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This work was supported by the US Department of Energy, Office of Safeguards and Security, and by the Program for Technical Assistance to IAEA Safeguards.

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LA-9493-M
Manual
(ISPO-178)

UC-15
Issued: August 1982

LA--9493-II

DE82 021261

Neutron Coincidence Counter for MOX Fuel Pins in Storage Trays: Users' Manual

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NEUTRON COINCIDENCE COUNTER FOR MOX FUEL PINS IN STORAGE TRAYS: USERS' MANUAL

by

L. Cowder and H. Menlove

ABSTRACT

The neutron coincidence counter for measurement of mixed-oxide fuel pins in storage trays is described. The special detector head has been designed so that the detectors, high-voltage junction boxes, and electronics are interchangeable with those of the high-level neutron coincidence counter system.

This manual describes the system components and the operation and maintenance of the counter. The counter was developed at Los Alamos National Laboratory for in-plant inspection applications by the International Atomic Energy Agency.

1. INTRODUCTION

A special neutron coincidence counter detector head has been designed at Los Alamos National Laboratory for verification of fast-breeder-reactor (FBR) mixed-oxide (MOX) fuel pins contained in storage trays. The detector is part of a family of detectors based on the high-level neutron coincidence counter (HLNCC).¹ The ³He detector banks, preamplifier box, and electronics are identical with those of the HLNCC system.

The tray counter consists of a flat array of ³He tubes in polyethylene slabs; it uses standard HLNCC (HEC-100) electronics and a Hewlett-Packard HP-97 calculator for data collection and reduction. A through slot in the counter provides a cavity for insertion of the stainless steel tray used by the facility operator to handle fuel pins in batches of 24. The tray can be inserted into the front of the counter and removed from the front or back as the user desires.

Unlike the more desirable geometry found in cylindrical or hexagonal counters, the tray counter is flat. It is therefore necessary to match the individual detector banks to obtain a uniform spatial response. The uniform response region is approximately 55 cm long, corresponding to the active plutonium region of the fuel pins.

2. MECHANICAL COMPONENTS

The complete assay system, including the detector body, preamplifier box, electronics, and calculator, is shown in Fig. 1. Figure 2 gives a front view showing the rectangular cavity for the pin tray to enter the system.

2.1 Counter Body

The counter body is made up of two polyethylene slabs (79 cm long by 61 cm wide by 7.6 cm thick) that have been cross-drilled through the width to accept



Fig. 1.
Top view of assay system.

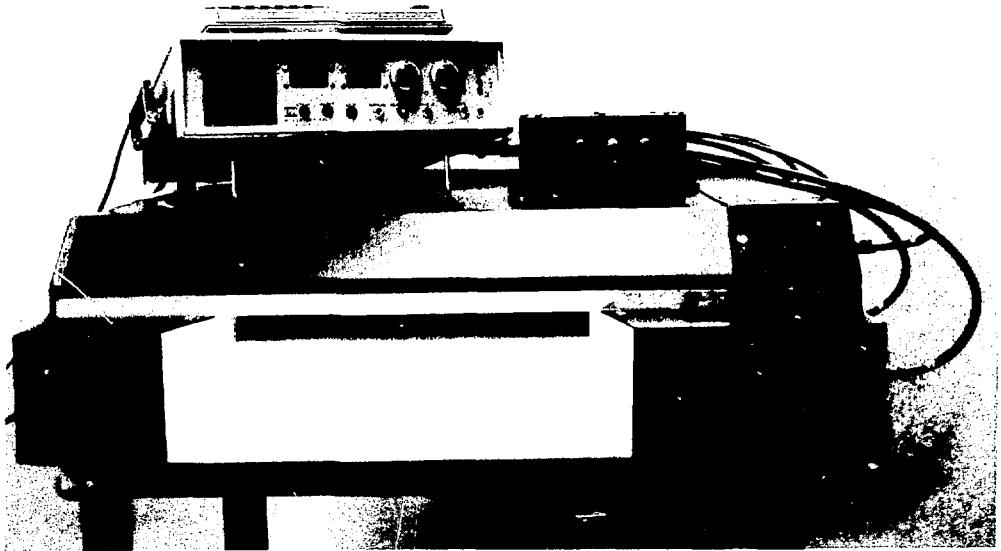


Fig. 2.
Front view of assay system.

the ^3He tubes. The ^3He tubes are in banks of three tubes and are interchangeable (including junction box) with those used in the HLNCC hexagonal well counter. Six banks of the tubes are positioned front to back, three banks to a slab, as shown in Fig. 3. The tube banks are staggered to provide as flat a response as possible over the length of the counter.

