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^{252}Cf Assay System for FBR Fuel Pins:
Description and Operating Procedures Manual

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ABSTRACT

This manual describes the ^{252}Cf assay system for the measurement of FBR fuel pins. The following topics are included: a general description of the system, details concerning the neutron moderator and shield, a description of the gamma-ray detectors and electronics, the automated system control and associated software, and data evaluation and error analyses. The system herein described is in operation at the Westinghouse-HEDL Pu fuel facility in Richland, Washington.

I. GENERAL DESCRIPTION AND PRINCIPLE OF OPERATION

A. Principle of Operation

The ^{252}Cf fuel rod assay system utilizes both active and passive techniques for the measurement of fissile content and pellet-to-pellet uniformity in FBR-type fuel rods.

For the active portion of the measurement, a 200-600 μg ^{252}Cf source is used to interrogate the fuel rods. The source is positioned in the center of the moderator shown in Fig. 1, and the fuel rods are moved past the source and into the gamma-ray detectors. The total fissile content is then determined by counting the high-energy delayed gamma rays resulting from the induced fission reactions.

The neutron moderator is designed to give a fast-neutron irradiation (the irradiation channel is lined with Cd) as well as a high fissile (fertile fission ratio (400/1). More detailed information

concerning the neutron moderator and irradiation energy can be found in Sec. II.

B. Detector and Data Collection

In order to measure the delayed gamma rays from the fuel rod, two 5 in. by 5 in. diam NaI detectors with through-holes for the passage of the fuel rods are positioned near the ^{252}Cf shield as shown in Fig. 1. Only the high-energy delayed gamma rays (>1200 keV) are used for the total fissile measurement because of their higher penetration through the rod and good signal-to-background ratio.

In addition to the total fissile active assay, it is also possible to determine the pellet-to-pellet uniformity simultaneously by counting the relatively much more intense lower-energy passive gamma rays from the fuel using the same NaI detectors. Each of the two NaI detectors examines a different low-energy window on a pellet-to-pellet basis using a tungsten sleeve with a collimation slit of ≤ 0.2 in.

Fig. 1. Schematic diagram of the ^{252}Cf fast neutron assay system for FBR-type fuel rods. The delayed gamma rays induced by the fast neutron irradiation are subsequently counted with the two NaI detectors which also measure the passive gamma rays to determine pellet-to-pellet uniformity.

One detector counts 60 keV gamma rays which are mainly from ^{241}Am while the second detector counts primarily plutonium gamma rays in the range of 100 to 500 keV. The window at 60 keV acts as a batch monitor because the ^{241}Am content of the fuel is time dependent. The 100 to 500 keV window provides a qualitative measure of the fissile plutonium in the rod.

During operation, up to ~ 30 fuel rods are placed in the loading magazine of the fuel rod translator. The automated translator picks up the rod to be assayed and moves it through the NaI crystals and the ^{252}Cf assembly at a rate of 2.5 in./sec in order to take a background count of the unirradiated rod. The direction of travel is then reversed and the rod is withdrawn at 0.36 in./sec during which time the delayed fission gamma-ray data is acquired and the pellet-to-pellet scans are made. After the irradiation and scan of the fuel column, the rod is unloaded in the tray directly below the loading magazine and the cycle is repeated for the next rod. The translator speeds are set to give a 5 min cycle per rod and

Fig. 2. Fast neutron ^{252}Cf assay system for FFTF fuel rods. System includes 500 μg ^{252}Cf source and shield, two 5 by 5 in. NaI detectors to count the delayed gamma rays, automated fuel rod handling, and data reduction system.

it is necessary to wait ~ 1 h before a repeat run on a given rod because of residual delayed gamma-ray activity in the rod. With the above assay cycle and typical FFTF fuel rods, the count rate (sum of both crystals for gamma-ray energies above 1.2 MeV) for the total fissile measurement is ~ 6000 cps with a net signal-to-background ratio of 3/1 for a 600 μg ^{252}Cf source. The background rate from the ^{252}Cf and the room is ~ 800 cps and the unirradiated Pu rod contributes an additional ~ 600 cps. Typical rates in the 60 keV and 100 to 500 keV pellet-to-pellet windows are 80,000 cps and 50,000 cps, respectively. Additional information on the detectors and statistical precision is given in Secs. III and V, respectively.

C. System Description

Figure 2 shows a photograph of the complete assay system which includes the following major components:

1. The ^{252}Cf neutron moderator and shield.
2. The two NaI through-hole detectors with their Pb shield.
3. The automated fuel rod loader and precision translator with two directional and multispeed capability.

4. Electronics rack for signal collection and processing.

5. Electronics rack for automated system control and data readout.

The heart of the automated control system is a HP-9100B programmable calculator with its HP-9101A extended memory unit. It communicates with the data collection electronics through a BEC-9507 interface unit and the assay results and diagnostic information are printed out using an IBM typewriter (see Sec. IV for detailed information on the system control logic).

II. ^{252}Cf NEUTRON MODERATOR AND SHIELD

A. Neutron Irradiation Assembly

Neutron transport calculations using both S_n and Monte Carlo techniques were used in the de-

sign of the ^{252}Cf source moderator to give an intense fast neutron irradiation as well as a high fissile/fer- tile fission ratio. The calculations led to the design of the cylindrical moderator assembly shown in Fig. 3 with a 2.5 cm radius W core surrounded by a 7.5 cm thick shell of Be followed by 5 cm of Ni and Pb for fast neutron reflection. The calculated neutron spectrum from a ^{252}Cf source for this sys- tem is shown in Fig. 4 with (cross-hatched area) and without the cylindrical Ni fast-flux trap. The pres- ence of the Ni reflector increased the fission rate by $\sim 70\%$ over the Pb reflector. This moderator re- sulted in a $^{239}\text{Pu}/^{238}\text{U}$ fission ratio of $\sim 400/1$ for irradiation neutrons above the Cd cut-off energy (0.4 eV). Since FFTF fuel has a $^{239}\text{Pu}/^{238}\text{U}$ mass ratio of $\sim 1/4$, the ^{238}U content contributes about 1% to the induced signal.

Fig. 3. Photograph of moderator and shield assembly for a fast neutron ^{252}Cf assay system. The ^{252}Cf source is positioned in the center of the tungsten and the sample is placed in the nickel reflector for the neutron irradiation.

Fig. 4. Calculated neutron spectra from a ^{252}Cf source for the system shown in Fig. 3 with (cross-hatched area) and without the cylindrical nickel fast-flux trap.

Table I lists the major isotopes in typical FFTF-type fuel which contribute to the induced signal.

TABLE I
ISOTOPIC CONTRIBUTION TO FISSION RATE
IN FFTF FUEL RODS^a

Isotope	Wt (%)	Relative Contribution per Atom of Isotope	Contribution to Total Fission Rate (%)
Pu-238	0.016	9.6	0.016
Pu-239	19.79	45	91
Pu-240	2.66	1.6	0.45
Pu-241	0.424	100	4.4
Pu-242	0.040	5.0	0.02
U-235	0.476	58	2.9
U-238	64.78	0.16	1.1

^a The fission cross sections and self-shielding factors were obtained from HEDL-TME-71-36 (March 1971) and HEDL-TME-71-153 (October 1971).

Since the delayed gamma rays are used for the induced signal, the relative importance of each isotope will depend on its delayed gamma ray yield per fission event. However, at ~ 70 sec after fission when the delayed gamma rays are measured in the NaI detector, the relative yields of all the isotopes are roughly the same.

Because about 70% of the fission events are induced by neutrons in the resonance energy region (0.4 - 100 eV), there are some resonance absorption effects in the rods resulting in a non-linear calibration curve (see Sec. V). To correct for these effects, it is expected that the calibration standard rods contain the same nominal isotopic composition as the rods to be assayed.

B. ²⁵²Cf Source Containment and Shielding

The ²⁵²Cf source (619 µg on April 23, 1972) is contained in a doubly encapsulated welded stainless steel container of the type ORNL-Dwg-71-

1678R1. Details on the source containment and replacement can be found in Appendix A. The neutron shield is made of borated WEP (65% water extended polyester resin) with an anti-freeze additive to avoid freeze cracking. This solid material is contained in the welded steel cylinder shown in Fig. 1. The measured neutron and gamma dose rates at various distances from the shield are given in Table II.

TABLE II
NEUTRON AND GAMMA DOSE RATES
FOR 600 µg ²⁵²Cf SOURCE IN SHIELD^a

Distance from Shield (ft)	Measured Dose	
	Neutrons (mrem/h)	Gammas (mr/h)
1	7	7
2	3.5	3.5
3	2.1	2.0

^a A 3/8 in. thick Pb blanket is attached to the exterior of the tank shown in Fig. 1 to reduce the gamma dose to the values listed in this table.

The combined neutron and gamma dose rate in the normal working area is less than 2 mrem/h.

III. DETECTORS AND ELECTRONICS

A. NaI Detectors and Collimators

The two NaI detectors (manufactured by Harshaw Chemical Company) are in the form of right circular cylinders 5 in. long by 5 in. diam. There is an RCA 8055 photomultiplier tube coupled to each end of the crystals, each tube having a mu-metal magnetic shield. Two photomultipliers are used on each crystal in order to avoid long-term tube fatigue and count rate dependent gain changes which are problems which might have arisen because of the high ($> 10^5 \text{ sec}^{-1}$) gross count rates used in the assay system. The energy resolution is also somewhat improved by the use of two photomultipliers.

