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A Portable Microcomputer for the Analysis of Plutonium Gamma-Ray Spectra

Vol. I. Data Analysis Methodology and Hardware Description

W. D. Ruhter

ISPO Task A.104

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ABSTRACT

A portable microcomputer has been developed and programmed for the International Atomic Energy Agency (IAEA) to perform in-field analysis of plutonium gamma-ray spectra. The unit includes a 16-bit LSI-11/2 microprocessor, 32-K words of memory, a 20-character display for user prompting, a numeric keyboard for user responses, and a 20-character thermal printer for hard-copy output of results. The unit weights 11 kg and has dimensions of 33.5 x 30.5 x 23.0 cm. This compactness allows the unit to be stored under an airline seat. Only the positions of the 148-keV ^{241}Pu and 208-keV ^{237}U peaks are required for spectral analysis that gives plutonium isotopic ratios and weight percent abundances.

Vol. I of this report provides a detailed description of the data analysis methodology, operation instructions, hardware, and maintenance and troubleshooting. Vol. II describes the software and provides software listings.

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1. INTRODUCTION

The Department of Energy (DOE) provides the International Atomic Energy Agency (IAEA) with technical assistance in nuclear safeguards. The Lawrence Livermore National Laboratory (LLNL) is one of several DOE laboratories that are participating in this effort. Over the past several years we have designed, programmed, and tested a portable microcomputer unit for field use by IAEA inspectors to analyze plutonium gamma-ray spectra for relative plutonium isotopic abundances.

To quantitatively measure plutonium in a sample using the nondestructive techniques of high-level neutron coincidence counting (HLNCC) or calorimetry also requires plutonium isotopic abundance measurements. High-resolution gamma-ray spectrometry measurements are performed on Pu samples to determine their isotopic composition. Sophisticated spectral analysis techniques must be applied to the spectral data to obtain isotopic information with a high confidence level. Up to now, IAEA inspectors have taken plutonium gamma-ray spectra with a Silena multichannel analyzer (MCA) and recorded the data on cassette tapes that are later analyzed at IAEA Headquarters. To provide timely verification of a sample and to satisfy operational constraints, however, it is necessary to obtain results in-situ.

The portable microcomputer unit measures 33.5 x 30.5 x 23.0 cm (which allows the unit to be stored under an airline seat), weighs 11 kg (24 lb), and operates on either 110-V AC (60 Hz) or 220-V AC (50 Hz). A photograph of the unit is shown in Fig. 1. A 16-bit Digital Equipment Corporation (DEC) LSI-11/2 microprocessor is used as the central processor to produce a powerful, fast, and easy-to-use data analysis unit. The software is stored on 16K words of erasable, programmable, read-only memory. Random access memory of 12K words is used for data storage during the analysis process. Data transfer between the unit

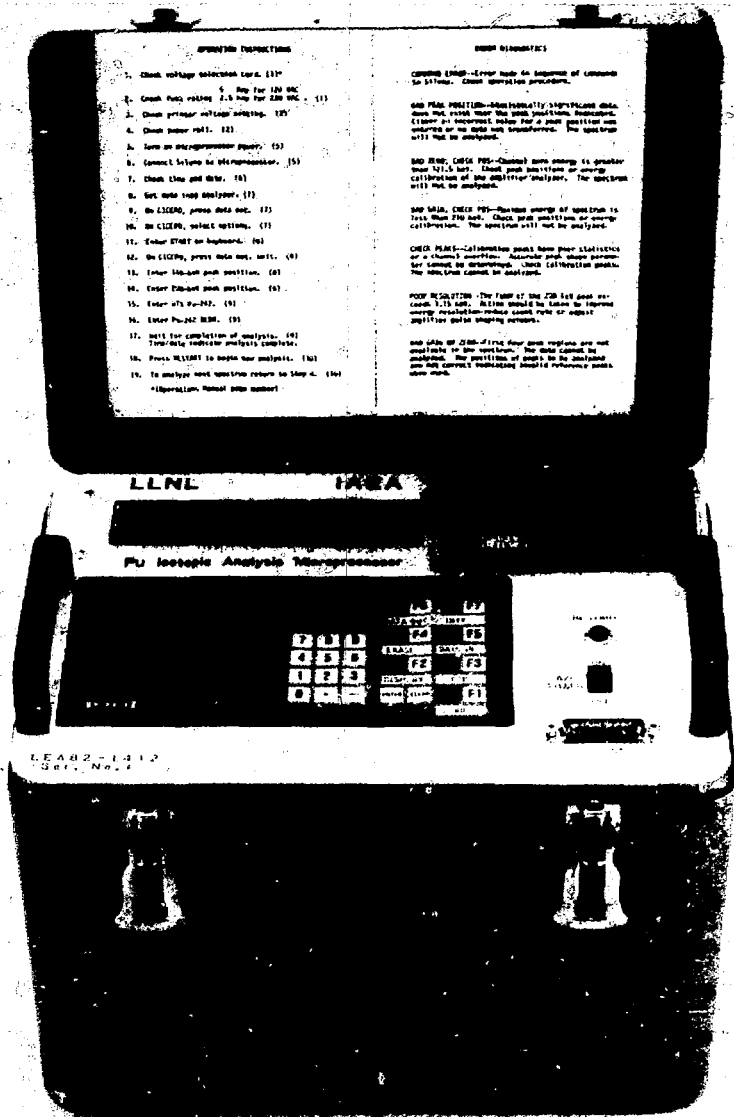


FIG. 1. The portable plutonium isotopic analysis microcomputer unit.

and a Silena CICERU MCA occurs via a parallel interface. A 20-character alphanumeric display is used to prompt the user for input and to display messages. A simple numeric keyboard allows the user to make the responses necessary for the analysis. Hardcopy printout of the results is produced by a 20-character thermal printer.

The spectral analysis problem requires sophisticated data analysis techniques, but to enhance the practical aspects of inspector use the unit must be portable and simple to use. Only the positions of the 148-keV ^{241}Pu and 208-keV ^{237}U peaks need to be entered by the inspector to initiate a complete analysis. The analysis determines plutonium isotopic ratios from gamma-ray peaks in the 110- to 400-keV region of the spectral data. This requires both a proper description of peak shape and background continuum and a method of unfolding peak multiplets. Because complicated iterative peak-fitting software is not suitable for a portable, simple-to-operate unit, the analysis is done using the non-iterative technique of component response function fitting to the peak multiplets.

Isotopic-component profiles are generated for each peak grouping by using known gamma-ray energies and peak shapes. The peak shapes are determined from the 148- and 208-keV gamma-ray peaks in the spectrum; this information is then parameterized as a function of energy. The response spectra are fitted to the observed multiplet by a linear least-squares technique to yield the amounts of the isotopic components they represent. Therefore, all essential information is obtained once the locations of the two peak positions are specified.

This is intended to be a final report on this work. We describe in detail the data analysis methodology, the hardware components used in assembling the unit, the software (Vol. II), and the operation and maintenance of the portable plutonium analysis microcomputer.

Extensive tests on the performance of the unit and the data analysis methodology have been conducted.¹ Recent tests of the unit have been performed by the IAEA, and the results of these tests can be found in IAEA report STR-145.²

2. DATA ANALYSIS METHODOLOGY

The general method for determining plutonium isotopic abundance ratios using high-resolution gamma-ray spectrometry is based on a principle commonly expressed by the following equation:

$$\frac{N_i}{N_j} = \frac{I_i * B_j * \epsilon_j * t_j}{I_j * B_i * \epsilon_i * t_i} , \quad (1)$$

where N_i/N_j is the atom ratio of isotopes i and j , I is the observed peak intensity, B is the gamma-ray branching intensity, ϵ the counting efficiency, and t is the half life. The branching intensities and half lives are known, and the peak intensities are measured, so the only remaining unknowns are the efficiencies. The influence of efficiency and attenuation, physical factors that are functions of energy, is minimized by taking ratios of gamma-ray peak intensities for pairs of peaks that are nearly equal in energy. Small differences can be accurately determined using a curve established from other neighboring peaks that are due to gamma emissions of known relative intensities; this technique is commonly known as the intrinsic calibration method.³

Determination of peak intensities must be precise to give accurate final results. A careful analysis and interpretation of gamma-ray peaks includes the proper delineation of the peak shape, a reproducible description of the background continuum under the peak or peak grouping, and a method for unfolding peak multiplets and removing small interferences. The basic equation⁴ for describing peak shapes, developed by Gunnink,⁴ is written as follows:

$$y_i = y_0 e^{\alpha(x_i - x_0)^2} + Ay_0 e^{B(x_i - x_0)} \left[1 - e^{C\alpha(x_i - x_0)^2} \right] \delta , \quad (2)$$

where

- y_i = net data counts
- y_0 = peak height
- α = peak width parameter
- x_i = channel value of the i -th point
- x_0 = peak centroid position
- A, B, C = shape parameters describing the tailing function
- δ = 1 for $x_i - x_0 < 0$
- δ = 0 for $x_i - x_0 > 0$.

Six parameters -- y_0 , x_0 , α , A, B, and C--characterize a particular gamma-ray peak (see Fig. 2). The parameters α , A, B, and C are needed to describe the peak shape but normally are not of great interest by themselves. It simplifies the peak-fitting process if their values are predetermined from the given spectrum and then treated as fixed rather than free parameters.

The peak width is commonly specified by the full width at half maximum (FWHM = 2.355σ). This is related to α by

$$\alpha = 1.0/2\sigma^2$$

The width of a peak results primarily from the summing of instrumental noise (Γ_n) and an energy-dependent term (Γ_s) resulting from statistical fluctuations in the number of ion pairs formed in the detector. To a first approximation, the statistical term is linear with energy, and the noise contribution is constant. Thus, the observed total peak width Γ_t may be expressed as

$$\Gamma_t^2 = \Gamma_n^2 + \Gamma_s^2 = K_1 + K_2 \cdot E$$

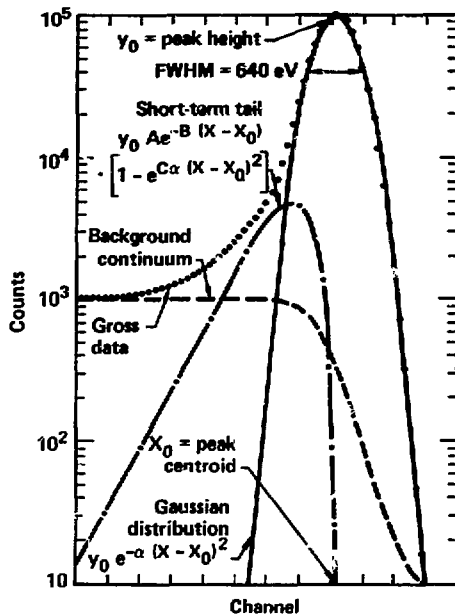


FIG. 2. A detail showing the mathematical components used to describe gamma-ray peak shape.

FWHM can be expressed in terms of energy as

$$[(FWHM)^2 - 0.462] \cdot (\text{gain})^2 = K_1 + K_2 \cdot E \quad (3)$$

The values of K_1 and K_2 can be calculated by determining the FWHM of low- and high-energy peaks in a spectrum. The value 0.462 is a Sheppard's correction for the error that results from treating all of the counts in a given channel as if they were concentrated at the channel center.

The quantities A and B characterize the amplitude and slope of an exponentially rising term that describes the tailing occurring on the low-energy side of a gamma-ray peak. This term is multiplied by $\left[1 - e^{-C(x-x_0)^2}\right]$ to reduce its contribution to zero at the peak centroid. The quantity C is a rather insensitive parameter, and a value of 0.4 appears suitable for all germanium detector systems.

