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A COMPUTER-BASED SCANNING SYSTEM

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ABSTRACT

A computer-based scanning system intended for on-line operation with a dual-head rectilinear scanner is described. A simple scanner-computer interface requires only five signals to fully describe the scan for the minicomputer. Display during acquisition and immediate processing and display of the data from the completed scan permit fast evaluation both for quality of scan and for possible abnormalities. Four display formats as well as smoothing by weighted averaging, antiscatter and antipenetration correction, and bounding are included in the software. Additional useful and informative routines included are a multicontrast enhancement display which provides an immediate quantitative assessment of the data and a validator routine which specifies small but statistically sound deviations that might be considered abnormal.

INTRODUCTION

The Oak Ridge Scanning System is a complete on-line, computer-based system for the acquisition, processing, and display of rectilinear scan images (1,2). The system is intended to stand alone, requiring no support from a computing center. The scan image is observed in raw form as it is formed during scanning, and within 1 to 3 minutes after the end of the scan it can be processed, examined, and photographed. The usual data reduction processes are provided: smoothing, data bounding, image subtraction or addition, background erase, and contrast enhancement. In addition, two processes not previously available have been added. These are: 1) a program for reducing the effects of collimator septum penetration and gamma-ray scattering in the patient (3), and 2) a validator program. The validator program eliminates (or strongly reduces) high or low regions of small extent (that might be small tumors) unless these small regions are found to be statistically sound by exceeding a ring average surrounding them by a selected number of standard deviations. Regions thus confirmed are unmistakably flagged for investigation.

Features of the system are: 1) low cost, 2) good reliability, 3) excellent repairability, 4) simplicity of operation, 5) compatibility with clinical use with large patient throughput, and 6) no program limitation on scan width or length. The only limitation to picture size within the system is the total number of picture elements: 16,000 in each of two images or 32,000 in one image.

SIGNAL REQUIREMENTS

The system may be applied to any rectilinear scanner, single or dual head, and requires a minimum of information from the scanner. The scan line is divided into picture elements either by a rotating slotted disk with lamp and photodiode attached to the sweep motor, or by a similar device attached by a cord to the moving detector (4). These picture-element signals are simple pulses marking the motion of the scan head through any chosen fixed distance (say $\frac{1}{4}$ or $\frac{1}{2}$ cm). The identification of scan lines is secured in either of two ways: 1) an end-of-line signal, or 2) a reference-line signal. The end-of-line signal begins when the scan head reaches the preset limit switch and remains until the scan head has reversed and reached this limit traveling in the opposite direction. The reference-line signal indicates when the scan head passes a specific position near the center of the scan motion. This reference signal is arranged to occur between two picture-element pulses. Either method provides sufficient information to keep the scan data in order. The second method permits either or both of the scan-width limits to be changed during a scan.

Other signals required from the scanner are, of course, the stream of γ -generated pulses from the detector, or two such streams from a dual-detector scanner. Two streams may also be derived from two spectrometers each set for a particular energy, the chosen energies derived either from two photons emitted by the same nuclide or from two radionuclides administered to the patient. Finally, landmark signals indicating critical structures on the patient are exceedingly useful. To provide them, a photodiode is inserted in the central hole of the detector collimator, and it views small (2 mW) light bulbs attached to anatomical bench marks on

the patient. These landmark signals are detected during the scans and are recorded along with, but separate from, the gamma-ray pulses. In the displayed image they may be turned off or on as desired.

These four signals (or five for two gamma-count channels) are transmitted to the computer for processing; no precounting or other processing is performed.

COMPUTER REQUIREMENTS

A computer for this system requires 8K words of core and a 32K word magnetic disk.* The system programs all reside in the lower 4K of core at the same time; the disk is reserved exclusively for image and comment data. The external mass storage required to keep permanent patient records is provided by any of several inexpensive cartridge or cassette magnetic tapes.†

The reliability of the system and the small tapes is very good. We have produced more than 150 separate patient images since we began using the system, without losing one of them.

COMPUTER PROGRAMS

The computer programs operate with the program interrupt enabled: that is, the computer will respond to an external request from the scanner interface or from the Teletype. The programs have been grouped functionally into two main modes: 1) the data-acquisition mode, and 2) the

* We are using a Digital Equipment Corp. PDP-8/I and a DF-32 disk.