Each crystal has embedded at the midpoint of the side a small ($< 1/4$ in. diam) piece of ^{241}Am doped NaI. This doped "seed" acts as a constant-rate generator of nearly fixed-amplitude pulses. In both detectors the amplitude of the pulses produced by the "light pulses seed" is roughly equivalent to that produced by a 3 MeV gamma ray and the rate is approximately 1500 sec^{-1} . (See Fig. 4 for better values of gamma equivalent energy.) This "built-in" constant-amplitude pulse is used in conjunction with the CI 1520 stabilizer units to reduce the effects of long-term gain changes in the photo-multiplier-preamplifier-amplifier chain. It is also easier to set gains correctly using the light pulser-stabilizer combination.

Each NaI detector crystal has a diametrical hole bored through the center of the crystal, each through-hole being equipped with a tungsten alloy collimator. See Fig. 1 for a schematic representation of the crystal-collimator arrangement. As seen from the figure the holes in the two crystals are of different sizes. The first crystal (nearest the Cf shield) has a hole i.d. of 0.90 in. Its W collimator thickness is 0.25 in. with a gap of 0.063 in. tapered back at 30° . The second crystal has a hole i.d. of 2.00 in. Its W collimator is 0.81 in. thick with a gap of 0.20 in. tapered back at 30° . In addition a sheet of cadmium 0.03 in. thick covers the gap. In both collimators the i.d. is 0.386 in., sufficient to accommodate the nylon tube which guides the fuel pins through the complete assembly. The tungsten alloy used in the collimators (90% W, 6% Ni, 4% Cu, $\rho = 16.7 \text{ g/cc}$) is considerably better than lead as a gamma ray shield and is used for that reason. How the two collimators interact with the detector crystals to produce the desired information on both total fissile content and pellet-by-pellet distribution is described below.

B. Pulse Height Energy Spectra and Spatial Resolution

Let it first be emphasized that the delayed gamma rays from the induced fissions are only

about 10% as intense as the naturally emitted gamma rays in the energy region up to $\sim 450 \text{ keV}$. All the pellet-by-pellet information comes from gamma rays of energies less than 450 keV. The irradiation thus contributes little to the pellet-to-pellet information. On the other hand, at energies greater than 1 MeV the delayed gamma rays from the induced fission are several times as intense as the combined backgrounds (see Sec. I B for more details). Thus the determination of total fissile content depends completely on the irradiation while the pellet-by-pellet scan would be nearly the same without any irradiation at all. By using appropriate collimation it becomes, however, convenient and efficient to obtain the total fissile determination and the pellet-by-pellet scans simultaneously.

Let us first consider the detector with the 0.90 in. diam hole. Figure 5 shows the pulse-height spectrum of a cold FFTF test pin up to an

Fig. 5. Gamma-ray spectra from unirradiated FFTF fuel pins positioned in W collimators in 5 by 5 in. NaI through-hole detectors.

energy of about 500 keV as seen by that detector through its collimator. The main features are the weak peak at 26 keV due to ^{241}Am , the very intense peak at 60 keV also due to ^{241}Am , the x rays at ~ 100 keV, the peak at 208 keV from ^{237}U in equilibrium with ^{241}Pu , and the broad complex centered near 385 keV mainly from ^{239}Pu but having some activity from ^{237}U (daughter of ^{241}Pu) and other isotopes. The attenuation coefficient for tungsten is so high at 60 keV that there is essentially no leakage through the 0.25 in. collimator and essentially all the 60 keV peak is coming from the portion of pin viewed by the 0.063 in. gap in the collimator. On the other hand, the leakage is so much greater in the 385 keV region that the 385 keV complex in the spectrum is mainly from leakage and hence is useless for obtaining pellet-by-pellet information. However, for energies greater than 1 MeV, about 66% of the gamma rays penetrate the collimator, hence the collimator gap is of no importance. A single channel analyzer (SCA) is set over the 60 keV peak to provide pellet-by-pellet information on the ^{241}Am . Because of the extremely short penetration of the 60 keV gamma rays in the pellets, the observed signal is proportional to the product of ^{241}Am concentration and the surface area viewed. A second SCA is set to count events between 1.2 and 2.7 MeV. This signal provides $\sim 75\%$ of the counts for the total fissile determination.

For the second detector (i.e. the one with the 2.00 in. diam hole), Fig. 5 also shows its spectrum of the unirradiated FFTF fuel pin. It is clear that the spectra are similar but the 0.030 in. Cd has much reduced the low energy ^{241}Am peaks. In this case the 0.81 in. W collimator walls are sufficiently attenuating that about 80% of the events in the 100-450 keV region are from the portion of the pin viewed by the 0.20 in. collimator gap. The SCA set over this region provides pellet-by-pellet information on the fissile content ($^{241}\text{Pu} + ^{239}\text{Pu}$) though it is not very quantitative.

A second SCA is set over the 1.2 - 2.7 MeV region which contributes only $\sim 25\%$ of the counts for the total fissile determination--the thicker collimator walls letting through fewer of the high energy gamma rays.

Detailed instructions for setting the SCA windows correctly are given in Appendix B.

C. Electronics

Figure 6 presents a generalized block diagram of the detector electronics. Details on the various units along with recommended setting are found in Appendix C. As seen, the two photomultipliers of each detector are ganged together into a single preamplifier which feeds a main amplifier which in turn drives a stabilizer. The stabilizer as mentioned previously is locked onto the "light pulser" peak to minimize gain shifts. The stabilizer in turn drives two single channel analyzers. In each case one of the SCAs is set on a low energy region to obtain pellet-by-pellet information, the output driving a ratemeter which in turn drives one pen of the dual pen chart recorder. The other SCA of both detectors is set on the 1.2 - 2.7 MeV region to obtain total fissile counts which are summed together by the summer-inverter and presented to the scaler. From the scaler the numerical information passes into the systems control and data processing

Fig. 6. Block diagram showing the electronic components for the two NaI detectors.

portions of the total system described below. It should be noted here that the CI 810 amplifiers and the photomultiplier tube bases have been modified to optimize the performance at high rates. Neither of these units should be replaced without having the appropriate changes made. Details are in Appendix C. The filter indicated in the high voltage line is also essential to correct performance, as are the filters indicated between the SCAs and the strip chart recorder. Details again are in Appendix C.

IV. SYSTEM CONTROL AND CALCULATOR SOFTWARE

A. Fuel Rod Translator

The fuel pin translator, loading mechanism, and loading-unloading magazines are shown in Fig. 7. The chain-drive translator is powered by a SLO-SYN Precision Stepping Motor (type HS50E, 200 steps/sec, 50-100 oz-in. of torque) which is

Fig. 7. Photograph showing fuel pin loader-translator with the loading and unloading magazines.

driven by a SLO-SYN Translator (type HTR 400).

When the "load button" in Fig. 7 is pressed, the polyethylene wheels pick up the fuel pin in the translator channel and unload it on the lower fuel pin magazine. The front rod on the upper loading magazine is then picked up by the rotating wheel and placed in the translator channel. Pressing the "start button" (see Fig. 7) then initiates the measurement procedure which is controlled by the computer software and the control logic module described in the following sections.

B. Control Logic Module and System Control

The relationship between the Control Logic Module and the rest of the system is shown in the block diagram in Fig. 8. The control module is coupled to the H-P 9100B Programmable Calculator through the BEC-9507 Interface. The control module is also coupled to the timer scaler, the chart

Fig. 8. Block diagram showing components for automated fuel pin transfer, data collection and reduction, and assay results printout.

recorder, and the chain drive sprocket to sense the fuel pin position.

The control logic module performs the following functions:

1. Senses fuel pin position by means of servo-pot attached to chain drive sprocket.
2. Controls stepping motor direction and speed.
3. Contains variable oscillator for determining speed of stepping motor.
4. Contains crystal controlled oscillator for use as an accurate timing source.
5. Provides "chart drive" and "pen lift" signals to the Houston Chart Recorder.
6. Provides an "initialize" signal to the interface module for the purpose of resetting the software program at the beginning of a measurement cycle.
7. Provides a "continue" instruction to Interface module for the software control of scalers.

The top servo-pot (P-O) on the control module sets the speed of the forward translation, and it is calibrated to read inches/sec. The reverse translation is set for 1/7 of the forward speed. It is during this reverse motion that the primary activation of the pin takes place and the pellet-to-pellet scan is performed. There are four servo-pots on the control module to control the following positions of the fuel pin:

1. Position pot (P-1) sets the initial and final location of the fuel pin (loading-unloading position).
2. Position pot (P-2) sets the position for "start counting" background and "stop counting" foreground.
3. Position pot (P-3) sets the position for "stop counting" background and "start counting" foreground.
4. Position pot (P-4) determines the location for the translator to reverse direction of travel.

All of the pots are calibrated in inches.

C. Description of Software

The software for the active assay system consists of four programs which reside in the H-P 9101A Extended Memory and one program which is available only on a magnetic program card. These programs are designated as follows:

- #0 Initialize Core
- #1 Calibration Update
- #2 Assay Data Reduction
- #5 Collect Calibration Data
- #6 Fit Calibration Data (on card only)

The extended memory also contains several constants used by the above programs. These constants and the registers in which they are stored are shown in the 9101A Memory Map in Appendix D. The remainder of the Extended Memory is devoted to storage for the accumulation and manipulation of calibration data. Brief descriptions of the software programs are given in this section, and a listing of the software programs also appears in Appendix D.