The slope parameter B is detector dependent only, whereas the amplitude parameter A is both detector and energy dependent. A simple algorithm, given by $\ln A = C_1 + C_2 \cdot E$, describes the approximate relationship between parameter A and the gamma-ray energy. As in the case for α , two or more peaks can be used to evaluate the constants C_1 and C_2 in this expression. Therefore, the peak shapes for a given spectrum, can be predetermined from two peaks and specified in terms of five parameters: K_1 and K_2 (used to determine α), C_1 and C_2 (used to calculate A), and B.

To determine these parameters, the 148.6-keV peak of ^{241}Pu and the 208-keV peak of ^{237}U are used. Usually, these two peaks are the most intense peaks in the spectrum, especially for high burnup plutonium. Good statistical significance is required to accurately determine the energy dependence of the tail parameter A, and in most cases, the spectra encountered are not statistically good. In addition, the 148.6-keV peak also has interferences on the low-energy side, which increases the uncertainty in A at that energy. Because changes in A over an interval of 100 keV are 1% or less, the analysis code determines the tail parameters A and B from the 208-keV peak and treats A as a constant for the spectrum. The area of the tail is not included in the total area of the peak in this analysis.

The 148.6-keV and 208-keV peaks are also used as reference peaks for determining the gain and channel-zero energy of the spectrum. Using this information (assuming that the conversion gain is linear), we can compute the exact positions of the peaks to be

analyzed. If the value of x_0 in Eq. 2 is also known (in addition to the other shape parameters), the only free parameter remaining is the peak height. The resulting equation becomes linear in form and can be solved by a linear least-squares method rather than by an iterative technique.

Data points, Y_i , in an overlapping peak multiplet are considered linear combinations of the appropriate contribution from each peak j so that

$$Y_i = \sum_{j=1}^n y_{0j} \cdot f(j, \text{peak parameters}) .$$

However, not all of the peak heights in a group need to be free parameters, because peaks belonging to a given isotopic component can be related by their known branching intensities. Consequently, a response envelope for isotopic components rather than for each peak can be computed, thereby reducing the number of unknowns. This also provides for removal of interferences where peaks severely overlap.

Before determining the net area of a peak, the background beneath the peak or peak grouping must be removed. This is usually done by interpolating the background, using a straight line or a polynomial function. However, such a procedure is, in principle, incorrect and may lead to erroneous results. Thus, the following explicit function is used to interpolate background values beneath the peak grouping:

$$B_i = b_n + (b_m - b_n) \cdot \left(\frac{\sum_{j=n}^{i-1} Y_j}{\sum_{k=n}^{k-m} Y_k} \right) , \quad (4)$$

where

B_i = computed background at channel i

Y_j = spectrum count of channel j

b_n = average background level of the low-energy side of the peak

b_m = average background level of the high-energy side of the peak.

This function produces smoothed background steps that occur at each peak position. It works equally well for single peaks and complex peak groupings.

The choice of gamma-ray peaks for analysis to determine the desired isotopic ratios is limited to the energy ranges of the spectra normally taken by the IAEA inspectors. The energy ranges usually measured are from 110 to 220 keV or from 110 to 400 keV. In the 110- to 220-keV energy interval, there are seven energy regions containing a peak(s) that are analyzed by the data analysis code. The energies and intensities of the gamma rays analyzed in these regions are listed in Table 1. Most of the energy and intensity information used in the data analysis program is taken from a report published by Gunnink.⁵ In certain instances, however, changes have been made to reflect results obtained by others^{6,7} and ourselves. This analysis assumes that the ^{237}U is in secular equilibrium with its parent ^{241}Pu . The details of analyzing these regions follow.

a. 122- to 130-keV Region

Gamma rays from ^{239}Pu and ^{241}Am exist in this region. The 125.29- and 129.29-keV peaks contribute to the determination of the $^{241}\text{Am}/^{239}\text{Pu}$ ratio. The 125.29-keV peak is a member of an unresolved triplet whose other components are the ^{239}Pu peaks at 124.51 and 125.21 keV. These interferences in the ^{241}Am 125.29-keV peak are removed by ratioing the ^{239}Pu 124.51- and 125.21-keV peaks to the Pu-239 129.29-keV peak. The ^{239}Pu 123.62-keV peak is also ratioed to the 129.29-keV peak. The ratios are determined from the branching intensities of these peaks. These ratios are incorrect to the degree that the detection efficiency differs

TABLE 1. Energy regions analyzed by the data analysis software.

Isotope	Energy (keV)	Intensity	Isotope	Energy (keV)	Intensity
<u>Region 1</u>			<u>Region 2</u>		
^{239}Pu	122.926	1.00×10^{-5}	^{239}Pu	141.567	3.20×10^{-7}
^{239}Pu	123.62	1.97×10^{-7}	^{239}Pu	144.211	2.83×10^{-6}
^{239}Pu	124.51	6.13×10^{-7}	^{239}Pu	146.077	1.19×10^{-6}
^{239}Pu	125.21	7.11×10^{-7}	^{241}Am	146.557	4.61×10^{-6}
^{241}Am	125.292	4.08×10^{-5}	^{241}Pu	148.567*	1.87×10^{-6}
^{239}Pu	129.29 ⁺	6.26×10^{-5}	^{241}Am	150.11	7.40×10^{-7}
<u>Region 3</u>			<u>Region 4</u>		
^{241}Pu	159.955	6.74×10^{-8}	^{238}Pu	152.68*	9.32×10^{-6}
^{239}Pu	160.19	6.20×10^{-8}	sum peak	154.2	
^{240}Pu	160.308	4.02×10^{-6}			
^{239}Pu	161.482	1.20×10^{-6}			
^{241}Pu - 237	164.597* ⁺	4.53×10^{-7}			
^{241}Am	164.597	6.67×10^{-7}			
^{241}Am	165.93	2.32×10^{-7}			
<u>Region 5</u>			<u>Region 6</u>		
^{235}U	185.72*	0.561	^{239}Pu	203.537* ⁺	5.60×10^{-6}
<u>Region 7</u>			<u>Region 8</u>		
^{241}Pu - 237	208.0* ⁺	5.33×10^{-6}	^{241}Pu - 237	332.385	2.98×10^{-7}
^{241}Am	208.0	7.91×10^{-6}	^{241}Am	332.385	1.49×10^{-6}
			^{239}Pu	332.853	5.06×10^{-6}
			^{241}Pu - 237	335.43	2.39×10^{-8}
			^{241}Am	335.43	4.96×10^{-6}
			^{239}Pu	336.104	1.13×10^{-6}
			^{239}Pu	341.517	6.62×10^{-7}
			^{239}Pu	345.011* ⁺	5.59×10^{-6}
			<u>Region 9</u>		
			^{239}Pu	367.050	8.65×10^{-7}
			^{239}Pu	368.546	9.03×10^{-7}
			^{241}Pu - 237	368.603	1.05×10^{-8}
			^{241}Am	368.603	2.17×10^{-6}
			^{241}Pu - 237	370.933	2.71×10^{-8}
			^{241}Am	370.933	5.23×10^{-7}
			^{239}Pu	375.042* ⁺	1.57×10^{-5}
			^{241}Am	376.59	1.38×10^{-6}
			^{239}Pu	380.166	3.05×10^{-6}
			^{239}Pu	382.74	2.59×10^{-6}

* Peaks used as group reference peak.

+ Peaks used in determination of relative detection efficiency.

between the lower energy peaks and the 129.29-keV peak. Because the relative detection efficiencies cannot be established until all of the peak areas are determined, it is impossible to correct these ratios at this point in the analysis. A correction is made during the calculation of the isotopic ratios from the peak areas, which is described later.

A difficulty in the analysis of this region is the determination of the low-energy background. This is because of the close proximity of the $K\alpha$ x rays. Background levels are determined both below the ^{241}Am 123-keV peak and between the 125.3- and 129.3-keV peaks. If the former background level exceeds the latter, then the latter background level is used in the analysis.

b. 141- to 151-keV Region

This region contains gamma rays from ^{239}Pu , ^{241}Pu , and ^{241}Am . The only information used from this region is that of the ^{241}Pu 148.6-keV peak area. The other peaks are included in the analysis only to determine a satisfactory background for the 148-keV peak. The weak ^{241}Am 150.1-keV peak is ratioed to the ^{241}Am 146.6-keV peak. Again any corrections to this ratio for relative detection efficiency differences are made later. The weak ^{239}Pu 146.1-keV peak is ratioed to the 144.21-keV peak.

c. 152- to 155-keV Region

A gamma ray from ^{238}Pu exists in this region. The intensity listed in Table 1 is 2.5% smaller than the value given by Gunnink.⁵ In addition, there is a possibility of a sum peak occurring at 154.2 keV because of summing of the ^{241}Am 59.54-keV gamma ray with the uranium 94.66-keV $K\alpha_2$ x ray. To ensure that the sum peak

does not compromise the determination of the high-energy background for the 152.7-keV peak, this region is widened to include the sum peak, if it exists. Every effort should be made to eliminate this sum peak and others (see next region) with the proper combination of absorbers.

d. 159- to 166-keV Region

Gamma rays from ^{239}Pu , ^{240}Pu , ^{241}Pu , ^{237}U , and ^{241}Am are analyzed in this region. Note that the energy of the ^{240}Pu gamma ray is different from that given by Gunnink.⁵

This region is important for the determination of the ^{240}Pu abundance. The 160.308-keV gamma ray from ^{240}Pu forms an unresolved multiplet with the 159.96-keV peak from ^{241}Pu and the 160.19-keV peak from ^{239}Pu . In the analysis of this multiplet, the 160.19-keV peak is ratioed to the 161.482-keV peak.

In addition to the severe overlap of peaks in this region, the analysis is made even more difficult by the possibility of sum peaks in this region. The sum peaks are the result of the ^{241}Am 59.53-keV gamma ray summing with the Np and U K α x rays. One of these sum peaks directly interferes with the 160.3-keV ^{240}Pu peak, while two other sum peaks interfere with the determination of the low-energy background level. By reducing the number of channels used to determine the low-energy background level, one can avoid these sum peaks, if they are present. However, as a result, the precision in the determination of this background level is reduced considerably. The possible interference with the ^{240}Pu 160.3-keV peak cannot be avoided or corrected for by means of data manipulation or calculation; consequently, the ^{240}Pu result will be biased, if the sum peaks are not eliminated.

e. 184- to 187-keV Region

This region contains the strongest gamma ray from ^{235}U . The intensity of this gamma ray is used to determine the $^{235}\text{U}/^{239}\text{Pu}$ ratio.

f. 203- to 205-keV Region

A gamma ray from ^{239}Pu exists in this region. Corrections must be made to this region for counts caused by the low-energy tail of the 208-keV gamma-ray peak, especially for high burnup material. One possible method for making this correction is to analyze the 203.5- and 208-keV peaks together. However, this approach shows biases resulting from the determination of the high-energy background for this expanded region. If the peaks are analyzed together, the high-energy background taken above the 208-keV peak does not accurately reproduce the background beneath the 203.5-keV peak. This is especially true, if the spectrum shows the effects of pileup (see next region). Better results are obtained when these peaks are analyzed separately and the 208-keV peak tail contribution is removed from the 203-keV region by other means.

g. 206- to 211-keV Region

A gamma ray from ^{241}Pu - ^{237}U and ^{241}Am is present in this region. This gamma ray is normally the strongest in the spectrum. If pulse pileup caused by high counting rates occurs, the spectral effects are readily evident on the high-energy side of the 208-keV peak. The spectral effects of pulse pileup cause distorted peak shapes and may cause biases in the determination of the high-energy background level leading to inaccuracies in the determination of the

peaks areas. Normally, the high-energy background level is determined in an energy interval immediately above the gamma-ray peak. In the analysis of the 208-keV peak, the high-energy background energy interval has been moved higher in energy to avoid counts caused by pulse pileup.

