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Procedures for PuO_2 Field Measurements with an HLNC-II

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DISCLAIMER

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WITH AN HLNC-II

by

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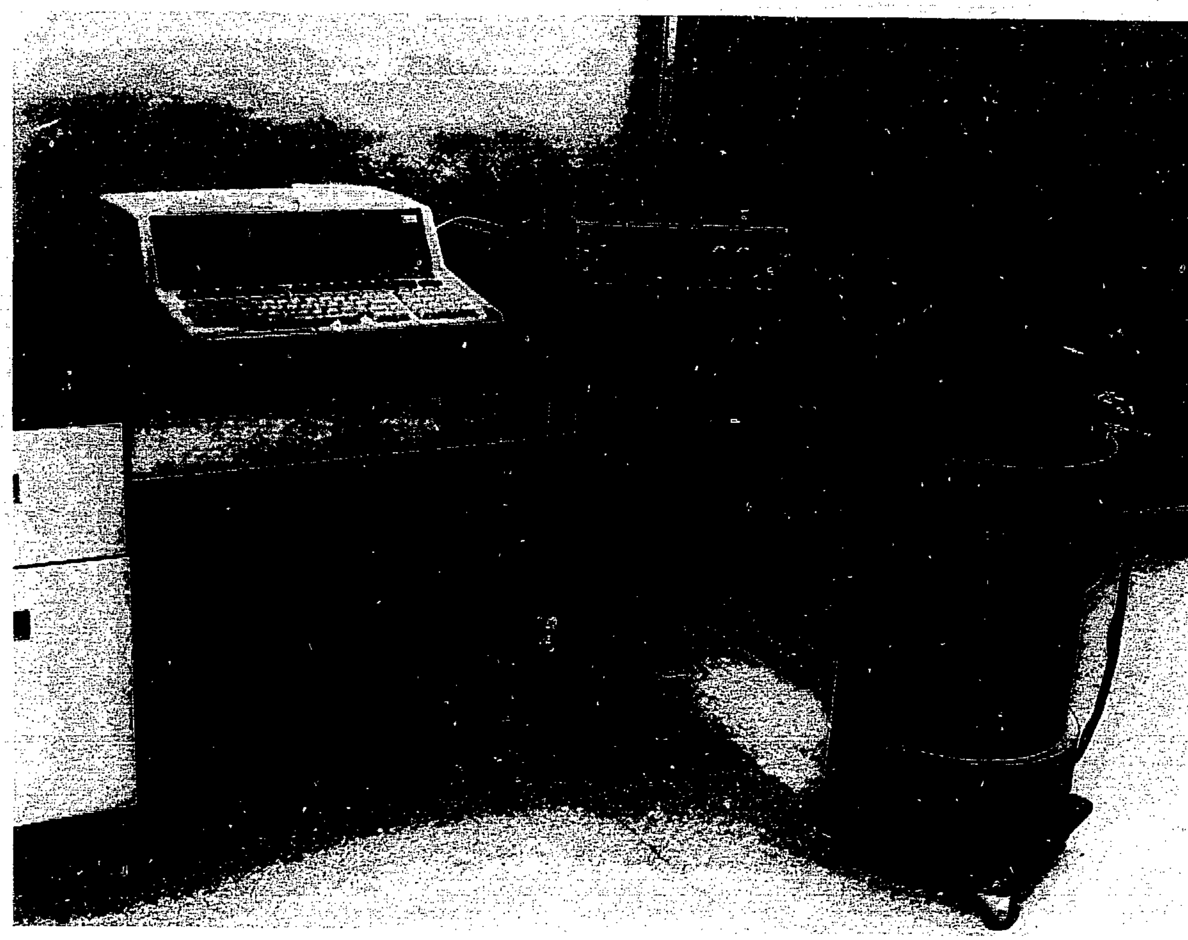
ABSTRACT

An upgraded version of the high-level neutron coincidence counter (HLNC-II) has been designed with faster electronics, higher counting efficiencies, a more uniform counting response within the sample cavity, and improved ruggedness and portability. These procedures describe the assay of PuO_2 powder for plutonium mass using the new HLNC-II along with the JOMAR JSR-11 electronics package, a Hewlett-Packard HP-85B computer, and the CC12 computer program.



GENERAL

These procedures describe the assay of plutonium in PuO_2 powder using the HLNC-II, a portable high-performance neutron coincidence counter developed by the Los Alamos National Laboratory, which is contained in three separate suitcases. Its mechanical and electrical components have been described in detail by Menlove and Swansen.[1]

Passive assay of plutonium is based on the detection of spontaneous-fission neutrons emitted by the even isotopes ^{238}Pu, ^{240}Pu, and ^{242}Pu.[2] When the isotopic abundances are known, the coincidence count from spontaneous fissions can be related to the masses of each isotope and thus to the total plutonium mass.

The complete system for PuO_2 assay includes three main components:

- the HLNC-II, which consists of 18 ^3He tubes embedded in a cylindrical polyethylene body surrounding the sample wall and an internal AMPTEK A111 charge-sensitive preamplifier/discriminator;
- an electronics package that contains the detector high-voltage supply, coincidence logic circuits, measurement controls, and data displays; and
- a Hewlett-Packard HP-85B programmable computer with paper tape readout and magnetic tape storage.

GENERAL

The following procedure covers the initial unpacking and setup of the HP-85B computer for use with the HLNC-II. It is sufficient for the purposes at hand; further information is available in the Owner's Manual and Programming Guide.[3]

UNPACKING AND INITIAL EQUIPMENT CHECK-OUT

The HP-85B is packed in its own carrying case (see Fig. 1). The case carries the computer as well as the serial interface module, power cord, instruction manuals, roll of paper, and several tape cartridges. Specific tape cartridges for making HLNC measurements are packed elsewhere.

Fig. 1. HP-85B computer and carrying case.

UNPACKING AND INITIAL EQUIPMENT CHECK-OUT (cont)

Unzip the carrying case and **remove** the computer and accessories.

Carefully **check** the computer for any physical damage sustained during shipment.

CAUTION! If the cathode-ray tube (CRT) display shows any sign of cracks, do not turn on the computer but plan instead to use a spare.

Identify and **inventory** the contents against the list in Table I.

Check to see that the correct power cord is present for the facility to be inspected (see Appendix B of the Owner's Manual).[3]

CAUTION! The HP-85B is equipped with a three-conductor power cord that, when connected to an appropriate power receptacle, grounds the computer. Do not operate the computer from a power outlet that has no earth ground connection.

TABLE I

HP-85B COMPUTER COMPONENTS

Accessory	Part Number
HP-85B computer	
HP-85B Owner's Manual and Programming Guide	00085-90990
Roll of thermal printer paper	
Fuses and fuse cap holders	
Serial interface to electronics package	82939A
Blank tape cartridges	

UNPACKING AND INITIAL EQUIPMENT CHECK-OUT (cont)

Review and **understand** the rear-panel layout and features (Fig. 2) to assure safe and efficient operation of the computer.

NOTE: The rear-panel layout and features are fully described in Appendix B of the Owner's Manual.[3]

Check to see that the voltage selector switch (1) and fuses (2) located on the rear panel are correct for the supply mains of the facility being inspected. If not, see Setup and Operation on p. 7.

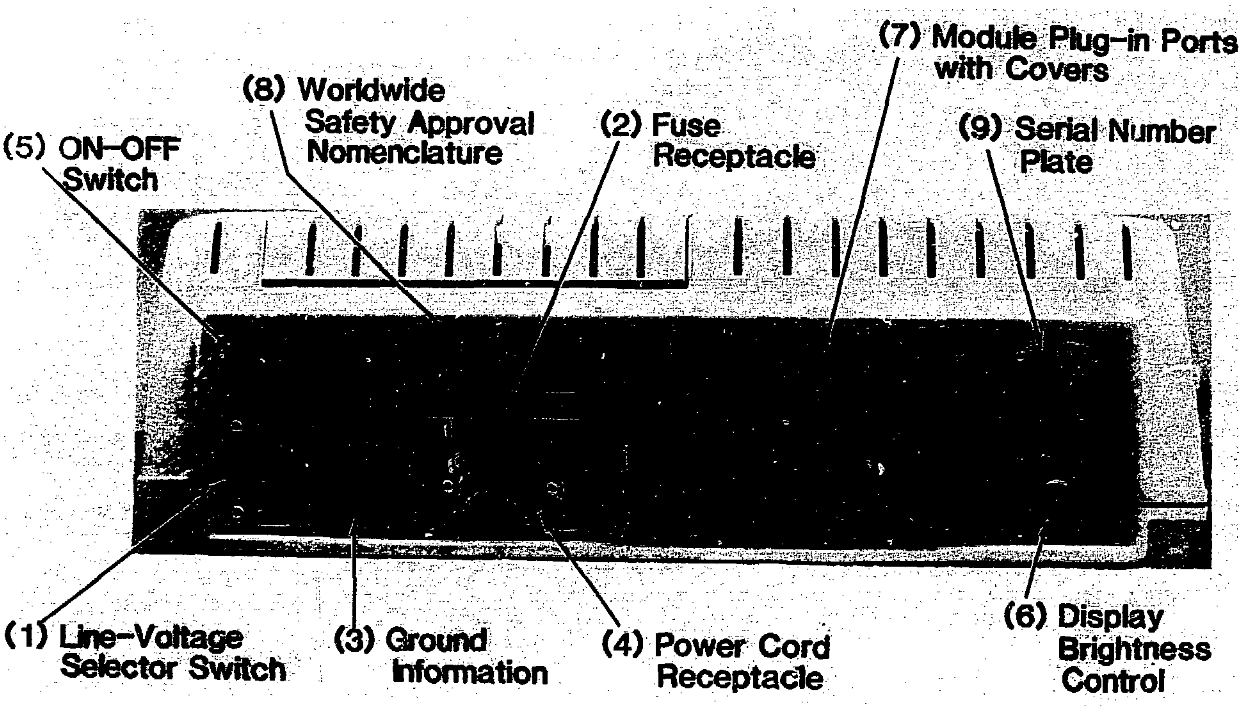


Fig. 2. Rear panel of the HP-85B computer.

UNPACKING AND INITIAL EQUIPMENT CHECK-OUT (cont)

NOTE: The HP-85B has the following power and fuse requirements.

Line Voltage	
115 Vac nominal	110/117 Vac
230 Vac nominal	220/240 Vac
Line Frequency	50/60 Hz
Power Consumption	40 W nominal
Fuse Requirements	
115 Vac	750 mA
230 Vac	1400 mA

SETUP AND OPERATION

Begin with the power cord disconnected from the computer and with the ON/OFF switch (5) **OFF.**

Recheck that the voltage selector switch (1) is set for the voltage range of the facility being inspected.

NOTE 1: If the setting must be changed, insert the tip of a small screwdriver or coin into the slot on the switch and slide the switch up or down so that the position of the slot corresponds to the desired voltage setting.

NOTE 2: If the fuse must be changed, install the proper fuse in the fuse receptacle (2) located on the rear panel (see Fig. 3).

CAUTION! To avoid the chance of electrical shock and possible overloading of the fuse, always be sure that the computer is disconnected from the power source before installing or replacing a fuse.

Connect the power cord to the power input receptacle (4) on the back of the computer (see

SETUP AND OPERATION (cont)

Fig. 3). Plug the other end of the cord into the ac power outlet.