† At present we use a Tennecomp #TP-1351 tape unit and a #1346 autoloader.

data-handling mode. Operation in the former mode may be interrupted by signals from either the scanner or the Teletype keyboard; in the data-handling mode the program can be effectively interrupted only from the keyboard.

The elementary keyboard monitor responds primarily to single-letter or single-letter-and-number commands (see Table 1). Specific commands are acceptable in each of the two modes, but each mode responds only to commands contained in itself. Should an inappropriate (or any noncommand) character be given, the command is ignored and a question mark is typed. Processing routines and a comment entry routine are called from the data-handling mode by the two-key command CTRL-C followed by the program name of the process.

Transfer of control between the two command modes is effected by the two-key commands, CTRL-P (which activates the processing mode) and CTRL-A (activating the access mode). This transfer can be made at any time.

DATA ACCESS

When the scanner is started, the accessing program is activated by typing G (for G0) on the keyboard. The computer begins to count the picture elements after the first end-of-line signal appears. When the next end-of-line occurs, the computer knows the chosen line length; it then begins to retain the data and display them in raw form. If the reference-line system is being used, the occurrence of two reference-line signals permits the first two half lines to be displayed. At each succeeding passage of the reference line, information is available for the correct display of the preceding excursion of the scan from reference line to edge

TABLE 1. ORSS-72 COMMANDS

DATA ACQUISITION (ACCESS) MODE COMMANDS

All commands must be committed to action by the carriage return key.

- G - GO, start taking a scan or restart taking a scan.
- Dn - Display level $n = 0, 3$. Changes level of display in factors of 2. Has no effect on recorded data.
- U, U1 - Display upper or lower head image.
- C - Enter comment mode, subsequent characters show on screen. Leave comment mode by CTRL-FORM. May be entered any number of times. See CTRL-CNOTE below.
- Q - QUIT, stop accessing scan, rearrange scan, enter comments on disk, ask for ID.
- Imnop - Enter ID number, transfer to data-handling mode.
- CTRL-P - Go to data-handling mode.

DATA-HANDLING MODE COMMANDS

--- Display Commands ---

- Dn - Change display scale to n . $n = 0, 7$. Each step is a factor of 2. D5 is data $\times 1$, D0 = data $\times \frac{1}{32}$, D7 = data $\times 4$.
 - Sn - Subtract n counts from each data element.
 - En - Extend display size to n units/element.
 - X - FLIP-X. Exchange X coordinates.
 - Y - FLIP-Y. Exchange Y coordinates.
 - B - BACK, go to first data block in one block mode, exit from other display modes except C and M. Type out image ID.
 - F - FORWARD, go to next block.
 - T - TOTAL, display all blocks as one image.
 - Zn - ZPROFILE, show profile of line or column n and light up location in intensity map. Z99 sets for ZX profiles, Z100 sets for ZY profiles. Exit by L or any D or S command. Must be used in one block mode.
 - M - Multicycle contrast enhancement (MCCE) mode. Exit by M1 or MM.
 - Cm, Cn - Area contour mode; show only elements from count = m to $m+n$.
 - Cn - One line contour; show line where intensity passes thru n counts/element.
 - Vp - Lower contour a step after each p sweeps of display.
 - L - Landmarks, turn on if off, turn off if on.
 - In - Isometric plot of all blocks of image. Rotated position of image controlled by n .
 - P - Photo. Ring bell, wait, give n sweeps, ring bell, wait, resume display. Change n by typing Pn once.
 - Ø - LITEUP, show quantitation marks.
 - 1n - Move upper edge of rectangle to line n .
 - 2n - Move left edge of rectangle to element n on line.
 - 3n - Make rectangle n lines high.
 - 4n - Make rectangle n elements wide.
- Quantitation mark commands may be given repeatedly in any order.
- K - Print sum of counts in rectangle.
 - K1 - Print array of content of elements in rectangle.
 - K2 - Plot histogram of content of elements in rectangle.
 - N - Show and perform actions with first half of disk (Upper head image).
 - N1 - Show and perform actions with second half of disk (Lower head image).

DATA PROCESSING COMMANDS

CTRL-Cname - CALL name. Calls program or process named.