However, where peaks overlap, the pileup of one may fall beneath the other, causing an incorrect determination of its area. There is no accurate way of correcting for this interference; therefore, every effort should be made to prevent pulse pileup by operating at reasonable count rates.

Two additional energy regions – 332 to 345 keV and 367 to 385 keV – are included in the analysis, if the gain and channel-zero energy are set to include these regions in the spectrum. Inclusion of these regions adds to the precision of the determination of the $^{241}\text{Pu}/^{239}\text{Pu}$ and the $^{241}\text{Am}/^{239}\text{Pu}$ isotopic ratios as long as sufficient statistical precision is obtained for peaks in these regions.

Before analyzing these regions, the data analysis program redetermines the gain and zero of the spectrum by determining the position of the ^{239}Pu 375.04-keV peak. This is done to ensure that these energy regions are properly located by the data analysis program should nonlinearity exist in the spectrum. The details of analyzing these regions follow.

h. 332- to 347-keV Region

Gamma rays from the decay of ^{239}Pu , ^{241}Pu , ^{237}U , and ^{241}Am contribute to this region. The gamma-ray peaks at 332.3 keV and 335.4 keV caused by ^{241}Pu - ^{237}U and ^{241}Am have interferences from ^{239}Pu that are removed in the

fitting process by ratioing their intensities to the ^{239}Pu 345-keV peak. These ratios are corrected for efficiency differences later in the analysis.

i. 336- to 385-keV Region

This region contains gamma rays from ^{239}Pu , ^{241}Pu - ^{237}U , and ^{241}Am . The two weaker ^{239}Pu peaks at 367 and 368.5 keV that interfere with the ^{241}Pu - ^{237}U , ^{241}Am peak at 368.6 keV are removed by ratioing their intensities to the ^{239}Pu 375-keV peak.

The data analysis program analyzes each region separately. First, the background distribution is removed from the peak grouping, and then the position of a reference peak in each region is determined by fitting the top of that peak. The peaks used as reference peaks in each region are denoted by asterisks in Table 1. The positions of the remaining peaks in each region are located relative to the reference peak using the gain and channel-zero energy of the spectrum. With this position information and the other peak shape parameters, one can generate a response function for each peak or combination of peaks. A set of linear equations with the peak heights as the unknowns is solved by a simple matrix inversion procedure. Before performing the least-squares fit, the equations are appropriately weighted. This is done by dividing each channel count equation by the square root of the gross channel count. The diagonal matrix elements of the inverted matrix are used to assign errors to the peak heights obtained from the fit.

The peak areas are calculated using the integral of a gaussian from the peak heights and the appropriate full-width-half-maximum values, which are calculated from the predetermined peak shape parameters using Eq. 3. The errors on the peak areas are

determined from the square root of the sum of the square of the peak height error and the square of the error in the determination of the background for the region. After the analysis of each region, the results – peak energies, areas, and errors – are printed on the thermal printer. An example of the printout is shown in Fig. 3.

```

10:28      8/2/82
Spec # 3; LT = 2300 S

Peak en    Counts    %ER
185.72     0.          60.1

Gain = 0.1145 keV/CH

CHNL zero E = 113.955

FWHM (208 keV) = 0.907

Peak en    Counts    %ER
122.92     20323.     0.9
123.61     288.       FIXD
124.50     910.       FIXD
125.21     848.       FIXD
125.29     78873.     0.4
129.29     92923.     0.4

238PU/239PU = 0.003577
              +- 0.000075
240PU/239PU = 0.263086
              +- 0.007487
241PU/239PU = 0.038897
              +- 0.000576
241AM/241PU = 0.619975
              +- 0.010919
235U/239PU = 0.000000
              +- 0.000000

Peak en    Counts    %ER
141.57     204.       46.3
141.21     4428.     2.5
146.08     1669.     FIXD
146.56     9738.     1.5
148.56     191185.   0.2
150.11     1577.     FIXD

Time since Sep =
3671.+- 52. days

%238 = 0.272 +-0.006
%239 = 75.933 +-0.442
%240 = 19.977 +-0.580
%241 = 2.954 +-0.47
%242 = 0.864 CALC
%AM/PU = 1.831 +-0.43

Peak en    Counts    %ER
152.68     14428.    1.4
154.20     0.        52.0

Peak en.   Counts    %ER
159.96     6037.     FIXD
160.20     86.       FIXD
160.29     5965.     2.3
161.45     1672.     5.7
164.58     46304.    0.5
165.93     347.      25.5

```

FIG. 3. Typical data analysis printout of results
for the 120- to 220-keV region.

The next step in the data analysis is to determine isotopic ratios from the peak areas. As shown in Eq. 1, this requires corrections for the influence of counting efficiency and gamma-ray attenuation (caused by the sample matrix or other absorbing materials) on gamma-ray peak areas. Because ratios of peak areas are involved, it is not necessary to determine the corrections absolutely, but only the relative relationship between the corrections, which is then applied to the peak area ratio. To minimize these corrections and consequently make them less sensitive to errors in their determination, the ratios of peak areas are taken of pairs of gamma rays that are as close as possible in energy. If the energies are close, attenuation and efficiency differences are small, thus making the corrections small.

An intrinsic calibration technique is used to determine these corrections from peak areas measured in each spectrum. Peak areas from ^{239}Pu and ^{241}Pu - ^{237}U gamma rays (denoted by + in Table 1) are corrected for gamma-ray branching intensities and fitted to the functional form

$$\ln\left(\frac{I_i}{B_i}\right) = a_0 + a_1 \delta_i + \sum_{j=1}^{2 \text{ or } 3} [a_{j+1} (\ln E_i)^j] \quad (5)$$

The term E_i is the energy of the corresponding gamma ray in MeV. The coefficient a_1 normalizes the ^{239}Pu data points to the ^{241}Pu - ^{237}U data points. If the 330- and 370-keV regions are included in the spectrum, a cubic function is fit to the data (the sum of j is to 3). The ^{241}Pu 148.6-keV peak area is not used in the determination of the relative efficiency curve, because it would require correction of the ^{241}Pu - ^{237}U 165- and 208-keV peaks for the ^{241}Am contribution, which is unknown at this point in the analysis.

From this functional relationship, one can calculate the necessary corrections to the peak area ratios. The methodology⁸ used to calculate isotopic ratios from peak areas is best illustrated by an example. Consider the 203/208-keV peak pair, which belongs to ²³⁹Pu, ²⁴¹Pu-²³⁷U, and ²⁴¹Am. If A²⁰³ and A²⁰⁸ represent the net areas of the two peaks, the following equations can be written to describe their observed values

$$A^{203} = \epsilon^{203} B_2^{203} X_2$$

and

$$A^{208} = \epsilon^{208} B_4^{208} X_4 + \epsilon^{208} B_5^{208} X_5 ,$$

where components 2, 4, and 5 represent ²³⁹Pu, ²⁴¹Pu, and ²⁴¹Am, respectively, and X equals the amount of each isotopic component. A single linear equation is obtained by ratioing one equation to the other, which is rewritten in the following form

$$B^{203} - \frac{A^{203} \epsilon^{208} B_4^{208} X_4}{A^{208} \epsilon^{203} X_2} - \frac{A^{203} \epsilon^{208} B_5^{208} X_5}{A^{208} \epsilon^{203} X_2} = 0 . \quad (6)$$

The ratio $\epsilon^{208}/\epsilon^{203}$ is calculated from the relative efficiency curve given by Eq. 5. The unknowns are the ratios X_4/X_2 and X_5/X_2 , which represent disintegration ratios for ²⁴¹Pu/²³⁹Pu and ²⁴¹Am/²³⁹Pu, respectively. Equations similar to Eq. 6 are developed for the 125/129, 148/129, 152/148, 160/165, 332/345, and 368/375-keV peak pairs. At this point in the analysis, certain interferences that were removed by ratioing branching intensities as described earlier are corrected for efficiency differences. This is done by recombining these peak areas and including the interferences as part of the equations described above. After the complete set of linear equations has been formed and weighted, it is solved by the method of least squares. A simple matrix inversion yields the disintegration ratios and their attendant errors. The

weighting of each equation involves the peak area errors and the relative efficiency for the energy region represented by the equation.

The disintegration ratios must be corrected for isotopic half lives and mass differences to obtain isotopic weight ratios. The half lives used for the plutonium isotopes and ^{241}Am are listed in Table 2. The isotopic weight ratios and their absolute total errors are printed on the thermal printer. The printout also includes the age of the sample since separation from ^{241}Am . This age is calculated on the basis of the $^{241}\text{Am}/^{241}\text{Pu}$ ratio, using the standard parent-daughter relationship. This portion of the printout is shown in Fig. 3 .

TABLE 2. Pu and Am half lives recommended in ANSI 15.22.

<u>Isotope</u>	<u>Half Life (y)</u>
^{238}Pu	87.79
^{239}Pu	24082
^{240}Pu	6537
^{241}Pu	14.35
^{241}Am	434.1

The weight percent value of each plutonium isotope and the ^{241}Am abundance versus total plutonium are also printed out. Calculation of these values requires information on the ^{242}Pu abundance. Because the ^{242}Pu gamma rays are not measurable, it is necessary to either input this information, if known, or to calculate it using an isotopic correlation. The data analysis program has been written to allow the user to enter the ^{242}Pu weight percent value along with its relative error, when known. If the user enters zero for the ^{242}Pu weight percent, then the analysis program calculates the ^{242}Pu abundance based on a correlation⁹ that includes the ^{241}Pu abundance, i.e.,

$$[242] = \frac{K [240][241]}{[239]^2} \quad (7)$$

where [242], [240], [241], and [235] are corresponding isotopic abundances. A value of 52 for K has been obtained by fitting the correlation to a set of plutonium isotopic data that were decay corrected to the time of reactor discharge. This correlation is linear and in general is quite independent of the reactor type. Uncertainties associated with ^{242}Pu determinations using this correlation are usually less than 10% for a wide range of materials, provided that the cooling time (time since reactor discharge) is known.

The ^{241}Pu abundance in Eq. 7 must be corrected for decay since removal from the reactor. The data analysis program only corrects for decay since the last separation, because additional decay caused by cooling or other americium separations is usually unknown. Each year of cooling time not corrected for results in a bias of ~5% in the ^{241}Pu abundance. Experience indicates that the above correlation is the best one available at the present time for IAEA safeguards use.

An extensive test and evaluation of the portable microcomputer has been conducted by Mr. Max DeCarolis of the IAEA. The most recent results from these tests have been published in IAEA report STR-145.² Measurements were made on plutonium samples, rods, and bulk materials with well-known isotopic compositions.

The measurements were carried out using a planar germanium detector with a volume of 13 cm³. The energy resolution was 610 eV at 122 keV. The data were collected with a Silena CICERO MCA, which includes an amplifier and an ADC. The conversion gain and digital offset were adjusted in such a way that gamma rays in the energy region from 100 to 420 keV were collected in 2000 channels.

