFERENT FILE? '$)
        ACCEPT 230,IANS
230     FORMAT(A1)
        IF(IANS.NE.'Y') GO TO 500
        TYPE 140
140     FORMAT(' ENTER THE FILE NAME: '$)
        ACCEPT 240,(LFILE(I),I=1,6)
240     FORMAT(6A1)
        GO TO 600
500     CALL EXIT
        END
```

A.2. Correlation Routine

```
C*********************************************************************
C                                                                    *
C       SUBROUTINE CORREL                                            *
C                                                                    *
C           BY JIM SHEA         AUGUST 5,1982                        *
C                                                                    *
C*********************************************************************
C                                                                    *
C       THIS SUBROUTINE PERFORMS A CORRELATION ON A DATA             *
C       SET OF UP TO 100 POINTS.  IT RETURNS THE CORRELATION         *
C       COEFFICIENT, MEANS, AND STANDARD DEVIATIONS.                 *
C                                                                    *
C*********************************************************************
C
        SUBROUTINE CORREL(N,ARRAY1,ARRAY2,MEAN1,MEAN2,STD1,STD2,R)
        REAL X,Y,XY,X2,Y2,ARRAY1(100),ARRAY2(100)
        REAL MEAN1,MEAN2
C
        X=0.
        Y=0.
        XY=0.
        X2=0.
        Y2=0.
C
        DO 10 I=1,N
           X=ARRAY1(I)+X
           Y=ARRAY2(I)+Y
           XY=ARRAY1(I)*ARRAY2(I)+XY
           X2=ARRAY1(I)**2+X2
           Y2=ARRAY2(I)**2+Y2
10      CONTINUE
        SCAN=FLOAT(N)
        MEAN1=X/SCAN
        MEAN2=Y/SCAN
        STD1=SQRT((X2-X**2/SCAN)/(SCAN-1.))
        STD2=SQRT((Y2-Y**2/SCAN)/(SCAN-1.))
        R=(XY-(X*Y)/SCAN)/(SCAN-1.)
C       IF STD1=0 OR STD2=0 WE HAVE A DETERMINISTIC SYSTEM.
        IF((STD1.LT.1E-10).OR.(STD2.LT.1E-10)) GO TO 20
        R=R/(STD1*STD2)
        RETURN
20      R=10
        RETURN
        END
```

A.3. Integration Function

```
C*****************************************************************
C                                                                *
C       FUNCTION SUBROUTINE INTEG                                *
C                                                                *
C               BY JIM SHEA AUGUST 5,1982                        *
C                                                                *
C*****************************************************************
C
C
C       THIS FUNCTION INTEGRATES THE DIODES AND RETURNS A REAL
C       RESULT.
C
        REAL FUNCTION INTEG(CNTR,INT)
        INTEGER INT,CNTR,IDATA(1024)
        COMMON/ARRAY/IDATA
C
        IF((CNTR-12).GT.INT) GO TO 10
        TYPE 100
100     FORMAT(' INTEGRATION ERROR')
C
10      INTEG=0.
        DO 20 I=(CNTR-INT),(CNTR+INT)
           INTEG=INTEG+FLOAT(IDATA(I))
20      CONTINUE
        INTEG=INTEG/FLOAT(2*INT+1)
        RETURN
        END
```

A.4. Filter Function

```
C*************************************************************
C
C       FUNCTION SUBROUTINE INTEG
C
C             BY JIM SHEA AUGUST 5,1982
C
C*************************************************************
C
C
C       THIS FUNCTION APPLIES A GAUSSIAN FILTER TO THE DIODES
C       AND RETURNS A REAL RESULT.
C
        REAL FUNCTION INTEG(CNTR,FWHM)
        INTEGER INT,CNTR,IDATA(1024),BAKDIO
        COMMON/ARRAY/IDATA
        COMMON/NOSP/BAKDIO
C
C       CALCULATE SIGMA IN ANGSTROMS
C
        SIGMA=FWHM/2.354
        INTEG=0.
        DO 10 I=CNTR-6*IFIX(SIGMA),CNTR+6*IFIX(SIGMA)
           TEMP=(FLOAT(I-CNTR)*.52)**2/(2.*(SIGMA**2))
           TEMP=.39894*(1./SIGMA)*EXP(-TEMP)
           IF((I.LT.12).OR.(I.GT.1023)) GO TO 20
           INTEG=INTEG+IDATA(I)*TEMP
           GO TO 10
 20        INTEG=INTEG+IDATA(BAKDIO)*TEMP
 10     CONTINUE
        RETURN
        END
```

A.5. Disk Read Routine

```
      SUBROUTINE READIT (LFILE,SCAN,IDATA,FILEND)
C THIS SUBROUTINE READS A FILE FROM DISK.
      INTEGER SCAN,DBLK(4),IDATA(1024)
      BYTE LFILE(6)
C
      DATA IDNAM/3RDM/
      DATA DBLK(1)/3RDM1/,DBLK(4)/3RDAT/
C
      FILEND=1.
C
CCALCULATE BLOCK NUMBER FROM SCAN NUMBER.
      ISCAN=SCAN*4
      CALL IRAD50(6,LFILE,DBLK(2))
C GET THE DISK HANDLER
      IF(IFETCH(IDNAM).NE.0) STOP 'FETCH ERROR'
C ALLOCATE CHANNEL FOR DATA TRANSFER.
      ICHAN=IGETC()
C CHECK FOR CHANNEL ALLOCATION ERROR
      IF(ICHAN.LT.0) STOP 'CHANNEL ALLOCATION ERROR'
C FIND THE FILE IN THE DISK
      IF(LOOKUP(ICHAN,DBLK).LT.0)  STOP ' LOOKUP ERROR'

C READ THE FILE AND STORE IT IN IDATA AND CHECK FOR ERRORS
      IF(IREADW(1024,IDATA,ISCAN,ICHAN).LT.0) GO TO 10
C
C CLOSE THE CHANNEL
      CALL CLOSEC(ICHAN)
      CALL IFREEC(ICHAN)
C
      RETURN
C
C  SET FILEND (END OF DATA TO 0)
10    FILEND=0.
      CALL CLOSEC(ICHAN)
      CALL IFREEC(ICHAN)
      RETURN
      END
C
C
C--------------------------------------------------------------
C
C       SUBROUTINE CONV(IDATA)
C  THIS SUBROUTINE CONVERTS DATA FROM THE ADAC A/D REPRESENTATION
C  TO INTEGER FORMAT.
C
      SUBROUTINE CONV(IDATA)
C
      INTEGER*2 IDATA(1024)
C
      DO 10 I=12,1024
         IDATA(I)=-IDATA(I)/IDATA(7)*4.38
```

```
       IF(IDATA(I).LE.0) IDATA(I)=IDATA(I)+4096*4.88
10    CONTINUE
      RETURN
      END
```

APPENDIX B

STATISTICAL ANALYSIS OF SPECTRAL DATA

B.1. Variation of Hydrogen Concentration in Shield Gas

B.1.1. Data Set No. 1

B.1.2. Data Set No. 2

B.1.3. Data Set No. 3

B.2. Variation of Travel Speed

B.2.1. 1 Percent Hydrogen

B.2.2. 0.5 Percent Hydrogen

B.3. Filter Simulation on Data Set No. 1

B.3.1. 10 Å Filter

B.3.2. 20 Å Filter

B.3.3. 50 Å Filter

B.3.4. 100 Å Filter

B.1. Variation of Hydrogen Concentration in Shield Gas

B.1.1. Data Set No. 1

File Name	Hydrogen Concentration (%)
HD00	0.00
HD01	0.25
HD02	0.50
HD03	0.75
HD04	1.00
HD05	1.25
HD06	1.50
HD07	1.75
HD08	2.00
HD09	2.25
HD10	2.50
HD11	2.75
HD12	3.00

Element	Wavelength (Å)	Diode Number
Iron	6494.98	77
Hydrogen	6563.82	204
Iron	6677.99	421
Argon	6752.83	564
Argon	6965.43	974

```
.RUN MANYSP

ENTER THE FILE NAME: HD

ENTER THE DIODE NUMBER OF THE LINE OF INTEREST:204
HOW MANY DIODES SHOULD BE INTEGRATED ON EITHER SIDE OF THE LINE:7

ENTER THE DIODE NUMBERS OF THE LINES TO BE USED FOR AVERAGING.
TO STOP DATA ENTRY ENTER A RETURN
 RATIO DIODE NUMBER 1:564
NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE  OF THE LINE :7
 RATIO DIODE NUMBER 2:974
NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE  OF THE LINE :7
 RATIO DIODE NUMBER 3:77
NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE  OF THE LINE :7
 RATIO DIODE NUMBER 4:421
NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE  OF THE LINE :7
DO YOU WANT TO USE A NON-STANDARD BACKGROUND REGION :Y
ENTER THE BACKGROUND DIODE NUMBER:625
ENTER THE NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE OF THE LINE:10


     FILE NAME : HD00

  ****** UNRATIOED STATISTICS *****
      MEAN OF LINE OF INTEREST : 137.775
      STANDARD DEVIATION OF LINE OF INTEREST :  12.867
               NORMALIZED STANDARD DEVIATION :  0.0934
 STATISTICS OF LINES USED FOR RATIOING
        DIODE NUMBER OF RATIO LINE     564         974          77          421
                              MEAN  93.061     611.964     249.497      103.909
                STANDARD DEVIATION   7.824      42.251      51.049       20.807
    NORMALIZED STANDARD DEVIATION  0.0841      0.0690      0.2046       0.2002
           CORRELATION COEFFICIENT  0.7665      0.6583      0.6772       0.7207

