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PACIFIC NORTHWEST LABORATORY

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BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

BNWL-508
UC-37, Instruments

By

Instrumentation Section
Applied Physics and Electronics Department

September, 1967

SPAIN INVESTIGATION 4 162

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

A PORTABLE GAMMA SPECTROMETER FOR SAFEGUARDS USE

E. M. Sheen, J. I. Forsberg, and C. A. Ratcliffe

ABSTRACT

A compact, portable gamma spectrometer was developed for use by the United States Atomic Energy Commission Division of International Affairs in safeguarding inventories of ^{235}U contained in nuclear reactor unirradiated fuel elements or in various other sources. General purpose gamma spectrometry is also conveniently carried out using the instrument.

Main chassis solid state circuitry, excluding the scintillation probe and preamplifier, comprises a wide-range high voltage supply, double delay line pulse amplifier, split-window gain stabilizer, single channel pulse height, analyzer, six decade scaler, automatic timer, count rate meter, low voltage regulators, and a battery charger. Instrument power is supplied by a NiCd rechargeable battery, also located in the main chassis, which provides a maximum of 25 hr continuous operation. All electronic circuits, except the battery charger, are fabricated in plug-in modules. The modular electronics, probe, and probe stand are mounted in two rugged compact fiberglass transit cases.

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INTRODUCTION

This report describes a compact portable single channel gamma spectrometer developed for the US-AEC Division of International Affairs. Gamma spectrometers have been used in a number of ways to evaluate the quantity or enrichment level of unirradiated fuel elements. One of the simpler techniques has been to use 4π geometry to determine the quantity of uranium within a fuel element.⁽¹⁾ This determination requires both the enrichment level of the uranium and the fuel geometry to be the same in all cases. Another method of using a gamma spectrometer has been to determine enrichment level using a difference technique.⁽²⁾ The difference technique uses the spectrometer to differentiate between the emanations from ^{235}U and ^{238}U . This technique is applicable for determining enrichment of uranium samples of identical size and shape. A ratio technique has been developed for determining enrichment level of uranium of various sizes and shapes.⁽³⁾ This technique uses the ratio of the activities of the emanations from the two uranium isotopes of interest, thereby essentially eliminating the geometry factor. The accuracy of this technique can be degraded by non-equilibrium of the decay chains comprising the ^{238}U continuum, however. Although the above methods lend themselves well to the laboratory situation, the required instrumentation is bulky and not easily moved to the field.

The United States Atomic Energy Commission Division of International Affairs (AEC-DIA) audits the ^{235}U enrichment of nuclear reactor unirradiated fuels to safeguard quantity inventories. Use of gamma spectrometry in this effort is described by Tubbs.⁽⁴⁾ For this work in identifying fuel elements in a nondestructive manner and for general purpose gamma spectrometry,

a portable, light weight spectrometer is necessary because of the world-wide locations of the materials. Multichannel analysis would be desirable except that a complete analyzer and data readout system is inappropriately large and consumes excessive battery power. Single channel analysis permits the instrument to be operated from modest rechargeable batteries, thus avoiding difficulties in powering the instrument from ac mains in the field.

DISCUSSION

For the portable gamma spectrometer, all of the electronic circuitry except the preamplifier is of the low power solid state type and is packaged in a single 17 x 13 x 3 in. chassis. This chassis also includes a 2 A-hr NiCd rechargeable battery and the battery charger. The solid state preamplifier is contained in the probe, and the probe, probe stand, and collimators are carried in a separate transit case. Figure 1 illustrates the physical characteristics of the main chassis showing the eight modular principal circuits (Layout details are shown later in Figure 9). In Figure 2, the bottom view of the modules, battery, meter, and other components are shown with the bottom cover removed. Figure 3 shows the two transit cases with the main chassis modules in one and the probe, collimators, and probe stand in the other.

Each major circuit--high voltage supply, pulse amplifier, gain stabilizer, single channel analyzer, scaler, automatic timer, count rate circuits, and low voltage regulator--is fabricated in a small plug-in module measuring 6 x 1.5 x 3 in. These major circuits, the detector, probe voltage divider, and preamplifier, are discussed individually in the following portions of this report. An appendix includes both detailed and condensed operating instructions and detailed specifications.

3

BNWL-508

PNL 0670303-4

FIGURE 1. Main Chassis with Modules

PNL 0670303-5

FIGURE 2. Bottom View of Main Chassis

PNL 0670303-1

FIGURE 3. *Instrument and Probe with Transit Cases*

DETECTOR, PROBE AND PREAMPLIFIER

The detector, chosen to facilitate automatic gain stabilization, is an integral assembly* photomultiplier and NaI(Tl) scintillation crystal containing a small ^{241}Am source that causes generation of light pulses equivalent to gamma-caused pulses in the 3 to 5 MeV range. Figure 4 contains the instrument block diagram as well as circuit diagrams for the probe, preamplifier, main amplifier, and high voltage supply.

In the voltage divider circuit for the photomultiplier, resistors of higher than conventional values are used to avoid requiring a high-current-capacity, high voltage supply. However, silicon low power signal diodes (1N4149) are used in the reverse bias direction to assure low dynamic resistance for the ninth and tenth dynodes. Use of this technique resulted in only 30 μA being typically required from the high voltage supply, yet maintained the ninth and tenth dynode voltages stable to within 0.25 V to 0.5 V at approximately one mR/hr (^{60}Co) in a test using a 3-in. x 3-in. NaI(Tl) scintillation crystal. For this test, an amplifier gain of 300 was used for pulse height analysis with a high voltage setting of 800 to 900 V dc.