Plutonium sample-detector distances were adjusted to maintain the ADC deadtime at about 20-25%. The quality of the spectra is good. There is very little evidence of pulse pileup in the spectra. A 1.6-mm-thick cadmium absorber was used to reduce the intensity of the ^{241}Am 60-keV gamma ray.

The results obtained in these measurements were generally in agreement with the "expected" results. The best agreement was obtained for the ^{239}Pu , ^{241}Pu , and ^{241}Am abundances while the results for the ^{238}Pu and ^{240}Pu abundances were not as good. This is a result of the poor counting statistics of the two gamma-ray peaks, 152.7 and 160.3 keV, available for these isotopes. The interference encountered in the determination of the 160.3-keV peak area also reduce the precision of the ^{240}Pu result. The errors given by the analysis program on the ^{240}Pu abundances for these measurements were at best 4% for normal burnup plutonium. This was observed with approximately 1×10^7 input counts. At higher burnups the ^{240}Pu precision worsens because of the stronger interference from ^{241}Pu at 160 keV.

The good results obtained in these measurements are a result not only of a rigorous data analysis methodology, but also of the quality of equipment and proper measurement procedures. Adequate absorbers were used to prevent gamma-ray summing, and the amplifier performed well at the observed count rates. The measurement procedures and the consequent spectral quality are an important part of the measurement results.

3. OPERATION INSTRUCTIONS

In this section, brief, step-by-step instructions are given for using the portable microcomputer to analyze plutonium gamma-ray spectra for isotopic abundances. Several steps important in the setup of the Siena MCA are included to emphasize the need for proper measurement procedure to ensure high-quality spectral data. Good results cannot be obtained from poor spectral data!

a. Operating Steps

(1) Setting up the Siena MCA

Comprehensive instructions for setup of Siena MCAs are given in the Agency's Instruction Manual for Instruments (IMI). These instructions should be followed carefully. Several instructions that pertain to the performance of the portable microcomputer are repeated here for further emphasis.

Spectral data to be analyzed by the portable microcomputer should not be collected in more than 2K channels, because the portable microcomputer can only analyze spectra up to 2K channels in size.

The gain of the amplifier and the digital offset should be set to ensure maximum utility of the 2K channels. For measurement of the 110- to 400-keV region, the gain should be set so that the 208-keV peak is located at approximately channel 1516 before applying a zero offset. For measurements of the 110- to 220-keV region, the gain should be set so that the 59-keV peak is located at channel 1160 before applying a zero offset.

Then, before applying a zero offset, observe the intensity of the 59-keV peak relative to the intensity of the strongest peak in the 100-keV region. Insert sufficient cadmium absorber between the sample and detector, so that the intensity of the 59-keV peak is less than the intensity of the strongest peak in the 100-keV region.

The zero offsets for the gains given above should be 776 channels for the 100- to 400-keV region and 2200 channels for the 110- to 220-keV region. These settings will make full use of the 2K channels for the energy region being measured. The upper level discriminator (ULD) should not be used to eliminate the 300-keV regions from a 100- to 400-keV measurement to obtain a 100- to 220-keV spectrum. Instead, the gain and zero offset should be changed so that the 110- to 220-keV region uses the entire 2K channels.

The sample-detector distance should be adjusted, so that the system deadtime does not exceed 50%. Higher count rates may cause pulse pileup resulting in spectral peak shape distortion. It will also result in a throughput that is less than what would be observed at a lower count rate during an equivalent real-time interval.

(2) Selecting the Microcomputer Voltage/Fuse

DO NOT TURN ON POWER.

The microcomputer unit will operate from either a 120- or 220-V AC- 50 to 60-Hz nominal power input source. Check that the voltage selection card and fuse in the power receptacle have the proper values before turning on the portable microcomputer. The number on the left-hand side of the voltage selection card should match the available AC voltage. If it does not match, change the voltage selection and the fuse.

Pull the small lever marked FUSE PULL outward to force the fuse out of its holder. Remove the voltage selection card (small pliers may be required) and orient the printed circuit (PC) board so that it shows the desired voltage on the top left side of the card, as shown in Fig. 4. Re-insert the card. The contact strips on the card energize the proper terminals on the power supply. Return the fuse lever to its normal position and install the correct fuse. The fuse rating is 5A at 120 V AC and 2.5A at 220 V AC. Slide the transparent cover back over the voltage selection card and the fuse. DO NOT TURN THE POWER ON YET.

(3) Setting the Printer Voltage

The printer also has a voltage selection switch/jumper that must be set correctly before the power can be turned on. To set this switch/jumper, withdraw the front panel assembly of the printer. Slide out the printer mechanism by first loosening the front panel thumbscrew counterclockwise until it stops. Firmly pull the thumbscrew straight out, and the front panel/printer mechanism will slide out all the way (a small force is needed to release the internal PC connection). Inside the printer housing, on the second printed circuit card from the left-hand side, is a blue switch mechanism on older printer models (APP-20A2) and a blue jumper on newer models (APP-20A21) labeled ^{110V} 220V . Set the switch or jumper to the available voltage. No fuse change is required.

(4) Checking the Paper Roll

While the front panel assembly of the printer is out, check the quantity of paper on the paper roll. Approximately 35 cm. of paper are used for a data analysis printout. Older printers have a mechanical pointer that rides on the paper roll to detect the amount of paper and a gauge indicating the relative amount of paper remaining: "F" indicates a full roll, and "E" indicates an empty roll. On newer printers, a red LED beneath the label



FIG. 4. Voltage selection card oriented to indicate the desired supply voltage. Insert as shown for 120-V AC.

PAPER OUT is lit when the paper roll is empty. The paper detection mechanism also activates a microswitch that turns off the printer when the paper roll is near empty.

(5) Changing the Paper Roll

To change the paper roll, follow these steps:

- E.1 Shut off all power to the microcomputer unit.
- E.2 Slide out the printer mechanism by first loosening the panel thumbscrew counterclockwise until it stops. Pull the thumbscrew straight out; the front panel/printer mechanism will then slide out all the way (a small force is needed to release the internal connection).
- E.3 Remove the paper roll by depressing the thermal printhead assembly at the rear near the paper roll to release any remaining paper (see Fig. 5).
- E.4 Pull the remaining paper backward from under the printhead. On older printer models (such as the APP-20A2), grasp both ends of the paper roll axle below the retaining spring and pull up. On newer models (such as the APP-20A21), remove the empty paper roll by gently spreading the sides of the print module assembly and letting the roll drop out.
- E.5 Slide the paper roll axle out of the used paper roll and reinsert the axle in a new roll. DO NOT DISCARD THE AXLE! The paper is supplied in boxes of ten rolls. Order Box Number 32-11578-1, \$30.00 plus



**FIG. 5. Removal of paper roll from printer mechanism
(model APP-20A21).**

shipping costs from any of the DATEL international sales offices.

E.6 On older models, slide the new roll and the axle past the retaining springs. On the newer models, gently spread the sides of the printer assembly and insert the new paper roll. Be sure that the grommets snap into the center of the paper roll and the paper spins freely. Insert the paper under the printhead while pressing down on the printhead assembly. Push the paper until it appears at the front panel slot. Be sure that the paper comes from the rear of the roll and passes over the roll to the printhead. Only the paper surface on the outside of the roll is treated for printing.

E.7 Pull paper through the front panel slot and lower the printhead. Slide the printer mechanism back into the housing as far as it will go. This will reseat the internal PC board connection.

E.8 Rotate the thumbscrew clockwise until it stops; then turn on the power. Advance the paper by using the feed switch on the front panel.

(6) Connecting the Silena MCA to the Microcomputer

Connect the flat ribbon cable from the microcomputer to the 25-pin connector at the rear of the CICERO analyzer labeled J4-PUNCH.

(7) Turning on the Power to the Microcomputer

Plug the line cord into the microcomputer's power receptacle; then plug the line cord into the power source. Once again, recheck the voltage selection on the right rear side of the box. If the correct supply voltage is indicated, then switch the AC power ON to the microcomputer.

(8) Checking the Time and Date

When the power to the microcomputer is turned on or the RESTART button is pressed, the time and date are displayed. To correct either the time or the date, the INIT and ENTER keys on the microcomputer keyboard must be pressed consecutively. This activates the software necessary to change the time and date on the internal clock board. After pressing these keys, the message ENTER TIME (HH.MM) will be displayed. Enter the hour and minute(s) separated by a decimal on the keyboard. If the time shown on the keyboard display is correct, press the ENTER key. If not, press CLEAR. After the correct information is received, the display shows the message ENTER DATE (DD.MM). Enter the day and month separated by a decimal point on the keyboard; then press the ENTER key. Once the day and month information is received, the display shows the message ENTER YEAR (YY). Enter the last two digits of the year on the keyboard and then press the ENTER key. Once the information is received, the display will show the current time and date. Note: The correct year will not be displayed until a minute elapses or the RESTART pushbutton is pressed.

(9) Getting the Data into the Analyzer

Prior to beginning the analysis of a spectrum, data must be in the analyzer memory, either because they have been read into memory from a cassette tape or because they have just recently been collected.

(10) Pressing DATA OUT on the Analyzer

This step displays a menu of data-out options on the CICERO CRT. There are three data-out options on the CICERO that must be set correctly for data to be transferred to the microcomputer unit. The first option, MEM. RANGE, must be set to either QUARTER 1 for 2,048-channel transfer or EIGHTH 1 for 1,024-channel transfer. To change this option, first press 1 on the CICERO numeric keypad and then press 3 and 1 consecutively to select the first quarter, or 4 and 1 to select the first eighth of the analyzer memory for data transfer. The second option, PERIPHERALS, should be set to PUNCH. To select PUNCH, press 2 and then 2 again on the CICERO numeric keypad. The third option, OUT. MODE, should be set to TOTAL. Press 3 on the keypad until the correct option is selected. Now proceed to the next step.

(11) Entering START on the Microcomputer Keyboard

Press the START function key on the keyboard and then the ENTER key, which initializes the software in the microcomputer to begin receiving data from the analyzer. The data transfer does not start until the next step is completed.

(12) Pressing DATA OUT Again

Pressing DATA OUT again on the CICERO starts the data transfer. Approximately 20 sec are required for transfer of a 1,024-channel spectrum and 40 sec for a 2,048-channel

spectrum. When the data transfer is completed, the light above the DATA OUT pushbutton goes out and a few seconds elapse before the time/date and spectrum number/livetime are printed.

(13) Enter 148- and 208-keV Peak Positions

Determine the nearest channel address corresponding to the peak channel position of the ^{241}Pu 148.6-keV gamma-ray peak. Enter this channel number value on the microcomputer's numeric keyboard. If the value shown on the keyboard display is correct, press the ENTER key. If the displayed value is incorrect, press the CLEAR key and enter the correct value. The entered value will appear on the alphanumeric display for approximately five seconds, and then the message 208 PEAK POS will appear. Enter the nearest channel location of the ^{237}U 208-keV peak. The entered value will appear on the alphanumeric display. The microcomputer program continues with a query for the ^{242}Pu weight percent abundance.

(14) Entering Wt % ^{242}Pu

Enter the appropriate value on the keyboard and then press the ENTER key. The value entered will be shown on the display. If you do not know the ^{242}Pu weight percent, then press the CLEAR and ENTER keys consecutively; this results in a 0 entry. If zero is entered, the program will calculate the ^{242}Pu abundance based on the ^{239}Pu , ^{240}Pu , and ^{241}Pu abundances. If the value is nonzero, then the message ENTER PU-242 %ERR will appear.