  ***** RATIOED DATA *****
 DIODE NUMBER OF RATIO LINE:       564          974          77          421
      MAXIMUM OF THE RATIOS:  1.7362       0.2674      0.7925      1.7910
      MINIMUM OF THE RATIOS:  1.2987       0.1841      0.4167      1.0086
                       MEAN   1.4817       0.2253      0.5694      1.3644
          STANDARD DEVIATION  0.0914       0.0167      0.0946      0.2157
 NORMALIZED STANDARD DEVIATIONO.0617       0.0740      0.1661      0.1581
```

FILE NAME : HD01

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 299.327

STANDARD DEVIATION OF LINE OF INTEREST : 26.166

NORMALIZED STANDARD DEVIATION : 0.0874

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	564	974	77	421
MEAN	160.956	938.247	383.171	153.339
STANDARD DEVIATION	11.304	68.115	73.302	29.000
NORMALIZED STANDARD DEVIATION	0.0702	0.0726	0.1913	0.1891
CORRELATION COEFFICIENT	0.8777	0.6921	-0.6336	-0.5997

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	564	974	77	421
MAXIMUM OF THE RATIOS:	2.0739	0.4050	1.6558	4.0938
MINIMUM OF THE RATIOS:	1.6460	0.2764	0.5052	1.3064
MEAN	1.8589	0.3193	0.8215	2.0569
STANDARD DEVIATION	0.0803	0.0218	0.2312	0.6073
NORMALIZED STANDARD DEVIATION	0.0432	0.0683	0.2814	0.2952

FILE NAME : HD02

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 283.828

STANDARD DEVIATION OF LINE OF INTEREST : 20.839

NORMALIZED STANDARD DEVIATION : 0.0734

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	564	974	77	421
MEAN	111.560	701.944	329.752	135.580
STANDARD DEVIATION	7.905	50.596	53.986	19.980
NORMALIZED STANDARD DEVIATION	0.0709	0.0721	0.1642	0.1474
CORRELATION COEFFICIENT	0.8961	0.7812	0.2227	0.2569

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	564	974	77	[illegible]
MAXIMUM OF THE RATIOS:	2.8039	0.4513	1.2380	2.8484
MINIMUM OF THE RATIOS:	2.3933	0.3647	0.6245	1.5541
MEAN	2.5451	0.4047	0.8847	2.1332
STANDARD DEVIATION	0.0841	0.0197	0.1490	0.3173
NORMALIZED STANDARD DEVIATION	0.0331	0.0488	0.1684	0.1488

FILE NAME : HD03

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 384.708

STANDARD DEVIATION OF LINE OF INTEREST : 34.348

NORMALIZED STANDARD DEVIATION : 0.0893

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	564	974	77	421
MEAN	120.015	775.598	313.426	130.207
STANDARD DEVIATION	9.174	48.915	31.066	13.248
NORMALIZED STANDARD DEVIATION	0.0764	0.0631	0.0991	0.1017
CORRELATION COEFFICIENT	0.8157	0.7546	0.4136	0.3024

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	564	974	77	421
MAXIMUM OF THE RATIOS:	4.0774	0.6380	1.4461	3.7367
MINIMUM OF THE RATIOS:	2.9218	0.4537	0.9341	2.1990
MEAN	3.2063	0.4959	1.2344	2.9757
STANDARD DEVIATION	0.1697	0.0299	0.1203	0.3274
NORMALIZED STANDARD DEVIATION	0.0529	0.0603	0.0975	0.1100

FILE NAME : HD04

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 707.599

STANDARD DEVIATION OF LINE OF INTEREST : 63.945

NORMALIZED STANDARD DEVIATION : 0.0904

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	564	974	77	421
MEAN	163.269	973.485	323.460	133.690
STANDARD DEVIATION	11.843	76.782	62.781	26.577
NORMALIZED STANDARD DEVIATION	0.0725	0.0789	0.1941	0.1988
CORRELATION COEFFICIENT	0.7332	0.5033	-0.6266	-0.4844

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	564	974	77	421
MAXIMUM OF THE RATIOS:	5.4433	1.0194	3.6516	8.3753
MINIMUM OF THE RATIOS:	3.8280	0.6124	1.0487	2.4026
MEAN	4.3331	0.7292	2.2931	5.5513
STANDARD DEVIATION	0.2879	0.0684	0.5746	1.3720
NORMALIZED STANDARD DEVIATION	0.0664	0.0938	0.2506	0.2472

FILE NAME : HD05

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 719.343

STANDARD DEVIATION OF LINE OF INTEREST : 32.558

NORMALIZED STANDARD DEVIATION : 0.0453

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	564	974	77	421
MEAN	136.437	860.171	311.285	131.487
STANDARD DEVIATION	7.619	36.887	31.006	12.918
NORMALIZED STANDARD DEVIATION	0.0558	0.0429	0.0996	0.0982
CORRELATION COEFFICIENT	0.5638	0.4343	0.3449	0.2697

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	564	974	77	421
MAXIMUM OF THE RATIOS:	6.1413	0.9938	2.9647	6.7995
MINIMUM OF THE RATIOS:	4.7482	0.7586	1.9199	4.5620
MEAN	5.2816	0.8372	2.3306	5.5183
STANDARD DEVIATION	0.2610	0.0408	0.2264	0.5518
NORMALIZED STANDARD DEVIATION	0.0494	0.0487	0.0972	0.1000

FILE NAME : HD06

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 675.676

STANDARD DEVIATION OF LINE OF INTEREST : 58.541

NORMALIZED STANDARD DEVIATION : 0.0866

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	564	974	77	421
MEAN	121.131	650.846	498.933	206.711
STANDARD DEVIATION	9.188	55.633	35.695	17.631
NORMALIZED STANDARD DEVIATION	0.0758	0.0855	0.0715	0.0853
CORRELATION COEFFICIENT	0.8829	0.8894	-0.0755	-0.0056

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	564	974	77	421
MAXIMUM OF THE RATIOS:	6.3006	1.1237	2.0455	4.9929
MINIMUM OF THE RATIOS:	5.2092	0.9505	1.1064	2.7469
MEAN	5.5777	1.0389	1.3625	3.2949
STANDARD DEVIATION	0.2251	0.0417	0.1730	0.4439
NORMALIZED STANDARD DEVIATION	0.0404	0.0402	0.1270	0.1347

FILE NAME : HD07

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 704.242

STANDARD DEVIATION OF LINE OF INTEREST : 69.095

NORMALIZED STANDARD DEVIATION : 0.0981

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	564	974	77	421
MEAN	101.851	554.259	432.321	172.825
STANDARD DEVIATION	10.450	61.511	38.370	16.802
NORMALIZED STANDARD DEVIATION	0.1026	0.1110	0.0888	0.0972
CORRELATION COEFFICIENT	0.8470	0.9402	-0.0454	0.0465

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	564	974	77	421
MAXIMUM OF THE RATIOS:	7.9554	1.4020	2.4874	6.1464
MINIMUM OF THE RATIOS:	6.0349	1.1856	1.1782	2.9515
MEAN	6.9289	1.2733	1.6421	4.1106
STANDARD DEVIATION	0.3896	0.0506	0.2241	0.5586
NORMALIZED STANDARD DEVIATION	0.0562	0.0398	0.1365	0.1359

FILE NAME : HD08

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 857.252

STANDARD DEVIATION OF LINE OF INTEREST : 72.032

NORMALIZED STANDARD DEVIATION : 0.0840

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	564	974	77	421
MEAN	97.065	543.973	400.770	160.923
STANDARD DEVIATION	11.677	70.072	46.928	22.841
NORMALIZED STANDARD DEVIATION	0.1203	0.1288	0.1171	0.1419
CORRELATION COEFFICIENT	0.6542	0.7027	0.1758	0.2447

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	564	974	77	421
MAXIMUM OF THE RATIOS:	11.1584	2.0253	3.0207	7.2348
MINIMUM OF THE RATIOS:	7.3677	1.3819	1.6314	3.9502
MEAN	8.9034	1.5912	2.1653	5.4212
STANDARD DEVIATION	0.8487	0.1592	0.2943	0.8176
NORMALIZED STANDARD DEVIATION	0.0953	0.1001	0.1359	0.1508

FILE NAME : HD09

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 888.800

STANDARD DEVIATION OF LINE OF INTEREST : 130.986

NORMALIZED STANDARD DEVIATION : 0.1474

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	564	974	77	421
MEAN	86.412	503.994	319.554	[illegible]
STANDARD DEVIATION	15.616	83.887	53.164	21.816
NORMALIZED STANDARD DEVIATION	0.1807	0.1664	0.1664	0.1748
CORRELATION COEFFICIENT	0.8758	0.9191	0.4834	0.5143

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	564	974	77	421
MAXIMUM OF THE RATIOS:	13.1722	2.0226	4.0447	10.0063
MINIMUM OF THE RATIOS:	8.7826	1.5802	2.1169	5.3944
MEAN	10.3947	1.7727	2.8225	7.2385
STANDARD DEVIATION	0.9587	0.1142	0.4538	1.1534
NORMALIZED STANDARD DEVIATION	0.0922	[illegible]	0.1608	0.1593

FILE NAME : HD10

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST :1091.270

STANDARD DEVIATION OF LINE OF INTEREST : 154.739

NORMALIZED STANDARD DEVIATION : 0.1418

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	564	974	77	421
MEAN	98.122	554.735	386.627	154.668
STANDARD DEVIATION	13.934	81.128	51.702	24.302
NORMALIZED STANDARD DEVIATION	0.1420	0.1462	0.1337	0.1571
CORRELATION COEFFICIENT	0.8825	0.9293	0.1680	0.2175

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	564	974	77	421
MAXIMUM OF THE RATIOS:	13.2840	2.2976	3.7824	9.8355
MINIMUM OF THE RATIOS:	9.3293	1.7646	2.0492	5.0631
MEAN	11.1531	1.9724	2.8678	7.2057
STANDARD DEVIATION	0.7643	0.1112	0.5197	1.3864
NORMALIZED STANDARD DEVIATION	0.0685	0.0564	0.1812	0.1924

FILE NAME : HD11

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST :1144.680

STANDARD DEVIATION OF LINE OF INTEREST : 167.743

NORMALIZED STANDARD DEVIATION : 0.1465

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	564	974	77	421
MEAN	86.662	520.158	299.674	118.789
STANDARD DEVIATION	13.165	89.891	29.701	13.436
NORMALIZED STANDARD DEVIATION	0.1519	0.1728	0.0991	0.1131
CORRELATION COEFFICIENT	0.9360	0.9196	0.2692	0.3885

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	564	974	77	421
MAXIMUM OF THE RATIOS:	15.5657	2.8605	5.1697	12.4413
MINIMUM OF THE RATIOS:	11.6925	1.9404	2.7450	7.2993
MEAN	13.2429	2.2150	3.8413	9.6981
STANDARD DEVIATION	0.7699	0.1642	0.5738	1.3990
NORMALIZED STANDARD DEVIATION	0.0581	0.0741	0.1494	0.1443

FILE NAME : HD12

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST :1442.935

STANDARD DEVIATION OF LINE OF INTEREST : 169.586

NORMALIZED STANDARD DEVIATION : 0.1175

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	564	974	77	421
MEAN	108.956	623.079	418.244	175.411
STANDARD DEVIATION	12.825	80.844	37.237	17.298
NORMALIZED STANDARD DEVIATION	0.1177	0.1297	0.0890	0.0986
CORRELATION COEFFICIENT	0.9330	0.9503	0.4447	0.5345

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	564	974	77	421
MAXIMUM OF THE RATIOS:	14.6190	2.5696	4.3395	10.1174
MINIMUM OF THE RATIOS:	12.0312	2.0881	2.7890	6.5569
MEAN	13.2577	2.3220	3.4603	8.2534
STANDARD DEVIATION	0.5678	0.0987	0.3924	0.8847
NORMALIZED STANDARD DEVIATION	0.0420	0.0425	0.1134	0.1072

B.1.2. Data Set No. 2

File Name	Hydrogen Concentration (%)
HL00	0.00
HL01	0.25
HL02	0.50
HL03	0.75
HL04	1.00
HL05	1.25
HL06	1.50
HL07	1.75
HL08	2.00
HL09	2.25
HL10	2.50
HL11	2.75
HL12	3.00

Element	Wavelength (Å)	Diode Number
Iron	6494.98	77
Hydrogen	6563.82	204
Iron	6677.99	421
Argon	6752.83	562
Argon	6965.43	972

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.RUN MANYSP

ENTER THE FILE NAME: HL

ENTER THE DIODE NUMBER OF THE LINE OF INTEREST:204
HOW MANY DIODES SHOULD BE INTEGRATED ON EITHER SIDE OF THE LINE:7

ENTER THE DIODE NUMBERS OF THE LINES TO BE USED FOR AVERAGING.
TO STOP DATA ENTRY ENTER A RETURN
 RATIO DIODE NUMBER 1:562
NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE  OF THE LINE :7
 RATIO DIODE NUMBER 2:972
NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE  OF THE LINE :7
 RATIO DIODE NUMBER 3:77
NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE  OF THE LINE :7
 RATIO DIODE NUMBER 4:421
NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE  OF THE LINE :7
DO YOU WANT TO USE A NON-STANDARD BACKGROUND REGION :Y
ENTER THE BACKGROUND DIODE NUMBER:623
ENTER THE NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE OF THE LINE:10



    FILE NAME : HL00

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST :  86.082
     STANDARD DEVIATION OF LINE OF INTEREST :  12.453
               NORMALIZED STANDARD DEVIATION :  0.1447
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE       562         972          77          421
                            MEAN    83.746     631.363     194.993       76.639
           STANDARD DEVIATION   11.808      70.247      48.430       19.283
   NORMALIZED STANDARD DEVIATION   0.1410      0.1113      0.2484       0.2516
        CORRELATION COEFFICIENT   0.8724      0.7955      0.6196       0.6460

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      562         972         77          421
     MAXIMUM OF THE RATIOS:  1.1928      0.1641     0.7077      1.9588
     MINIMUM OF THE RATIOS:  0.8687      0.1100     0.2873      0.7142
                      MEAN  1.0299      0.1363     0.4592      1.1701
       STANDARD DEVIATION  0.0758      0.0120     0.0921      0.2395
NORMALIZED STANDARD DEVIATION0.0736      0.0878     0.2006      0.2047
```