The preamplifier is a two transistor (Q101 and 102), unity gain, complementary doublet with an output impedance of 50 Ω to permit driving long 50 Ω coaxial cables if desired. A decay time of approximately 50 to 100 μsec for the negative voltage pulses is provided by the preamplifier to assure proper input voltage to the double delay line linear pulse amplifier. A small printed circuit card serves for the preamplifier components and is mounted on a plastic sleeve at the base of the photomultiplier socket of the probe.

HIGH VOLTAGE SUPPLY

Simple transistor blocking oscillator high voltage supplies with corona-tube shunt regulators are frequently used in

* Type A8S8/2, Harshaw Chemical Company

FIGURE 4. Block Diagram, Probe and Preamplifier, Pulse Amplifier, and High Voltage Supply

portable nuclear instrumentation.^(5,6) Inherent disadvantages of shunt voltage regulation are avoided by a feedback technique that maintains constant corona-tube current and uses the tube as a voltage reference instead of as a current shunt. A high voltage supply employing the feedback technique was developed for this portable spectrometer application. The conventional blocking oscillator supply requires initial adjustment and, in general, is adjusted for one corona tube and a specific output voltage. With the feedback technique, no adjustment is required and several corona tubes can be switched to provide corresponding output voltages.

Figure 4 shows the simple 4-transistor circuit that uses the feedback technique and provides up to 30 μ A load current with 700, 800, 900, 1,000, 1,100 or 1,200 V dc output. The corona-tube current is maintained at approximately 15 μ A by R409 and Q404 base current. This current is amplified by the forward current gain of both Q404 and Q403 with the resulting current translated to voltage by the low pass filter, C404 and R405 and R406. An emitter follower, Q402, drives resistor R403 to provide the proper average base current in transistor Q401, which results in sufficient blocking oscillator output current to drive the load and give constant corona-tube current. Transistor Q401 and associated components form the high output voltage blocking oscillator. A prototype of this circuit was stable with temperature within the temperature coefficient of the reference element at constant current (0.009%/°C).

LINEAR PULSE AMPLIFIER

The linear pulse amplifier (Figure 4) is a double delay line type quite similar to a design by R. L. Chase.⁽⁷⁾ To assure design compatibility with the other circuitry and to operate the complete instrument from only two low voltage buses (± 8 V dc), the collector resistors in common emitter

stages were replaced with transistor current sources. The double delay line amplifier provides bipolar output pulses to avoid placing a charge component, during a pulse, on any coupling capacitors connected to the amplifier. This technique avoids large photopeak energy shift at high count rates.

Transistors Q201, Q202, Q203, and associated components form a simple high frequency pulse operational amplifier with the current summing point at the base of Q202. Transistor Q201 is a current source to give a high ac impedance at the collector of Q202 and correspondingly to increase the open loop voltage gain. Closed loop voltage gain is adjusted by switch SW201-A, which adjusts the gain by varying the feedback resistance. R215, R216, or R217. Transistors Q208, Q209, and Q210 form a second amplifier, similar to the first, which inverts the delayed input pulse and, through R213, connects it to the current summing junction at the base of Q202. Potentiometer P201 is adjusted to cause the direct input current to just equal the delayed and inverted current, resulting in an output pulse which is unipolar and clipped to approximately 0.7 μ sec in length. Diodes D221 and D222 limit the maximum amplitude of this pulse which appears at test point TP201.

The second delay line clipping stage similarly uses two pulse-operational amplifiers, with the delayed and inverted pulse in this stage giving the second portion of the bipolar pulse at the output of the complementary emitter follower, Q206 and Q207. This output also appears on test point TP202. The bipolar shaped output pulse is amplified and inverted by two parallel output stages with different voltage gains to operate the single channel analyzer and the automatic gain stabilizer. Potentiometer P203 is adjusted to align the energy scale, allowing for the variation of ^{241}Am gamma equivalent pulse height from different integral assemblies. The amplifier output connecting with the single channel analyzer is amplitude limited

to ± 3 V by current feedback from reverse biased diodes D216, D217 and feedback capacitor C214. In normal operation only negligible current flows through this capacitor.

Tests on the prototype system indicated approximately one keV of photopeak shift of the 184 keV peak from ^{235}U in changing the integral count rate from 100,000 counts/min above 20 keV to 1.5×10^6 counts/min above 20 keV. The test source was 4.7 g of ^{235}U spaced 8 in. and 0.125 in. respectively from the end of the 2-in. x 2-in. scintillator crystal.

Other amplifier specifications of interest are as follows:
Delay Lines: 0.7 μsec clipping time for each line
Output Voltage: 0 to ± 2.5 V bipolar (positive, then negative)
X100 Overload Recovery: 5 μsec (with full gain)
Differential Linearity: $\pm 1\%$ (10% to 100% of full scale).