(15) Entering ^{242}Pu % Error

Enter the percentage error associated with the ^{242}Pu weight percent abundance that was entered. If the error on the ^{242}Pu weight percent abundance is 10%, enter 10 (decimal) using the numeric keyboard and then press ENTER.

(16) Waiting for Completion of the Analysis

The complete analysis of a spectrum takes approximately 90 sec. At the end of an analysis, the current time and date are displayed indicating the end of the analysis. On rare occasions an arithmetic error may occur in the analysis, i.e., division by zero or attempting to take the square root of a negative number. This will cause the data analysis program to stop running with no indication except that the analysis is not completed within 90 sec. To recover from this condition, the user must press the RESTART pushbutton; this causes the microcomputer to return to the beginning of the program.

(17) Pressing RESTART To Begin a New Analysis

Once the data analysis is completed, the RESTART pushbutton must be pressed to initialize the microcomputer's software. When the RESTART pushbutton is pressed, the time and date are refreshed on the display.

(18) Analyzing Next Spectrum Return to Step I

b. Error Diagnostics

Several checks are incorporated into the software to detect situations that might cause errors or poor results. If certain conditions are not met by the spectral data or the

information entered by the user, the appropriate following error message(s) will be flashed on the alphanumeric display.

BAD PEAK POSITION. If statistically significant data do not exist near the peak positions indicated by the user in response to the peak-position queries, the error message BAD PEAK POSITION is flashed on the display. This indicates that either an incorrect value was entered for a peak position or no data were transferred from the analyzer to the microcomputer.

This error condition is also displayed, if an incorrect reference peak(s) is (are) used. The calculated gain and zero may satisfy the necessary conditions and will be printed out; however, the program will check to make sure that the 129.3-keV peak is found in the correct position. Instead of continuing, the program returns to the beginning and waits for the user to take corrective action and restart the analysis.

BAD ZERO; CHECK POS. If statistically significant peaks are found, the software proceeds to determine more accurate peak positions from which the gain and channel-zero energy of the spectrum are calculated. If the channel-zero energy is greater than 121.5 keV, the message BAD ZERO; CHECK POS is flashed on the display. This indicates that the channel-zero energy precludes analysis of the 120-keV peak grouping, which is required by the software. This condition may exist because of an incorrect peak position entry or an improper energy calibration of the amplifier/analyzer.

BAD GAIN; CHECK POS. If the product of the spectrum gain and maximum channel in the spectrum (1024 or 2048) plus the zero-channel energy is less than 210 keV, the message BAD GAIN; CHECK POS is displayed. The microcomputer software cannot analyze the spectrum, if the 208-keV peak region is not included. Again, either the correct peak position must be entered or the spectrum retaken once the energy calibration of the amplifier is corrected.

CHECK PEAKS. An error may occur in the determination of the FWHM parameter as a function of energy. If the peak shape analysis results in unrealistic values, the message CHECK PEAKS is flashed on the display. This may occur if the calibration peaks, 148.6 and 208 keV, have very poor counting statistics, or incorrect peak positions were entered, or either peak has a channel that has overflowed. This condition is most likely to occur for the 208-keV peak and results in a distorted peak shape. The user must guard against such overflow because it cannot be corrected and thus such a spectrum cannot be analyzed.

POOR RESOLUTION. If the full-width-at-half-maximum of the 208-keV peak exceeds 1.15 keV, a warning message is flashed on the display. This is to warn the user that the spectral resolution is not good and the results may be questionable. Although the data will be analyzed, the user should take action to improve the energy resolution. This action may involve simply reducing the count rate or it may involve adjusting the amplifier pole zero and shaping time constant (consult the IMI for more details). Energy resolution of 1.15 keV for the 208-keV peak is a reasonable value for a large coaxial germanium detector; for smaller planar detectors, however, 0.8 keV or better can be obtained. Because the software is written for all types of germanium detectors, an energy resolution upper limit of 1.15 keV at 208 keV is used for all spectra.

4. HARDWARE

The portable plutonium spectrum analysis microcomputer unit (Fig. 1) measures 33.5 x 30.5 x 22.9 cms, weighs 11 kg (24 lb), and operates on either 110-V AC (60 Hz) or 220-V AC (50 Hz). It uses an LSI-11/2 microprocessor (Digital Equipment Corporation) and two memories -- a programmable read-only memory (PROM) for storing operating software and a random access memory (RAM) for storing data during analysis. The operator interacts with the unit through a decimal keyboard and a 20-character display. A 7-key function and a 10-digit keyboard provide control of the data analysis program and the entry of data into the unit. Communication between the unit and the Silena MCA is accomplished by a parallel interface module. Hard copies of the data-analysis results are produced by a 20-character thermal printer.

a. Central Processor Unit

The LSI-11/2 from Digital Equipment Corporation, which is the central processor unit (CPU) of the portable microcomputer unit, is capable of addressing 32K ($K = 1,024$) 16-bit words of memory. A 16-bit buffered parallel input/output LSI-11 bus with asynchronous operation allows the the processor and its system components to run at the highest speed possible. An Extended and Floating-point Instruction Set (EIS/FIS) chip has been added to the board to provide hardware fixed-point multiplication, division, and multiple shifting in double-precision arithmetic, as well as floating-point addition, subtraction, multiplication, and division. Figure 6 shows the location of the EIS/FIS chip on the board.

The processor board shown in Fig. 6 is a KD11-HA dual-height (14. x 21.6 cm) module. Its power requirements are +5 V at 1.0 A and + 12 V at 0.22 A. The board is configured with wirewrap jumpers W5 and W6 removed (see Fig. 6). These jumpers select the



FIG. 6. LSI-11/2 module KD11-HA.

power-up mode. The mode selected places the processor in a sequence that fetches the contents of memory locations 24 and 26 and loads their contents into the program counter (PC) and processor status (PS) register, respectively. The processor then begins program execution with the current contents of the PC as the starting address. Consequently, this power-up mode provides automatic startup of the program.

b. Programmable Read-Only Memory (PROM)

The unit has 16K words of programmable read-only memory (PROM) for storing operating software. The PROM is not volatile; it retains its contents when operating power is removed. Thus, programs are still available when operating power is restored.

A PROM is identified by the type of integrated circuit (IC) chip it uses; some PROMS use IC chips that can be programmed only once, and others, commonly referred to as erasable and programmable read-only memories (EPROM), use IC chips that can be erased by high-intensity ultraviolet light and then reprogrammed. The PROM in the microcomputer uses INTEL 2716-type erasable IC chips that have a capacity of 1k 16-bit words.

MLSI-MRV-004 PROM modules from MDB Systems, Inc., Orange, CA, are used in the microcomputer. Each module as shown in Fig. 7 has eight sockets that provide 8K of address space with the 2716-type PROM IC. Thus, two PROM modules are necessary to provide 16K of PROM address space. The modules are dual height in size, and the power requirements for each are +5 V at 0.58 A and +12 V at 0.5 A. Each module must be configured with the appropriate wirewrap jumpers to provide the correct address space. On both modules, switches 1 - 5 on the five-pole DIP switch in module location 2D must be ON. On both modules, the following wirewrap jumpers must be in place in

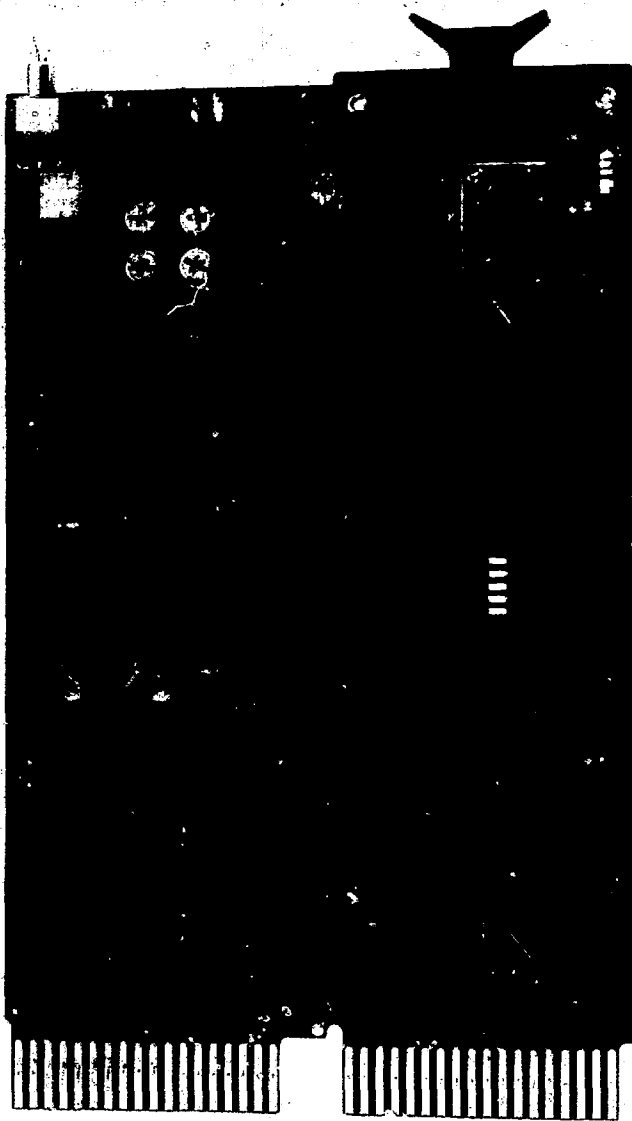


FIG. 7. Upper 8K MDB MLSI-MRV-004 PROM module.

module locations 3F, 4F, and 3B to configure the modules for use with the 2716-type PROM IC. (See Fig. 8.)

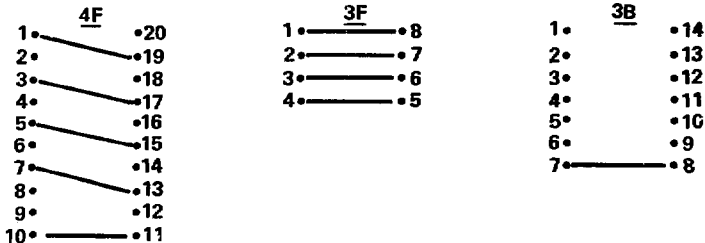


FIG. 8. Wirewrap jumpers that must be in place in PROM module locations 3B, 3F, and 4F.

The module with the first 8K of address space must have the wirewrap jumpers in place in module location 8F, as shown in Fig. 9.



FIG. 9. Wirewrap jumpers that must be in place in PROM module location 8F.

The module with the second 8K of address space must have a wirewrap jumper from 3U to 2U rather than from 3T to 2U as shown above.

The PROM IC chips containing the low byte of each word must be in row C on each module, and the IC chips containing the high byte must be in row E on each module.

The IC chips must be placed in the sockets with the indentation on each chip oriented toward the top of the module.

c. Random Access Memory (RAM)

The programs in PROM use RAM to store variables during data analysis. For instance, spectral data from the MCA are stored in RAM. The RAM is volatile -- when operating power is removed, its contents are lost.

The RAM occupies 12K words of address space beginning at the 16K word address boundary (where PROM address space ends). The starting byte address of RAM is 100000g. Consequently, the RAM module must provide for starting address selection.

Dual-height RAM modules from two different manufacturers have been used in the portable microcomputer units. The second unit uses a RAM module from Christin Industries, Inc. The power requirements are +5 V at 1.0 A and +12 V at 0.3 A. To configure them for the RAM address space, open all switches on DIP switch SW1 and close switches 1-6 on DIP switch SW2. Switches 7 and 8 on SW2 should be open.