Basic manipulation of the calculator and the extended memory is described in Appendix E.

#0 Initialize Core

This program provides a single means of restoring constants into the H-P 9100B calculator core, if for some reason the contents of the core are destroyed. It transfers the most current calibration parameters from the extended memory into the calculator for use by programs #1 and #2, and zeros register -d and the line counter (used for page spacing). It can always be used whenever there is any doubt about the condition of the program.

#1 Calibration Update

The calibration curve for the assay system needs to be updated periodically (perhaps once or twice per day) in order to compensate for possible electronic drifts and, in the long term, to remove the effect of source decay. Since the shape of the calibration curve (parameter B) is determined by the rod geometry and the neutron interrogation spectrum, only the scale of the curve (parameter A) needs to be adjusted. The calibration update

program assays each of two standard rods (they must be run in proper order) using the previous values for the calibration parameter. The program then takes the measured responses for the standards and performs a weighted least-squares fit to obtain a new value for parameter A. The resulting value is stored in register 99 of the extended memory and in register -a of the calculator for use by the data reduction program (#2).

This program also decodes the current date entered on the manual data entry module into days-since-original-calibration and prints the ratio of the current value of A to the value of A at the time of initial calibration corrected for ^{252}Cf source decay. This ratio should be approximately 1.00; any significant deviation from unity is an indication of possible changes in the system or electronics and should be investigated.

Information concerning the date of the initial calibration is stored as program steps in a subprogram of program #1 to facilitate the computation of the number of days since calibration. The location of these data is shown in the program listing (Appendix D), and the data should be changed and the program restored whenever the system is completely recalibrated.

The program expects to find zero stored initially in register -d of the calculator as an index that the rod being run is the first standard and not the second. If either program #0 or #2 has been run previously with no intervening destruction of the contents of the calculator memory, this index will be properly set.

The printout consists of three lines:

Line 1: Assayed fissile content of std #1; ratio of the assayed value to the standard value.
Line 2: Ditto for std #2.
Line 3: New value for A; ratio of new A to original A: B.

Program #1 automatically calls program #2 (Data Reduction) into the calculator core; thus the system is immediately ready for rod assay.

#2 Data Reduction

This program collects and reduces the assay data. For proper page spacing, one line of identification and a RETURN must be typed by hand. This can be done either before the run is started, or (with proper timing) during the run. The printout consists of a single line containing

the assayed fissile content of the rod,
date,
net response (counts/sec),
background (counts/sec),
assay time (sec),
value of A used in the data reduction.

#5 Collect Calibration Data

Data may be collected for several rods (~10); however, only the data for the first two rods (defined as standards) in the set will be used to establish the calibration curve. Data on the other rods in the set provide additional information on the precision of the instrument. The set of rods must be run in the same order each time. The program stores and prints for each rod the running mean response and the standard deviation of the mean.

#6 Fit Calibration Data

This program performs a weighted non-linear least-squares fit of the curve $R = A(1 - e^{-\lambda t})$ to the data collected by program #5 for the first two rods of the set. An iterative procedure is used. The printout consists of one line (A;B) for each iteration.

D. Operation of Software Programs

1. General

For proper page spacing, the line counter (register 98 in the extended memory) must be zero when a new page is started. This can be accomplished by running program #0 or will be taken care of automatically if either program #1 or #2 has done the page spacing. The number of lines per page and the number of lines to be skipped between pages are stored in registers 97 and 96, respectively.

The masses of the pin designated first standard must be stored in register 92 of the extended

memory, and the mass of the second standard must be in register 93.

2. Program #0 - Initialize Core

Press CLEAR, FMT, GO TO, END, CONT. The number 98 in the x-display indicates completion of the program.

3. Program #1 - Calibration Update

Prestore zero in register -d (or run program #0 or program #2). The two standards must be run in the proper order. Call the program (1, FMT, GO TO) and run the rods. For proper page spacing, do not type any identification. Do not run standards more often than once per hour because of residual activation.

4. Program #2 - Data Reduction

The data reduction program will be in core if the calibration update program (#1) has just been run or may be called (2, FMT, GO TO). If the program is to be called into core (i. e. program #1 has not just been run), run program #0 first.

This program expects to have one line of information and a RETURN typed in by hand for proper page spacing.

5. Program #5 - Collect Calibration Data

Prestore zero into register -d of the calculator, in order to indicate the beginning of data accumulation. Also, the number of rods in the group being run must be prestored into register -e. The two rods designated as standards must be run first and second in the group. Call in the program (5, FMT, GO TO, END, CONT) and run the rods. The printout for the first pass will show only the response; thereafter the printout will show the response, the running mean response, and the standard deviation of the mean.

6. Program #6 - Fit Calibration Data

Enter the program from the magnetic card into the calculator. An initial guess of the parameters A and B must be prestored in registers -a and -b. The first iteration is computed and printed by pressing END, CONT. Subsequent iterations are obtained by pressing CONT. Usually less than

ten iterations are necessary for satisfactory convergence, if the initial estimates of A and B are reasonable. The final values for A and B are left in registers -a and -b; they must also be stored in the extended memory. Store A in both register 91 and 99, and store B in register 90.

V. CALIBRATION AND ERROR ANALYSES

A. Precision and Calibration

In order to calibrate the system, at least two fuel rod standards whose characteristics closely approximate those of the unknown rods must be available. HEDL provided one fuel rod standard for both of the nominal enrichments they expect to be assaying. In addition, there were available two rods at each enrichment having fuel columns shorter than the nominal 36 inches, but whose Pu fissile content was well known.

The response of each of these six rods was measured at least 15 times in order to assess the precision of the assay system. These measurements were made over a period of $2\frac{1}{2}$ days, since a given rod cannot be run through the system more often than ~ once per hour due to residual gamma-ray activity. The mean response of each of the rods is given in Table III, along with the estimated standard deviation of the mean. Also shown in Table III are the fuel column length, and the Pu fissile content and estimated standard deviation for each rod. The standard deviation of a single measurement of each rod estimated from these data is in excellent agreement with the estimate computed (assuming a Poisson distribution) from the total counts accumulated during the measurement, which is evidence that no noticeable electronic drifts occurred during the $2\frac{1}{2}$ days of data accumulation.

Only rods #177 and #269 were suitable for use in calibrating the system, since only these rods have fuel-column lengths within specifications. The fuel-column length is important because it is intended that the system be calibrated to measure variations in the Pu fissile content of rods all having

TABLE III
Pu FISSILE CONTENT AND RESPONSE OF HEDL STANDARDS

Rod Number	Fuel Column Length (inches)	Pu Fissile Mass (grams)	Std. Dev. of Mass ^a (grams)	Number of Runs	Mean Response (counts/sec)	Std. Dev. of Mean (counts/sec)
269	36.125	30.453	0.201	17	4470.2	2.4
177	35.983	35.147	0.085	16	4910.0	2.4
005	35.596	36.165	0.236	16	5045.7	3.5
167	35.537	29.546	0.109	15	4372.6	3.7
203	35.187	29.319	0.109	16	4354.6	2.8
218	35.243	35.837	0.234	16	5016.0	2.3

^a Does not include any contribution from weighing of fuel column.

the same length. The response from a rod having a given uniform enrichment is directly proportional to its length; i. e., the response R_L of a fixed enrichment rod as a function of fuel length L is $R_L = R_0(L/L_0)$ where L_0 is the fuel length of the standard rod and R_0 is the response of a rod of mass m_0 with uniform enrichment and standard length.

Thus, the calibration curve for this situation (fixed enrichment and varying length) would be a straight line. In contrast, the fixed-length variable enrichment calibration curve which is actually used exhibits nonlinearity due to neutron flux depression. For this reason, it is necessary that the standards used to calibrate the system all have the same nominal length.

The average response of rods #177 and #269 were used with the known mass of each of these rods to obtain the calibration curve shown in Fig. 9. The curve has the form $R = A(1 - e^{-B \text{ Pu}})$ where R is the high-energy gamma ray response from a rod having fissile content Pu . The calibration parameters A and B are on the order of 1×10^4 and -0.02 , respectively. Parameter A will decrease gradually as the ^{252}Cf source decays, but is redetermined frequently as described elsewhere in this report.