- CTRL-CAVn - Average with averager n. 7 x 7 matrix average.
- CTRL-CPmAVn - Antiscatter process and average with collimator response table m and averager n.
- CTRL-CPm - Antiscatter process without averaging using coarse and fine collimator tables m.
- CTRL-CBOUNDn - Bound data to within 1 (or 1.4 or 2) standard deviations of the average (by averager n) at each point.
- CTRL-CVAL - Validate. Mark data points with a landmark and leave them unchanged if they exceed 1 (or 1.4 or 2) standard deviations from a ring average around each point; otherwise replace the points by this average.
- CTRL-CNOTE - Enter comment mode. (Same as C in acquisition mode.)
CTRL-K erases all comment in buffer.
RUBOUT erases last character.
CTRL-FORM exits from comment mode.
All other characters enter the buffer and are displayed.
- CTRL-CPUT - Write the content of the comment buffer into the image corresponding to the current N state. This command is not needed in access mode since the comments are written automatically.
- CTRL-CMON - Go to Disk Monitor. Monitor must be on disk. Use REFRESH with a magnetic-tape copy of Monitor if necessary before giving this command.
- +n(-n) - Add (or subtract) from image being displayed, n times the image on the other half of the disk. n is decimal factor (1000 = 1.000). Limit is 2000. Gives tentative action on the block being viewed. + (or -) 4000 forces permanent action on whole image. Change temporary action by another + or - command, B, S or D.
- CTRL-A - Change to acquisition (data access) mode.
- Q - QUIT, abort action in progress, wait for next command. Applies to all actions of data-handling mode.

DATA STORAGE OR RETRIEVAL COMMANDS

- \$n - DUMP entire content of disk onto track n of tape.
 - #n - REFRESH entire disk from track n of tape.
 - Wn - WRITE 16K words from disk area corresponding to current N state onto track n of tape.
 - Rn - READ 16K words from track n of tape into disk area corresponding to current N state.
 - = - COPY DOWN. Copies last half of disk into first half.
 - =1 - COPY UP. Copies first half of disk into last half.
-

and back to reference line. As the scan grows, element by element, the display matches it point by point.

This image, during access, is invaluable for ensuring correct patient placement and correct operation of the scanner. The intensity of the displayed image may be adjusted during the scan by keyboard commands without altering the recorded data in any way. When two-detector (or two-energy) scans are being made, the operator may shift the display from one image to the other whenever he desires.

During scan acquisition the scan information (scan number, patient's name, date, dose and isotope, scan speed, collimator used, and other useful information) is entered from the Teletype. When the command C is given, subsequent typing is entered into the buffer and displayed below the growing scan image. Exit from the comment mode is made by the command CTRL-FORM, and exit or entrance may be made as many times as needed. At the end of the scan the comments are recorded with each image. The upper-head and lower-head images are firmly labelled: the program automatically enters a U or an L as the first character of the comment.

When the scan is completed, a Q (for QUIT) command is typed and the data files are immediately reordered from the boustrophedonic format into array format. This done, the computer requests a scan identification number, which is supplied via keyboard. The scan data are then automatically displayed, ready for immediate examination, processing, or magnetic-tape storage.

DATA PROCESSING

The data-processing facilities of the system are all designed for quick and immediate action. Routinely, the data in raw form and the accompanying comments are dumped onto a small magnetic-tape cartridge for later recovery if required; the data images in the computer can then be processed at once.

The matrix averaging process used is performed in the following way. The array of raw data points may be represented by

$$\begin{vmatrix} u_{0,0} & u_{1,0} & u_{2,0} & \cdot \cdot \cdot & u_{\text{MXELE}-1,0} \\ u_{0,1} & u_{1,1} & u_{2,1} & \cdot \cdot \cdot & u_{\text{MXELE}-1,1} \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ u_{0,\text{LINE}-1} & u_{1,\text{LINE}-1} & u_{2,\text{LINE}-1} & \cdot \cdot \cdot & u_{\text{MXELE}-1,\text{LINE}-1} \end{vmatrix} \quad (1)$$

A symmetrical 7 x 7-element weighting array may be represented by its 10 (decimal) typical elements:

$$\begin{vmatrix} b_{0,0} & b_{1,0} & \cdot \cdot \cdot & b_{6,0} \\ b_{0,1} & b_{1,1} & \cdot \cdot \cdot & b_{6,1} \\ b_{0,2} & b_{1,2} & \cdot \cdot \cdot & b_{6,2} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ b_{0,6} & b_{1,6} & \cdot \cdot \cdot & b_{6,6} \end{vmatrix} = \begin{vmatrix} a_0 & x & x & x & x & x & x \\ a_1 & a_4 & x & x & x & x & x \\ a_2 & a_5 & a_7 & x & x & x & x \\ a_3 & a_6 & a_{10} & a_{11} & x & x & x \\ x & x & x & x & x & x & x \\ x & x & x & x & x & x & x \\ x & x & x & x & x & x & x \end{vmatrix} \quad (2)$$

Each point, $v_{j,k}$, in the smoothed array is obtained by multiplying each

point of a 7 x 7-element region around the point by the corresponding weight factor and summing the resulting products.