The slabs are separated by 2.5-cm-thick polyethylene spacers placed on the left and right sides to define the opening for the tray. Additional sheets of polyethylene are added at the ends (top and bottom) to flatten the response.

Cadmium sheets (0.4 mm thick) are placed on the top and bottom external surfaces to reduce the background from external thermal neutrons. In addition, a sheet of cadmium is glued to the top inner surface of the sample cavity to inhibit crosstalk between the upper and lower ^3He tube banks. This cadmium essentially eliminates the effect of the tray on the measurement. It is covered by thin aluminum to protect it from damage during use. Aluminum top and side covers complete the assembly, as shown in Fig. 3. A stainless steel cradle is affixed to the body to provide more convenient movability and additional protection.

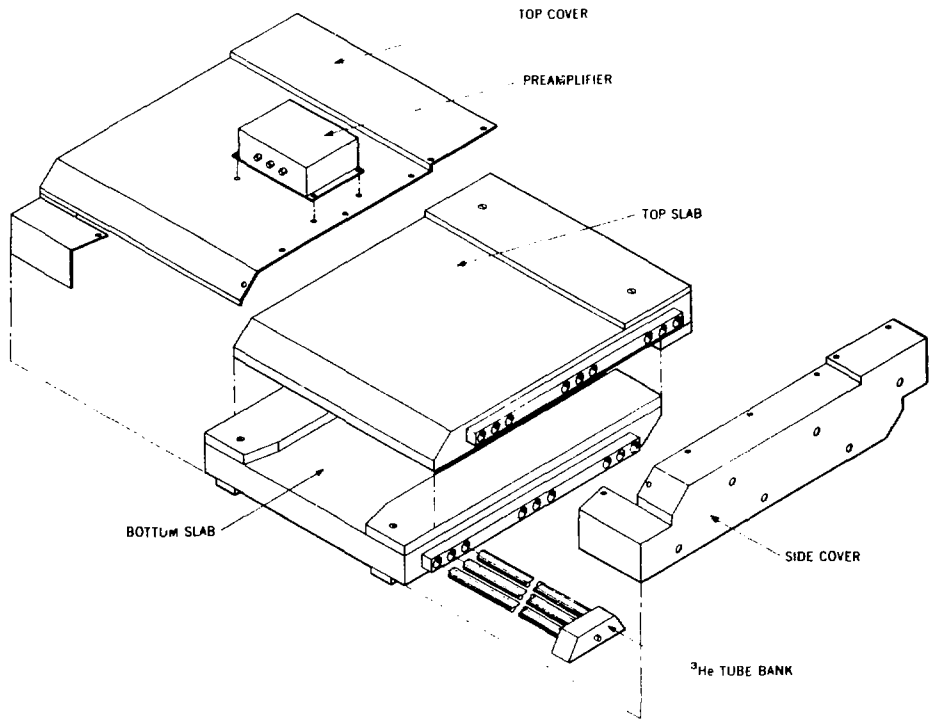


Fig. 3.
Tray counter.

2.2 Mechanical Assembly

The counter is normally shipped in a reusable crate. The detector is in an assembled condition and requires little additional assembly except that the preamplifier-to-junction-box cables are not attached. These cables are custom made to conform to length requirements and are distinctly labeled for reassembly.

After removal from its packing crate, the counter should be placed on a surface that is suitable in height for convenient operation. Tests using different materials under the counter to evaluate their use as supporting surfaces (Sec. 4.3.2) indicated that this variable has negligible effect on the response.

The ³He tube banks are shipped installed in the counter. Should it prove necessary to remove these tubes temporarily, they should be returned to their original positions. The tube banks are numbered, as are their positions in the

slabs (Fig. 4). The access plate side of each ^3He junction box should be placed in the down position. Inside each junction box is a container of dessicant to help prevent moisture build-up and high-voltage breakdown. See Sec. 5 for periodic maintenance information.

