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Modification of a Multi-Isotope Color Scanner for Multi-Purpose Scanning[1]

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In recent publications from our laboratories, a technique using dual pulse height analyzer count rate systems has been described for electronic subtraction of one gamma photopeak from another allowing unhindered visualization of a second photopeak. By this method, subtraction of the ^{198}Au photopeak from the ^{75}Se photopeak permits elimination of the liver scan from the pancreatic scan (1-3). Applying similar circuitry to a commercially available color scanner,[2] the instrument may be modified to simultaneously scan two isotopes which emit photons of two different energy levels and display on the recording paper the distribution of each isotope in a different color. The overlying parts are displayed in intermediate colors or shades of two colors. Combining the "Subtract" and the "Two-Color" circuits to the color scanner, a variety of modes of operation for multi-isotope scanning is possible.

THE BLOCK DIAGRAM

The block diagram of the entire system is illustrated in Fig. 1. The following parts are added to the conventional scanner: input mixing box, a dual channel analyzer, an output mixing box, two dual ratemeters, a DC-Frequency converter and a DC-Isolator. An additional pulse amplifier was wired into the scanner ratemeter chasses (EXT. PLS.—AMP on Fig. 1), to permit independent recording on the photo and print systems. The modes of operation of the modified scanner are selected by turning a single 6-deck rotary switch, which is also

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[2]Picker Nuclear, Magnascanner V.

shown in Fig. 1. Fig. 2 is a photograph of the modified scanner.[1] An additional modification is the introduction of a "one-way circuit" to the mechanism of the scanner. This circuit permits the scanner to record while moving in one direction only, returning over the same line at a 200 cm/min speed. Since scalloping results from a delay in printout of alternate scan lines due to the factor of time constant, this type of scanning eliminates scalloping completely, thus making high-speed, slow time constant scanning possible. The relatively slow time constant (1 sec) is necessary mainly for subtract scanning to permit sufficient time for the subtraction event.

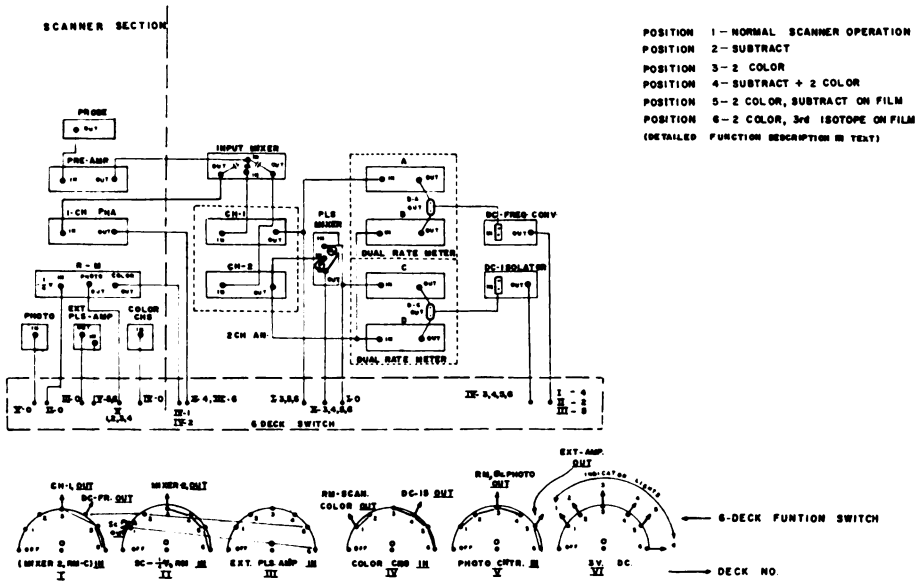


Fig. 1. A block diagram of the scanner, adjunct equipment and switching arrangement for various modes of operation.

LOGIC AND PROCEDURE

Position 1

In this position the scanner will function as a conventional color scanner, only the original components of the scanner being included in the circuit.

Position 2

This is the mode of operation previously described in detail (1-3). Pulses of different energies from two isotopes are discriminated by two pulse height analyzers, fed to individual components of a dual ratemeter, subtracted one from the second, and fed through a DC to frequency converter, designed and constructed in our laboratory, to the $-\frac{1}{4}$ V input of the scanner ratemeter. The difference of the pulses may be recorded on both the photo and mechanical

[1] In Fig. 2, a 4-channel analyzer is shown. Actually only two of the four channels are required and used.

recording devices. The major application of the mode of scanning appears to us to be for pancreatic scanning. Selenium-75-methionine and colloidal ^{198}Au are administered to the patient simultaneously. Equating the ^{75}Se pulses in a positive mode to the ^{198}Au pulses in a negative mode gives a net picture of the distribution of ^{75}Se-methionine outside the liver, the last being subtracted through the negative recording of the ^{198}Au pulses. The procedure and results of pancreatic scanning by this method have been described and discussed in references 1, 2 and 3. Fig. 3 illustrates pancreatic photoscans obtained by this procedure. This position is useful also in the scanning of ^{125}I in the presence of ^{131}I (or any low-energy gammas in the presence of a higher energy gamma).

