

## Perforated Tape Recorder for Digital Scan Data Store With Grey Shade and Numeric Readout<sup>1</sup>

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### INTRODUCTION

Current directions for improvement in radioisotope scanning emphasize faster collection of data, more detail in images, and quantitative analysis of the data. The information extracted from the study depends crucially on how data are recorded, displayed, and analyzed.

In the earliest scan records, counting data were presented as rows of black stylus marks made on paper (1). Later, color coding was introduced to improve the contrast of mark recordings (2). Now scan data are usually recorded as grey shade images on photographic film (3). In most photorecorders, film is exposed by a light source coupled mechanically to the detector, but cathode ray tube oscilloscopes with cameras have been used as photographic recorders for special purposes (4, 5). For more optimum choices of image contrast, closed circuit television viewing (6) and rescanning densitometry (7) have been used for analysis of the photographic record after scanning. Other approaches for optimizing image contrast have included magnetic tape recording of scan data followed by time compression replay with oscilloscope camera film recording (8) or storage tube display (9). Numeric printout has been used when the quantitative counting data were of more importance than picture quality (10, 11). Recently, perforated tape recording of the counting data has been employed by some workers as a prelude to the use of a large computer for data analysis (12, 13, 14, 15).

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We have evolved a data system that has been efficient and reliable in the processing of several thousand scans over the past two years (16, 17, 18) (Fig. 1). Instrument cost is commensurate with that of present day rectilinear scanning systems. In operation, digitized counting and position data are recorded on a strip of perforated paper tape without significant loss or distortion. Rapid playback converts these data to a recognizable form. For visual inspection, a grey shade picture is generated on Polaroid film, with contrast under operator's control. For quantitative retrieval, the counting data are presented as a matrix of typewritten numbers. The inexpensive length of perforated paper tape remains a part of the patient's permanent record, available for future analysis if needed.

#### INSTRUMENT DESIGN

*2.1 Recorder.* We required that recording and display instrumentation be separated physically so as to permit simultaneous independent use. The recording medium was to be small in size and inexpensive, so that data might be retained permanently in original form. Continuous-speed magnetic-tape recording would produce a longer and more expensive tape than desired; multiple-channel incremental-feed magnetic recording would produce a short tape but would be a costly instrument investment. Perforated paper tape recording was chosen as the preferred technique. Perforators are well adapted to the slow rates of data collection inherent in present day scanning, and the short length of paper record is convenient to handle and store.

In this system, each character on the paper tape is made to represent the counts integrated in a predetermined elapsed detector travel distance. Originally, we used a predetermined elapsed time based sampling interval. This was replaced with spatial sampling intervals to avoid distortion of the final image matrix through unavoidable small fluctuations in scan speed. With time based sampling, for example a one per cent fluctuation in scan speed will add or subtract one picture element of a scan line that should be 100 picture elements wide. With spatial sampling, the number of elements in the line remains at 100; the one per cent change in collected counts is insignificant. Also, image generation with spatial sampling requires retained knowledge of picture element size alone, much less complicated knowledge than the scan speed required with time based sampling.

The operation of the recorder is illustrated in Figure 2. Pulses from the detector are processed in a pulse height analyzer and inserted into the scaler. The scaler produces an output pulse representing 1, 2, 4, or 8 input pulses, depending on the selection of the scale factor.

The scaler output pulse is inserted into the counter where six flip-flop circuits are connected for serial counting. The parallel output of these circuits provides a binary representation of the accumulated counts.

Meanwhile, the spatial trigger unit has received an input signal from the scanner which represents a predetermined elapsed detector travel distance. This signal is used to activate two univibrators. The first univibrator generates a pulse of one microsecond duration which is introduced to the counter and to the storage register. Upon receipt of this trigger pulse, the counter stops, resets to zero, remains inactive for a one microsecond dead time, and then resumes counting. The

second univibrator in the trigger unit generates a 30 millisecond signal which activates the punch mechanism but does not contribute to the overall dead time of the system.