FILE NAME : HL01

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 145.070

STANDARD DEVIATION OF LINE OF INTEREST : 16.737

NORMALIZED STANDARD DEVIATION : 0.1154

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	562	972	77	421
MEAN	80.278	556.308	292.532	96.840
STANDARD DEVIATION	8.797	52.679	63.319	23.816
NORMALIZED STANDARD DEVIATION	0.1096	0.0947	0.2241	0.2459
CORRELATION COEFFICIENT	0.9235	0.7821	0.4509	0.5234

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	562	972	77	421
MAXIMUM OF THE RATIOS:	2.0187	0.2983	0.9574	2.7472
MINIMUM OF THE RATIOS:	1.6462	0.2187	0.3591	1.0709
MEAN	1.8077	0.2609	0.5348	1.5735
STANDARD DEVIATION	0.0827	0.0188	0.1175	0.3695
NORMALIZED STANDARD DEVIATION	0.0457	0.0720	0.2197	0.2348

FILE NAME : HL02

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 216.054

STANDARD DEVIATION OF LINE OF INTEREST : 26.677

NORMALIZED STANDARD DEVIATION : 0.1235

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	562	972	77	421
MEAN	85.230	582.179	317.886	109.479
STANDARD DEVIATION	9.307	64.646	48.107	19.229
NORMALIZED STANDARD DEVIATION	0.1092	0.1110	0.1513	0.1756
CORRELATION COEFFICIENT	0.8858	0.8070	0.2330	0.3285

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	562	972	77	421
MAXIMUM OF THE RATIOS:	2.9418	0.4262	1.1194	3.1865
MINIMUM OF THE RATIOS:	2.2409	0.3188	0.5095	1.4504
MEAN	2.5349	0.3716	0.6926	2.0194
STANDARD DEVIATION	0.1450	0.0282	0.1293	0.3746
NORMALIZED STANDARD DEVIATION	0.0572	0.0760	0.1867	0.1855

FILE NAME : HL03

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 282.401

STANDARD DEVIATION OF LINE OF INTEREST : 36.632

NORMALIZED STANDARD DEVIATION : 0.1297

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	562	972	77	421
MEAN	88.853	549.199	421.428	148.776
STANDARD DEVIATION	11.833	68.751	70.971	27.753
NORMALIZED STANDARD DEVIATION	0.1332	0.1252	0.1684	0.1865
CORRELATION COEFFICIENT	0.9426	0.9235	0.7088	0.7092

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	562	972	77	421
MAXIMUM OF THE RATIOS:	3.5192	0.5898	0.9506	2.9945
MINIMUM OF THE RATIOS:	2.8564	0.4729	0.5714	1.5315
MEAN	3.1820	0.5144	0.6794	1.9365
STANDARD DEVIATION	0.1413	0.0258	0.0916	0.3046
NORMALIZED STANDARD DEVIATION	0.0444	0.0501	0.1349	0.1573

FILE NAME : HL04

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 314.233

STANDARD DEVIATION OF LINE OF INTEREST : 35.860

NORMALIZED STANDARD DEVIATION : 0.1141

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	562	972	77	421
MEAN	74.593	471.224	331.594	114.321
STANDARD DEVIATION	6.880	48.207	49.586	21.004
NORMALIZED STANDARD DEVIATION	0.0922	0.1023	0.1495	0.1837
CORRELATION COEFFICIENT	0.8351	0.8399	0.0842	0.0482

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	562	972	77	421
MAXIMUM OF THE RATIOS:	4.8824	0.7670	1.7723	4.8750
MINIMUM OF THE RATIOS:	3.7327	0.5758	0.7391	1.9661
MEAN	4.2114	0.6671	0.9699	2.8469
STANDARD DEVIATION	0.2602	0.0391	0.2031	0.6773
NORMALIZED STANDARD DEVIATION	0.0618	0.0586	0.2094	0.2381

FILE NAME : HL05

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 409.948

STANDARD DEVIATION OF LINE OF INTEREST : 59.739

NORMALIZED STANDARD DEVIATION : 0.1457

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	562	972	77	421
MEAN	78.168	490.357	347.849	123.041
STANDARD DEVIATION	10.286	64.202	68.152	26.108
NORMALIZED STANDARD DEVIATION	0.1316	0.1309	0.1959	0.2122
CORRELATION COEFFICIENT	0.8402	0.8097	0.3087	0.2522

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	562	972	77	421
MAXIMUM OF THE RATIOS:	7.7713	1.0904	2.0913	6.3699
MINIMUM OF THE RATIOS:	4.5844	0.6735	0.8837	2.4093
MEAN	5.2559	0.8377	1.2237	3.4924
STANDARD DEVIATION	0.4954	0.0779	0.3060	0.9732
NORMALIZED STANDARD DEVIATION	0.0943	0.0930	0.2500	0.2786

FILE NAME : HL06

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 562.159

STANDARD DEVIATION OF LINE OF INTEREST : 172.686

NORMALIZED STANDARD DEVIATION : 0.3072

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	562	972	77	421
MEAN	77.493	521.384	204.064	70.724
STANDARD DEVIATION	20.296	132.208	44.842	17.633
NORMALIZED STANDARD DEVIATION	0.2619	0.2536	0.2197	0.2493
CORRELATION COEFFICIENT	0.9600	0.9590	-0.0593	-0.0961

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	562	972	77	421
MAXIMUM OF THE RATIOS:	8.4010	1.5715	4.8371	14.0603
MINIMUM OF THE RATIOS:	3.8130	0.6327	0.7050	1.7760
MEAN	7.1707	1.0662	2.8790	8.4282
STANDARD DEVIATION	0.9231	0.1390	1.0027	3.0441
NORMALIZED STANDARD DEVIATION	0.1287	0.1304	0.3483	0.3612

```
   FILE NAME : HL07

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 378.568
     STANDARD DEVIATION OF LINE OF INTEREST :  97.903
             NORMALIZED STANDARD DEVIATION :  0.2586
 STATISTICS OF LINES USED FOR RATIOING
       DIODE NUMBER OF RATIO LINE     562         972          77           421
                             MEAN   60.191     293.899     375.770      130.675
                STANDARD DEVIATION   10.189      80.481      63.330       21.184
     NORMALIZED STANDARD DEVIATION   0.1693      0.2738      0.1685       0.1621
          CORRELATION COEFFICIENT   0.7624      0.8143     -0.0717      -0.0094

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      562         972          77          421
     MAXIMUM OF THE RATIOS:  9.2280      2.2079      2.6796      7.2162
     MINIMUM OF THE RATIOS:  4.4949      0.8207      0.5942      1.7605
                      MEAN  6.2747      1.3080      1.0466      2.9948
         STANDARD DEVIATION  1.0928      0.2250      0.4018      1.0893
NORMALIZED STANDARD DEVIATIONO.1742      0.1720      0.3839      0.3637



RATIO LINE DIODE NUM   3WENT BELOW BACKGROUND ON SCAN 27
   FILE NAME : HL08

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 589.419
     STANDARD DEVIATION OF LINE OF INTEREST : 165.271
             NORMALIZED STANDARD DEVIATION :  0.2804
 STATISTICS OF LINES USED FOR RATIOING
       DIODE NUMBER OF RATIO LINE     562         972          77           421
                             MEAN   85.226     370.372     505.029      208.875
                STANDARD DEVIATION   17.665     130.121     126.054       40.275
     NORMALIZED STANDARD DEVIATION   0.2073      0.3513      0.2496       0.1928
          CORRELATION COEFFICIENT   0.8429      0.9021      0.0451      -0.2165

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      562         972          77          421
     MAXIMUM OF THE RATIOS: 14.6135      6.3861      1.7695      4.5960
     MINIMUM OF THE RATIOS:  1.7875      1.1830     -0.5094      0.3732
                      MEAN  6.9953      1.8144      1.1641      2.9188
         STANDARD DEVIATION  1.5981      0.9062      0.4413      0.9443
NORMALIZED STANDARD DEVIATIONO.2284      0.4994      0.3791      0.3235
```

FILE NAME : HL09

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 734.707

STANDARD DEVIATION OF LINE OF INTEREST : 161.602

NORMALIZED STANDARD DEVIATION : 0.2200

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	562	972	77	421
MEAN	99.680	415.113	626.464	252.980
STANDARD DEVIATION	13.283	102.935	74.812	26.823
NORMALIZED STANDARD DEVIATION	0.1333	0.2480	0.1194	0.1060
CORRELATION COEFFICIENT	0.8433	0.8223	-0.3303	-0.3231

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	562	972	77	421
MAXIMUM OF THE RATIOS:	9.8105	3.7135	1.7824	4.2995
MINIMUM OF THE RATIOS:	3.9161	0.9939	0.4546	1.2136
MEAN	7.3142	1.8307	1.1956	2.9515
STANDARD DEVIATION	1.0307	0.4411	0.3100	0.7534
NORMALIZED STANDARD DEVIATION	0.1409	0.2410	0.2593	0.2553

FILE NAME : HL10

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 666.657

STANDARD DEVIATION OF LINE OF INTEREST : 170.250

NORMALIZED STANDARD DEVIATION : 0.2554

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	562	972	77	421
MEAN	83.481	348.321	547.437	221.905
STANDARD DEVIATION	11.926	98.044	75.116	28.533
NORMALIZED STANDARD DEVIATION	0.1429	0.2815	0.1372	0.1286
CORRELATION COEFFICIENT	0.8691	0.8557	-0.4570	-0.3777

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	562	972	77	421
MAXIMUM OF THE RATIOS:	10.2191	3.3258	2.2349	5.0915
MINIMUM OF THE RATIOS:	3.7415	1.1934	0.3221	0.8620
MEAN	7.8886	1.9603	1.2578	3.0835
STANDARD DEVIATION	1.2708	0.3732	0.4061	0.9432
NORMALIZED STANDARD DEVIATION	0.1611	0.1904	0.3228	0.3059

FILE NAME : HL11

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 705.964

STANDARD DEVIATION OF LINE OF INTEREST : 157.127

NORMALIZED STANDARD DEVIATION : 0.2226

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	562	972	77	421
MEAN	89.507	343.138	625.925	255.717
STANDARD DEVIATION	9.589	93.939	80.461	33.677
NORMALIZED STANDARD DEVIATION	0.1071	0.2738	0.1285	0.1317
CORRELATION COEFFICIENT	0.7922	0.7904	-0.5251	-0.5517

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	562	972	77	421
MAXIMUM OF THE RATIOS:	9.8556	3.3642	2.1505	5.1115
MINIMUM OF THE RATIOS:	3.6335	1.4329	0.3648	0.8294
MEAN	7.8272	2.1209	1.1637	2.8513
STANDARD DEVIATION	1.2611	0.4102	0.3617	0.8777
NORMALIZED STANDARD DEVIATION	0.1611	0.1934	0.3108	0.3078