It is of interest to investigate the uncertainty in the measured Pu fissile content of an FFTF fuel rod assayed in this system. Since the calibration curve is smooth and only slightly nonlinear in the

Fig. 9. Calibration curve for fast neutron ^{252}Cf assay system using standard FFTF fuel pins at HEDL.

mass region of interest, * the usual formula for the "propagation of error" may be used:

$$\sigma_M^2 \approx \left(\frac{\partial M}{\partial R}\right)^2 \sigma_R^2 + \left(\frac{\partial M}{\partial A}\right)^2 \sigma_A^2 + \left(\frac{\partial M}{\partial B}\right)^2 \sigma_B^2 + 2 \text{COV}(A, B) \left(\frac{\partial M}{\partial A}\right) \left(\frac{\partial M}{\partial B}\right),$$

where M is the fissile mass, σ^2 represents the variance of the variable indicated by the subscript and COV (A, B) is the covariance between the calibration parameters A and B. The covariance term must be included because the parameters are very highly correlated. The variance of the response can be estimated from the total counts accumulated during background and assay count periods or from a series of repeated measurements performed on the standards; the variance of A and B and the covariance of A and B can be estimated by a fitting program.¹ When only two standards (i. e., two data points) are used to obtain a two-parameter curve, the "fit" is perfect; however, in this case we can use the data collected for the "short" standards (corrected for the difference in fuel-column length) to provide additional data points in a weighted least-squares fit from which estimates of σ_A^2 , σ_B^2 , and COV (A, B) can be made. In addition, the uncertainties in the masses of the standards can be included in the weight of each data point.² The results of such an exercise indicate the standard deviation in an assayed mass in the range 30-35 grams is ~ 0.2 grams. Approximately half of the variance is due to the count rates (i. e., the precision of the system), and the remainder is due to the uncertainties in the masses of the standards, the fitting procedure, etc.

B. Pellet-to-Pellet Uniformity

The two NaI detectors measure different energy regions of the passive gamma ray spectrum

in order to determine pellet-to-pellet uniformity.

Details concerning the energy windows and the electronic components can be found in Section III. The 60 keV (^{241}Am) energy window gave a count rate of 80,000 counts/sec with a spatial resolution of ~ 0.125 in. (FWHM) and the 100-500 keV (^{241}Pu and ^{239}Pu) energy window in the second NaI detector gave a count rate of 50,000 counts/sec with a resolution of ~ 0.350 in. (FWHM).

An error analysis model³ was used to predict the minimum detectable "off-specs" pellet for the above rates and resolutions. For the good pellet rejection criteria of $\pm 4\sigma$ and the additional bad pellet detection probability of 97% the following results were obtained:

1. 60 keV window: $\pm 3.1 - 4.1\%$ for a single pellet and $\pm 2.4 - 2.7\%$ for a bad pellet doublet. The optimum counting time interval was 0.65 sec.
2. 100-500 keV window: $\pm 5.4 - 6.6\%$ for a single pellet and $\pm 3.3 - 3.5\%$ for a bad pellet doublet.

A pellet-to-pellet test pin was fabricated by HEDL to help evaluate the accuracy of the scanning system. This pin contains various combinations of different Pu pellet enrichments as shown in the bottom of Fig. 10. The top curve in Fig. 10 corres-

Fig. 10. FFTF fuel pin with various combinations of Pu enrichments for pellet-to-pellet scanning. Top curve corresponds to 60 keV energy window and bottom curve corresponds to 100-500 keV window.

* The more definitive requirement that the product of second-order (and higher) derivatives and higher moments of the distributions of the parameters be small compared to the product of squares of first derivatives and the variances is also satisfied.

ponds to a recorder trace of the 60 keV energy window, and the bottom curve corresponds to the 100-500 keV energy window. It can be seen that the small enrichment variations (1.7 - 3.1% relative) can be easily observed in the top curve but not so readily in the bottom curve. These detectability limits are consistent with the error analysis mentioned above.

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source container were designed and fabricated by L. G. Speir, D. E. Helfer, J. W. Woolsey and T. R. Capelli.

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2. W. Edwards Deming, Statistical Adjustment of Data, Wiley and Sons, New York (1943) (A technique is discussed for including errors in the independent variable in a least-squares fit.)
3. R. A. Forster, to be published as a LAMS report (1972).

APPENDIX A

^{252}Cf NEUTRON SOURCE CONTAINMENT AND REPLACEMENT

The ^{252}Cf neutron source is contained in a doubly encapsulated welded stainless steel container of the standard type ORNL-Dwg-71-1678R1. The assay system is designed to operate with a source in the range from 200-600 μg ^{252}Cf ; thus the 619 μg source (on 4/23/72) will require replacement in ~ 4 years ($T_{1/2} = 2.62$ y for ^{252}Cf).

For replacement, a source positioning rod of the type shown in Fig. A-1 should be fabricated and delivered to the source encapsulator. The source can then be attached to the rod using the hot-cell manipulators. When the source and the holding rod arrive at the assay device, the source can be transferred from the shipping container to the assay system by hand.

Access to the source positioning rod in the assay system is accomplished by unlocking the cover on the back side of the ^{252}Cf shield tank shown in Fig. 1.

Fig. A-1. Diagram of ^{252}Cf source and positioning rod.

APPENDIX B

PROCEDURES FOR SETTING THE SCA WINDOWS

It is clearly essential that the SCA windows picking off the various energy regions of the spectra be correctly set. If suspicious changes in rates from standards should occur, the SCA settings ought to be checked. The window may be set in a straightforward fashion with the following items.

1. Good general purpose oscilloscope.
2. A 1 μsec delay line (one is provided with systems).
3. FFTF test pin--here used as calibration source.
4. ^{60}Co calibrations source (one is provided with systems).

The procedure in general consists of presenting to the oscilloscope through the delay line the same signal being presented to the SCAs. The

SCA output is used as an external trigger for the oscilloscope. Thus only the portion of the spectrum within the SCA window is displayed on the scope and the LLD and ULD controls are set to display that portion of the spectrum desired. The delay line is essential, of course, because there is some delay in the SCAs. Without an appropriate delay a given pulse would arrive at the oscilloscope before the corresponding trigger pulse from the SCA and would therefore not be displayed by the oscilloscope. A word of caution is in order. Do not use any delay unit of such low impedance that the output of the stabilizer to the SCA's changes when the delay unit is applied. Such a situation would result in correct settings only so long as the delay unit were connected.

A few words might first be said about setting the amplifier gain. The amplifier gain setting is accomplished by setting the stabilizer controls as recommended (or as otherwise desired) for the desired location of the light pulser peak. Then by observing the indicator lights on the stabilizer units and an oscilloscope to monitor the amplitude of the light pulser peak, one can easily "lock on" to the peak. If for some reason the system is shut down the stabilizer will generally "catch" the peak and return the system to correct gain with no further adjustment. This can be verified by observing that both lights on the stabilizer are blinking at the same rate.

Now consider the setting of windows for the detector with the 0.90 in. hole (nearest Cf shield). Connect the output of the appropriate stabilizer to scope through the delay line and trigger the scope from the SCA intended for the 60 keV window.

Place a fuel pin inside the detector collimator so that the collimator gap views the pin. First trigger the scope internally. Bright bands will be seen corresponding to the prominent peaks in the upper spectrum of Fig. 5. Identify the "60 keV" band. Then trigger externally and adjust LLD and ULD so that only the 60 keV band is triggered.

Note that the amplitude of this peak is only ~ 0.2 V.

Having set the 60 keV window, remove the FFTF fuel pin, replace it with the ^{60}Co source and trigger on the SCA intended for the high energy (total fissile) window. By observing the internally triggered oscilloscope display one can easily determine when the ^{60}Co source is centered in the collimator gap. One will then see bands corresponding to the peaks of the upper spectrum of Fig. B-1. ^{60}Co is a convenient calibration source for this application because its 1173 keV gamma ray provides a good lower edge for the high energy

Fig. B-1. ^{60}Co spectra for checking NaI detector resolution and for setting high-energy (1.2 - 2.7 MeV) window to obtain total fissile counts. Top spectrum corresponds to 5 x 5 in. NaI with 0.90 in. through-hole and bottom spectrum corresponds to 5 x 5 in. NaI with 2.00 in. through-hole.

window while the 2505 keV sum peak provides a good high energy check. Set the LLD and ULD controls so that the region indicated on the spectrum of Fig. B-1 is displayed, the region extending from ~ 1170 keV to ~ 2700 keV.

The procedure is then repeated for the SCAs associated with the 2.00 in. hole detector. In this case the low energy window extends through the higher energy region: (~ 80 keV to ~ 450 keV) shown in the lower spectrum of Fig. 5. The high energy window is the same as it was with the other detector.

APPENDIX C

DETECTOR ELECTRONICS

See Fig. 6 for a block diagram of the detector electronics. Each item will be discussed below with control settings which might be regarded as standard.

1. Photomultiplier Tube Sockets

The sockets used have been modified from the standard Harshaw configuration and are not interchangeable with standard sockets. In order to obtain optimum performance of the Tennelec TC 145 preamplifiers, the blocking capacitor (C1 on standard Harshaw schematic) has been removed and the load resistor (R3 on standard Harshaw schematic) has been changed from 100 K to 1 M. The result is not only optimum performance but the appearance of the High Voltage on the signal out connector of the sockets. The only protection is the 1-M resistor so HV precautions must be taken in handling the socket output. Do not interchange these boxes with unmodified ones, and turn off the HV before handling the signal output to the preamplifiers. The necessary blocking capacitor is inside the preamps.

2. High Voltage Power Supply

The unit supplied is a Tennelec TC 940. The instruction book provided by Tennelec is, in fact, the Power Designs manual.

As set up the HV is at 900 V. As an adjunct to the power supply, there is a small high frequency filter mounted in the high voltage line to the PMTs. It is mounted on the table holding the crystals and the HV is divided off to the four PMTs immediately after the filter. The purpose of the filter is to remove high frequency oscillations from the NIM type power supply. These low amplitude oscillations could interfere with the 60 keV window region.