2.3 Source and Source Holder

All calibration and response normalization tests on the tray counter were made using ^{252}Cf source No. C-431. An aluminum source holder is provided to enable the user to repeat the source positioning accurately. The source holder has five machined grooves numbered 1 to 5 (front to back), as shown in Fig. 4. The holder (minus the source) can be in place (generally, at the extreme right side) during a pin-tray run as an alignment aid. Locations of the source for calibration measurements are indicated in the figure.

3. ELECTRICAL COMPONENTS

3.1 Electronics

As stated above, the tray counter utilizes the standard HLNCC electronics (HEC-100) package and the Hewlett-Packard HP-97 calculator for data collection and reduction. Care should be taken before starting a measurement program to ensure that the electronics package is set up properly as described in the

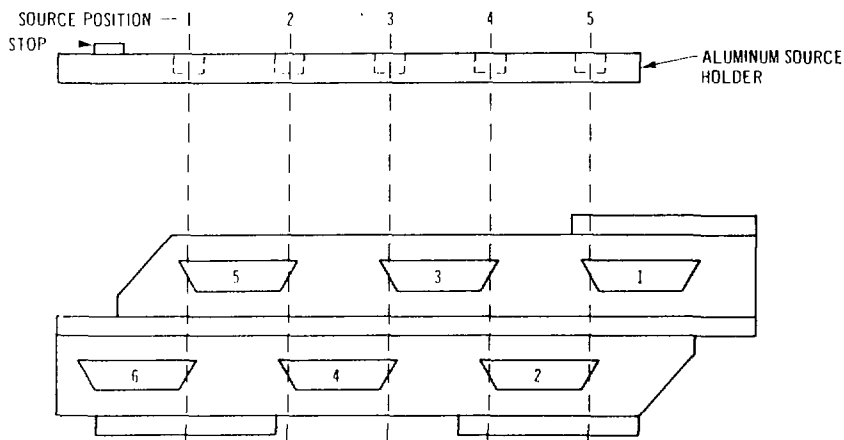


Fig. 4.
Source holder and ^3He tube bank positions.

HLNCC operation manual.¹ In general, the settings given in the International Atomic Energy Agency Instruction Manual for Instruments (IMI) or in the HLNCC manual are suitable (see Sec. 3.3). Use of the ³He tubes in a slab geometry causes a greater sensitivity to sample position than is found in the HLNCC. In the tray counter, the six channels of electronics must be closely matched to obtain a uniform response over the sample.

3.2 Settings for Normal Operation

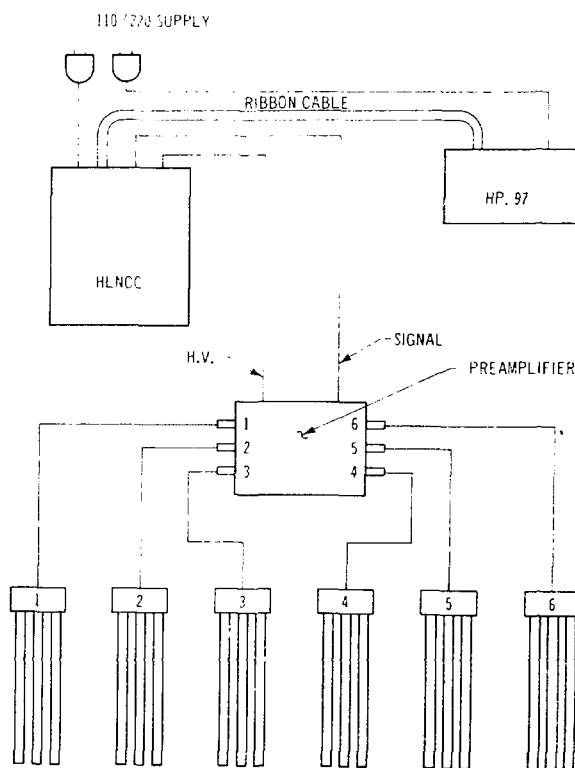
For normal operation, the six amplifier channels are connected as shown in Fig. 5.

Front panel:

Gate = 64 μ s
 High voltage = 7.5 x 200 (1500 V)
 Disc = 3.0 x 0.5 (1.5 V)
 Time (as needed).

Rear panel:

Power input to appropriate line
 Voltage
 Select switch to INT.