GAIN STABILIZER

Voltage pulses resulting from the ^{241}Am -caused scintillations are maintained at constant amplitude by circuitry that adjusts the photomultiplier high voltage. The distribution of these pulse heights is centered about the centerline of a dual-window pulse height analyzer as a result of gain control by the gain stabilizer. Circuitry for the gain stabilizer is shown by Figure 5. Basic pulse height discrimination for the dual window analyzer is accomplished by three voltage comparators for the lower, center, and upper discrimination levels. Each of these comparators consists of a matched, dual npn transistor, Q301, Q302, or Q303, with the left hand transistor "off" biased and with a tunnel diode current discriminator in the collector circuit. The tunnel diode peak current is approximately 1 mA and the current through the resistor connecting with the emitter pair is 2 mA. Thus, at the tunnel diode peak point current, the current through each transistor of the dual is approximately balanced and the emitter-base voltages are balanced. Tests on

this circuit indicated excellent temperature stability with less than 0.002%/°C drift at a 1 V reference level using 1 μ sec pulse widths. Output pulses from the tunnel diodes are shaped by monostable multivibrators (Q304 through Q309). Input pulses greater than the lower discrimination level, but less than the center level, trigger the lower monostable multivibrator. The negative output pulse appearing on the collector of Q309 (TP307) is differentiated by C315. The trailing or positive edge of this pulse then causes Q314 to conduct and an output pulse to appear at TP308, the lower window binary input. Transistor Q314 is inhibited from conduction by Q313 if the input pulse crosses both the lower and center discrimination voltage levels. Operation of the voltage window between the center and upper windows is similar, with the output pulses appearing at TP303, the upper window binary input. Output voltage pulses from the upper window binary are converted to increments of positive charge and stored on capacitor C326. Lower window pulses are converted to increments of negative charge and are also stored on C326. Thus, if the gain stabilizer input pulse height distribution is centered about the center line, no voltage change occurs on C326. However, if the distribution is not centered, an error voltage appears on C326 and is amplified by the solid state operational amplifier, which increases or decreases the probe photomultiplier cathode voltage to change the gain and restore the pulse height distribution about the center line.

A differential count rate meter with a fast time constant is used to accomplish easily and rapidly the initial system gain adjustment by nulling the ratemeter reading. This positions the pulse height distribution about the gain stabilizer voltage discrimination centerline. Transistor Q324 and associated diode pumps and other components comprise the ratemeter.

An "out of limits" detector circuit in the gain stabilizer examines the operational amplifier output voltage and energizes a small flashing red lamp, IL301, to warn the operator that the gain has drifted beyond the compensation limits of the gain stabilizer circuitry. A maximum gain adjustment of ± 5 V to the photomultiplier is thus permitted and excursions beyond this are considered to be caused by abnormal drift.

SCALING TIME

The scaler can be timed either manually or automatically by the scaling time circuitry shown by Figure 6. For low power consumption and compact fabrication, the scaling time base is a very low frequency unijunction transistor relaxation oscillator, Q606, providing one pulse each 15/16 sec. These pulses are frequency divided by a chain of low power binaries giving a stop pulse at the end of 1/4, 1/2, 1, 2, ..., and 32 min. A quartz crystal oscillator (10 kHz) is provided to check both the low frequency time base and the scaler for proper operation. Transistors Q612 through Q615 with associated components form the 10 kHz oscillator.

Single channel analyzer pulses are connected to the count rate circuit and scaler through a pulse gate, transistors Q610 and Q611, which are controlled by a binary, Q607 and Q608. Actuating the start-stop switch from stop to start sets the binary by applying base current through R612 to turn on Q607 and Q610. Transistor Q610 applies collector voltage to Q611 through R623. At the conclusion of the switch action, a positive pulse appears at the emitter of Q606, an emitter follower, which resets the timer binaries 1 through 12. Also, the collector current of emitter follower Q606 principally comes from the base of Q605 and turns on Q605 to give a reset pulse to the scaler circuitry to automatically reset the scaler following the stop-to-start switch action. At the conclusion of the scaling time selected by the scaling time switch, SW602, a positive pulse

from the selected binary resets the gate control binary by turning on Q608, through R618. Gate transistor Q611 thus has no collector voltage, and no output pulses appear on the collector of Q611 to operate either the count rate circuit or the scaler.

For the purposes of this instrument, temperature stability of the unijunction time base proved adequate (-0.33% drift from 70 to 110 °F) and the accuracy adjusted to $\pm 0.5\%$. For higher accuracy and stability, a quartz crystal frequency standard could be used and the output frequency divided by using additional binaries, but there would be the corresponding disadvantage of increased complexity and power dissipation.

SINGLE CHANNEL ANALYZER

The single channel analyzer circuitry is also shown by Figure 5 and the principle of operation is identical to one window of the gain stabilizer. However, off-bias for the left hand transistors of the dual transistor units is derived from the 10 turn base line potentiometer, P801. The right hand transistor bases are referenced to ground potential for the lower level pair and 0 to 1.25 V for the upper level pair by P803, which provides the window adjustment. Output pulses from the single channel analyzer appear at the collector of Q809 and connect through gating circuitry in the scaling time module to either the count rate meter circuit or the scaler. Integral or differential counting mode is accomplished by switch SW801, which removes the positive inhibiting pulse from the base of gating transistor Q807.

COUNT RATE CIRCUIT

The count rate circuit used with this instrument is also shown in Figure 6. A binary, Q701 and Q702, operates switching transistors Q703 and Q704, and the collector of Q704 connects to the bases of a complementary emitter follower, Q705 and Q706,

which drives one of the range capacitors, C705 through C710, as selected by SW701. This capacitor discharges through D703 and places charge on the time constant capacitors C712, C713, or C714, selected by SW702. The input capacitor charges from the output of emitter follower Q707, which has approximately the same emitter voltage as the voltage from the base to the anode of D705. Thus, the charge transferred through the input capacitor is independent of the output voltage, and the count rate circuit operation is linear. Count rate indication is obtained by measuring the current through R713 with the 1 mA panel meter. Linearity of the circuit is approximately 1% of full scale. Calibration is accomplished by adjustment of P701.

For this instrument, the count rate circuit is principally used in gamma energy calibration "peaking" or checking integral count rate above some base line setting slightly above the electronic noise level, approximately 20 keV.