3. Preamplifier

The two preamplifiers are Tennelec TC 145. The power for both preamps is provided by a Tennelec TC 930 preamp power supply. There is a

CAPACITY switch on the preamps which should remain set at 0. The outputs from both PMTs of a single NaI are ganged into the preamp input.

4. Main Amplifiers

The CI model 810 amplifiers have been considerably modified to optimize high rate performance. The changes have been made on the schematics of the CI instruction manuals provided. The main change is that the unit is now a single delay line clipped unipolar amplifier with a 0.25 μ sec delay line. The pole-zero adjustment pot associated with the delay line also had to be modified. Finally a pole zero adjustment was added to the input to match the amplifier to the preamplifier fall time. As now set up the amplifier produces a positive unipolar pulse only about 0.8 μ sec wide. The narrow pulse considerably eases the pile up problem otherwise encountered at the high counting rates.

Control settings for the amplifiers are as follows:

Set MODE switch to DL

Set OUTPUT switch to INV

COARSE GAIN = 16

FINE GAIN ~ 8-9 (as of 6/21/72)

The fine gain is adjusted to lock the "light pulser" peak into the stabilizer at the correct amplitude. The two pole-zero trim pots have been set for optimum performance.

5. Analog Stabilizers

The units used are CI Mode 1520. See the instruction manual for details of operation. Control settings for this system are:

Gate switch set to INH

Restorer switch set to IN

Stabilizer switch set to ON or OFF as required, but normally ON

Window level = 8.75

Window spacing = 5.00

Window width = 4.00

These window control settings are recommended since they center the ²⁴¹Am light pulser peak at 9.0 V amplitude in the dynamic range of 10.0 V.

6. Single Channel Analyzers

The units employed are the CI 1431. See the CI instruction book for details of operation.

For this system control settings are as follows:

Rise Time Adj - Set full CCW

MODE switch - 10% ΔE for two low energy regions
100% ΔE for two high energy regions

LLD Pot - Set as required for energy region desired

ULD/ ΔE Pot - Set as required for energy region desired

7. Ratemeters

The units are Tennelec model TC 590.

Two modifications have been made. The chart recorder output has been changed to give up to 10 V out rather than the factory provided 50 mV. The

10% setting of the Standard Deviation switch has been changed to an approximately 0.5% setting (done simply by changing C6 from .01 μF to 4.7 μF). In addition a nonlinear filter has been placed between the ratemeter and the strip chart recorder. It's a small box attached to the output connector of the ratemeter. The filter allows fast response to large variations in output but filters the small random variations quite strongly. Initial control settings were:

CPS Full Scale switches $10^5 \times 1$

% Standard Deviation switch set at 1%

8. Summer Inverter

The unit is a Tennelec model TC 212. See the manual for details. There are no external adjustments or settings.

9. Scalers

The units used are Tennelec model TC 550P.

The scalers are unmodified. The only adjustment is the threshold pot which should be set to scale the output of the summer-inverter correctly.

APPENDIX D

EXTENDED MEMORY MAP AND PROGRAM LISTINGS

The locations in the extended memory of the software programs described in Section IV C and the constants required by these programs are given in Table D-1. The program listings are given in Tables D-2 through D-7.

TABLE D-1
9101A EXTENDED MEMORY MAP

Location	Contents	Location	Contents
0-1	program #0: initialize core	93	m_2 , mass of second standard
2-24	program #1: calibration update-part one	96	number of lines to skip for page spacing
25-41	program #3: calibration update-part two	97	number of lines/page
42-57	program #2: assay data reduction	98	line counter
58-76	program #5: collect calibration data	99	parameter A: current value
90	parameter B at initial calibration	100-210	storage for calibration data accumulation
91	parameter A at initial calibration	211-215	storage for sums used in fitting procedure
92	m_1 , mass of first standard		

TABLE D-2
PROGRAM #0 INITIALIZE CORE

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
0.0	CLR	20	0.7	9	11	1.0	9	11	1.7	CLX	37
0.1	XTO	23	0.8	9	11	1.1	0	00	1.8	XEY	30
0.2	-	34	0.9	FMT	42	1.2	FMT	42	1.9	9	11
0.3	c	16	0.a	π	56	1.3	π	56	1.a	8	10
0.4	XTO	23	0.b	XTO	23	1.4	XTO	23	1.b	FMT	42
0.5	-	34	0.c	-	34	1.5	-	34	1.c	YTO	40
0.6	d	17	0.d	a	13	1.6	b	14	1.d	END	46

TABLE D-3
PROGRAM #1 CALIBRATION UPDATE - PART ONE

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
0.0	CLX	37	1.a	FMT	42	3.5	d	17	5.0	2	02
0.1	XEY	30	1.b	EEX	26	3.6	X=Y	50	5.1	RUP	22
0.2	XFR	67	1.c	XTO	23	3.7	4	04	5.2	PNT	45
0.3	-	34	1.d	.	34	3.8	7	07	5.3	PSE	57
0.4	d	17				3.9	RUP	22	5.4	RUP	22
0.5	X>Y	53	2.0	f	15	3.a	PNT	45	5.5	9	11
0.6	0	00	2.1	XFR	67	3.b	RUP	22	5.6	2	02
0.7	8	10	2.2	-	34	3.c	9	11	5.7	FMT	42
0.8	GTO	44	2.3	a	13	3.d	3	03	5.8	π	56
0.9	SUB	77	2.4	DIV	35				5.9	CNT	47
0.a	d	17	2.5	1	01	4.0	FMT	42	5.a	CNT	47
0.b	8	10	2.6	XEY	30	4.1	π	56	5.b	DIV	35
0.c	YTO	40	2.7	-	34	4.2	CNT	47	5.c	RUP	22
0.d	e	12	2.8	XEY	30	4.3	CNT	47	5.d	XFR	67
			2.9	LNK	65	4.4	GTO	44			
1.0	STP	41	2.a	XEY	30	4.5	5	05	6.0	-	34
1.1	GTO	44	2.b	XFR	67	4.6	b	14	6.1	b	14
1.2	SUB	77	2.c	-	34	4.7	SFG	54	6.2	X	36
1.3	d	17	2.d	b	14	4.8	RDN	31	6.3	1	01
1.4	c	16				4.9	7	07	6.4	XEY	30
1.5	e	12	3.0	DIV	35	4.a	GTO	44	6.5	EXP	74
1.6	-	34	3.1	CLX	37	4.b	SUB	77	6.6	-	34
1.7	YTO	40	3.2	RUP	22	4.c	-	34	6.7	YEX	24
1.8	-	34	3.3	XFR	67	4.d	4	04	6.8	-	34
1.9	e	12	3.4	-	34				6.9	9	11

PROGRAM #1 CALIBRATION UPDATE - PART ONE (CONT.)

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
6. a	1	01	9. 3	-	34	b. c	PSE	57	-0. 6	.	21
6. b	XEY	30	9. 4	3	03	b. d	PSE	57	-0. 7	PSE	57
6. c	DIV	35	9. 5	6	06				-0. 8	PSE	57
6. d	DN	25	9. 6	RUP	22	c. 0	PSE	57	-0. 9	FMT	42
			9. 7	PNT	45	c. 1	PSE	57	-0. a	IFG	43
7. 0	UP	27	9. 8	PNT	45	c. 2	PSE	57	-0. b	PSE	57
7. 1	YEX	24	9. 9	PSE	57	c. 3	PSE	57	-0. c	PSE	57
7. 2	-	34	9. a	1	01	c. 4	PSE	57	-0. d	FMT	42
7. 3	9	11	9. b	GTO	44	c. 5	PSE	57			
7. 4	XEY	30	9. c	SUB	77	c. 6	PSE	57	-1. 0	EEX	26
7. 5	X	36	9. d	-	34	c. 7	3	03	-1. 1	XEY	30
7. 6	XEY	30				c. 8	FMT	42	-1. 2	EEX	26
7. 7	X	36	a. 0	5	05	c. 9	GTO	44	-1. 3	3	03
7. 8	XEY	30	a. 1	4	04	c. a	STP	41	-1. 4	DIV	35
7. 9	YEX	24	a. 2	IFG	43	c. b	STP	41	-1. 5	YTO	40
7. a	-	34	a. 3	-	34	c. c	STP	41	-1. 6	f	15
7. b	c	16	a. 4	7	07	c. d	STP	41	-1. 7	FMT	42
7. c	+	33	a. 5	c	16				-1. 8	EEX	26
7. d	YEX	24	a. 6	PSE	57	d. 0	STP	41	-1. 9	XEY	30
			a. 7	PSE	57	d. 1	STP	41	-1. a	DIV	35
8. 0	-	34	a. 8	PSE	57	d. 2	STP	41	-1. b	UP	27
8. 1	c	16	a. 9	PSE	57	d. 3	STP	41	-1. c	DN	25
8. 2	XFR	67	a. a	PSE	57	d. 4	STP	41	-1. d	DIV	35
8. 3	-	34	a. b	PSE	57	d. 5	STP	41			
8. 4	e	12	a. c	PSE	57	d. 6	STP	41	-2. 0	XFR	67
8. 5	X	36	a. d	PSE	57	d. 7	STP	41	-2. 1	-	34
8. 6	XFR	67				d. 8	CLX	37	-2. 2	9	11
8. 7	-	34	b. 0	PSE	57	d. 9	XTO	23	-2. 3	+	33
8. 8	d	17	b. 1	PSE	57	d. a	-	34	-2. 4	YTO	40
8. 9	+	33	b. 2	PSE	57	d. b	9	11	-2. 5	-	34
8. a	YTO	40	b. 3	PSE	57	d. c	FMT	42	-2. 6	9	11
8. b	-	34	b. 4	PSE	57	d. d	CLX	37	-2. 7	DN	25
8. c	d	17	b. 5	PSE	57				-2. 8	8	10
8. d	RDN	31	b. 6	PSE	57	-0. 0	FMT	42	-2. 9	0	00
			b. 7	PSE	57	-0. 1	CLR	20	-2. a	EEX	26
9. 0	3	03	b. 8	PSE	57	-0. 2	FMT	42	-2. b	CHS	32
9. 1	GTO	44	b. 9	PSE	57	-0. 3	CHS	32	-2. c	7	07
9. 2	SUB	77	b. a	PSE	57	-0. 4	STP	41	-2. d	X	36
			b. b	PSE	57	-0. 5	FMT	42			

PROGRAM #1 CALIBRATION UPDATE - PART ONE (CONT.)

