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POSITRON/SCINTILLATION CAMERA DATA ACQUISITION AND DISPLAY SYSTEM

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Abstract

This report describes a Positron/Scintillation camera data acquisition and display system located at the LLL 100 MeV Linear Accelerator facility. The camera consists of two identical 16-in. diam Anger Scintillation detectors. The camera outputs are sampled, digitized and routed through a PDP-15 computer onto a high-speed drum storage device. A software operating and display system has been developed. Some applications are described.

Introduction

A Positron/Scintillation camera has been constructed at the LLL Linear Accelerator (Linac) facility. The isotope producing ability of the Linac combined with the data acquisition and storage capabilities of the Linac computing center provide an exceptional location for an imaging instrument of this type. This report describes the camera, system electronics, computer interface, data collection and display software, and some applications.

Camera System

POSITRON/SCINTILLATION CAMERA

The camera is composed of two, position-sensitive, scintillation detectors developed by H.O. Anger at Donner Laboratories.[1-3] The essential components of each detector are a 16-in. diam, 1/2-in. thick NaI(Ti) scintillator, a close-packed array of 37 photomultiplier tubes, a lucite light pipe that transmits scintillation light to the photomultiplier tubes and a network of precision capacitors. The capacitors are used to derive scintillation intensity and position information from the photomultiplier tube outputs by charge division. Provisions have been incorporated into the camera design to facilitate changing the scintillator for future applications to neutron radiography.

Figure 1 shows the camera and a cross section of one of the detectors. Each detector is mounted separately on movable hoists. Normal operation of the camera is remote from the data acquisition system, therefore each scintillator, including its power supplies and signal preamplifiers, are moved as a unit and connected to the Linac computing center by three, 50-Ω cables. One of the three

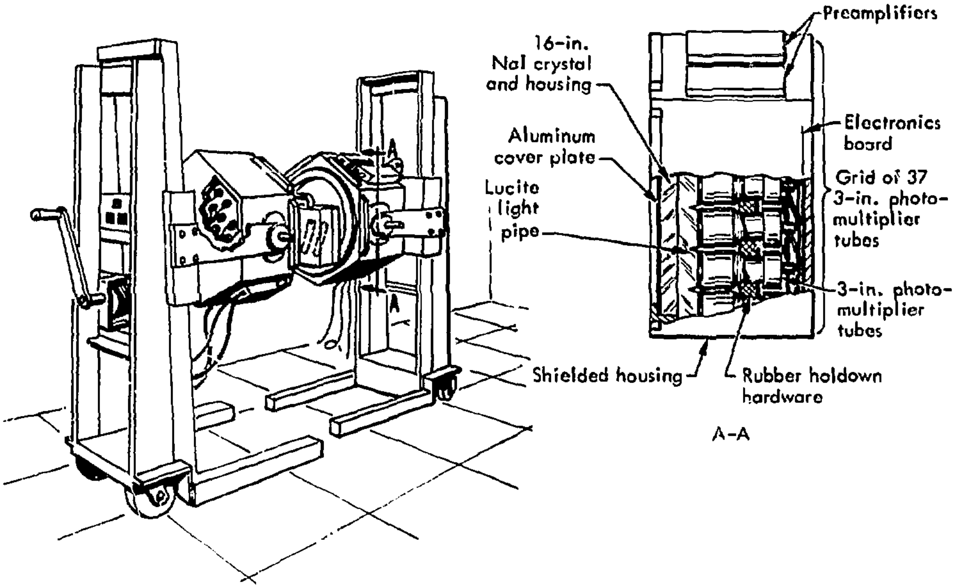


Fig. 1. Camera and cross section of one detector.

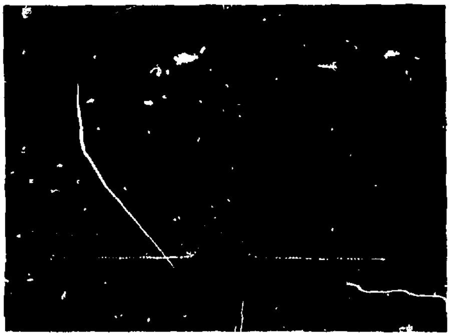


Fig. 2. ^{22}Na source in 3/4-in. × 7/16-in. diam cylindrical aluminum housing. Source moved 1-in. horizontally in plane midway between detectors. Detectors are 20 in. apart. There were 12,288 positron events. The full width at half maximum is approximately 0.65 in.

connecting cables transmits scintillation intensity information and the other two cables carry scintillation position information.

When used to detect positrons, the pair of detectors are positioned facing each other and the positron emitting object is placed between the detectors as shown in Fig. 1. A valid event is recorded whenever simultaneous 0.51 MeV annihilation γ-rays are observed in the two detectors. Also, either of the two detectors can be utilized as a position-sensitive scintillation detector when configured as a pinhole camera or when used with a suitable collimator.