3.3 Amplifier Setup

For the initial setup, the ²⁵²Cf source should be used to check the proper operation of all six channels. Use the following procedure:

(1) Place the ²⁵²Cf source (C-431) in position 1 of the aluminum source holder. Place the source holder in the counter on the far right-hand side and take one or more 100-s counts.

- (2) Repeat this procedure for source positions 2-5.
- (3) Calculate the average coincidence rate (\bar{R}) and the deviation from the average for the five positions. The deviation for each of the positions should not exceed $\pm 10\%$.
- (4) If any of the amplifier channels are outside the $\pm 10\%$ limits, refer to Sec. 5.2 to make adjustments.

Fig. 5.
External wiring.

3.4 ^3He Detectors

Specifications for the detectors are given in Table I. The Reuter-Stokes tubes are matched in all properties to the same standard as that used for HLNCC detectors. A schematic diagram of the detector bank (three tubes) is shown in Fig. 6. The detector junction box and tubes are interchangeable with those of the HLNCC.

TABLE I

^3He DETECTOR SPECIFICATIONS

Model	RS-P4-0820-103
Active length	50.8 cm
Diameter	2.54 cm
Tube material	aluminum
Gas	^3He
Pressure	4 atm

4. PERFORMANCE AND CALIBRATION

4.1 Response Uniformity

The tray counter was designed to give a uniform or flat response over the plutonium region of the pins in the storage tray. This region is roughly 30 cm wide by 55 cm long. The tray requires a clearance height of about 2 cm.

For reasons of standardization and replacement, standard HLNCC tubes and junction boxes were used in the design of the new unit. This led to the mechanical configuration shown in Fig. 4, with rather large gaps between the tube banks. To obtain a flat response, it was necessary to shim the moderator with cadmium and polyethylene to bring the ends up to the same rate as that of the center region.

A series of measurements were performed using the ^{252}Cf source (C-431) to map the spatial response

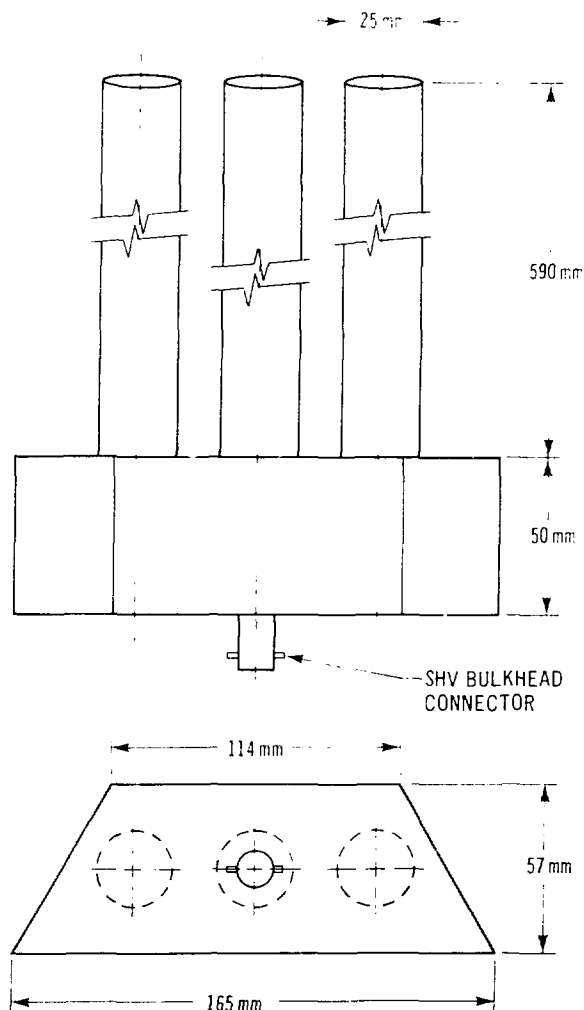


Fig. 6.
 ^3He tube bank.

of the detector. Figure 7 shows the normalized total rate (T) and the net coincidence rate (R) for the source as a function of front-to-back position. During this measurement, the source was moved through a plastic tube placed in the middle of the tray opening. The coincidence rate deviated more from the average value than the totals rate because the coincidence rate varies as the square of any changes in the counting efficiency. The coincidence rate stayed within $\pm 5\%$ of the average value over a distance of ~ 55 cm. Figure 8 shows the front-to-back data obtained using the aluminum source holder positioned on the left and right sides, respectively.