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
-3.0	1	01	-4.5	-	34	-5. a	π	56	-7.0	X=Y	50
-3.1	XEY	30	-4.6	FMT	42	-5. b	XEY	30	-7.1	X<Y	52
-3.2	-	34	-4.7	X=Y	50	-5. c	9	11	-7.2	6	06
-3.3	RDN	31	-4.8	X<Y	52	-5. d	7	07	-7.3	c	16
-3.4	DIV	35	-4.9	4	04				-7.4	CLX	37
-3.5	SUB	77	-4. a	5	05	-6.0	X>Y	53	-7.5	XEY	30
-3.6	UP	27	-4. b	1	01	-6.1	7	07	-7.6	9	11
-3.7	1	01	-4. c	GTO	44	-6.2	a	13	-7.7	8	10
-3.8	+	33	-4. d	SUB	77	-6.3	7	07	-7.8	FMT	42
-3.9	-	34				-6.4	XEY	30	-7.9	YT $\wedge$	40
-3. a	FMT	42	-5.0	5	05	-6.5	9	11	-7. a	CNT	47
-3. b	X>Y	53	-5.1	4	04	-6.6	6	06	-7. b	SUB	77
-3. c	X<Y	52	-5.2	CNT	47	-6.7	FMT	42	-7. c	FMT	42
-3. d	3	03	-5.3	SUB	77	-6.8	π	56	-7. d	PSE	57
			-5.4	XEY	30	-6.9	X	36			
-4.0	9	11	-5.5	9	11	-6. a	1	01	-8.0	STP	41
-4.1	SUB	77	-5.6	8	10	-6. b	+	33	-8.1	STP	41
-4.2	UP	27	-5.7	FMT	42	-6. c	-	34	-8.2	END	46
-4.3	1	01	-5.8	+	33	-6. d	FMT	42			
-4.4	+	33	-5.9	FMT	42						

TABLE D-4
SUB-PROGRAM #3 CALIBRATION UPDATE - PART TWO

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
0.0	XFR	67	0. c	YTO	40	1.9	f	15	2.6	RDN	31
0.1	-	34	0. d	-	34	1. a	UP	27	2.7	-	34
0.2	d	17				1. b	RUP	22	2.8	EEX	26
0.3	XEY	30	1.0	a	13	1. c	EEX	26	2.9	CHS	32
0.4	XFR	67	1.1	XEY	30	1. d	4	04	2. a	2	02
0.5	-	34	1.2	PNT	45				s. b	XEY	30
0.6	c	16	1.3	PSE	57	2.0	DIV	35	2. c	X	36
0.7	DIV	35	1.4	XTO	23	2.1	XEY	30	2. d	XEY	30
0.8	9	11	1.5	-	34	2.2	INT	64			
0.9	9	11	1.6	9	11	2.3	XTO	23	3.0	INT	64
0. a	FMT	42	1.7	XFR	67	2.4	f	15	3.1	XTO	23
0. b	YTO	40	1.8	-	34	2.5	X	36	3.2	e	12

SUB-PROGRAM #3 CALIBRATION UPDATE - PART TWO (CONT.)

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
3.3	RUP	22	5. c	+	33	8.6	2	02	b.0	1	01
3.4	EEX	26	5. d	e	12	8.7	LNx	65	b.1	1	01
3.5	2	02				8.8	X	36	b.2	XFR	67
3.6	X	36	6.0	+	33	8.9	9	11	b.3	-	34
3.7	RDN	31	6.1	GTO	44	8.a	6	06	b.4	b	14
3.8	-	34	6.2	8	10	8.b	0	00	b.5	PNT	45
3.9	YTO	40	6.3	6	06	8.c	DIV	35	b.6	PNT	45
3.a	-	34	6.4	f	15	8.d	XEY	30	b.7	PNT	45
3.b	e	12	6.5	XEY	30				b.8	PSE	57
3.c	See note 1		6.6	See note 4		9.0	EXP	74	b.9	2	02
3.d	"		6.7	"		9.1	XTO	23	b.a	XEY	30
			6.8	X=Y	50	9.2	f	15	b.b	9	11
4.0	X=Y	50	6.9	8	10	9.3	3	03	b.c	8	10
4.1	6	06	6.a	1	01	9.4	GTO	44	b.d	FMT	42
4.2	4	04	6.b	See note 5		9.5	SUB	77			
4.3	See note 2		6.c	"		9.6	-	34	c.0	+	33
4.4	"		6.d	-	34	9.7	1	01	c.1	FMT	42
4.5	-	34				9.8	1	01	c.2	π	56
4.6	3	03	7.0	3	03	9.9	XFR	67	c.3	XEY	30
4.7	6	06	7.1	0	00	9.a	-	34	c.4	9	11
4.8	5	05	7.2	·	21	9.b	9	11	c.5	7	07
4.9	X	36	7.3	4	04	9.c	UP	27	c.6	FMT	42
4.a	See note 3		7.4	1	01	9.d	RUP	22	c.7	π	56
4.b	"		7.5	7	07				c.8	UP	27
4.c	"		7.6	X	36	a.0	9	11	c.9	RDN	31
4.d	+	33	7.7	See note 6		a.1	1	01	c.a	X>Y	53
			7.8	"		a.2	FMT	42	c.b	-	34
5.0	f	15	7.9	+	33	a.3	π	56	c.c	1	01
5.1	RUP	22	7.a	e	12	a.4	DIV	35	c.d	b	14
5.2	1	01	7.b	+	33	a.5	f	15			
5.3	-	34	7.c	GTO	44	a.6	X	36	d.0	RDN	31
5.4	3	03	7.d	8	10	a.7	RDN	31	d.1	XEY	30
5.5	0	00				a.8	PNT	45	d.2	-	34
5.6	·	21	8.0	6	06	a.9	PSE	57	d.3	9	11
5.7	4	04	8.1	e	12	a.a	5	05	d.4	6	06
5.8	1	01	8.2	XEY	30	a.b	GTO	44	d.5	FMT	42
5.9	7	07	8.3	See note 7		a.c	SUB	77	d.6	π	56
5.a	X	36	8.4	"		a.d	-	34	d.7	XEY	30
5.b	RDN	31	8.5	-	34				d.8	-	34

SUB-PROGRAM #3 CALIBRATION UPDATE - PART TWO (CONT.)

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
d. 9	7	07	-0.5	d	17	-1.0	b	17	-1. b	1	01
d. a	X	36	-0.6	CLX	37	-1.1	UP	27	-1. c	XTO	23
d. b	1	01	-0.7	XEY	30	-1.2	1	01	-1. d	-	34
d. c	+	33	-0.8	9	11	-1.3	+	33			
d. d	-	34	-0.9	8	10	-1.4	-	34	-2.0	d	17
			-0. a	FMT	42	-1.5	FMT	42	-2.1	2	02
-0.0	FMT	42	-0. b	YTO	40	-1.6	X>Y	53	-2.2	FMT	42
-0.1	X=Y	50	-0. c	GTO	44	-1.7	X<Y	52	-2.3	GTO	44
-0.2	X<Y	52	-0. d	1	01	-1.8	1	01	-2.4	STP	41
-0.3	+	33				-1.9	4	04	-2.5	STP	41
-0.4	d	17				-1. a	SUB	77	-2.6	END	46

Notes: Various constants involving the date of initial calibration must be supplied as program steps.

- 1) year of calibration (currently 72)
- 2) year of calibration plus one (73)
- 3) days left in year of calibration (186)
- 4) month of calibration (06)
- 5) month of calibration plus one (07)
- 6) days left in month of calibration (02)
- 7) day of calibration (28)

TABLE D-5
PROGRAM #2 ASSAY DATA REDUCTION

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
0.0	CLX	37	0. c	XTO	40	1.9	e	12	2.6	XEY	30
0.1	XEY	30	0. d	e	12	1. a	FMT	42	2.7	-	34
0.2	XFR	67				1. b	EEX	26	2.8	XEY	30
0.3	-	34	1.0	STP	41	1. c	XTO	23	2.9	LNK	65
0.4	d	17	1.1	GTO	44	1. d	-	34	2. a	XEY	30
0.5	X>Y	53	1.2	SUB	77				2. b	XFR	67
0.6	7	07	1.3	8	10	2.0	f	15	2. c	-	34
0.7	6	06	1.4	3	03	2.1	XFR	67	2. d	b	14
0.8	GTO	44	1.5	e	12	2.2	-	34			
0.9	SUB	77	1.6	-	34	2.3	a	13	3.0	DIV	35
0. a	8	10	1.7	YTO	40	2.4	DIV	35	3.1	RDN	31
0. b	3	03	1.8	-	34	2.5	1	01	3.2	PNT	45

PROGRAM #2 ASSAY DATA REDUCTION (CONT.)