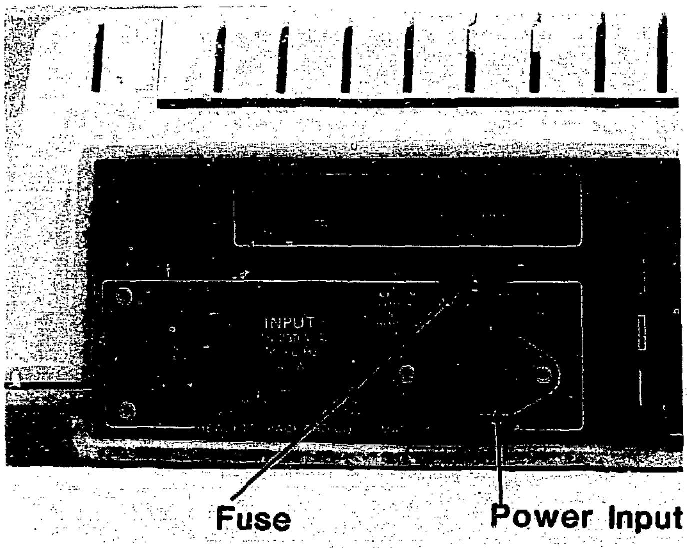


Fig. 3. Fuse and power cord receptacle.

Switch the HP-85B ON using switch (5) on the upper-left side of the rear panel.

Wait approximately 7-8 s until the underscore cursor appears in the upper-left corner of the CRT.

NOTE: Each time the power is turned on, the computer performs a self-test operation. When the cursor appears, the computer is ready to go to work. Should the cursor not appear or the words "Error 23: Self-Test" appear on the display, turn the machine OFF, then ON again. If this does not correct the problem, the computer is inoperable.

SETUP AND OPERATION
(cont)

If necessary, **adjust** the brightness of the display as desired with the brightness knob (5) on the right side of the rear panel.

Switch the computer **OFF.**

With the label upward, **plug in** the HP 82939A OPT .001 SERIAL INTERFACE module to one of the ports (7) in the rear panel (see Figs. 4 and 5). Retain the protective covers on those ports not used.

Fig. 4. SERIAL INTERFACE module.

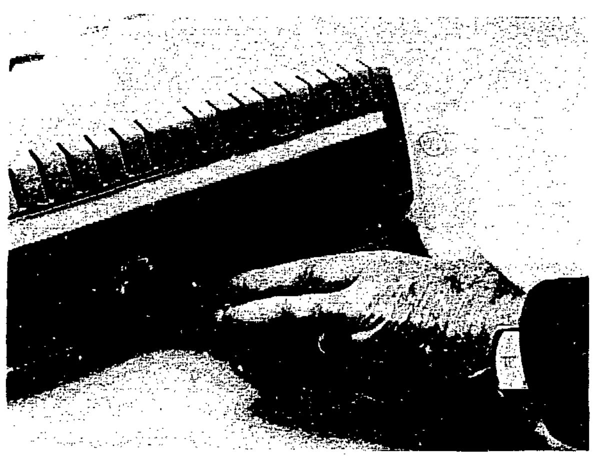


Fig. 5. Plugging in the SERIAL INTERFACE module.

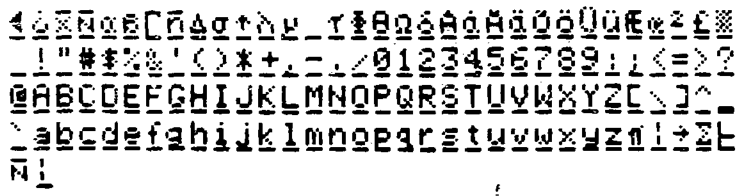
SETUP AND OPERATION
(cont)

CAUTION! The computer and any peripherals involved must be switched OFF when inserting or removing the module.

NOTE: The INTERFACE module must be inserted firmly to obtain data transfer from the electronics package.

Switch the computer **ON**.

To make an internal electronic check of all internal components, including read-only memory (ROM), main memory, display, and printer, **press** the TEST key while **holding down** the SHIFT key. If operation is proper, the HP-85B displays and prints the following characters at the end of the test and then beeps.



NOTE 1: When using the HP-85B with the HLNC-II, additional ROMs are, in general, not required.

NOTE 2: If the system is not operating correctly, it will display

Error 23: SELF TEST
or
Error 112 nnnnROM

where nnnn identifies the malfunctioning enhancement ROM.

If either error message occurs, replace the computer with a spare, or try replacing the ROM if that is indicated.

SETUP AND OPERATION
(cont)

NOTE 3: To reset the computer in case it becomes inoperative because of a system or input/output malfunction, press RESET while holding down SHIFT. This clears the display and returns the cursor to the "home" position. Resetting the computer aborts all system activity and returns the computer, as well as some peripherals and interfaces, to a ready state.

The HP-85B is now ready to be connected to the HLNC-II. **Turn** power **OFF.**

Unplug the power cord from the facility's mains.

GENERAL

The following procedure covers the initial unpacking and setup of the HLNC-II, as well as other information that is important when first using the instrument.

UNPACKING AND INITIAL EQUIPMENT CHECKS

The HLNC-II is packed in two polyform-lined transportation cases (see Figs. 6 and 7). One case contains the electronics package and the other the detector unit.

Unpack both cases and carefully **check** all parts for any physical damage sustained during shipment.

CAUTION! Because the detector unit weighs 43 kg, lifting it out of the transportation case is intended to be a two-person task.

Identify and **inventory** the contents listed in Tables II and III.

Review and **understand** the panel layouts of the electronics package.

NOTE: A ^{252}Cf calibration source and positioning rod may be available at the facility to be inspected or may need to be shipped in a separate package (see Fig. 8).

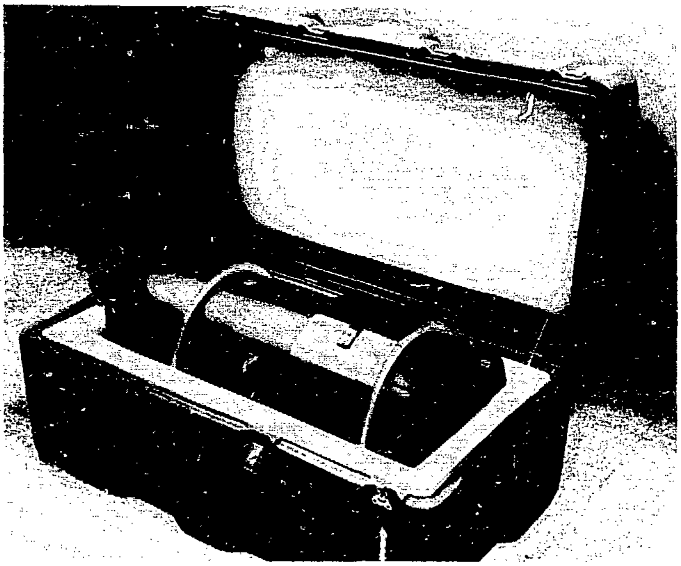


Fig. 6. HLNC-II and carrying case.

Fig. 7. Electronics package and carrying case.

UNPACKING AND INITIAL EQUIPMENT CHECKS (cont)

TABLE II

DETECTOR TRANSPORTATION CASE CONTENTS

No. of Items	Description
1	Detector unit consisting of 18 ^3He proportional counter tubes embedded in a cylindrical polyethylene body. Figure 9 shows a cross-section view of the detector.
2	Two reflector end plugs (see Fig. 10).
1	Electronics cable package consisting of one high-voltage cable, one signal cable, and one 5-V cable. All cables are ~3 m long (see Fig. 11).

TABLE III

ELECTRONICS PACKAGE TRANSPORTATION CASE

No. of Items	Description
1	Electronics package
1	Power cord
1	Power plug adapter

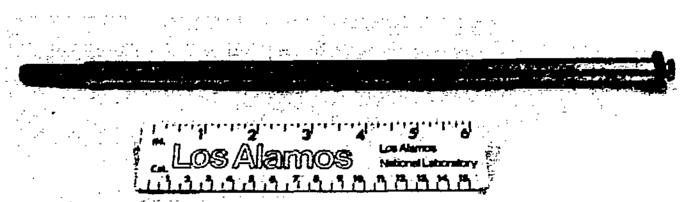


Fig. 8. Californium-252 calibration source and positioning rod.

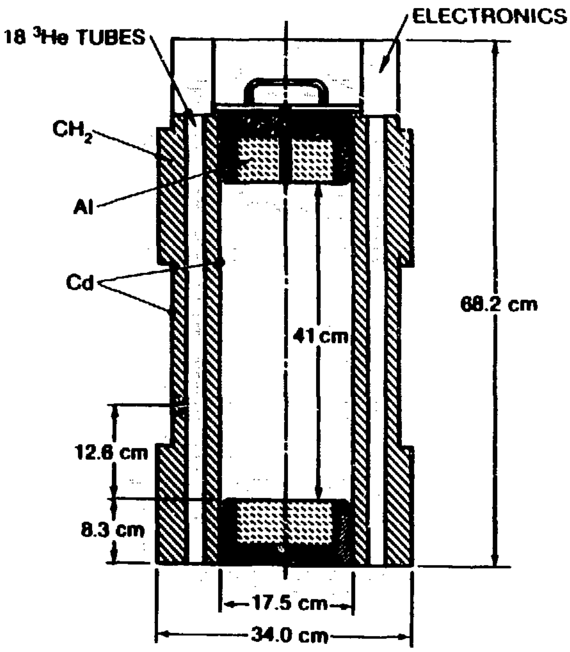


Fig. 9. Cross-section diagram of HLNC-II.

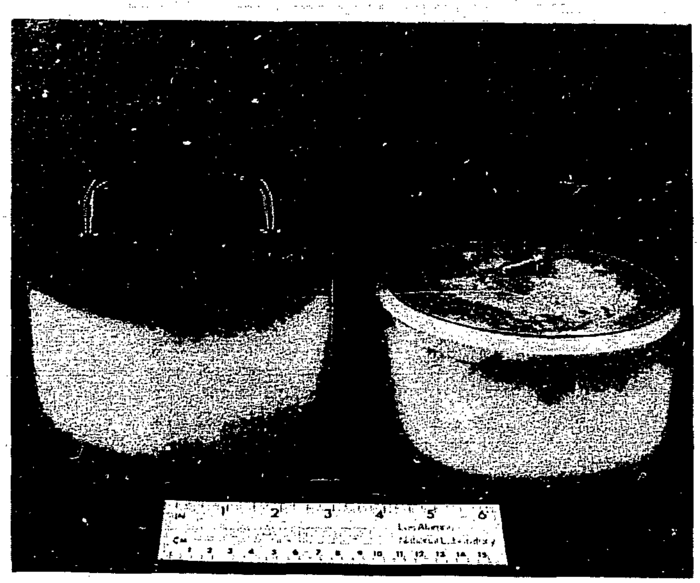


Fig. 10. Top- and bottom-reflector end plugs.

UNPACKING AND INITIAL EQUIPMENT CHECKS (cont)

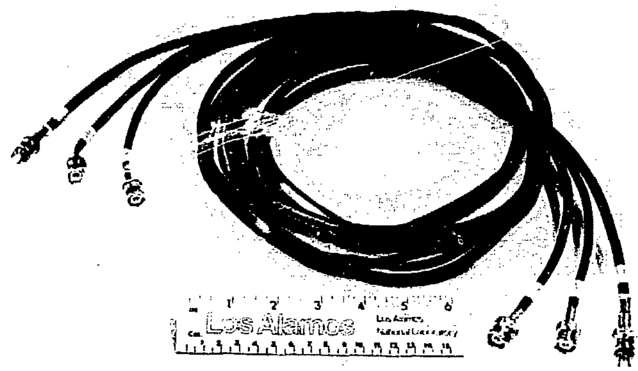


Fig. 11. Electronics cable package.

