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**ANL SMALL-SAMPLE CALORIMETER
SYSTEM DESIGN AND OPERATION**

by

**C. T. Roche, R. B. Perry, R. N. Lewis,
E. A. Jung, and J. R. Haumann**

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ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

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ANL SMALL-SAMPLE CALORIMETER

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I. INTRODUCTION

The Small-Sample Calorimetric System (Fig. 1) is a portable instrument designed to measure the thermal power produced by radioactive decay of plutonium-containing fuels. The mass of plutonium in a sample is related to the measured power through the weighted average of the product of the isotopic decay energies and the decay constants of the plutonium isotopes present. The uranium content of the fuel will not affect the measurement, since the thermal power produced by the uranium nuclides is insignificant when compared to plutonium. This is the result of the longer half-life of uranium relative to the Pu isotopes. The principal radiations from plutonium are alpha particles and low-energy photons. As a consequence of the low penetration power of this radiation, greater than 99.9% of the decay energy will be degraded to thermal energy measurable by the small-sample calorimeter. (A more detailed discussion of the physical principles involved in calorimetry is included in *A Portable Calorimeter System for Nondestructive Assay of Mixed-Oxide Fuels*, ISPO-16.)

The small-sample calorimeter is capable of measuring samples producing power up to 32 milliwatts at a rate of one sample every 20 minutes. This power corresponds to samples containing approximately 10 g of low burn-up plutonium oxide. The measurement precision for the baseline power $[\sigma(P_0)/P_0]$ is better than 0.1%. Samples containing 1.5 g of plutonium (2.5 mW) have to be assayed within this precision. The small-sample calorimeter can assay unknowns having milligram amounts of plutonium; however, the measurement precision may deteriorate.

The instrument is contained in two packages; a data-acquisition module consisting of a microprocessor with an 8K-byte nonvolatile memory, and a mea-

Fig. 1. The ANL small-sample calorimetric system.

surement module consisting of the calorimeter and a sample preheater. The total weight of the system is 18 kg.

II. IAEA SMALL-SAMPLE CALORIMETRIC SYSTEM

The Small-Sample Calorimetric System (SSCS) is a portable instrument designed for in-field operation. Care has been taken to minimize the effects of nonideal environments encountered during the course of a typical assay. Field conditions have been simulated in the laboratory, and a set of operating conditions which ensure maintenance of a 0.1% measurement precision have been developed. Although these operating requirements are broad and should not restrict the inspector, reasonable care should be exercised in choosing a sampling location. Operation in any unfamiliar setting should be preceded by a calibration and a thorough check-out.

A. Environmental Operating Conditions

1. Temperature

The calorimeter unit is adjusted for a maximum sample power of 32 mw. The temperatures of the coconcentric chambers comprising this unit are: T_0 , 45.1°C; T_2 , 44.4°C; T_1 , 42.9°C; T_3 , 40.7°C; T_A , 39.7°C. The system was tested in an environmental chamber between 10.5°C and 35.0°C. Over this temperature range, a drift in the measurement precision of less than 0.1%/°C was experienced.

2. Power Requirements

The IAEA SSCS is designed to be operated with a voltage of either 110 VAC (60 Hz) or 220 VAC (50 Hz). The device was tested for voltage fluctuation with a 110-VAC line. Operation was unaffected by fluctuations under 20%. The calorimeter was also operated on a power line exhibiting ± 8 V noise spikes. No degradation in performance was observed.

B. System Setup

1. Line Voltage Selection

The appropriate line voltage (110 VAC or 220 VAC) MUST be selected before attaching the power cable. The line-voltage selection switch is located in the cover of the calorimetric unit. Attempted operation of this device in the wrong power mode may result in serious damage to the unit.

2. System Interconnection

The calorimeter and its data-acquisition system (DAS) MUST be connected prior to applying line voltage. The multipin connectors on the calorimetric unit, labeled P1, P2, should be connected to their respective receptacles on the DAS. Two identical AMP cables, which are stored in the DAS case, are provided for this purpose.

3. Power Up

A North American standard three-prong power cord is provided to attach the SSCS to the building power line. After the system has been set up, it must be allowed to reach equilibrium at operating temperature before assaying samples. This takes approximately two hours at 20°C.

III. CALORIMETER

A. Physical Description

The calorimetric unit is housed in a 30-cm × 41-cm × 26-cm drawn-aluminum case and has a total weight of 13 kg. The layout of the various components is shown in Fig. 2. Detailed circuit schematics are provided in Appendix

The heart of the unit is the CALORIMETRIC SAMPLE CHAMBER which is comprised of four (4) temperature-controlled regions. These regions are constructed from a set of concentric aluminum cylinders upon which noninductive heater coils

Fig. 2 Schematic of the front panel of the calorimeter module.

and temperature-sensitive elements are mounted. The cylinders are set at increasingly higher temperature as the center is approached ($T_0 < T_1 < T_2 < T_3$), and are insulated from each other by styrofoam. This design ensures that the heat flow will remain constant in the outward radial direction. The entire assembly is encapsulated in styrofoam (see Figs. 3, 4).

Adjacent to the sample chamber is the SAMPLE PREHEATER in which capsules containing material to be assayed are brought to the temperature of the inner cylinder (T_3). Preheating the sample in this manner greatly reduces the waiting period for the sample to reach equilibrium.

The CIRCUIT MONITOR SWITCH enables the operator to measure the temperatures and voltages of various points within the calorimeter. The locations of these test points are given in Appendix A. The results will be shown on the LIQUID CRYSTAL DISPLAY (LCD). Temperatures are continuously monitored by YSI thermistors, with the exception of T_3 . In order to measure the temperature of the most sensitive inner coil (T_3), the button labeled READ must be depressed. This connects the thermistor to the measurement circuit. The TEST position on this switch enables the user to monitor various points in the control circuits with an on-board digital voltmeter (DVM) in conjunction with the TEST PROBE.

The operator may obtain access to the temperature-control circuits through the lid in the upper right-hand corner of the instrument face. The control circuits are located on three plug-in type printed-circuit boards which may be removed for servicing. The inner coil (T_2 , T_3) circuits are housed in a temperature-controlled box (T_A) in the rear of the cavity. Final testing of these boards should be performed in their temperature-controlled environment. The circuits for the less sensitive regions are located on the blue (T_1 , T_0) and red (T_A , T_{PH}) boards. In order to facilitate circuit testing and calibration, a circuit-extender board is supplied. A set of fifty (50) test points are supplied to assist the operator in troubleshooting the device. The locations and expected values of these points are given in the TEST POINT TRUTH TABLE (Appendix A).

Fig. 3. A block diagram of the small-sample calorimeter with its measurement and control components.

Fig. 4. Internal assembly of calorimeter module.

B. Calorimeter Checkout and Adjustment

The calorimetric control circuits have been adjusted for a maximum sample power of 32 mW at a room temperature of 20°C. This permits a maximum sample size of about 13 g of ZPR-3 fuel ($^{238}\text{Pu} < 0.1\%$, $^{239}\text{Pu} \sim 94.7\%$, $^{240}\text{Pu} \sim 5.1\%$, $^{241}\text{Pu} \sim 0.2\%$, $^{241}\text{Am} \sim 0.2\%$). If it is necessary to assay samples emitting larger amounts of heat, the following procedure should be performed.

NOTE: The instrument is very sensitive to the temperature-power settings. Changes in these settings should only be made by trained personnel (preferably at ANL). It is recommended that the user make these adjustments ONLY IF ABSOLUTELY NECESSARY.

1. Place the microprocessor in the RESET mode (press RST). This insures that no electrical calibration power will be accidentally applied to the inner chamber (T_3).

2. Calculate the approximate desired voltage for the inner coils.

$$E = \sqrt{P \times R} \quad R = 900 \, \Omega$$

3. Adjust the T_3 coil to the desired voltage. The measurement chamber, T_3 , is adjusted by manipulating the T3TEMP pot while monitoring the T_3 coil voltage [TP10 (V_V) on the TA box]. The T3TEMP pot is a 25-turn 5- Ω pot in the A5A amplifier feedback loop which controls the temperature set point. The immediate effect of this adjustment will be to send the control circuits into either saturation (maximum power applied) or cutoff (no power applied). Sufficient time must then be allowed for the instrument to stabilize at the new operating conditions. In general, only T_3 should need adjustment; however, any changes necessary to preserve the coil relation $T_3 > T_2 > T_1 > T_0$ should be made at this time. T_2 is monitored on TP4 while T2TEMP pot is changed. T_1 and T_0 are monitored using on-board DVM while adjusting the labeled pots on the "blue" printed-circuit board. (After completion of this adjustment, the next section, 4, must also be performed.)

4. Calibrate T_3 heater-coil electrometer. This adjustment is made by zeroing the T_3 amplifier A5A. The T_3 current output, TP9, should be monitored during this operation. Depress the PUSH FOR V_I ZERO button to isolate A5A. While this button is depressed, adjust V_I ZERO pot so TP9 is zeroed to within 10 μ V. Next, connect a high-impedance DVM across calibration points TP13 and TP14. Adjust V_I CAL for $0.0000 \text{ V} \pm 10 \mu\text{V}$.

NOTE: While monitoring TP9, the DVM should be grounded to the ground posts on the T_A box.

5. Calibrate electrical calibration coil electrometer. This procedure adjusts the amplifier A5B network which controls the electrical calibration. Connect a jumper from TP12 (V_{CAL}) to TP15 ($-I_{\text{CAL}}$) to isolate A5B. Adjust $-I_{\text{CAL}}$ ZERO pot to zero TP15 within 10 μ V. Adjust $+I_{\text{CAL}}$ ZERO pot to zero TP11 within 20 μ V.

6. Reference voltage calibration. The 10 V and 1 V reference voltages are read from TP16 and TP17. These may be adjusted by manipulating the appropriate pots on T_A box.

NOTE: Always adjust +10 V pot first.

IV. DATA ACQUISITION SYSTEM

A. Physical Description

The Data Acquisition System (DAS) is housed in a 47 cm $\times$ 35 cm $\times$ 16 cm attaché case and has a total weight of 5 kg. It is a totally dedicated microprocessor-controlled device, designed around the INTEL 8085. The system memory consists of 8K bytes of erasable, programmable, read-only memory (EPROM) and 1K bytes of random-access memory (RAM). The program resides in the permanent memory, EPROM, and does not need to be reentered after the device is powered down. The EPROM is organized on four 2K-byte INTEL-2716 chips, the last 2K bytes being exchangeable. The RAM is organized on four 256-byte INTEL-8156 chips and serves as scratch-pad storage for the program. The microprocessor receives input either from the calorimeter through the

12-bit ADC or from the 25-key multifunctional keyboard. System output is through either the BOMAR TP3120-2 printer or the Liquid Crystal Display (LCD). A set of 6 LEDs are available to reflect system status. Detailed schematics and a copy of the μ P program are included in Appendix B.

B. Keyboard Action-Response

1. RST $\equiv$ Restart

Function: To place the system in an idle mode, where it will monitor the keyboard for a user command. All data processing is stopped. System default values are restored. The results of any uncompleted calculation will not be available to the user. The system will return to this mode after completing any noncyclical routine.

Use: This key should be used when first powering-up the system or when aborting a particular routine.

Status Light: READY

Printer: "SMALL SAMPLE READY"

2. ENTR $\equiv$ Enter

Function: To signal the end of a numeric input.

Use: This key should be used when responding to a μ P prompt statement with a numerical value. It also acts as a "NO" in a situation requiring a YES/NO response.

Printer: Carriage return - Line feed

3. BS $\equiv$ Backspace

Function: To permit the user to erase an undesired response to a μ P prompt statement.

Use: This key repositions the input ASCII array by one character each time it is pressed.

Printer: Backspace

4. EXT $\equiv$ Execute external program

Function: To enable to user to expand the computational abilities of the DAS. The DAS is designed so that the last 2K of the 8K PROM memory is interchangeable by replacing the chip in the zero force socket with a different INTEL 2716 containing a new program.

Use: To be determined by user.

Status Light: EXT

Printer: Program dependent.

5. TP $\equiv$ Diagnostic test points

Function: To enable the user to examine the voltages of any of 32 selected locations within the calorimeter. (See Appendix A for TP locations within the calorimeter.)

Use: This routine may be used either to continuously monitor a particular point on the Liquid Crystal Display or to obtain a print-out of all 32 points. To change TP during continuous monitoring, press "TP" and the number of the desired test point. Use RST to exit from continuous monitoring.

Status Light: A/D

Liquid Crystal Display: TP voltage

Printer: "TEST PNTS"

"ALL?" - μ P prompt statement

User Response - YES - all TP's printed (Option 1)

- #, ENTR - individual TP displayed
(Option 2)

6. PRINT $\equiv$ Print

Function: To allow user to obtain a printed record of a test point which is being continuously monitored or of a power which is being displayed on the Liquid Crystal Display.

Printer: Numeric output

7. INIT $\equiv$ Initial data input

Function: To permit the user to input parameters which will be used in the data analysis by the μ P.

Use: Input isotopic mass % + uncertainty, elapsed time since last isotopic analysis, default value of effective specific power, power normalization factor, system uncertainty.

Status Light: RSVP after μ P prompts

Printer: "DATA INPUT MASS %"

"AM241" - μ P prompt statement

A μ P prompting statement will be printed for ^{241}Am and for each isotope $^{238-242}\text{Pu}$. After each prompt, enter the isotopic mass % and its uncertainty. (Note: 1) Include the leading zero in numbers less than 1.0, i.e., type 0.01, not .01. 2) Am % is defined as $[\text{Mass}(\text{Am})/\text{Mass}(\text{Pu})] \times 100.$)

"TIME-DAYS"

Enter the time elapsed since last isotopic analysis was performed.

"POWER mW/g"

Enter a default value if it is decided not to calculate the Effective Specific Power from the isotopic mass fractions.

"P NORM"

This parameter relates the measured thermal power to a calibrated source-produced power (i.e., $P_{\text{measured}} = P_{\text{source}} \div \text{PNORM}$). A value of 1.0 was experimentally determined and is included as a default value. This value may be altered if necessary (see Sections V, VI).

"SIG(SY)"

This parameter contains the nonstatistical contributions to the measurement precision. The default value is zero, meaning no systematic error is included. We have experimentally determined the systematic uncertainty in the power measurement. If the operator wishes to include this factor, he should enter a value of 0.028 (approx. 0.1% relative standard deviation) after performing a "P₀" and before a "RUN". The components of this parameter are discussed in Section VI. (NOTE: The default values of PNORM and SIG(SY) are restored after an RST).

NOTE: The remaining keys (FRAC, SP, P₀, RUN, and CAL) activate major subroutines used in data acquisition and analysis. Brief descriptions are given below. More detailed discussions are included in the sections on Recommended Procedures and on Data Analysis.

8. **FRAC** $\equiv$ Mass Fraction decay correction

Function: To calculate the changes in the mass percentages in a previously isotopically analyzed sample resulting from radioactive decay. A current set of mass % will be generated which may be used to calculate effective specific power.

Use: The program requires that the initial mass % and the elapsed time be entered through INIT prior to execution.

Printer: The decay-corrected isotopic mass % are printed.

9. SP $\equiv$ Effective Specific Power calculation

Function: To determine the power emitted per gram of the material to be assayed as well as the uncertainty associated with this calculation.

Use: The program requires that the mass % be available prior to execution.

Printer: The effective specific power and its uncertainty.

10. P₀ $\equiv$ Empty chamber baseline analysis

Function: To determine the power supplied by the calorimeter to maintain a constant temperature when no heat-producing source is present.

11. RUN $\equiv$ Sample assay

Function: To determine the calorimeter-supplied power in the presence of a Pu-containing material; to compare this with the empty chamber results and derive the sample power and mass.

12. CAL $\equiv$ Electrical calibration

Function: To supply a series of known electrical powers to the sample chamber, and to determine the resulting measured powers, thus allowing the user to derive a relation between the measured and actual sample power.

NOTE: A simulated output tape showing the results of typical operations is given in Appendix C.

V. RECOMMENDED PROCEDURES

A. Sample Encapsulation

The sample containers supplied with the Small-Sample Calorimeter are designed to maximize the rate of heat transfer and to thus decrease the sample assay time. The encapsulation technique chosen by the IAEA inspectors will depend on the physical state of the material (solid, powder, or liquid) and may differ from facility to facility. The system equilibration time will vary depending upon the material used in constructing the sample holders. With the double-metal technique developed at ANL, a measurement precision of 0.1% can be obtained in an equilibration time of 15 min. However, experiments using sources double-bagged in polyethylene showed an increase of the equilibration time to 30 min. A double-encapsulation technique should be used to decrease the chance of radioactive contamination of the instrument. Regardless of the method chosen, it is important to minimize the air gap between the sample and the inner chamber walls. It is also important to determine the length of the equilibration time PRIOR to using the instrument in an assay situation.

B. Assay Procedure

1. Remove previously assayed sample from SAMPLE CHAMBER.

NOTE: a) The settling time of this system is strongly dependent upon the degree to which the unit is disturbed during the process of sample changing. A procedure should be developed which will minimize the length of time during which the sample and sample chamber are exposed to ambient-temperature conditions. The same sequence should be followed during all assays.

b) The lid of the sample chamber is constructed from styro-foam and is fragile.

c) The sample holder has been machined to fit the sample chamber with a close tolerance. Samples should be removed slowly

from the chamber to avoid creating a suction which might alter the orientation of the inner chamber.

2. Remove the sample to be assayed from the PREHEATER, insert it in the SAMPLE CHAMBER, and replace the lid.

NOTE: Do not force the sample holder into the chamber. Allow it to settle by gravity.

3. Place the next sample in the PREHEATER.

It is important that the samples be preheated prior to insertion into the sample chamber. Lack of preheating can increase the equilibration time by a factor of four (x4). A sample should be allowed to preheat for approximately one measurement cycle (delay time plus data acquisition time).

4. Reset microprocessor-controlled DATA ACQUISITION SYSTEM.

Operator Action: Press RST

System Response: "SMALL SAMPLE READY"

5. a) Sample Baseline Reading

Operator Action: Press P0

System Response: "EMPTY MEAS"
 "PRINT ALL?" (Print each PWR
 measurement)

Operator Action: YES = Yes
ENTR = No (Usual response)

System Response: "DELAY-MIN" (delay period to permit system to equilibrate)

Operator Action: 15 ENTR (Note: This value may differ with sample composition.)

System Response: "SIGMA-%" (Limit of acceptable precision of $\bar{P}$)

Operator Action: 0.02 ENTR (2σ limit) If the operator wishes the instrument to repeatedly measure the same sample, enter 0.0001

System Response: "#DP/RUN" (~ 25 DP/min)

Operator Action: 100 ENTR (4 min)

The system then enters the DATA ACQUISITION MODE, and the following sequence will occur:

- 1) The E·I products are monitored until $\bar{P} < 35$ mW. This indicates that the heater circuits are no longer in saturation, and the system is approaching equilibrium.
- 2) The system enters an operator-determined delay period during which no data is accepted.
- 3) The μP accepts E, I digital data from the ADC. The E·I product is calculated. An operator-determined number of data points is collected. The value of the calorimeter applied power and the number of data points left to be acquired are alternately displayed on the liquid crystal display. (Note: Numbers greater than 256 will not be displayed.) $\bar{P}$ and the sample standard deviation of the mean are calculated. The results are compared with "SIGMA-%". If the precision is acceptable, the data is stored and printed; otherwise, a new set of data will be accumulated.

4) The system is reset if the experiment is not to be repeated.

5. b) Sample Assay

Operator Action: Press RUN

System Response: "MEAS"

At this point, the operator's options are identical to those just discussed in Section 5.a, above. An example of a set of typical responses and the results of an assay are shown in Appendix C.

C. Electrical Calibration Procedure

1. Place preheated dummy sample (capsule containing a non-heat-producing mass) in the SAMPLE CHAMBER.

NOTE: Please refer to Section B of the Recommended Procedures for instructions on sample handling.

2. Perform a sample baseline reading (P_0). (See Section 5.a of recommended Assay Procedure.)

NOTE: This assay is not used in the calibration calculation. The purpose of this measurement is to ensure that the system is at equilibrium and to provide a check on the calibration-determined empty chamber intercept (P_0).

3. Reset DAS (if necessary).
4. Electrically calibrate system.

Operator Action: Press CAL

System Response: "CALIBRATE"
"CAL PNTS" (μ P prompt statement)

Operator Action: 5 ENTR This determines the number of points used to calculate the calibration parameters.

At this point, the same set of options discussed in Section 5.a of the Recommended Procedures is available. The following responses are suggested, since they produce an accurate set of fitting parameters within a 75-min period. Thus the calibration sequence may be set up to complete itself during a lunch break.

<u>μP Prompt Statement</u>	<u>Operator Response</u>
CAL PNTS	5
DELAY MIN	7
SIGMA %	0.02
#DP/RUN	100

The μP determines the incremental calibration voltage by dividing the empty chamber power by the number of calibration points. This value will be added to the applied calibration voltage through a digital analog converter. The microprocessor will then enter the operator-selected decay period to permit the system to reach equilibrium. Since the measurement chamber is not disturbed by changing the sample between calibration voltage increases, the time necessary to reach equilibrium is significantly shorter than in an actual assay. Equilibrium will be reached in as few as five (5) minutes. (A delay period of 7 min is suggested.) The operator-determined #DP/RUNs are then collected and analyzed, and then the μP measures the input calibration voltage. The data is printed, and the process is repeated for the next calibration point.