The process is represented by the equation

$$v_{j,k} = \sum_{\ell=-3}^{\ell=+3} \sum_{m=-3}^{m=+3} b_{\ell+3,m+3} u_{j+\ell,k+m} \quad , \quad (3)$$

with the following conditions:

- a. if any subscript becomes negative it is replaced by zero;
- b. if any element (x-direction) subscript becomes greater than MXELE-1 it is replaced by MXELE-1; and
- c. if any line (y-direction) subscript becomes greater than LINE-1 it is replaced by the value LINE-1.

These permit the edge values of the image to be extended as far as needed to substitute for the unknown data values beyond the edges. The b values are obtained from the typical elements of the weighting array (A-matrix) by a table procedure. The weighting values now in use are Gaussian. The curve of normal error was used with x values from 0.5 per element for the broadest averages to 1.5 per element for the sharpest. Since only integer numbers can be stored in the image matrix, the weights and normalizing factors were so chosen as to provide a total weight of 4; this permits the resulting values to represent the averaged value more smoothly.

The correction process for scatter and septum penetration uses the point-source response of the system. This response is determined by scanning a small source of the radionuclide of interest in a scattering medium (water), and with the collimator used for the scan. A number of such responses are required, one for each collimator-and-isotope combination. A square region of more than 49 picture elements on a side must be scanned

to cover the full range of the correction. The departure of this actual point-source response from the "optical" response curve of the collimator, of course, represents the combination of scatter and septum penetration that is now spoiling the images produced by conventional systems.

The unwanted part of the point-source response — i.e., the part left after the optical response is subtracted — is converted into two symmetrical 7 x 7 matrices that are represented by their list of 10 typical elements. One of these matrices (F-matrix) comes from the central block of 7 x 7 elements surrounding the axial element. The one-time-only formation of these matrix lists is performed by a special overlay to the standard program. The other matrix (C-matrix) is obtained by compressing the whole 49 x 49 matrix into a 7 x 7 array by summing 7 x 7 blocks for each element. These fine- and coarse-matrix elements are used to obtain fine- and coarse-correction values which are subtracted from the original data. The processes are represented below.

Let the raw data be represented by a matrix of u value as in Eq. (1). An element, $v_{j,k}$, of the fine-corrected matrix is obtained by

$$v_{j,k} = u_{j,k} - \sum_{\ell=-3}^{\ell=+3} \sum_{m=-3}^{m=+3} f_{\ell+3,m+3} u_{j+\ell,k+m} \quad (4)$$

The same conditions on the subscripts are applied as for Eq. (3) so that no reference is made to nonexistent data points. If negative values occur in the subtraction the result is set to zero. While this process is being carried out, a coarse matrix of data values $\{s_{0,0} \cdot \cdot \cdot s_{\text{CMXELE}-1,\text{CLINE}-1}\}$ is formed by summing 7 x 7-element blocks of the raw data before the fine correction has been applied.

From the coarse response matrix (C-matrix) and the coarse data matrix (S-matrix) a corresponding matrix of coarse corrections is formed. An element of this matrix is obtained by:

$$k_{j,k} = \sum_{\ell=-3}^{\ell=+3} \sum_{m=-3}^{m=+3} c_{\ell+3,m+3} s_{j+\ell,k+m} \quad (5)$$

Corresponding limits to the subscripts are applied as for Eq. (5) to prevent referencing nonexistent points.

This coarse-correction matrix represents the corrections contributed by points rather remote from the data value under consideration, and thus they are rather constant over small regions of the scan. They do, however, constitute the principal correction and must be applied carefully. Each member of the correction array represents the whole value to be subtracted in some manner from all points of the corresponding 7 x 7-element square of the image matrix which has already been corrected for the fine correction. We chose to distribute the correction to columns of 7 data points at a time. A list of the 7 column addresses is used cyclically and one count is subtracted from each addressed point unless it is already zero. The selection of successive addresses in the column continues until the correction is exhausted or until a pass through the list is made with no resulting correction. The address list pointer is not reset for the next column to give a less patterned subtraction.