POSITIONING AND ASSEMBLY

Move the detector to the selected measurement location, isolated to the extent practical from neutron background.

NOTE: Finding a low-background area may require that arrangements be made in advance with the facility operator (see Neutron Background on p. 36).

Slide the bottom reflection end plug (if it is not already in place) into the bottom of the detector well and **place** the detector in its vertical position (see Fig. 12).

NOTE: A thumbscrew (handling tool) can be threaded into the top surface of the end plug to provide a handle for lowering the plug into the bottom of the detector well. Thumbscrews are normally stored in special threaded holes in the base plate (wheel plate) of the detector. If a thumbscrew is not available, the detector should be placed on its side on the floor to allow the end plug to be inserted carefully by hand.

POSITIONING AND ASSEMBLY
(cont)

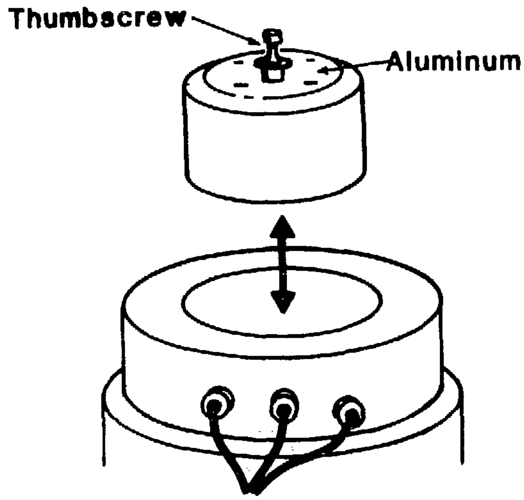


Fig. 12. Inserting the bottom reflector end plug.

Connect the high-voltage cable to the (HV IN) connector on the detector unit and the (HV) connector (18) on the rear panel of the electronics package (see Figs. 13 and 14).

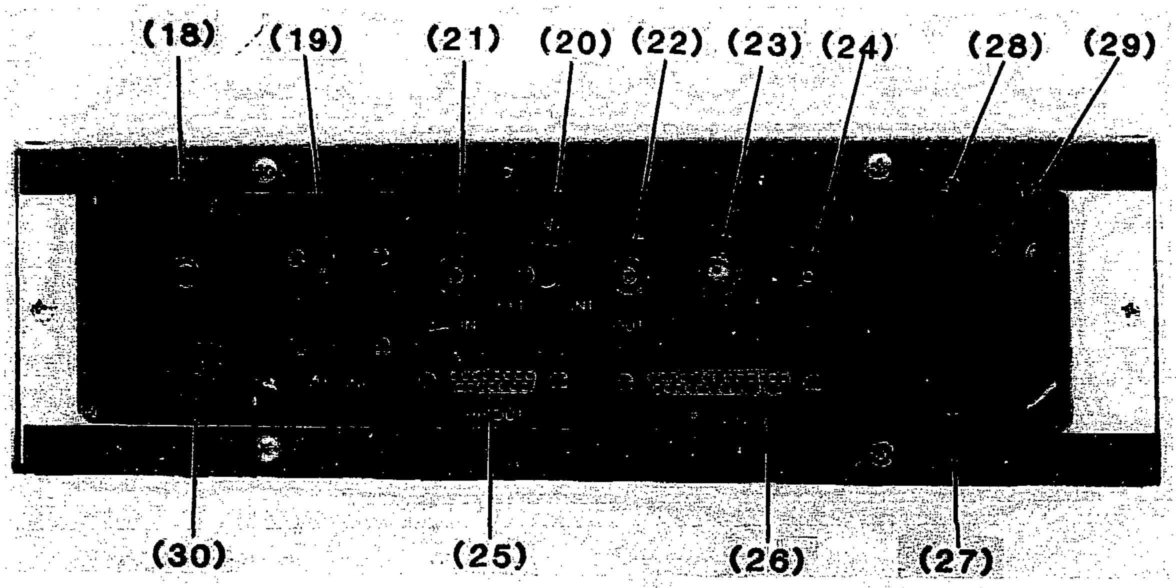
Connect the 5-V cable to the (+5 V) connector on the detector unit and to the (+5 V) connector (30) on the rear panel of the electronics package (see Figs. 13 and 14).

Connect the signal cable to the (SIG OUT) connector on the detector unit and to the (IN) connector (21) on the rear panel of the electronics package (see Figs. 13 and 14).

NOTE: Because the pins on both ends of the cable package have the same assignments, installation can be made either way. Check again to see that the three cables are connected properly at both ends.

POSITIONING AND ASSEMBLY

(cont)



(18) High-voltage Output Connector

(19) AMPlifier INPUT Connector
(Not used with HLNC-II)

(20) EXTernal/INTernal SELECT Switch
(Select EXTernal)

(21) Shift-register INput

(22) DISCriminator OUTput
(Not used with HLNC-II)

(23) DC INput
(Not used)

(24) Microprocessor RESET Pushbutton

(25) HP OUT Interface Connection
(Not used with HP-85)

(26) RS-232 (to HP-85) Interface
Connection

(27) Fuse Holder

(28) AC Power Selector Switch

(29) Electronics Package Power Line
Receptacle with Ground Pin

(30) +5 V Output

Fig. 13. Rear panel of electronics package.

POSITIONING AND ASSEMBLY
(cont)

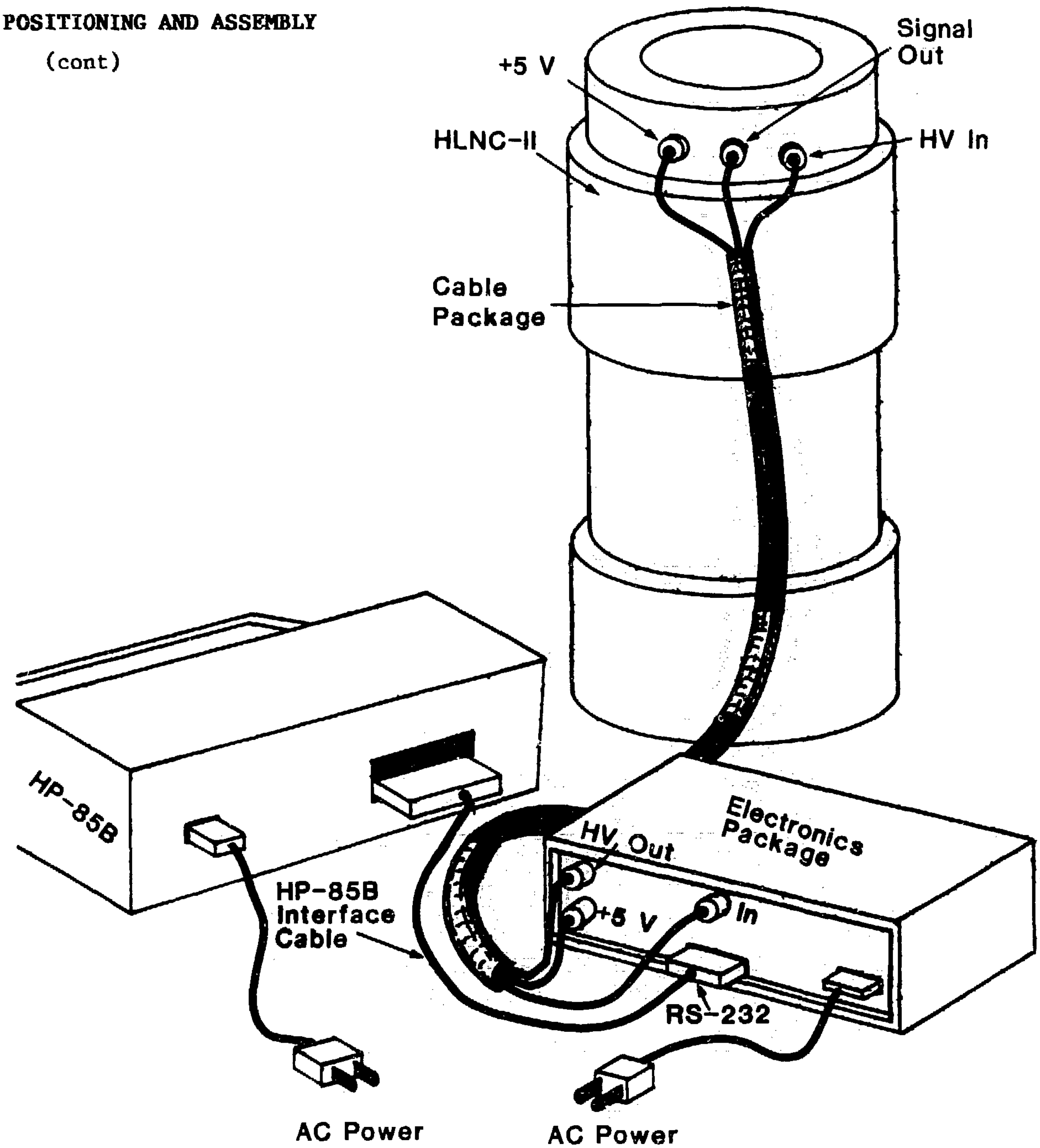


Fig. 14. Cable connections for the HLNC-II, electronics package, and HP-85B computer.

POSITIONING AND ASSEMBLY (cont)

Plug in the HP 82939A OPT .001 SERIAL INTERFACE module with the label upward, into the rear panel of the HP-85B (see Figs. 5 and 14).

NOTE: This step should have already been completed in HP-85B computer procedure on p. 9.

Connect the interfacing cable from the HP-85B computer to the (RS-232) connector (26) on the rear panel of the electronics package (see Figs. 13 and 14).

NOTE: The bottom row of pins on the RS-232 connector is the smaller.

Connect the power cord to the electronics package.

CAUTION! Do not yet plug the power cord into the ac mains. Make sure the proper adapter is on the cord for the facility to be inspected, and that the power outlet has an earth ground connection.

NOTE: The HLNC-II has the following power requirements:

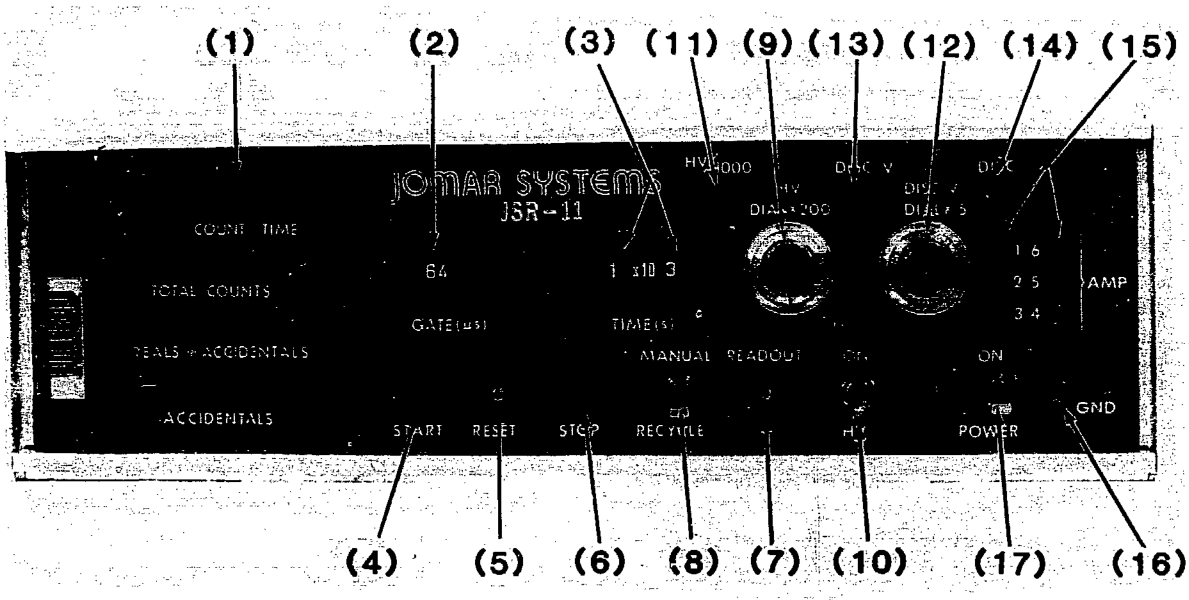
Line Voltage	
115 Vac nominal	100/117 Vac
230 Vac nominal	220/240 Vac
Line Frequency	50/60 Hz
Power Consumption	24 W
Fuse Requirements	1/2 A "SLO-BLO" or 1 A, depending on the model of electronics package

ELECTRONICS PACKAGE SETTINGS

NOTE: The numbers in parentheses below refer to the controls shown in Figs. 13 and 15.