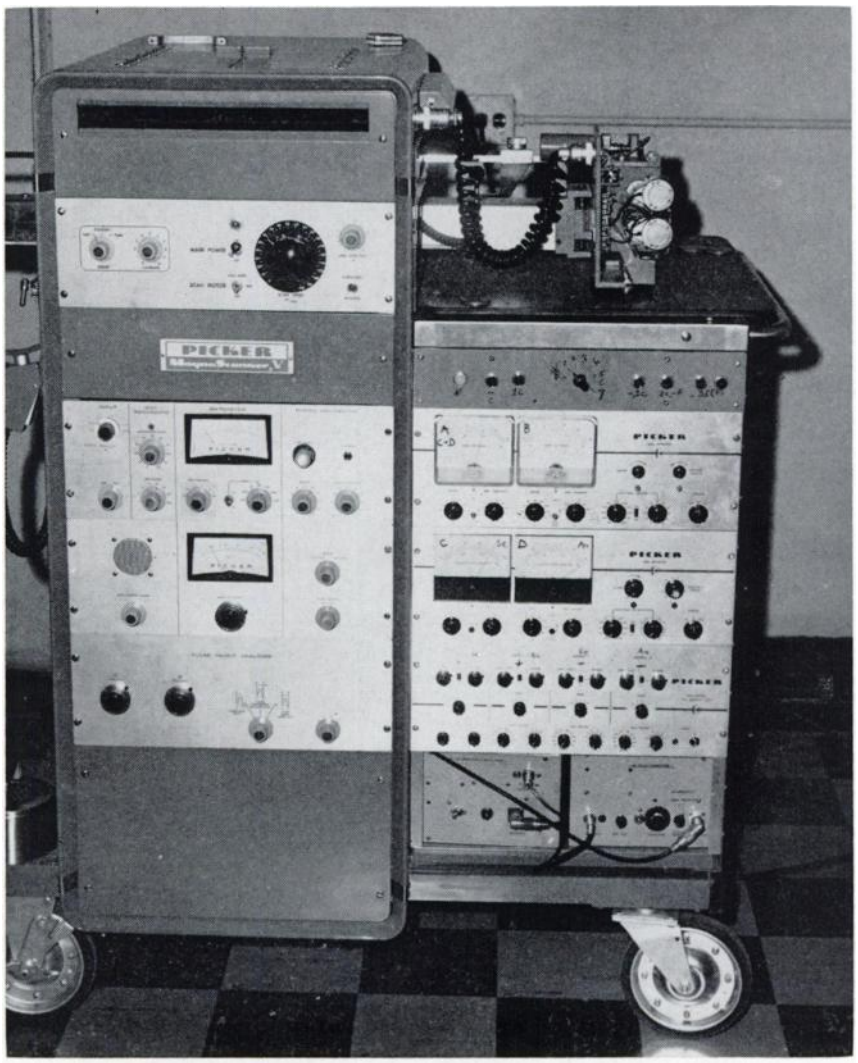


Fig. 2. The scanner modified for multiple modes of operation.

To accomplish this, Channel 2 (ratemeter B) in Fig. 1 is peaked for ^{125}I, Channel 1 (ratemeter A) for iodine-131. An ^{131}I source is placed under the detector. The settings of the window width of Channel 1 and ratemeter A are selected so that the deflection on ratemeter A equals the deflection on ratemeter B, so that the difference B − A = O. At this point no ^{131}I counts will be recorded at the output of the subtract circuit, B − A. If an object or organ containing both ^{131}I and ^{125}I is now placed under the detector, only counts from the ^{125}I will be recorded at the B − A output, as the ^{131}I countrate in ratemeter B will be subtracted by identical countrates from ratemeter A.

$$B\ (^{131}I) - A\ (^{131}I) = O$$
$$A\ (^{125}I) = O$$
$$B\ (^{125}I) - A\ (^{125}I) = B\ (^{125}I)$$

Therefore $[B(^{131}I) + B(^{125}I)] - [A(^{131}I) + A(^{125})] = B(^{125}I)$

Position 3

In this position, two isotopes emitting photons of different energy levels may be scanned simultaneously and a color display of the distribution of each of the isotopes in a different color obtained. The overlying parts will appear on the scan in intermediate shades of the two colors. Pulses from the preamplifier are fed into a dual channel analyzer. The outputs of the two channels are split, feeding a dual ratemeter and a mixing circuit consisting of two diodes to prevent feedback from one channel to the other. The pulses from the mixing circuit are fed through the scanner ratemeter and drive the stylus. The ratemeter outputs