The remaining microcomputer units use MSV11-D RAM modules from Digital Equipment Corporation. This dual-height module shown in Fig. 10 requires +5 V at 0.7 A and +12 V at 0.37A. The five switches on the five-pole DIP switch select the desired starting address. Switch 3 should be OFF, and the remaining switches should be ON.

d. LSI-11 Communication Modules

The microcomputer unit requires both a serial interface module and a parallel interface module. The keyboard, the alphanumeric display, and the printer communicate with the

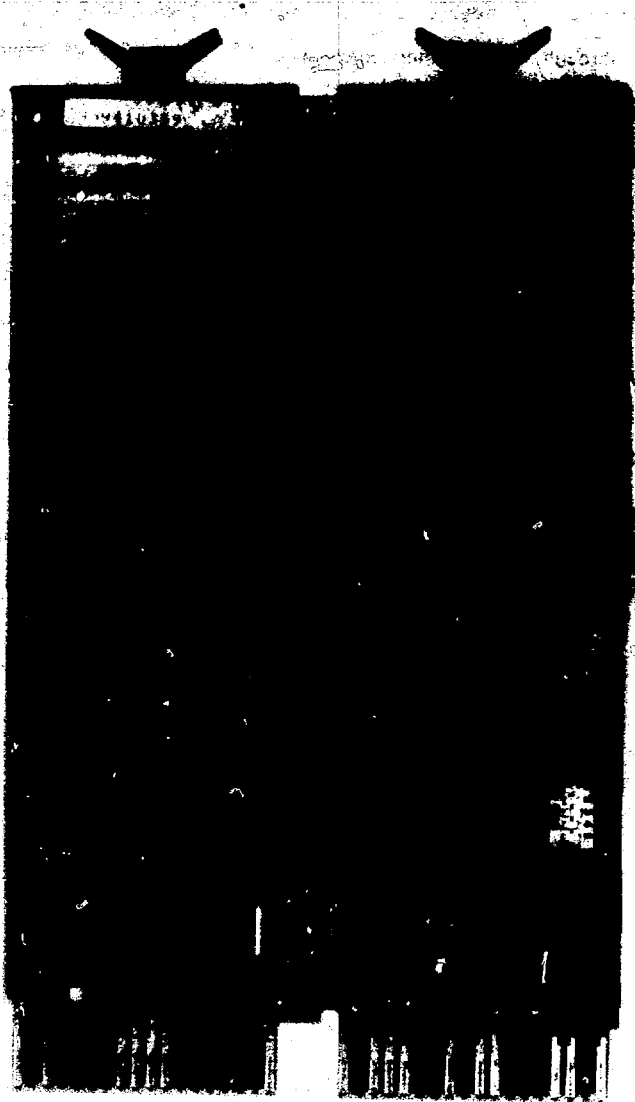


FIG. 10. DEC MSV-11D RAM module.

LSI-11 through serial interface channels, and the Siena MCA and the LSI-11 communicate through a parallel interface channel.

(1) Serial Interface

The microcomputer unit uses the dual-height DLV11-J asynchronous serial-line interface module shown in Fig. 11. This module controls four independent serial input/output channels to the LSI-11 bus, three of which are used as labeled in Fig. 11. Baud rates from 150 to 38.4K bits/sec can be selected by wirewrap jumpers for each channel. The device register addresses and baud rates are given in Table 3. The power requirements of the module are +5 V at 1.0 A and +12 V at 0.25 A.

The interface connector furthest to the right on the module in Fig. 11 (channel 0) is connected to the numeric keyboard. This channel is set to operate at a baud rate of

TABLE 3. Peripheral device DLV11-J register address assignments.

Eurr-Brown Keyboard

Baud rate = 300 bits/sec

Receiver status register	- 176500g
Receiver buffer	- 176502g
Transmitter status register	- 176504g
Transmitter buffer	- 176506g

Alpha.umeric Display

Baud rate = 1,200 bits/sec

Transmitter status register	- 176514g
Transmitter buffer	- 176516g

Datel Alphanumeric Printer

Baud rate = 9,600 bits/sec

Transmitter status register	- 176524g
Transmitter buffer	- 176526g

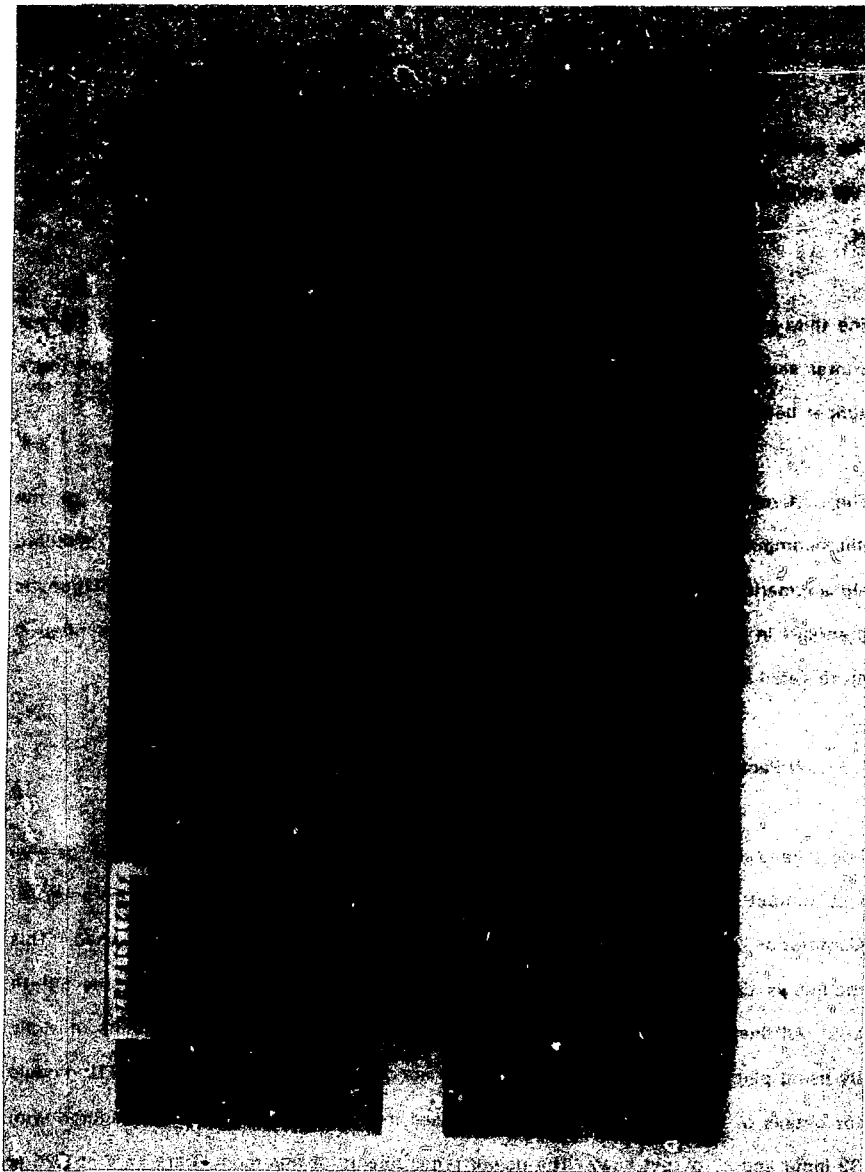


FIG. 11. DEC DLV11-J serial interface.

300 bits/sec by placing a jumper between pins 0 and T, which are located at the upper center of the board.

The next connector to the left (channel 1) is connected to the alphanumeric display. This channel is set to operate at 1,200 bits/sec by placing a jumper between pins 1 and W.

The third connector from the right (channel 2) is connected to the alphanumeric thermal printer and is set to operate at 9,600 bits/sec. This baud rate is selected by placing a jumper between pins 2 and N.

The left-most connector (channel 3) is not used during normal operation of the microcomputer unit. This channel is configured for a console device (a standard alphanumeric terminal) operating at 9,600 bits/sec that may be used for diagnostic purposes in the event of a malfunction in the microcomputer unit. This is described in more detail in Section 5.

(2) Parallel Interface

The Silena MCA communicates with the microcomputer through a 64-line parallel input/output module with TTL logic. The model 1664 TTL module from ADAC Corporation, 70 Tower Office Park, Woburn, MA 01801, shown in Fig. 12 is used. This module is capable of connecting 64 external parallel input/output lines to the LSI-11 bus. All lines can be configured as either input or output lines, in increments of eight, by using plug-in components. (Consult the instruction manual for the 1664 TTL module for details of the setup.) The module as used in the microcomputer is configured with 32 input and 32 output lines. The power requirements of this module are +5 V at 1.25 A.

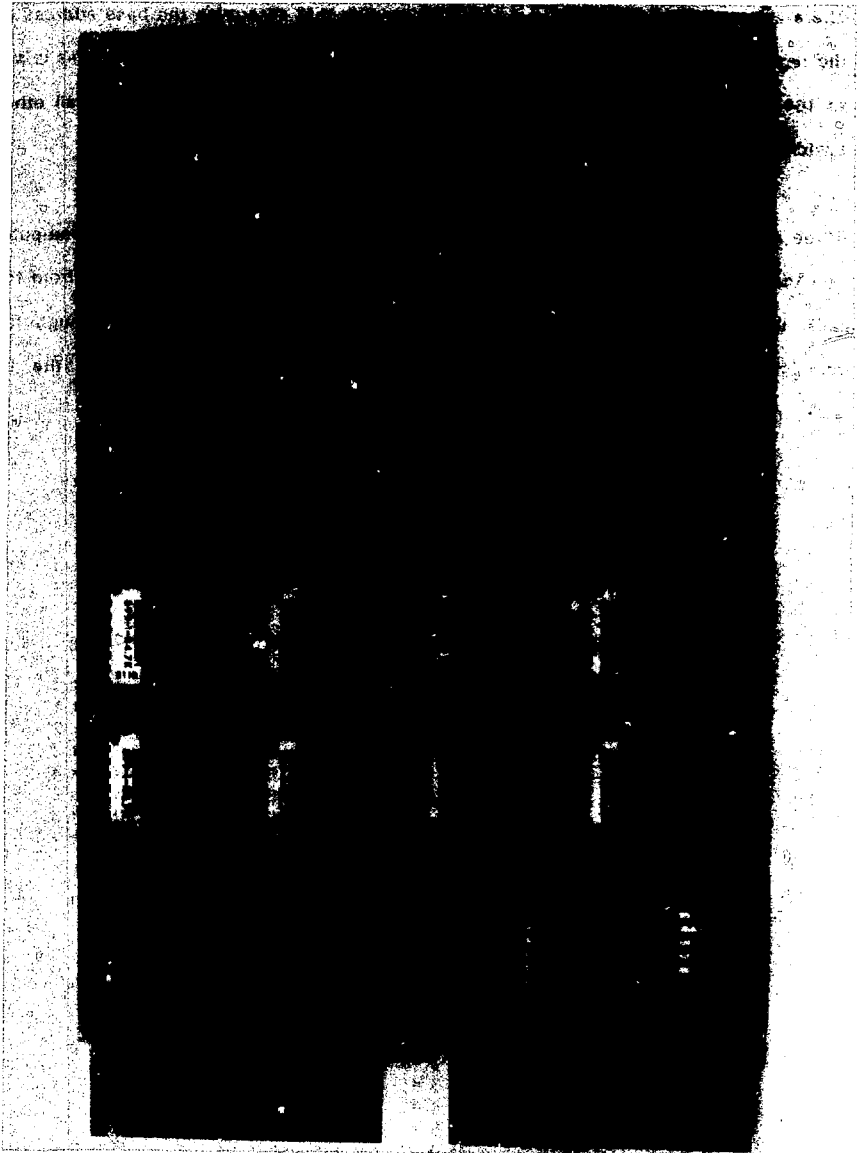


FIG. 12. ADAC 1654 TTL parallel interface.