After the calibration has been completed, the operator may extract the zero-power intercept, and the power linearity factor (slope) with a linear least squares fitting technique. This calculation is discussed in the Data Analysis section of the manual. Measurement of the power slope gives a value of -0.995. However, the associated uncertainties of the measurement, and a cross-calibration with a known Pu heat source have led us to recommend a value of 1.0 for PNORM.

VI. DATA ANALYSIS

A. Effective Specific Power

In order to obtain maximum utility from the calorimeter, the measured sample power must be combined with additional isotopic information to determine the plutonium content of the sample. If the unknown contains only one isotope of plutonium, the generated heat is related to the sample mass by the equation

$$W_U = 2.1193 \times M \times Q / T_{\frac{1}{2}} \times A$$

where

W	=	power (mW)
M	=	mass of Pu (g)
Q	=	total disintegration energy (MeV)
$T_{\frac{1}{2}}$	=	half-life of the isotope of Pu (yrs)
A	=	gram atomic weight (g)

Under normal assay conditions, nuclear fuel will contain a mixture of radionuclides, the principal power producers being $^{238-242}\text{Pu}$ and ^{241}Am . Consequently, the sample power may be obtained from

$$W_U = M \cdot \sum R_i \cdot P_i = M \cdot P_{\text{eff}}$$

where

R_i	=	mass fraction of the radionuclide
P_i	=	specific power of a Pu isotope mW/g
P_{eff}	=	effective specific power of the sample

Two techniques are suggested for determining the effective specific power.¹ Representative samples may be subsequently analyzed chemically to determine the Pu content (mW/g). This method usually requires multiple measurements distributed in time to account for isotopic decay. The second

technique requires that the isotopic composition be determined by gamma-ray or mass spectrometry.² Determination of radionuclide abundances by gamma-ray spectrometry has the advantage of being nondestructive and may be conducted concurrently with a calorimetric analysis. While the method chosen may differ from assay to assay, the programs supplied will work with either technique.

1. Radioactive-Decay Correction

The isotopic mass ratios are continually changing owing to radioactive decay within the sample. In particular, the beta decay of ^{241}Pu to ^{241}Am , which is a short-lived alpha emitter, results in an increase in the effective specific power with time. If a detailed isotopic analysis of the sample material has been made at an earlier date, an on-site determination of the mass fractions may be unnecessary. The present composition may be calculated by means of the following decay equations:

$$F_i = F_i^0 \cdot \exp(-\lambda_i t) / \Sigma F_i^0 \cdot \exp(-\lambda_i t)$$

$$F_{AM} = [1/\Sigma F_i^0 \cdot \exp(-\lambda_i t)] \cdot \{F_{AM}^0 \cdot \exp(-\lambda_{AM} t) + [\lambda_{241} \cdot F_{241}^0 / (\lambda_{241} - \lambda_{AM})] \cdot [\exp(-\lambda_{AM} t) - \exp(-\lambda_{241} t)]\}$$

where

- F_i^0 = mass % of Pu isotope at last analysis
- F_{AM}^0 = mass % of ^{241}Am (relative to Pu) at last analysis
- λ_i = decay constant of Pu isotope (day^{-1})
- λ_{AM} = decay constant of ^{241}Am (day^{-1})
- t = time elapsed since last analysis (days)

<u>Isotope</u>	<u>Decay Constant (day⁻¹)</u>
²³⁸ Pu	2.1617 • 10 ⁻⁵
²³⁹ Pu	7.880 • 10 ⁻⁸
²⁴⁰ Pu	2.903 • 10 ⁻⁷
²⁴¹ Pu	1.322 • 10 ⁻⁴
²⁴² Pu	5.08 • 10 ⁻⁹
²⁴¹ Am	4.372 • 10 ⁻⁶

The 8080-μP code for these calculations is given in Appendix B.

2. Effective Specific Power Calculation

The effective specific power is defined as the weighted sum of the isotopic specific powers. The uncertainty in this value is dependent upon the measurement errors in both the isotopic mass fractions and the specific power.

$$P_{\text{eff}} = \sum_i F_i \cdot P_i / \sum_i F_i$$

$$\sigma^2(P_{\text{eff}}) = \sum_i \left(\frac{F_i P_i}{\sum_i F_i} \right)^2 \left(\frac{\sigma^2(F_i)}{F_i^2} + \frac{\sigma^2(P_i)}{P_i^2} \right)$$

where

F_i	=	mass % of the radioisotope
$\sigma(F_i)$	=	uncertainty in F_i
P_i	=	isotopic specific power (mW/g)
$\sigma(P_i)$	=	uncertainty in P_i (mW/g)
P_{eff}	=	effective specific power (mW/g)
$\sigma(P_{\text{eff}})$	=	uncertainty in P_{eff} (mW/g)

<u>Isotope</u>	<u>Specific Power (mW/g)</u>
^{238}Pu	567.16 $\pm$ 0.57
^{239}Pu	1.9293 $\pm$ 0.0053
^{240}Pu	7.098 $\pm$ 0.015
^{241}Pu	3.390 $\pm$ 0.002
^{242}Pu	0.1146 $\pm$ 0.0003
^{241}Am	114.23 $\pm$ 0.16

In general there is a negligible increase in the uncertainty reported in the isotopic mass % as a result of radioactive decay. This is not always the case for ^{241}Am . If ^{241}Am was absent at the time of the original analysis, or only present in minute amounts, then changes in $\sigma(^{241}\text{Am})$ must be considered.

$$\sigma^2(^{241}\text{Am}) \approx [1.034t(\lambda_{241} - \lambda_{\text{AM}}) \cdot \sigma(^{241}\text{Pu})]^2 + \sigma^2(^{241}\text{Am})$$

The 8080 μP code for these calculations is given in Appendix B.

B. Analysis of Sample Power

1. Data Acquisition

The calorimeter feedback circuitry adjusts the power supplied to the inner cylinder coils so that a constant temperature environment for the sample chamber is maintained. (See Fig. 5.) The inner coil (T_3) voltage and current are alternately monitored by a 12-bit analog-to-digital converter (ADC), which transmits data to the microprocessor at a rate of ten readings/sec. Software multiplication of each voltage-current pair produces an "instantaneous" T_3 power. Ten such measurements are averaged to produce a two-second reading which is displayed on the liquid crystal display. The system will then calculate the average power $[E(P_1)]$ supplied by the calorimeter, and the sample standard deviation $[s(P_1)]$ associated with the measurement. Since the microprocessor performs floating-point arithmetic with 5-digit software (NOVONICS FP 70B), it is necessary to use the following biased-average approach to maintain sufficient accuracy.

Fig. 5. Resistance thermometry and feedback control circuitry in ANL air-chamber calorimeters.

DATA ACQUISITION ROUTINE

Fig. 6. Data acquisition flowchart.

Fig. 7. The measurement-chamber temperature and power relations in ANL air-chamber calorimeters.

Given a set of power measurements

$$P_i \quad i = 1, N$$

Define a new set

$$\hat{P}_i = (P_i - P_1) \quad i = 1, N$$

then

$$E(\hat{P}_i) = \sum \hat{P}_i / N = E(P_i) - P_1$$

$$\therefore E(P_i) = E(\hat{P}_i) + P_1$$

and

$$\sigma^2(\hat{P}_i) = E(\hat{P}_i^2) - [E(\hat{P}_i)]^2 = \sigma^2(P_i)$$

$$s^2(P_i) = (N/N - 1) \cdot \sigma^2(\hat{P}_i)$$

$$\equiv \sum [P_i - E(P_i)]^2 / (N - 1)(N)$$

A flowchart describing the data-acquisition process is given in Fig. 6.

2. Analysis of Data

The inner sample chamber is held at a constant temperature of 45.1°C. When no heat-producing source is present, the calorimeter supplies a constant power, P_0 , of 32 mW to maintain this temperature. If a sample containing heat-producing plutonium is placed in the calorimeter, the power which the circuitry must supply to maintain 45.1°C drops to a lower value, P_c . Consequently, we may determine the power produced by the plutonium, as shown graphically in Fig. 7. Using the effective specific power, P_{eff} (see Section VI-A), we may determine the plutonium mass by:

$$M_{Pu} = \bar{P}_{Pu} / \bar{P}_{eff}$$

where

$$\bar{P}_{Pu} = F(\bar{P}_0 - \bar{P}_c)$$

F = Pu normalization factor = 1.0
(determined from an electrical calibration
and a Pu calibration)

The measurement precision is defined by

$$\frac{s^2(P)}{\bar{P}^2} = \frac{s^2(SYS)}{\bar{P}_0^2} + \frac{s^2(STAT)}{\bar{P}_c^2}$$

where

s(STAT) is the uncertainty of the mean which is defined as
(standard deviation)/ $\sqrt{N}$

s(SYS) is the uncertainty due to systematic imprecision $\approx 0.08\%$,

the components of which are

- a) system reproducibility error, s(REP)
- b) sample heat distribution error, s(HDE)
- c) calibration uncertainty, s(CALIB)
- d) thermal interferences, s(TEMP)

$$s^2(\bar{M}_{Pu}) = M_{Pu}^2 \left[\frac{s^2(\bar{P}_{eff})}{\bar{P}_{eff}^2} + \frac{s^2(\bar{P}_{Pu})}{\bar{P}_{Pu}^2} \right]$$

The code for the calculation of the sample mass and uncertainty is included in Appendix B.

A more rigorous analysis which may be performed off-line by the user is presented below.

1) Electrical Calibration

$$\bar{P}_M = A + B \cdot \bar{P}_A$$

where

$$\bar{P}_M = \text{measured power} = \frac{\sum P_{M_i} / s_i^2}{\sum 1/s_i^2}$$

$$\bar{P}_A = \text{applied power} = \frac{\sum P_{A_i} / s_i^2}{\sum 1/s_i^2}$$

$$s_i = \text{uncertainty in the mean of } P_{M_i} \text{ (statistical)}$$

The sample statistical uncertainty is defined as

$$s^2(\bar{P}) = \sum [P_i - E(P_i)] / n(n-1)$$

which is

$$s^2(\bar{P}) = s^2(P_i) / n$$

This is the uncertainty in the mean of the power distribution, rather than the uncertainty in a single measurement $[s(P_i)]$.

$$B = \frac{\sum (P_{A_i} / s_i - \bar{P}_A / s_i) (P_{M_i} / s_i - \bar{P}_M / s_i)}{\sum (P_{A_i} / s_i - \bar{P}_A / s_i)^2}$$

$$A = \bar{P}_M - B\bar{P}_A$$

2) Sample Power

$$\bar{P}_S = (\bar{P}_M - A)/B$$

relating the power (P_A) actually measured to the source-produced power (P_M).

$$s^2(P_A) = \left(\frac{\partial P_A}{\partial P_M}\right)^2 s^2(P_M) + \sum \left(\frac{\partial P_A}{\partial P_i}\right)^2 s^2(P_i)$$

where

$P_i \equiv$ measured calibration observations

$s^2(P_M) \equiv$ includes statistical and all other sources of error

$$\left(\frac{\partial P_A}{\partial P_i}\right) = \frac{\partial[(P_M - A) \cdot B^{-1}]}{\partial P_i} = - \left(\frac{P_S}{B} \times \frac{\partial B}{\partial P_i} + \frac{1}{B} \times \frac{\partial A}{\partial P_i}\right)$$

$$\therefore \sum \left(\frac{\partial P_A}{\partial P_i}\right)^2 s^2(P_i) = \sum \frac{s^2(P_i)}{B^2} \left[\frac{1}{n} + \frac{(P_S - \bar{\mu})^2}{q\mu^2}\right]$$

where $\bar{\mu} = (\sum P_i) / n$

$$q\mu^2 = \sum (P_i - \mu)^2$$

$$\text{and } \left(\frac{\partial P_A}{\partial P_M}\right)^2 s^2(P_M) = \left(\frac{1}{B}\right)^2 s^2(P_M)$$

3) Source Normalization

$$K_{Pu} = (W_{238}/P_{238}) \cdot P_A$$

where

W_{238} represents the actual power output of a calibrated ^{238}Pu source

P_{238} represents the calorimeter-determined output of the calibrated source

4) Sample Mass

Thus, by combining the above

$$\bar{M}_{Pu} = K_{Pu} (\bar{P}_M - A) / BP_{eff}$$

and the uncertainty is obtained from

$$s^2(M) = s^2(\bar{P}_{Pu}) + s^2(P_{eff})$$

where

$$\begin{aligned} \frac{s^2(\bar{P}_{Pu})}{\bar{P}_{Pu}^2} &= \frac{s^2(\text{HDE})}{\bar{P}_0^2} + \frac{s^2(\text{REP})}{\bar{P}_0^2} + \frac{s^2(\text{CALIB})}{\bar{P}^2} \\ &+ \frac{s^2(\bar{P}_M)}{\bar{P}_M^2} + \frac{s^2(\text{TEMP})}{\bar{P}_0^2} \end{aligned}$$

5) System Baseline Check

During multiple sample analysis, the system baseline should be checked periodically by using the relation

$$t = |\bar{P}_0 - A| / [s^2(P_0) + s^2(A)]^{\frac{1}{2}}$$

where

$\bar{P}_0$ is the current calorimeter-supplied power to an empty chamber.

If

$$t > 1.95$$

then a baseline shift must be assumed to have occurred, and a correction should be made to the zero-power intercept (A).

APPENDIX A

CALORIMETRIC UNIT CIRCUIT DIAGRAMS #1-12

IAEA Small-Sample Calorimeter:

1. Power distribution
2. Htr - thermistor interface
3. Preheater control
4. TA control
5. T₀ control
6. T₁ control
7. T₂ control
8. T₃ control
9. T₃ control notes
10. Temperature readout
11. Diagnostic interface
12. Test point truth table

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SHEET

1

OF

12

THIS PWR CKTRY IN INSTRUMENT LID
6PC066

POWER CONNECTIONS TO DAS

+15v	→	P1	PIN 14	&	P2	PIN 23
-15v	→	P1	15	&	P2	22
+5v	→	P1	16	&	P2	13
PWR COM	→	P1	12,13	&	P2	24

TO DAS
VIA P1 & P2REVISION
NO.

REVISIONS

DATE

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BY

TITLE

IAEA SMALL SAMPLE CALORIMETER
POWER DISTRIBUTION

DRAWING NO.

L3546-7801-DB-00

DRN. BY

DATE 1-31-78

SHEET 1 OF 12

MODEL NO. CDP 29

DESIGN BY E A JUNG

BUILT FOR R. PERRY

DIV. SPM

SYSTEM NO.

ANL 382 (7-76)

2

TERMINAL BD.

6PC067

BD TERMINATION

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OF

12

NOTES -

1 - "Ø" DENOTES KNOT TIED IN WIRE FOR IDENTIFICATION
 2 - YSI PROBE IS TYPE 44018.

P.H.

TITLE

I.A.E.A. SMALL SAMPLE CALORIMETER
 HTR - THERMISTOR INTERFACE

DESIGN BY

E A JUNG

BUILT FOR

R. PERRY

DRAWING NO.

3546 - 7801 - DB-00

DRN. BY

DATE 1-27-78

SHEET 2 OF 12

MODEL NO. CDD 29

DIV.

SPM

SYSTEM NO.

DATE

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2

DRAWING NO.

L3546-7801-DB-00

SHEET

3

OF

12

NOTES -

- 1 - A5 & A6 ARE OPIOCY WITH PINS 5 & 12 TO +15V, 7 & 14 TO -15V.
- 2 - A7 IS AD506KH WITH PIN 7 TO +15, 4 TO -15V.
- 3 - A8 IS RC4558DN WITH PIN 8 TO +15, 4 TO -15V.
- 4 - ALL RESISTORS ARE METAL FILM.
- 5 - THIS CKT PART OF 6PC04B WITH RED IDENTIFIER MARK. REST ON SHEET 4 & 10
- 6 - FOR "O", ">>" & "Dk" NOTATIONS, SEE NOTES 1, 2 & 3, SHEET B.

2

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TITLE

I.A.E.A. SMALL SAMPLE CALORIMETER
PREHEATER CONTROL.

DRAWING NO.

L3546-7801-DB-00

DRN. BY EUG

SHEET 3 OF 12

DATE 1-30-78

MODEL NO. CDP 29

DESIGN BY E A JUNG

BUILT FOR R. PERRY

DIV. SPM

SYSTEM NO.

7-THERM's
GB35J1
 $R_{TOT} = 17.85K$
@ 43°C
 $\Delta R = 630 \Omega / ^\circ C$

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SHEET

4 OF 12

NOTES -

- 1 - A1 & A2 ARE OP10CY WITH PIN 5 & 12 TO +15
7 & 14 TO -15.
- 2 - A3 IS AD506 WITH PIN 7 TO +15, 4 TO -15.
- 3 - A4 IS RC4558DN WITH PIN 8 TO +15, 4 TO -15.
- 4 - ALL RESISTORS 1/4 WATT METAL FILM, U.O.S.
- 5 - 14 TRANSISTORS, TIP140 IN PARALLEL
WITH 8.2 Ω , 1/2 W IN EACH EMITTER LEG.
- 6 - THIS CKT PART OF 6PC048 WITH RED
IDENTIFIER MARK. REST ON SHEET
3 & 10.
- 7 - FOR "O", ">>>", & "Dx" NOTATIONS, SEE
NOTES 1, 2, & 3, SHEET 8.

2

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TITLE

T.A.E.A. SMALL SAMPLE CALORIMETER
TA CONTROL

DRAWING NO.

3546-7801-DB-00

DRN. BY EJA

SHEET 4 OF 12

DATE 1-31-78

MODEL NO. CDP 29

DESIGN BY E A JUNG

BUILT FOR R. PERRY

CIV. SPM

SYSTEM NO.

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SHEET 5 OF 12

NOTES -

- 1 - A1 & A2 ARE B.B. 3510CM
- 2 - A3 IS OPIOCY WITH PINS 5 & 12 TO +15
7 & 14 TO -15
- 3 - A4 IS AD506 WITH PIN 7 TO +15V, 4 TO -15V.
- 4 - A5 IS RC4558DN WITH PIN 8 TO +15, 4 TO -15
- 5 - ALL RESISTORS ARE METAL FILM, U.O.S.
- 6 - ALL RESISTORS & POTS MARKED "*" ARE
VISHAY S102 & 1210W RESPECTIVELY.
- 7 - THIS CKT PART OF 6PC049 WITH BLUE
IDENTIFIER MARK. REST ON SHEET 6.
- 8 - FOR "0", ">>" & "Dx" NOTATIONS, SEE
NOTES 1, 2 & 3, SHEET 8.

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R. PERRY		DRN. BY <i>SPM</i>	SHEET 5 OF 12
		DATE 1-30-78	MODEL NO. CDP 29
DIV. SPM		SYSTEM NO.	

DRAWING NO.
3546 - 7801 - DB - 00
 SHEET 6 OF 12

NOTES -

- 1 - A6 & A7 ARE B.B. 3510 CM
- 2 - A8 IS OP10CY WITH PINS 5 & 12 TO +15V,
7 & 14 TO -15V.
- 3 - A9 IS AD506KH WITH PIN 7 TO +15V, 4 TO -15V.
- 4 - A10 IS RC4558DN WITH PIN 8 TO +15, 4 TO -15V.
- 5 - ALL RESISTORS ARE METAL FILM, U.S.
- 6 - ALL RESISTORS & POTS MARKED "*" ARE
VISHAY S102 & 1210W RESPECTIVELY.
- 7 - THIS CKT. PART OF 6PC049 WITH BLUE
IDENTIFIER MARK. REST ON SHEET 5.
- 8 - FOR "◇", "➤" & "Dx" NOTATIONS, SEE
NOTES 1, 2, & 3, SHEET 8.

2

REVISION NO.	REVISIONS	DATE	CHANGED BY
CALORIMETER		DRAWING NO.	
		L 3645 - 7801 - DB - 00	
		DRN. BY	SHEET 6 OF 12
		DATE 1-30-78	MODEL NO. CDP 29
R. PERRY		DIV. SPM	SYSTEM NO.

DRAWING NO.

L3645 -7801 -DM-00

SHEET

7

OF

12

NOTES

- A/D CAL
6 (+10.000)
7 (+1.000)
- 1 - "◇" REFERS TO TEST POINTS ON SUB PANEL
 - 2 - "➤" REFERS TO PIN ON CARD EDGE CONN.
 - 3 - D_x REFERS TO DIAGNOSTIC NO. (SEE SHEET 10)
 - 4 - A1 & A2 ARE B.B. 3510CM.
 - 5 - A7 IS RC4558DN
 - 6 - Q1 & Q3 ARE 2N4036 ; Q2 IS 2N2405
 - 7 - ALL RESISTORS ARE 1/4 WATT M.F. EXCEPT "K" ARE VISHAY 5102.
 - 8 - PART OF 6PC050; REST ON SHEET 8.
 - 9 - CIRCUITRY ON SHEETS 7 & 8 ENCLOSED IN TA CHAMBER.

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TITLE

I.A.E.A. SMALL SAMPLE CALORIMETER
T2 CONTROL

DRAWING NO.

L3546 -7801 -DB-00

DRN. BY

DATE 1-24-78

SHEET 7 OF 12

MODEL NO. CDP 29

DESIGN BY E A JUNG

BUILT FOR R. PERRY

DIV. SPM

SYSTEM NO.