ELECTRONICS PACKAGE

SETTINGS
(cont)

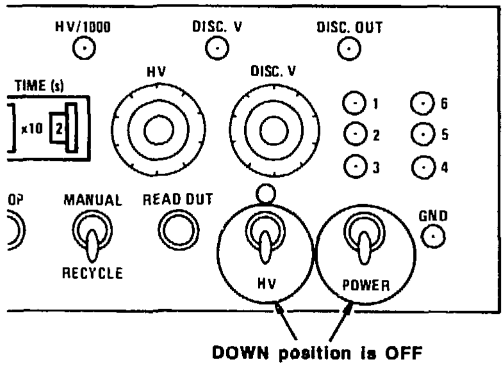


(1) Count Display
(2) Gate-Width Thumbwheel Switch
(3) Counting-Time Thumbwheel Switches
(4) START Push Button
(5) RESET Push Button
(6) STOP Push Button
(7) READOUT Push Button
(8) MANUAL/RECYCLE Switch
(9) High-Voltage Potentiometer
(10) High-Voltage Switch
(11) High-Voltage Test Point
(12) Discriminator Potentiometer (Not used with HLNC-II)
(13) Discriminator Test Point
(14) Discriminator Output Test Point
(15) Amplifier Test Points (Not used with HLNC-II)
(16) Ground Test Point
(17) Power Switch

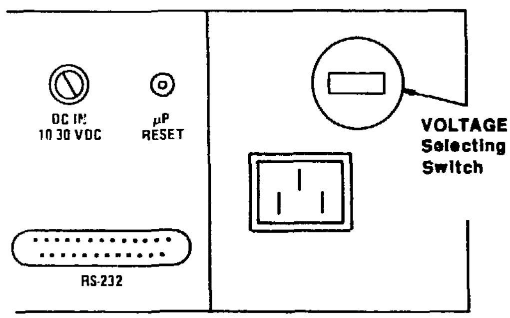
Fig. 15. Front panel of the electronics package.

ELECTRONICS PACKAGE SETTINGS (cont)

Put the PWR switch (17) and the HV switch (10) on the front of the panel in their OFF positions (down).



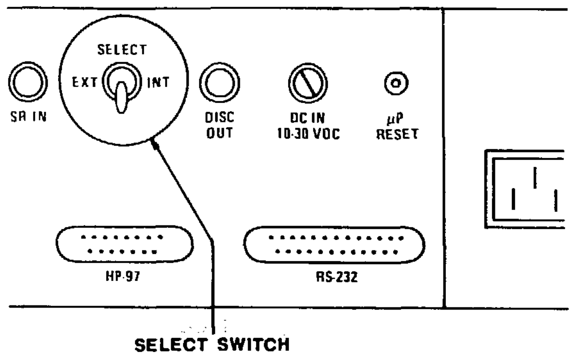
Set the ac power selection switch (28) on the back panel for the voltage range of the facility being inspected.



NOTE: On the newer electronics package model, JOMAR JSR-11, the lock on the switch must be released by pulling up on the body of the switch. The location is cramped and a tool such as long-nose pliers may be needed to reach and grasp the body of the switch.

ELECTRONICS PACKAGE SETTINGS (cont)

Put SELECT switch (20) on the back panel into the EXT position to connect the shift-register circuitry directly to the six AMPTEK-based amplifier/discriminator boards in the high-voltage junction box at the top of the detector package (see Fig. 16).



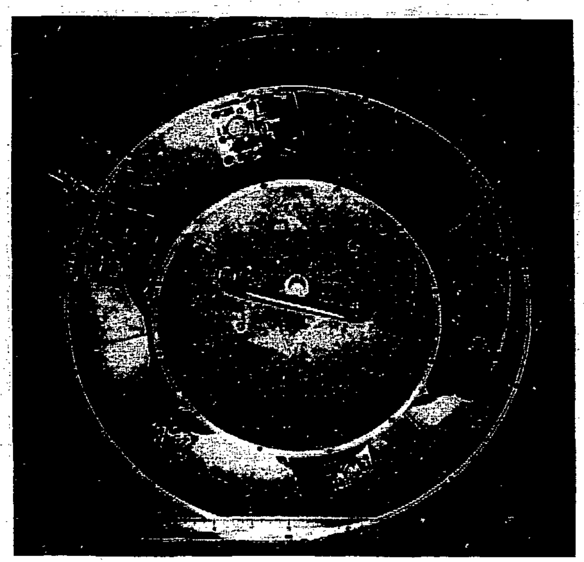
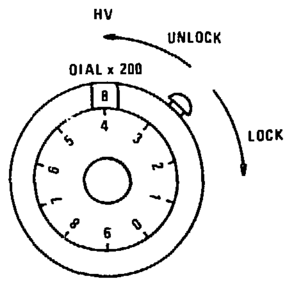


Fig. 16. Top view of the AMPTEK-based amplifier/discriminator boards in the high-voltage junction box of HLNC-II.

ELECTRONICS PACKAGE SETTINGS (cont)

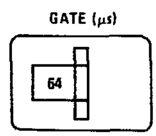
NOTE: The discriminator potentiometer (12), discriminator test points (13) and (14), and amplifier test points (15) on the front of the electronics package are not used with HLNC-II.

Set the high-voltage HV DIAL X 200 (9) on the front of the console to 8.4. **Lock** the dial by placing the locking arm in its lower position.

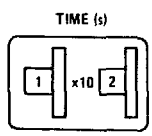


NOTE: This setting corresponds to 1680 V (8.4 turns of the dial times 200 V per turn). Nominal voltage in the ^{3}He counters is 1680 V. The exact voltage required for the detector package is printed on the side near the (HV INPUT) connector. Adjust the HV DIAL, as required.

Set the coincidence gate to 64 μs with the GATE (μs) thumbwheel (2) on the front of the console.



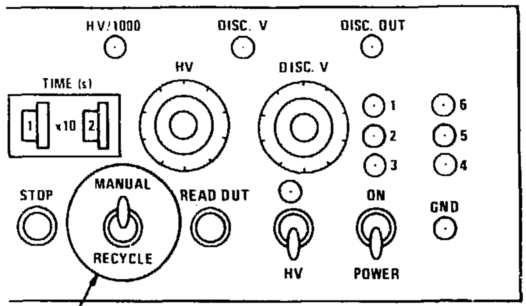
Set count time TIME (s) thumbwheels (3) to 100 s.



ELECTRONICS PACKAGE SETTINGS (cont)

NOTE: The count time is written as a number between 0 and 9, which is multiplied by 10^0 to 10^9; thus 100 s is 1 x 10^2.

Set the MANUAL/RECYCLE switch (8) on the front panel to the MANUAL position. This will then require using the START push button to start each count cycle.



POWERING UP AND CHECK-OUT

Connect the power cord from the HP-85B to the mains ac power and **switch** the computer ON.

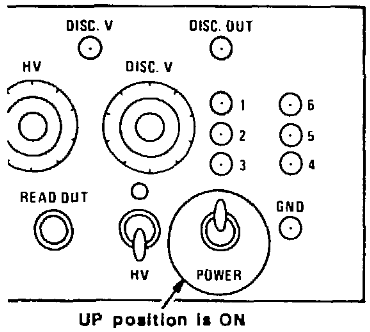
CAUTION! All steps in the check-out procedure for the HP-85B on pp. 7-11 shall have been carried out before powering the computer.

Recheck that the ac power selector switch (28) on the rear panel of the electronics package is set correctly.

Connect the power cord from the electronic package to the main ac power and **turn on** (up position) the ac power with the power switch (17).

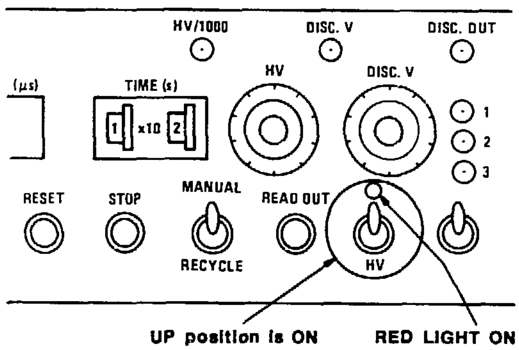
NOTE: The HLNC-II is powered through the electronics package.

POWERING UP AND CHECK-OUT
(cont)



Turn on the high-voltage HV switch (10) on the front panel of the electronics package.

NOTE: To move the switch, the locking handle must be pulled. The small red light above the switch will come on when the switch is activated.



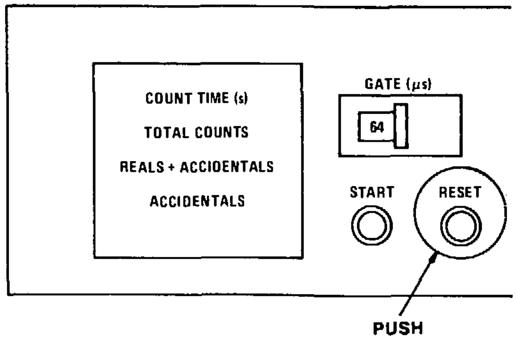
Background Check

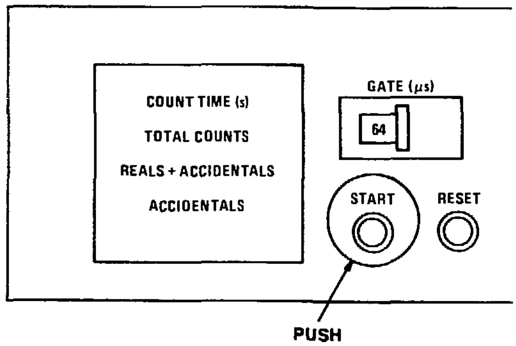
Remove the ^{252}Cf neutron source a considerable distance (several meters) away from the neutron detector in preparation for a background check.

Place the top reflector plug onto the detector. The bottom plug should already be in place (see Positioning and Assembly on p. 16).

Background Check (cont)

Make a 100-s count by first **pushing** the RESET button (5) and then **pushing** the green START button (4). The START button will light up.