To determine the response uniformity from side to side, the ^{252}Cf neutron source was positioned in the tray at each pin slot. The side-to-side profile was measured at three different detector positions: front, middle, and back. The results of the measurements are shown in Fig. 9. There is a $\pm 5\%$ variation for positions 1 and 2 (front and middle); the back (position 5) is flat but below the other two positions.

4.2 Response Function

Standard MOX fuel pins, available at Los Alamos, were used to determine the response of the detector. To facilitate this work, we fabricated a

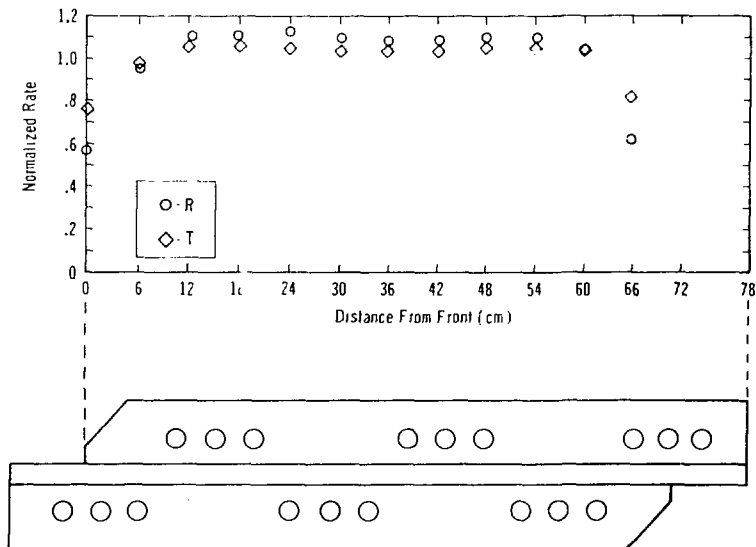


Fig. 7.
Response profile (front to back) at center.

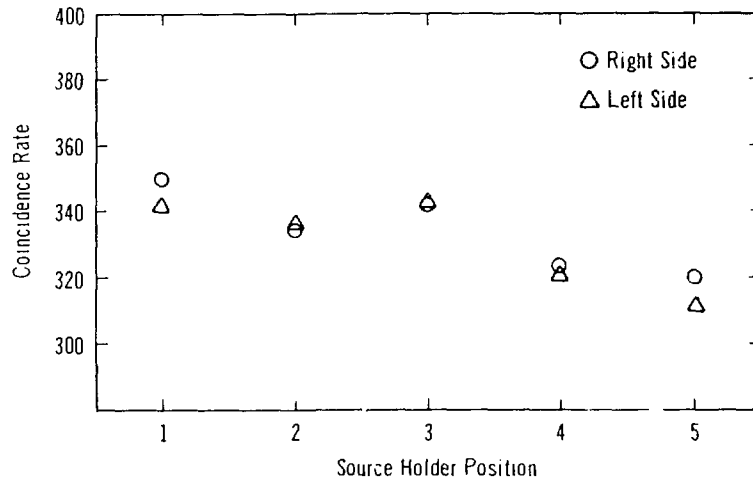


Fig. 8.
Five-position profile (front to back) on left and right sides.