Upon receipt of the transfer signal from the trigger unit, six flip-flop circuits in the storage register assume the state of the six inputs received from the counter. These storage register circuits are directly connected to the perforated drive where power transistors are matched to tape perforator punch coils. Upon receipt of the punch command from the trigger unit, these power transistors are activated through gating circuits, whereupon tape columns one through six are punched to represent the count in binary code.

The paper tape coding is shown in Figure 3. Detector position is specified using three command codes; *raster start*, *line start*, and *raster end*. These codes are generated by the raster encoder after receipt of electrical signals describing the position of the detector during scanning. The data punch is activated only during the traverse portion of the raster.

When multiple detectors (A, B, C) are used with this method, an additional analyzer, scaler, counter, and storage register are required for each detection system. The overall dead time of the system is not increased. Data characters from

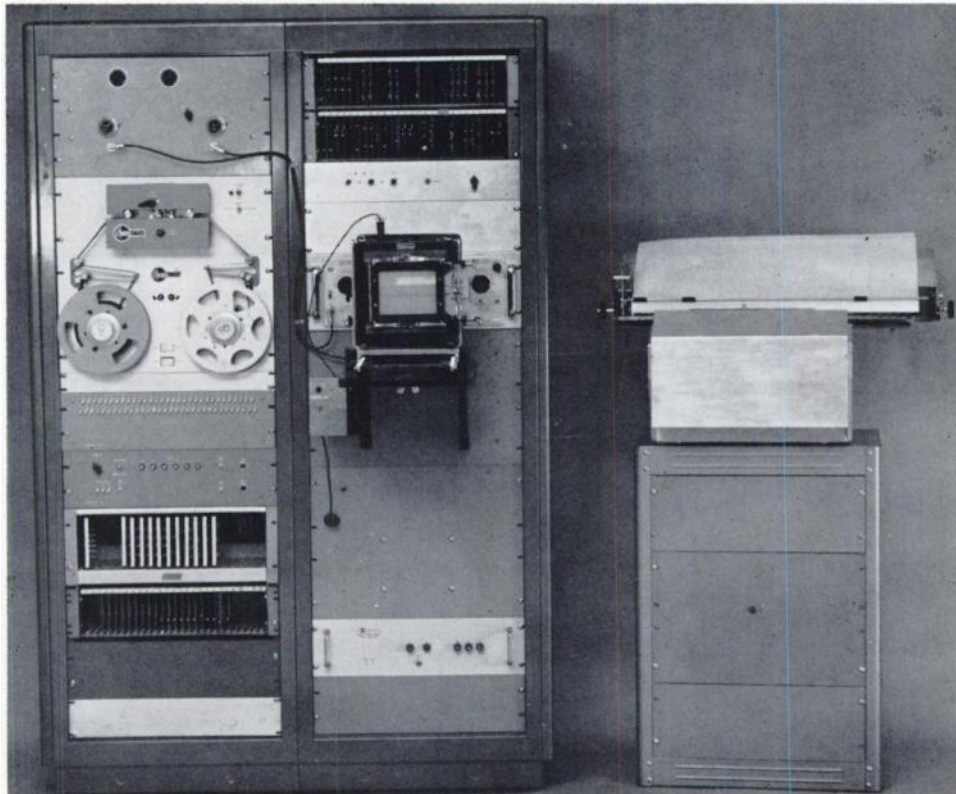


Fig. 1. The scan picture generator includes a perforated-paper tape reader, digital logic circuitry, a display cathode-ray tube with camera, and an automatic typewriter.

the first detector are identified by a punch in column seven. Data characters from the additional detectors are identified by their sequence following this punch.

**2.2 Grey Shade Picture Readout.** The operation of the picture generator is diagrammed in Figure 4. At the completion of the scan procedure, the tape record is introduced to an eight-column perforated tape reader operating in unidirectional mode at a rate of 300 characters per second. When a single detector is used, an average tape record of 9,000 picture elements is 75 feet in length and is read in approximately 30 seconds.

The tape reader signals are introduced to the decoder which provides outputs representing the three position command codes, a sprocket track signal, and six binary count levels.