FILE NAME : HL12

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 813.254

STANDARD DEVIATION OF LINE OF INTEREST : 175.520

NORMALIZED STANDARD DEVIATION : 0.2158

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	562	972	77	421
MEAN	96.374	337.255	700.970	281.021
STANDARD DEVIATION	7.945	90.150	88.778	36.426
NORMALIZED STANDARD DEVIATION	0.0824	0.2673	0.1267	0.1296
CORRELATION COEFFICIENT	0.6143	0.8391	-0.6702	-0.6724

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	562	972	77	421
MAXIMUM OF THE RATIOS:	10.5692	4.9314	2.3168	5.7088
MINIMUM OF THE RATIOS:	3.5955	1.3598	0.3465	0.8227
MEAN	8.4060	2.5214	1.1992	2.9888
STANDARD DEVIATION	1.5578	0.6101	0.3568	0.8674
NORMALIZED STANDARD DEVIATION	0.1853	0.2420	0.2975	0.2902

B.1.3. Data Set No. 3

File Name	Hydrogen Concentration (%)
HA00	0.00
HA01	0.25
HA02	0.50
HA03	0.75
HA04	1.00
HA05	1.25
HA06	1.50
HA07	1.75
HA08	2.00
HA09	2.25
HA10	2.50
HA11	2.75
HA12	3.00

Element	Wavelength (Å)	Diode Number
Hydrogen	6563.82	146
Argon	6752.83	506
Argon	6965.43	916

```
.RUN FIXSPC

ENTER THE FILE NAME: HA
 EDICR ^C
ENTER THE DIODE NUMBER OF THE LINE OF INTEREST:146
 3 \IXR6
HOW MANY DIODES SHOULD BE INTEGRATED ON EITHER SIDE OF THE LINE:7

ENTER THE DIODE NUMBERS OF THE LINES TO BE USED FOR AVERAGING.
TO STOP DATA ENTRY ENTER A RETURN
 RATIO DIODE NUMBER 1:506
NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE  OF THE LINE :7
 RATIO DIODE NUMBER 2:916
NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE  OF THE LINE :7
 RATIO DIODE NUMBER 3:
DO YOU WANT TO USE A NON-STANDARD BACKGROUND REGION :Y]
ENTER THE BACKGROUND DIODE NUMBER:569
ENTER THE NUMBER OF DIODES TO BE INTEGRATED ON EITHER SIDE OF THE LINE:10




    FILE NAME : HA00


 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 101.552
     STANDARD DEVIATION OF LINE OF INTEREST :  10.786
             NORMALIZED STANDARD DEVIATION :  0.1062
 STATISTICS OF LINES USED FOR RATIOING
       DIODE NUMBER OF RATIO LINE      506         916
                             MEAN   69.416     523.042
             STANDARD DEVIATION      7.469      46.699
   NORMALIZED STANDARD DEVIATION    0.1076      0.0893
         CORRELATION COEFFICIENT    0.6612      0.6595

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      506          916
     MAXIMUM OF THE RATIOS:  1.7127       0.2308
     MINIMUM OF THE RATIOS:  1.1291       0.1611
                      MEAN   1.4682       0.1945
       STANDARD DEVIATION   0.1249       0.0158
NORMALIZED STANDARD DEVIATION0.0851       0.0813
```

FILE NAME : HA01

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 110.179		
STANDARD DEVIATION OF LINE OF INTEREST :		8.927
NORMALIZED STANDARD DEVIATION :		0.0810
STATISTICS OF LINES USED FOR RATIOING		
DIODE NUMBER OF RATIO LINE	506	916
MEAN	58.558	426.276
STANDARD DEVIATION	4.298	41.387
NORMALIZED STANDARD DEVIATION	0.0734	0.0983
CORRELATION COEFFICIENT	0.7308	0.7559

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	506	916
MAXIMUM OF THE RATIOS:	2.1138	0.3031
MINIMUM OF THE RATIOS:	1.6930	0.2227
MEAN	1.8833	0.2594
STANDARD DEVIATION	0.1090	0.0170
NORMALIZED STANDARD DEVIATION	0.0579	0.0657

FILE NAME : HA02

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 134.664		
STANDARD DEVIATION OF LINE OF INTEREST :		10.423
NORMALIZED STANDARD DEVIATION :		0.0774
STATISTICS OF LINES USED FOR RATIOING		
DIODE NUMBER OF RATIO LINE	506	916
MEAN	51.479	362.011
STANDARD DEVIATION	3.952	24.776
NORMALIZED STANDARD DEVIATION	0.0768	0.0684
CORRELATION COEFFICIENT	0.6380	0.5773

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	506	916
MAXIMUM OF THE RATIOS:	3.0465	0.4314
MINIMUM OF THE RATIOS:	2.3659	0.3120
MEAN	2.6217	0.3726
STANDARD DEVIATION	0.1758	0.0249
NORMALIZED STANDARD DEVIATION	0.0670	0.0669

FILE NAME : HA03

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 189.030

STANDARD DEVIATION OF LINE OF INTEREST : 11.149

NORMALIZED STANDARD DEVIATION : 0.0590

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	506	916
MEAN	60.108	399.860
STANDARD DEVIATION	3.250	21.837
NORMALIZED STANDARD DEVIATION	0.0541	0.0546
CORRELATION COEFFICIENT	0.5062	0.8124

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	506	916
MAXIMUM OF THE RATIOS:	3.6960	0.5206
MINIMUM OF THE RATIOS:	2.8567	0.4372
MEAN	3.1489	0.4729
STANDARD DEVIATION	0.1809	0.0165
NORMALIZED STANDARD DEVIATION	0.0574	0.0349

FILE NAME : HA04

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 410.393

STANDARD DEVIATION OF LINE OF INTEREST : 26.592

NORMALIZED STANDARD DEVIATION : 0.0648

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	506	916
MEAN	98.222	500.448
STANDARD DEVIATION	6.999	44.324
NORMALIZED STANDARD DEVIATION	0.0713	0.0886
CORRELATION COEFFICIENT	0.7533	0.8839

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	506	916
MAXIMUM OF THE RATIOS:	4.7617	0.9123
MINIMUM OF THE RATIOS:	3.8536	0.7578
MEAN	4.1848	0.8223
STANDARD DEVIATION	0.1996	0.0363
NORMALIZED STANDARD DEVIATION	0.0477	0.0441

FILE NAME : HA05

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 439.062

STANDARD DEVIATION OF LINE OF INTEREST : 24.944

NORMALIZED STANDARD DEVIATION : 0.0568

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	506	916
MEAN	91.496	432.201
STANDARD DEVIATION	7.420	45.215
NORMALIZED STANDARD DEVIATION	0.0811	0.1046
CORRELATION COEFFICIENT	0.8257	0.9084

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	506	916
MAXIMUM OF THE RATIOS:	5.3689	1.1959
MINIMUM OF THE RATIOS:	4.3904	0.9225
MEAN	4.8112	1.0216
STANDARD DEVIATION	0.2248	0.0629
NORMALIZED STANDARD DEVIATION	0.0467	0.0616

FILE NAME : HA06

****** UNRATIOED STATISTICS *****

MEAN OF LINE OF INTEREST : 521.294

STANDARD DEVIATION OF LINE OF INTEREST : 39.096

NORMALIZED STANDARD DEVIATION : 0.0750

STATISTICS OF LINES USED FOR RATIOING

DIODE NUMBER OF RATIO LINE	506	916
MEAN	93.049	429.557
STANDARD DEVIATION	8.293	53.894
NORMALIZED STANDARD DEVIATION	0.0891	0.1255
CORRELATION COEFFICIENT	0.8334	0.9115

***** RATIOED DATA *****

DIODE NUMBER OF RATIO LINE:	506	916
MAXIMUM OF THE RATIOS:	6.3563	1.4659
MINIMUM OF THE RATIOS:	4.9865	1.0675
MEAN	5.6162	1.2226
STANDARD DEVIATION	0.2889	0.0838
NORMALIZED STANDARD DEVIATION	0.0514	0.0686

```
FILE NAME : HA07

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 690.943
    STANDARD DEVIATION OF LINE OF INTEREST :  38.140
             NORMALIZED STANDARD DEVIATION :  0.0552
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      506         916
                           MEAN 108.751      521.176
           STANDARD DEVIATION     7.424       40.865
  NORMALIZED STANDARD DEVIATION  0.0683       0.0784
        CORRELATION COEFFICIENT  0.5921       0.6690

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      506          916
     MAXIMUM OF THE RATIOS:  7.2322        1.4794
     MINIMUM OF THE RATIOS:  5.7980        1.1612
                      MEAN  6.3685         1.3300
        STANDARD DEVIATION  0.3665         0.0779
NORMALIZED STANDARD DEVIATIONO.0576        0.0586
```

```
FILE NAME : HA08

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 693.981
    STANDARD DEVIATION OF LINE OF INTEREST :  38.002
             NORMALIZED STANDARD DEVIATION :  0.0548
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      506         916
                           MEAN 104.302      458.279
           STANDARD DEVIATION     6.183       32.619
  NORMALIZED STANDARD DEVIATION  0.0593       0.0712
        CORRELATION COEFFICIENT  0.8174       0.8769

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      506          916
     MAXIMUM OF THE RATIOS:  7.3571        1.6308
     MINIMUM OF THE RATIOS:  6.2740        1.4006
                      MEAN  6.6591         1.5167
        STANDARD DEVIATION  0.2333         0.0532
NORMALIZED STANDARD DEVIATIONO.0350        0.0351
```

```
FILE NAME : HA09

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 744.037
    STANDARD DEVIATION OF LINE OF INTEREST :  59.515
             NORMALIZED STANDARD DEVIATION :  0.0800
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE     506         916
                         MEAN 102.531       452.203
           STANDARD DEVIATION   8.373        40.209
  NORMALIZED STANDARD DEVIATION  0.0817       0.0889
       CORRELATION COEFFICIENT  0.8651       0.9085

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      506         916
     MAXIMUM OF THE RATIOS:  8.1152      1.7963
     MINIMUM OF THE RATIOS:  6.8566      1.5361
                      MEAN  7.2643      1.6480
       STANDARD DEVIATION  0.3108      0.0641
NORMALIZED STANDARD DEVIATION0.0428      0.0389
```

```
FILE NAME : HA10

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 789.286
    STANDARD DEVIATION OF LINE OF INTEREST :  71.788
             NORMALIZED STANDARD DEVIATION :  0.0910
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE     506         916
                         MEAN  99.469       432.121
           STANDARD DEVIATION   9.638        44.560
  NORMALIZED STANDARD DEVIATION  0.0969       0.1031
       CORRELATION COEFFICIENT  0.9235       0.9094

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      506         916
     MAXIMUM OF THE RATIOS:  8.6417      2.0093
     MINIMUM OF THE RATIOS:  7.2959      1.6196
                      MEAN  7.9453      1.8305
       STANDARD DEVIATION  0.2920      0.0800
NORMALIZED STANDARD DEVIATION0.0367      0.0437
```

```
FILE NAME : HA11

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST :1454.224
    STANDARD DEVIATION OF LINE OF INTEREST : 271.739
             NORMALIZED STANDARD DEVIATION :  0.1869
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      506          916
                           MEAN 121.562       659.471
             STANDARD DEVIATION  13.915       125.715
  NORMALIZED STANDARD DEVIATION  0.1145        0.1906
        CORRELATION COEFFICIENT  0.9071        0.9119

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:     506          916
     MAXIMUM OF THE RATIOS: 13.7920       2.8950
     MINIMUM OF THE RATIOS:  8.0720       1.7200
                      MEAN 11.8677       2.2178
         STANDARD DEVIATION  1.3067       0.2150
NORMALIZED STANDARD DEVIATIONO.1101       0.0970
```

```
FILE NAME : HA12

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 780.359
    STANDARD DEVIATION OF LINE OF INTEREST : 263.059
             NORMALIZED STANDARD DEVIATION :  0.3371
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      506          916
                           MEAN  71.192       421.036
             STANDARD DEVIATION  10.093       141.157
  NORMALIZED STANDARD DEVIATION  0.1418        0.3353
        CORRELATION COEFFICIENT  0.8186        0.8684

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:     506          916
     MAXIMUM OF THE RATIOS: 16.5502       2.5669
     MINIMUM OF THE RATIOS:  5.5244       0.9000
                      MEAN 10.7575       1.8913
         STANDARD DEVIATION  2.5125       0.3417
NORMALIZED STANDARD DEVIATIONO.2336       0.1807
```