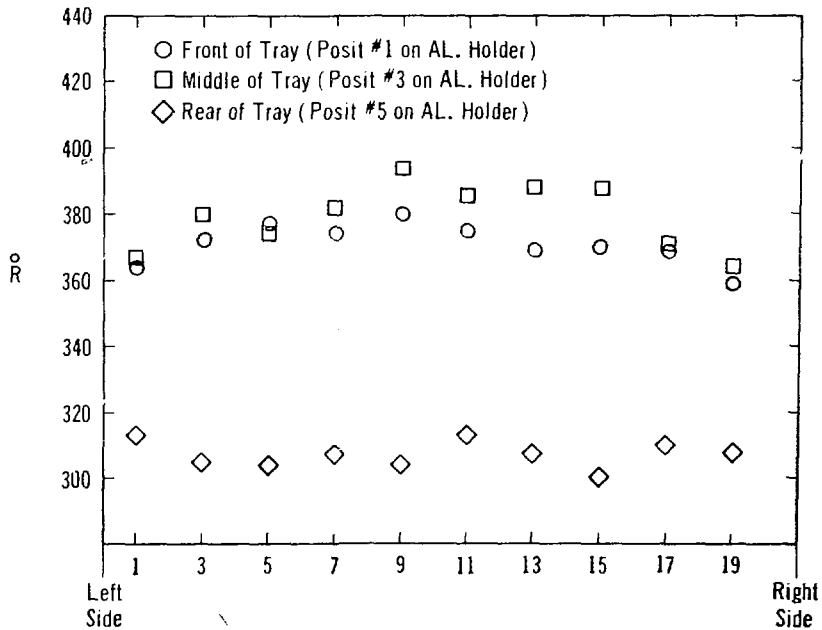


Fig. 9.
Response profile (side to side) with ^{252}Cf source positioned in stainless steel tray.

stainless steel tray similar to that used at the MOX fabrication facility. A schematic drawing of the pin tray is shown in Fig. 10. Characteristics of the standard MOX fuel pins used for the experiments are given in Table II.

To study the response of the system as a function of pin loading, the tray was placed in the counter and MOX pins were added until the tray was full. Table III lists the net coincidence response for each loading of pins in the tray. Figure 11 shows the coincidence response as a function of the number of pins. The increase in the response per pin at higher loadings is caused by multiplication in the fuel. Corrections for this effect can be made using the P/T ratio as described by Ensslin and Krick.²

The MOX pins used in the present work have an active length that is longer than that of normal FBR pins. Thus, it is necessary to correct the response to relate the results to the shorter pins. This correction can be approximated by using the coincidence profile shown in Fig. 7 or by using pins with the appropriate length.

Another approach that can be used to relate the two response functions is to perform two counts. First, count the tray of shorter pins with the active length of the pins stopping halfway through the counter (that is, 30 cm from the front). Then push the tray through so that the back end of the plutonium region is at the center (30-cm line) and the rest of the fuel extends out the back of the counter. The sum of the counts for these two runs should be approximately the same as the counts for a single run of pins having double the fuel length. This approximation assumes that the multiplication and reflection are the same for the two cases.

In summary, long pins (>55 cm) have a reduced response per gram ²⁴⁰Pu because the ends do not get counted with the same efficiency as the center 55-cm region. These end losses can be estimated using the above procedures to relate the geometry of the long pins to that of normal 55-cm pins.

4.3 Effects of Counter Location

4.3.1 Room Background. Because of weight considerations, the counter has no external neutron shielding except for the 0.4-mm sheets of cadmium. Thus, the measurements should be performed as far away from plutonium storage areas as possible.

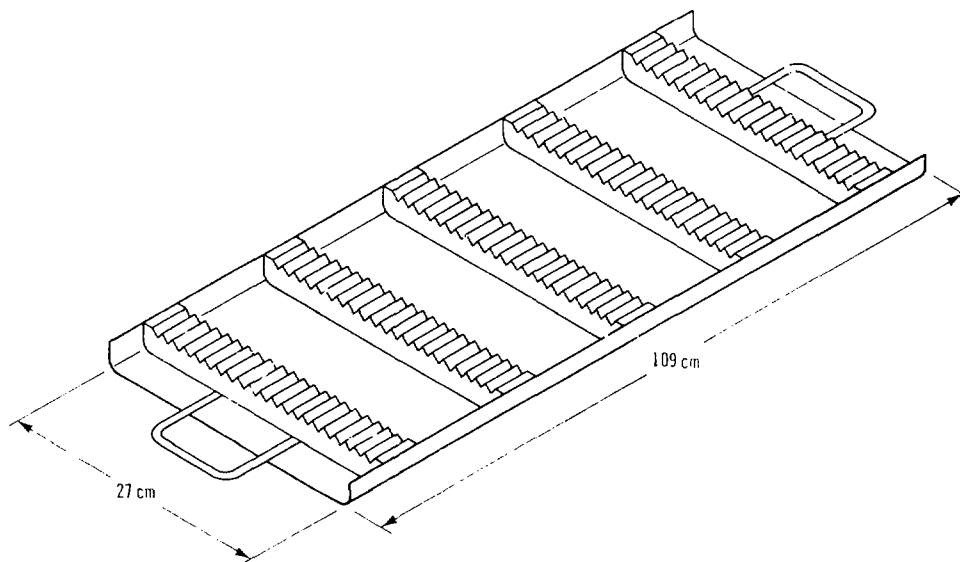


Fig. 10.
Stainless steel fuel pin tray.