DRAWING NO. 3645 - 7801 - DB - 00

SHEET 8 OF 12

SEE SHEET 8 FOR NOTES

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REVISIONS

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BY**

TITLE	DATE	TIME
I.A.E.A. SMALL SAMPLE CALORIMETER T3 CONTROL		

DRAWING NO.

L 3645-7801-DB-00

DRN. BY *EG*

SHEET 8 OF 12

DATE 1-23-79

MODEL NO. **CDP 29**

DESIGN BY E A JUNG

BUILT FOR R. PERRY

DIV. **SPM**

SYSTEM NO.

NOTES FOR T3 CONTROL

- 1 - "O" REFERS TO TEST POINTS ON SUB PANEL
- 2 - ">>" REFERS TO PIN ON CARD EDGE CONNECTOR
- 3 - "D_x" REFERS TO DIAGNOSTIC NO. (SEE SHEET 10)
- 4 - A3 & A4 ARE B.B. 3510CM
- 5 - A5 & A6 ARE 0P10CY
- 6 - Q4 & Q6 ARE 2N2405
- 7 - Q5 IS 2N4036
- 8 - ALL RESISTORS MARKED "*" DENOTES VISHAY S102
- 9 - PART OF 6PC050; REST ON SHEET 6.
- 10 - CIRCUITRY ON SHEETS 6 & 7 ENCLOSED IN TA CHAMBER

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SHEET

9

OF 12

T3 ZERO & CALIBRATION PROCEDURE

- 1 - ADJ T3 TEMP FOR DESIRED OPERATING TEMP.
- 2 - ALLOW SUFFICIENT TIME FOR INSTRUMENT TO REACH STABILIZED OPERATING CONDITIONS.

HTR COIL ELECTROMETER CAL

- 3 - DEPRESS PUSH FOR $V_{\pm}$ ZERO & ADJ $V_{\pm}$ ZERO FOR $0.0000, \pm 10 \mu V$
- 4 - CONNECT A HI Z DVM FROM TP13 TO TP14.
ADJ $V_{\pm}$ CAL FOR $0.0000 V, \pm 10 \mu V$.

CAL COIL ELECTROMETER CAL

- 5 - CONNECT JUMPER FROM TP12 TO TP15.
- 6 - ADJ $-I_{CAL}$ ZERO FOR $0.0000 V, \pm 10 \mu V$ @ TP15.
- 7 - ADJ $+I_{CAL}$ ZERO FOR $0.0000 V, \pm 20 \mu V$ @ TP11.
- 8 - REMOVE JUMPER FROM TP12 & 15.

2

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I.A.E.A. SMALL SAMPLE CALORIMETER
T3 CONTROL NOTES

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SHEET 9 OF 12

MODEL NO. CDP 29

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DIV. SPM

SYSTEM NO.

ANL 382 (7-76)

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- 1 - A9 & A10 ARE DPIOCY.
- 2 - ALL RESISTORS ARE VISHAY S102, .5%, 5PPM, U.O.S.
- 3 - THIS CKT PART OF 6PC048 WITH RED IDENTIFIER MARK. REST ON SH. 3 & 4.
- 4 - CALIBRATION:
 - A. REMOVE REF 02, JUMPER TP15 & TP16 AND ZERO A10A, A9A, A9B IN THIS ORDER.
 - B. CONNECT A DMM BETWEEN CONN. PINS 16 & 17 AND ZERO A10B. REPLACE REF-02.
 - C. ADJ P_C FOR $-5.000V @ TP16$, P_A FOR $-3.0862V @ TP13$ & P_B FOR $-2.83525V @ TP14$.

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CALORIMETER		DRAWING NO. L3645-7801-DB-00	
ADOUT		DRN. BY ES	SHEET 10 OF 12
		DATE 1-27-78	MODEL NO. CDP 29
R. PERRY		DIV. SPM	SYSTEM NO.

ANL 382 (7-76)

DIAGNOSTICS

DIAG #	DESCRIPTION	CARD	PIN #
1	T3 COIL VOLTAGE (1V/V)	T3 (BOX)	16
2	T3 COIL CURRENT (1V/MA)	T3 "	18
3	T3 CAL COIL VOLTAGE (1V/V)	T3 "	21
4	T3 CAL COIL CURRENT (1V/MA)	T3 "	9
5	T3 Q4 EMITTER	T3 "	10
6	A/D CAL REF, 10.000	T3 "	15
7	A/D CAL REF, 1.0000	T3 "	7
8	T3 SIGNAL COM	T3 "	3
9	T2 Q1 EMITTER	T2 "	4
10	T2 A2 OUTPUT	T2 "	8
11	T2 HTR VOLTAGE	T2 "	7
12	T2 BOOST COIL VOLTAGE	T2 "	6
13	T1 A6 OUTPUT	T1 (BLUE BD.)	17
14	T1 A7 OUTPUT	T1 " "	18
15	T1 H1 HTR VOLTAGE	T1 " "	21
16	T1 L0 HTR VOLTAGE	T1 " "	19
17	T0 A1 OUTPUT	T0 " "	5
18	T0 A2 OUTPUT	T0 " "	6
19	T0 HTR VOLTAGE	T0 " "	11
20	TA A1A OUTPUT	TA (RED BD)	5
21	TA A1B OUTPUT	TA " "	3
22	TA Q2 COLLECTOR	TA " "	6
23	P.H. A5A OUTPUT	P.H. " "	12
24	P.H. A5B OUTPUT	P.H. " "	7
25	P.H. HTR. VOLTAGE	P.H. " "	13
26	TEMP READOUT (.1V/°C)	TEMP " "	22
27	TEST PROBE VOLTAGE	TEMP " "	17
28	TEMP READOUT REF. -5.000	TEMP " "	15
29	SPARE	—	
30	+5 SUPPLY	+5V BUS	
31	+15 SUPPLY ÷ 2	+15V BUS	
32	-15 SUPPLY ÷ 2	-15 BUS	

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SHEET

11

OF 12

CONN #	PIN #	EXPECTED VALUE	DIAG #
P ₁	8 OR/WHT	+5.3v EMPTY CHAMBER	1
P ₁	7 BRN/WHT	+5.9v " "	2
P ₁	6 RED/W/YEL	APPLIED CAL COIL VOLTAGE	3
P ₁	5 YEL	$\approx D3 \div 900$ (1v/mA)	4
P ₁	4 VIO	-5.3v EMPTY CHAMBER	5
P ₁	3 WHT	+10.000v	6
P ₁	2 GRY	+1.0000v	7
P ₁	1 GRN	0	8
P ₁	9 BLK/W/YEL	-5v SUPPLY (-4.7 ACTUAL)	9
P ₁	10 GRN/WHT	≈ 0.5	10
P ₁	11 YEL/WHT	+4.7v	11
P ₁	21 VIO/WHT	-4.7v	12
P ₁	22 BLU/WHT	-4.7v	13
P ₁	23 BLK/WHT	≈ 0 (4mV/mK)	14
P ₁	24 GRY/WHT	+4.1v	15
P ₁	25 RED/WHT	-4.5v	16
P ₂	3 BLK/W/ORG	-4.7v	17
P ₂	4 BRN/W/BLU	≈ 0 (4mV/mK)	18
P ₂	5 BRN/W/GRN	-7.7v	19
P ₂	6 BLK/W/GRN	-5.0	20
P ₂	7 RED/W/ORG	≈ 0 (3.5mV/mK)	21
P ₂	8 BRN/W/ORG	$\approx -11v$	22
P ₂	9 BLK/W/BLU	-1.0v	23
P ₂	10 RED/W/GRN	≈ 0	24
P ₂	2 RED/W/BLK	-3.4v	25
P ₂	20 GRY/W/BRN	0.1v/°C	26
P ₂	19 RED/W/BRN	SAME AS DPM READING	27
P ₂	18 VIO/W/BRN	-5.000v	28
—	—	—	29
P ₂	16 BLK/W/VIO	+5v SUPPLY	30
P ₂	15 BLK/W/BRN	+7.5v	31
P ₂	14 BLK/W/GRY	-7.5v	32

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BY

ON

TITLE

I.A.E.A. SMALL SAMPLE CALORIMETER
DIAGNOSTIC INTERFACE

DRAWING NO.

3546-7801-DB-00

DRN. BY

PES

SHEET 11 OF 12

DATE

1-27-78

MODEL NO. CDP 29

DESIGN BY

E A JUNG

BUILT FOR

R. PERRY

DIV.

SPM

SYSTEM NO.

ANL 382 (7-76)

2

TP #	CKT	DESCRIPTION	VALUE	TP #
1	TA	-VREF (-TP15) *	-5.000	1
2	TA	ERROR AMP OUTPUT	0	2
3	TA	INT. OUTPUT	+1.0	3
4	TA	PRE-DRIVER OUTPUT	+3.8	4
5	TA	DRIVER OUTPUT	-3.8	5
6	TA	Q2 COLLECTOR	-13.15	6
7	PH	-VREF (-TP17)	-1.0	7
8	PH	ERROR AMP OUTPUT	0	8
9	PH	INT. OUTPUT	-0.8	9
10	PH	Nx OUTPUT	+1.7	10
11	PH	DRIVER OUTPUT	-3.5	11
12	PH	COIL VOLTAGE	-3.35	12
13	BD.	CAL PT. *	-3.0862	13
14	BD.	CAL PT. *	-2.83325	14
15	BD.	+5V REF *	+5.000	15
16	BD.	-5V REF *	-5.000	16
17	PH	+REF (-TP17)	+1.0	17
18	PH	SPARE	-	18
1	TO	-VREF	-4.75	1
2	TO	ERROR AMP OUT	0	2
3	TO	INT. OUT	-0.3	3
4	TO	A5A OUT	+1.4	4
5	TO	Nx OUT	+3.6	5
6	TO	HTR VOLTAGE	-7.3	6

NOTE - ALL TEST VOLTAGES TAKEN WITH ON-BOARD DVM, EXCEPT "*"; UNDER EMPTY CHAMBER CONDITIONS WITH PCAL = 0.

ELECTRONICS DIVISION

ARGONNE NATIONAL LABORATORY
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DRAWING NO.

3546-7801-DB-00

SHEET

12

OF

12

7	-4.75	-VREF	T1	8
8	0	ERROR	T1	9
9	-0.5	INT OUT	T1	
10	+2.1	A10A OUT	T1	10
11	+4.6	NX OUT	T1	11
12	+4.1	+ HTR VOLTS	T1	12
13	-4.6	- HTR VOLTS	T1	13
14	+4.75	T1, T2 + VREF		14
15	—	SPARE		15
1	-5.35	A1 OUT	T2	1
2	-4.7	-VHTR	T2	2
3	+0.5	ERROR AMP OUT	T2	3
4	+4.7	HTR VOLTAGE	T2	4
5	-4.68	BOOST COIL VOLTAGE	T2	5
6	-5.34	-VHTR		6
7	-5.9	A3 OUT		7
8	+6.5	ERROR AMP OUT		8
9	+5.93	VI OUT		9
10	+5.34	HTR VOLTAGE		10
11	0	ICAL (NO INPUT)		11
12	0	V _{cal} (NO INPUT)		12
13	—	CAL PT (SHEET 9, NOTE 4)		13
14	—	CAL PT. (SHEET 9, NOTE 4)		14
15	0	-ICAL (NO INPUT)		15
16	10.000	A/D HI CAL *		16
17	1.0000	A/D LO CAL *		17

REVISION
NO.

REVISIONS

DATE

CHANGED
BY

TITLE

I.A.E.A. SMALL SAMPLE CALORIMETER
TEST POINT TRUTH TABLE

DRAWING NO.

3546-7801-DB-00

DRN. BY

DATE 2-1-78

SHEET 12 OF 12

MODEL NO. CDP 29

DESIGN BY

E A JUNG

BUILT FOR

R. PERRY

DIV.

SYSTEM NO.

APPENDIX B

DATA ACQUISITION SYSTEM

I. CIRCUIT DIAGRAMS #1-7

1. Keyboard layout and connections
2. Keyboard decode
3. Analog multiplexer
4. Display
5. Analog output
6. Printer output
7. 8085 microprocessor system

DRAWING NO.		ISSUE
EL -		
SHEET	OF	

Y1-1, 9, 17, 25
Y2-2, 10, 18, 33
Y3-3, 4, 26, 34
Y4-11, 12, 19, 20
Y5-27, 28, 35, 36

X1-8, 14, 30, 31, 48
X2-7, 13, 16, 32, 47
X3-6, 15, 22, 24, 46
X4-5, 21, 23, 32, 37

A 38 RST
B 41 EXT
C 42 BS
D 45 DP
E 49 ENTR
F PAPER ADV

GND 39, 40, 43, 44, 50, PAPER ADV.

E/K	J/M	≤/0	9/4	°/8
INIT	RUN	P.	SP	FRAC
3/J	✓/L	9/H	+/#	-/%
YES		PRNT	CAL	TP
U/E	V/F	W/G	X/H	Y/I
5	6	7	8	9
P/=	9/A	R/B	5/C	T/D
L	1	2	3	4
		NUMB.	SHIFT	SPACE
RST	EXT	BS	.	ENTR

ELECTRONICS DIVISION ARGONNE NATIONAL LABORATORY THIS DRAWING IS THE PROPERTY OF THE ARGONNE NATIONAL LABORATORY	TITLE KEYBOARD LAYOUT AND CONNECTIONS				DRAWING NO. EL -		
					SHEET 1 OF 7		
	DESIGN BY		DRN. BY		DATE		
BUILT FOR		DIV.		CHK. BY		APPD. BY	
						MODEL NO.	
						SYSTEM NO.	

DRAWING NO. EL -		ISSUE
SHEET	OF

ELECTRONICS DIVISION ARGONNE NATIONAL LABORATORY THIS DRAWING IS THE PROPERTY OF THE ARGONNE NATIONAL LABORATORY	TITLE KEYBOARD DECODE			DRAWING NO. EL -	
				SHEET 2 OF 7	
	DESIGN BY		DRN. BY	DATE	
	BUILT FOR		DIV.	CHK. BY	APPD. BY
			MODEL NO.		SYSTEM NO.

EL-23 (12-75)

DRAWING NO.

EL -

ISSUE

SHEET

OF

TITLE

ANALOG MULTIPLEXER

DRAWING NO.

EL -

SHEET 3 OF 3

MODEL NO.

SYSTEM NO.

DESIGN BY

DRN. BY

DATE

BUILT FOR

DIV.

CHK. BY

APPD. BY

OUT 3A 8170
 IC "H" 8171
 8172
 8173

OUT 39
 IC "H"

IC "H"
 OUT 3B

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DRAWING NO. EL -		ISSUE
SHEET	OF

2

NON ATORY Y OF ORATORY	TITLE DISPLAY				DRAWING NO. EL -	
	DESIGN BY				SHEET 4 OF 7	
	BUILT FOR				MODEL NO.	
	DIV.				SYSTEM NO.	
DRN. BY				DATE		
CHK. BY				APPD. BY		

DRAWING NO.		ISSUE
EL -		
SHEET	OF

2

TITLE				DRAWING NO.	
ANALOG OUTPUT				EL -	
DESIGN BY		DRN. BY	DATE	SHEET 5 OF 8	
BUILT FOR		CHK. BY	APPD. BY	MODEL NO.	
DIV.				SYSTEM NO.	

DRAWING NO. EL -		ISSUE
SHEET	OF	

DIP SOCKET

2

ION	TITLE			DRAWING NO.	
	PRINTER OUTPUT			EL -	
ATORY	DESIGN BY			SHEET 6 OF 7	
ITY OF	BUILT FOR			MODEL NO.	
ORATORY	DIV.			SYSTEM NO.	
	CHK. BY			DATE	
	APPD. BY				

DRAWING NO.		ISSUE
EL -		
SHEET	OF	

DIP SOCKET

ION	TITLE				DRAWING NO.	
	PRINTER OUTPUT				EL -	
ATORY	DESIGN BY				SHEET 6 OF 7	
	BUILT FOR				MODEL NO.	
ORY OF	DIV.				DATE	
	CHK. BY				SYSTEM NO.	
RATORY	APPD. BY					

APPENDIX B

II. LISTING OF MICROPROCESSOR PROGRAM

0000 3E 46	0000 BGIN MVI A,46H
0002 D3 20	0005 OUT 20H STOP COUNTER INIT 20-27
0004 3E 4F	0010 MVI A,4FH
0006 D3 28	0015 OUT 28H STOP COUNTER INIT 28-2F
0008 3E 40	0020 MVI A,40H
000A D3 30	0025 OUT 30H STOP COUNTER INIT 30-37
000C 3E 4F	0030 MVI A,4FH
000E D3 38	0035 OUT 38H STOP COUNTER INIT 38-3F
0010 3E 0F	0040 MVI A,0FH
0012 D3 3A	0045 OUT DIS DISPLAY DATA
0014 3E 3F	0050 MVI A,3FH
0016 D3 39	0055 OUT DIS DISPLAY CONTROL 'OFF'
0018 AF	0060 XRA A GET A ZERO
0019 D3 39	0065 OUT DIS
001B D3 3B	0070 OUT LED LED'S OFF
001D D3 3A	0075 OUT DIS
001F 3E 40	0080 MVI A,40H
0021 C3 40 00	0085 JMP 40H
0024	0090 ORG 24H TRAP=RESET
0024 C3 00 00	0095 JMP BGIN
0027	0100 ORG 20H RST 5.5=TERMINAL COUNT
002C C3 00 70	0105 JMP TC
002F	0110 ORG 34H RST 6.5=PAPER ADVANCE
0034 CD DB 00	0115 CALL CRLF
0037 FB	0120 EI
0038 C9	0125 RET
0039	0130 ORG 30H RST 7.5=EXTERNAL FROM
003C C3 00 18	0135 JMP 1800H
003F	0140 ORG 40H
0040 D3 39	0145 OUT DIS DP OFF
0042 AF	0150 XRA A
0043 D3 39	0155 OUT DIS
0045 31 FF 38	0160 LXI SP,STACK
0048 CD 06 05	0165 CALL DTD
004B 3E 85	0170 MVI A,85H
004D 32 80 30	0175 STA MOTOR
0050 CD DB 00	0180 CALL CRLF
0053 0E 01	0181 MVI C,01
0055 11 00 80	0182 LXI D,8000H
0058 21 C4 30	0183 LXI H,F
005B CD 67 02	0184 CALL STOR
005E 0E 76	0185 MVI C,76H
0060 11 54 D4	0186 LXI D,0D454H
0063 21 30	0187 LXI H,330
0066 CD 67 02	0188 CALL STOR
0069 21 00 17	0189 LXI H,MS61
006C CD CF 00	0190 CALL SCRN
006F CD 6B 01	0195 CALL BLK1
0072 21 0D 17	0200 LXI H,MS62
0075 CD CF 00	0205 CALL SCRN

0078 31 FF 38	0210 EOR LXI SP,STACK
007B CD DB 00	0215 CALL CRLF
007E 3E 01	0220 MVI A,01H BUSY NOT LED
0080 D3 3B	0225 OUT LED
0082 3E 08	0230 MVI A,08H MASK FOR RST INTERRUPTS
0084 30	0235 DB 30H "SIM" INSTRUCTION
0085 FB	0240 EI
0086 CD A7 00	0245 EOR1 CALL IN8
0089 FE 0A	0250 CPI 0AH NUMERIC?
008B DA 86 00	0255 JC EOR1 NO COMMAND
008E FE 14	0260 CPI 14H
0090 D2 86 00	0265 JNC EOR1 NO COMMAND
0093 D6 0A	0270 SUI 0AH
0095 47	0275 MOV B,A
0096 87	0280 ADD A X2
0097 80	0285 ADD B X3
0098 21 40 16	0290 LXI H,COMM
009B 5F	0295 MOV E,A
009C 16 00	0300 MVI D,0
009E 19	0305 DAD D
009F 11 78 00	0310 LXI D,EOR
00A2 D5	0315 PUSH D RETURN ADDRESS
00A3 AF	0320 XRA A
00A4 D3 3B	0325 OUT LED
00A6 E9	0330 PCHL
00A7 DB 23	0335 IN8 IN KST
00A9 E6 04	0340 ANI 04H
00AB C2 A7 00	0345 JNZ IN8
00AE DB 21	0350 IN8C IN KEY
00B0 47	0355 MOV B,A
00B1 DB 23	0360 IN8B IN KST
00B3 E6 04	0365 ANI 04H
00B5 DB 21	0370 IN KEY
00B7 CA B1 00	0375 JZ IN8B
00BA 78	0380 MOV A,B
00BB E6 80	0385 ANI ENTR
00BD C2 CD 00	0390 JNZ IN8A
00C0 78	0395 MOV A,B
00C1 E6 40	0400 ANI 40H DP
00C3 C2 CD 00	0405 JNZ IN8A
00C6 78	0410 MOV A,B
00C7 E6 20	0415 ANI 20H BS
00C9 78	0420 MOV A,B
00CA C8	0425 RZ
00CB 3E 20	0430 MVI A,20H
00CD 47	0435 IN8A MOV B,A
00CE C9	0440 RET
00CF 46	0445 SCRN MOV B,M GET CHAR
00D0 3E 00	0450 MVI A,00H
00D2 B8	0455 CMP B CR? END
00D3 C8	0460 RZ