The screen position of an oscilloscope<sup>1</sup> spot is controlled by the tape position codes. The raster start code provides a master reset signal to all spot positioning circuitry. For a transverse positioning, the track signal is fed to a bidirectional X axis binary counter which is alternately conditioned by the line start code into the up-count and down-count modes. The X axis counter has a capacity of seven binary bits which yield a possible 127 picture elements per line. The output of the X counter is introduced into the X axis D/A converter which provides

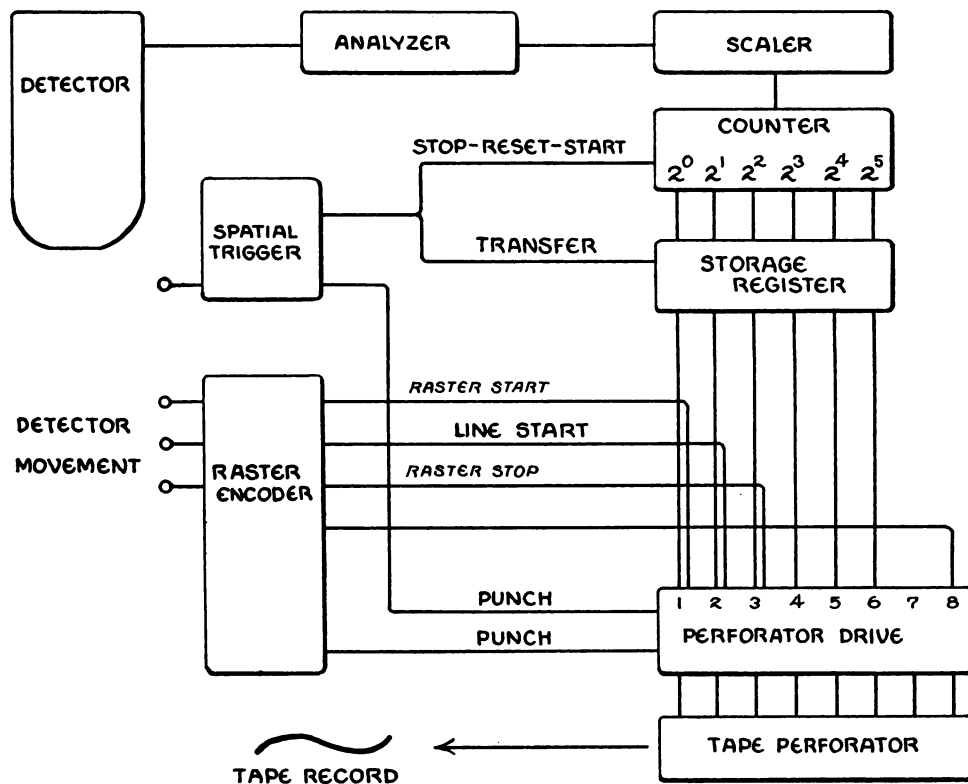


Fig. 2. Recorder. Digital counting and position data are recorded on a strip of perforated paper tape.

<sup>1</sup>P-11 phosphor, 3000 volts accelerating potential

either an ascending or descending staircase analogue signal, depending on the preconditioning by the line start code. This analogue signal is then introduced to the X axis of the oscilloscope to cause the spot to move across the screen in either direction, to correspond to the motion of the detector. For line spacing, the line start code is also fed into a unidirectional Y axis binary counter which has a capacity of seven binary bits, yielding a possible 127 lines. The output of the Y axis binary counter is fed to the Y axis D/A converter which produces an ascending staircase analogue voltage, each step corresponding to a scan line. This output is introduced to the Y axis of the oscilloscope to cause the spot to ascend the screen according to the scan line spacing. This combination of X and Y axis signals reconstitutes the rectilinear raster of the detector on the oscilloscope screen.

For representation of the counting data, the six count outputs of the decoder are translated to corresponding analogue voltages in a Z axis D/A converter. These analogue signals are then introduced to the contrast control, an operational amplifier with adjustable gain and offset which modulates the oscilloscope spot brightness (Fig. 5). The beam is turned on with receipt of the raster start code and turned off with receipt of the raster end code.

A saw-tooth oscillator is used to provide a rectangular spot shape of adjustable dimensions. The spot width is adjusted to correspond to the spatial interval of count integration; the spot height is made to correspond to the line spacing.