B.2. Variation of Travel Speed

B.2.1. 1 Percent Hydrogen

File Name	Travel Speed (cm/min)
SA4	10
SA8	20
SA12	30
SA16	40
SA20	50
SA24	60

Element	Wavelength (Å)	Diode Number
Hydrogen	6563.82	146
Argon	6752.83	506
Argon	6965.43	916

SA4

```
****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 372.307
     STANDARD DEVIATION OF LINE OF INTEREST :  23.838
            NORMALIZED STANDARD DEVIATION :  0.0640
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      506         916
                             MEAN  75.226      542.641
              STANDARD DEVIATION   4.732       35.230
   NORMALIZED STANDARD DEVIATION  0.0629       0.0649
          CORRELATION COEFFICIENT  0.7450       0.7148

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      506          916
      MAXIMUM OF THE RATIOS:  5.5555       0.7721
      MINIMUM OF THE RATIOS:  4.5866       0.6294
                       MEAN   4.9541       0.6869
        STANDARD DEVIATION   0.2265       0.0326
NORMALIZED STANDARD DEVIATIONO.0457       0.0475

DO YOU WANT TO CALCULATE THESE STATISTICS FOR A DIFFERENT FILE? Y


ENTER THE FILE NAME: SA8
A8


 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 305.441
     STANDARD DEVIATION OF LINE OF INTEREST :  27.622
            NORMALIZED STANDARD DEVIATION :  0.0904
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      506         916
                             MEAN  61.337      464.935
              STANDARD DEVIATION   5.145       36.557
   NORMALIZED STANDARD DEVIATION  0.0839       0.0786
          CORRELATION COEFFICIENT  0.8657       0.8456

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      506          916
      MAXIMUM OF THE RATIOS:  5.5020       0.7458
      MINIMUM OF THE RATIOS:  4.4477       0.5819
                       MEAN   4.9823       0.6571
        STANDARD DEVIATION   0.2286       0.0316
NORMALIZED STANDARD DEVIATIONO.0459       0.0480
```

SA12

```
****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 353.500
    STANDARD DEVIATION OF LINE OF INTEREST :  25.782
             NORMALIZED STANDARD DEVIATION :  0.0729
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      506          916
                           MEAN   68.741      514.323
             STANDARD DEVIATION    5.030       40.656
  NORMALIZED STANDARD DEVIATION   0.0732       0.0790
        CORRELATION COEFFICIENT   0.8416       0.8581

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      506          916
     MAXIMUM OF THE RATIOS:  5.6556       0.7498
     MINIMUM OF THE RATIOS:  4.4021       0.6366
                      MEAN   5.1470       0.6882
        STANDARD DEVIATION   0.2143       0.0290
NORMALIZED STANDARD DEVIATION0.0416       0.0421

DO YOU WANT TO CALCULATE THESE STATISTICS FOR A DIFFERENT FILE? Y


ENTER THE FILE NAME: SA16
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SA16

```
****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 239.846
    STANDARD DEVIATION OF LINE OF INTEREST :  23.612
             NORMALIZED STANDARD DEVIATION :  0.0984
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      506          916
                           MEAN   47.795      357.359
             STANDARD DEVIATION    4.469       37.835
  NORMALIZED STANDARD DEVIATION   0.0935       0.1059
        CORRELATION COEFFICIENT   0.9173       0.8479

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      506          916
     MAXIMUM OF THE RATIOS:  5.4652       0.7778
     MINIMUM OF THE RATIOS:  4.6140       0.6028
                      MEAN   5.0199       0.6728
        STANDARD DEVIATION   0.2001       0.0388
NORMALIZED STANDARD DEVIATION0.0399       0.0577
```

SA20

```
****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 208.666
     STANDARD DEVIATION OF LINE OF INTEREST :  16.503
            NORMALIZED STANDARD DEVIATION :  0.0791
 STATISTICS OF LINES USED FOR RATIOING
       DIODE NUMBER OF RATIO LINE      506         916
                             MEAN  43.278      314.325
            STANDARD DEVIATION   4.921       29.244
    NORMALIZED STANDARD DEVIATION  0.1137       0.0930
          CORRELATION COEFFICIENT  0.7996       0.8031

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      506         916
     MAXIMUM OF THE RATIOS:  5.7001       0.7743
     MINIMUM OF THE RATIOS:  4.2623       0.5896
                      MEAN  4.8493       0.6656
        STANDARD DEVIATION  0.3460       0.0373
NORMALIZED STANDARD DEVIATIONO.0714       0.0560

DO YOU WANT TO CALCULATE THESE STATISTICS FOR A DIFFERENT FILE? Y
```

S

```
ENTER THE FILE NAME: SA24
```

SA24

```
****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 354.159
     STANDARD DEVIATION OF LINE OF INTEREST :  42.568
            NORMALIZED STANDARD DEVIATION :  0.1202
 STATISTICS OF LINES USED FOR RATIOING
       DIODE NUMBER OF RATIO LINE      506         916
                             MEAN  75.367      525.757
            STANDARD DEVIATION   7.804       65.438
    NORMALIZED STANDARD DEVIATION  0.1035       0.1245
          CORRELATION COEFFICIENT  0.8729       0.9181

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      506         916
     MAXIMUM OF THE RATIOS:  5.2337       0.7560
     MINIMUM OF THE RATIOS:  4.1843       0.6098
                      MEAN  4.6984       0.6748
        STANDARD DEVIATION  0.2820       0.0338
NORMALIZED STANDARD DEVIATIONO.0600       0.0501
```

B.2.2. 0.5 Percent Hydrogen

File Name	Travel Speed (cm/min)
SPN4	10
SPN8	20
SPN12	30
SPN16	40
SPN20	50
SPN24	60

Element	Wavelength (Å)	Diode Number
Hydrogen	6563.82	204
Argon	6752.83	564
Argon	6965.43	974

SPN4

```
****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 373.325
    STANDARD DEVIATION OF LINE OF INTEREST :  97.991
             NORMALIZED STANDARD DEVIATION :  0.2625
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE     564          974
                           MEAN 146.525       817.685
            STANDARD DEVIATION  28.663       219.845
   NORMALIZED STANDARD DEVIATION  0.1956        0.2689
         CORRELATION COEFFICIENT  0.9772        0.9562

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      564          974
     MAXIMUM OF THE RATIOS:  3.1307       0.6770
     MINIMUM OF THE RATIOS:  1.5801       0.3365
                      MEAN  2.5026       0.4626
        STANDARD DEVIATION  0.2807       0.0510
NORMALIZED STANDARD DEVIATIONO.1122       0.1103

DO YOU WANT TO CALCULATE THESE STATISTICS FOR A DIFFERENT FILE? Y



ENTER THE FILE NAME: SPN8

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 403.479
    STANDARD DEVIATION OF LINE OF INTEREST :  72.835
             NORMALIZED STANDARD DEVIATION :  0.1805
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE     564          974
                           MEAN 158.147       852.178
            STANDARD DEVIATION  23.520       141.765
   NORMALIZED STANDARD DEVIATION  0.1487        0.1664
         CORRELATION COEFFICIENT  0.9671        0.9022

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      564          974
     MAXIMUM OF THE RATIOS:  2.7270       0.6356
     MINIMUM OF THE RATIOS:  1.8344       0.3125
                      MEAN  2.5364       0.4747
        STANDARD DEVIATION  0.1753       0.0466
NORMALIZED STANDARD DEVIATIONO.0691       0.0982

DO YOU WANT TO CALCULATE THESE STATISTICS FOR A DIFFERENT FILE? Y
```

```
ENTER THE FILE NAME: SPN12

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 439.889
     STANDARD DEVIATION OF LINE OF INTEREST :  74.592
             NORMALIZED STANDARD DEVIATION :  0.1696
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      564          974
                            MEAN 149.031      775.424
             STANDARD DEVIATION  11.603        53.851
   NORMALIZED STANDARD DEVIATION  0.0779        0.0694
         CORRELATION COEFFICIENT  0.4370        0.6338

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      564          974
     MAXIMUM OF THE RATIOS:  5.6065       0.9475
     MINIMUM OF THE RATIOS:  2.6371       0.5041
                      MEAN   2.9520       0.5661
        STANDARD DEVIATION   0.4508       0.0724
NORMALIZED STANDARD DEVIATIONO.1527       0.1279

DO YOU WANT TO CALCULATE THESE STATISTICS FOR A DIFFERENT FILE? Y


ENTER THE FILE NAME: SPN16

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 361.544
     STANDARD DEVIATION OF LINE OF INTEREST :  41.047
             NORMALIZED STANDARD DEVIATION :  0.1135
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      564          974
                            MEAN 129.272      674.216
             STANDARD DEVIATION  10.993        50.845
   NORMALIZED STANDARD DEVIATION  0.0850        0.0754
         CORRELATION COEFFICIENT  0.8595        0.8265

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      564          974
     MAXIMUM OF THE RATIOS:  3.1341       0.6213
     MINIMUM OF THE RATIOS:  2.3987       0.4285
                      MEAN   2.7937       0.5355
        STANDARD DEVIATION   0.1703       0.0366
NORMALIZED STANDARD DEVIATIONO.0610       0.0683

DO YOU WANT TO CALCULATE THESE STATISTICS FOR A DIFFERENT FILE? Y
```

```
ENTER THE FILE NAME: SPN20

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 394.835
     STANDARD DEVIATION OF LINE OF INTEREST :  59.530
               NORMALIZED STANDARD DEVIATION :  0.1508
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      564          974
                            MEAN 147.900      753.609
               STANDARD DEVIATION  16.597      80.323
   NORMALIZED STANDARD DEVIATION  0.1122      0.1066
          CORRELATION COEFFICIENT  0.9675      0.9480

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      564          974
     MAXIMUM OF THE RATIOS:  2.9313       0.5805
     MINIMUM OF THE RATIOS:  2.3339       0.4684
                      MEAN  2.6605       0.5221
          STANDARD DEVIATION  0.1343       0.0306
NORMALIZED STANDARD DEVIATIONO.0505       0.0586

DO YOU WANT TO CALCULATE THESE STATISTICS FOR A DIFFERENT FILE?