Resolution of the camera is dependent on many factors and has not been precisely measured. However, resolution is in the neighborhood of 1/2 in. when

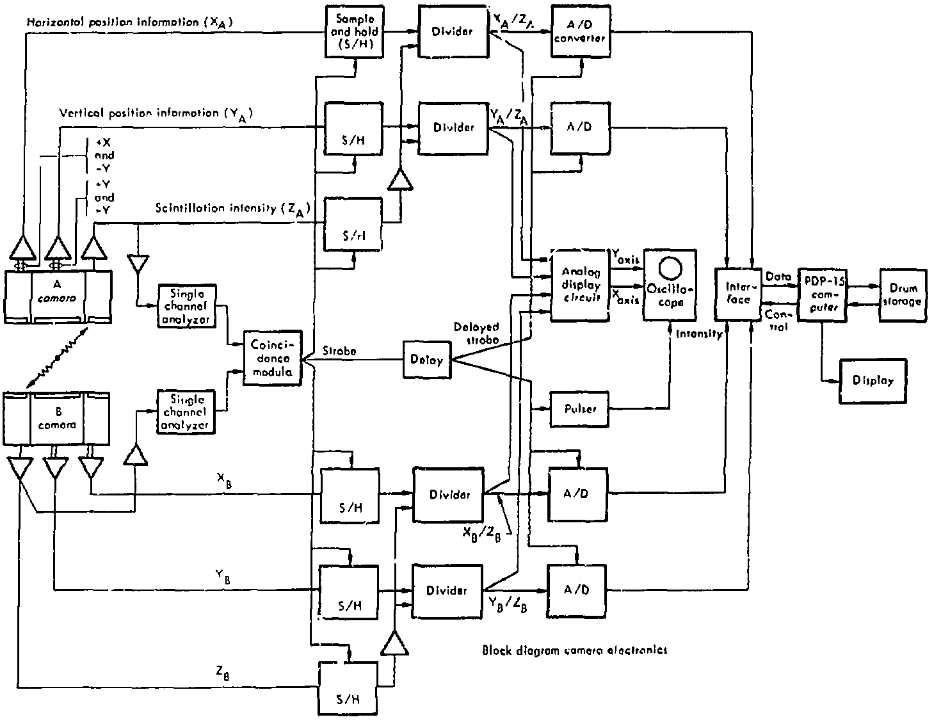


Fig. 3. Block diagram of the camera electronics.

operated as a positron detector, see Fig. 2. Maximum data rate is 0.9 × 10^5 scintillation events per second and is limited by the drum storage transfer rate. Total drum storage capacity is slightly more than 3 × 10^6 scintillation events.

SYSTEM ELECTRONICS

A simplified block diagram of the camera data acquisition system is shown in Fig. 3. Each camera has five buss outputs obtained from its charge division network. Two outputs contain horizontal scintillation position information (+X and -X), two outputs contain vertical scintillation position information (+Y and -Y), and one output is proportional to scintillation intensity (Z). The position signals are obtained by directing a portion of the output of each photomultiplier tube to one of the four position busses. The percentage of each photomultiplier tube signal sent to a particular buss is determined by the location of the photomultiplier tube in the photomultiplier tube array. Thus, a photomultiplier tube located at the top of the camera would direct most of its signal to the +Y buss, while a tube at the bottom would send most of its output to