There are two DIP switches on the 1664 TTL module that determine the base address of the registers accessed by the microcomputer software. The base register address is set to 164100g, which requires that switch 2 on both DIP switches are OFF while all other switches are ON.

Three registers on the module are used for communication between the microcomputer and the Silena MCA. The microcomputer receives data and status information from the MCA through two of these registers and sends operational commands through the remaining register. Table 4 shows the addresses of the registers and the bit assignments in each register to the data, status, and control lines of the MCA.

TABLE 4. 1664 TTL module register addresses and bit assignments.

Input Registers

Status Register		Data Register	
Address=	164100g	Address=	164102g
Bit 0 =	DATA IN	Bit 0 =	Data bit 0
Bit 1 =	DATA OUT	Bit 1 =	Data bit 1
Bit 2 =	DISPLAY	Bit 2 =	Data bit 2
Bit 3 =	DATA READY	Bit 3 =	Data bit 3
		Bit 4 =	Data bit 4
		Bit 5 =	Data bit 5
		Bit 6 =	Data bit 6
		Bit 7 =	Data bit 7

Output Register

Command Register	
Address=	164104g
Bit 0 =	Set DATA IN
Bit 1 =	Set DATA OUT
Bit 2 =	Set DISPLAY
Bit 3 =	Set ERASE
Bit 4 =	Set STOP
Bit 5 =	Set REMOTE DATA OUT
Bit 6 =	not used
Bit 7 =	RESET DATA READY

There are two connectors on the 1664 TTL module labeled J1 and J2 for which cabling must be prepared to connect pins between these connectors and the MCA. Connector J1 receives input signals, while output signals occur at the J2 connector. The pin assignments of the connectors are given in Table 5.

(3) Clock Module

The TCU-50 DYR clock module from Digital Pathways, Inc., 1060 East Meadow Circle, Palo Alto, CA 94303, shown in Fig. 13 is a real-time programmable clock for LSI-11 computers. This module provides the microcomputer unit with the time, date, and year. Software is provided in the microcomputer unit to allow the user to set the time and date in the module (see Sections 3 and 5 for more details).

TABLE 5. SILENA input/output cable wiring.

SILENA Pins		Parallel Interface Connector Pins
1	DATA BIT 0	J1 - 32
2	DATA BIT 1	J1 - 31
3	DATA BIT 2	J1 - 28
4	DATA BIT 3	J1 - 27
5	DATA BIT 4	J1 - 24
6	DATA BIT 5	J1 - 23
7	DATA BIT 6	J1 - 20
8	DATA BIT 7	J1 - 19
11	DATA READY	J1 - 30
21	DATA IN	J1 - 29
22	DATA OUT	J1 - 34
23	DISPLAY	J1 - 25
12	RESET DATA READY	J2 - 22
13	Ground	J2 - 35
14	SET DATA IN	J2 - 29
15	SET DATA OUT	J2 - 34
16	SET DISPLAY	J2 - 25
17	SET ERASE	J2 - 30
18	SET STOP	J2 - 21
19	SET REMOTE DATA OUT	J2 - 26
25	Ground	J2 - 35

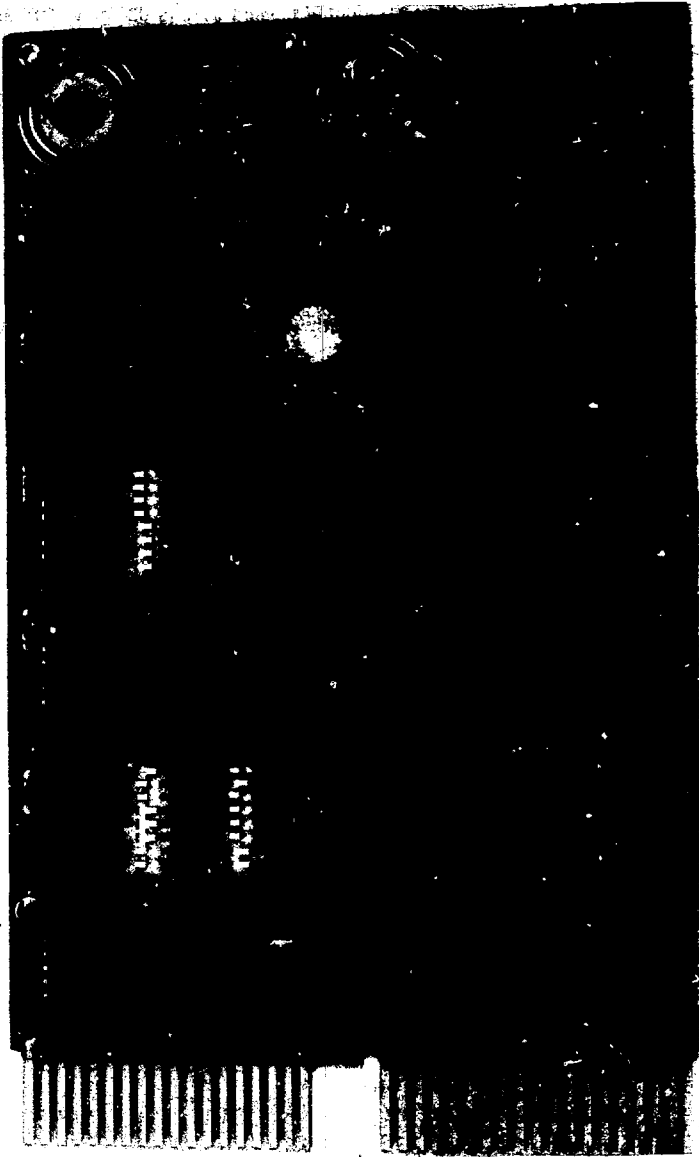


FIG. 13. Digital Pathways TCU-50 Dyr clock module.

The power requirements of the dual-height module are +5 V at 0.27 A. When the power is off, the time and date are maintained on the module for up to three months, using power from its own rechargeable batteries. **CAUTION:** Avoid letting the module contact any conducting material that may result in damage to the module.

Three eight-pole DIP switches are provided on the module for selection of its address, interrupt vectors, and other options available with the module. The clock module in the microcomputer unit is configured with the address 1607.08 (factory default) and the interrupt disabled. This requires the following switch settings:

<u>Switch</u>	<u>SW1</u>	<u>SW2</u>	<u>SW3</u>
1	OFF	ON	OFF
2	OFF	OFF	ON
3	OFF	OFF	OFF
4	OFF	ON	OFF
5	ON	ON	OFF
6	ON	ON	OFF
7	ON	OFF	ON
8	ON	OFF	ON

e. Input/Output Peripherals

(1) Alphanumeric Display

The 20-character vacuum fluorescent display model DE/320 from Digital Electronics Corporation, 197 Airport Blvd., Burlingame, CA 94010, is used to display messages by the

microcomputer. The serial interface of the unit operates at 1,200 bits/sec and receives standard ASCII code characters. The unit operates on 5-V DC with typical current requirements of 500 mA. (Note: Production of this unit has been discontinued and no replacement models have been found. Consequently, every effort should be made to repair a malfunctioning unit.)

(2) Numeric Keyboard

A model TM25-300NT numeric keyboard from Burr-Brown is used for entry of analysis information and control of the microcomputer. The terminal receives and transmits ASCII code characters through a serial line at 300 bits/sec. An eight-digit display in the keyboard, along with the CLEAR and ENTER keys, allows entries to be changed and verified before they are transmitted to the microcomputer. The keyboard unit operates on 15-V DC at a 250-mA maximum.

(3) Alphanumeric Thermal Printer

Model APP-20A2 or newer model APP-20A21 non-impact thermal printers from Datel-Intersil are used for hard-copy output of the analysis results. The printer accepts serial data that have been ASCII formatted at 9,600 bits/sec. The full ASCII code character set is printed in 20 columns across 58.6-mm-wide paper, at a rate of 1 line/sec, regardless of the number of characters/line. The printer operates in an inverted text output mode. In this mode, the printout appears to be upside down with respect to the front panel. However, by mounting the printer with the front panel upside down, the text is up and the last line is at the bottom as normal text would be.

The printer operates on either 115- or 230-V AC, 47 to 400 Hz. An internal switch (APP-20A2) or jumper plug (APP-20A21), accessible when the front panel assembly is removed, selects either voltage.

f. Power Supplies, Backplane, Fan, and Power Receptacle

All of the modules and peripheral input/output devices (except the printer) in the microcomputer operate on direct current (DC). Hence, a device that converts from alternating current (AC) and frequencies to direct current is required. A 75-watt switching power supply model 315 from RO Associates, Inc., 246 Caspian Drive, Sunnyvale, CA 94086, fulfills this need. A switching power supply has definite advantages over linear-type supplies because of its small volume and low weight. The unit has two DC outputs: one with a rating of 5 V at 8 A and the other with a rating of 12 V at 2 A. The AC input specifications are 105- to 130-/ 200- to 265-V AC at 47 to 1000 Hz.

Because the numeric keyboard operates on 15-V DC, a DC/DC converter is used to step up the 12-V DC from the main power supply to 15-V DC. A model PM814 12V/15V converter from Power Products, 1400 N.W. 70th St., Fort Lauderdale, FA 33309, is used for this purpose.

A model H9281-BB backplane from Digital Equipment Corporation accepts eight 14-cm-wide (dual-height) circuit-board modules and distributes the 5-V and 12-V DC power to the modules. Seven of the eight available slots are used in the microcomputer unit. Each module is kept firmly in a backplane connector slot by a rugged but lightweight card guide assembly. The LSI-11 bus is completely contained in the backplane, because bus lines are prewired to each module location.

A model 6J4 connector with voltage selection from Corcom, Inc., 1600 Winchester Road, Libertyville, IL 60048, connects the switching power supply to the AC line power. This connector eliminates the need to change internal wiring for operation at different AC voltages by providing the user with a voltage selection card to change connections to the power supply. It also provides a convenient fuse holder. This is a safe way to change connections and fuses because the power line cord must be removed from the receptacle before the fuse or voltage selection card can be accessed.

To cool the internal components of the microcomputer unit, a model WS2107FL-7 BOXER fan from IMC Magnetics Corp., 570 Main Street, Westbury, NY 11591, is used. The fan measures 11.9-cm square by 3.8-cm deep, operates on either 115- or 230-V AC, and delivers 115 cfm of air. The fan has a sleeve bearing for longer, more efficient operation.

All of these components are assembled into a compact package that fits into a Zero Corporation model ZIP840 extruded aluminum carrying case. By removing a screw from each side of the carrying case, the entire package of components can be easily removed, thus allowing access to the components for maintenance, as shown in Fig. 14. An umbilical power cord between the power receptacle and the component package allows operation of the unit while disassembled for testing purposes (see Section 5 for maintenance and troubleshooting).