If no scaler is incorporated into a portable instrument or if the rate meter is to be used in obtaining reasonably accurate data, a 1, 3, 10, 30 switching sequence would clearly be preferable to decade steps. The only added complexity would be an increase in the number of input capacitors.

SCALER

A principal consideration in scaler design for portable nucleonic instrumentation is power consumption. Neon type indicating devices require a voltage greater than normal portable instrument battery voltages and thus require a dc to dc converter.

The total power consumption for scaler indication by either incandescent or neon lamps is excessive. Very miniature low-voltage indicating incandescent lamps, available in dissipations of only 15 to 25 mW, could be used. Another useful technique is to connect the indicators only during actual scaler observation or during reading of the stored count.⁽⁸⁾ A technique requiring a maximum power of only a few mW is employed in this scaler to read the count serially, one decade at a time, on a zero through nine meter scale of a panel meter. The same meter can, of course, be used for other functions. Scaler circuitry for the low power 6 decade scaler is shown by Figure 7. To operate the panel meter, the decade scaler binary output voltages are converted to 1, 2, 4, 8 weighted currents and summed with the meter. Thus, a B+ voltage of 8 V dc and weighting resistors of 80 k Ω , 40 k Ω , and 10 k Ω respectively give 0.1, 0.2, 0.4, and 0.8 mA respectively to operate a one mA full scale meter with a zero through nine scale with 0.1 mA per division. Resistors R8, R18, R27, and R36 are the current weighting resistors for the first decade, and R6, R14, R21 and R28 are typical current weighting resistors for the other decades. Saturating transistor switches, Q3, Q6, Q9, and Q12, are used to buffer the binary outputs and prevent panel switch action from changing the binary state.

The developed instrument uses a 6-decade scaler for reading the stored count and requires only 25 mA from an 8 V dc bus to drive the scaler and provide readout. At the time this scaler was designed, integrated circuits required more power per binary than did discrete components units. However, recently available integrated circuits can permit a factor of two improvement over the discrete component design.⁽⁹⁾ These or similar low-power integrated circuits could probably be incorporated advantageously into any future portable nucleonic instrumentation requiring scalers. The discrete component scaler of Figure 7 operated with a 1 μ sec pulse pair resolution.

FIGURE 7. Scaler Circuits

LOW VOLTAGE REGULATORS

Battery terminal voltage variation with life or charge cycle requires provision of regulated voltages for critical points such as single channel analyzer base line potentiometers, etc. Internal Zener diodes may be applied at these critical points or high quality voltage regulators can be designed to supply all circuits with stable B+ voltages. The latter method may improve stability of some circuits and reduce total power consumption.

The developed portable instrument has two voltage regulators, shown in Figure 8, which regulate the ± 11 to ± 15 V dc battery terminal voltages to ± 8.0 V dc. These voltages are maintained constant to within approximately 0.014 V over the battery working voltage by the regulator circuits. Dual transistors Q904 and Q908 compare a fraction of the output voltage with the voltage developed across the voltage reference diodes D901 and D902 respectively. Any error or difference voltage is amplified by the dual transistors to operate emitter followers Q903 or Q907 which drive the base connections of the pass elements, transistors Q901 and Q902; Q905 and Q906.

BATTERIES

Two 12 V (nominal), rechargeable, 2 A-hr, NiCd batteries were used with a 75 mA load on the +12 V battery and 62 mA on the -12 V unit. The calculated maximum battery operating time between charge cycles is thus in excess of 25 hr. Normal operation of the instrument would be for 8 hr or less with subsequent recharge to assure maximum battery life.

BATTERY CHARGER

Requirements for this instrument include operation over a line voltage range of 115 to 230 V ac without manual switching, and simultaneously, a frequency range of 50 to 60 Hz. These requirements were met with a fairly simple charger shown in the circuit diagram, Figure 8. A unity turns-ratio isolation transformer,

T901, is driven by an ac current source with the current approximately equal to the input voltage divided by the capacitive reactance of C903. This alternating current is rectified for charging the battery by a bridge rectifier, D903 through D906. Excess current caused by high frequency or high input voltage is shunted through a shunt regulator, Q909. Power dissipation during charging is not a principle consideration unless it results in excessive heating. For this instrument at 250 V ac, 60 Hz input, the shunt element dissipates approximately 6 W, and the heat is conducted through the main chassis frame to the front panel. Use of the capacitance input technique also avoids transformer damage or fuse opening resulting from attempted operation from a dc line.

PANEL AND CONTROL LAYOUT

Main chassis panel positions of the electronic circuit modules, panel meter, ac line connector, and controls are shown in Figure 9, which also shows the dimensions of the panels and references the engraving vendor.

TRANSIT CASES

The transit cases are manufactured commercially* from fiberglass and epoxy. These cases are sturdy enough that the instrument chassis with padding suffers no damage with a 200 lb man standing on the center of a flat side of the case. Total case weight with padding is 11 to 12 lb. Case measurements are 14 x 19 x 6 in. Drawings and other information are given in Figures 10 and 11.