Screen exposure time for each element is determined by the tape reader character speed and is the same for all rasters. At a reader speed of 300 characters per second, each element brightens the screen for one three-hundredth of a second.

An open shutter oscilloscope camera records the scan image on high speed self developing positive film which has a ten second developing time<sup>1</sup>. In all pictures, an increase in count is represented as an increase in blackening on the final prints. With positive film in the oscilloscope camera, negative modulation is used for the spot brightness. Zero count spot brightness is adjusted to just saturate the film and thereby, produce a white spot. With increase in count, the spot becomes more dim; the picture representation becomes darker. Positive modulation can be obtained for use with negative film by incorporating an inverting operational amplifier in the Z axis line.

<i>Column number</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>
Raster start	X							X
Line start		X						X
Raster end			X					X
A detector count	$2^0$	$2^1$	$2^2$	$2^3$	$2^4$	$2^5$	X	
B detector count	$2^0$	$2^1$	$2^2$	$2^3$	$2^4$	$2^5$		
C detector count	$2^0$	$2^1$	$2^2$	$2^3$	$2^4$	$2^5$		

Fig. 3. Paper tape coding. Each character expresses either position data, specified by three command codes, or counting data, representing counts integrated in a predetermined elapsed detector travel distance.

<sup>1</sup>F-8 lens operating; Polaroid type 57 film, ASA rating 3000

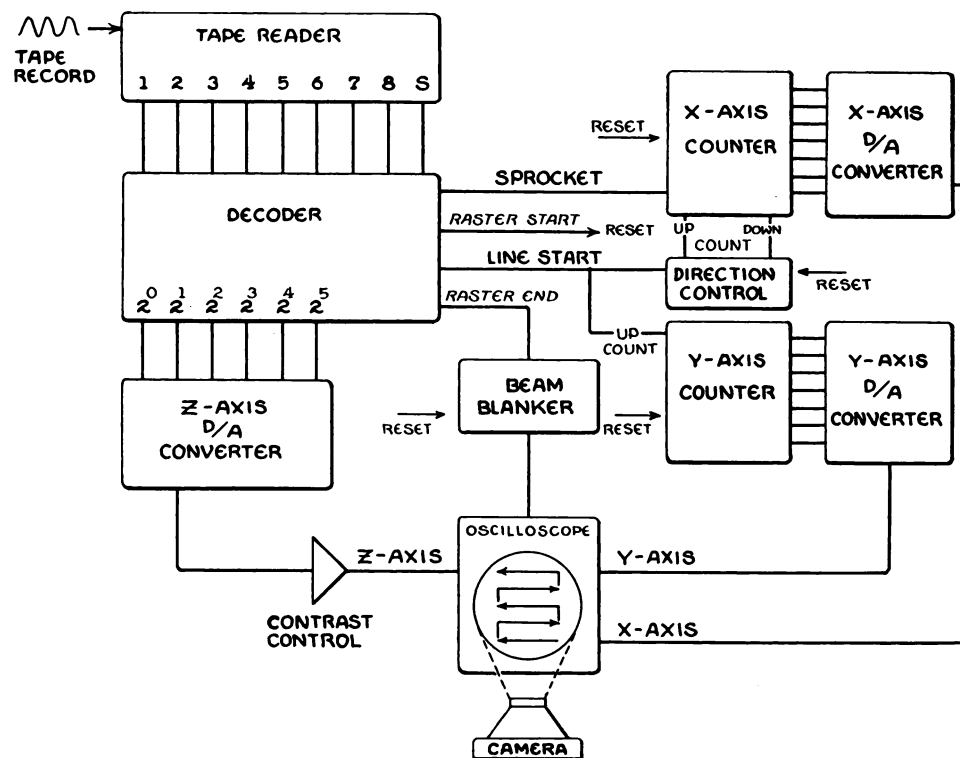


Fig. 4. Grey shade picture readout. Rapid playback converts the perforated tape data to a grey shade picture on Polaroid film.