                                                               Y

ENTER THE FILE NAME: SPN24

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 400.757
     STANDARD DEVIATION OF LINE OF INTEREST :  54.704
               NORMALIZED STANDARD DEVIATION :  0.1365
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      564          974
                            MEAN 147.095      821.879
               STANDARD DEVIATION  17.913      94.016
   NORMALIZED STANDARD DEVIATION  0.1218      0.1144
          CORRELATION COEFFICIENT  0.9766      0.9416

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      564          974
     MAXIMUM OF THE RATIOS:  2.9284       0.5293
     MINIMUM OF THE RATIOS:  2.3462       0.3977
                      MEAN  2.7185       0.4865
          STANDARD DEVIATION  0.0993       0.0237
NORMALIZED STANDARD DEVIATIONO.0365       0.0488

DO YOU WANT TO CALCULATE THESE STATISTICS FOR A DIFFERENT FILE?
```

B.3. Filter Simulation on Data Set No. 1.

B.3.1. 10 Å Filter

```
.RUN FILTER

ENTER THE FILE NAME: HD

ENTER THE DIODE NUMBER OF THE LINE OF INTEREST:204
WHAT IS THE FWHM (IN ANGSTROMS) OF THE FILTER: 10.

ENTER THE DIODE NUMBERS OF THE LINES TO BE USED FOR AVERAGING.
TO STOP DATA ENTRY ENTER A RETURN
 RATIO DIODE NUMBER 1:974
WHAT IS THE FWHM (IN ANGSTROMS) OF THE FILTER: 10.
 RATIO DIODE NUMBER 2:
DO YOU WANT TO USE A NON-STANDARD BACKGROUND REGION :Y
ENTER THE BACKGROUND DIODE NUMBER:625
WHAT IS THE FWHM (IN ANGSTROMS) OF THE FILTER: 10.
```

```
    FILE NAME : HD00

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 247.015
     STANDARD DEVIATION OF LINE OF INTEREST :  25.716
               NORMALIZED STANDARD DEVIATION :  0.1041
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                             MEAN 854.721
               STANDARD DEVIATION  59.193
   NORMALIZED STANDARD DEVIATION  0.0693
         CORRELATION COEFFICIENT  0.6020

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:     974
     MAXIMUM OF THE RATIOS:  0.3519
     MINIMUM OF THE RATIOS:  0.2285
                      MEAN  0.2891
        STANDARD DEVIATION  0.0253
NORMALIZED STANDARD DEVIATIONO.0876
```

```
FILE NAME : HD01

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 518.644
    STANDARD DEVIATION OF LINE OF INTEREST :  35.955
             NORMALIZED STANDARD DEVIATION :  0.0693
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                           MEAN1305.669
           STANDARD DEVIATION  93.513
  NORMALIZED STANDARD DEVIATION  0.0716
        CORRELATION COEFFICIENT  0.6080

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  0.4967
     MINIMUM OF THE RATIOS:  0.3509
                      MEAN  0.3981
        STANDARD DEVIATION  0.0261
NORMALIZED STANDARD DEVIATIONO.0655
```

```
FILE NAME : HD02

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 489.576
    STANDARD DEVIATION OF LINE OF INTEREST :  35.656
             NORMALIZED STANDARD DEVIATION :  0.0728
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                           MEAN 980.243
           STANDARD DEVIATION  70.745
  NORMALIZED STANDARD DEVIATION  0.0722
        CORRELATION COEFFICIENT  0.7279

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  0.5622
     MINIMUM OF THE RATIOS:  0.4475
                      MEAN  0.5001
        STANDARD DEVIATION  0.0270
NORMALIZED STANDARD DEVIATIONO.0540
```

```
   FILE NAME : HD03

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 647.067
     STANDARD DEVIATION OF LINE OF INTEREST :  56.773
                NORMALIZED STANDARD DEVIATION :  0.0877
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                          MEAN1083.350
            STANDARD DEVIATION  68.303
   NORMALIZED STANDARD DEVIATION  0.0630
        CORRELATION COEFFICIENT  0.7408

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  0.7694
     MINIMUM OF THE RATIOS:  0.5461
                      MEAN  0.5972
        STANDARD DEVIATION  0.0361
NORMALIZED STANDARD DEVIATIONO.0604


   FILE NAME : HD04

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST :1158.936
     STANDARD DEVIATION OF LINE OF INTEREST :  96.197
                NORMALIZED STANDARD DEVIATION :  0.0830
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                          MEAN1355.200
            STANDARD DEVIATION 106.655
   NORMALIZED STANDARD DEVIATION  0.0787
        CORRELATION COEFFICIENT  0.4894

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.1973
     MINIMUM OF THE RATIOS:  0.7331
                      MEAN  0.8583
        STANDARD DEVIATION  0.0783
NORMALIZED STANDARD DEVIATIONO.0912
```

```
   FILE NAME : HD05

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST :1176.520
     STANDARD DEVIATION OF LINE OF INTEREST :  53.836
              NORMALIZED STANDARD DEVIATION :  0.0458
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                          MEAN1200.090
             STANDARD DEVIATION  51.906
   NORMALIZED STANDARD DEVIATION  0.0433
         CORRELATION COEFFICIENT  0.4444

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.1656
     MINIMUM OF THE RATIOS:  0.8976
                      MEAN  0.9814
        STANDARD DEVIATION  0.0478
NORMALIZED STANDARD DEVIATIONO.0487


   FILE NAME : HD06

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST :1130.920
     STANDARD DEVIATION OF LINE OF INTEREST :  93.709
              NORMALIZED STANDARD DEVIATION :  0.0829
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                          MEAN 907.073
             STANDARD DEVIATION  77.619
   NORMALIZED STANDARD DEVIATION  0.0856
         CORRELATION COEFFICIENT  0.8853

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.3428
     MINIMUM OF THE RATIOS:  1.1405
                      MEAN  1.2481
        STANDARD DEVIATION  0.0501
NORMALIZED STANDARD DEVIATIONO.0402
```

```
FILE NAME : HD07

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST :1172.442
    STANDARD DEVIATION OF LINE OF INTEREST : 109.941
             NORMALIZED STANDARD DEVIATION :  0.0938
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                           MEAN 772.402
            STANDARD DEVIATION  85.726
  NORMALIZED STANDARD DEVIATION  0.1110
        CORRELATION COEFFICIENT  0.9438

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.6978
     MINIMUM OF THE RATIOS:  1.4133
                      MEAN  1.5218
        STANDARD DEVIATION  0.0604
NORMALIZED STANDARD DEVIATIONO.0397


FILE NAME : HD08

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST :1414.567
    STANDARD DEVIATION OF LINE OF INTEREST : 118.585
             NORMALIZED STANDARD DEVIATION :  0.0838
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                           MEAN 757.834
            STANDARD DEVIATION  97.705
  NORMALIZED STANDARD DEVIATION  0.1289
        CORRELATION COEFFICIENT  0.7300

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  2.3745
     MINIMUM OF THE RATIOS:  1.6507
                      MEAN  1.8842
        STANDARD DEVIATION  0.1820
NORMALIZED STANDARD DEVIATIONO.0966
```

```
FILE NAME : HD09

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST :1457.847
    STANDARD DEVIATION OF LINE OF INTEREST : 215.317
             NORMALIZED STANDARD DEVIATION :  0.1477
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                           MEAN 702.099
            STANDARD DEVIATION 116.607
  NORMALIZED STANDARD DEVIATION  0.1661
        CORRELATION COEFFICIENT  0.9220

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  2.3673
     MINIMUM OF THE RATIOS:  1.9809
                      MEAN  2.0868
        STANDARD DEVIATION  0.1323
NORMALIZED STANDARD DEVIATIONO.0634


FILE NAME : HD10

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST :1790.991
    STANDARD DEVIATION OF LINE OF INTEREST : 253.256
             NORMALIZED STANDARD DEVIATION :  0.1414
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                           MEAN 773.178
            STANDARD DEVIATION 113.173
  NORMALIZED STANDARD DEVIATION  0.1464
        CORRELATION COEFFICIENT  0.9291

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  2.6992
     MINIMUM OF THE RATIOS:  2.0712
                      MEAN  2.3227
        STANDARD DEVIATION  0.1309
NORMALIZED STANDARD DEVIATIONO.0564
```

```
   FILE NAME : HD11

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST :1869.459
    STANDARD DEVIATION OF LINE OF INTEREST : 273.589
             NORMALIZED STANDARD DEVIATION :  0.1463
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                          MEAN 724.986
            STANDARD DEVIATION 125.294
  NORMALIZED STANDARD DEVIATION  0.1728
       CORRELATION COEFFICIENT  0.9165

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  3.3671
     MINIMUM OF THE RATIOS:  2.2680
                      MEAN  2.5958
        STANDARD DEVIATION  0.1966
NORMALIZED STANDARD DEVIATIONO.0757
```

```
   FILE NAME : HD12

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST :2367.771
    STANDARD DEVIATION OF LINE OF INTEREST : 281.549
             NORMALIZED STANDARD DEVIATION :  0.1189
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                          MEAN 868.188
            STANDARD DEVIATION 112.319
  NORMALIZED STANDARD DEVIATION  0.1294
       CORRELATION COEFFICIENT  0.9491

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  3.0211
     MINIMUM OF THE RATIOS:  2.4419
                      MEAN  2.7338
        STANDARD DEVIATION  0.1150
NORMALIZED STANDARD DEVIATIONO.0421
```

B.3.2. 20 Å Filter

```
   FILE NAME : HD00

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 202.713
    STANDARD DEVIATION OF LINE OF INTEREST :  24.109
             NORMALIZED STANDARD DEVIATION :  0.1189
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                            MEAN 468.543
            STANDARD DEVIATION  32.304
  NORMALIZED STANDARD DEVIATION  0.0689
        CORRELATION COEFFICIENT  0.5468

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  0.5476
     MINIMUM OF THE RATIOS:  0.3287
                      MEAN  0.4328
        STANDARD DEVIATION  0.0453
NORMALIZED STANDARD DEVIATIONO.1047
```

```
   FILE NAME : HD01

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 408.484
    STANDARD DEVIATION OF LINE OF INTEREST :  22.158
             NORMALIZED STANDARD DEVIATION :  0.0542
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                            MEAN 713.230
            STANDARD DEVIATION  49.201
  NORMALIZED STANDARD DEVIATION  0.0690
        CORRELATION COEFFICIENT  0.3807

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  0.7105
     MINIMUM OF THE RATIOS:  0.4979
                      MEAN  0.5746
        STANDARD DEVIATION  0.0411
NORMALIZED STANDARD DEVIATIONO.0716
```

```
FILE NAME : HD02

****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 383.178
     STANDARD DEVIATION OF LINE OF INTEREST :  29.323
             NORMALIZED STANDARD DEVIATION :  0.0765
STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                           MEAN 538.008
             STANDARD DEVIATION  38.168
   NORMALIZED STANDARD DEVIATION  0.0709
         CORRELATION COEFFICIENT  0.6536

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
      MAXIMUM OF THE RATIOS:  0.8087
      MINIMUM OF THE RATIOS:  0.6299
                      MEAN  0.7132
         STANDARD DEVIATION  0.0443
NORMALIZED STANDARD DEVIATIONO.0620
```

```
FILE NAME : HD03

****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 491.254
     STANDARD DEVIATION OF LINE OF INTEREST :  42.473
             NORMALIZED STANDARD DEVIATION :  0.0865
STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                           MEAN 593.254
             STANDARD DEVIATION  37.260
   NORMALIZED STANDARD DEVIATION  0.0628
         CORRELATION COEFFICIENT  0.7147

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
      MAXIMUM OF THE RATIOS:  1.0704
      MINIMUM OF THE RATIOS:  0.7526
                      MEAN  0.8281
         STANDARD DEVIATION  0.0513
NORMALIZED STANDARD DEVIATIONO.0620
```