RESULTS AND CONCLUSIONS

Use of the developed portable spectrometer during six months of international inspection trips by the AEC-DIA, demonstrated the usefulness of the instrument. Basic goals of performance

* Koch & Sons, Inc., Box 102, Corte Madera, California

FIGURE 8. Voltage Regulators, Battery Charger, and Panel Switching

TOP VIEW
COVER NOT SHOWN

PART NO	PART DIA	PART DEPTH
A	5/16	2/16
B	3/8	.593
C	15/32	2/8
D	1"	1"
E	3/32	2/8
F	3/8	2/8
G	3/8	2/8
H	3/32	3/32
J	2/8	2/8
K	4 1/2	2/16
L	15/16	2/8
M	1 1/4	3/8
N	2/8	2/16
P	11/16	9/16

E.L. "A-A"

NOTES

1. TRANSIT CASE SHALL BE CONSTRUCTED OF FIBERGLASS WITH DOUBLE ACTION DRAW BOLT, SST PIANO HINGE & LOCK.
2. FOAM PAD SHALL WEIGH 3" / CU FT.
3. CASE COLOR SHALL BE AIR FORCE BLUE.
4. FOR CONSTRUCTION OF TRANSIT CASE & FOAM PAD, SEE H. KOCH & SONS, INC., CORTE MEDERA, CALIFORNIA, DWGS 310 CASE MOD PAD-JET DWG. 310-11835 DWG. 159-11836

FIGURE 10. Spectrometer Transit Case Details

NOTES

1. TRANSIT CASE TO BE CONSTRUCTED OF FIBERGLASS WITH DOUBLE ACTION DRAW BOLT, SST PIANO HINGE & LOCK.
 2. FOAM PAD SHALL WEIGH 3" / CU FT.
 3. CASE COLOR SHALL BE AIR FORCE BLUE.
 4. FOR CONSTRUCTION OF TRANSIT CASE & FOAM PAD, SEE H. KOCH & SONS, INC., CORTE MEDEA, CALIFORNIA, DWGS
- PAD-BODY - DWG. 159-11857
PAD-TOP - DWG. 159-11858
TRANSIT CASE- MODEL 310 MODIFIED

FIGURE 11. Details of Detector Transit Case

comparable to normal laboratory instrumentation were fully achieved with a rugged, portable, self-powered instrument.

Packaging the electronics in suitcase-style transit cases with foam padding between the components and case wall was successful. The instrument survived ordinarily luggage handling during the many trips. The described technique of interrogating the scaler and reading the stored count on a multipurpose panel meter was found to be convenient by most operators.

As the original probe stand, fabricated from stainless steel, was found to be excessively heavy, a lightweight aluminum stand was designed and fabricated which reduced the weight approximately 9 lb.

Instruments of this type developed in the near future should probably incorporate the new low power integrated circuits to further reduce size, weight, cost, and power requirement.

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BNWL-508

APPENDIX I
DETAILED OPERATING INSTRUCTIONS

APPENDIX I
DETAILED OPERATING INSTRUCTIONS
UNPACKING INSTRUMENT AND CONNECTING PROBE

1.1

The transit case locks are identical and a proper key will open either case. After unlocking, release the side drawbolts and then release the front drawbolts and open the case lid for both cases. Figure 3 shows the electronic system and probe components.

1.2

If the main selector switch is in the POWER OFF position as shown below, proceed. If it is in any other position turn it to OFF and proceed.

Neg PNL 0670551-11

1.3

Assemble the probe stand and place the probe with main shield attached and connector end down on a table.

1.4

Insert the Harshaw Integral Assembly into the probe gently and align the socket keys by slowly rotating the assembly. The

assembly will drop slightly and resist further rotations when the key is aligned. Press the integral assembly firmly in the socket with the thumb, as shown below.

1.5

Attach a collimator if desired, being careful not to use excessive force. The collimators attach with a twist cap.

1.6

Refer to the figure in step 1.3 and adjust the yoke height to $x = \text{___ inches}$.

1.7

Place the probe carefully into the yoke after slowly turning the probe over with the integral assembly down and after determining that the socket has sufficient friction to hold the integral assembly. If a collimator is used, it holds the assembly in the probe.

1.8

Discharge the high voltage supply with the 40 M Ω resistor load supplied if the instrument has been in a main selector switch position other than OFF within the hour. Failure to observe this step should not damage the probe preamplifier, but does stress it and possibly could cause failure.

Neg PNL 0670551-1

1.9

Connect the cables, carefully aligning the key on the signal multipin connectors. NOTE: To avoid confusion, the cable-connector arrangement allows only one possible connection.

1.10

The instrument should now be ready for initial tests to determine if it is in operating order. The normal position of the screwdriver adjustments are shown here. The GAIN STABILIZER is normally ON, but the instrument can be used without it. In this case turn it OFF.

NOTE: Use 3 or 10 sec time constant for very low count rates to reduce meter fluctuation. Base line controls must then be moved much more slowly.

Neg PNL 0670551-1

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APPENDIX II
TESTS AFTER TRANSPORTING

APPENDIX II TESTS AFTER TRANSPORTING

2.1

Rotate the main selector switch (MSS) as shown below.

NOTE: The READJUST lamp may flash once when the MSS is rotated. This is normal and serves to check the lamp occasionally.

MSS

Neg PNL 0670551-12

The battery voltage is now indicated on the meter and a fully charged battery should read above 58 on the top scale. A reading above 55 will probably permit 4 hr or more of operation. The battery is a 2 A-hr unit and provides a calculated operating time (from a fully charged state) of approximately 25 hr. Normally one should recharge after 10 to 15 hr of operation. If the batteries read less than 52 on the meter, proceed to Section III of these instructions.

2.2

Rotate the MSS to the position BATT. CHECK -, and repeat the measurement of 2.1. Refer to 2.1 for position of the MSS.

2.3

Rotate the MSS and GAIN TRIM controls as shown below.

Neg PNL 0670551-1

MSS

Neg PNL 0670551-13

Increase (clockwise rotation) the COARSE GAIN TRIM control slowly while observing the meter. The meter reading should go up scale and then down to fluctuating about zero due to count rate statistics from the internal radiation source in the NaI(Tl) crystal. Refer to the following sketch.