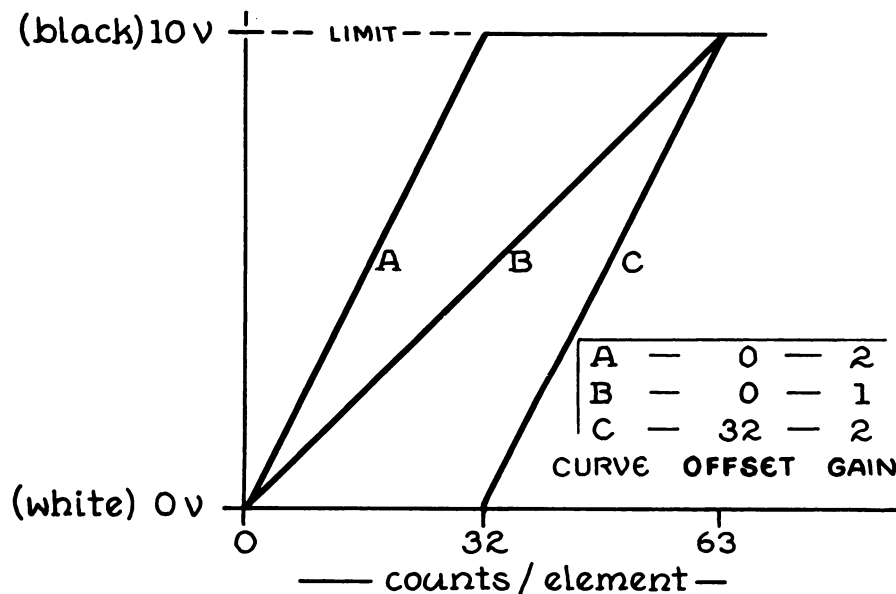


Fig. 5. Contrast control. The offset and gain controls can be adjusted by the operator to modify the information transforming function.

**2.3 Numeric Readout.** When quantitative retrieval of counting data is more important than picture quality, the scan data on the perforated tape can be presented as a matrix of typewritten numbers.

Data characters on the tape are oriented according to the bidirectional detector motion. A unidirectional orientation of characters is required for the typewriter input, so that numbers will align correctly when each line is typed in the conventional left to right direction. Therefore, the reader is programmed to read the first and all odd numbered scan lines in the reverse direction; the second and all even numbered scan lines are read in forward direction.

The operation of the automatic typewriter system is illustrated in Figure 6. The command code signals, raster start, line start, and raster end, are separated in the decoder and matrix driver and delivered to the tape feed control and the typewriter control. In accordance with these codes, the tape feed control causes the tape reader to read forward, read reverse, or end reading; the typewriter control causes the typewriter to return carriage and advance the paper roller. With each command code, the tape reader is stopped until completion of the required typewriter operation, whereupon it delivers a *go* signal to the tape feed control.

Counting data in the selected tape channel (A, B, or C) is detected in the decoder and matrix driver and a signal is sent to the tape feed control to stop the reader. The first and second diode matrices translate the six level binary code originating from punches in tape columns one through six into a two character decimal circuit accommodating numbers ranging from 00 to 63. The six level parallel binary count signals are converted by relay drivers to six paired binary levels of sufficient power to drive the first diode matrix. This matrix converts the six paired wire binary levels to 63 wire single levels representing all possible