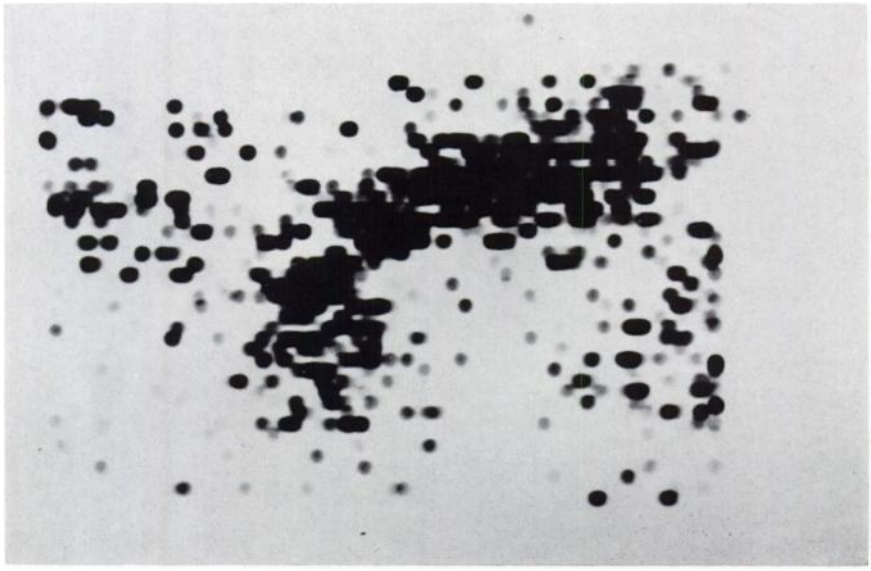


Fig. 3. A pancreatic scan obtained by subtraction of the liver image allowing unimpeded visualization of the pancreas. (Reprinted[3])

are subtracted one from the other by a built-in circuit.[1] The difference, which may be positive or negative, used to subtract one isotope from the other may now display the subtracted isotope in one color and the positive in another color by driving the scanner's color control through a DC isolator designed and constructed in this laboratory. This isolator is essential, as the DC output of the subtractor and the DC input of the color drive are isolated. The DC isolator schematic diagram is shown in Fig. 4. In operation, the DC output of the subtract circuit is connected to a #6977 Amperex light source. Any change in the DC output, positive or negative, will alter the light intensity of this lamp. The light output is measured by a CdS cell; the DC output of the CdS cell drives the color control. This output is proportional to the light output and thus proportional to the relative output from the two ratemeters.

The standard color tape of the scanner consists of seven usable colors, with black at one extreme and dark red at the other; purple, blue, green, orange and a light red are intermediate colors. The color tape has been modified using only two colors—blue and red, and four shades of each, diminishing in darkness from the extremes to the center. The range of color is controlled by the scanner "color calibrate" potentiometer control and by the resistor switch in Fig. 4. The center color is set by the potentiometer in Fig. 4.

The dual ratemeter is set in test postition. Both range scales are at 10K. At these settings, the difference of the two outputs is zero, and the center color is selected by means of the DC isolator potentiometer in Fig. 4. The range of color (or shades) is established, with the aid of the above mentioned resistor switch and "color calibrate" potentiometer by setting one ratemeter range to 3K and the second to 30K scales, to provide maximum differences. This step

[1]Picker-Nuclear Dual Ratemeter Model #5846.

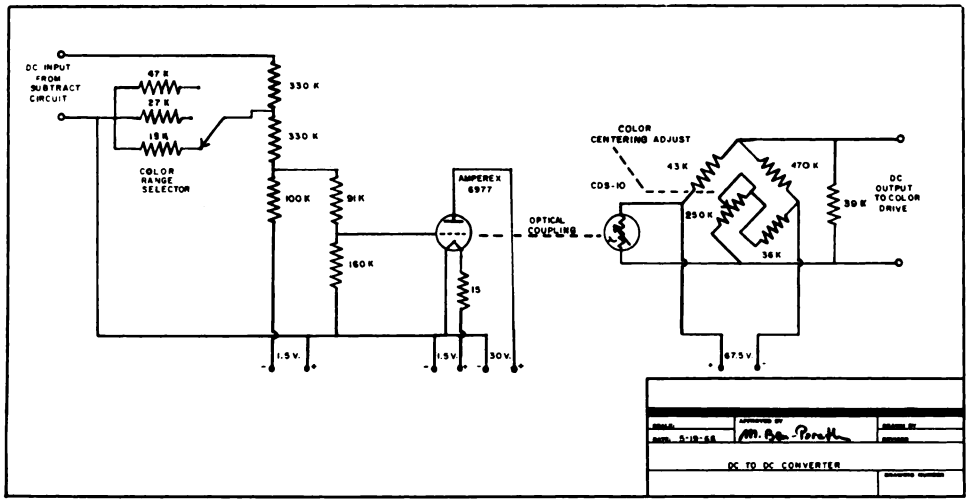


Fig. 4. Wiring diagram of the "color calibrate" circuitry.