At the proper operating point, advancing the FINE GAIN control clockwise should cause the meter to go below zero to the downscale stop. Rotating the FINE GAIN control counterclockwise should cause upscale deflection. CAUTION: If this is not so, start over with the COARSE gain fully counterclockwise and repeat the above instructions.

NOTE: The MSS position CHECK <50 is normally not used, but can be used to observe the gain stabilizer control. The small red READJUST lamp flashes if the meter exceeds approximately 80. During normal data taking the reading is not expected to exceed 50 due to compensating for phototube gain drift during a few hours.

2.4

Set the SCALING TIME and MSS controls as shown below and wait 4 or 5 sec.

Neg PNL 0670551-6

MSS

Neg PNL 0670551-19

Change the START-STOP switch from STOP to START and observe the meter fluctuating with periodic motion. When the meter needle stops fluctuating the scaler should read 150,000 $\pm$ 750 from counting the 10 kHz oscillator pulses for 1/4 min. The scaler is read on the meter as shown below. In this example the scaler reads 150,293. Repeat for other times if desired.

Neg PNL 0670551-20 (1)

Neg PNL 0670551-19 (2)

Neg PNL 0670551-9 (3)

Neg PNL 0670551-8 (4)

Neg PNL 0670551-10 (5)

Neg PNL 0670551-14 (6)

Record: 150,293 as noted above.

NOTE: Rotating the DECADE switch should not change the stored number.

2.5

Repeat 2.4 for other times to test the timer. For example, if one min counting times are to be used in obtaining data, repeating step 2.4 with the SCALING TIME switch in the 1 position instead of the 1/4 position, the test oscillator should cause 10,000 pulses per sec for 60 sec or $600,000 \pm 1/2\%$ (or 3,000 pulses) to accumulate in the scaler. The scaler is, of course, read as in the example of 2.4.

2.6

Set the SCALING TIME and MSS controls as shown below.

Neg PNL 0670551-3

Neg PNL 0670551-18

Move this switch from STOP to START to begin an indefinite counting period.

2.7

Set the SINGLE CHANNEL ANALYZER as shown below.

250

Neg PNL 0670551-3

The window control is shown on 055 = 25 keV. For other window widths use the calibration chart supplied or assume 50 keV per turn.

2.8

Center a known calibration source with a gamma ray peak from 50 keV to one MeV.

USE SOURCE _____
 (has photopeaks at _____)
 Check height set in step 1.3 _____ inches
 DATE _____
 SIGNATURE _____

2.9

If the source selected in 2.8 is ^{235}U , set the MSS SINGLE CHANNEL ANALYZER and SCALING TIME controls as shown below.

Neg PNL 0670551-3

Example: Meter reads
420,000 c/min.

Neg PNL 0670551-18

Changing the START-STOP from STOP to START begins an indefinite count (done in step 2.6). If a source other than ^{235}U is used, note the highest photopeak in step 2.8 and set the BASELINE control well above this energy. Reduce the BASELINE setting slowly to find the photopeak by observing the

meter for maximum indication. Range changing may be necessary. If no meter deflection is observed, be sure the SCALING TIME START-STOP was changed from STOP to START.

The meter peak reading should occur with the BASELINE control at approximately the photopeak energy less 1/2 the window width in keV. Thus, ^{235}U should have the 184 keV photopeak at $184 - 25/2 \approx 172$. Typically this has been at room temperature, 177 to 178 on the BASELINE control (see 1.10).

CAUTION: If the READJUST lamp starts flashing during this step, repeat the ADJ. NULL procedure of step 2.3. This caution holds during any period that count information is obtained.

2.10

Set the MSS and SCALING TIME controls as shown below to check a known source using the scaler.

Neg PNL 0670551-2

MSS

Neg PNL 0670551-14

Begin a count by changing the START-STOP switch from STOP to START and observe the meter fluctuation. The counting time has elapsed when the meter has stopped fluctuating. The scaler is read out identically as before in step 2.4. Repeat this count several times to determine if the recorded number is within the expected established limits of the average data previously taken

Source # _____

should give _____ $\pm$ _____

If out of these limits, repeat the calibration and attempt the check again.

APPENDIX III
OPERATING FROM LINE AND RECHARGING THE BATTERY

APPENDIX III
OPERATING FROM LINE AND RECHARGING THE BATTERY

3.1

The instrument circuits are always powered from the internal batteries, but if the charger is operated while the instrument is in use, the result is much the same as if it were simply powered from the line. CAUTION: The green wire or round pin of the standard U.S. power plug connects internally, grounding the probe and instrument case. If the probe is touched to a grounded conductive table or other ground sources, circulating currents may cause noise or instrument malfunction. Further, if through a faulty plug or adapter the green wire or instrument ground is accidentally energized, the probe and instrument aluminum parts are energized and potentially hazardous. This is true of all equipment that has a ground wire. Thus, great care must be used to assure that the ground wire is really grounded, earthed, etc.

The simplest and safest method of using the instrument is probably to always operate it from the batteries and later recharge it from a convenient line with the probe disconnected, and the instrument in the fiberglass transit case.

3.2

The batteries are recharged by connecting the line cord and pressing the charger switch (red button). The red neon pilot indicates that the charger is powered. Check for power line over voltage, as shown below.

MSS

Neg PNL 0670551-15

This check assures that the input line current is less than the thermal limit current rating for the transformer. Full scale of 100 means 240 V ac, 60 Hz. Accidentally using dc line voltages less than 300 V does not damage the instrument but will not charge the batteries.