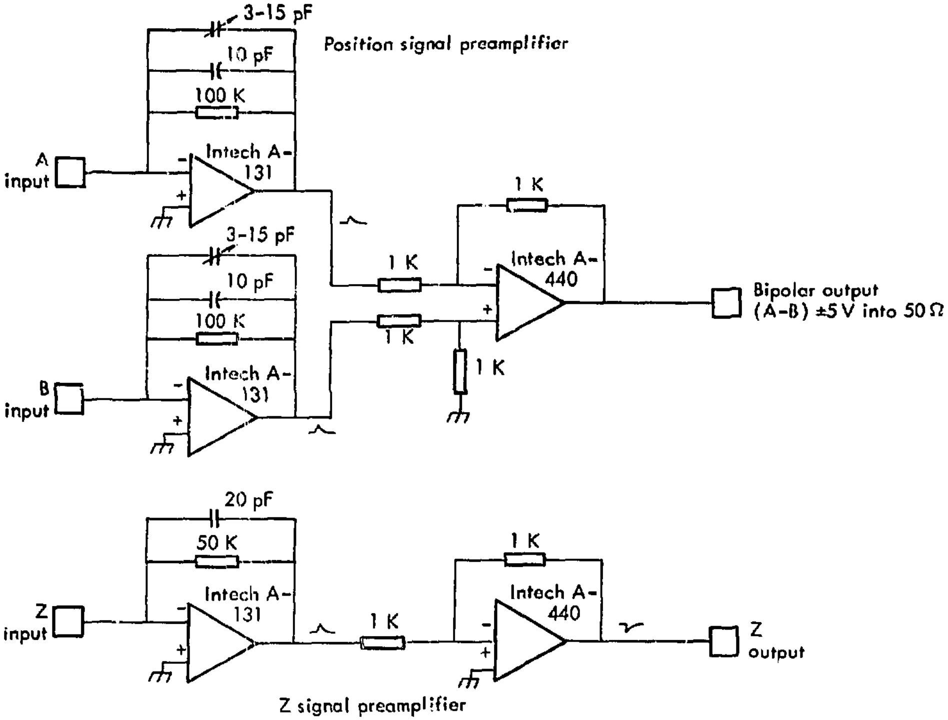


Fig. 4. Simplified schematic of the positron signal preamplifier and the Z axis preamplifier.

the -Y buss. The +X and -X signals are similarly obtained. The scintillation intensity signal is obtained by directing an equal percentage of each photomultiplier tube output to the Z buss.

These five, unipolar, buss outputs are connected to charge sensitive preamplifiers mounted on the camera housing. Here, the pairs of unipolar position signals are combined to form a single bipolar horizontal signal (X) and a single bipolar vertical signal (Y). Figure 4 shows a simplified schematic of the position signal preamplifier and the Z axis preamplifier.

The position preamplifier consists of two, charge-sensitive, input stages driving a differential amplifier. This combination produces a single, bipolar, position pulse. A zero voltage output corresponds to a scintillation at the camera center while large positive or negative signals indicate scintillations at the camera edges. The Z axis preamplifier consists of a charge sensitive input stage followed by a cable driving power inverter.

The three outputs (X, Y and Z) of each camera are now connected to sample and hold circuits. The Z outputs are also connected to single channel analyzers (SCA's) consisting of EG&G TD101/N differential discriminators. The SCA's are adjusted to allow triggering by only those signals having a pulse height corresponding to the energy band of interest. The timing outputs of the two SCA'a are connected to a coincidence unit that detects simultaneity between the A and B cameras and generates the strobe pulse when the system is operated as a positron camera. When the system is used as a position sensitive scintillator, the coincidence unit is bypassed and the strobe pulse is initiated by the A camera SCA. In this mode, the B camera and its electronics circuitry are not used. The coincidence unit strobe pulse initiates the start of the data acquisition operation by triggering holding action in the sample/hold circuits. All six camera outputs are held for approximately 10 μsec. This time is necessary to allow the outputs of the dividing circuits to settle and the A/D converters to operate. The sample/hold circuits utilize an Analog Devices SHA-II unit having a 10 nsec acquisition time. The sampled outputs are connected to the divider (ratio) circuits where the X and Y position outputs are used as the numerators and the amplified Z outputs are used as the denominators.

The divider circuits form the ratios X/Y and Y/Z and compensate for position errors due to the finite SCA window size. The dividers are Analog Device Models 530K. These units are integrated circuits having approximately 1% accuracy and a 1-MHz, small-signal bandwidth. The divider outputs go to the A/D converters and the analog display unit.

The A/D converters are Phoenix Data Systems model ADC 700 having an 8-bit accuracy and a 3.5-μsec conversion time. 8-bits allows a resolution of 1 part in 256 which corresponds to a camera distance of 1/16 in. The start of the A/D conversion is initiated by the delayed strobe pulse that lags the sampling strobe by 5 μsec. This delay is necessary to allow the divider outputs to settle after large excursions or overloads. The A/D converter outputs consist of eight data lines plus a conversion complete signal and are tied into the PDP-15 interface. The analog display unit provides immediate viewing of scintillation position when the camera is used as a positron detector. In this mode of operation, the A camera and B camera position coordinates define the line along which the γ-rays originated. By taking weighted averages of these coordinates, the camera can be focused to any plane between cameras. The analog display unit forms the averaging functions:

$$X = \alpha X_B + (1 - \alpha)X_A$$

$$Y = \alpha Y_B + (1 - \alpha)Y_A$$

where α is the normalized distance from camera A to the focus plane. Figure 5 shows the basic display circuit and its geometric equivalent. The display unit outputs are attached to an X-Y oscilloscope and are displayed during the A/D conversion time by pulsing the oscilloscope unblanking circuit. Figure 6 shows the focusing properties when the camera is used as a positron detector.