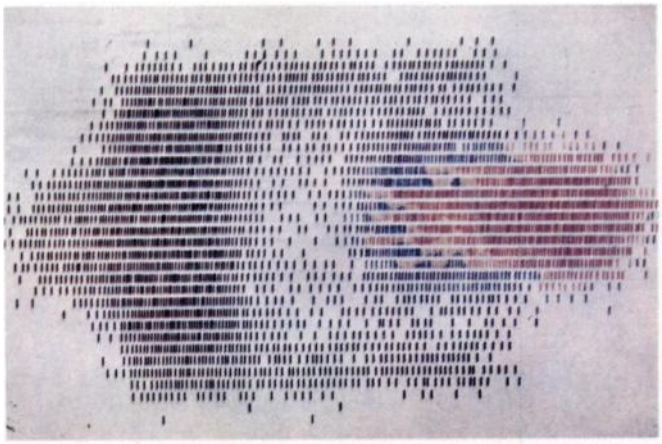


Fig. 5. A color scan showing ^{75}Se in small container distinguished from ^{198}Au in the large container.

Fig. 6. The liver and pancreas are visualized in separate colors by simultaneously scanning the ^{75}Se and ^{198}Au energy in one channel and the ^{75}Se energy in the other.

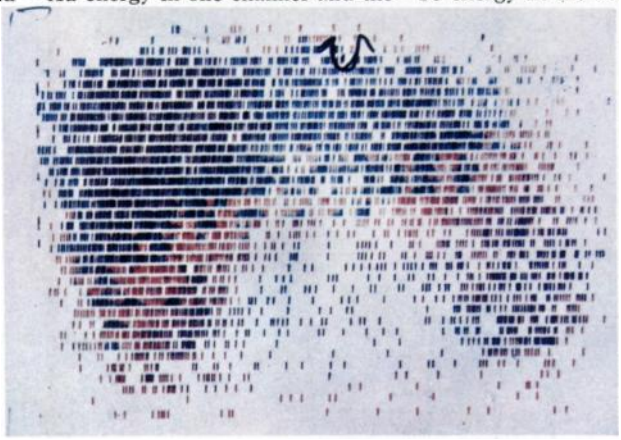
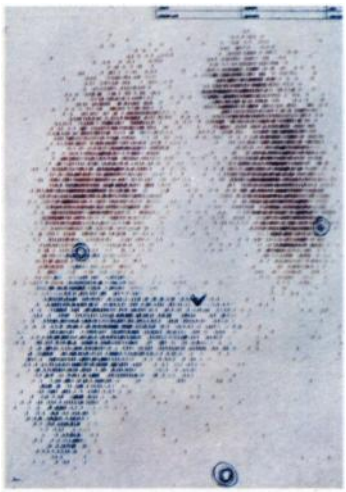


Fig. 7. The kidneys containing ^{197}Hg chlormerodrin are distinguished from the liver labeled with ^{198}Au by the two color scan technique.

is then repeated, inverting the settings of the two ratemeters to obtain deflection of the color tape in the opposite direction. The ratemeter is reset to normal position. The patient is then scanned manually and the ratemeter scales determined. The scales should be set so that the maximum deflections (not count rates) on each meter are of an equal magnitude. This condition can be achieved by selecting proper scale ranges for each meter and, if necessary, by altering the channel width on the corresponding analyzers. This procedure could best be accomplished by a balancing circuit between the two meters.

The patient and the instrument are now set for energy-color scanning. If only pulses of energy A are detected, the color band will be deflected to one extreme and the pulses will be recorded in color A. If only pulses of energy B are detected, the color band will be deflected in the opposite direction and only color B will be printed. If pulses of both energies are detected, the color band will move between the extremes printing out intermediate shades of the two colors. If A is greater than B, the lighter shades of color A will be printed, the darker shades indicating the magnitude of the difference. If A is less than B, shades of color B will be printed. The intensity of the counts is indicated by the density of impulses printed, which is controlled by the sum of A + B.