3.3

To check the charging current to the batteries, set the controls as shown below. Full scale charging current is 200 mA, and does not vary linearly with the input line voltage. The instrument should not be damaged by leaving the charge on longer than the time required to fully charge the batteries. Check the battery voltage as in step 2.1 and 2.2 with charger OFF! Leaving the charger on overnight for 16 hr should not damage the instrument and should fully charge the batteries if initially at the end point voltage (50 on meter in steps 2.1 and 2.2). However, if the instrument is only used for 8 hr or so, recharging for 4 or 5 hr should replace the charge used.

MSS

Neg PNL 0670551-17

3.4

When disconnecting the line power connector from the instrument, depress the small black button located nearest the case hinge on back of instrument and pull out the connector.

CAUTION: Before connecting probe cable, discharge the high voltage supply after turning the main selector switch to the POWER OFF position. Refer to step 1.8.

3.5

The regulated voltage supplied to all modules is ± 8 V dc and can be checked by the meter, as shown.

MSS

Neg PNL 0670551-16

Both + and - positions on the MSS should read $50 \pm 1/2$ on the meter. Only the + position is shown.

APPENDIX IV
PACKING AND TRANSPORTATION INSTRUCTIONS

APPENDIX IV PACKING AND TRANSPORTATION INSTRUCTIONS

4.1

CAUTION: Turn the main selector switch to the power OFF position as shown below or the batteries will discharge while the instrument is in transit.

MSS

Neg PNL 0670551-11

4.2

To pack the probe cables, etc., reverse the procedure used in unpacking (Appendix I).

4.3

CAUTION: Be sure and remove the NaI(Tl) INTEGRAL DETECTOR ASSEMBLY and carefully transport it with personal belongings when traveling by air. Avoid the thermal shock of transporting it with the regular checked baggage. Severe mechanical shock is thus avoided also.

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APPENDIX V
DETAILED SPECIFICATIONS

APPENDIX V

DETAILED SPECIFICATIONS

BATTERIES

Power drain: +12 V, 75 mA

-12 V, 62 mA

with all circuits operating.

Voltage operating range: 11 to 15 V each.

Battery check meter calibration: 22 V full scale. Meter
should read 50 to 65 each
battery (+ and -).

Battery discharge time (calculated): $\frac{2,000 \text{ mA hr}}{75 \text{ mA}} = 26.6 \text{ hr}$

Sonotone $\pm$ 12 V, 2 A-hr.

BATTERY CHARGER

Line input voltages: 75 to 240 V ac, 50 to 60 Hz input power
8 W at 115 V ac, 60 Hz. DC input does
not damage charger because of input
capacitor.

Line input current: Full scale line current (ac line <100
position of main switch) is 0.4 A rms @ 240
V ac 60 Hz. Fuse 1/2 A (one A, if needed).

Charging current to battery: 80 mA @ 75 V rms 60 Hz

150 mA @ 125 V rms 60 Hz

200 mA @ 250 V rms 60 Hz

Full scale meter calibration
for battery charging current:
200 mA; on "charge rate"
position of main switch.

LOW VOLTAGE REGULATOR

Input: $\pm$ (11 to 15 V dc) from batteries

Output: $\pm$ 8 V nominal

Stability with battery voltage variation: 0.014 V on 8 V bus as input varies from 11 to 15 V.

HIGH VOLTAGE SUPPLY

Output voltage: 700, 800, 900, 1,000, 1,100 V.

Output current: 40 μ A max, to special probe.

PULSE AMPLIFIER

Double delay line: 0.7 sec clipping time of each line.

Output voltage bipolar: 2.5 V full scale.

Differential linearity: $\pm 1\%$ (10% to 100% of full scale).

X100 overload recover: 5 μ sec.

GAIN STABILIZER

Split window analyzer and differential counter with operational amplifier to trim cathode voltage by ± 5 V to change gain approximately $\pm 5\%$. Warning indicator included for readjustment above ± 4 V. Approximately one minute slew time for 4 V change. Energy scale shift is -4 keV for 30,000 to 400,000 counts/min in 50 keV window @ ^{137}Cs photopeak.

SCALER

Six decade.

One microsecond pulse pair resolution.

Negative 8 V, 1/4 μ sec input pulse.

Output: 1,2,4,8, weighted current from 8V bus with decimal
9 = 0.9 mA. 10, 20, 40, 80 k Ω weighting resistors
with transistor switches.

Load: 25 mA from 8 V bus.

TIMER

Unijunction transistor oscillator, with unijunction selected to minimize drift.

Temperature stability: $-1/3\%$ total drift from 70 °F to 110 °F.

Counting periods: 1/4, 1/2, 1, 2, 4, 8, 16, 32 min.

The timer START-STOP switch automatically resets the scaler when moved to START.

Crystal controlled test oscillator included to check timer and scaler for time drift and proper operation of scaler.

SINGLE CHANNEL ANALYZER

Baseline: 0 to 1 MeV with original energy alignment and adjusted with 10 turn potentiometer (noise level approximately 25 keV).

Baseline linearity: overall differential linearity with amplifier $\pm 1\%$ for approximately 100 keV to 1 MeV.

Window: 0 to 1/2 MeV with original energy alignment and adjustment with a 10 turn potentiometer, nominally 50 keV/turn. See attached calibration curve.

COUNT RATE METER

Included for convenience in checking the energy calibration. 10^3 , 10^4 , 10^5 , 10^6 , 10^7 counts/min full scale.