TABLE II
MOX FUEL PIN CHARACTERISTICS

Length (active)	177.8 cm
Diameter (fuel)	0.944 cm
UO ₂ enrichment	natural
Cladding material	stainless steel
Cladding thickness	0.08 cm
Linear density	0.33 g Pu/cm
Pu/Pu + U	0.052
²³⁹ Pu/Pu	0.77
²⁴⁰ Pu/Pu	0.18
²⁴¹ Pu/Pu	0.02
²⁴² Pu/Pu	0.005
²³⁸ Pu/Pu	0.001
²⁴⁰ Pu-effective ^a	0.063 g/cm

^a²⁴⁰Pu-effective = 2.43 ²³⁸Pu + ²⁴⁰Pu + 1.69 ²⁴²Pu.

TABLE III
COINCIDENCE RATE VS NUMBER OF MOX FUEL PINS IN TRAY

No. of Pins ^a	Rate (counts/s) ^b	g ²⁴⁰ Pu-effective (g/cm)
1	55.7	0.063
2	113.4	0.126
3	177.7	0.189
4	250.9	0.252
6	390.0	0.378
8	556.8	0.504
10	703.3	0.630
12	883.3	0.756
14	1042.4	0.882
16	1221.9	1.01
18	1398.9	1.13
20	1574.9	1.26

^aThe 177.8-cm pins (active length) extend well beyond both ends of the detector counting region.

^bThe coincidence response would be reduced by ~0.84 if the active length were 55 cm with the same linear loading (g/cm).

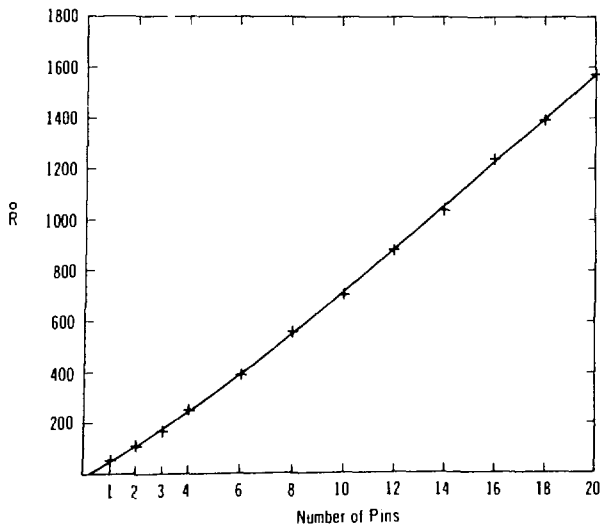


Fig. 11.
Response vs number of pins.

Because the coincidence counting eliminates the neutron background in the signal, high backgrounds affect the statistical error only through accidental pileup.

4.3.2 Counter Support. The counter is normally placed on a table or cart for use in a facility. The supporting surface can reflect neutrons back into the counter and increase the effective efficiency. To investigate the effect of the supporting surface on the count rate, we measured the rate for the following surfaces: (1) metal table, (2) 5-cm-thick wood table, (3) 5-cm-thick polyethylene surface, and (4) concrete floor. The results of the measurements are shown in Fig. 12. The response of the detector was similar for all of the surfaces except the concrete floor, which gave a ~3% higher response. In practice, this is not important as long as the ^{252}Cf neutron source normalization procedure is used to relate to the MOX calibration curve. The source normalization procedure automatically corrects for the reflection effect, but the surface must not change during the measurements.