When the camera is used as a scintillation detector, the analog display circuit

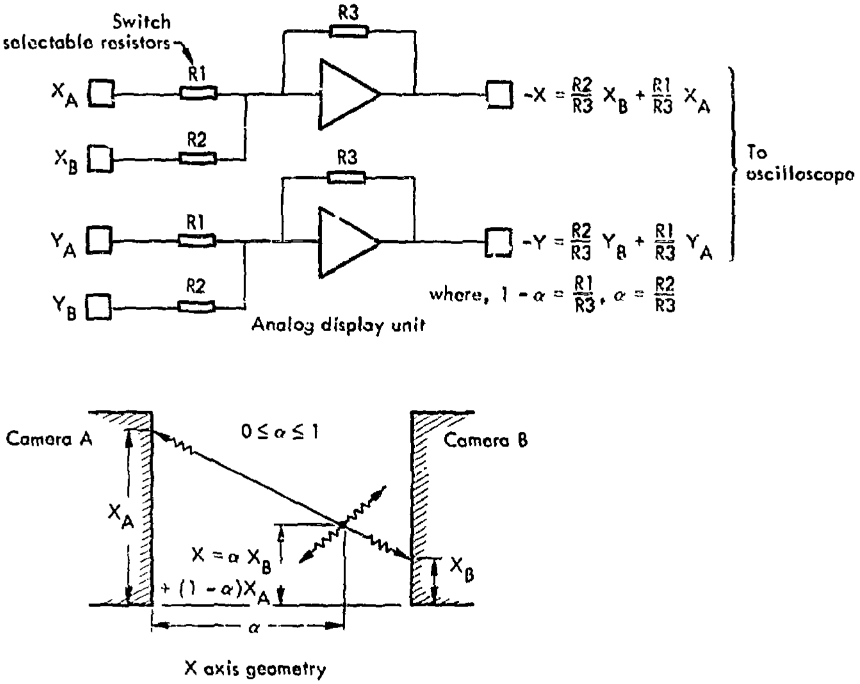


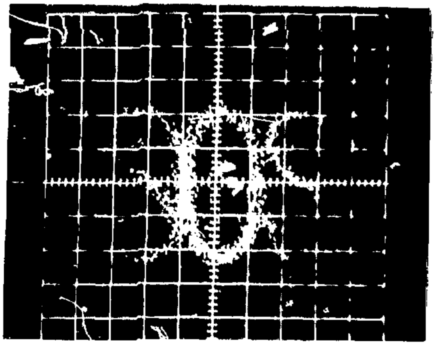
Fig. 5. Basic analog display circuit and its geometric equivalent.

is bypassed and the camera A divider outputs are applied directly to the oscilloscope. Figure 7 shows the analog display when the unit is used in a pinhole camera configuration. The object is a disc of ^{239}Pu with the SCA window set from 0.4 to 0.5 MeV.

Computer Interface

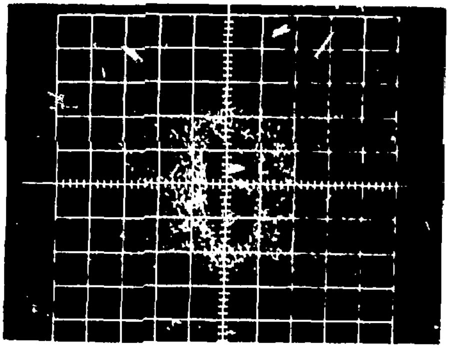
The computer interface transmits the camera's A/D converter output data into the PDP-15's core memory. When the camera is operated as a single detector scintillator, only camera A is utilized and the data consists of single, 16-bit, x-y coordinate words. For positron operation, both camera A and B outputs are placed into memory and the data consists of pairs of 16-bit words. In addition to the data, two lines called STROBE AH and STROBE BH connect to the interface. Signals on these lines indicate when camera A and B A/D converters are ready to transmit data. A simplified logic diagram of the interface is shown in Fig. 8.

The input data words are connected to two, 16-bit, storage registers. These



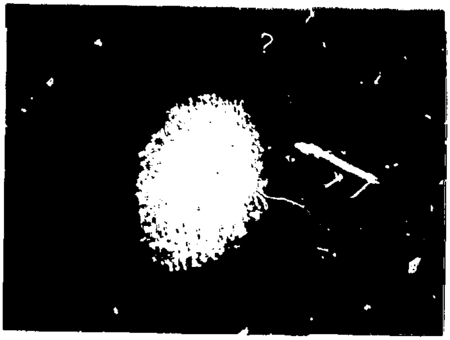
Analog display 1-min exposure
$\alpha = 0.5$