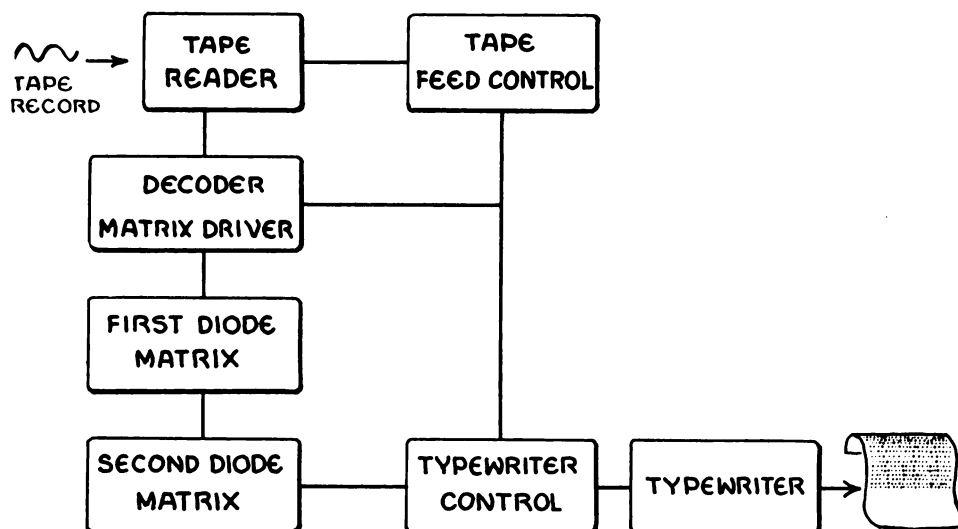


Fig. 6. Numeric readout. For quantitative retrieval, the scan data on the perforated tape are presented as a matrix of numbers by the automatic typewriter.

integers from zero to 63. The 63 wire output is introduced to the second diode matrix and converted to a 17 wire output. The first seven wires represent the first decimal characters zero to six, and the remaining ten wires represent the second decimal characters zero through nine.

The typewriter control contains timing circuitry which permits the typewriter to print the first character, print the second character, and then space before signalling the tape feed control to advance the tape to the next appropriate character.

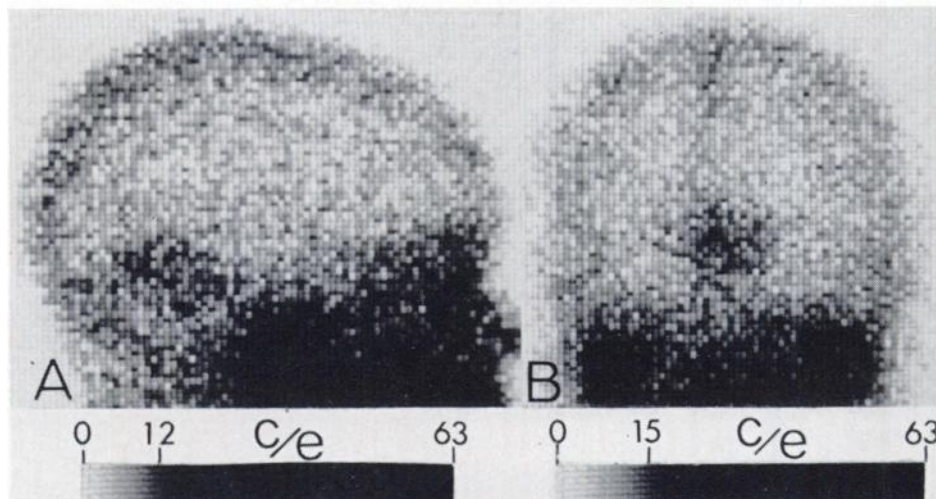
The typewriter is a modified manual office machine with a carriage that accommodates a sheet of paper 66 centimeters wide. Power transistors drive solenoid plungers on the number keys, space bar, and paper roller advance. A motor and clutch are used for carriage return.

After loading the tape reader and inserting a blank piece of paper into the typewriter, the operation of the typewriter system is fully automatic. The typewriter operates at a speed comparable to a fast manual typist and completes the printout of an average scan raster in approximately 45 minutes.