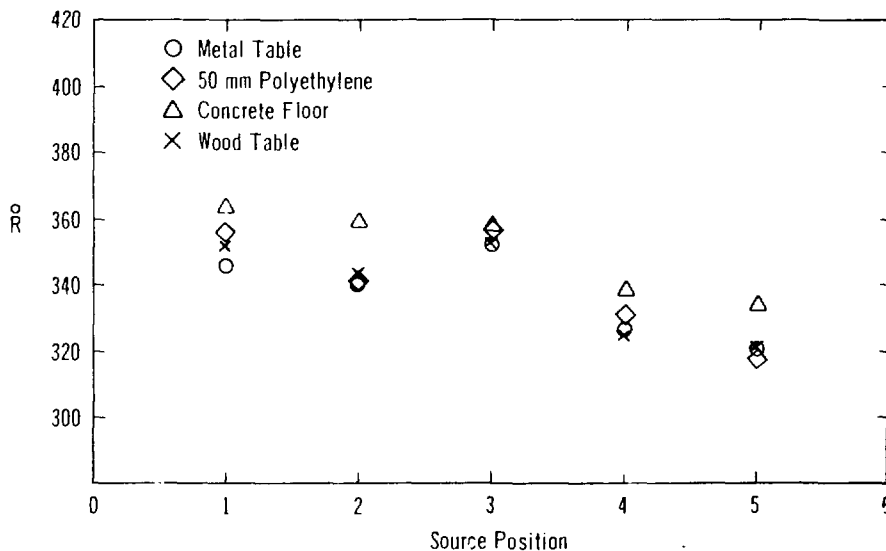


Fig. 12.
Response for different support materials.

5. MAINTENANCE

Having no moving parts, the tray counter requires little periodic mechanical maintenance. Maintenance and repair of the electronics package is the same as for the HLCC.

5.1 Detector Body

The dessicant in the junction boxes of the detector body should be changed approximately once per year. To do this, use the following procedure:

- (1) Shut off the high voltage. Remove all high-voltage cables from the tube banks.
- (2) Remove the screws holding the large side panel in place. Remove the panel from the tray counter.
- (3) On each individual junction box, remove the screws holding the lid in place. Care should be taken not to damage the rubber gasket.
- (4) Remove the dessicant holder from the under surface of the lid and discard the old dessicant.
- (5) Replace the dessicant and reassemble the holder. (Note that the old dessicant can be rejuvenated by placing it in an oven overnight at $\sim 150^{\circ}\text{C}$ or until it regains its blue indicating color.)
- (6) Redate the junction boxes for future reference.

5.2 Amplifier Test Procedures

If the initial measurements described in Sec. 3.2 indicate that one or more of the amplifier channels are out of specification ($\pm 10\%$ from the average), then additional tests are necessary.

The six amplifier test jacks on the instrument front panel allow the user to observe the analog signal from each of the six channels at the input to the discriminator circuits. The pulse-shaping amplifiers produce positive-leading bipolar pulses with $0.5\text{-}\mu\text{s}$ integrating and differentiating time constants. The ground test jack is connected to the signal ground and is intended for use with the signal test jacks. The six amplification channels can be observed independently to verify the correct operation of the analog circuit.¹ Proceed as follows:

- (1) Connect a high-impedance oscilloscope probe to test jack 1; connect the ground probe to the ground test jack.

- (2) Place the ^{252}Cf source (C-431) in the aluminum source holder position.
- (a) Put the source holder into the counter on the right side, fully against the stop. Using one of the longest high-voltage cables, connect tube bank 6 to preamplifier input 1. This will produce pulses on test jack 1 resulting from the thermal neutron capture in the ^3He counters in bank 6. The positive peak amplitude should be 6.0 V. A photograph of an oscilloscope display taken under normal operating conditions with a ^{252}Cf source is shown in Fig. 13. Verify that the shape of the pulses is as shown, that the positive pulse amplitude is 6.0 V (± 0.2), and that the pulses recover in $\sim 4 \mu\text{s}$.
- (b) If the amplifier output is out of adjustment, turn off the power and remove the two screws from the back of the top cover on the HEC-100 electronics. Slide the cover to the back, exposing the top circuit board. Adjust the potentiometer located near the center on the extreme right amplifier section (this is amplifier 1). Rotating the potentiometer to the right or left while observing the oscilloscope trace will determine the proper movement needed to increase or decrease the voltage as required.
- (3) Repeat step 2 for amplifiers 2 through 6, moving the input cable to the appropriate preamplifier input. Amplifiers on the printed circuit board are numbered 1 through 6, beginning at the right side and moving to the left.



Fig. 13.
Oscilloscope display of an amplifier test point signal with the ^{252}Cf calibration source in the detector. Vertical scale = 2 V/ div; horizontal scale = 1 μs / div.

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2. M. Krick, "Neutron Multiplication Corrections for Passive Thermal Neutron Well Counters," Los Alamos Scientific Laboratory report LA-8460-MS (ISPO-89) (July 1980).