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
3.3	PSE	57	5. c	SUB	77	8.6	CLR	20	b.0	DIV	35
3.4	3	03	5. d	b	14	8.7	FMT	42	b.1	SUB	77
3.5	GTO	44				8.8	CHS	32	b.2	UP	27
3.6	SUB	77	6.0	2	02	8.9	STOP	41	b.3	1	01
3.7	b	14	6.1	f	15	8. a	FMT	42	b.4	+	33
3.8	2	02	6.2	PNT	45	8. b	.	21	b.5	-	34
3.9	XFR	67	6.3	PSE	57	8. c	PSE	57	b.6	FMT	42
3. a	-	34	6.4	5	05	8. d	PSE	57	b.7	X>Y	53
3. b	f	15	6.5	GTO	44				b.8	X<Y	52
3. c	PNT	45	6.6	SUB	77	9.0	FMT	42	b.9	b	14
3. d	PSE	57	6.7	b	14	9.1	IFG	43	b. a	5	05
			6.8	2	02	9.2	PSE	57	b. b	SUB	77
4.0	5	05	6.9	XFR	67	9.3	PSE	57	b. c	3	03
4.1	GTO	44	6. a	-	34	9.4	FMT	42	b. d	XEY	30
4.2	SUB	77	6. b	a	13	9.5	EEX	26			
4.3	b	14	6. c	PNT	45	9.6	XEY	30	c.0	9	11
4.4	2	02	6. d	PNT	45	9.7	EEX	26	c.1	8	10
4.5	XFR	67				9.8	3	03	c.2	FMT	42
4.6	-	34	7.0	PSE	57	9.9	DIV	35	c.3	+	33
4.7	e	12	7.1	CNT	47	9. a	YTO	40	c.4	FMT	42
4.8	PNT	45	7.2	GTO	44	9. b	f	15	c.5	π	56
4.9	1	01	7.3	SUB	77	9. c	FMT	42	c.6	XEY	30
4. a	5	05	7.4	b	14	9. d	EEX	26	c.7	9	11
4. b	XEY	30	7.5	c	16				c.8	7	07
4. c	GTO	44	7.6	CLX	37	a.0	XEY	30	c.9	FMT	42
4. d	SUB	77	7.7	XTO	23	a.1	DIV	35	c. a	π	56
			7.8	-	34	a.2	UP	27	c. b	UP	27
5.0	-	34	7.9	c	16	a.3	DN	25	c. c	RDN	31
5.1	1	01	7. a	XTO	23	a.4	8	10	c. d	X>Y	53
5.2	1	01	7. b	-	34	a.5	0	00			
5.3	5	05	7. c	d	17	a.6	EEX	26	d.0	-	34
5.4	GTO	44	7. d	GTO	44	a.7	CHS	32	d.1	1	01
5.5	SUB	77				a.8	7	07	d.2	0	00
5.6	b	14	8.0	-	34	a.9	X	36	d.3	RDN	31
5.7	2	02	8.1	1	01	a. a	1	01	d.4	XEY	30
5.8	e	12	8.2	9	11	a. b	XEY	30	d.5	-	34
5.9	PNT	45	8.3	FMT	42	a. c	-	34	d.6	9	11
5. a	5	05	8.4	CLX	37	a. d	RDN	31	d.7	6	06
5. b	GTO	44	8.5	FMT	42				d.8	FMT	42

PROGRAM #2 ASSAY DATA REDUCTION (CONT.)

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
d.9	π	56	-0.3	FMT	42	-0.c	FMT	42	-1.6	1	01
d.a	XEY	30	-0.4	X=Y	50	-0.d	YTO	40	-1.7	3	03
d.b	-	34	-0.5	X<Y	52				-1.8	SUB	77
d.c	7	07	-0.6	0	00	-1.0	SUB	77	-1.9	FMT	42
d.d	X	36	-0.7	2	02	-1.1	1	01	-1.a	PSE	57
			-0.8	CLX	37	-1.2	+	33	-1.b	STP	41
-0.0	1	01	-0.9	XEY	30	-1.3	-	34	-1.c	STP	41
-0.1	+	33	-0.a	9	11	-1.4	PSE	57	-1.d	END	46
-0.2	-	34	-0.b	8	10	-1.5	X<Y	52			

TABLE D-6

PROGRAM #5 COLLECT CALIBRATION DATA

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
0.0	CLX	37	1.8	-	34	3.0	+	33	4.8	X>Y	53
0.1	XEY	30	1.9	d	17	3.1	XTO	23	4.9	5	05
0.2	XFR	67	1.a	PNT	45	3.2	f	15	4.a	2	02
0.3	-	34	1.b	PSE	57	3.3	XFR	67	4.b	1	01
0.4	d	17	1.c	f	15	3.4	-	34	4.c	0	00
0.5	X=Y	50	1.d	RUP	22	3.5	f	15	4.d	0	00
0.6	c	16				3.6	XEY	30			
0.7	5	05	2.0	1	01	3.7	XFR	67	5.0	FMT	42
0.8	GTO	44	2.1	+	33	3.8	-	34	5.1	+	33
0.9	SUB	77	2.2	XEY	30	3.9	e	12	5.2	f	15
0.a	9	11	2.3	+	33	3.a	X>Y	53	5.3	XEY	30
0.b	8	10	2.4	XEY	30	3.b	-	34	5.4	1	01
0.c	YTO	40	2.5	RDN	31	3.c	0	00	5.5	-	34
0.d	e	12	2.6	FMT	42	3.d	b	14	5.6	XEY	30
			2.7	+	33				5.7	FMT	42
1.0	STP	41	2.8	DN	25	4.0	RUP	22	5.8	π	56
1.1	GTO	44	2.9	UP	27	4.1	PNT	45	5.9	XEY	30
1.2	SUB	77	2.a	X	36	4.2	PSE	57	5.a	1	01
1.3	9	11	2.b	RDN	31	4.3	1	01	5.b	0	00
1.4	8	10	2.c	XEY	30	4.4	XEY	30	5.c	0	00
1.5	e	12	2.d	FMT	42	4.5	XFR	67	5.d	FMT	42
1.6	-	34				4.6	-	34			
1.7	XFR	67				4.7	d	17			

PROGRAM #5 COLLECT CALIBRATION DATA (CONT.)

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
6.0	π	56	8.9	2	02	b.3	XEY	30	d.c	XTO	23
6.1	XTO	23	8.a	+	33	b.4	DIV	35	d.d	-	34
6.2	e	12	8.b	RDN	31	b.5	UP	27			
6.3	DIV	35	8.c	FMT	42	b.6	DN	25	-0.0	f	15
6.4	f	15	8.d	YTO	40	b.7	8	10	-0.1	1	01
6.5	RUP	22				b.8	0	00	-0.2	XEY	30
6.6	1	01	9.0	RDN	31	b.9	EEX	26	-0.3	1	01
6.7	+	33	9.1	PNT	45	b.a	CHS	32	-0.4	0	00
6.8	RDN	31	9.2	PNT	45	b.b	7	07	-0.5	0	00
6.9	FMT	42	9.3	PSE	57	b.c	X	36	-0.6	FMT	42
6.a	YTO	40	9.4	GTO	44	b.d	1	01	-0.7	YTO	40
6.b	RDN	31	9.5	-	34				-0.8	GTO	44
6.c	PNT	45	9.6	1	01	c.0	XEY	30	-0.9	1	01
6.d	PSE	57	9.7	0	00	c.1	-	34	-0.a	0	00
			9.8	FMT	42	c.2	RDN	31	-0.b	RUP	22
7.0	RUP	22	9.9	CLX	37	c.3	DIV	35	-0.c	PNT	45
7.1	f	15	9.a	FMT	42	c.4	SUB	77	-0.d	PNT	45
7.2	FMT	42	9.b	CLR	20	c.5	9	11			
7.3	π	56	9.c	FMT	42	c.6	9	11	-1.0	XFR	67
7.4	UP	27	9.d	CHS	32	c.7	RUP	22	-1.1	-	34
7.5	DN	25				c.8	1	01	-1.2	e	12
7.6	RDN	31	a.0	STP	41	c.9	+	33	-1.3	XEY	30
7.7	X	36	a.1	FMT	42	c.a	RDN	31	-1.4	XFR	67
7.8	e	12	a.2	.	21	c.b	FMT	42	-1.5	-	34
7.9	X	36	a.3	PSE	57	c.c	YTO	40	-1.6	d	17
7.a	RDN	31	a.4	PSE	57	c.d	RUP	22	-1.7	X<Y	52
7.b	-	34	a.5	FMT	42				-1.8	2	02
7.c	DN	25	a.6	IFG	43	d.0	2	02	-1.9	4	04
7.d	RDN	31	a.7	PSE	57	d.1	0	00	-1.a	CLX	37
			a.8	PSE	57	d.2	0	00	-1.b	XTO	23
8.0	X	36	a.9	FMT	42	d.3	X>Y	53	-1.c	-	34
8.1	-	34	a.a	EEX	26	d.4	c	16	-1.d	d	17
8.2	RDN	31	a.b	XEY	30	d.5	8	10			
8.3	DIV	35	a.c	EEX	26	d.6	9	11	-2.0	9	11
8.4	XEY	30	a.d	3	03	d.7	8	10	-2.1	8	10
8.5	$\sqrt{\quad}$	76				d.8	XTO	23	-2.2	XTO	23
8.6	RUP	22	b.0	DIV	35	d.9	f	15	-2.3	f	15
8.7	f	15	b.1	FMT	42	d.a	CHS	32	-2.4	XFR	67
8.8	RUP	22	b.2	EEX	26	d.b	1	01	-2.5	-	34

PROGRAM #5 COLLECT CALIBRATION DATA (CONT.)