00D4 CD 6D 01	0465 CALL OUT8 OUTPUT
00D7 23	0470 INX H
00D8 C3 CF 00	0475 JMP SCRN
00DB CD E2 00	0480 CRLF CALL HOME
00DE CD 55 01	0485 CALL LJUST
00E1 C9	0490 RET
00E2 DB 33	0495 HOME IN 33H EDT SWITCH
00E4 E6 01	0500 ANI 01H MASK
00E6 C8	0505 RZ
00E7 CD 0F 01	0510 CALL GORT STEP RIGHT
00EA C3 E2 00	0515 JMP HOME
00ED E5	0520 GOLF PUSH H
00EE F5	0525 PUSH PSW
00EF 21 80 30	0530 LXI H,MOTOR
00F2 7E	0535 MOV A,M
00F3 CD FD 00	0540 CALL GLF1
00F6 77	0545 MOV M,A
00F7 CD 3A 01	0550 CALL PRNT
00FA F1	0555 POP PSW
00FB E1	0560 POP H
00FC C9	0565 RET
00FD FE 85	0570 GLF1 CPI 85H
00FF CA 37 01	0575 JZ SET6
0102 FE 86	0580 CPI 86H
0104 CA 34 01	0585 JZ SETA
0107 FE 8A	0590 CPI 8AH
0109 CA 31 01	0595 JZ SET9
010C 3E 85	0600 MVI A,85H
010E C9	0605 RET
010F E5	0610 GORT PUSH H
0110 F5	0615 PUSH PSW
0111 21 80 30	0620 LXI H,MOTOR
0114 7E	0625 MOV A,M
0115 CD 1F 01	0630 CALL GRT1
0118 77	0635 MOV M,A
0119 CD 3A 01	0640 CALL PRNT
011C F1	0645 POP PSW
011D E1	0650 POP H
011E C9	0655 RET
011F FE 85	0660 GRT1 CPI 85H
0121 CA 31 01	0665 JZ SET9
0124 FE 89	0670 CPI 89H
0126 CA 34 01	0675 JZ SETA
0129 FE 8A	0680 CPI 8AH
012B CA 37 01	0685 JZ SET6
012E 3E 85	0690 MVI A,85H
0130 C9	0695 RET
0131 3E 89	0700 SET9 MVI A,89H
0133 C9	0705 RET
0134 3E 8A	0710 SETA MVI A,8AH
0136 C9	0715 RET

0137 3E 86	0720 SET6 MVI A,86H	
0139 C9	0725 RET	
013A D3 22	0730 PRNT OUT 22H	
013C 3E 08	0735 MVI A,08H	
013E D3 23	0740 OUT 23H	
0140 AF	0745 XRA A	
0141 D3 23	0750 OUT 23H	
0143 DB 33	0755 PNT1 IN 33H	
0145 E6 02	0760 ANI 02H	
0147 CA 43 01	0765 JZ PNT1	
014A E5	0770 PUSH H	
014B 26 7D	0775 MVI H,125 3 MS	
014D E3	0780 PNT2 XTHL	
014E E3	0785 XTHL	
014F 25	0790 DCR H	
0150 C2 4D 01	0795 JNZ PNT2	
0153 E1	0800 POP H	
0154 C9	0805 RET	
0155 D5	0810 LJST PUSH D	
0156 CD E2 00	0815 CALL HOME	
0159 16 15	0820 MVI D,21	
015B CD ED 00	0825 L1 CALL GOLF	
015E 15	0830 DCR D	
015F C2 5B 01	0835 JNZ L1	
0162 AF	0840 XRA A	
0163 32 81 30	0845 STA DIGT	DIGIT COUNT
0166 D1	0850 POP D	
0167 C9	0855 RET	
0168 CD 6B 01	0860 BLK2 CALL BLK1	
016B 06 20	0865 BLK1 MVI B,20H	
016D 78	0870 OUT3 MOV A,B	
016E FE 0D	0875 CPI 0DH	CR?
0170 CA DB 00	0880 JZ CRLF	
0173 FE 0A	0885 CPI 0AH	LF?
0175 CA DB 00	0890 JZ CRLF	
0178 FE 08	0895 CPI 08H	BS?
017A CA ED 00	0900 JZ GOLF	
017D F5	0905 PUSH PSW	
017E C5	0910 PUSH B	
017F 3A 81 30	0915 LDA DIGT	
0182 3C	0920 INR A	
0183 32 81 30	0925 STA DIGT	
0186 FE 13	0930 CPI 19	18 DIGITS ONLY
0188 CC DB 00	0935 CZ CRLF	GET NEW LINE
018B C1	0940 POP B	
018C F1	0945 POP PSW	
018D E6 7F	0950 ANI 7FH	
018F CD 3A 01	0955 CALL PRNT OUTPUT IT	
0192 CD 0F 01	0960 CALL GORT MOVE HEAD	
0195 C9	0965 RET	
0196 3A 81 30	0970 BS LDA DIGT	

0199	FE	00	0975	CPI	0
019B	C2	ED 00	0980	JNZ	GOLF
019E	C9		0985	RET	
019F	DB	3B	0990	IN5	IN LED
01A1	F6	02	0995	ORI	02H RSVP
01A3	D3	3B	1000	OUT	LED
01A5	21	00 FF	1005	LXI	H, OFF00H
01A8	00		1010	NOP	
01A9	00		1015	NOP	
01AA	2E	00	1020	MVI	L, 0
01AC	0E	00	1025	MVI	C, 0
01AE	11	00 00	1030	LXI	D, 0
01B1	CD	EB 01	1035	CALL	LIN1
01B4	4F		1040	MOV	C, A
01B5	C2	C1 01	1045	JNZ	IN5A
01B8	00		1050	NOP	
01B9	7C		1055	MOV	A, H
01BA	FE	FF	1060	CPI	OFFH
01BC	CA	9F 01	1065	JZ	IN5
01BF	00		1070	NOP	
01C0	00		1075	NOP	
01C1	CD	EB 01	1080	IN5A	CALL LIN1
01C4	87		1085	ADD	A
01C5	87		1090	ADD	A
01C6	87		1095	ADD	A
01C7	87		1100	ADD	A
01C8	57		1105	MOV	D, A
01C9	00		1110	NOP	
01CA	CD	EB 01	1115	CALL	LIN1
01CD	47		1120	MOV	B, A
01CE	7A		1125	MOV	A, D
01CF	E6	F0	1130	ANI	0F0H
01D1	B0		1135	DRA	B
01D2	57		1140	MOV	D, A
01D3	CD	EB 01	1145	CALL	LIN1
01D6	87		1150	ADD	A
01D7	87		1155	ADD	A
01D8	87		1160	ADD	A
01D9	87		1165	ADD	A
01DA	5F		1170	MOV	E, A
01DB	00		1175	NOP	
01DC	CD	EB 01	1180	CALL	LIN1
01DF	47		1185	MOV	B, A
01E0	7B		1190	MOV	A, E
01E1	E6	F0	1195	ANI	0F0H
01E3	B0		1200	DRA	B
01E4	5F		1205	MOV	E, A
01E5	CD	EB 01	1210	LIN2	CALL LIN1
01E8	C3	E5 01	1215	JMP	LIN2
01EB	CD	A7 00	1220	LIN1	CALL IN8
01EE	FE	80	1225	CPI	ENTR

01F0 CA 26 02	1230 JZ LIN3
01F3 FE 20	1235 CPI BSP
01F5 CA 12 02	1240 JZ BACK
01F8 FE 40	1245 CPI DP
01FA CA 09 02	1250 JZ LIN4
01FD FE 0A	1255 CPI 0AH
01FF D2 EB 01	1260 JNC LIN1 NOT NUMERIC
0202 CD 44 02	1265 CALL IND
0205 2C	1270 INR L
0206 E6 0F	1280 ANI 0FH
0208 C9	1285 RET
0209 65	1290 LIN4 MOV H,L
020A 06 2E	1295 MVI B,2EH ASCII DP
020C CD 6D 01	1300 CALL OUT8
020F C3 EB 01	1305 JMP LIN1
0212 06 08	1310 BACK MVI B,08H
0214 CD 6D 01	1315 CALL OUT8
0217 E3	1320 BCK1 XTHL
0218 7D	1325 MOV A,L
0219 D6 0C	1330 SUI 12
021B 6F	1335 MOV L,A
021C 7C	1340 MOV A,H
021D DE 00	1345 SBI 0
021F 67	1350 MOV H,A
0220 E3	1355 XTHL
0221 7C	1360 MOV A,H
0222 BD	1365 CMP L
0223 C8	1370 RZ
0224 2D	1375 DCR L
0225 C9	1380 RET
0226 DB 3B	1385 LIN3 IN LED
0228 E6 FD	1390 ANI 0FDH
022A D3 3B	1395 OUT LED RSVP NOT
022C 7C	1400 MOV A,H
022D FE FF	1405 CPI 0FFH
022F CA 3F 02	1410 JZ LIN5
0232 B7	1415 ORA A
0233 CA 3B 02	1420 JZ LIN6
0236 7C	1425 MOV A,H
0237 3D	1430 DCR A
0238 47	1435 MOV B,A
0239 E1	1437 POP H
023A C9	1440 RET
023B 06 41	1445 LIN6 MVI B,41H
023D E1	1447 POP H
023E C9	1450 RET
023F 7D	1455 LIN5 MOV A,L
0240 3D	1460 DCR A
0241 47	1465 MOV B,A
0242 E1	1470 POP H
0243 C9	1473 RET

0244 FE 40	1475 IND CPI 40H
0246 C2 4E 02	1480 JNZ \$+5
0249 06 2E	1485 MVI B,2EH ASCII DP
024B C3 51 02	1490 JMP \$+3
024E C6 30	1495 ADI 30H
0250 47	1500 MOV B,A
0251 CD 6D 01	1505 CALL OUT8
0254 78	1510 MOV A,B
0255 C9	1515 RET
0256 D5	1520 GETB PUSH D
0257 46	1525 MOV B,M
0258 23	1530 INX H
0259 56	1535 MOV D,M
025A 23	1540 INX H
025B 5E	1545 MOV E,M
025C 23	1550 INX H
025D EB	1555 XCHG
025E D1	1560 POP D
025F C9	1565 RET
0260 4E	1570 GETC MOV C,M
0261 23	1575 INX H
0262 56	1580 MOV D,M
0263 23	1585 INX H
0264 5E	1590 MOV E,M
0265 23	1595 INX H
0266 C9	1600 RET
0267 71	1605 STOR MOV M,C
0268 23	1610 INX H
0269 72	1615 MOV M,D
026A 23	1620 INX H
026B 73	1625 MOV M,E
026C 23	1630 INX H
026D C9	1635 RET
026E 78	1640 SWAP MOV A,B
026F 41	1645 MOV B,C
0270 4F	1650 MOV C,A
0271 EB	1655 XCHG
0272 C9	1660 RET
0273 CD 60 02	1665 OUTH CALL GETC GET DATA
0276 CD 00 0C	1670 OUTB CALL HEXB MAKE BCD
0279 2E 05	1675 OUTD MVI L,5 # OF DIGITS
027B 79	1680 MOV A,C
027C B7	1685 ORA A
027D CA EC 02	1690 JZ ZERO
0280 78	1695 MOV A,B
0281 E6 7F	1700 ANI 7FH
0283 67	1705 MOV H,A
0284 78	1710 MOV A,B
0285 E6 80	1715 ANI 80H
0287 06 2D	1720 MVI B,'-'
0289 C4 6D 01	1725 CNZ OUT8

028C 7C	1730	MOV A,H
028D E6 40	1735	ANI 40H EXP SIGN
028F CA C0 02	1740	JZ OUT3 POS EXP
0292 7C	1745	MOV A,H
0293 FE 44	1750	CPI 44H
0295 D2 F2 02	1755	JNC DOUTF-1 FLOAT PT OUT
0298 E6 03	1760	ANI 03H
029A 67	1765	MOV H,A
029B 06 30	1770	MVI B,'0'
029D CD 6D 01	1775	CALL OUT8
02A0 06 2E	1780	MVI B,'.'
02A2 CD 6D 01	1785	CALL OUT8
02A5 06 30	1790	OUT1 MVI B,'0'
02A7 25	1795	DCR H
02A8 CA B5 02	1800	JZ OUT2
02AB FA EC 02	1805	JM ZERO
02AE 2D	1810	DCR L
02AF CD 6D 01	1815	CALL OUT8
02B2 C3 A5 02	1820	JMP OUT1
02B5 CD 2C 03	1825	OUT2 CALL DOUT2
02B8 CD DC 02	1830	CALL DIGIT
02BB 2D	1835	DCR L
02BC C2 B5 02	1840	JNZ OUT2
02BF C9	1845	RET
02C0 7C	1850	OUT3 MOV A,H
02C1 FE 05	1855	CPI 5
02C3 D2 F2 02	1860	JNC DOUTF-1 FLOAT PT OUT
02C6 24	1865	INR H
02C7 CD 2C 03	1870	OUT4 CALL DOUT2
02CA CD DC 02	1875	CALL DIGIT
02CD 2D	1880	DCR L
02CE C8	1885	RZ
02CF 25	1890	DCR H
02D0 CC D6 02	1895	CZ OUT5
02D3 C3 C7 02	1900	JMP OUT4
02D6 06 2E	1905	OUT5 MVI B,'.'
02D8 CD 6D 01	1910	CALL OUT8
02DB C9	1915	RET
02DC 41	1920	DIGIT MOV B,C
02DD 7A	1925	MOV A,D
02DE E6 F0	1930	ANI 0F0H
02E0 0F	1935	RRC
02E1 0F	1940	RRC
02E2 0F	1945	RRC
02E3 0F	1950	RRC
02E4 4F	1955	MOV C,A
02E5 EB	1960	XCHG
02E6 29	1965	DAD H
02E7 29	1970	DAD H
02E8 29	1975	DAD H
02E9 29	1980	DAD H

02EA EB	1985 XCHG
02EB C9	1990 RET
02EC 06 30	1995 ZERO MVI B,'0'
02EE CD 6D 01	2000 CALL OUT8
02F1 C9	2005 RET
02F2	2010 *PRINT A DECIMAL FLOATING POINT NUMBER
02F2	2015 *NO SIGN IS PRINTED
02F2 44	2020 MOV B,H
02F3 C5	2025 DUF1 PUSH B
02F4 78	2030 MOV A,B
02F5 CD 2C 03	2035 CALL DUF2
02F8 06 2E	2040 MVI B,'.'
02FA CD 6D 01	2045 CALL OUT8
02FD 2E 04	2050 MVI L,4
02FF CD DC 02	2055 CALL DIGIT
0302 CD 2C 03	2060 DUF1 CALL DUF2
0305 CD DC 02	2065 CALL DIGIT
0308 41	2070 MOV B,C
0309 2D	2075 DCR L
030A C2 02 03	2080 JNZ DUF1
030D CD 6B 01	2085 CALL BLK1
0310 06 45	2090 MVI B,'E'
0312 CD 6D 01	2095 CALL OUT8
0315 C1	2100 POP B
0316 48	2105 MOV C,B
0317 78	2110 MOV A,B
0318 E6 40	2115 ANI 40H EXP SIGN
031A 06 2D	2120 MVI B,'-'
031C 04 6D 01	2125 CNZ OUT8
031F 79	2130 MOV A,C
0320 E6 30	2135 ANI 30H
0322 CA 2C 03	2140 JZ DUF2
0325 07	2145 RLC
0326 07	2150 RLC
0327 07	2155 RLC
0328 07	2160 RLC
0329 CD 2D 03	2165 CALL DUF2+1
032C 79	2170 DUF2 MOV A,C
032D E6 0F	2175 ANI 0FH
032F 06 30	2180 ADI 30H
0331 47	2185 MOV B,A
0332 CD 6D 01	2190 CALL OUT8
0335 C9	2195 RET
0336	2200 *OUTPUT TO THE DISPLAY A NUMBER BETWEEN
0336	2205 *0.001 THRU 99.999 AND 0
0336 CD 6D 02	2210 DISH CALL GETC
0339 F5	2215 DISB PUSH PSM
033A C5	2220 PUSH B
033B D5	2225 PUSH D
033C E5	2230 PUSH H
033D CD 00 0C	2235 CALL HEXB

0340 CD 15 04	2240 DISP CALL PTCK PRINT CHECK
0343 C5	2245 PUSH B
0344 E1	2250 POP H
0345 22 BD 30	2255 SHLD OLDD
0348 D5	2260 PUSH D
0349 E1	2265 POP H
034A 22 BF 30	2270 SHLD OLDD+2
034D 79	2275 MOV A,C
034E B7	2280 ORA A
034F CA DB 03	2285 JZ DIS6 ZERO
0352 3E 0F	2290 MVI A,0FH BLANK
0354 D3 3A	2295 OUT DISD DISPLAY DATA
0356 78	2300 MOV A,B
0357 E6 80	2305 ANI 80H
0359 CA 60 03	2310 JZ \$+4
035C 3E 0E	2315 MVI A,0EH
035E D3 3A	2320 OUT DISD
0360 3E 20	2325 MVI A,20H MSD
0362 CD 0D 04	2330 CALL DISC
0365 78	2335 MOV A,B
0366 E6 3F	2340 ANI 3FH
0368 FE 03	2345 CPI 3
036A D2 E6 03	2350 JNC DISE
036D 78	2355 MOV A,B
036E E6 40	2360 ANI 40H
0370 CA AD 03	2365 JZ DIS2 POS EXP
0373 3E 01	2370 MVI A,1 LEFT DP
0375 D3 3A	2375 OUT DISD
0377 3E 40	2380 MVI A,40H
0379 CD 0D 04	2385 CALL DISC
037C 78	2390 MOV A,B
037D E6 0F	2395 ANI 0FH
037F 6F	2400 MOV L,A NEG EXP
0380 26 05	2405 MVI H,5 NUMBER OF DIGITS
0382 AF	2410 XRA A
0383 D3 3A	2415 OUT DISD
0385 3E 10	2420 MVI A,10H
0387 2D	2425 DCR L
0388 CA 99 03	2430 JZ DIS1+1
038B CD 0D 04	2435 CALL DISC
038E 25	2440 DCR H
038F 0F	2445 RRC
0390 2D	2450 DCR L
0391 CA 99 03	2455 JZ DIS1+1
0394 CD 0D 04	2460 CALL DISC
0397 25	2465 DCR H
0398 0F	2470 DIS1 RRC
0399 F5	2475 PUSH PSM
039A 79	2480 MOV A,C
039B D3 3A	2485 OUT DISD
039D F1	2490 POP PSM

039E CD 0D 04	2495 CALL DISC	
03A1 F5	2500 PUSH PSW	
03A2 CD DC 02	2505 CALL DIGIT	SHIFT DIGITS
03A5 F1	2510 POP PSW	
03A6 25	2515 DCR H	# OF DIGITS
03A7 C2 98 03	2520 JNZ DIS1	NEXT OUTPUT
03AA C3 D6 03	2525 JMP DIS5	
03AD 78	2530 DIS2 MOV A,B	
03AE E6 03	2535 ANI 03H	
03B0 47	2540 MOV B,A	
03B1 04	2545 INR B	
03B2 05	2550 DCR B	
03B3 3E 02	2555 MVI A,02H	SECOND DP
03B5 CA BA 03	2560 JZ DIS3	
03B8 3E 04	2565 MVI A,04H	
03BA D3 3A	2570 DIS3 OUT DISD	
03BC 3E 40	2575 MVI A,40H	
03BE CD 0D 04	2580 CALL DISC	
03C1 26 05	2585 MVI H,5	
03C3 06 10	2590 MVI B,10H	
03C5 79	2595 DIS4 MOV A,C	
03C6 D3 3A	2600 OUT DISD	
03C8 78	2605 MOV A,B	
03C9 CD 0D 04	2610 CALL DISC	
03CC CD DD 02	2615 CALL DIGIT+1	
03CF 78	2620 MOV A,B	
03D0 0F	2625 RRC	
03D1 47	2630 MOV B,A	
03D2 25	2635 DCR H	
03D3 C2 C5 03	2640 JNZ DIS4	
03D6 E1	2645 DIS5 POP H	
03D7 D1	2650 POP D	
03D8 C1	2655 POP B	
03D9 F1	2660 POP PSW	
03DA C9	2665 RET	
03DB AF	2670 DIS6 XRA A	
03DC D3 3A	2675 OUT DISD	
03DE 3E 5F	2680 MVI A,5FH	
03E0 CD 0D 04	2685 CALL DISC	
03E3 C3 D6 03	2690 JMP DIS5	
03E6 3E 0F	2695 DISE MVI A,0FH	ERROR
03E8 D3 3A	2700 OUT DISD	
03EA 3E 3F	2705 MVI A,3FH	
03EC CD 0D 04	2710 CALL DISC	
03EF AF	2715 XRA A	
03F0 D3 3A	2720 OUT DISD	
03F2 3E 40	2725 MVI A,40H	
03F4 CD 0D 04	2730 CALL DISC	
03F7 C3 D6 03	2735 JMP DIS5	
03FA	2740 *DISPLAY AN INTERGER NUMBER	
03FA F5	2745 DIS1 PUSH PSW	