Target



Analog display 1-min exposure
$\alpha = 0.4$

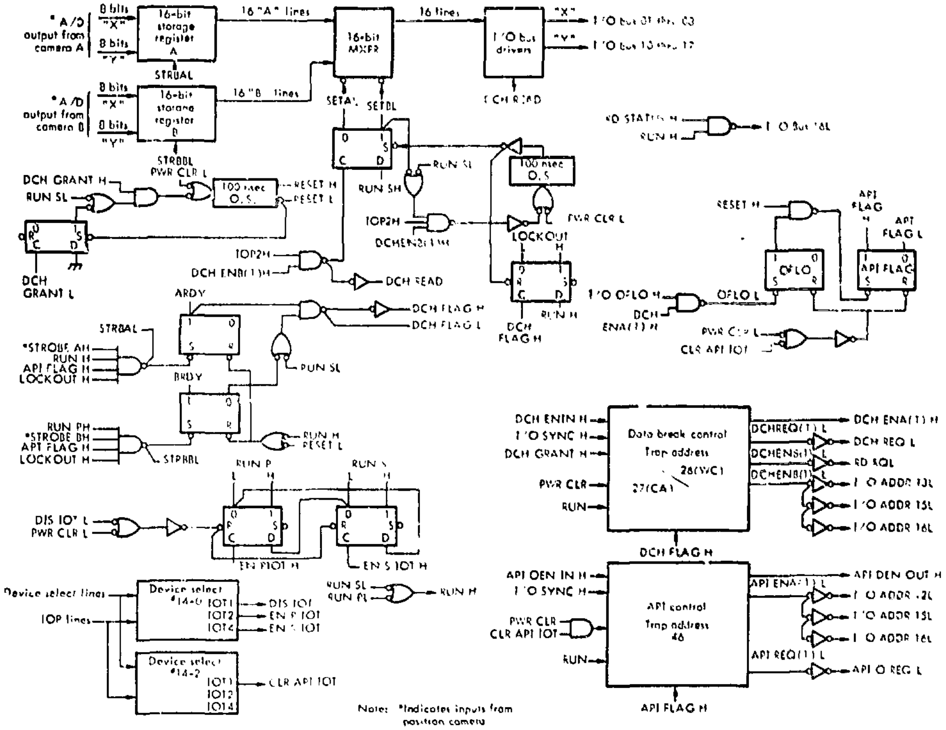
Fig. 6. Focusing properties of a camera used as a positron detector. ^{13}N source. Tubing has 1/8-in. i.d. Target is placed in a plane midway between detectors. Detectors are 24 in. apart.



1-min exposure

Fig. 7. Analog display for a pinhole camera configuration utilizing a 4-in. thick lead shielding with a 1/2-in. diam tapered hole. The object is a disc of ^{239}Pu within a stainless steel container.

registers store the input data when their related strobe lines come true. Once the registers have been set, further data words are locked out until the stored data has been transferred to the computer. The two storage registers are connected to a 16-bit multiplexer that can connect either register to the PDP-15 memory via the I/O bus drivers. For scintillator operations, the register A is continually connected to the bus drivers and the transfer operation consists of a single data word transfer. For positrons, registers A and B are alternately connected to the bus drivers and both data registers A and B are transferred for every valid camera event. The remainder of the interface logic consists of control and timing circuitry necessary to utilize the computer's I/O device select lines, three-cycle data break and automatic priority interrupt (API) facilities. The detailed operation of these and other PDP-15 interface hardware is given in Ref. 4



Note: *Indicates inputs from positron camera

Fig. 8. Simplified logic diagram of the PDP-15 positron camera interface.

Software

GENERAL

Camera software is composed of data collection, manipulation and display routines integrated into an operating system. The software system can be conveniently subdivided into four parts; Data Collection, Matrix Formation, Matrix Smoothing and Matrix Display. These routines occupy approximately 4000_8 storage locations and utilize the Linac's high speed drum for data storage. Once the program has been started all user interaction is through the console teletype.

DATA COLLECTION

Data collection is performed using the camera interface and the multicycle data break facility of the PDP-15. Data from the interface is double buffered onto the high speed drum where it resides until data collection is complete. Drum transfers are made by the drum handler subroutine that is utilized by both the data collection and matrix formation routines. Machine time not utilized by data transfers is used to display the just-filled buffer on the console X-Y oscilloscope.

The data collection interface is controlled by four software commands:

a. Enable Positron Operation	(ENPIOT) 701402
b. Enable Scintillator Operation	(ENSIOT) 701404
c. Disable Camera Interface	(DISIOT) 701401
d. Clean Camera API Flag	(CLR API IOT) 701421

Before issuing any interface commands, the collection routine initialized the word count and current address locations required for three-cycle, data-break operation. These locations define the address and length of the first core memory buffer to be filled. The user then specifies the start and end drum storage tracks, chooses whether the camera is being used as a scintillator or to detect positrons, and sets the camera focus point if the camera is used for positrons. The data collection routine then initializes the drum handler program. The Input-Output Transfer (IOT) commands are now issued to turn on the interface and the PDP-15's API system is enabled starting the data collection.

Data collection continues until the first buffer is filled. At this point data collection halts while the software reinitializes the word count and current address location in order to direct transfers to the second of the two memory buffers. The drum handler program is then started to transfer the just-filled memory buffer to the designated drum track. The camera interface is now reenabled and camera data begins filling the second buffer. Concurrently, the drum handler subroutine is transferring the just-filled 3000_8-word, memory-data buffer contents onto the designated 3000_8-word, drum-storage track. An average data collection rate of 0.9×10^5 words/second or less is required to insure that the current buffer to drum transfer is completed before the next buffer is filled. This data rate corresponds to 0.9×10^5 events per second in the scintillator mode of operation or one-half that in the positron mode. When the second buffer is filled, the reinitializing and drum-handler activation procedure repeats. Now data is directed again to the first buffer while the just-filled second buffer contents is transferred to the drum. When the final track, as previously specified by the user, is to be transferred, the interface is disabled, the final drum transfer completed and the data collection portion of the software is complete.