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
-2.6	d	17	-2.c	d	17	-3.4	+	33	-3.b	+	33
-2.7	XEY	30	-2.d	XFR	67	-3.5	YTO	40	-3.c	YTO	40
-2.8	1	01				-3.6	-	34	-3.d	f	15
-2.9	+	33	-3.0	-	34	-3.7	f	15			
-2.a	YTO	40	-3.1	f	15	-3.8	f	15	-4.0	STP	41
-2.b	-	34	-3.2	XEY	30	-3.9	XEY	30	-4.1	STP	41
			-3.3	1	01	-3.a	2	02	-4.2	END	46

TABLE D-7
PROGRAM #6 FIT CALIBRATION DATA

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
0.0	CLR	20	1.b	DIV	35	3.7	DIV	35	5.3	XEY	30
0.1	2	02	1.c	1	01	3.8	1	01	5.4	X	36
0.2	1	01	1.d	0	00	3.9	0	00	5.5	RDN	31
0.3	0	00				3.a	7	07	5.6	EXP	74
0.4	RUP	22	2.0	3	03	3.b	FMT	42	5.7	RUP	22
0.5	1	01	2.1	FMT	42	3.c	π	56	5.8	UP	27
0.6	+	33	2.2	π	56	3.d	ACC+	60	5.9	DN	25
0.7	RDN	31	2.3	ACC+	60				5.a	X	36
0.8	FMT	42	2.4	9	11	4.0	9	11	5.b	1	01
0.9	YTO	40	2.5	2	02	4.1	3	03	5.c	RUP	22
0.a	RUP	22	2.6	FMT	42	4.2	FMT	42	5.d	-	34
0.b	2	02	2.7	π	56	4.3	π	56			
0.c	1	01	2.8	GTO	44	4.4	GTO	44	6.0	YTO	40
0.d	6	06	2.9	SUB	77	4.5	SUB	77	6.1	-	34
			2.a	4	04	4.6	4	04	6.2	e	12
1.0	X>Y	53	2.b	d	17	4.7	d	17	6.3	DN	25
1.1	0	00	2.c	CLR	20	4.8	CNT	47	6.4	YTO	40
1.2	5	05	2.d	1	01	4.9	GTO	44	6.5	-	34
1.3	1	01				4.a	+	33	6.6	f	15
1.4	XEY	30	3.0	XEY	30	4.b	a	13	6.7	X	36
1.5	1	01	3.1	1	01	4.c	6	06	6.8	e	12
1.6	0	00	3.2	0	00	4.d	XEY	30	6.9	X	36
1.7	4	04	3.3	8	10				6.a	2	02
1.8	FMT	42	3.4	FMT	42	5.0	XFR	67	6.b	1	01
1.9	π	56	3.5	π	56	5.1	-	34	6.c	5	05
1.a	DIV	35	3.6	DIV	35	5.2	b	14	6.d	FMT	42

PROGRAM #6 FIT CALIBRATION DATA (CONT.)

<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>	<u>Step</u>	<u>Key</u>	<u>Code</u>
7.0	+	33	9.7	FMT	42	c.0	1	01	-0.7	f	15
7.1	DN	25	9.8	+	30	c.1	4	04	-0.8	X	36
7.2	RDN	31	9.9	f	15	c.2	FMT	42	-0.9	RDN	31
7.3	X	36	9.a	RUP	22	c.3	π	56	-0.a	-	34
7.4	RUP	22	9.b	X	36	c.4	RUP	22	-0.b	2	02
7.5	e	12	9.c	e	12	c.5	X	36	-0.c	1	01
7.6	RUP	22	9.d	X	36	c.6	RDN	31	-0.d	3	03
7.7	X	36				c.7	-	34			
7.8	2	02	a.0	2	02	c.8	2	02	-1.0	FMT	42
7.9	1	01	a.1	1	01	c.9	1	01	-1.1	π	56
7.a	2	02	a.2	3	03	c.a	2	02	-1.2	+	33
7.b	FMT	42	a.3	FMT	42	c.b	FMT	42	-1.3	f	15
7.c	+	33	a.4	+	33	c.c	π	56	-1.4	DIV	35
7.d	f	15	a.5	SUB	77	c.d	RUP	22	-1.5	XFR	67
			a.6	CLR	20				-1.6	-	34
8.0	RUP	22	a.7	2	02	d.0	X	36	-1.7	a	13
8.1	X	36	a.8	1	01	d.1	e	12	-1.8	+	33
8.2	e	12	a.9	5	05	d.2	DIV	35	-1.9	PNT	45
8.3	X	36	a.a	FMT	42	d.3	-	34	-1.a	PSE	57
8.4	2	02	a.b	π	56	d.4	X	36	-1.b	YTO	40
8.5	1	01	a.c	XEY	30	d.5	XFR	67	-1.c	-	34
8.6	4	04	a.d	2	02	d.6	-	34	-1.d	a	13
8.7	FMT	42				d.7	a	13			
8.8	+	33	b.0	1	01	d.8	X	36	-2.0	XFR	67
8.9	XFR	67	b.1	1	01	d.9	RDN	31	-2.1	-	34
8.a	-	34	b.2	FMT	42	d.a	DIV	35	-2.2	f	15
8.b	e	12	b.3	π	56	d.b	YTO	40	-2.3	XEY	30
8.c	UP	27	b.4	ACC+	60	d.c	-	34	-2.4	XFR	67
8.d	X	36	b.5	RUP	22	d.d	f	15	-2.5	-	34
			b.6	2	02				-2.6	b	14
9.0	RUP	22	b.7	1	01	-0.0	e	12	-2.7	+	33
9.1	e	12	b.8	3	03	-0.1	X	36	-2.8	PNT	45
9.2	RUP	22	b.9	FMT	42	-0.2	XFR	67	-2.9	PNT	45
9.3	X	36	b.a	π	56	-0.3	-	34	-2.a	YTO	40
9.4	2	02	b.b	RUP	22	-0.4	a	13	-2.b	-	34
9.5	1	01	b.c	X	36	-0.5	X	36	-2.c	b	14
9.6	1	01	b.d	2	02	-0.6	RUP	22	-2.d	END	46

APPENDIX E
BASIC MANIPULATION OF THE HP-9100B CALCULATOR AND
MODEL 9101A EXTENDED MEMORY

Operation of the calculator and the extended memory is outlined on a pull-out card on each device (on the front of the extended memory and under the calculator); however, some of the manipulations will be described in more detail in this appendix. The pullout on the calculator also gives the calculator octal key code necessary to interpret a program listing.

1. Store Constants

Enter the constant into the x display register of the calculator. For storage into a calculator register (e.g., the -a register), press the keys labelled "XTO", "-", "a". For storage into an extended memory register, transfer the constant from the x into the y display register (XEY or RUP), enter the desired storage register number into the x display and press FMT, YTO.

2. Recall Constants

In order to recall a constant from a calculator storage register (e.g., from the -a register), press XFR, -, a. To recall from an extended memory register, enter the register number into the x display and press FMT, π. In both cases the constant is recalled into the x display but is not destroyed in memory.

3. Enter a Program from a Magnetic Card

Insert the magnetic card arrow down into the slot at the upper right corner of the keyboard and press END, ENTER. If the program requires both sides of the card, rotate the card, insert it into the slot, and press ENTER.

4. Extended Memory Protect Line

The contents of the Extended Memory storage registers are protected from accidental de-

struction by a "protect line". The contents of storage registers above the protect line (register 0 to the last protected register) can be read but cannot be altered. The protect line moves automatically to protect programs being stored in the extended memory or may be moved manually by the operator to protect previously stored data. The protect line is moved manually by turning the "file protect" switch on the front of the extended memory off, entering the register number of the desired new protect-line position (i.e., the number of the first unprotected register) into the x display on the calculator and pressing FMT, SET FLAG.

5. Store a Program in the Extended Memory

A program must be resident in the calculator memory before it can be transferred into the extended memory and have a program number assigned to it. The program may be keyed into the calculator memory or may be entered from a magnetic program card. Then enter the assigned program number into the x display register and press FMT, FMT.

6. Recall a Program from the Extended Memory

Enter the assigned program number into the calculator x display and press FMT, GO TO.

7. List a Program

Transfer the program into the calculator memory. On the typewriter coupler depress the "x" and "RET" keys; then press END on the calculator and LIST on the coupler. The contents of the calculator memory will be printed in one vertical column showing program address and key code. When listing is completed, return the coupler to its original setup.