NOTE 1: When the START button is pushed, the COUNT TIME display will begin displaying the time in seconds. The TOTAL COUNTS display will indicate the background counts as they are recorded. At the end of 100 s, the TOTAL COUNTS should usually be <50 000. The REALS + ACCIDENTALS and the ACCIDENTALS counts should usually be <1800 counts each. In a very low background location, these counts may be less than 10 000 and 100, respectively (see Neutron Background on p. 36).

NOTE 2: The net number of REALS, (REALS + ACCIDENTALS) - (ACCIDENTALS), should be zero within counting statistics. If REALS is found to be greater than three times its statistical counting uncertainty, there is electronic noise in the system. The HLNC cannot work properly unless the source of the electronic noise is identified and eliminated (see NOTE on amplifier signal lights on p. 30).

Californium-252 Source Check

The following steps confirm the response of the detector by using the ^{252}Cf source as a reference standard.

NOTE: The ^{252}Cf source supplied with the particular HLNC should always remain with the same instrument to check the consistency of the detector's overall response over time. Because the radioactive half-life of ^{252}Cf is only 2.65 years, a correction is required to account for that decay.

Insert the ^{252}Cf source into the hole provided in the top reflection plug (see Fig. 17).

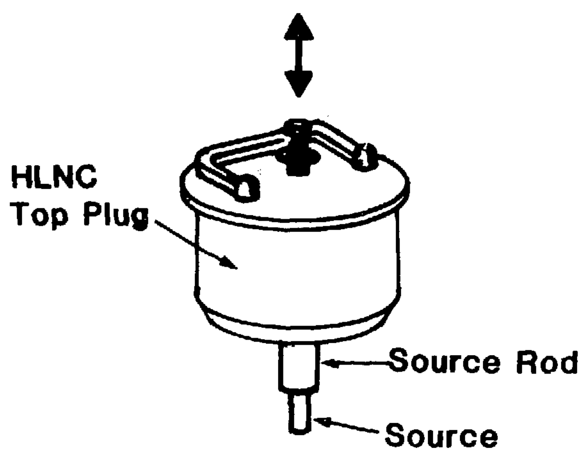
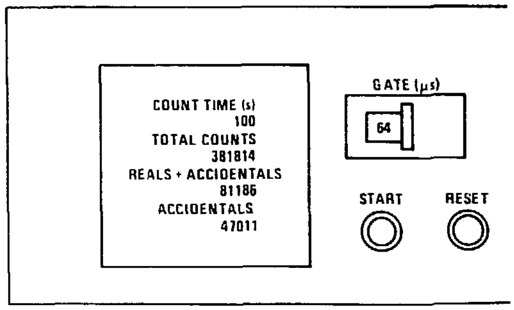


Fig. 17. Insertion of ^{252}Cf source into HLNC.

NOTE: When completely inserted, the cap on the source-positioning rod will rest on the top reflection plug, with the source located at the center of the detector well.

Californium-252 Source Check (cont)

Make a 100-s count of the source by first **resetting** the counter with push button RESET (5) and then **pushing** the START button (4).



EXAMPLE OF ^{252}Cf COUNTS

NOTE: The TOTAL COUNTS should be large; several hundred thousand counts. The REALS + ACCIDENTALS count should be much larger than the ACCIDENTALS.

Calculate the coincidence count rate, C_m, detected during the 100 s by taking the difference between the number of REALS + ACCIDENTALS counts and the number of ACCIDENTALS counts and dividing the difference by 100 s, the count time.

C_m = Measured coincidence count rate, counts/s

$$= \frac{\text{(REALS + ACCIDENTALS) - (ACCIDENTALS)}}{\text{COUNT TIME}} .$$

Calculate the expected coincidence rate of the source, C_e, at the date of the measurement by

Californium-252 Source Check
(cont)

calculating the decay using the decay constant of $7.172 \bullet 10^{-4}$ days^{-1}.

$$C_e = C_o \, e^{-7.172 \bullet 10^{-4} \bullet t} \quad ,$$

where t is the time in days since the original coincidence rate C_o was determined.

NOTE 1: The original coincidence neutron count rate of the ^{252}Cf source for a specific date, C_o, should be supplied with the source.

NOTE 2: The HLNC is working properly if the coincidence count rate actually measured, C_m, agrees within a few percent of the expected count rate, C_e.

NOTE 3: The six amplifier signal lights near the top of the detector package indicate the signal from each of the AMPTEK amplifier/discriminator units. A dead unit gives no pulses and a noisy unit gives pulses with no source present. Field repairs of the AMPTEK units can be made by plugging in spare boards. However, if only one or two units are out, the detector can still be used at low- to moderate-count rates by normalizing the coincidence (C_m) response to that expected for the ^{252}Cf calibration source (C_o).

NOTE 4: The ^{252}Cf response check is also available automatically with computer program CC12 written for the HP-85B computer; the computer method described is preferred (see Normalization Measurement on p. 45).

After assuring that the HLNC is working correctly, **remove** the ^{252}Cf source and **locate** it a considerable distance (several meters) away from the

Californium-252 Source Check (cont)

detector so that it will not interfere with subsequent measurements.

NOTE: The location should be one agreed to by the facility operator and be secured.

Additional Checks

Additional checks of the HLNC operation can be performed if time permits.

Compare the measured ACCIDENTALS counting rate with that calculated from the following relation:

$$\text{ACCIDENTALS RATE} = (\text{TOTALS RATE})^2 \bullet \text{GATE WIDTH}$$

$$= \left(\frac{\text{TOTAL COUNTS}}{\text{COUNT TIME}}\right)^2 \bullet 64 \bullet 10^{-6}$$

NOTE: The measured rate should agree with the calculated rate within statistical counting errors.

Calculate the totals-to-coincidence ratio:

$$\frac{\text{TOTALS RATE - BACKGROUND RATE}}{\text{REALS RATE}} = \frac{3.76\varepsilon}{\varepsilon_c} .$$

Additional Checks (cont)

NOTE 1: For the HLNC-II, this ratio should be ~5.2. When checking this ratio, BACKGROUND RATE should be <1% of TOTALS RATE.

NOTE 2: Here the totals counting efficiency (ε) is defined as TOTALS per source neutron and the coincidence counting efficiency (ε_c) is defined as REALS per fission. However, this equation is independent of both the ^{252}Cf source rate and the definition of efficiencies.

As an optional exercise, calculate the totals counting efficiency (ε) and the coincidence counting efficiency (ε_c) from the relations

$$\varepsilon = \frac{\text{TOTALS RATE} - \text{BACKGROUND RATE}}{^{252}\text{Cf TOTAL SOURCE RATE (n/s)}}$$

and

$$\varepsilon_c = \frac{3.76\ \text{REALS RATE}}{^{252}\text{Cf TOTAL SOURCE RATE (n/s)}} .$$

NOTE: For the HLNC-II, ε is about 18% and ε_c is about 13%. Measured values may vary significantly because of uncertainties in the ^{252}Cf source rate. Absolute source rates (total neutrons/second) are generally not well known to the user at a facility.

GENERAL

The plutonium oxide powder samples to be measured in the HLNC-II have important characteristics that must be known, or in some cases at least considered, for data taking and analysis and for determination of plutonium content.

DENSITIES

Although the theoretical density of PuO_2 is 11.46 g/cm^3, the actual density of the oxide powder inside the sample containers may vary from <2.0 g/cm^3 as produced to a tap density of >3.0 g/cm^3. Density differences affect primarily the self-multiplication factor and are automatically corrected for by the HP-85B computer program CC12 in the multiplication-corrected results (see p. 37).

CONTAINERS, MATERIALS, AND GEOMETRY

Plutonium oxide samples are typically enclosed in double containers of aluminum, mild steel, or stainless steel. Container thicknesses may vary from one to a few millimeters. Bag-out procedures may also introduce a plastic liner between the double containers. Single stainless steel containers, several millimeters thick, are also in use for storing and handling PuO_2.

Differences in container material and thickness affect detector efficiency through differences in neutron moderation, reflection, and absorption. Steel introduces inelastic scattering effects, whereas plastics increase the elastic scattering. Those effects must be either incorporated into the calibration procedure by having calibration standards with the same container characteristics or corrected for by a factor in the data analysis.

CONTAINERS, MATERIALS, AND GEOMETRY (cont)

Samples with the same PuO_2 mass but different sample geometries, for example, tall cylinders vs flat cylinders, will produce different responses in the HLNC-II. The contribution to this effect because of nonuniform detector efficiency is small, because the counting efficiency is nearly constant throughout most of the sample chamber volume. The differences in self-multiplication within samples of different geometry contribute the most to this effect. Without multiplication correction, calibration of standard samples with different geometries will give a family of calibration curves. But with the multiplication correction, a single calibration curve should be obtained regardless of different standard sample geometries. Nevertheless, for calibration it is preferable to use standards whose geometry is similar to that of the samples to be measured because the multiplication correction does not account for any small efficiency variations.

PLUTONIUM ISOTOPIC COMPOSITION

Passive assay of plutonium is based on detection of spontaneous-fission neutrons emitted by the even isotopes. Of these, ^{240}Pu has the largest concentration in typical reactor fuel. Because each even isotope contributes its specific number to the total spontaneous-fission neutrons, the coincident rate (REALS RATE) is related to an "effective mass" of ^{240}Pu in the PuO_2 sample by the equation

$$M_{240}^{eff} = 2.49M_{238} + M_{240} + 1.57M_{242} ,$$

PLUTONIUM ISOTOPIC COMPOSITION (cont)

where M_{238}, M_{240}, and M_{242} represent the isotopic masses of ^{238}Pu, ^{240}Pu, and ^{242}Pu, respectively. When the isotopic abundances are known (for example, from gamma-ray spectrometry; see Isotopic Measurements, p. 56), $M_{240}eff$ can be converted to total plutonium mass or to the masses of each isotope. This conversion is performed automatically in the CC12 program written for the HP-85B computer.

IMPURITIES

Although many trace contaminants may be found in PuO_2, the impurities H_2O and F are the most common causes for increasing the (α,n) neutron production. This increased (α,n) neutron production leads to an increased coincidence rate (REALS RATE) through induced fissions (multiplication). The multiplication correction in the CC12 computer program accounts for (α,n) neutron production only in pure PuO_2 (see Multiplication Correction on p. 37). It does not account for multiplication because of the enhanced (α,n) neutron production from impurities such as H_2O or F. Further analysis of H_2O and F multiplication effects may at some time provide additional corrections for H_2O and F impurities when their concentrations are known.

GENERAL

Neutron background, background TOTALS RATE, is an input variable for the CC12 computer program. Measurement procedures are described on p. 43.

AMBIENT BACKGROUND

For measurement purposes, the HLNC detector should be in a location isolated to the extent practicable from neutron background, for example, background TOTALS RATE <100 counts/s. In a facility environment, however, the ambient background TOTALS RATE may be high (>1000 counts/s). If the background TOTALS RATE exceeds 10% of the sample TOTALS RATE, the detector should preferably be relocated to a lower background location.

TRANSIENT BACKGROUND

If possible, samples waiting to be measured should be placed at a shielded location at least a few meters away from the HLNC detector. Otherwise the samples may cause variations in the background count during data collection if persons, acting as a shield, move between the samples and the detector. Also, movement of samples from their shielded location during measurements may cause background changes. The background correction in the CC12 computer program must be that of the actual background during data collection; otherwise a systematic error is introduced into the analysis.

Background measurements should be taken frequently during sample verification measurements, particularly if there is reason to believe that the background has changed.