03FB C5	2750	PUSH B	
03FC D5	2755	PUSH D	
03FD E5	2760	PUSH H	
03FE CD 15 04	2765	CALL PTCK	PRINT CHECK
0401 3E 0F	2770	MVI A,0FH	
0403 D3 3A	2775	OUT DISD	
0405 3E 20	2780	MVI A,20H	
0407 CD 0D 04	2785	CALL DISC	
040A C3 C1 03	2790	JMP DIS4-4	
040D F5	2795	DISC PUSH PSW	
040E D3 39	2800	OUT 39H	CONTROL PORT
0410 AF	2805	XRA A	
0411 D3 39	2810	OUT 39H	
0413 F1	2815	POP PSW	
0414 C9	2820	RET	
0415 DB 23	2825	PTCK IN KST	
0417 E6 04	2830	ANI 04H	
0419 C0	2835	RNZ	
041A C5	2840	PUSH B	
041B CD A7 00	2845	CALL INB	
041E FE 0E	2850	CPI 0EH	PRINT?
0420 C1	2855	POP B	
0421 C0	2860	RNZ	
0422 F5	2865	PUSH PSW	
0423 C5	2870	PUSH B	
0424 D5	2875	PUSH D	
0425 E5	2880	PUSH H	
0426 2A BD 30	2885	LHLD OLDD	
0429 E5	2890	PUSH H	
042A C1	2895	POP B	
042B 2A BF 30	2900	LHLD OLDD+2	
042E EB	2905	XCHG	
042F CD 79 02	2910	CALL OUTD	PRINT
0432 CD DB 00	2915	CALL CRLF	
0435 C3 D6 03	2920	JMP DIS5	
0438	2925	♦GET ANALOG VOLTAGE AND RETURN IN BI FP	
0438	2930	♦'A' CONTAINS MULTIPLEXER INPUT NUMBER	
0438	2935	♦OVERFLOW OF A/D RETURNS FP OF 1FFFH	
0438 E6 1F	2940	ATOD ANI 1FH	
043A D3 29	2945	OUT MUL	
043C F5	2950	PUSH PSW	
043D DB 3B	2955	IN LED	
043F F6 08	2960	ORI 08H	
0441 D3 3B	2965	OUT LED	
0443 3E 85	2970	MVI A,133	1 MS DELAY
0445 3D	2975	DCR A	
0446 C2 45 04	2980	JNZ \$-4	
0449 DB 29	2985	IN MUL	
044B F6 20	2990	ORI 20H	
044D D3 29	2995	OUT MUL	START A/D
044F E6 1F	3000	ANI 1FH	

0451 D3 29	3005	OUT MUL	
0453 DB 32	3010 AD1	IN AD+1	
0455 E6 40	3015	ANI 40H	
0457 CA 53 04	3020	JZ AD1	A/D BUSY
045A DB 32	3025	IN AD+1	
045C E6 20	3030	ANI 20H	
045E CA 6A 04	3035	JZ AD2	
0461 11 FF 1F	3040	LXI D,1FFFH	OVERFLOW
0464 01 00 00	3045	LXI B,0	
0467 C3 7B 04	3050	JMP AD3	
046A DB 32	3055 AD2	IN AD+1	
046C E6 10	3060	ANI 10H	SIGN
046E CA 97 04	3065	JZ AD4	POSITIVE
0471 DB 32	3070	IN AD+1	
0473 2F	3075	CMA	
0474 E6 0F	3080	ANI 0FH	MS BITS
0476 57	3085	MOV D,A	
0477 DB 31	3090	IN AD	
0479 2F	3095	CMA	
047A 5F	3100	MOV E,A	
047B CD 39 0E	3105 AD3	CALL FLOT FP OF A/D	
047E DB 32	3110	IN AD+1	
0480 07	3115	RLC	
0481 07	3120	RLC	
0482 07	3125	RLC	
0483 E6 80	3130	ANI 80H	SIGN
0485 B1	3135	DRA C	
0486 4F	3140	MOV C,A	
0487 06 78	3145	MVI B,78H	
0489 21 FC EF	3150	LXI H,0EFFCH	0.0036621 FOR 15V FS
048C CD 2C 0F	3155	CALL MULT	
048F DB 3B	3160	IN LED	
0491 E6 F7	3165	ANI 0F7H	
0493 D3 3B	3170	OUT LED	
0495 F1	3175	POP PSW	
0496 C9	3180	RET	
0497 DB 32	3185 AD4	IN AD+1	
0499 E6 0F	3190	ANI 0FH	MS BITS
049B 57	3195	MOV D,A	
049C DB 31	3200	IN AD	
049E C3 7A 04	3205	JMP AD3-1	
04A1	3210	♦GET TWO A/D'S AND MULTIPLY TOGETHER	
04A1	3215	♦ALSO MULTIPLY BY POWER CONSTANT	
04A1	3220	♦MAKE 10 MEASUREMENTS AND AVERAGE AND DISPLAY THEM	
04A1	3225	♦ASSUME "E" MULTIPLEX COMES IN 'A'	
04A1	3230	♦ASSUME "I" MULTIPLEX = "E"+1	
04A1 32 85 30	3235 PWR	STA PLEX	
04A4 CD 97 0F	3240	CALL CLR ZERO REGISTERS	
04A7 21 82 30	3245	LXI H,POWER	
04AA CD 67 02	3250	CALL STOR	
04AD 3E 0A	3255	MVI A,10	

04AF F5	3260 PWR1 PUSH PSW
04B0 3A 85 30	3265 LDA PLEX MULTIPLEXER OUTPUT
04B3 CD 38 04	3270 CALL ATOD
04B6 D5	3275 PUSH D
04B7 C5	3280 PUSH B SAVE MEASUREMENT
04B8 3C	3285 INR A
04B9 CD 38 04	3290 CALL ATOD
04BC 79	3295 MOV A,C
04BD C1	3300 POP B
04BE E1	3305 POP H GET FIRST MEASUREMENT
04BF 41	3310 MOV B,C
04C0 4F	3315 MOV C,A
04C1 CD 2C 0F	3320 CALL MULT
04C4 06 01	3325 MVI B,01H
04C6 21 00 80	3330 LXI H,8000H PWR CONST=1
04C9 CD 2C 0F	3335 CALL MULT
04CC 79	3340 MOV A,C
04CD E6 7F	3345 ANI 7FH POSITIVE POWER ONLY
04CF 4F	3350 MOV C,A
04D0 21 82 30	3355 LXI H,POWER
04D3 CD 56 02	3360 CALL GETB
04D6 CD 86 0E	3365 CALL ADD
04D9 21 82 30	3370 LXI H,POWER
04DC CD 67 02	3375 CALL STOR
04DF F1	3380 POP PSW NUMBER OF ADDS
04E0 3D	3385 DCR A
04E1 C2 AF 04	3390 JNZ PWR1
04E4 06 04	3395 MVI B,04H
04E6 21 00 A0	3400 LXI H,0A000H TEN
04E9 CD 6E 02	3405 CALL SWAP
04EC CD 7C 0F	3410 CALL DIV
04EF C5	3415 PUSH B
04F0 D5	3420 PUSH D
04F1 3A AC 30	3421 LDA DCNT
04F4 47	3422 MOV B,A
04F5 E6 01	3423 ANI 01H
04F7 CA 00 05	3424 JZ PWR2
04FA 58	3425 MOV E,B
04FB 16 00	3426 MVI D,0
04FD CD 39 0E	3427 CALL FLOT
0500 CD 39 03	3428 PWR2 CALL DISB DISPLAY ALT PWR & POINT
0503 D1	3430 POP D
0504 C1	3435 POP B
0505 C9	3440 RET
0506	3445 *OUTPUT 'A' TO THE D TO A CONVERTER
0506 D3 2A	3450 DTOR OUT DA
0508 F5	3455 PUSH PSW
0509 DB 23	3460 IN 23H
050B F6 10	3465 ORI 10H
050D D3 23	3470 OUT 23H LOAD D/A
050F E6 EF	3475 ANI 0EFH

0511 D3 23	3480	OUT 23H
0513 F1	3485	POP PSW
0514 C9	3490	RET
0515	3495	ORG 1660H
1660 C3 78 00	3500	JMP EDR
1663 C3 A7 00	3505	JMP IN8
1666 C3 9F 01	3510	JMP IN5
1669 C3 6D 01	3515	JMP OUT8
166C C3 CF 00	3520	JMP SCRN
166F C3 DB 00	3525	JMP CRLF
1672 C3 68 01	3530	JMP BLK1
1675 C3 68 01	3535	JMP BLK2
1678 C3 73 02	3540	JMP DUTH
167B C3 76 02	3545	JMP DUTB
167E C3 79 02	3550	JMP DUTD
1681 C3 F3 02	3555	JMP DUTF
1684 C3 36 03	3560	JMP DISH
1687 C3 39 03	3565	JMP DISB
168A C3 FA 03	3570	JMP DISI
168D C3 38 04	3575	JMP ATOD
1690 C3 06 05	3580	JMP DTDH
1693 C3 A1 04	3585	JMP PMR
1696 C3 8E 05	3590	JMP SDEV
1699 C3 50 05	3595	JMP AVE
169C C3 60 02	3600	JMP GETC
169F C3 56 02	3605	JMP GETB
16A2 C3 67 02	3610	JMP STOR
16A5 C3 6E 02	3615	JMP SWAP
16A8 C3 C1 01	3616	JMP IN5A
16AB C3 44 02	3617	JMP IN0
16AE C3 AE 00	3618	JMP IN8C
16B1	3620	ORG 1640H
1640 C3 78 00	3625	COMM JMP EDR
1643 C3 6D 13	3630	JMP INIT
1646 C3 78 00	3635	JMP EDR
1649 C3 7F 08	3640	JMP RUN
164C C3 78 00	3645	JMP EDR
164F C3 8C 07	3650	JMP P0
1652 C3 C5 09	3655	JMP CAL
1655 C3 27 12	3660	JMP SPDM
1658 C3 05 08	3665	JMP TEST
165B C3 00 10	3670	JMP FRAC
165E	3675	SP EQU 6
165E	3680	PSW EQU 6
165E	3685	STACK EQU 38FFH
165E	3690	DISD EQU 3AH
165E	3695	DIS EQU 39H
165E	3700	LED EQU 3BH
165E	3705	MSG2 EQU 170DH
165E	3710	TC EQU 7000H
165E	3715	KST EQU 23H

165E	3720	KEY	EQU	21H
165E	3725	ENTR	EQU	80H
165E	3730	BSP	EQU	20H
165E	3735	HEXB	EQU	0C00H
165E	3740	DP	EQU	40H
165E	3745	INIT	EQU	136DH
165E	3750	RUN	EQU	087FH
165E	3755	SPDM	EQU	1227H
165E	3760	P0	EQU	078CH
165E	3765	CAL	EQU	09C5H
165E	3770	TEST	EQU	0B05H
165E	3775	FRAC	EQU	1000H
165E	3780	AD	EQU	31H
165E	3785	MUL	EQU	29H
165E	3790	DA	EQU	2AH
165E	3795	FLOT	EQU	0E39H
165E	3800	MULT	EQU	0F2CH
165E	3805	MSG1	EQU	1700H
165E	3810	ADD	EQU	0E86H
165E	3815	DIV	EQU	0F7CH
165E	3820	CLR	EQU	0F97H
165E	3830	MOTOR	EQU	3080H
165E	3835	DIIGT	EQU	3081H
165E	3840	POWER	EQU	3082H
165E	3845	PLEX	EQU	3085H
165E	3855	OLID	EQU	30BDH
165E	3860	AVE	EQU	0550H
165E	3865	SDEV	EQU	058EH
165E	3870	F	EQU	30C4H
165E	3875	SSQ	EQU	30BDH
165E	3880	DCNT	EQU	30ACH

DISK-

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0550
0550
0550
0550 2A 87 30
0553 23
0554 22 87 30
0557 21 89 30
055A CD 9F 16
055D CD 83 0E
0560 21 8C 30
0563 CD A2 16
0566 21 8F 30
0569 CD 9F 16
056C CD 86 0E
056F 21 8F 30
0572 CD A2 16
0575 21 8C 30
0578 CD 9C 16
057B CD 2B 0E
057E 21 92 30
0581 CD 9F 16
0584 CD 86 0E
0587 21 92 30
058A CD A2 16
058D C9
058E
058E
058E
058E
058E 2A 87 30
0591 EB
0592 CD 39 0E
0595 21 95 30
0598 CD A2 16
059B 21 8F 30
059E CD 9F 16
05A1 CD 7C 0F
05A4 21 8C 30
05A7 CD A2 16
05AA CD 2B 0E
05AD 21 95 30
05B0 CD 9F 16
05B3 CD 2C 0F
05B6 21 95 30
05B9 CD A2 16
05BC 21 8C 30
05BF CD 9C 16
05C2 21 89 30
05C5 CD 9F 16
05C8 CD 83 0E
05CB 21 C4 30
05CE CD 9F 16
05D1 CD 2C 0F
05D4 21 98 30
05D7 CD A2 16
05DA 2A 87 30
05DD 2B

3500 ♦THIS STORES SUM OF P0-PM & SUM (P0-PM) SQ
3505 ♦N IS THE NUMBER OF SAMPLES
3510 ♦ASSUME POWER IS IN CDE IN BINARY FP
3515 AVE LHLD N
3520 INX H
3525 SHLD N
3530 LXI H,P0
3535 CALL GETB
3540 CALL SUB
3545 LXI H,PI
3550 CALL STOR
3555 LXI H,SUM
3560 CALL GETB
3565 CALL ADD
3570 LXI H,SUM
3575 CALL STOR
3580 LXI H,PI
3585 CALL GETC
3590 CALL SQ
3595 LXI H,SMSQ
3600 CALL GETB
3605 CALL ADD
3610 LXI H,SMSQ
3615 CALL STOR
3620 RET
3625 ♦THIS ROUTINE CALCULATES THE MEAN
3630 ♦AND THE DEVIATION FROM THE MEAN
3635 ♦PAVE=F (P0-SUM (P0-PN)) /N
3640 ♦SIGM=((SUM (P0-PN) SQ-N (PAVE) SQ) /
      (N(N-1))+SSQ) SQRT
3645 SDEV LHLD N
3650 XCHG
3655 CALL FLOT
3660 LXI H,TEMP
3665 CALL STOR
3670 LXI H,SUM
3675 CALL GETB
3680 CALL DIV
3685 LXI H,PI
3690 CALL STOR
3695 CALL SQ (AVE) SQ
3700 LXI H,TEMP
3705 CALL GETB
3710 CALL MULT N(AVE) SQ
3715 LXI H,TEMP
3720 CALL STOR
3725 LXI H,PI
3730 CALL GETC
3735 LXI H,P0
3740 CALL GETB
3745 CALL SUB
3746 LXI H,F
3747 CALL GETB
3748 CALL MULT
3750 LXI H,PAVE
3755 CALL STOR STORE AVERAGE POWER
3760 LHLD N # OF SAMPLES
3765 DC& H...N-1..

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05DE EB	3770 XCHG
05DF CD 39 0E	3775 CALL FLOT
05E2 21 9B 30	3780 LXI H, SIGM
05E5 CD A2 16	3785 CALL STOR
05E8 2A 87 30	3786 LHLD N
05EB EB	3787 XCHG
05EC CD 39 0E	3788 CALL FLOT
05EF 21 9B 30	3789 LXI H, SIGM
05F2 CD 9F 16	3790 CALL GETB
05F5 CD 2C 0F	3791 CALL MULT
05F8 21 9B 30	3792 LXI H, SIGM
05FB CD A2 16	3793 CALL STOR
05FE 21 92 30	3794 LXI H, SMSQ
0601 CD 9C 16	3795 CALL GETC
0604 21 95 30	3800 LXI H, TEMV N(AVE) SQ
0607 CD 9F 16	3805 CALL GETB
060A CD 83 0E	3810 CALL SUB
060D 21 9B 30	3815 LXI H, SIGM N(N-1)
0610 CD 9F 16	3820 CALL GETB
0613 CD A5 16	3825 CALL SWAP
0616 CD 7C 0F	3830 CALL DIV
0619 21 C1 30	3831 LXI H, SSQ
061C CD 9F 16	3832 CALL GETB
061F CD 8E 30E	3833 CALL ADD SUB
0622 CD E3 0D	3835 CALL SQRT
0625 21 9B 30	3840 LXI H, SIGM
0628 CD A2 16	3845 CALL STOR STORE SIGMA
062B C9	3850 RET
062C	3855 *DELAY IN MINUTES DELAY STORED AT TIME
062C DB 3B	3860 DELA IN LED
062E F6 20	3865 ORI 20H
0630 D3 3B	3870 OUT LED
0632 2A 9E 30	3875 LHLD TIME
0635 C3 4A 06	3880 JMP DEL3
0638 0E 3C	3885 DEL0 MVI C, 60 60 SECONDS
063A 11 B8 88	3890 DEL1 LXI D, 35000
063D E3	3895 DEL2 XTHL
063E E3	3900 XTHL
063F 1B	3905 DCX D
0640 7A	3910 MOV A, D
0641 B3	3915 ORA E
0642 C2 3D 06	3920 JNZ DEL2 NOT 1 SEC
0645 0D	3925 DCR C
0646 C2 3A 06	3930 JNZ DEL1 NOT 1 MIN
0649 2B	3935 DCX H
064A E5	3940 DEL3 PUSH H
064B EB	3945 XCHG
064C CD A7 0D	3950 CALL BCD
064F 0E 0F	3955 MVI C, 0FH
0651 3E F0	3960 MVI A, 0F0H
0653 B2	3965 ORA D
0654 57	3970 MOV D, A
0655 CD 8A 16	3975 CALL DISI
0658 E1	3980 POP H
0659 7C	3983 MOV A, H

065A B5	3985	DRA L
065B C2 38 06	3990	JNZ DELO NOT TIME
065E DB 3B	3995	IN LED
0660 E6 DF	4000	ANI 0DFH
0662 D3 3B	4005	OUT LED
0664 C9	4010	RET
0665	4015	*GET AND STORE POWER PROMPTS
0665 AF	4020	PRMT XRA A
0666 32 A0 30	4025	STA FLAG1
0669 21 0F 00	4030	LXI H,15 DEFAULT TIME
066C 22 9E 30	4035	SHLD TIME
066F 0E 7D	4040	MVI C,7DH
0671 11 CC CC	4045	LXI D,0000CH DEFAULT SIGMA=0.1
0674 21 A1 30	4050	LXI H,SIGF
0677 CD A2 16	4055	CALL STOR
067A 21 B4 00	4060	LXI H,180 DEFAULT #DP/RUN
067D 22 A4 30	4065	SHLD DAPT
0680 21 30 17	4070	LXI H,MSG6 PRINT ALL?
0683 CD 6C 16	4075	CALL SCRN
0686 CD 75 16	4080	CALL BLK2
0689 CD 18 07	4085	CALL RSVP
068C 32 A0 30	4090	STA FLAG1
068F FE 0A	4095	CPI YES
0691 CA 9D 06	4100	JZ PRM0
0694 21 E9 17	4105	LXI H,MSG0 NO
0697 CD 6C 16	4110	CALL SCRN
069A C3 A3 06	4115	JMP PRM1
069D 21 E5 17	4120	PRM0 LXI H,MSGP YES
06A0 CD 6C 16	4125	CALL SCRN
06A3 CD 6F 16	4130	PRM1 CALL CRLF
06A6 21 25 17	4135	LXI H,MSG5 DELAY-MIN
06A9 CD 6C 16	4140	CALL SCRN
06AC CD 75 16	4145	CALL BLK2
06AF CD 18 07	4150	CALL RSVP
06B2 DA C2 06	4155	JC PRM2
06B5 CD FF 0C	4160	CALL BCDH
06B8 CD 63 0E	4165	CALL FIXX
06BB EB	4170	XCHG
06BC 22 9E 30	4175	SHLD TIME
06BF C3 C8 06	4180	JMP PRM3
06C2 2A 9E 30	4185	PRM2 LHLD TIME
06C5 CD 4C 07	4190	CALL OUTI
06C8 CD 6F 16	4195	PRM3 CALL CRLF
06CB 21 1B 17	4200	LXI H,MSG1 SIGMA-%
06CE CD 6C 16	4205	CALL SCRN
06D1 CD 75 16	4210	CALL BLK2
06D4 CD 18 07	4215	CALL RSVP
06D7 DA E6 06	4220	JC PRM4
06DA CD FF 0C	4225	CALL BCDH
06DD 21 A1 30	4230	LXI H,SIGF
06E0 CD A2 16	4235	CALL STOR
06E3 C3 EC 06	4240	JMP PRM5
06E6 21 A1 30	4245	PRM4 LXI H,SIGF
06E9 CD 78 16	4250	CALL DUTH
06EC CD 6F 16	4255	PRM5 CALL CRLF
06EF 21 13 17	4260	LXI H,MSG3 #DP/RUN