#### INSTRUMENT USE

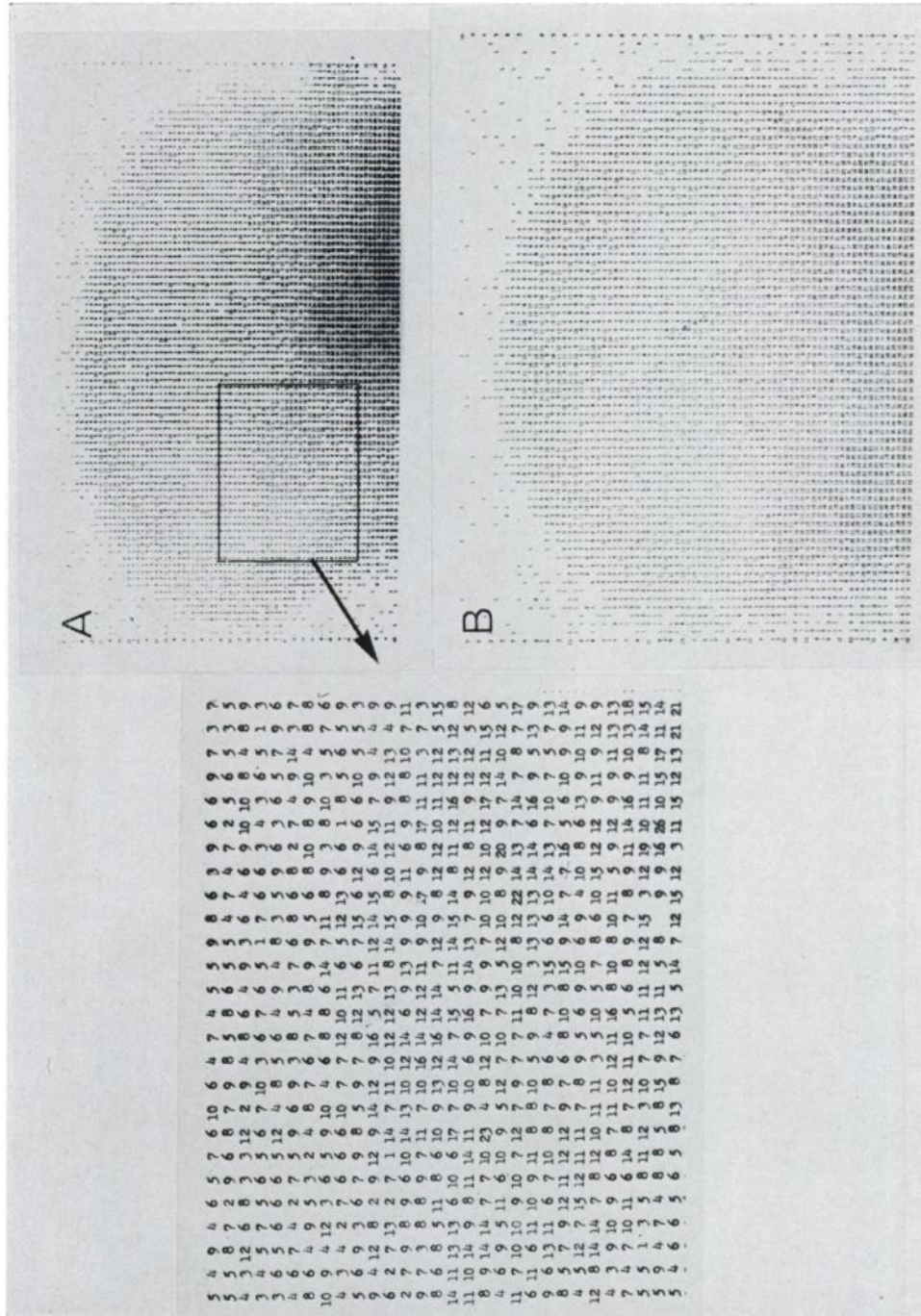
**3.1 Picture Element Size.** The choice of picture element size is important when pictures are to be generated from digital data. The width of the picture element is determined by the selection of spatial interval for count integration. The picture element height is determined by the selection of line spacing. If the picture element is too small, the large number of required scan lines prolong the study. On the other hand, if the picture element is too large, picture detail is destroyed and the checkerboard pattern interferes with perception of the image.

If the collimator has been correctly chosen for the study, the best choice of picture element size is related to the minimum diameter of view of the detector. The picture element should probably be no wider than one-fourth of the minimum diameter of view of the detector if destruction of detail is to be avoided. For ex-



**Fig. 7.** Grey shade brain scan pictures. Cerebellar astrocytoma grade I in 15-year-old girl. (A) Right lateral and, (B) Posterior views. Calibration bands are below each picture.





**Fig. 8. Numeric printouts corresponding to scan pictures shown in Figure 7. (A) Right lateral and, (B) Posterior views. Enlarged segment shows range of count values comprising tumor image.**

ample, we used a collimated detector that had a 1.25 cm minimum diameter of view to scan point sources arrayed with different separations. We found that source separations as small as .75 cm could be distinguished, when the picture element was .25 cm square. However, when a .5 cm square picture element was used, individual sources could not be distinguished at separations less than 1.25 centimeters. In this instance, the preferred relationship of picture element size, .25 cm, to minimum diameter of view, 1.25 cm, is analogous to the accepted practice of choosing sampling rates four or five times the maximum frequency of the input signal in analogue to digital conversion systems.