Figure 5 shows the energy-color scan of a phantom, consisting of 50 μC ^{198}Au in a Marinelli Beaker and 50μC ^{75}Se in a cylindrical container inserted ¾ into the hollow part of the beaker. The gold is printed out in black, the selenium in red, and the overlapping part in the intermediate colors. Figure 6 is a scan of the liver containing ^{75}Se and ^{198}Au shown in blue and the pancreas containing ^{75}Se in red. In Figure 7, the liver (^{198}Au, black) overlies most of the right kid-



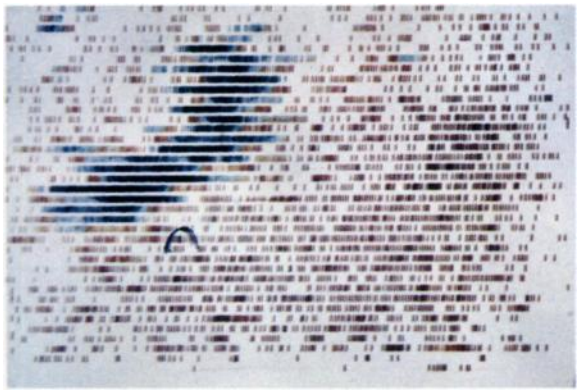


Fig. 8. (left) Demonstrates the simultaneous visualization in different colors of the lungs and liver by scanning the ^{131}I albumin macroaggregate and the ^{198}Au colloidal gold in the two organs.

Fig. 9. (right) The two color display in conjunction with the subtract mode is used to visualize ^{198}Au in the liver and ^{75}Se in the pancreas.

Fig. 10. A subtract scan of the area of the liver and pancreas showing an area of intense ^{75}Se concentration.

Fig. 12. The conventional ^{198}Au scan of the patient's liver revealing a "cold" spot at the tumor site.

Fig. 11. Two color subtract scan showing the liver in red by ^{198}Au concentration and the ^{75}Se selenomethionine concentration within the liver.

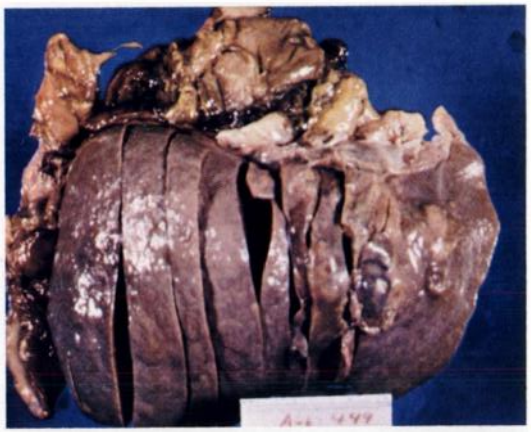


Fig. 11a. The patient's liver at necropsy revealing a large hepatoma.

Fig. 13a. A conventional scan of the thyroid using ^{125}I, revealing a relative "hot" area in left lobe.

Fig. 13b. The same thyroid scanned with ^{131}I two days following the ^{125}I scan. Thyroid stimulating hormone (TSH) was administered in the interim causing enhanced pickup in the right lobe.

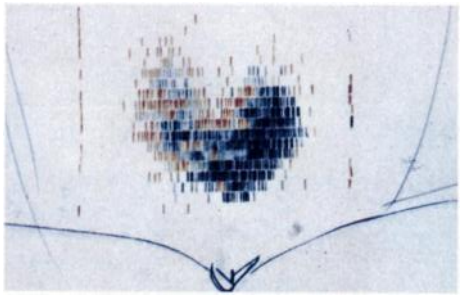


Fig. 13c. The two color subtract mode of scanning reveals the simultaneous distribution of ^{125}I and ^{131}I.

Fig. 14a. The two color subtract mode visualizes ^{125}I HSA in the heart blood and ^{131}IHSA macroaggregate in the lungs of an individual with a normal chest.

Fig. 14b. The same mode of visualization as in (a) above reveals a space about the heart of an individual with pericardial effusion.

ney (^{197}Hg, red); nevertheless both organs are individually visualized by intermediate colors. Figure 8 is a lung (R^{131}ISA Macroaggregate) and liver (^{198}Au collodial) scan. The patient was suspected of a right subdiaphragmatic abscess (4). The scan excludes this possibility, as the overlying part of the liver and right lung lobe are outlined in the intermediate shades. The pathology indicated in the upper and medial left lung were confirmed by radiological findings.