06F2	CD	6C	16	4265	CALL	SCRN
06F5	CD	75	16	4270	CALL	BLK2
06F8	CD	18	07	4275	CALL	RSVP
06FB	DA	0B	07	4280	JC	PRM6
06FE	CD	FF	0C	4285	CALL	BCDH
0701	CD	63	0E	4290	CALL	FIXX
0704	EB			4295	XCHG	
0705	22	A4	30	4300	SHLD	DAPT
0708	C3	11	07	4305	JMP	PRM7
070B	2A	A4	30	4310	PRM6	LHLD DAPT
070E	CD	4C	07	4315	CALL	OUTI
0711	CD	6F	16	4320	PRM7	CALL CRLF
0714	CD	6F	16	4325	CALL	CRLF
0717	C9			4330	RET	
0718	DB	3B		4335	RSVP	IN LED
071A	F6	02		4340	ORI	02H
071C	D3	3B		4345	OUT	LED
071E	11	00	00	4350	LXI	D,0
0721	CD	63	16	4355	CALL	IN8
0724	FE	0A		4360	CPI	YES
0726	37			4365	STC	
0727	CA	43	07	4370	JZ	RSV1
072A	FE	80		4375	CPI	ENTR
072C	37			4380	STC	
072D	CA	43	07	4385	JZ	RSV1
0730	21	41	07	4390	LXI	H,RSV2
0733	E5			4395	PUSH	H RETURN ADDRESS
0734	CD	AB	16	4400	CALL	INO
0737	4F			4410	MOV	C,A
0738	21	01	FF	4411	LXI	H,OFF01H
073B	11	00	00	4413	LXI	D,0
073E	C3	A8	16	4415	JMP	IN5A
0741	37			4420	RSV2	STC
0742	3F			4425	CMC	
0743	F5			4430	RSV1	PUSH PSW
0744	DB	3B		4435	IN	LED
0746	E6	FD		4440	ANI	0FDH
0748	D3	3B		4445	OUT	LED
074A	F1			4450	POP	PSW
074B	C9			4455	RET	
074C	EB			4460	OUTI	XCHG
074D	CD	A7	0D	4465	CALL	BCD
0750	EB			4470	XCHG	
0751	7C			4475	MOV	A,H
0752	B7			4480	DRA	A
0753	C4	57	07	4485	CNZ	OUT
0756	65			4490	MOV	H,L
0757	7C			4495	OUT	MOV A,H
0758	0F			4500	RRC	
0759	0F			4505	RRC	
075A	0F			4510	RRC	
075B	0F			4515	RRC	
075C	E6	0F		4520	ANI	0FH
075E	F6	30		4525	ORI	30H MAKE ASCII
0760	47			4530	MOV	B,A
0761	CD	69	16	4535	CALL	OUT8

0764	7C	4540	MOV A,H
0765	E6 0F	4545	ANI 0FH
0767	F6 30	4550	ORI 30H MAKE ASCII
0769	47	4555	MOV B,A
076A	CD 69 16	4560	CALL OUT8
076D	C9	4565	RET
076E		4570	*WAIT UNTIL POWER LEVEL IS BELOW 35 MW
076E	DB 3B	4575	WAIT IN LED
0770	F5	4580	PUSH PSW
0771	3E 20	4585	MVI A,20H
0773	D3 3B	4590	OUT LED
0775	3E 00	4595	WAI1 MVI A,00
0777	CD 93 16	4600	CALL PWR
077A	06 06	4605	MVI B,06H
077C	21 00 8C	4610	LXI H,8C00H 35 MW
077F	CD 83 0E	4615	CALL SUB 35-PM
0782	79	4620	MOV A,C
0783	E6 80	4625	ANI 80H SIGN BIT
0785	C2 75 07	4630	JNZ WAI1 PM>35 MW
0788	F1	4635	POP PSW
0789	D3 3B	4640	OUT LED
078B	C9	4645	RET
078C		4650	*MEASURE EMPTY CHAMBER POWER
078C	21 D8 17	4655	EMPT LXI H,MSGN EMPTY
078F	CD 6C 16	4660	CALL SCRN
0792	CD 72 16	4665	CALL BLK1
0795	21 BB 17	4670	LXI H,MSGJ MEAS
0798	CD 6C 16	4675	CALL SCRN
079B	CD 6F 16	4680	CALL CRLF
079E	CD 65 06	4685	CALL PRMT
07A1	CD 6E 07	4690	CALL WAIT
07A4	CD 2C 06	4695	CALL DELA
07A7	3E 00	4700	EMP1 MVI A,0
07A9	32 BB 30	4705	STA EPORT
07AC	CD 0C 08	4710	CALL MEAS
07AF	CD 8E 05	4715	CALL SDEV
07B2	21 70 17	4720	LXI H,MSGA POWER MW
07B5	CD 6C 16	4725	CALL SCRN
07B8	CD 6F 16	4730	CALL CRLF
07BB	21 98 30	4735	LXI H,PAVE
07BE	CD 78 16	4740	CALL DUTH
07C1	21 7A 17	4745	LXI H,MSGB +/-
07C4	CD 6C 16	4750	CALL SCRN
07C7	21 9B 30	4755	LXI H,SIGM
07CA	CD 78 16	4760	CALL DUTH
07CD	CD 6F 16	4765	CALL CRLF
07D0	21 98 30	4770	LXI H,PAVE
07D3	CD 9C 16	4775	CALL GETC
07D6	21 A6 30	4780	LXI H,PMT EMPTY POWER
07D9	CD A2 16	4785	CALL STOR
07DC	21 9B 30	4790	LXI H,SIGM
07DF	CD 9C 16	4795	CALL GETC
07E2	21 A9 30	4800	LXI H,SGMT SIGMA EMPTY
07E5	CD A2 16	4805	CALL STOR
07E8	CD 5B 08	4810	CALL CHEK
07EB	CA 03 08	4815	JZ EMP2

07EE 21 DE 17	4820 LXI H,MSGD AGAIN?
07F1 CD 6C 16	4825 CALL SCRNI
07F4 CD 75 16	4830 CALL BLK2
07F7 21 E5 17	4835 LXI H,MSGP YES
07FA CD 6C 16	4840 CALL SCRNI
07FD CD 6F 16	4845 CALL CRLF
0800 C3 A7 07	4850 JMP EMP1
0803 CD 9C 09	4855 EMP2 CALL AGAI AGAIN?
0806 CA A7 07	4860 JZ EMP1
0809 C3 60 16	4865 JMP EOR
080C 2A A4 30	4875 MEAS LHLD DAPT * DATA POINTS
080F 22 AC 30	4880 SHLD DCNT DOWN COUNTER
0812 CD 97 0F	4885 BGIN CALL ZERO
0815 22 87 30	4890 SHLD N
0818 21 8F 30	4895 LXI H,SUM
081B CD A2 16	4900 CALL STOR
081E 21 92 30	4905 LXI H,SMSQ
0821 CD A2 16	4910 CALL STOR
0824 3A BB 30	4915 LDA EPORT
0827 CD 93 16	4920 CALL PWR
082A 21 89 30	4925 LXI H,P0
082D CD A2 16	4930 CALL STOR
0830 C3 39 08	4935 JMP BGNC
0833 3A BB 30	4940 BGN1 LDA EPORT
0836 CD 93 16	4945 CALL PWR
0839 3A A0 30	4950 BGNC LDA FLAG1 PRINT?
083C FE 0A	4955 CPI YES
083E C2 4B 08	4960 JNZ BGN2 NO PRINT
0841 C5	4965 PUSH B
0842 D5	4970 PUSH D
0843 CD 7B 16	4975 CALL OUTB
0846 CD 6F 16	4980 CALL CRLF
0849 D1	4985 POP D
084A C1	4990 POP B
084B CD 50 05	4995 BGN2 CALL AVE
084E 2A AC 30	5000 LHLD DCNT
0851 2B	5005 DCX H
0852 22 AC 30	5010 SHLD DCNT
0855 7C	5015 MOV A,H
0856 B5	5020 ORA L
0857 C2 33 08	5025 JNZ BGN1
085A C9	5030 RET
085B	5035 *((SIGM/PAVE)/100-SIGF)*80H
085B 21 98 30	5040 CHEK LXI H,PAVE
085E CD 9C 16	5045 CALL GETC
0861 21 9B 30	5050 LXI H,SIGM
0864 CD 9F 16	5055 CALL GETB
0867 CD 7C 0F	5060 CALL DIV
086A 06 07	5065 MVI B,07H
086C 21 00 C8	5070 LXI H,0C800H 100
086F CD 2C 0F	5075 CALL MULT
0872 21 A1 30	5080 LXI H,SIGF
0875 CD 9F 16	5085 CALL GETB
0878 CD 83 0E	5090 CALL SUB
087B 79	5095 MOV A,C
087C E6 80	5100 ANI 80H IS SIGN MINUS.

087E C9	5105 RET
087F	5110 +MEASURE SAMPLE AND CALCULATE PU MASS
087F 21 BB 17	5115 RUN LXI H,MSGJ MEAS
0882 CD 6C 16	5120 CALL SCRN
0885 CD 6F 16	5125 CALL CRLF
0888 CD 65 06	5130 CALL PRMT
088B CD 6E 07	5135 CALL WAIT
088E CD 2C 06	5140 CALL DELA
0891 CD 9A 08	5145 RUN0 CALL RUN1
0894 CA E2 08	5150 JZ RUN2
0897 C3 CD 08	5155 JMP RUN3
089A 3E 00	5160 RUN1 MVI A,0
089C 32 BB 30	5165 STA EPORT
089F CD 0C 08	5170 CALL MEAS
08A2 CD 8E 05	5175 CALL SDEV
08A5 21 BB 17	5180 LXI H,MSGJ MEAS
08A8 CD 6C 16	5185 CALL SCRN
08AB 21 70 17	5190 LXI H,MSGA POWER MM
08AE CD 6C 16	5195 CALL SCRN
08B1 CD 6F 16	5200 CALL CRLF
08B4 21 98 30	5205 LXI H,PAVE
08B7 CD 78 16	5210 CALL DUTH
08BA 21 7A 17	5215 LXI H,MSGB +/-
08BD CD 6C 16	5220 CALL SCRN
08C0 21 9B 30	5225 LXI H,SIGM
08C3 CD 78 16	5230 CALL DUTH
08C6 CD 6F 16	5235 CALL CRLF
08C9 CD 5F 08	5240 CALL CHEK
08CC C9	5245 RET
08CD 21 DE 17	5250 RUN3 LXI H,MSGD AGAIN?
08D0 CD 6C 16	5255 CALL SCRN
08D3 CD 75 16	5260 CALL BLK2
08D6 21 E5 17	5265 LXI H,MSGP YES
08D9 CD 6C 16	5270 CALL SCRN
08DC CD 6F 16	5275 CALL CRLF
08DF C3 91 08	5280 JMP RUN0
08E2 21 70 17	5285 RUN2 LXI H,MSGA POWER MM
08E5 CD 6C 16	5290 CALL SCRN
08E8 CD 6F 16	5295 CALL CRLF
08EB 21 98 30	5300 LXI H,PAVE
08EE CD 9C 16	5305 CALL GETC
08F1 21 A6 30	5310 LXI H,PMT
08F4 CD 9F 16	5315 CALL GETB
08F7 CD 83 0E	5320 CALL SUB
08FA 21 AE 30	5325 LXI H,PMEA P MEASURE
08FD CD A2 16	5330 CALL STOR
0900 CD 7B 16	5335 CALL DUTB
0903 CD 6F 16	5340 CALL CRLF
0906 21 6D 17	5345 LXI H,MSG9 PU
0909 CD 6C 16	5350 CALL SCRN
090C CD 72 16	5355 CALL BLK1
090F 21 B3 17	5360 LXI H,MSGH+1 G
0912 CD 6F 16	5365 CALL CRLF
0915 21 2A 30	5370 LXI H,AVSP
0918 CD 9C 16	5375 CALL GETC
091B 21 AE 30	5380 LXI H,PMEA

091E	CD	9F	16	5385	CALL	GETB	
0921	CD	7C	0F	5390	CALL	DIV	
0924	21	B1	30	5395	LXI	H, MASS	
0927	CD	A2	16	5400	CALL	STOR	(P0-PM)/SP
092A	CD	7B	16	5405	CALL	OUTB	
092D	21	7A	17	5410	LXI	H, MSGB	+/-
0930	CD	6C	16	5415	CALL	SCRN	
0933	21	A9	30	5420	LXI	H, SGM	
0936	CD	9C	16	5425	CALL	GETC	
0939	CD	2B	0E	5430	CALL	SQ	
093C	21	95	30	5435	LXI	H, TEMV	
093F	CD	A2	16	5440	CALL	STOR	
0942	21	9B	30	5445	LXI	H, SIGM	
0945	CD	9C	16	5450	CALL	GETC	
0948	CD	2B	0E	5455	CALL	SQ	
094B	21	95	30	5460	LXI	H, TEMV	
094E	CD	9F	16	5465	CALL	GETB	
0951	CD	86	0E	5470	CALL	ADD	
0954	21	AE	30	5475	LXI	H, PMEA	
0957	CD	9F	16	5480	CALL	GETB	
095A	CD	A5	16	5485	CALL	SWAP	
095D	CD	7C	0F	5490	CALL	DIV	
0960	21	95	30	5495	LXI	H, TEMV	
0963	CD	A2	16	5500	CALL	STOR	((SGMT)SQ + (SIGM)SC)/(PMEA)
0966	21	06	00	5505	LXI	H, SP	
0969	CD	9C	16	5510	CALL	GETC	
096C	21	2D	30	5515	LXI	H, SGSP	
096F	CD	9F	16	5520	CALL	GETB	
0972	CD	7C	0F	5525	CALL	DIV	
0975	CD	2B	0E	5530	CALL	SQ	
0978	21	95	30	5535	LXI	H, TEMV	
097B	CD	9F	16	5540	CALL	GETB	
097E	CD	86	0E	5545	CALL	ADD	
0981	CD	E3	0D	5550	CALL	SORT	
0984	21	B1	30	5555	LXI	H, MASS	
0987	CD	9F	16	5560	CALL	GETB	
098A	CD	2C	0F	5565	CALL	MULT	
098D	CD	7B	16	5570	CALL	OUTB	
0990	CD	6F	16	5575	CALL	CRLF	
0993	CD	9C	09	5580	CALL	AGAI	AGAIN?
0996	CA	91	08	5585	JZ	RUN0	
0999	C3	60	16	5590	JMP	EDR	
099C	21	DE	17	5595	AGAI	LXI H, MSGD	AGAIN
099F	CD	6C	16	5600	CALL	SCRN	
09A2	CD	75	16	5605	CALL	BLK2	
09A5	3E	02		5610	MVI	A, 02H	
09A7	D3	3B		5615	OUT	LED	
09A9	CD	63	16	5620	CALL	INB	
09AC	FE	0A		5625	CPI	YES	
09AE	F5			5630	PUSH	PSW	
09AF	AF			5635	XRA	A	
09B0	D3	3B		5640	OUT	LED	
09B2	F1			5645	POP	PSW	
09B3	F5			5650	PUSH	PSW	
09B4	21	E5	17	5655	LXI	H, MSGP	YES
09B7	CA	BD	02	5660	JZ	\$+3	

09BA 21 E9 17	5665 LXI H,MSG0 NO
09BD CD 6C 16	5670 CALL SCRN
09C0 CD 6F 16	5675 CALL CRLF
09C3 F1	5680 POP PSW
09C4 C9	5685 RET
09C5	5690 *CALIBRATE AND STORE AT CALS=2800H
09C5	5695 *MEASURE=6 BYTES CALIBRATE=6 BYTES
09C5 21 9E 17	5700 CAL LXI H,MSGF
09C8 CD 6C 16	5705 CALL SCRN
09CB CD 6F 16	5710 CALL CRLF
09CE 3E 05	5715 MVI A,5
09D0 32 B4 30	5720 STA CLPT
09D3 21 A8 17	5725 LXI H,MSG6 CAL PNTS
09D6 CD 6C 16	5730 CALL SCRN
09D9 CD 75 16	5735 CALL BLK2
09DC CD 66 16	5740 CALL IN5
09DF CD FF 0C	5745 CALL BCDH
09E2 7A	5750 MOV A,D
09E3 FE 00	5755 CPI 0
09E5 CA F2 09	5760 JZ CAL0
09E8 CD 63 0E	5765 CALL FIXX
09EB 7B	5770 MOV A,E
09EC 32 B4 30	5775 STA CLPT
09EF C3 FB 09	5780 JMP CAL1
09F2 3A B4 30	5785 CAL0 LDA CLPT
09F5 6F	5790 MOV L,A
09F6 26 00	5795 MVI H,0
09F8 CD 4C 07	5800 CALL OUTI
09FB CD 6F 16	5805 CAL1 CALL CRLF
09FE CD 65 06	5810 CALL PRMT
0A01 3A B4 30	5815 LDA CLPT
0A04 5F	5820 MOV E,A
0A05 16 00	5825 MVI D,0
0A07 CD 39 0E	5830 CALL FLOT
0A0A C5	5835 PUSH B
0A0B D5	5840 PUSH D
0A0C 21 A6 30	5845 LXI H,PMT
0A0F CD 9F 16	5850 CALL GETB
0A12 0E 03	5855 MVI C,03H
0A14 11 00 E0	5860 LXI D,0E000H 7 MW
0A17 CD 83 0E	5865 CALL SUB
0A1A EB	5870 XCHG
0A1B 79	5875 MOV A,C
0A1C D1	5880 POP D
0A1D C1	5885 POP B
0A1E 47	5890 MOV B,A
0A1F CD 7C 0F	5895 CALL DIV (PMT-7MW)/CLPT
0A22 21 B5 30	5900 LXI H,PSTP
0A25 CD A2 16	5905 CALL STOR
0A28 21 B8 30	5910 LXI H,PSET
0A2B CD A2 16	5915 CALL STOR
0A2E 21 00 28	5920 LXI H,CALS
0A31 3E 5D	5925 MVI A,93 OVERCOME DIODE DROP
0A33 3C	5930 CAL2 INR A
0A34 CD 90 16	5935 CALL DTDH
0A37 F5	5940 PUSH PSW

0A38 E5	5945	PUSH H
0A39 3E 02	5950	MVI A, 02H CAL1 VOLTAGE
0A3B CD 93 16	5955	CALL PWR
0A3E 21 B8 30	5960	LXI H, PSET
0A41 CD 9F 16	5965	CALL GETB
0A44 CD 83 0E	5970	CALL SUB PSET-PDUT
0A47 79	5975	MOV A, C
0A48 E6 80	5980	ANI 80H
0A4A C2 52 0A	5985	JNZ CAL3
0A4D E1	5990	POP H
0A4E F1	5995	POP PSW
0A4F C3 33 0A	6000	JMP CAL2
0A52 CD 2C 06	6005	CAL3 CALL DELA
0A55 3E 02	6010	CAL5 MVI A, 02H CAL VOLTAGE
0A57 32 BB 30	6015	STA EPORT
0A5A 3E 04	6020	MVI A, 04H
0A5C D3 3B	6025	OUT LED
0A5E CD 0C 08	6030	CALL MEAS
0A61 AF	6035	XRA A
0A62 D3 3B	6040	OUT LED
0A64 CD 8E 05	6045	CALL SDEV
0A67 21 9E 17	6050	LXI H, MSGF CALIBRATE
0A6A CD 6C 16	6055	CALL SCRN
0A6D 21 76 17	6060	LXI H, MSGA+6 MW
0A70 CD 6C 16	6065	CALL SCRN
0A73 CD 6F 16	6070	CALL CRLF
0A76 21 98 30	6075	LXI H, PAVE
0A79 CD 9C 16	6080	CALL GETC
0A7C E1	6085	POP H
0A7D CD A2 16	6090	CALL STOR
0A80 E5	6095	PUSH H
0A81 CD 7B 16	6100	CALL OUTB
0A84 21 7A 17	6105	LXI H, MSGB +/-
0A87 CD 6C 16	6110	CALL SCRN
0A8A 21 9B 30	6115	LXI H, SIGM
0A8D CD 9C 16	6120	CALL GETC
0A90 E1	6125	POP H
0A91 CD A2 16	6130	CALL STOR
0A94 E5	6135	PUSH H
0A95 CD 7B 16	6140	CALL OUTB
0A98 CD 6F 16	6145	CALL CRLF
0A9B 3E 04	6150	CAL4 MVI A, 04H
0A9D D3 3B	6155	OUT LED
0A9F CD 9A 08	6160	CALL RUN1
0AA2 AF	6165	XRA A
0AA3 D3 3B	6170	OUT LED
0AA5 21 98 30	6175	LXI H, PAVE
0AA8 CD 9C 16	6180	CALL GETC
0AAB E1	6185	POP H
0AAC CD A2 16	6190	CALL STOR
0AAF E5	6195	PUSH H
0AB0 21 9B 30	6200	LXI H, SIGM
0AB3 CD 9C 16	6205	CALL GETC
0AB6 E1	6210	POP H
0AB7 CD A2 16	6215	CALL STOR
0ABA CA D9 0A	6220	JZ CAL7 MEASURE OK