```
   FILE NAME : HD04

****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 846.039
     STANDARD DEVIATION OF LINE OF INTEREST :  61.873
                NORMALIZED STANDARD DEVIATION :  0.0731
STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE       974
                              MEAN 739.524
           STANDARD DEVIATION  57.534
  NORMALIZED STANDARD DEVIATION  0.0778
        CORRELATION COEFFICIENT  0.4457

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.5996
     MINIMUM OF THE RATIOS:  1.0008
                      MEAN  1.1488
        STANDARD DEVIATION  0.1028
NORMALIZED STANDARD DEVIATIONO.0895
```

```
   FILE NAME : HD05

****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 859.170
     STANDARD DEVIATION OF LINE OF INTEREST :  40.881
                NORMALIZED STANDARD DEVIATION :  0.0476
STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE       974
                              MEAN 654.922
           STANDARD DEVIATION  30.327
  NORMALIZED STANDARD DEVIATION  0.0463
        CORRELATION COEFFICIENT  0.4290

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.5718
     MINIMUM OF THE RATIOS:  1.2087
                      MEAN  1.3136
        STANDARD DEVIATION  0.0685
NORMALIZED STANDARD DEVIATIONO.0522
```

```
   FILE NAME : HD06

****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 849.058
     STANDARD DEVIATION OF LINE OF INTEREST :  67.162
              NORMALIZED STANDARD DEVIATION :  0.0791
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                             MEAN 499.562
             STANDARD DEVIATION  40.807
  NORMALIZED STANDARD DEVIATION  0.0817
        CORRELATION COEFFICIENT  0.9699

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.8314
     MINIMUM OF THE RATIOS:  1.5433
                      MEAN   1.7014
        STANDARD DEVIATION  0.0695
NORMALIZED STANDARD DEVIATION0.0409
```

```
   FILE NAME : HD07

****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 875.748
     STANDARD DEVIATION OF LINE OF INTEREST :  77.950
              NORMALIZED STANDARD DEVIATION :  0.0890
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                             MEAN 424.625
             STANDARD DEVIATION  45.520
  NORMALIZED STANDARD DEVIATION  0.1072
        CORRELATION COEFFICIENT  0.9372

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  2.3492
     MINIMUM OF THE RATIOS:  1.9177
                      MEAN   2.0678
        STANDARD DEVIATION  0.0847
NORMALIZED STANDARD DEVIATION0.0409
```

```
   FILE NAME : HD08

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST :1043.320
    STANDARD DEVIATION OF LINE OF INTEREST :  87.909
           NORMALIZED STANDARD DEVIATION :  0.0843
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE     974
                          MEAN 415.338
           STANDARD DEVIATION  53.645
  NORMALIZED STANDARD DEVIATION  0.1292
        CORRELATION COEFFICIENT  0.7456

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:     974
     MAXIMUM OF THE RATIOS:  3.1487
     MINIMUM OF THE RATIOS:  2.2301
                      MEAN  2.5351
        STANDARD DEVIATION  0.2386
NORMALIZED STANDARD DEVIATIONO.0941
```

```
   FILE NAME : HD09

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST :1066.821
    STANDARD DEVIATION OF LINE OF INTEREST : 158.442
           NORMALIZED STANDARD DEVIATION :  0.1485
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE     974
                          MEAN 382.504
           STANDARD DEVIATION  62.834
  NORMALIZED STANDARD DEVIATION  0.1643
        CORRELATION COEFFICIENT  0.9197

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:     974
     MAXIMUM OF THE RATIOS:  3.1837
     MINIMUM OF THE RATIOS:  2.5248
                      MEAN  2.8017
        STANDARD DEVIATION  0.1782
NORMALIZED STANDARD DEVIATIONO.0636
```

```
FILE NAME : HD10

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST :1311.342
    STANDARD DEVIATION OF LINE OF INTEREST : 184.930
             NORMALIZED STANDARD DEVIATION :  0.1410
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE     974
                          MEAN 423.156
            STANDARD DEVIATION  60.701
  NORMALIZED STANDARD DEVIATION  0.1434
       CORRELATION COEFFICIENT  0.9211

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  3.6229
     MINIMUM OF THE RATIOS:  2.7454
                      MEAN  3.1068
        STANDARD DEVIATION  0.1811
NORMALIZED STANDARD DEVIATIONO.0583
```

```
FILE NAME : HD11

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST :1358.319
    STANDARD DEVIATION OF LINE OF INTEREST : 198.908
             NORMALIZED STANDARD DEVIATION :  0.1464
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE     974
                          MEAN 394.348
            STANDARD DEVIATION  66.908
  NORMALIZED STANDARD DEVIATION  0.1697
       CORRELATION COEFFICIENT  0.9057

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  4.5334
     MINIMUM OF THE RATIOS:  3.0230
                      MEAN  3.4665
        STANDARD DEVIATION  0.2735
NORMALIZED STANDARD DEVIATIONO.0789
```

```
   FILE NAME : HD12

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST :1731.665
     STANDARD DEVIATION OF LINE OF INTEREST : 210.023
              NORMALIZED STANDARD DEVIATION :  0.1213
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                            MEAN 475.506
              STANDARD DEVIATION  60.234
   NORMALIZED STANDARD DEVIATION  0.1267
         CORRELATION COEFFICIENT  0.9403

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  4.0074
     MINIMUM OF THE RATIOS:  3.2272
                      MEAN  3.6480
        STANDARD DEVIATION  0.1580
NORMALIZED STANDARD DEVIATIONO.0433
```

B.3.3. 50 Å Filter

```
.RUN NTYPE

.RUN FILTER

ENTER THE FILE NAME: HD

ENTER THE DIODE NUMBER OF THE LINE OF INTEREST:204
WHAT IS THE FWHM (IN ANGSTROMS) OF THE FILTER: 50.

ENTER THE DIODE NUMBERS OF THE LINES TO BE USED FOR AVERAGING.
TO STOP DATA ENTRY ENTER A RETURN
 RATIO DIODE NUMBER 1:974
WHAT IS THE FWHM (IN ANGSTROMS) OF THE FILTER: 50.
 RATIO DIODE NUMBER 2:
DO YOU WANT TO USE A NON-STANDARD BACKGROUND REGION :Y
ENTER THE BACKGROUND DIODE NUMBER:625
WHAT IS THE FWHM (IN ANGSTROMS) OF THE FILTER: 50.



    FILE NAME : HD00

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 134.690
     STANDARD DEVIATION OF LINE OF INTEREST :  19.760
              NORMALIZED STANDARD DEVIATION :  0.1467
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                             MEAN 200.120
              STANDARD DEVIATION  13.690
   NORMALIZED STANDARD DEVIATION  0.0684
         CORRELATION COEFFICIENT  0.4817

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:     974
     MAXIMUM OF THE RATIOS:  0.9009
     MINIMUM OF THE RATIOS:  0.4782
                      MEAN  0.6730
        STANDARD DEVIATION  0.0908
NORMALIZED STANDARD DEVIATION0.1348
```

```
   FILE NAME : HD01

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 258.575
     STANDARD DEVIATION OF LINE OF INTEREST :  15.049
              NORMALIZED STANDARD DEVIATION :  0.0582
 STATISTICS OF LINES USED FOR RATIOING
       DIODE NUMBER OF RATIO LINE      974
                             MEAN 297.193
              STANDARD DEVIATION  18.966
    NORMALIZED STANDARD DEVIATION  0.0638
         CORRELATION COEFFICIENT -0.1861

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.0955
     MINIMUM OF THE RATIOS:  0.7180
                      MEAN  0.8742
        STANDARD DEVIATION  0.0828
NORMALIZED STANDARD DEVIATIONO.0947


   FILE NAME : HD02

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 240.733
     STANDARD DEVIATION OF LINE OF INTEREST :  21.210
              NORMALIZED STANDARD DEVIATION :  0.0881
 STATISTICS OF LINES USED FOR RATIOING
       DIODE NUMBER OF RATIO LINE      974
                             MEAN 229.464
              STANDARD DEVIATION  15.574
    NORMALIZED STANDARD DEVIATION  0.0679
         CORRELATION COEFFICIENT  0.5191

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.2030
     MINIMUM OF THE RATIOS:  0.9825
                      MEAN  1.0506
        STANDARD DEVIATION  0.0830
NORMALIZED STANDARD DEVIATIONO.0790
```

```
   FILE NAME : HD03

****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 293.017
     STANDARD DEVIATION OF LINE OF INTEREST :  25.693
              NORMALIZED STANDARD DEVIATION :  0.0877
STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                              MEAN 250.477
              STANDARD DEVIATION  15.533
  NORMALIZED STANDARD DEVIATION  0.0620
         CORRELATION COEFFICIENT  0.6456

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.5170
     MINIMUM OF THE RATIOS:  1.0422
                      MEAN  1.1703
        STANDARD DEVIATION  0.0803
NORMALIZED STANDARD DEVIATIONO.0686


   FILE NAME : HD04

****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 473.207
     STANDARD DEVIATION OF LINE OF INTEREST :  29.290
              NORMALIZED STANDARD DEVIATION :  0.0619
STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                              MEAN 306.057
              STANDARD DEVIATION  22.981
  NORMALIZED STANDARD DEVIATION  0.0751
         CORRELATION COEFFICIENT  0.2677

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  2.1700
     MINIMUM OF THE RATIOS:  1.3340
                      MEAN  1.5540
        STANDARD DEVIATION  0.1452
NORMALIZED STANDARD DEVIATIONO.0934
```

```
   FILE NAME : HD05

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 483.731
    STANDARD DEVIATION OF LINE OF INTEREST :  25.207
             NORMALIZED STANDARD DEVIATION :  0.0521
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                           MEAN 273.102
           STANDARD DEVIATION  13.518
  NORMALIZED STANDARD DEVIATION  0.0495
        CORRELATION COEFFICIENT  0.2989

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  2.1615
     MINIMUM OF THE RATIOS:  1.6158
                      MEAN  1.7744
        STANDARD DEVIATION  0.1110
NORMALIZED STANDARD DEVIATIONO.0626


   FILE NAME : HD06

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 500.983
    STANDARD DEVIATION OF LINE OF INTEREST :  37.127
             NORMALIZED STANDARD DEVIATION :  0.0741
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                           MEAN 210.992
           STANDARD DEVIATION  15.958
  NORMALIZED STANDARD DEVIATION  0.0752
        CORRELATION COEFFICIENT  0.8054

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  2.5958
     MINIMUM OF THE RATIOS:  2.1183
                      MEAN  2.3767
        STANDARD DEVIATION  0.1104
NORMALIZED STANDARD DEVIATIONO.0465
```

```
   FILE NAME : HD07

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 512.388
     STANDARD DEVIATION OF LINE OF INTEREST :  41.666
             NORMALIZED STANDARD DEVIATION :  0.0913
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                         MEAN 177.998
             STANDARD DEVIATION  17.878
   NORMALIZED STANDARD DEVIATION  0.1004
         CORRELATION COEFFICIENT  0.9016

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
      MAXIMUM OF THE RATIOS:  3.4340
      MINIMUM OF THE RATIOS:  2.6456
                       MEAN  2.8871
         STANDARD DEVIATION  0.1388
NORMALIZED STANDARD DEVIATIONO.0481


   FILE NAME : HD08

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 597.730
     STANDARD DEVIATION OF LINE OF INTEREST :  49.997
             NORMALIZED STANDARD DEVIATION :  0.0835
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                         MEAN 173.761
             STANDARD DEVIATION  22.510
   NORMALIZED STANDARD DEVIATION  0.1295
         CORRELATION COEFFICIENT  0.7364