**3.2 Brain Scan Example.** When the collimator described above is used for brain scanning with  $^{99m}\text{Tc}$  pertechnetate, we give an intravenous dose of 200  $\mu\text{C/kg}$  of body weight and begin scanning 15 minutes later. Counts are integrated at a .25 cm spatial interval and a .25 cm line spacing is used to produce the square picture element. With a scan speed of 2 cm per second, the maximum recording capacity of 63 counts per picture element is seldom exceeded, except over the parotid gland. An 80 line scan frame measuring 25 cm by 20 cm requires less than 15 minutes of scan time. The picture is a matrix of 8000 picture elements (Figs. 7, 8).

The count content of each picture element can be represented in the Polaroid readout as a scale factor times any number from zero to 63. Therefore, there is a potential range of 64 shades of grey available. In practice, each recording is displayed as a series of high contrast pictures, each of which displays a portion of the entire count range as a change from white to black (Fig. 7).

**3.3 Smoothing Random Fluctuation.** The scan pictures in Figure 7 are representative noisy images where the counts per picture element are low and random fluctuation impairs perception. The spottiness of these images can be diminished by integrating counts over areas wider than one picture element. This can be done

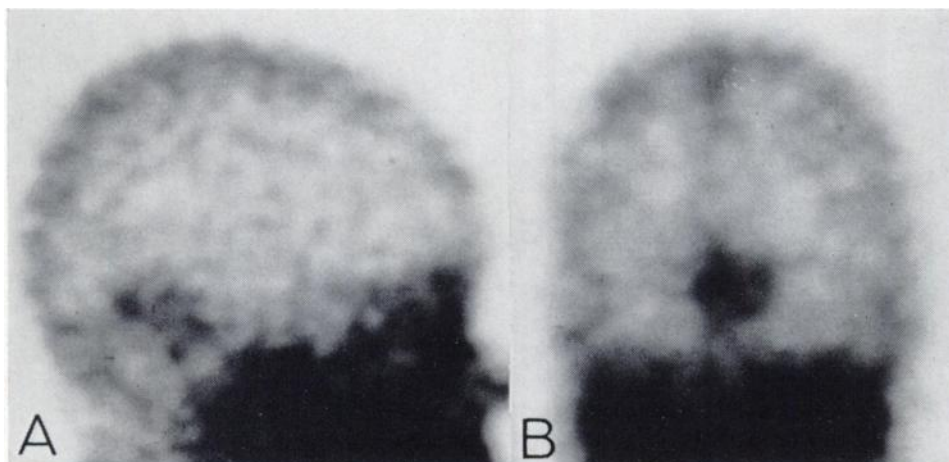


Fig. 9. Smoothing random fluctuation by printing a defocused scan picture. In this instance, the oscilloscope light spot was made larger than each individual picture element. For better control of spatial averaging, a hand held glass diffusion filter may be used when reading a picture printed in focus.

by printing the picture with the oscilloscope light spot larger than each individual element (5, 19) (Fig. 9). However, we prefer another method of spatial averaging. For better control, we print the picture elements in sharp focus and perform the optical blurring with a hand-held glass diffusion filter at time of interpretation (20). Our more recent experience with digital techniques for secondary processing of scan data is described elsewhere (21).

#### SUMMARY

The design and operation of a scan data system is described. Digitized counting and position data are recorded on a strip of perforated paper tape without significant loss or distortion. Rapid playback converts these data to a recognizable form. For visual inspection, a grey shade picture is generated on Polaroid film, with contrast under operator control. For quantitative retrieval, the counting data are presented as a matrix of typewritten numbers. The inexpensive length of perforated paper tape remains part of the patient's permanent record, available for future analysis if needed. Instrument cost is commensurate with present day rectilinear scanners. The data system has proved to be efficient and reliable in the processing of several thousand scans over the past two years.

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