0ABD 2B	6225	DCX H	
0ABE 2B	6230	DCX H	
0ABF 2B	6235	DCX H	
0AC0 2B	6240	DCX H	
0AC1 2B	6245	DCX H	
0AC2 2B	6250	DCX H	
0AC3 E5	6255	PUSH H	
0AC4 21 DE 17	6260	LXI H,MSGD	AGAIN?
0AC7 CD 6C 16	6265	CALL SCRN	
0ACA CD 75 16	6270	CALL BLK2	
0ACD 21 E5 17	6275	LXI H,MSGP	YES
0AD0 CD 6C 16	6280	CALL SCRN	
0AD3 CD 6F 16	6285	CALL CRLF	
0AD6 C3 9B 0A	6290	JMP CAL4	
0AD9 E5	6295	CAL7 PUSH H	
0ADA 3A B4 30	6300	LDA CLPT	
0ADD 3D	6305	DCR A	
0ADE 32 B4 30	6310	STA CLPT	
0AE1 CA FE 0A	6315	JZ CAL6	
0AE4 21 B8 30	6320	LXI H,PSET	
0AE7 CD 9C 16	6325	CALL GETC	
0AEA 21 B5 30	6330	LXI H,PSTP	
0AED CD 9F 16	6335	CALL GETB	
0AF0 CD 86 0E	6340	CALL ADD	
0AF3 21 B8 30	6345	LXI H,PSET	
0AF6 CD A2 16	6350	CALL STOR	
0AF9 E1	6355	PDP H	
0AFA F1	6360	PDP PSM	
0AFB C3 33 0A	6365	JMP CAL2	DO NEXT
0AFE AF	6370	CAL6 XRA A	
0AFF CD 90 16	6375	CALL DTDH	
0B02 C3 60 16	6380	JMP EDR	
0B05	6385	♦GET TEST POINTS	
0B05 21 C0 17	6390	TEST LXI H,MSGK	TEST PT
0B08 CD 6C 16	6395	CALL SCRN	
0B0B 06 53	6400	MVI B,'S'	
0B0D CD 69 16	6405	CALL OUT8	
0B10 3E FF	6410	MVI A,0FFH	
0B12 32 BC 30	6415	STA POINT	
0B15 32 A0 30	6420	STA FLAG1	
0B18 CD 6F 16	6425	TES0 CALL CRLF	
0B1B 21 98 17	6430	LXI H,MSGE	ALL?
0B1E CD 6C 16	6435	CALL SCRN	
0B21 CD 75 16	6440	CALL BLK2	
0B24 CD 18 07	6445	TES7 CALL RSVP	
0B27 FE 0A	6450	CPI YES	
0B29 CA 46 0B	6455	JZ TES1	
0B2C FE 80	6460	CPI ENTR	
0B2E CA 46 0B	6465	JZ TES1	
0B31 CD FF 0C	6470	CALL BCDH	
0B34 CD 63 0E	6475	CALL FIXX	
0B37 7B	6480	MOV A,E	
0B38 FE 33	6485	CPI 33H	
0B3A D2 18 0B	6490	JNC TES0	
0B3D 32 BC 30	6495	STA POINT	
0B40 CD 6E 16	6500	CALL CRLF	

0B43	C3	5A	0B	6505		JMP TES4	
0B46	21	E5	17	6510	TES1	LXI H, MSGP	YES
0B49	CD	6C	16	6515		CALL SCRNI	
0B4C	CD	6F	16	6520		CALL CRLF	
0B4F	3E	0A		6525		MVI A, YES	
0B51	32	A0	30	6530		STA FLAG1	
0B54	CD	6F	16	6535		CALL CRLF	
0B57	C3	71	0B	6540		JMP TES5	
0B5A	CD	AE	16	6544	TES4	CALL IN8C	
0B5D	FE	12		6545		CPI 12H	
0B5F	CA	24	0B	6546		JZ TES7	
0B62	3A	BC	30	6547	TES8	LDA POINT	
0B65	3D			6550		DCR A	
0B66	F5			6555		PUSH PSW	
0B67	CD	8D	16	6560		CALL ATOD	
0B6A	CD	87	16	6565		CALL DISB	*
0B6D	F1			6570		POP PSW	
0B6E	C3	5A	0B	6575		JMP TES4	
0B71	AF			6580	TES5	XRA A	
0B72	F5			6585		PUSH PSW	
0B73	3C			6590		INR A	
0B74	32	BC	30	6595		STA POINT	
0B77	26	00		6600	TES6	MVI H, 0	
0B79	6F			6605		MOV L, P	
0B7A	3A	A0	30	6610		LDA FLAG1	
0B7D	FE	0A		6615		CPI YES	
0B7F	F5			6620		PUSH PSW	
0B80	CC	4C	07	6625		CZ OUTI	
0B83	F1			6630		POP PSW	
0B84	CC	75	16	6635		CZ BLK2	
0B87	F1			6640		POP PSW	MULTIPLEXER #
0B88	F5			6645		PUSH PSW	
0B89	CD	8D	16	6650		CALL ATOD	
0B8C	CD	87	16	6655		CALL DISB	
0B8F	3A	A0	30	6660		LDA FLAG1	
0B92	FE	0A		6665		CPI YES	
0B94	F5			6670		PUSH PSW	
0B95	CC	7B	16	6675		CZ OUTB	
0B98	F1			6680		POP PSW	
0B99	CC	6F	16	6685		CZ CRLF	
0B9C	F1			6690		POP PSW	MULTIPLEXER #
0B9D	3C			6695		INR A	
0B9E	F5			6700		PUSH PSW	
0B9F	3A	BC	30	6705		LDA POINT	
0BA2	C6	01		6710		ADI 1	
0BA4	32	BC	30	6715		STA POINT	
0BA7	FE	21		6720		CPI 33	
0BA9	C2	77	0B	6725		JNZ TES6	
0BAC	C3	60	16	6730		JMP EOR	
0BAF				6735		ORG 3080H	
3080				6740		MOTOR DS 1	DRIVE OUTPUT
3081				6745		DIGT DS 1	PRINT OUTPUTS
3082				6750		POWER DS 3	SUM OF POWERS
3085				6755		PLEX DS 2	MULTIPLEXER NUMBER
3087				6760		N DS 2	NUMBER OF SAMPLES TAKEN
3089				6765		P0 DS 3	FIRST POWER MEASUREMENT

308C	6770	PI	DS 3	P0-PM
308F	6775	SUM	DS 3	SUM OF PI
3092	6780	SM20	DS 3	SUM OF S0 OF PI
3095	6785	TEMP	DS 3	TEMPERARY VARIABLE
3098	6790	PAVE	DS 3	AVERAGE OF POWER
309B	6795	SIGM	DS 3	SIGMA OF POWER
309E	6800	TIME	DS 2	DELAY TIME
30A0	6805	FLAG1	DS 1	PRINT FLAG
30A1	6810	SIGF	DS 3	SIGMA DEFAULT
30A4	6815	DAPT	DS 2	NUMBER OF DATA POINTS
30A6	6820	PMT	DS 3	EMPTY POWER
30A9	6825	SGMT	DS 3	EMPTY SIGMA
30AC	6830	DCNT	DS 2	DOWN COUNTER
30AE	6835	PMEA	DS 3	PMT-PAVE
30B1	6840	MASS	DS 3	PU MASS
30B4	6845	CLPT	DS 1	CALIBRATE POINT
30B5	6850	PSTP	DS 3	POWER STEP
30B8	6855	PSET	DS 3	POWER SET
30BB	6860	EPORT	DS 1	VOLTAGE PORT
30BC	6864	POINT	DS 1	TEST POINT
30BD	6865	QLDD	DS 4	
30C1	6866	SSQ	DS 3	
30C4	6867	F	DS 3	
30C7	6870	EOR	EQU 1660H	
30C7	6875	IN8	EQU 1663H	
30C7	6880	IN5	EQU 1666H	
30C7	6885	IN5A	EQU 16A8H	
30C7	6886	IND	EQU 16ABH	
30C7	6887	IN8C	EQU 16AEH	
30C7	6890	OUT8	EQU 1669H	
30C7	6895	SCRN	EQU 166CH	
30C7	6900	CRLF	EQU 166FH	
30C7	6905	BLK1	EQU 1672H	
30C7	6910	BLK2	EQU 1675H	
30C7	6915	OUTH	EQU 1678H	
30C7	6920	OUTB	EQU 167BH	
30C7	6925	OUTD	EQU 167EH	
30C7	6930	OUTF	EQU 1681H	
30C7	6935	DISH	EQU 1684H	
30C7	6940	DISB	EQU 1687H	
30C7	6945	DISI	EQU 168AH	
30C7	6950	ATDD	EQU 168DH	
30C7	6955	ITQA	EQU 1690H	
30C7	6960	PWR	EQU 1693H	
30C7	6965	GETC	EQU 169CH	
30C7	6970	GETB	EQU 169FH	
30C7	6975	STOR	EQU 16A2H	
30C7	6980	SWAP	EQU 16A5H	
30C7	6985	ADD	EQU 0E86H	
30C7	6990	SUB	EQU 0E83H	
30C7	6995	DIV	EQU 0F7CH	
30C7	7000	MULT	EQU 0F2CH	
30C7	7005	SQ	EQU 0E2BH	
30C7	7010	SQRT	EQU 0DE3H	
30C7	7015	ZERD	EQU 0F97H	
30C7	7020	FIXX	EQU 0E63H	

3007	7025	FLOT	EQU	0E39H	
3007	7030	BCDH	EQU	0CFFH	
3007	7035	HEXB	EQU	0C00H	
3007	7040	BCD	EQU	0DA7H	
3007	7045	AVSP	EQU	302AH	
3007	7050	SGSP	EQU	302DH	
3007	7051	KST	EQU	23H	
3007	7055	YES	EQU	0AH	
3007	7060	ENTR	EQU	80H	
3007	7065	LED	EQU	3BH	
3007	7070	PSW	EQU	6	
3007	7075	SP	EQU	6	
3007	7080	MSG1	EQU	1700H	
3007	7085	MSG2	EQU	170DH	
3007	7090	MSG3	EQU	1713H	
3007	7095	MSG4	EQU	171BH	
3007	7100	MSG5	EQU	1725H	
3007	7105	MSG6	EQU	1730H	
3007	7110	MSG7	EQU	173BH	
3007	7115	MSG8	EQU	1743H	
3007	7120	MSG9	EQU	176DH	
3007	7125	MSGA	EQU	1770H	
3007	7130	MSGB	EQU	177AH	
3007	7135	MSGC	EQU	1780H	
3007	7140	MSGD	EQU	178DH	
3007	7145	MSGE	EQU	1798H	
3007	7150	MSGF	EQU	179EH	
3007	7155	MSGG	EQU	17A8H	
3007	7160	MSGH	EQU	17B2H	
3007	7165	MSGI	EQU	17B5H	
3007	7170	MSGJ	EQU	17BBH	
3007	7175	MSGK	EQU	17C0H	
3007	7180	MSGL	EQU	17C8H	
3007	7185	MSGM	EQU	17D2H	
3007	7190	MSGN	EQU	17D8H	
3007	7195	MSGO	EQU	17DEH	
3007	7200	MSGP	EQU	17E5H	
3007	7205	MSGQ	EQU	17E9H	
3007	7210	CALS	EQU	2800H	CALIBRATE STORAGE

1000		6735	♦	ROUTINE TO CALCULATE UPDATED VALUE OF
1000		6740	♦	THE SAMPLE ISOTOPIC MASS FRACTION.
1000	3E 04	6745	MF	MVI A,4 ;SET LED 3
1002	D3 3B	6750		OUT LED
1004	CD B8 11	6755		CALL NORM
1007	21 06 30	6760		LXI H,MSF
100A	22 1E 30	6765		SHLD TS2 ;MSF PNTR
100D	21 57 11	6770		LXI H,LAM
1010	22 1C 30	6775		SHLD TS1 ;LAMBDA PNTR
1013	3E 05	6780		MVI A,5
1015	32 1B 30	6785	MF1	STA TS0 ;STORE LOOP COUNTER
1018	CD 9C 16	6790		CALL GETC
101B	21 15 30	6795		LXI H,TIME
101E	CD 9F 16	6800		CALL GETB
1021	CD 2C 0F	6805		CALL MULT ;CDE=L♦T
1024	CD 66 11	6810		CALL NEXP ;CDE=EXP(-L♦)
1027	2A 1E 30	6815		LHLD TS2
102A	CD 9F 16	6820		CALL GETB
102D	CD 2C 0F	6825		CALL MULT ;CDE=F0♦EXP(L♦T)
1030	2A 1E 30	6830		LHLD TS2
1033	CD A2 16	6835		CALL STOR
1036	2A 1E 30	6840		LHLD TS2 ;INC PNTRS
1039	CD 50 11	6845		CALL INC3
103C	22 1E 30	6850		SHLD TS2
103F	2A 1C 30	6855		LHLD TS1
1042	CD 50 11	6860		CALL INC3
1045	22 1C 30	6865		SHLD TS1
1048	3A 1B 30	6870		LDA TS0
104B	3D	6875		DCR A
104C	C2 15 10	6880		JNZ MF1
104F	21 60 11	6885		LXI H,LAM1 ;UPDATE FAM
1052	CD 9C 16	6890		CALL GETC
1055	21 00 30	6895		LXI H,MSF1
1058	CD 9F 16	6900		CALL GETB
105B	CD 2C 0F	6905		CALL MULT ;CDE=L♦F0
105E	21 1B 30	6910		LXI H,TS0
1061	CD A2 16	6915		CALL STOR ;TS0=L1♦F1
1064	21 54 11	6920		LXI H,LAMA
1067	CD 9C 16	6925		CALL GETC
106A	21 60 11	6930		LXI H,LAM1
106D	CD 9F 16	6935		CALL GETB
1070	CD 83 0E	6940		CALL SUB ;CDE=L1-LA
1073	21 1B 30	6945		LXI H,TS0
1076	CD 9F 16	6950		CALL GETB
1079	CD 7C 0F	6955		CALL DIV
107C	21 1B 30	6960		LXI H,TS0
107F	CD A2 16	6965		CALL STOR ;TS0=L1♦F1/(1-LA)
1082	21 60 11	6970		LXI H,LAM1
1085	CD 9C 16	6975		CALL GETC
1088	21 15 30	6980		LXI H,TIME
108B	CD 9F 16	6985		CALL GETB

108E CD 2C 0F	6990	CALL MULT
1091 CD 66 11	6995	CALL NEXP ;CDE=EXP(-L1T)
1094 21 1B 30	7000	LXI H,TS0
1097 CD 9F 16	7005	CALL GETB
109A CD 2C 0F	7010	CALL MULT
109D 21 1E 30	7015	LXI H,TS2
10A0 CD A2 16	7020	CALL STOR ;TS2=(EXP(-L+T)+L1+F1)/(L1-LA)
10A3 21 54 11	7025	LXI H,LAMA
10A6 CD 9C 16	7030	CALL GETC
10A9 21 15 30	7035	LXI H,TIME
10AC CD 9F 16	7040	CALL GETB
10AF CD 2C 0F	7045	CALL MULT
10B2 CD 66 11	7050	CALL NEXP
10B5 21 21 30	7055	LXI H,TS5
10B8 CD A2 16	7060	CALL STOR ;TS5=EXP(-LAT)
10BB 21 1B 30	7065	LXI H,TS0
10BE CD 9F 16	7070	CALL GETB
10C1 CD 2C 0F	7075	CALL MULT ;CDE=EXP(-LAT)+L1+F1/(1-LA)
10C4 21 1E 30	7080	LXI H,TS2
10C7 CD 9F 16	7085	CALL GETB
10CA CD A5 16	7090	CALL SWAP
10CD CD 83 0E	7095	CALL SUB
10D0 21 1B 30	7100	LXI H,TS0
10D3 CD A2 16	7105	CALL STOR ;TS0=(EXP(-L+T)-EXP(-L+T))L1
10D6	7110	+F1/(L1-LA)
10D6 21 03 30	7115	LXI H,MSFA
10D9 CD 9C 16	7120	CALL GETC
10DC 21 21 30	7125	LXI H,TS5
10DF CD 9F 16	7130	CALL GETB
10E2 CD 2C 0F	7135	CALL MULT ;CDE=FA*EXP(LA+T)
10E5 21 1B 30	7140	LXI H,TS0
10E8 CD 9F 16	7145	CALL GETB
10EB CD 86 0E	7150	CALL ADD
10EE 21 03 30	7155	LXI H,MSFA
10F1 CD A2 16	7160	CALL STOR ;MSFA=FAM
10F4 CD B8 11	7165	CALL NORM ;NORMALIZE MSS FRCT.
10F7 21 3B 17	7170	LXI H,MFHD ;PRINT RESUTS
10FA CD 6C 16	7175	CALL SCRN
10FD CD 6F 16	7180	CALL CRLF
1100 CD 6F 16	7185	CALL CRLF
1103 21 03 30	7190	LXI H,MSFA
1106 22 1E 30	7195	SHLD TS2 ; MSF POINTER
1109 21 43 17	7200	LXI H, A1
110C 22 1C 30	7205	SHLD TS1 ; LABLE POINTR
110F 3E 06	7210	MVI A,6
1111 32 1B 30	7215	STA TS0 ;LOOP CNTR.
1114 CD 6C 16	7220	CALL SCRN
1117 CD 6F 16	7225	CALL CRLF
111A 2A 1E 30	7230	LHLD TS2
111D CD 9C 16	7235	CALL GETC
1120 21 24 12	7240	LXI H,H100

1180 21 27 30	7500 LXI H,TMP3
1183 CD 9F 16	7505 CALL GETB
1186 CD 2C 0F	7510 CALL MULT ;CDE=(Y+ATBL)*X
1189 2A 25 30	7515 LHLD TMP2
118C CD 50 11	7520 CALL INC3
118F 22 25 30	7525 SHLD TMP2
1192 3A 24 30	7530 LDA TMP1
1195 3D	7535 DCR A
1196 C2 77 11	7540 JNZ NE1
1199 21 B5 11	7545 LXI H,ATB1 ;ADD 1
119C CD 9F 16	7550 CALL GETB
119F CD 86 0E	7555 CALL ADD ;CDE=EXP(-X)
11A2 C9	7560 RET
11A3 77	7565 ATBL DB 77H ;1/720
11A4 B6	7570 DB 0B6H
11A5 00	7575 DB 00H
11A6 FA	7580 DB 0FAH ;-1/120
11A7 88	7585 DB 88H
11A8 88	7590 DB 88H
11A9 7C	7595 DB 7CH ;1/24
11AA AA	7600 DB 0AAH
11AB AB	7605 DB 0ABH
11AC FE	7610 DB 0FEH ;-1/6
11AD AA	7615 DB 0AAH
11AE AB	7620 DB 0ABH
11AF 00	7625 DB 00H ;1/2
11B0 80	7630 DB 80H
11B1 00	7635 DB 00H
11B2 81	7640 DB 81H ;-1
11B3 80	7645 DB 80H
11B4 00	7650 DB 00H
11B5 01	7655 ATB1 DB 01H ;1
11B6 80	7660 DB 80H
11B7 00	7665 DB 00H
11B8	7670 ♦ SUBROUTINE TO NORMALIZ THE SAMPL ISOTOPIC
11B8	7675 ♦ MASS FRACTIONS TO UNIT
11B8 CD 97 0F	7680 NORM CALL ZERO
11BB 21 18 30	7685 LXI H,SUMF
11BE CD A2 16	7690 CALL STOR
11C1 21 06 30	7695 LXI H,MSF ;MSF PNTR
11C4 22 1C 30	7700 SHLD TS1
11C7 3E 05	7705 MVI A,5
11C9 32 1B 30	7710 N1 STA TS0 ;LOOP CONUTER
11CC CD 9F 16	7715 CALL GETB
11CF CD 86 0E	7720 CALL ADD ;CDE=SUM OF F
11D2 2A 1C 30	7725 LHLD TS1
11D5 CD 50 11	7730 CALL INC3
11D8 22 1C 30	7735 SHLD TS1
11DB 3A 1B 30	7740 LDA TS0
11DE 3D	7745 DCR A

1123	CD	9F	16	7245	CALL	GETB
1126	CD	2C	0F	7250	CALL	MULT
1129	CD	7B	16	7255	CALL	OUTB
112C	CD	6F	16	7260	CALL	CRLF
112F	CD	6F	16	7265	CALL	CRLF
1132	2A	1E	30	7270	LHLD	TS2
1135	CD	50	11	7275	CALL	INC3
1138	22	1E	30	7280	SHLD	TS2
113B	2A	1C	30	7285	LHLD	TS1
113E	CD	50	11	7290	CALL	INC3
1141	CD	50	11	7295	CALL	INC3
1144	23			7300	INX	H
1145	22	1C	30	7305	SHLD	TS1
1148	3A	1B	30	7310	LDA	TS0
114B	3D			7315	DCR	A
114C	C2	11	11	7320	JNZ	MF2
114F	C9			7325	RET	
1150				7330	♦	SUBROUTINE TO INCREMEN HL-POINTE 3 BYTES
1150	23			7335	INC3	INX H
1151	23			7340		INX H
1152	23			7345		INX H
1153	C9			7350		RET
1154	6F			7355	LAMA	DB 6FH ;4.372♦E-6
1155	92			7360		DB 92H
1156	63			7365		DB 63H
1157	71			7370	LAM	DB 71H ;2.1619♦E-5
1158	B5			7375		DB 0B5H
1159	00			7380		DB 00H
115A	69			7385		DB 69H ;7.88♦E-8
115B	A9			7390		DB 0A9H
115C	39			7395		DB 39H
115D	6B			7400		DB 6BH ;2.903♦E-7
115E	96			7405		DB 96H
115F	DB			7410		DB 0DBH
1160	74			7415	LAM1	DB 74H ;1.322♦E-4
1161	8A			7420		DB 8AH
1162	9F			7425		DB 9FH
1163	65			7430		DB 65H ;4.907♦E-9
1164	A8			7435		DB 0A8H
1165	9B			7440		DB 9BH
1166				7445	♦	SUBROUTINE TO CALCULAT THE EXPONNTIAL OF
1166				7450	♦	SMALL NEGATIVE #
1166	21	27	30	7455	NEXP	LXI H,TMP3
1169	CD	A2	16	7460		CALL STOR ;TMP3=X
116C	CD	97	0F	7465		CALL ZERO
116F	21	A3	11	7470		LXI H,ATBL
1172	22	25	30	7475		SHLD TMP2 ;TABLE PNTR.
1175	3E	06		7480		MVI A,6
1177	32	24	30	7485	NE1	STA TMP1 ;LOOP COUNTER
117A	CD	9F	16	7490		CALL GETB
117D	CD	86	0E	7495		CALL ADD ;CDE=Y+ATBL