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
      MAXIMUM OF THE RATIOS:  4.2712
      MINIMUM OF THE RATIOS:  3.0165
                       MEAN  3.4721
         STANDARD DEVIATION  0.3299
NORMALIZED STANDARD DEVIATIONO.0950
```

```
   FILE NAME : HD09

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 602.622
     STANDARD DEVIATION OF LINE OF INTEREST :  88.535
                NORMALIZED STANDARD DEVIATION :  0.1469
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE       974
                              MEAN 158.565
              STANDARD DEVIATION  25.024
   NORMALIZED STANDARD DEVIATION  0.1578
         CORRELATION COEFFICIENT  0.9097

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  4.3498
     MINIMUM OF THE RATIOS:  3.3762
                      MEAN  3.8142
        STANDARD DEVIATION  0.2453
NORMALIZED STANDARD DEVIATIONO.0643


   FILE NAME : HD10

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 739.252
     STANDARD DEVIATION OF LINE OF INTEREST : 101.293
                NORMALIZED STANDARD DEVIATION :  0.1370
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE       974
                              MEAN 176.854
              STANDARD DEVIATION  23.852
   NORMALIZED STANDARD DEVIATION  0.1349
         CORRELATION COEFFICIENT  0.8898

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  4.9684
     MINIMUM OF THE RATIOS:  3.6446
                      MEAN  4.1897
        STANDARD DEVIATION  0.2729
NORMALIZED STANDARD DEVIATIONO.0651
```

```
   FILE NAME : HD11

****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 753.917
     STANDARD DEVIATION OF LINE OF INTEREST : 108.098
             NORMALIZED STANDARD DEVIATION :  0.1434
STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                            MEAN 163.237
           STANDARD DEVIATION  26.584
   NORMALIZED STANDARD DEVIATION  0.1629
        CORRELATION COEFFICIENT  0.8630

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  6.2246
     MINIMUM OF THE RATIOS:  3.9261
                      MEAN  4.6501
        STANDARD DEVIATION  0.4220
NORMALIZED STANDARD DEVIATIONO.0907


   FILE NAME : HD12

****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 968.400
     STANDARD DEVIATION OF LINE OF INTEREST : 117.383
             NORMALIZED STANDARD DEVIATION :  0.1212
STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                            MEAN 198.608
           STANDARD DEVIATION  23.596
   NORMALIZED STANDARD DEVIATION  0.1188
        CORRELATION COEFFICIENT  0.9040

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  5.5148
     MINIMUM OF THE RATIOS:  4.1804
                      MEAN  4.8807
        STANDARD DEVIATION  0.2541
NORMALIZED STANDARD DEVIATIONO.0521
```

B.3.4. 100 Å Filter

```
.RUN FILTER

ENTER THE FILE NAME: HD

ENTER THE DIODE NUMBER OF THE LINE OF INTEREST:204
WHAT IS THE FWHM (IN ANGSTROMS) OF THE FILTER: 100.

ENTER THE DIODE NUMBERS OF THE LINES TO BE USED FOR AVERAGING.
TO STOP DATA ENTRY ENTER A RETURN
 RATIO DIODE NUMBER 1:974
WHAT IS THE FWHM (IN ANGSTROMS) OF THE FILTER: 100.
 RATIO DIODE NUMBER 2:
DO YOU WANT TO USE A NON-STANDARD BACKGROUND REGION :Y
ENTER THE BACKGROUND DIODE NUMBER:625
WHAT IS THE FWHM (IN ANGSTROMS) OF THE FILTER: 100.
```

```
    FILE NAME : HD00

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST :  91.391
     STANDARD DEVIATION OF LINE OF INTEREST :  15.386
              NORMALIZED STANDARD DEVIATION :  0.1684
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                            MEAN   93.367
              STANDARD DEVIATION    7.415
   NORMALIZED STANDARD DEVIATION   0.0794
         CORRELATION COEFFICIENT   0.1998

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.4378
     MINIMUM OF THE RATIOS:  0.6344
                      MEAN   0.9828
        STANDARD DEVIATION   0.1777
NORMALIZED STANDARD DEVIATIONO.1809
```

```
  FILE NAME : HD01

 ****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 173.804
    STANDARD DEVIATION OF LINE OF INTEREST :  12.642
             NORMALIZED STANDARD DEVIATION :  0.0727
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                             MEAN 134.925
             STANDARD DEVIATION  11.747
   NORMALIZED STANDARD DEVIATION  0.0871
          CORRELATION COEFFICIENT -0.4872

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.6784
     MINIMUM OF THE RATIOS:  0.9843
                      MEAN  1.3015
        STANDARD DEVIATION  0.1770
NORMALIZED STANDARD DEVIATIONO.1360
```

```
  FILE NAME : HD02

 ****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 157.524
    STANDARD DEVIATION OF LINE OF INTEREST :  15.973
             NORMALIZED STANDARD DEVIATION :  0.1014
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                             MEAN 105.179
             STANDARD DEVIATION   8.045
   NORMALIZED STANDARD DEVIATION  0.0765
          CORRELATION COEFFICIENT  0.1973

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  1.8469
     MINIMUM OF THE RATIOS:  1.1475
                      MEAN  1.5039
        STANDARD DEVIATION  0.1724
NORMALIZED STANDARD DEVIATIONO.1146
```

```
   FILE NAME : HD03

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 183.908
     STANDARD DEVIATION OF LINE OF INTEREST :  17.163
             NORMALIZED STANDARD DEVIATION :  0.0933
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                            MEAN 115.417
             STANDARD DEVIATION   8.417
   NORMALIZED STANDARD DEVIATION  0.0729
         CORRELATION COEFFICIENT  0.5233

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  2.0368
     MINIMUM OF THE RATIOS:  1.3546
                      MEAN  1.5963
        STANDARD DEVIATION  0.1344
NORMALIZED STANDARD DEVIATIONO.0842
```

```
   FILE NAME : HD04

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 284.180
     STANDARD DEVIATION OF LINE OF INTEREST :  16.753
             NORMALIZED STANDARD DEVIATION :  0.0590
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                            MEAN 140.619
             STANDARD DEVIATION  13.545
   NORMALIZED STANDARD DEVIATION  0.0963
         CORRELATION COEFFICIENT  0.0215

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  3.0480
     MINIMUM OF THE RATIOS:  1.6368
                      MEAN  2.0426
        STANDARD DEVIATION  0.2612
NORMALIZED STANDARD DEVIATIONO.1279
```

```
   FILE NAME : HD05

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 289.804
     STANDARD DEVIATION OF LINE OF INTEREST :  17.098
              NORMALIZED STANDARD DEVIATION :  0.0590
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                              MEAN 125.463
             STANDARD DEVIATION    7.024
   NORMALIZED STANDARD DEVIATION  0.0560
          CORRELATION COEFFICIENT  0.0440

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  2.9297
     MINIMUM OF THE RATIOS:  2.0472
                      MEAN  2.3172
         STANDARD DEVIATION  0.1917
NORMALIZED STANDARD DEVIATIONO.0827
```

```
   FILE NAME : HD06

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 313.668
     STANDARD DEVIATION OF LINE OF INTEREST :  22.592
              NORMALIZED STANDARD DEVIATION :  0.0720
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                              MEAN  87.584
             STANDARD DEVIATION    8.217
   NORMALIZED STANDARD DEVIATION  0.0938
          CORRELATION COEFFICIENT  0.6418

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  4.0098
     MINIMUM OF THE RATIOS:  2.9655
                      MEAN  3.5966
         STANDARD DEVIATION  0.2564
NORMALIZED STANDARD DEVIATIONO.0713
```

```
   FILE NAME : HD07

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 319.068
    STANDARD DEVIATION OF LINE OF INTEREST :  24.408
             NORMALIZED STANDARD DEVIATION :  0.0765
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                           MEAN  73.413
             STANDARD DEVIATION   8.518
  NORMALIZED STANDARD DEVIATION  0.1160
        CORRELATION COEFFICIENT  0.7921

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  5.6479
     MINIMUM OF THE RATIOS:  3.8369
                      MEAN  4.3762
        STANDARD DEVIATION  0.3470
NORMALIZED STANDARD DEVIATION0.0793
```

```
   FILE NAME : HD08

****** UNRATIOED STATISTICS *****
    MEAN OF LINE OF INTEREST : 364.895
    STANDARD DEVIATION OF LINE OF INTEREST :  29.955
             NORMALIZED STANDARD DEVIATION :  0.0821
STATISTICS OF LINES USED FOR RATIOING
     DIODE NUMBER OF RATIO LINE      974
                           MEAN  73.109
             STANDARD DEVIATION  10.084
  NORMALIZED STANDARD DEVIATION  0.1379
        CORRELATION COEFFICIENT  0.7113

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  6.5472
     MINIMUM OF THE RATIOS:  4.2467
                      MEAN  5.0492
        STANDARD DEVIATION  0.5409
NORMALIZED STANDARD DEVIATION0.1071
```

```
FILE NAME : HD09

****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 363.190
     STANDARD DEVIATION OF LINE OF INTEREST :  52.630
              NORMALIZED STANDARD DEVIATION :  0.1449
STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                              MEAN  68.322
              STANDARD DEVIATION  10.538
   NORMALIZED STANDARD DEVIATION  0.1542
        CORRELATION COEFFICIENT  0.8734

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  6.6327
     MINIMUM OF THE RATIOS:  4.5480
                       MEAN  5.3386
        STANDARD DEVIATION  0.4107
NORMALIZED STANDARD DEVIATIONO.0769
```

```
FILE NAME : HD10

****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 443.330
     STANDARD DEVIATION OF LINE OF INTEREST :  58.833
              NORMALIZED STANDARD DEVIATION :  0.1327
STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                              MEAN  75.679
              STANDARD DEVIATION  10.590
   NORMALIZED STANDARD DEVIATION  0.1399
        CORRELATION COEFFICIENT  0.8324

***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  7.1392
     MINIMUM OF THE RATIOS:  4.7891
                       MEAN  5.8849
        STANDARD DEVIATION  0.4700
NORMALIZED STANDARD DEVIATIONO.0799
```

```
   FILE NAME : HD11

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 445.517
     STANDARD DEVIATION OF LINE OF INTEREST :  62.023
              NORMALIZED STANDARD DEVIATION :  0.1392
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                            MEAN  71.197
              STANDARD DEVIATION  12.868
   NORMALIZED STANDARD DEVIATION  0.1807
         CORRELATION COEFFICIENT  0.7771

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  8.9480
     MINIMUM OF THE RATIOS:  4.7743
                      MEAN  6.3479
        STANDARD DEVIATION  0.8098
NORMALIZED STANDARD DEVIATIONO.1276
```

```
   FILE NAME : HD12

 ****** UNRATIOED STATISTICS *****
     MEAN OF LINE OF INTEREST : 572.520
     STANDARD DEVIATION OF LINE OF INTEREST :  68.233
              NORMALIZED STANDARD DEVIATION :  0.1192
 STATISTICS OF LINES USED FOR RATIOING
      DIODE NUMBER OF RATIO LINE      974
                            MEAN  84.074
              STANDARD DEVIATION  11.206
   NORMALIZED STANDARD DEVIATION  0.1333
         CORRELATION COEFFICIENT  0.7941

 ***** RATIOED DATA *****
DIODE NUMBER OF RATIO LINE:      974
     MAXIMUM OF THE RATIOS:  8.4979
     MINIMUM OF THE RATIOS:  5.2752
                      MEAN  6.8434
        STANDARD DEVIATION  0.5700
NORMALIZED STANDARD DEVIATIONO.0833
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