MULTIPLICATION CORRECTION

Passive assay of plutonium oxide in the HLNC-II is based on the detection of spontaneous-fission neutrons. Self-multiplication occurs when neutrons in the PuO_2 sample **induce** additional fission neutrons. These induced-fission neutrons contribute to the REALS RATE leading to an erroneously high value for the mass of ^{240}Pu effective. The "leakage multiplication" (M) of a sample is defined as the number of neutrons leaving the sample divided by the number of spontaneous-fission and (α,n) neutrons produced in the sample.

A correction factor (CF) to reduce the REALS RATE that is too high because of induced fissions can be expressed in terms of the ratio of REALS RATE to TOTALS RATE and the ratio of (α,n) neutrons to spontaneous-fission neutrons (α)[4]:

$$\text{REALS RATE}_{\text{corrected}} = \frac{\text{REALS RATE}_{\text{measured}}}{\text{CF}} \quad .$$

Figure 18 shows the measured coincidence rates (REALS RATES) before and after multiplication correction. Note that the multiplication correction also takes care of geometry effects and density variations because of voids with double- and triple-stacked containers.

The correction factor works very well for PuO_2 as long as the samples do not contain impurities

MULTIPLICATION CORRECTION
(cont)

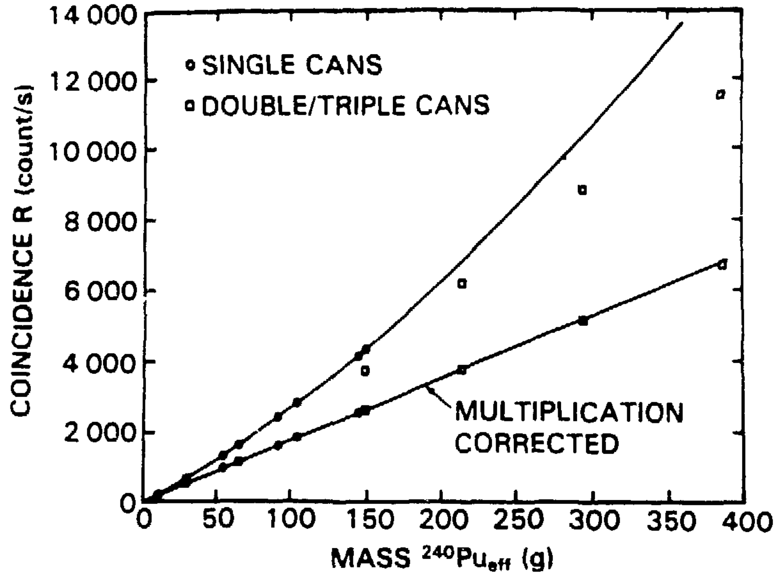


Fig. 18. Measured coincidence rates before and after multiplication corrections for pure PuO_2 powder.[1]

with high (α,n) production, for example, F or H_2O (see Impurities on p. 35).

The self-multiplication correction is handled automatically in the CC12 computer code (see the Appendix). It is important to note, however, that the correction parameters within the code are specific to pure PuO_2 and to the HLNC-II detector.

WALL EFFECTS

As a general rule, the HLNC should be located at least 50 cm from walls or other reflecting materials, including persons, which would generally enhance the detector response. The presence of any reflecting materials should be noted during both calibration measurements and verification

WALL EFFECTS (cont)

measurements. The ^{252}Cf normalization measurements taken during verification exercises (see Normalization Measurement on p. 45) should correct for most of the differences in response because of this effect.

DEADTIME LOSSES

Because of deadtime losses in the pulse processing circuitry, both the measured REALS RATE and TOTALS RATE will decrease from expected values as the TOTALS RATE increases. The correction factor for deadtime losses for both REALS RATE and TOTALS RATE is of the form

$$e^{(a + bT)T} ,$$

where T is the uncorrected TOTALS RATE and a and b are empirical deadtime constants that are different for the REALS RATE and TOTALS RATE corrections. The correction factor for TOTALS RATE is <1% up to T = 64 000 counts/s (~180 g ^{240}Pu eff). At this same TOTALS RATE, however, the correction factor for REALS RATE would be about 4%. The deadtime corrections, with empirical deadtime constants specific to the HLNC-II, are made automatically in the CC12 computer program.

GENERAL

Calibration curve parameters for the verification samples to be measured are required as input for the CC12 computer program. Calibration is usually carried out at some other location, laboratory, or facility prior to verification measurements. Calibration procedures, therefore, are summarized very briefly below only to explain the relationship to verification measurements.

CALIBRATION STANDARDS

Standards used for calibration must be well characterized with known mass, density, isotopic percentages and impurity content. Container materials and geometry should be as similar as possible to those of the verification samples.

The range of masses for the calibration standards should uniformly and completely span the range of verification samples. Extrapolation of the standards calibration curve to either lower verification masses or higher verification masses can lead to significant errors. If possible, six to eight standard masses should be used to obtain a statistically acceptable calibration curve. Calibration standards should be measured for counting times long enough to assure an error in REALS RATE of 1% or less.

CALIBRATION DATA

An HP-85 computer program, CAL4, is used to collect calibration data. Sample ID, mass, and isotopic percentages are entered on the keyboard. The effective ^{240}Pu masses, coincidence rates, and errors are calculated for each standard.

CALIBRATION DATA (cont)

These data are then keyed into the DEM6/4 computer program described below.

LEAST-SQUARES FITTING

An HP-85 computer program, DEM6/4, does a least-squares fit to the calibration data. The data, both with and without multiplication correction, are fit to calibration curves of the form

$$R = A + BM + CM^2 ,$$

where R is the coincidence rate (REALS RATE) and M is the effective ^{240}Pu mass.

Data points obtained from nonrepresentative standards (outliers) are eliminated to the extent that they can be identified. One arbitrary procedure used in the International Atomic Energy Agency (IAEA) is to define an outlier as a point with a residual >2%. Then data points with residuals >2% are eliminated and the least-squares fit is repeated with the remaining points.

After those points with residuals >2% have been completely eliminated, the program prints out the constant parameters A, B, and C with variances and covariances and plots the calibration curves, both with and without multiplication correction. Both sets of A, B, and C constants and errors are then manually entered into the CC12 program to provide standard calibration curves for verification measurements.

GENERAL

The following procedures describe the steps to be followed in making verification measurements of PuO_2 with the HLNC-II. All steps from pp. 7-11 and pp. 16-30 must have been completed before making verification measurements. Also, the user should understand thoroughly the operational procedures for the CC12 computer program described in the Appendix.

LOADING THE CC12 PROGRAM

Insert the CC12 program tape, with label side up, into the computer's tape drive.

Enter LOAD "CC12" on the keyboard and **press** END LINE.

If a reading error occurs, enter CTAPE on the keyboard and press END LINE. After the tape is conditioned, turn off the HP-85B and try again to enter LOAD "CC12."

After waiting about 1 minute for the HP-85B to read the CC12 program, the cursor will appear on the CRT display. **Press** RUN.

The program initially asks for user's name, facility name, date, time, magnetic tape storage (NO), run number, operation mode (NORMAL), and material type (PuO_2). **Enter** each response on the keyboard and **press** END LINE.

BACKGROUND MEASUREMENT

The program next asks for measurement type.

Enter 1 for Background and **press** END LINE. The program now asks for the number of background runs. The usual number is 3.

Enter your choice for number of runs and **press** END LINE. The HP-85B is now waiting for data from the electronics package.

Set the MANUAL/RECYCLE switch on the front panel of the electronics package to RECYCLE. The electronics package will automatically begin the next run after the data from the previous run are transferred to the HP-85B.

Remove the ^{252}Cf normalization source several meters away from the neutron detector. **Assure** that the verification samples waiting to be measured are at a shielded location several meters away from the HLNC detector.

Set the count time (TIME) thumbwheels on the electronics package to 300 s.

NOTE: 300 s is the usual count time, but this may be changed depending upon the background rates and sample sizes.

To begin the background measurement, **push** the RESET button and then the START button on the electronics package.

BACKGROUND MEASUREMENT (cont)

After each run is completed, the data are transferred to the HP-85B and are printed as in the example below.

```
Background runs
Number of runs        =    3
--------------------------------

Run # =      36
Date  = 840917
Clock =     934

Time   =          300
Totals=         3,812
R+A    =            6
A      =            4

--------------------------------
```

After the requested number of runs is completed, the program automatically processes the data to calculate background rates, both TOTALS and REALS, and prints the results as in the example below.

```
Series of  3 runs completed.
Results:

Totals rate for run #  38 is
  14.32% or   8.6σ from average


Background rates
T=    13.79 +/-   0.12
R=     0.01 +/-   0.01

Bkgd. totals rate (B)=    13.79


********************************
```

This background rate is now automatically introduced into the CC12 program as the background parameter used for data analysis. If for any reason the background changes during verification runs, then a systematic error would be introduced into the calculations (see discussion on p. 36).

BACKGROUND MEASUREMENT (cont)

NOTE: Background measurements should be taken frequently during verification measurements, particularly if there is reason to believe that the background has changed. This can be done easily any time the program asks for measurement type. The new value of background rate is automatically introduced into the CC12 program to replace the previous value.

After the results have been printed, the program automatically asks the user to select the next operation.

Enter 1 for Continue With Measurements and **press** END LINE. The program again asks for measurement type.

NORMALIZATION MEASUREMENT

Enter 2 for Normalization and **press** END LINE. The program now asks for confirmation of the ^{252}Cf reference source.

Insert the ^{252}Cf reference source into the hole provided in the HLNC top reflection plug (see ^{252}Cf Source Check on p. 28).

After the ^{252}Cf source is correctly in position, **press** END LINE. The program again asks for the number of runs. The usual number is 3.

Enter your choice for number of runs and press END LINE. The HP-85B is again waiting for data from the electronics package.

NORMALIZATION MEASUREMENT (cont)

Check to see that the MANUAL/RECYCLE switch on the front panel of the electronics package is set on RECYCLE.

Set the appropriate count time with the (TIME) thumbwheels on the electronics package (usually 300 s).

NOTE: Depending on the strength of the ^{252}Cf reference source, the count time should be set to give an error of 1% or less on REALS RATE.

To begin the normalization measurement, **push** the RESET button and then the START button on the electronics package.

NOTE: After each run is completed, the data are transferred to the HP-85B and are printed in the same form as the background measurement example on p. 44.

Following completion of the requested number of runs, the program automatically processes the data to calculate normalization rates, both TOTALS and REALS, and the normalization constant K and prints the results in the following form.