WEIGHT

Gamma Spectrometer	21 lb	
Spectrometer and Case	32 lb	
Probe, Stand and Cables	36 lb	(27 with aluminum stand)
Probe, Stand, Cables and Case	<u>48 lb</u>	(39 with aluminum stand)
TOTAL	80 lb	
		(71 with aluminum stand)

APPENDIX VI
CONDENSED OPERATING INSTRUCTIONS

APPENDIX VI
CONDENSED OPERATING INSTRUCTIONS*

I - UNPACKING AND CONNECTING PROBE

STEP	SWITCH POSITIONS	ACTION
1.1	MSS:OFF	Release side drawbolts, then front, for both transit cases.
1.2	MSS:OFF	Check MSS position
1.3	MSS:OFF	Assemble probe stand
1.4	MSS:OFF	Insert Harshaw Integral Assembly
1.5	MSS:OFF	Attach collimator
1.6	MSS:OFF	Set yoke height $X = \text{---} \frac{\text{inches}}{\text{---}}$
1.7	MSS:OFF	Place probe in yoke
1.8	MSS:OFF	Discharge HV supply if ON in the past hour
1.9	MSS:OFF	Connect cables, be careful to align signal connector key.
1.10	MSS:OFF HV Supply: 900 V Amp.: 16 Count-Rate Time- Constant: 1, 3, or 10 sec	NONE - This is a check

* For use after reader is thoroughly familiar with DETAILED OPERATING INSTRUCTIONS

II - TESTS AFTER TRANSPORTING

STEP	SWITCH POSITIONS	ACTION
2.1	MSS:BATT. CHECK +	Read meter - should be above 50. Above 58 means batteries are fully charged.
2.2	-	
2.3	MSS:ADJ NULL	HV GAIN TRIM: COARSE fully CCW, FINE to center, slowly increase the COARSE. Meter should in- crease then decrease to fluctu- ating about zero. Reducing gain CCW slightly should cause meter to increase.
2.4	MSS:SCALER, SCALING TIME:STOP, 1/4 MIN, TEST	Wait 5 sec then: STOP to START should cause $150,000 \pm 750$ counts to accumulate in scaler. Read scaler by rotating DECADE switch from 10^5 to 10^4 , 10^3 , 10^2 , 10^1 , 10^0 noting the number indicated by the meter. Do this after meter stops fluctuating, as fluctuation means count is in progress.
2.5	Same as 2.4 except 1 MIN or 1/2 MIN time	Repeat 2.4 Should get $600,000 \pm 3,000$ for 1 min count of 10 kHz crystal controlled pulse sources.
2.6	MSS:COUNT RATE, SCALING TIME: MANUAL, STOP, and USE	STOP to START begins an indefinite counting period.
2.7	Same as 2.6	Set WINDOW to 055 for 25 keV, BASELINE above photopeak
2.8	Same as 2.6	Center known source under probe

II - TESTS AFTER TRANSPORTING (contd)

STEP	SWITCH POSITIONS	ACTION
2.9	Same as 2.6	Reduce BASELINE slowly, observing count rate to find the position for maximum count rate. This should be roughly photopeak - 1/2 of window width keV
2.10	MSS:SCALER SCALING TIME: - STOP - USE - 1 MIN	Move the START-STOP switch to START and observe the meter fluctuate. When fluctuation stops, interrogate the scaler and record the number. Source # _____ Should give _____ ± _____

III - OPERATING FROM LINE AND RECHARGING THE BATTERY

STEP	SWITCH POSITIONS	ACTION
3.1		Green wire or round pin is used to ground the instrument aluminum parts. Note: This places probe metal parts at ground potential and circulating ground currents can cause noise pulses. In general, avoid grounding probe if power line is connected. <u>CAUTION:</u> Do not connect green wire or round plug pin to any "Hot" line with respect to ground as this would energize the metal parts.
3.2	MSS:AC LINE <100 Press red button by power cord to energize charger. Red pilot indicates charger ON.	This measures ac line current. Full scale of 100 means approximately 0.4 A rms corresponding to 240 V ac, 60 Hz, which is the maximum rated input voltage.
3.3	MSS:CHARGE RATE to read current. MSS:OFF while charging batteries.	Full scale means 200 mA to batteries and instrument circuits. Check battery voltage using steps 2.1 and 2.2 with charger OFF. Batteries should be fully charged by leaving charger ON overnight or approximately 16 hr. Leave MSS OFF for maximum charge rate to batteries. If the batteries are partially charged and the number of usage hours is known, a charge time less than 16 hr would be appropriate. For example, for 8 hr of use, charging 4 or 5 hr is ample.
3.4	MSS:OFF Red neon pilot OFF by depressing red push button	After recharging batteries, disconnect line power cord.

III - OPERATING FROM LINE AND RECHARGING THE BATTERY (contd)

STEP	SWITCH POSITIONS	ACTION
3.5	MSS:REG VOLT CHECK + or -	This test measures the regulated ± 8 V supplied to all modules and can be done at any time. Meter should read $50 \pm 1/2$ for 8 V from regulator. This test checks the LOW VOLTAGE REGULATOR module, and is normally not necessary.

IV - PACKING AND TRANSPORTING INSTRUCTIONS

STEP	SWITCH POSITIONS	ACTION
4.1	MSS:OFF	<u>CAUTION:</u> Leaving power ON will discharge the batteries while the instrument is in transit.
4.2	MSS:OFF	Pack probe, cables, etc.
4.3	MSS:OFF	<u>CAUTION:</u> Remove NaI(Tl) detector assembly and avoid severe thermal and mechanical shock.

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