110F C2 C9 11	7750	JNZ N1
11E2 21 18 30	7755	LXI H,SUMF
11E5 CD A2 16	7760	CALL STOR ;SUMF=SUM OFMASS FRCT.
11E8 21 03 30	7765	LXI H,MSFA
11EB 22 1C 30	7770	SHLD TS1
11EE 3E 06	7775	MVI A,6
11F0 32 1B 30	7780 N2	STA TS0 ; LOOP CNTR.
11F3 21 18 30	7785	LXI H,SUMF
11F6 CD 9C 16	7790	CALL GETC
11F9 2A 1C 30	7795	LHLD TS1
11FC CD 9F 16	7800	CALL GETB
11FF CD 7C 0F	7805	CALL DIV
1202 2A 1C 30	7810	LHLD TS1
1205 CD A2 16	7815	CALL STOR
1208 22 1C 30	7820	SHLD TS1
120B 3A 1B 30	7825	LDA TS0
120E 3D	7830	DCR A
120F C2 F0 11	7835	JNZ N2
1212 21 0F 30	7840	LXI H,MSF+9 ;MSF1
1215 CD 9C 16	7845	CALL GETC
1218 21 00 30	7850	LXI H,MSF1
121B CD A2 16	7855	CALL STOR
121E C9	7860	RET
121F 0F	7865 RRC4	RRC ;ROTATE ACC 4 SPACS
1220 0F	7870	RRC
1221 0F	7875	RRC
1222 0F	7880	RRC
1223 C9	7885	RET
1224 07	7890 H100	DB 07H
1225 C8	7895	DB 0C8H
1226 00	7900	DB 00H
1227	7905 *	ROUTINE TO CALCULATE SMPLE SPECIFIC POWER AND ITS ASSOCIATED UNCERTAINTY
1227	7910 *	
1227 3E 04	7915 SP	MVI A,4 ;SET LED 3
1229 D3 3B	7920	OUT LED
122B CD 97 0F	7925	CALL ZERO
122E 21 2A 30	7930	LXI H,AVSP
1231 CD A2 16	7935	CALL STOR
1234 21 2D 30	7940	LXI H,SGSP
1237 CD A2 16	7945	CALL STOR
123A CD B8 11	7950	CALL NORM
123D 21 49 13	7955	LXI H,ISPA
1240 22 1C 30	7960	SHLD TS1 ;ISP PNTR.
1243 21 03 30	7965	LXI H,MSFA
1246 22 1E 30	7970	SHLD TS2 ;MFS POINTER
1249 3E 06	7975	MVI A,6 ;LOOP CNTR.
124B 32 1B 30	7980 SP1	STA TS0
124E CD 9C 16	7985	CALL GETC
1251 2A 1C 30	7990	LHLD TS1
1254 CD 9F 16	7995	CALL GETB
1257 CD 2C 0F	8000	CALL MULT ;CDE=P*F

125A 21 2A 30	8005 LXI H,AVSP
125D CD 9F 16	8010 CALL GETB
1260 CD 86 0E	8015 CALL ADD
1263 21 2A 30	8020 LXI H,AVSP
1266 CD A2 16	8025 CALL STOR
1269 2A 1C 30	8030 LHLD TS1
126C CD 50 11	8035 CALL INC3
126F 22 1C 30	8040 SHLD TS1
1272 2A 1E 30	8045 LHLD TS2
1275 CD 50 11	8050 CALL INC3
1278 22 1E 30	8055 SHLD TS2
127B 3A 1B 30	8060 LDA TS0
127E 3D	8065 DCR A
127F C2 4B 12	8070 JNZ SP1
1282 CD 7D 14	8075 CALL UFAM ;SIGMA AM241
1285 21 49 13	8080 LXI H,ISPA
1288 22 1C 30	8085 SHLD TS1 ;TS1=P
128B 21 30 30	8090 LXI H,UMSF ;TS2=SIG F
128E 22 1E 30	8095 SHLD TS2
1291 21 03 30	8100 LXI H,MSFA
1294 22 20 30	8105 SHLD TS3 ;TS3=F
1297 21 5B 13	8110 LXI H,UISP
129A 22 22 30	8115 SHLD TS4 ;TS4=SIG P
129D 3E 06	8120 MVI A, 6
129F 32 1B 30	8125 SP2 STA TS0
12A2 CD 9C 16	8130 CALL GETC
12A5 2A 20 30	8135 LHLD TS3
12A8 CD 9F 16	8140 CALL GETB
12AB CD 2C 0F	8145 CALL MULT
12AE CD 2B 0E	8150 CALL SQ ;(F♦SIG P)♦♦2
12B1 21 2D 30	8155 LXI H,\$GSP
12B4 CD 9F 16	8160 CALL GETB
12B7 CD 86 0E	8165 CALL ADD
12BA 21 2D 30	8170 LXI H,\$GSP
12BD CD A2 16	8175 CALL STOR
12C0 2A 1C 30	8180 LHLD TS1
12C3 21 24 12	8185 LXI H,H100
12C6 CD 9C 16	8190 CALL GETC ;100
12C9 2A 1E 30	8195 LHLD TS2
12CC CD 9F 16	8200 CALL GETB ;SIG F
12CF CD 7C 0F	8205 CALL DIV ;CDE=SIG F/10
12D2 2A 1C 30	8210 LHLD TS1
12D5 CD 9F 16	8215 CALL GETB ;P
12D8 CD 2C 0F	8220 CALL MULT
12DB CD 2B 0E	8225 CALL SQ ;(P♦SIG F)♦♦2
12DE 21 2D 30	8230 LXI H,\$GSP
12E1 CD 9F 16	8235 CALL GETB
12E4 CD 86 0E	8240 CALL ADD
12E7 21 2D 30	8245 LXI H,\$GSP
12EA CD A2 16	8250 CALL STOR
12ED 2A 1C 30	8255 LHLD TS1

12F0	CD	50	11	8260	CALL INC3
12F3	22	1C	30	8265	SHLD TS1
12F6	2A	1E	30	8270	LHLD TS2
12F9	CD	50	11	8275	CALL INC3
12FC	22	1E	30	8280	SHLD TS2
12FF	2A	20	30	8285	LHLD TS3
1302	CD	50	11	8290	CALL INC3
1305	22	20	30	8295	SHLD TS3
1308	2A	22	30	8300	LHLD TS4
130B	CD	50	11	8305	CALL INC3
130E	22	22	30	8310	SHLD TS4
1311	3A	1B	30	8315	LDA TS0
1314	3D			8320	DCR A
1315	C2	9F	12	8325	JNZ SP2
1318	CD	E3	0D	8330	CALL SORT
131B	21	2D	30	8335	LXI H,SGSP
131E	CD	A2	16	8340	CALL STOR
1321	CD	6F	16	8345	CALL CRLF ;OUTPUT RESULTS
1324	21	70	17	8350	LXI H,SPHD
1327	CD	6C	16	8355	CALL SCRN
132A	CD	6F	16	8360	CALL CRLF
132D	21	2A	30	8365	LXI H,AVSP
1330	CD	9C	16	8370	CALL GETC
1333	CD	7B	16	8375	CALL OUTB
1336	21	7A	17	8380	LXI H,PDM
1339	CD	6C	16	8385	CALL SCRN
133C	21	2D	30	8390	LXI H,SGSP
133F	CD	9C	16	8395	CALL GETC
1342	CD	7B	16	8400	CALL OUTB
1345	CD	6F	16	8405	CALL CRLF
1348	C9			8410	RET
1349	07			8415	ISPA DB 07H ;114.23
134A	E4			8420	DB 0E4H
134B	76			8425	DB 76H
134C	0A			8430	DB 0AH ;567.16
134D	8D			8435	DB 8DH
134E	CA			8440	DB 0CAH
134F	01			8445	DB 01H ;1.9293
1350	F6			8450	DB 0F6H
1351	F3			8455	DB 0F3H
1352	03			8460	DB 03H ;7.098
1353	E3			8465	DB 0E3H
1354	23			8470	DB 23H
1355	02			8475	DB 02H ;3.390
1356	D8			8480	DB 0D8H
1357	F6			8485	DB 0F6H
1358	7D			8490	DB 7DH ;0.1146
1359	EA			8495	DB 0EAH
135A	64			8500	DB 64H
135B	7E			8505	UISP DB 7EH ;0.16
135C	A3			8510	DB 0A3H

135D D7	8515 DB 0D7H	
135E 80	8520 DB 80H ; 0.57	
135F 91	8525 DB 91H	
1360 E7	8530 DB 0E7H	
1361 79	8535 DB 79H ; 0.0053	
1362 AD	8540 DB 0ADH	
1363 A7	8545 DB 0A7H	
1364 77	8550 DB 77H ; 0.0015	
1365 04	8555 DB 0C4H	
1366 97	8560 DB 97H	
1367 78	8565 DB 78H ; 0.002	
1368 83	8570 DB 83H	
1369 13	8575 DB 13H	
136A 74	8580 DB 74H ; 0.0002	
136B D1	8585 DB 0D1H	
136C B7	8590 DB 0B7H	
136D	8595 * ROUTINE TO INPUT SAMPL MASS	
		FRACTION DATA
136D	8600 * AND ASSOCIATED UNCERTANTIES	
136D CD 6F 16	8605 PAR CALL CRLF	
1370 21 80 17	8610 LXI H, PRHD ; LABLE	
1373 CD 6C 16	8615 CALL SCRN	
1376 21 3C 17	8620 LXI H, MFHD+1	
1379 CD 6C 16	8625 CALL SCRN	
137C CD 6F 16	8630 CALL CRLF	
137F CD 6F 16	8635 CALL CRLF	
1382 21 03 30	8640 LXI H, MSFA	
1385 22 1E 30	8645 SHLD TS2 ; MF PNTR.	
1388 21 30 30	8650 LXI H, UMSF	
138B 22 20 30	8655 SHLD TS3 ; SIGMF PNTR.	
138E 21 43 17	8660 LXI H, A1	
1391 22 1C 30	8665 SHLD TS1 ; LABLE PNTR	
1394 3E 06	8670 MVI A, 6	
1396 32 1B 30	8675 PAR1 STA TS0	
1399 CD 6F 16	8680 CALL CRLF	
139C CD 6C 16	8685 CALL SCRN	
139F CD 6F 16	8690 CALL CRLF	
13A2 CD 66 16	8695 CALL IN5 ; INPUT MF	
13A5 CD FF 0C	8700 CALL BCDH	
13A8 2A 1E 30	8705 LHALD TS2	
13AB CD A2 16	8710 CALL STOR	
13AE 21 7A 17	8715 LXI H, POM	
13B1 CD 6C 16	8720 CALL SCRN	
13B4 CD 66 16	8725 CALL IN5 ; INPUT SIGMF	
13B7 CD FF 0C	8730 CALL BCDH	
13BA 2A 20 30	8735 LHALD TS3	
13BD CD A2 16	8740 CALL STOR	
13C0 CD 6F 16	8745 CALL CRLF	
13C3 2A 1E 30	8750 LHALD TS2	
13C6 CD 50 11	8755 CALL INC3	
13C9 22 1E 30	8760 SHLD TS2	

130C 2A 20 30	8765	LHLD TS3
130F CD 50 11	8770	CALL INC3
13D2 22 20 30	8775	SHLD TS3
13D5 2A 1C 30	8780	LHLD TS1
13D8 CD 50 11	8785	CALL INC3
13DB CD 50 11	8790	CALL INC3
13DE 23	8795	INX H
13DF 22 1C 30	8800	SHLD TS1
13E2 3A 1B 30	8805	LDA TS0
13E5 3D	8810	DCR A
13E6 C2 96 13	8815	JNZ PAR1
13E9 21 8D 17	8820	LXI H,TME
13EC CD 6F 16	8825	CALL CRLF
13EF CD 6C 16	8830	CALL SCRN
13F2 CD 6F 16	8835	CALL CRLF
13F5 CD 66 16	8840	CALL INS ;INPUT TIME
13F8 CD FF 0C	8845	CALL BCDH
13FB 21 15 30	8850	LXI H,TIME
13FE CD A2 16	8855	CALL STOR
1401 CD 6F 16	8860	CALL CRLF
1404 21 0F 30	8865	LXI H,MSF+9H
1407 CD 9C 16	8870	CALL GETC
140A 21 00 30	8875	LXI H,MSF1
140D CD A2 16	8880	CALL STOR
1410 21 70 17	8885	LXI H,SPHD
1413 CD 6F 16	8890	CALL CRLF
1416 CD 6C 16	8895	CALL SCRN
1419 21 B2 17	8900	LXI H,MSGH
141C CD 6C 16	8905	CALL SCRN
141F CD 6F 16	8910	CALL CRLF
1422 CD 66 16	8915	CALL INS ;INPUT SPC. PR.
1425 CD FF 0C	8920	CALL BCDH
1428 21 2A 30	8925	LXI H,AVSP
142B CD A2 16	8930	CALL STOR
142E 21 7A 17	8935	LXI H,PDM
1431 CD 6C 16	8940	CALL SCRN
1434 CD 66 16	8945	CALL INS ;INPUT SGSP
1437 CD FF 0C	8950	CALL BCDH
143A 21 2D 30	8955	LXI H, SGSP
143D CD A2 16	8960	CALL STOR
1440 CD 6F 16	8965	CALL CRLF
1443 21 EC 17	8975	LXI H,MSGR ;PWR NORM
1446 CD 6F 16	8980	CALL CRLF
1449 CD 6C 16	8985	CALL SCRN
144C CD 6F 16	8987	CALL CRLF
144F CD 66 16	8990	CALL INS ;INPUT F
1452 CD FF 0C	8995	CALL BCDH
1455 21 C4 30	9000	LXI H,F
1458 CD A2 16	9005	CALL STOR
145B CD 6F 16	9010	CALL CRLF
145E 21 F3 17	9020	LXI H,MSGT ;SIGMA(SYS)

14BA	9285	PDM	EQU	177AH
14BA	9290	TME	EQU	178DH
14BA	9295	SPHD	EQU	1770H
14BA	9300	MSGH	EQU	17B2H
14BA	9305	MSGR	EQU	17ECH
14BA	9310	MSGT	EQU	17F3H
14BA	9315	LED	EQU	003BH
14BA	9320	FLOT	EQU	0E39H
14BA	9321	F	EQU	30C4H
14BA	9322	SS0	EQU	30C1H
14BA	9325		DRG	3000H
3000	9330	MSF1	DS	3
3003	9335	MSFA	DS	3
3006	9340	MSF	DS	0FH
3015	9345	TIME	DS	3
3018	9350	SUMF	DS	3
301B	9355	TS0	DS	1
301C	9360	TS1	DS	2
301E	9365	TS2	DS	2
3020	9370	TS3	DS	1
3021	9375	TS5	DS	1
3022	9380	TS4	DS	2
3024	9385	TMP1	DS	1
3025	9390	TMP2	DS	2
3027	9395	TMP3	DS	3
302A	9400	AVSP	DS	3
302D	9405	S6SP	DS	3
3030	9410	UMSF	DS	12H
3042	9415	NDDP	DS	3
3045	9420	FNX	DS	3
3048	9425	PWRM	DS	3
304B	9430	PWRI	DS	3
304E	9435	SMM	DS	3
3051	9440	SMM2	DS	3
3054	9445	SMI	DS	3
3057	9450	SMMI	DS	3
305A	9455	NX	DS	1
305B	9460	NDCP	DS	1

APPENDIX C

I. SIMPLIFIED OPERATING INSTRUCTIONS

NOTE: This synopsis is intended to be a check list for system operation. DO NOT OPERATE this device without first reading the more detailed instructions.

1. Select system line voltage (110 or 220 VAC).
 2. Connect calorimeter unit to data-acquisition system.
 3. Connect system power cord to building power.
 4. Reset microprocessor (μP).
 5. Monitor μP diagnostic test point #1 (T_3 V).
 6. Insert dummy sample into measurement chamber. (It is recommended that the dummy sample have mass and thermal conductivity properties similar to the items being assayed.)
 7. Insert capsule with first Pu-containing sample into preheater.
 8. Wait for system to reach thermal equilibrium. (TP1 will read ~ 5.3 V. Total time ~ 2 hrs.) During this time, any additional sample encapsulation should be performed.
 9. Start sample baseline analysis of dummy sample (P_0).
Parameters	DELAY-MIN	-	0
	SIGMA %	-	0.02 (Statistical uncertainty only.)
	#DP/RUN	-	100
10. Examine results of (9). Repeat (9) to ensure that system is actually at thermal equilibrium.

11. Start thermal calibration (CAL).

Parameters	CAL PNTS	-	5
	DELAY-MIN	-	7
	SIGMA %	-	0.02
	#DP/RUN	-	100

12. Replace dummy sample with first Pu-containing capsule. Place next Pu-containing sample in preheater.

13. Enter sample assay parameters through INIT routine.

- a) Sample isotopic data
- b) Sample specific power
- c) Correction to power normalization (PNORM)
- d) Systematic measurement uncertainty [SIG(SY)]

14. Start sample assay.

Parameters	DELAY-MIN	-	20
	SIGMA %	-	0.2 (Systematic uncertainty included.)
	#DP/RUN	-	100

15. Repeat (12), (13). [A dummy sample should be run once every 4 samples to guard against baseline drift. This should be preceded by an RST, and followed by reentering PNORM and SIG(SY)].II. EXPLANATION OF TYPICAL OUTPUT TAPEUSER ACTION/RESPONSESYSTEM OUTPUTPress RST

SMALL SAMPLE READY

Press P_0

EMPTY MEAS

PRINT ALL? NO

Press ENTR (NO)

Input system equilibration time	DELAY-MIN	15
Limit of acceptable measurement uncertainty	SIGMA-%	0.02
Input system assay time ~ 25 pnts/min	#DP/RUN	100
Power supplied by calorimeter to maintain constant T ₃	POWER MW	30.665 +/- 0.003

Assay will automatically be repeated if

$\frac{\sigma(\bar{P}_0)}{\bar{P}} > \text{SIGMA \%}$. Otherwise, repetition is a user option

AGAIN?	YES
POWER MW	
	30.668 +/- 0.0028
AGAIN?	NO

Press CAL

CALIBRATE	
CAL PNTS	5
PRINT ALL?	NO

Input reequilibration time

DELAY-MIN	7
SIGMA %	0.02
#DP/RUN	100

Reference input power

CALIBRATE MW	
	4.7953 +/- 0.00212

Calorimeter-supplied power

MEAS POWER MW	
	26.075 +/- 0.03052

CALIBRATE MW	
	9.6148 +/- 0.00310

MEAS POWER MW	
	31.277 +/- 0.03907

(Calorimeter-supplied power)

CALIBRATE MW
14.419 +/- 0.00415

MEAS POWER MW
16.506 +/- 0.03319

CALIBRATE MW
19.288 +/- 0.00404

MEAS POWER MW
11.688 +/- 0.05019

CALIBRATE MW
23.897 +/- 0.00483

MEAS POWER MW
7.1144 +/- 0.06305

Press RST

SMALL SAMPLE READY

Press INIT

DATA INPUT MASS %

Enter numeric, followed by ENTR
(NOTE: 0.004, not .004)

AM241
0.24 +/- 0.004

NOTE: ^{241}Am content should be
entered relative to Pu value.

PU238
0.0065 +/- 0.0008

PU239
95.24 +/- 0.01

PU240
4.6 +/- 0.11

(Enter numeric)

PU241

0.19 +/- 0.003

PU242

0.01 +/- 0.001

TIME-DAYS

120

POWER MW/G

+/-

P NORM

1.0

Systematic measurement uncertainty

SIG(SY)

0.023

Press FRAC

MASS %

Microprocessor calculated values for
the sample isotopic composition.

AM241

0.24133

PU238

0.00648

PU239

95.195

PU240

4.5984

PU241

0.18841

(Microprocessor-calculated values)

PU242

0.00999

Press SP

POWER MW

Microprocessor-calculated sample

2.4833 +/- 0.01131

specific power P_{eff} (mW/g)Press RUN

MEAS

PRINT ALL? NO

System reequilibration time

following sample input

DELAY-MIN 15

SIGMA-% 0.2

4-min assay

#DP/RUN 100

Calorimeter-supplied power ($\bar{P}_c$)

MEAS POWER MW

20.534 +/- 0.02817

Sample-supplied power $\bar{P}_S = \bar{P}_0 - \bar{P}_c$

POWER MW

10.134

Sample mass, $\bar{M}_{\text{Pu}} = \bar{P}_S / P_{\text{eff}}$

PU

4.0810 +/- 0.0218

AGAIN? YES

MEAS POWER MW

20.540 +/- 0.02821

POWER MW

10.128

PU

4.0786 +/- 0.0218

AGAIN? NO