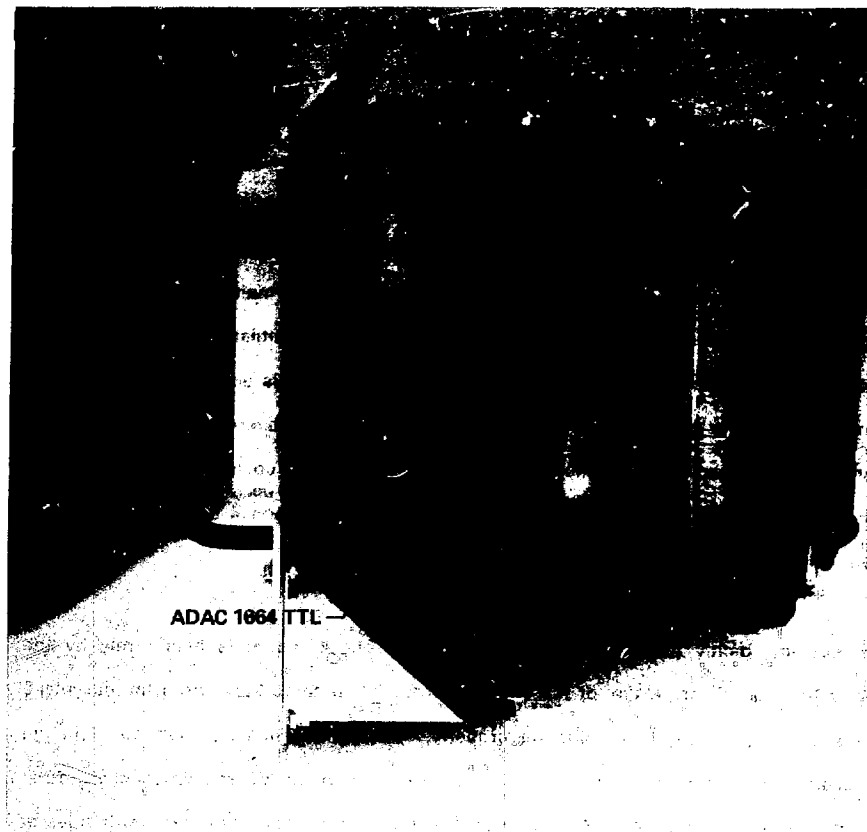


FIG. 14. Component package removed from case.

5. MAINTENANCE AND TROUBLESHOOTING

a. Preventative Maintenance

To ensure continuous operation of the portable microcomputer unit, it should be inspected periodically for accumulations of dust and lint and for loose connectors, circuit boards, and hardware. Accumulations of dust and lint in the ventilation screens on the unit will impede the air flow through the unit and thus may cause overheating of the unit, which could result in temporary or permanent malfunction of the unit. Periodically, dust and lint should be removed from the ventilation screens and the operation of the fan should be checked to ensure that there is adequate air flow. The unit should never be operated with the ventilation screens covered or blocked. If the fan bearing shows signs of failure (noises emanating from it could reveal this), the fan should probably be replaced before it fails totally. (See Section 4 on hardware for the fan's model number and manufacturer.)

Periodically, gently pull on each circuit board to check that it is held firmly by the backplane connector. If any of the circuit boards should come loose from the backplane connector, the unit will not operate properly. Before reseating a circuit board in the backplane connector, check to make sure that board components are not touching other boards and that the board is free from obstructions. Press down firmly on both sides of the board to seat it in the backplane connector. If the board does not go in, check for obstructions and readjust it in the guide to line it up with the backplane connector.

Check the unit periodically for structural integrity. Check for loose nuts and bolts. A loose nut inside the unit could cause a short circuit and severe damage to components.

Appropriate measures should be taken to retighten or replace any loose or missing nuts and bolts.

b. Printhead Cleaning/Preventative Maintenance

Cleaning should be performed every five to ten printing hours. For convenience, this may be done with each paper roll change. The need for printhead cleaning is evidenced when the printout becomes sparse or uneven, or if individual dots no longer print because of gummy deposits scraped from the paper's surface coating.

To maintain efficient operation, the thermal printhead must be periodically cleaned with isopropyl alcohol (isopropanol). Clinical grade isopropanol must be used to avoid the dissolved distillates found in industrial-grade isopropanol, which could foul the printhead.

In the first, easier method, remove the print module assembly and use a plastic squeeze-bottle to wet the print paper with a small amount of isopropanol upstream between the print head and the print roll only, making sure that no isopropanol gets onto any other part of the printer mechanism as damage to the printer bearings may result. Reinstall the print module assembly and advance the paper using the paper feed switch on the front panel. Check for proper operation by activating the self-test function (APP-20A21 models only), and repeat the procedure if necessary.

A more thorough cleaning may be performed by cleaning the printhead using a cotton swab moistened with isopropanol. Flatten and squeeze the wet cotton swab so that it will fit under the printhead. Lift the printhead away from the paper drive roller by depressing the head assembly at the rear near the paper roll. This will allow access to

the printhead. The roller may be advanced manually for cleaning. Other areas such as the door and guides may also be cleaned with the swab. The second method requires more effort but does a much more thorough job.

c. Troubleshooting

There are many possible reasons why the unit may fail to operate properly. This section cites a list of some possible symptoms of the failure of a unit and suggests specific items to check. The list is probably not inclusive, but it provides the user with a basic troubleshooting procedure for the unit. Care should always be used during troubleshooting to avoid damage to other components. Always turn the microcomputer power off when removing/inserting boards or connectors.

Possible failure symptoms:

- (1) Time/date are not displayed when the unit is turned on
 - (a) Remove power first. Check the voltage selection card in the power receptacle. Is the proper voltage selected?
 - (b) Check the fuse in the power receptacle. Is the fan running? If the fuse is fine but the fan does not run, then check the power source and the power receptacle. Check AC voltage to the power supply and the fan.
 - (c) If the display cursor is visible and blinking, switch the power to the unit off and on several times. Sometimes the processor fails to start up properly, and this procedure may correct the problem.
 - (d) If the cursor is visible and the time/date are not displayed by cycling the power to the microcomputer unit, then the problem is with one of the circuit board modules or the serial line connection. First check the serial connector to Channel 1, the second connector from the right on the

DLV11-J module (see Fig. 11). Make sure that the connector is firmly in place and check the connections to the back of the display unit. Check all circuit board modules to ensure that they are firmly in place.

- (e) If the display cursor is not visible, check the 5-V DC power supply. If there is no 5-V DC, check the switching power supply and check for electrical shorts. If 5-V DC power is available, then it is likely that a failure has occurred in the alphanumeric display unit. Because this unit is no longer manufactured, there are no replacements for it; it will have to be repaired.

The next step, if the problem is not alleviated, is to connect a terminal (preferably a VT-100 type terminal) to the empty connector (with microcomputer power off) on the left side of the DLV11-J module. Set the terminal baud rate to 9,600 bits/sec. Turn on the power to the microcomputer unit and observe the terminal.

If a six-digit number followed by at (@) is displayed on the terminal, there is a failure in either the processor or the memory modules. A message of ERR 61 on the terminal indicates a failure in one of the communication modules -- either the DLV11-J or the 1664 TTL module. Replace individual modules until the problem is corrected. Note: Nothing will be displayed on the terminal if the circuit-board modules are functioning properly.

If nothing is displayed on the terminal when the microcomputer power is turned on, then press the BREAK key on the terminal. This should halt the program. A six-digit number followed by an @ should be displayed on the terminal. If nothing happens when the BREAK key is pressed, then the problem is likely with the first 8K EPROM module.

If there is a response on the terminal, then type 176512/ following the @ on the terminal. The microcomputer should respond with 000200 on the terminal. If 000200 is not displayed on the terminal, there is a problem with the serial line in either the DLV11-J module or the display. If 000200 is displayed, type 215 followed by a return. This places the display in a self-test mode in which most of the ASCII characters are displayed. If this does not occur, then the problem is most likely with the display.

To ensure that the problem is with the display and not with the serial line, make sure that the power is off, disconnect the serial line to the display (Channel 1) from the DLV11-J module and connect the terminal to that channel. Set the terminal to operate at 1,200 bits/sec and turn on the microcomputer. The time/date should be displayed on the terminal. If they are, the problem is definitely with the display. If the time/date are not displayed, then there is a problem with one of the circuit-board modules.

(2) No printing on printer during analysis

Approximately 45 sec after initiating the data transfer between a Silena MCA and a microcomputer unit, the time/date are printed on the thermal printer. If this does not occur, the following steps are suggested:

- (a) If the message 148 PEAK POS is not shown on the display, a problem exists in the data transfer. Otherwise, skip to step (e). Check the cable connection between the Silena MCA and the microcomputer and the setup of the Silena MCA (see Sections 3f and 3j for operation instructions).

- (b) If there is no response after step (a), check the 1664 TTL module in the microcomputer unit. Make sure that the board is firmly in place and that the two cable connectors are in place. Check the cable between the board and the microcomputer front panel 25-pin connector. Check the cable between the microcomputer and the MCA for kinks and breaks.
- (c) If the problem remains, replace the 1664 TTL module. Make sure that the two cable connectors are placed in the proper positions on the module. They can be mistakenly inserted upside down.
- (d) If the problem persists, replace the Silena MCA or check that it is operating properly. If this fails, replace the remaining circuit-board modules in the microcomputer unit.
- (e) Is the LED labeled ON lighted on the front panel of the printer? If not, check the printer voltage selector (see Section 3c) and the printer fuse. The fuse is on the rear panel of the printer housing and can be accessed by removing the microcomputer component assembly from the blue aluminum enclosure. The fuse should be replaced with a 1/2-amp SLO-BLO, 3AG type, 0.25 in. diam x 1.25 in. long. Also check the 25-pin connector on the rear panel -- make sure that it is firmly in place.
- (f) If the LED is lit, press the feed switch down. Paper should feed out the front of the printer. If not, check the paper roll by removing the printer front panel assembly. On older APP-20A2 models, the printer is disabled if somewhat less than 10 ft of paper remain on the roll. On newer APP-20A21 models, a red LED labeled PAPER OUT is lit and the printer disabled when the paper roll is empty. If necessary, install a new roll of paper.
- (g) If there is sufficient paper, but it does not feed when the FEED switch is pressed, replace the printer unit.

- (h) On the newer APP-20A21 models, a self-test feature can be activated by pressing the FEED switch upward and then releasing it. The printer should begin printing the full 96 ASCII character set. The self-test mode will continue until you manually cancel it by pressing and holding the FEED switch down until blank paper feed occurs, then release it. If this test fails (Model APP-20A21 only), then replace the unit.
- (i) To determine if the problem is with the printer or the serial line, attach (with microcomputer power off) a terminal operating at 9,600 bits/sec to the connector on the DLV11-J module used by the printer (Channel 2; see Fig. 9). Now run an analysis; the results should be printed on the terminal as they are normally printed by the printer. If they do not appear on the terminal, then there is a problem with the DLV11-J or processor modules. If the results are displayed on the terminal, the problem is with the printer and it should be replaced.

(3) No display on the keyboard

When the microcomputer power is turned on, a 0. should be displayed on the keyboard. If anything else is displayed or any of the function keys are lit, then a problem exists in the keyboard or the 15-V DC power supply. If this symptom occurs, the following steps are suggested:

- (a) Check the 15-V DC output and the 12-V DC input of the DC/DC converter.
- (b) Check the power leads between the DC/DC converter and the keyboard. Also check the serial line connector to the DLV11-J module.
- (c) If the above items are fine, then you must replace the keyboard.

Other failure symptoms not described here may occur. Determination of the problem requires a step-by-step elimination of all of the various components. As indicated above, specific tests may be used to check certain components. It may be useful to connect a terminal operating at 9,600 bits/sec to the empty connector on the DLV11-J module to check the operation of the software and the peripherals.

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