During data collection, any unused processor time is directed to continuously scan the buffer being transferred and display the X-Y data coordinates on the console oscilloscope. For scintillation operation, the scintillation coordinates are directly displayed. For positron operation, a weighted average of the two scintillation coordinates is taken using the previously specified focus point to determine the weighting.

MATRIX FORMATION

Matrix formation software utilizes the X-Y coordinate data points stored on the magnetic drum to incrementary one location of a 100 × 100 array of memory locations. The memory location to be implemented is specified by the scintillation coordinates and by this procedure one obtains a three-dimensional plot of X-Y position vs scintillation counts (Z axis).

To start the Matrix formation routine, the user first specifies the start and end drum storage tracks containing the data to be used. The user then specifies whether the data is scintillator or positron data and, if positron data, sets the focus point. The routine now clears the memory locations used to store the array and then utilizes the drum handler subroutine to transfer the first specified drum track into a 3000_8-word, core-memory buffer. Each 18-bit data word contains X and Y position coordinates. Each of these is 8-bits long and represents a resolution of approximately 1/16 in. To fully display these coordinates would require a 256 X 256 grid or 65,536 memory locations. Since our present computer memory has 16,384 locations of which approximately 3600 are required for program storage, the matrix formation software utilizes 10,000 memory locations to form a 100 X 100 grid.

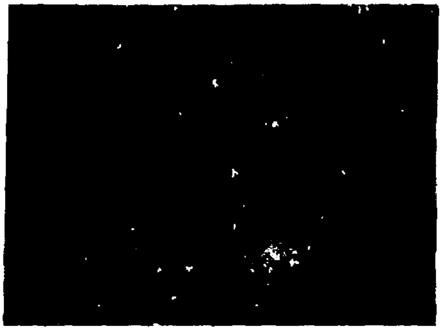
The software operates on the data word in the following manner. The least significant bits of both coordinates are ignored and the remaining 7 bits are tested to see if they are between 14 and 114. If either the X or Y coordinates are outside this range, the coordinate pair is discarded. This method of reducing data to a 100 X 100 array eliminates approximately 11% of the periphery of the camera picture and reduces resolution to approximately 1/8 in. With scintillator data, this testing is performed on the data words directly. With positron data, the pair of coordinates are first averaged using the specified focus point and the resultant coordinates tested. If both the X and Y coordinates pass this test, the matrix location specified is incremented and the next data word is examined. After all the data buffer words have been examined, the next drum storage track is transferred into the buffer and the process repeated. As the matrix is being formed, the valid X-Y coordinates are displayed on the oscilloscope. After all the specified drum tracks have been transferred and tested, the matrix formation portion of the software is complete.

MATRIX SMOOTHING ROUTINE

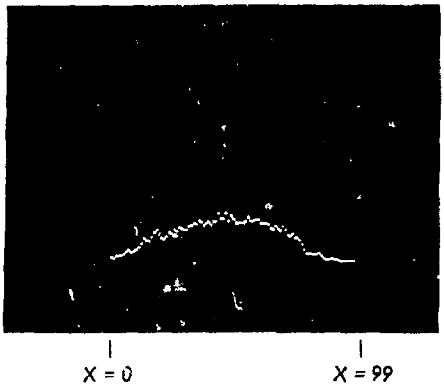
This routine takes two, 3-point averages about each nonboundary grid point, one average in the X direction and one average in the Y direction. The routine then averages these two results and replaces the original grid point number with this final average. Given that $N_{X_jY_j}$ is the number of counts in the grid location $X_j Y_j$, the resultant averaged count $\overline{N_{X_jY_j}}$ is given by

$$\overline{N_{X_jY_j}} = \frac{1}{6}\Big[N_{X_jY_{j-1}} + N_{X_jY_{j+1}} + 2N_{X_jY_j} + N_{X_{j-1}Y_j} + N_{X_jY_{2+1}}\Big].$$

Figure 9 shows the effect of the smoothing routine for a typical Y matrix line. Figures 10 and 11 also show the effect of smoothing on the different displays.



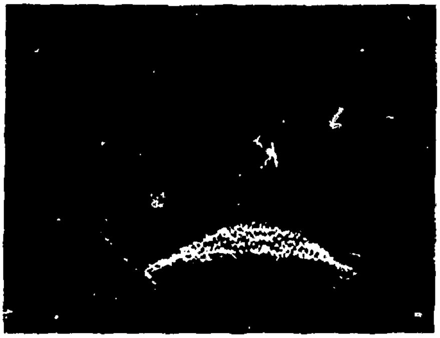
Unsmoothed data



Matrix smoothed once

Fig. 9. Effects of a smoothing routine for a typical Y matrix line. Cross section display when $Y - 41_8(33)$. Data from ^{239}Pu experiment with the camera in the single-detector, pinhole configuration.