NORMALIZATION MEASUREMENT

(cont)

```
---------------------------------

Series of  9 runs completed.
Results:

Totals rate for run #  76 is
   0.08% or   4.1σ from average


Bkgd.-corrected Cf-252 rates
T=  7637.80 +/-   0.47
R=  1466.50 +/-   0.51

Normalization constant:
K=  0.9994 +/- 0.0031

K is within 3σ of old value.
Old value of K retained.
Normalization constant:
K=  0.9974 +/- 0.0038

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

If the new value of K is not within 3σ of the old value, the new value is automatically introduced into the CC12 program for future data analyses.

NOTE: If possible, normalization measurements should be repeated at least daily during verification measurements. Should the HLNC be moved to a different location, the normalization constant should be reverified because the location of external reflectors and absorbers (for example, walls) will have changed. If at any time the HLNC seems to be working improperly, an additional ^{252}Cf normalization run should be made.

After the results are printed, the program automatically asks the user to select the next operation.

Enter 1 for Continue With Measurements and press END LINE. The program again asks for measurement type.

VERIFICATION MEASUREMENTS

Enter 3 for Verification and **press** END LINE. Now the program asks the user to enter the sample ID.

NOTE: The identification of each verification sample can be up to 25 characters long (but no commas are allowed).

Enter the appropriate ID for the sample to be measured and **press** END LINE. The user is now asked to select isotopic composition.

NOTE: For the initial measurement of samples from a single master blend (that is, samples whose plutonium isotopics are identical), the choice would be 2 for Enter From Keyboard. For subsequent measurement of samples from that same master blend, the choice would be 1 for Same as For Last Measurement.

Assuming an initial measurement, **enter** 2 and **press** END LINE. The user is now asked to enter the number of components in the sample.

NOTE: This number is usually 1. Should there be two different plutonium components, then the plutonium isotopics must be specified for each component (see the Appendix, p. 64). Examples are a single container with two smaller containers inside or a sample blended from two different batches of PuO_2.

Assuming one component, **enter** 1 and **press** END LINE. The program now asks the user to enter the declared plutonium mass (grams); the weight percent ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu (wt% Pu) and the plutonium analysis date (YYMMDD); and the

VERIFICATION MEASUREMENTS (cont)

^{241}Am content (ppm Pu) and the americium analysis date (YYMMDD).

Enter the appropriate values for each input and press END LINE. The isotopic data are now printed and the user is asked to verify correctness.

If correct, press END LINE. If not, enter the incorrect item number and the corrected value (for example, for new plutonium analysis date, enter 6, 840723). Then press END LINE.

The input data for the samples are then printed in the following form.

```
Verification runs
Material:
     PuO2 powder
Sample ID:5108
Declared mass= 1078.200

Isotopic data:
Pu-238:  0.050  Pu date: 840723
Pu-239: 87.090
Pu-240: 11.760
Pu-241:  0.900
Pu-242:  0.200
Am-241:   3456  Am date: 840718

Updated values:
Pu-238:  0.050
Pu-239: 87.098
Pu-240: 11.761
Pu-241:  0.894
Pu-242:  0.200
Am-241:   3521

Pu mass=  1078.100
Eff. Pu-240 mass =  131.517

Background rate=       210.86
Normaliz. const.(K)=    0.9987
Number of runs     =    3
--------------------------------
```

VERIFICATION MEASUREMENTS
(cont)

NOTE: An internal check is made to assure that the plutonium isotopes add up to 100%. If not, the total plutonium percent is displayed on the CRT and the user is asked, Do you want to re-enter data (Y or N)? If yes (Y), enter the incorrect item number and the corrected value as described above. If no (N), the program will automatically normalize all isotopic values to add up to 100% and print the corrected values.

After the correct sample data have been printed, the program now asks for the number of verification runs for that sample. The usual number is 3.

Enter your choice for number of runs and **press** END LINE. The HP-85B is again waiting for data from the electronics package.

Check to assure that the MANUAL/RECYCLE Switch on the electronics package is set on RECYCLE.

Set the count time (TIME) thumbwheels on the electronics package (usually 300 s).

Depending on the size of the sample, the count time should be set to give 1% error or less on REALS RATE.

Remove the ^{252}Cf normalization source several meters away from the HLNC.

CAUTION! If possible, verification samples waiting to be measured should be at a shielded location several meters away from the HLNC to reduce the effect of transient background (see p. 36).

VERIFICATION MEASUREMENTS (cont)

Lift out the top reflection plug and **insert** the sample container into the HLNC cavity.

NOTE: To position the sample container near the center of the cavity, it is usually necessary to place it on top of an empty container sitting on the bottom of the cavity. The REALS counting response is almost constant over the length of the cavity, except for the bottom 5 cm and the top 10 cm.

Replace the top reflection plug and **push** the RESET button and then the START button on the electronics package to begin the verification measurement.

NOTE: After each run is completed, the data are transferred to the HP-85B and are printed in the same form as the background measurement example (see p. 44).

Following completion of the requested number of runs, the program automatically processes the data and prints out the results of analysis (see pp. 53-54).

The user is then asked to enter descriptive comments, if any, about the assay results (see the Appendix, p. 69).

Enter comments, as desired, and **press** END LINE. The program now asks the user to select the next operation as follows:

VERIFICATION MEASUREMENTS (cont)

Select next operation:

(1) Continue with measurements.
(2) Change bkgd. or normalize.
(3) Change detector or material.
(4) Select operating features.
(5) Create new data tape.
(6) Terminate.

NOTE: See the Appendix, p. 70, for description of options.

To continue verification measurements, **enter** 1 and **press** END LINE. The program again asks for measurement type.

Return to the beginning of Verification Measurements on p. 48 and **repeat** the measurement procedures.

After all verification samples have been measured, **enter** 6 and **press** END LINE. The HP-85B displays "Program Terminated."

HP-85B PRINT-OUT

Following the completion of the requested number of runs for each verification sample, the program automatically processes the data and prints out the following results of analysis:

(1) Background-corrected rates and errors, both TOTALS and REALS.

(2) Assay masses and errors, both ^{240}Pu effective and plutonium.

(3) Declared mass plutonium (corrected to present date).

(4) Plutonium mass difference δ (assay-declared) and its error (1σ), both grams and percent.

(5) Multiplication-correction constants (see Multiplication Correction on p. 37), leakage multiplication (M), ratio of (α,n) neutrons to spontaneous-fission neutrons (α), and the correction factor (CF), which is displayed as (f).

(6) Multiplication-corrected REALS RATE, assay masses and errors, and plutonium mass difference and its error, both gra... and percent.

HP-85B PRINT-OUT (cont)

These results are automatically printed in the following form:

```
Series of  3 runs completed.
Results:

Bksd.-corrected & norm. rates:
T= 41566.00 +/- 102.73
R=  4167.00 +/-  26.17

Assay mass & error:
m(240e)=  132.850 +/-    0.747
m(Pu)  = 1082.466 +/-    6.124
Declared mass:
m(Pu)  = 1078.100

δ=     4.366 or    0.405 %
σ=     6.124 or    0.568 %

Multiplication calculations:
M=     1.126        α=  0.528
R= 2516.600         f=  1.656
Assay mass & error:
m(240e)=  130.910 +/-    1.714
m(Pu)  = 1073.121 +/-   14.048
Declared mass:
m(Pu)  = 1078.100