Position 4

In this position, both the subtract and the two color circuits are activated. The net output of the subtract is fed from the DC-frequency converter to one of the two ratemeters of the color control dual ratemeter and to the input of the

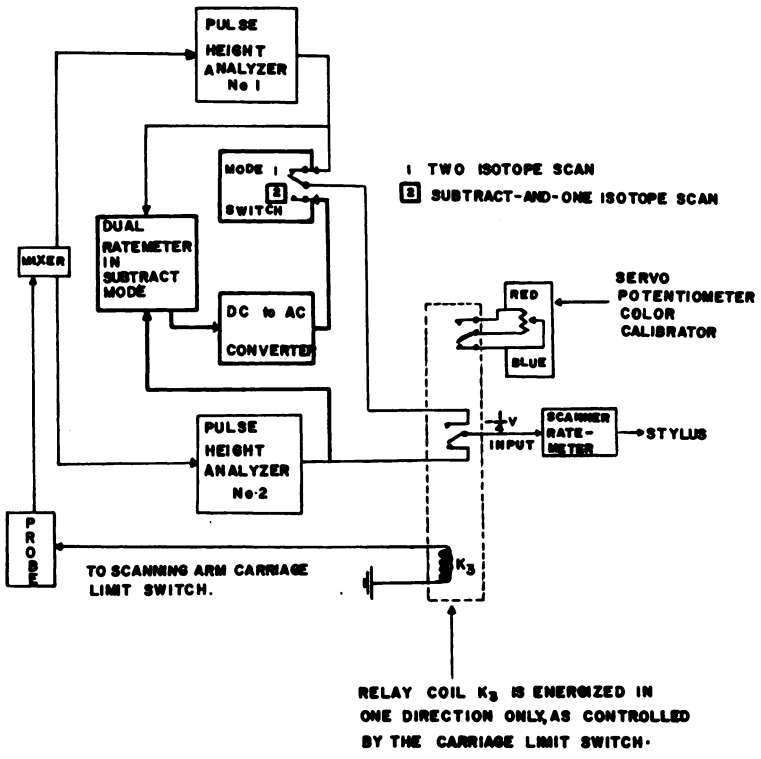


Fig. 15. Circuit diagram of one way one isotope scanner modification.

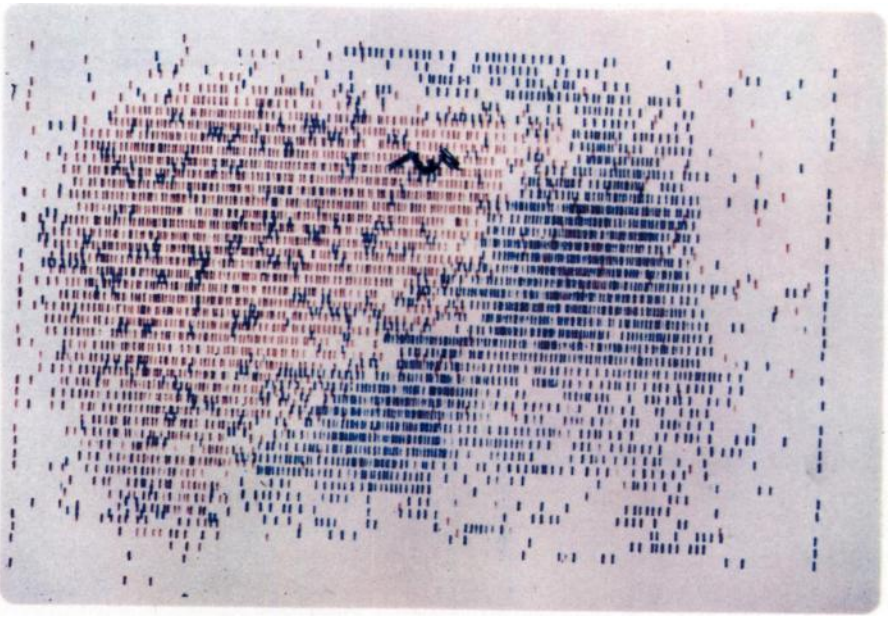


Fig. 16a. Normal pancreas visualized by scanning modification in Figure 15.