Unsmoothed matrix
Threshold = 2



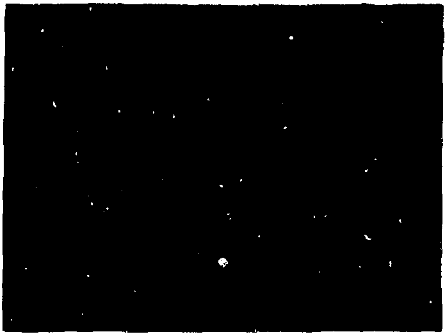
Matrix smoothed twice
Threshold = 2

Fig. 10. Typical isometric display of a matrix. Data obtained from a ^{239}Pu pinhole camera experiment.

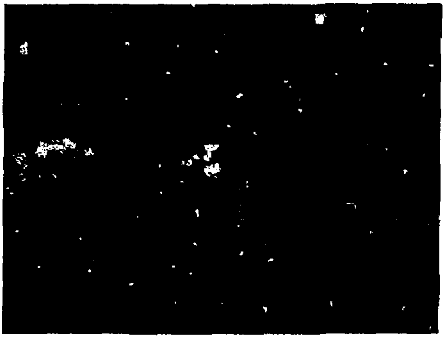
DISPLAY ROUTINES

Four software routines, used to display X-Y position vs count for all or part of the 100 X 100 X-Y matrix on the console oscilloscope, are as follows:

a. A cross-section display that plots count vs all X position values for any given Y position value.
b. A head-on display showing all matrix points and utilizing the three, oscilloscope-brightness levels to indicate count value.
c. An isometric display.
d. A contour display showing all matrix points but displaying only those locations having counts lying between two specified values.



Unsmoothed matrix
Threshold = 2



Matrix smoothed once
Threshold = 2

Matrix smoothed six times
Threshold = 2

Fig. 11. Head-on display data obtained from ^{239}Pu pinhole camera experiment.

Cross-Section Display

A typical cross-section display is shown in Fig. 9. To obtain this display, the octal value of the desired Y position is placed into the console switch register (switches 11-17). The program continually senses the switch register and generates the display for any Y position value between 0 and 144_8. Changing the switch register value immediately changes the display.

Isometric Display

A typical isometric display of the matrix is shown in Fig. 10. This display is composed of cross-section displays of all the even Y position values. The origin (X = 0) of each display is slightly offset to produce the isometric effect. Before the display starts, the user specifies a threshold value. The program then omits from the display those matrix locations having counts below the threshold value.

Head-On Display

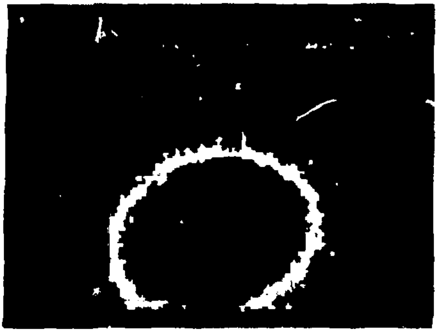
In this display, a 100 × 100 dot array is formed on the oscilloscope. The brightness of each dot is related to the number of counts in the corresponding matrix memory location. This is accomplished in the program by loading a two-bit, brightness register with either a binary 0, 1, 2, or 3. Normally only the 1, 2, and 3 brightness levels can be observed with the three level producing the brightest display. However, the zero level can be seen by adjusting the oscilloscope's brightness control. Before the display starts, the user specifies a threshold value and the program finds and prints out on the console teletype the value of the eighth largest matrix count called D1SC2. The display program now repeatedly scans the entire 10,000 matrix locations and examines each count. If the count is less than the threshold value, the corresponding oscilloscope dot is omitted. If the count lies between the threshold value and D1SC2/4, a zero is placed in the brightness register and the corresponding point displayed. If the count lies between D1SC2/4 and D1SC2/2, a one is placed in the brightness register and the point displayed. If the count lies between D1SC2/2 and D1SC2, the point is displayed with a two in the brightness register. The eight largest values are displayed at maximum brightness. Figure 11 shows the head-on display.

Contour Display

This display is an attempt to observe structure and boundaries within the matrix. It uses a 100 × 100 dot array on the oscilloscope. Those locations, having counts lying within a user specified band (window), are displayed at maximum brightness. Before starting the display, the user clears the console switch register. This will allow the window scan to occur as explained below. The display then determines and prints out the value of D1SC2 as was done in the head-on display. The user specifies a threshold value and the number of counts in the display band (DELTA). The program now scans the entire matrix, omitting those locations with counts less than threshold and displaying at maximum brightness those locations having counts lying between threshold and threshold + DELTA. All other locations are displayed at low brightness. When one scan has been completed, the window values are raised by two and the display repeated. Then, those locations having counts between threshold +2 and threshold + delta + 2 are displayed at maximum brightness. This process continues until the lower window value (called CLOW) is equal to or greater than DISCZ. At this point the display series repeats by starting again at the threshold value. Thus, the user observes a scanning of the matrix count contour by a moving window. During this display if any of the switch registers are enabled, the value of CLOW is printed out on the teletype and the window remains stationary. When the switch register is cleared, the window continues its scan. Figure 12 shows the contour display for three values of CLOW.