δ=    -4.979 or   -0.462 %
σ=    14.048 or    1.303 %
```

PLUTONIUM MEASUREMENT FORM

Once the verification measurements have been made with the HLNC-II, the results are transferred from the HP-85B print-out to a standard form used as a working paper summary. On the next page is an example of such a working paper. This form is not a universally accepted verification form but it is shown here to illustrate the procedure.

Transfer the relevant information from the HP-85B print-out to the appropriate column on this form.

PuO_2 DATA SHEET

											Assay Results			
											No mult. corr.		mult. corr.	
Meas. Type	Clock	ID	M (decl.)	Calib. Curve	$\dot{B}$	K	$\dot{T}$	$\dot{R}$	$\sigma(\dot{R})$	$\dot{R}_c$	M	ΔM(%)	M	ΔM(%)

NAME	DATE	HLNCC ID	ELECTRONICS ID	HV	DISC.	GATE LENGTH

GENERAL

As discussed on p. 34, the HLNC data give only ^{240}Pu effective mass, which must be combined with plutonium isotopic data to calculate total plutonium content. The plutonium isotopic data can be determined by nondestructive assay, that is, gamma-ray spectroscopy. Thus, gamma-ray spectroscopy can be considered an auxiliary measurement to the HLNC, enabling a total plutonium mass determination.

Another example of an auxiliary measurement is the determination of moisture content of a sample. In principle, if the moisture content were known, a correction could be applied to the REALS RATE, which would bring the data onto the dry sample calibration curve. This has not yet been put into practice (see p. 35).

ISOTOPIC MEASUREMENTS

These measurements are performed using a high-resolution germanium detector, a Silena 8000 channel analyzer (SLNC), and a plutonium isotopic analysis unit (PIAU). The procedures for making the measurements are found in Ref. 5. If these isotopic results are of high enough quality, they can be used directly with HLNC data to obtain a plutonium mass, completely independent of facility-declared values.

Another option is to compare the measured isotopics with the facility-declared values. If the two data sets agree to within the uncertainties, the facility-declared set can be used with the HLNC data. The rationale behind this option is

ISOTOPIC MEASUREMENTS (cont)

that the operator numbers, based on mass spectroscopy, should be more accurate.

GENERAL

These procedures summarize the general use of the CC12 program used with the HP-85B computer for verification measurements of PuO_2. For additional information and a listing of the CC12 program, see Ref. 6. Study of the HP-85B Owner's Manual and Programming Guide[3] is recommended but is not essential.

NOTE: Unless otherwise specified, mass is in grams, time in seconds, and count rate in 1/s. Errors are absolute standard deviations unless followed by %, in which case they are percent relative standard deviations.

GENERAL OPERATING PROCEDURES

The normal operating procedure is simply to follow the instructions given by the program. In each case, enter the response on the keyboard and press END LINE.

Keyboard Error Corrections

(1) Until END LINE is pressed, keying errors can be corrected by pressing BACK SPACE.

(2) After END LINE is pressed, the program performs some checks on the entry for consistency. If an unacceptable entry is detected, the input is ignored and the instruction is repeated.

(3) After the entry of isotopic data is completed, the program displays the data and gives the user a chance to make changes. The same is done for coincidence counter data entered from the keyboard.

Keyboard Error Corrections (cont)

(4) Other incorrect entries can be corrected by stopping the program and continuing from an earlier point (see sections below).

Stopping the Program

(1) When the program is interacting with the user by way of the keyboard, the user can stop the program by pressing PAUSE.

(2) When the program is waiting for data from the serial interface, pressing PAUSE has no effect. To stop the program in this case, press STOP, RESET, and READOUT on the coincidence electronics package. Wait until the program processes the data transferred and then press PAUSE.

Continuing the Program

After the program is stopped, enter CONT 9999 on the keyboard and press END LINE. The program then asks the user to select the next operation as shown in Next Operation Sequence on p. 70.

Restarting the Program

After the program is stopped, press RUN. The program restarts at the beginning.

Error Recovery

If an error occurs that is not protected by the program, the HP-85B sounds a beep and usually stops. Follow these steps one at a time until the program is restarted:

(1) Press CONT (Continue).

Error Recovery (cont)

(2) Press PAUSE, enter CONT 9999 and press END LINE.

(3) Press SHIFT-RESET and after several seconds press RUN. The program restarts at the beginning.

(4) Insert the program tape, turn off the power, and then turn the power on again.

Interrupting Measurements

To stop a series of runs in progress, follow these steps:

(1) Press STOP, READOUT on the coincidence electronics package.

(2) Wait for the data processing to finish.

(3) If the program is still waiting for data, press RESET, READOUT on the coincidence electronics package.

(4) Wait for the data processing to finish.

If the data from the run in progress are not needed, it is only necessary to press STOP, RESET, and READOUT on the coincidence electronics package and wait for the data processing to finish.

Determining the Source of Errors

(1) Stop the program if it is still running.

(2) Enter ERRN on the keyboard and press END LINE. The computer will display the error

Determining the Source of Errors (cont)

number of the last error that occurred. Appendix E in the HP-85B Owner's Manual and Programming Guide[3] contains a list of the error numbers and causes.

INITIAL OPERATING SEQUENCE

User and Facility Names

The program initially asks for the user's name and the facility name. The names can be up to 25 characters long (but no commas are allowed).

Examples:	Users	A. B. Cranshaw
		E. F. Gray
	Facilities	XYZ (Bldg. 2)
		ABC-123

Date and Time

The program then asks for the date and time in the formats YYMMDD and HHMM (HMM).

Examples:	Dates	830219
		831201
	Times	1432
		0916
		916

Data Storage on Magnetic Tape

The program asks whether tape storage of data is desired. Although tape storage is optional, it is considered to be the normal mode of operation (see p. 71 for details).

Run Numbers

Every measurement is assigned a run number for reference. When tape storage is not used, the program asks the user for the first run number (usually 1). This number is then increased by 1

Run Numbers (cont)

for each subsequent measurement. When tape storage is used, the computer assigns all the run numbers.

Normal Operation

The program asks the user whether he wants to run the program in the normal way. The usual answer is yes (Y). For instructions on the use of selectable features, see p. 73.

Material Type

The program asks the user to select the material type by entering the number (1-3) of the material in the list.

(1) PuO_2

(2) MOX

(3) ??

Measurement Type

The program asks the user to select one of the four measurement types:

(1) Background

(2) Normalization

(3) Verification

(4) Special

MEASUREMENT TYPE SEQUENCES

After the user has selected by number (1-4) one of the four measurement types, the appropriate sequence of instructions is followed. The program

MEASUREMENT-TYPE SEQUENCES (cont)

then asks for the number of runs (measurements) desired followed by the appropriate measurement sequence and the data analysis sequence.

The program then asks the user to select the next operation (see Next Operation Sequence on p. 70).

Background

The background totals rate B is initially set to B = 0. A background measurement automatically replaces B with the new measured value of the background totals rate.

Normalization

The normalization constant K is initially set to K = 1. A ^{252}Cf source measurement automatically determines a new value of K. The new value of K replaces the old value if K(old) = 1 or if the new value differs from the old value by $>3\sigma$ of the new value.

Verification

Verification measurements are used to determine the plutonium mass of inspection samples. Details on the calculations are given in Data Analysis for Plutonium Mass on p. 67.

Sample Identification ID. The program asks the user to enter the sample ID, which can be up to 25 characters long (but no commas are allowed).

Composite Samples. Some samples are declared to consist of X grams of type A material, Y grams of type B, etc. The program asks for the number of components in the sample and then asks for mass

Verification (cont)

and isotopic data for each component. Usually the sample has only one component.

Isotopic Composition. Isotopic composition data are needed to calculate the plutonium mass and perform multiplication corrections. The program gives four choices by number:

(1) Same as for last measurement
This is self-explanatory.

(2) Entry from keyboard
Keyboard entry requires entry of ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu as weight percent of plutonium, the plutonium analysis date, the ^{241}Am as parts per million (ppm) of plutonium and the americium analysis date.

(3) Entry from computer table
The computer table contains 30 sets of isotopic data that are frequently used in verification measurements. The program displays a table of isotopic composition codes and the user enters the item number of the desired set.

(4) Not available
If isotopic information is not available at the time of the measurement, the program calculates the effective ^{240}Pu mass, but not the plutonium mass.

Special — Any desired measurement that does not fit into the above three categories is called a special measurement. The program calculates the background-corrected and normalized totals and coincidence rates for special measurements, but does nothing with the results.

MEASUREMENT SEQUENCE

Number of Runs — The program asks for the number of runs (measurements) desired for each measurement sequence. Up to 100 runs can be requested. The HP-85B then awaits the transfer of data from the coincidence electronics. After each transfer, the data are printed (and stored on tape, if the tape is used).

Accidentals/Totals Test — Any measurement for which the totals rate and accidental coincidence rate are inconsistent is excluded from further analysis and does not count toward the requested number of runs. At present the rates are considered to be consistent if the calculated and measured accidental coincidence rates agree within 1%; the test is not made if the total counts are <100 000.

Average Rates — After the desired number of runs have been completed, the average totals and coincidence rates and their respective errors (standard deviations) are calculated.

3σ Test

The 3σ test checks the deviations of the totals and coincidence rates for each run from the average. If the coincidence rate for any run is >3σ from the average, where σ is the standard deviation of the coincidence rate for that run, then that run is rejected and another run is requested. If the totals rate fails the 3σ test, a warning is printed but the run is not rejected.

Completion of Measurement Sequence

After the requested number of acceptable runs is acquired, the program proceeds to process the data. Any further data transferred to the HP-85B from the coincidence electronics are ignored until a new series of measurements is initiated by the program.

DATA ANALYSIS FOR PLUTONIUM MASS

After completion of the measurement sequence for a verification run, the computer proceeds to process the data to calculate plutonium mass. The processing of the data for background, normalization, and special runs is explained on pp. 63-66.

Counting Rates

For plutonium mass calculations, the totals and coincidence rates are corrected for background and are normalized. The printed errors are standard deviations resulting from counting statistics and the normalization constant error.

Effective ^{240}Pu Mass and Plutonium Mass

The effective ^{240}Pu mass is calculated from calibration parameters stored in the program. The printed mass error is the estimated standard deviation and includes the error from counting statistics, the normalization-constant error, and the systematic error from the calibration procedure. The plutonium mass is then calculated from the isotopic composition; the relative error for the plutonium mass is taken as the relative error for the effective ^{240}Pu mass.

Mass Differences Assay vs Declared

The declared plutonium mass (corrected to the present date) is printed again for direct comparison. The plutonium mass difference δ = (assay - declared) is then printed in units of grams and also as percent of the declared plutonium mass. Immediately below the mass difference the measurement error (1σ) for the plutonium mass is printed in units of grams and also as percent of the declared plutonium mass.

Multiplication Correction

If the material being measured also has been calibrated with coincidence rates corrected for neutron multiplication, then a second assay is performed using the multiplication-corrected coincidence rate.

The program calculates and prints the following quantities:

(1) The neutron multiplication M.

(2) The (α,n) to spontaneous-fission neutron ratio.

Multiplication Correction (cont)

(3) The correction factor CF (printed as f) for the coincidence rate.

(4) The corrected coincidence rate R.

If the calculation results in a nonphysical value for M (M < 1 or imaginary M), then the mass calculation is skipped.

The assay mass and error and the (assay-declared) mass difference are again calculated (and again printed) from the corrected coincidence rate using the appropriate calibration curve. No attempt has been made to account for the error introduced by the multiplication-correction procedure, because the sources of error are not well known and because they tend to be calibrated out.

User Comments

After the completion of data analysis and printout, the program requests comments. Typical comments could be:

THIS SAMPLE CAN IS 12CM HIGH
INSTEAD OF THE USUAL 10CM.

ANOTHER SAMPLE WAS MOVED INTO
THE ROOM DURING THE 2ND RUN.

The comments can be up to 3 lines with up to 32 characters per line (full screen width). However, no commas can be used; use semicolons instead. If there are no (further) comments to be entered,

User Comments (cont)

just press END LINE. If tape storage is being used, the comments are then stored on tape.

NEXT OPERATION SEQUENCE

After the comments are entered, the program asks the user to select by number the next operation as follows:

(1) Continue with measurements
This is the usual choice. The program branches back and asks the user to select the next measurement type (see Measurement Type Sequences on p. 63).

(2) Change background or normalization
The values of the background totals rate B and the normalization constant K can be changed from the keyboard with this option. The program asks the user to enter B, K, and the standard deviation of K. Then the program repeats the request to select the next operation as shown above, at the beginning of this section.

(3) Change material
If option 3 is selected, the program branches back and asks the user to select the material type. This is the same as restarting the program, but saves re-entering the facility and user's names, date, and time.

NEXT OPERATION SEQUENCE (cont)

(4) Select operating features

Option 4 allows the operating features to be changed (see p. 73 for details). After the selection is made, the program repeats the request to select the next operation, as shown at the beginning of this section.

(5) Create a new data tape

Option 5 is an extra feature that allows the user to create a new data tape from a spare tape. The program asks the user to insert the spare tape and warns that the tape will be erased. The RECORD switch on the tape cassette must be placed in the position indicated by the arrow. It takes about 6 minutes to format a new tape. After the operation is completed, the program repeats the request to select the next operation, as shown above.

(6) Terminate

Option 6 stops the program. If tape storage is used, the data file is closed before the program stops. The HP-85B displays "Program terminated."

DATA STORAGE ON MAGNETIC TAPE

Data storage on magnetic tape is used to provide a back-up data file and to allow automated reanalysis of the data (for example, with an improved calibration curve). Although tape storage is optional, it is considered to be the normal mode of operation.

DATA STORAGE ON MAGNETIC TAPE (cont)

When tape storage is being used, a data record is written on tape for every set of measurement data transferred to the HP-85B. Every data record contains all of the information needed to reanalyze the coincidence counter data: raw data (time, totals, R&A coincidence counts and A coincidence counts), declared mass, isotopic data, sample ID, facility name, date, time, background totals rate, normalization constant, etc. Up to 400 measurements can be made for each data tape.

Data Tape

Data tapes are labeled "DATA CC." If a data tape is not available, one can be made as follows:

(1) Get a spare tape cassette. All old information on the tape will be lost.

(2) Put the RECORD switch on the cassette in the position shown by the arrow.

(3) Insert the tape into the HP-85B (label side up).

(4) Enter ERASETAPE, press END LINE, and wait for the tape directory to be cleared.

(5) Enter

```
CREATE "DATA," 400, 512
```

then press END LINE and wait about 6 minutes.

Operation

Simply follow the instructions given by the HP-85B. The program starts storing data in the first empty record found on the tape and sets the run number accordingly. For example, if the first empty record is the thirty-seventh record, the first run number will be 37. The run number is then increased by one for each subsequent measurement.

If a tape error occurs during the data storage operation, an error message is printed and the program automatically switches to operation without tape storage.

SELECTABLE OPERATING FEATURES

Some features of the program that can be selected by number by the user and changed during the operation of the program are:

(1) Accidentals/Totals Test
The accidentals/totals test is explained on p. 66. This test is performed in normal operation.

(2) 3σ Test
The 3σ test is explained on p. 67. This test is performed in normal operation.

(3) Intermediate Calculations
When two or more runs are made for a particular measurement condition, the user has the choice of calculating intermediate results (rates, masses, etc.) after each run or calculating results only after all

SELECTABLE OPERATING FEATURES (cont)

the runs are completed. Regardless of whether intermediate calculations are performed, the final calculation is based on the weighted average of all the runs. In normal operation intermediate calculations are not performed.

(4) Data from Keyboard
In normal operation, the coincidence counter data are transferred to the HP-85B on the serial (RS-232) interface. However, for reanalysis of data or program testing it is sometimes desirable to enter the data from the HP-85B keyboard. The user has the choice of data entry mode.

Operation

When the program is started, the user is asked whether he wants normal operation. If the answer is yes (Y), then the accidentals/totals test and 3σ test are performed, no intermediate calculations are done, and data are transferred to the HP-85B by the serial interface.

If the answer is no (N), then the user is asked to select by number the desired operation features described above.

Examples:

(1) If the user wants to enter data from the keyboard, but wants no tests or intermediate calculations, he enters 4 and presses END LINE.

Operation (cont)

(2) If the user wants all features, he enters 1234 and presses END LINE.

(3) Entering 12 and pressing END LINE is the same as selecting normal operation.

The features selected can be changed during operation of the program. When the program asks the user to select the next operation as explained on p. 70, he can choose item 4 (Select operating features).

ACKNOWLEDGMENTS

The pictorial style in these procedures follows that proposed by J. F. Foley in a working draft at Los Alamos in 1979, "Field Manual for the High-Level Neutron Coincidence Counter (HLNCC)." This same style was later incorporated into IAEA IMI 29, "Instructions for the Use of the IAEA High Level Neutron Coincidence Counter."

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