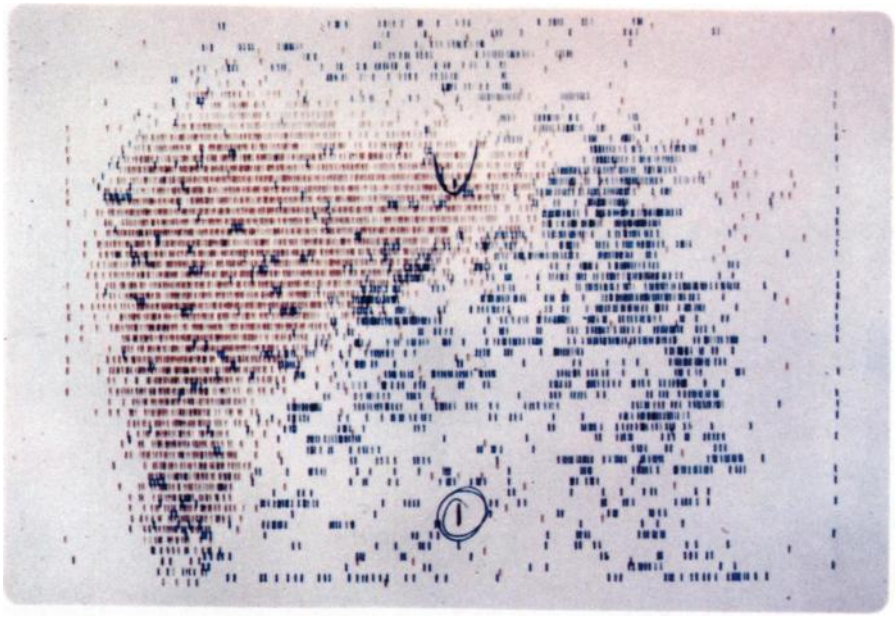


Fig. 16b. Carcinoma of the pancreas visualized by scanning modification in Figure 15.

output mixer box. In this setting scanning two isotopes, one will be displayed in one color and the "subtract" of the two in a second color. This factor is particularly useful if, for instance, the pancreas and the liver are to be displayed. Then the ^{198}Au will be displayed in one color and the extrahepatic ^{75}Se minus ^{198}Au pulses in the second color (Fig. 9). The usefulness of this position is demonstrated in the following case:

A pancreas scan by the subtract method was performed on a patient with suspected malignant involvement of the pancreas (Fig. 10). It was difficult to determine the meaning of the large mass of selenium concentration demonstrated in this scan. An energy-color scan was subsequently performed (Fig. 11). This scan showed the selenium mass to be in the liver. A liver scan utilizing the ^{198}Au already in the liver was performed (Fig. 12) and revealed a "cold" area, interpreted as a space occupying lesion at the identical location of the selenium mass visualized in Fig 11.

Fifty-two days after these scans were performed, a necropsy revealed a hepatoma and severe chronic pancreatitis. A massive tumor was found in the liver (Fig. 11a), precisely at the location revealed by the scan. Tumor cells were spread throughout the entire liver with several nodules of various sizes. Five gram specimens of various organs were obtained and the ^{75}Se concentration was determined (Table I) and revealed to be equal in both liver and hepatoma at 52-days post administration. No information is available concerning relative concentration at the time of scanning. Assuming equal concentration at the time of scanning, the ^{75}Se in the hepatoma would still be visualized by this method as ^{198}Au did not concentrate in the tumor allowing the nonsubtracted ^{75}Se in the hepatoma to be visualized as a separate color.

Another application of position four is demonstrated in Figure 13A, the ^{125}I thyroid scan visualizing a hot nodule in the left lobe. The patient then was given 10 units of TSH followed in 24 hours by iodine-131. The ^{131}I scan of the same thyroid in 13B indicates the right lobe is considerably intensified, compared to Figure 13A. Figure 13C is a position four scan of the thyroid after TSH. The blue area represents the ^{125}I concentration, the Orange-Red area the ^{131}I concentration, where-ever no ^{125}I is present in the gland. Thus, this area shows the part of the thyroid stimulated by TSH, which was "cold" prior to the TSH treatment. The thyroid uptake of the patient was 22% before and 50% after TSH. This mode of scanning was employed to simultaneously visualize the chambers of the heart with R^{125}ISA and the lungs with ^{131}I albumin macroaggregate in separate colors. A normal chest (Fig. 14A) may be compared with the scan of a patient with pericarditis (Fig. 14B). In the second patient the pericardial effusion is demonstrated as a non-colored space at the cardiac margin, proved by pericardial tap and having a water bottle heart on chest x-ray.

Position 5

It is possible to simultaneously visualize two organs in separate color on paper and the subtract scan demonstrating a single organ with the other subtracted on film. This technique is useful in two-color scanning of liver and

pancreas with a simultaneous black and white subtraction scan of the pancreas. This condition is accomplished by feeding the DC-Frequency converter output into the external pulse amplifier, which then drives the photorecording system, while the DC isolator output drives the color system and the sum of the pulses of both isotopes drive the stylus.

Position 6

In this mode of operation, two isotopes drive the color control and stylus as described in position 3, while the pulses of a third are fed through the scanner pulse height analyzer, bypassing the stylus mechanism through the external pulse amplifier and recorded on the film. This procedure permits simultaneous recording of three organs as, for instance, the liver (^{198}Au), spleen (^{203}Hg) and kidneys (^{197}Hg).