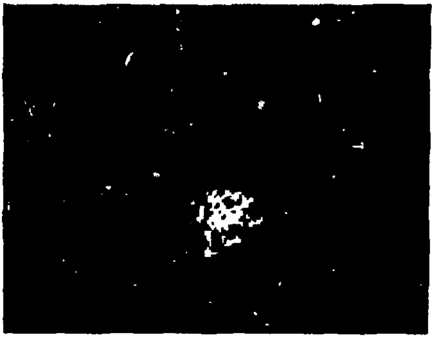
Applications

Since its construction, the positron/scintillation camera has been used in a number of applications with varying results. Two, neutron-resonance, radiography experiments were attempted utilizing one of the scintillation detectors and various subject materials. The experiments were performed with the detector's output gated to coincide with the time of arrival of the neutron energy of interest. In the first experiment, the detector was placed uncollimated in a time of flight line. In the second experiment, the detector was placed out of the line in a pinhole camera configuration. In both attempts, background radiation



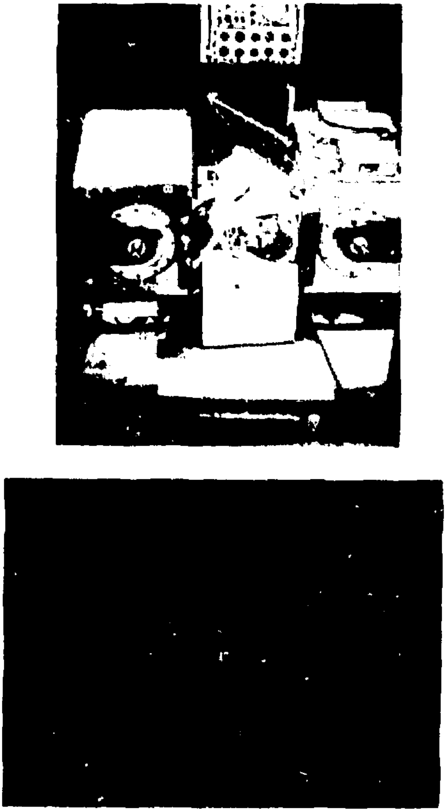
CLOW = 2
Displating counts from 2 to 5

CLOW = 10_8
Displating counts from 8 to 13



CLOW = 30_8
Displaying counts from 24 to 29

Fig. 12. Contour display data from ^{239}Pu Pu pinhole camera experiment. (Matrix smoothed twice, threshold = 2, delta = 5.)



Head-on display, matrix smoothed twice
Threshold = 2
Disc 2 = 78

Fig. 13. ^{15}O tracer experiment. 200_8 data tracks (98,604 positron events).

prevented observation of the resonance phenomena.

A tracer experiment was run using the camera as a positron detector. The subject was a dog breathing an air mixture containing ^{15}O. This experiment was performed primarily to develop techniques for future air pollution research concerning the ozone scrubbing properties of the throat. The ^{15}O was readily detected; however, no anatomical structure was observed. Figure 13 shows the experimental set-up and one of the resulting pictures.

A neutron activation experiment was also performed. A standard, half-liter, polyethylene bottle, containing ammonium nitrate, and a 1-in. X 1/4-in. copper bar were wrapped in a wool blanket and placed in a box. They were then irradiated with 14 MeV neutrons and later placed in the positron detector. The results are shown in Fig. 14.

Future experiments now being discussed include electron transport studies to be simulated using positrons and further medical type tracer experiments. In addition, the units are available for use in general gamma spectroscopy and radioactive material imaging.

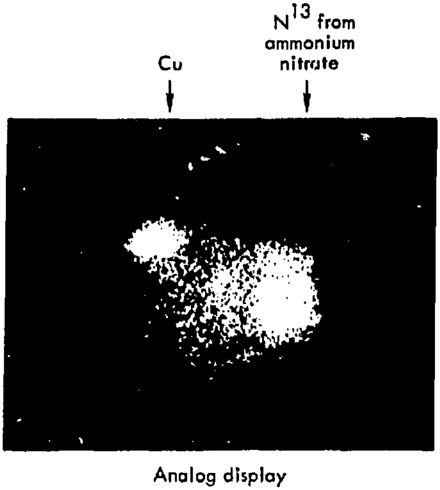


Fig. 14. Neutron activation experiment.

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