TABLE I

Organ	*^{75}Se Concentration*	*Organ Weight*	*% Administered Dose in Organ*
Liver tumor	$7.2 \times 10^{-3}\mu C/g$	2400 g	7.7
Liver	$8.1 \times 10^{-3}\mu C/g$		
Liver	$8.2 \times 10^{-3}\mu C/g$		
Kidneys	$10.2 \times 10^{-3}\mu C/g$	255 g	1.0
Spleen	$5.5 \times 10^{-3}\mu C/g$	600 g	1.3
Pancreas	$1.9 \times 10^{-3}\mu C/g$	80 g	< 0.1

^{75}Se concentration in different organs 52 days following 250 μC ^{75}Se-methionine administration. (Single case.)

Position 7

(Not described in Fig. 1.[1]) Position seven enables the visualization of the subtraction of two isotopes on film, while mechanically recording a third isotope. This procedure is important for some cases of pancreatic scans in which the kidneys concentrate a fair amount of ^{75}Se-methionine and are visualized on the pancreas scan. To determine whether this activity recorded is actually due to kidney concentration, ^{197}Hg Neohydrin is administered and a kidney scan is obtained simultaneously with the pancreas scan done by subtraction technique.

[1]One additional switching position "7" is required, (see Fig. 1), in which the following loops are added to pin #7 on each deck: I:7-blank; **:7-1; III:7-6; IV:7-2; V:7-6; VI:7-indicator light.

As indicated, current technical modification eliminates scalloping by printing while scanning in one direction the detector return at high speed without printing. Further modification has resulted in significant simplification of the circuitry seen in the block diagram (Fig. 15). Despite the prolongation of scanning time using this method, the quality of the scan is improved and the cost of the modification is considerably reduced, compared to the circuitry initially described in this paper. The standard color scanner is altered by addition of a single channel pulse height analyzer and a two-contact relay. In operation the probe, when moving from left to right, trips the carriage limit (probe reverse) micro switch at the end of a scan line. In addition to reversing scan direction, a relay is activated permitting only pulses from PHA1, set for isotope A, to be recorded in color A in the following line. At the end of that line, the second carriage limit micro switch activates PHA2 set for isotope B to be recorded in color B in the subsequent line. The two sequences alternate throughout the scan. Thus, one isotope will be recorded in a specific color while the probe is scanning in one direction and the second isotope in a different color, while the probe is scanning in the opposite direction. To prevent loss of space density, one-half of normal spacing should be employed, so that each isotope will be scanned at normal spacing. (e.g. If the normal spacing for liver and pancreas scanning is 4 mm, a spacing of 2 mm is used with this method. Scalloping is also eliminated using this technique, as each isotope is scanned in one direction. Displacement of the images in each color occurs relative to each other. Being a function of scanning speed and time constant, it can be calculated:

$$D = T \times S$$

where D = displacement in cm
T = Time constant in seconds
S = Scanning speed in cm/second

(e.g. If T = 0.1 second, S = 1 cm/second, D = 0.1 × 1 = 0.1 cm in each direction, which is negligible.)

The subtract circuit previously described by the authors (2) may also be used with this method, allowing the "subtract scan" to be visualized in one color and one of the two isotopes in a second color. A representative scan of a liver and pancreas in a normal individual and one with carcinoma of the pancreas is seen in Fig. 16a and b. To accomplish the subtract mode, a mode switch or DC to AC converter and a dual rate meter are added to the circuitry (Fig. 15).

SUMMARY

A simple method is described by which a standard color scanner may be converted into a multi-isotope scanner. The distribution of each isotope may be recorded in either positive or negative modes or combinations of the two. Up to three isotopes may be scanned simultaneously. Various clinical applications of this system are demonstrated.

ACKNOWLEDGMENT

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BIBLIOGRAPHY

1. KAPLAN, E., BEN-PORATH, M., FINK, S., CLAYTON, G. and JACOBSON, B., A Dual Channel Technique for Elimination of the Liver Image from Selenomethionine Pancreas Organ Scans. Progress in Biomedical Engineering, Books, Inc., Washington, D.C., 1966.

2. BEN-PORATH, M., CLAYTON, G. and KAPLAN, E., Selective Visualization of the Pancreas by Subtractive Double Radioisotope Scanning Technique. *Transactions of the American Nuclear Society*, 9:76, 1966.

3. KAPLAN, E., BEN-PORATH, M. FINK, S., CLAYTON, G. and JACOBSON, B., Elimination of Liver Interference from the Selenomethione Pancreas Scan, *Journal of Nuclear Medicine*, 7:807-816, 1966.

4. BROWN, D. W., Lung-Liver Radioisotope Scans in the Diagnosis of Subdiaphragmatic Abscess. *JAMA*, 197:728, 1966.