The corrected data matrix represents an improvement over the raw data: a better approximation to the image that would have been obtained if point-source response of the scanning system consisted of the optical peak only. This process could be repeated using this "improved" image as a source and

applying the desired corrections to the original data. One pass alone, however, provides a much improved image, and we have found little to be gained by repeating the process.

The antiscattering procedure does not produce a smoothed image. The product is somewhat more ragged than the original since a substantial subtraction has been performed. These images — and indeed all raw data images — must be smoothed (averaged) if full use is to be made of them.

The antiscattering and averaging may be combined by substituting the averaging process for the fine correction. The PAn commands perform this function. This combined operation is as fast as the antiscatter alone (see Table 2).

Dual-input scans can be added together or subtracted, picture element by picture element. Addition allows, for example, the formation of a composite posterior-and-anterior view of the patient. On the other hand, in a patient who has received both technetium sulfur colloid and selenomethionine, subtraction permits the liver image to be removed from the liver-plus-pancreas scan, thus unmasking the view of the pancreas (5). The add/subtract program may also be used to adjust the scale of an image by some exact factor so that images of a patient taken with different doses and physical decay factors may be directly compared. The addition-subtraction process is quick (see Table 2), but some time may be used in selecting the proper multiplying factor using preliminary trial images. The full data file can then be committed to the process.

TABLE 2. EXECUTION TIME FOR PROCESSES

Process	Time (sec)
7 x 7 Element weighted average	50-110
Antiscatter, coarse processing with matrix averaging	60-130
Antiscatter, fine and coarse processes without averaging	60-130
Validation (requires previous averaging)	50-110
Bounding	50-110
Full image subtraction or addition	5-10
Tentative 1 block image subtraction or addition	3
Background erase (subtraction)	0.2
Contrast enhancement (scaling)	0.2

DATA DISPLAY

Scanning systems have previously been plagued by the poor quality of their output, the hard copy of the scan image. One-shot records, such as from the dot-tappers and photo-recorders, do not usually provide the quality required for good, easy interpretation of the scan, and of course the data are not recoverable for processing. Intensity mapping using symbols on a line printer produces poor images with rather bad resolution.

A better display system is one that: 1) avoids destruction of the basic data, 2) provides a copy without excessive delay, 3) is inexpensive, and 4) provides good smoothness even with the limited number of data values. Photographic copies of CRT displays with data interpolation approach these requirements. The grey scale of Polaroid film is adequate for scan interpretation if more than one image is available, and it avoids the risk of finding a bad picture in a group of records after some time delay for film processing with its attendant cost in time to rerun the record, reprocess and rephotograph it. Variable scaling, background erase, and various display formats are used to provide different views of the same data, varying in emphasis and thereby clarifying different features of the image. For instance, interpretability may be enhanced by the use of different views of the same data averaged by coarse and sharp averages. In this manner, bumps due only to statistics can be recognized and discounted in the interpretation. This requires quick recall of the basic data for multiple processing and viewing. The variable-resolution averaging recommended by some provides a more difficult recognition problem, since random fluctuations have different ranges in different parts of the same image.

Contrasted with data processing, display manipulation is very fast. Some of these manipulations are: changes in background erase level, contrast enhancement factors, image size, and orientation or image type (intensity map, contour, profile, multicycle contrast enhancement, or isometric). These changes are completed as fast as the commands are typed. The swiftness of change allows rapid choice of proper display constants to enhance any part of the image for optimum photography. Once the desired parameters have been selected, the photo command (P) ensures pre-selected number of passes for photography.

Examples of the display types available are shown in Fig. 1. The standard intensity map (Fig. 1A) and the multicycle contrast enhancement display (Fig. 1B) are interpolated displays; that is, the number of points displayed is four times as large as the number of data points in core. An average is added in between each adjacent pair of data points. This yields an exceptionally smooth and readable picture. Figure 2 shows a comparison of interpolated and non-interpolated images.

The isometric plot (Fig. 1C), sometimes called a volumetric plot, is a two-dimensional representation of a three-dimensional figure where activity or count value is plotted as the third dimension. These images may be rotated to right or left by keyboard command. Two types of contour plots are available, except that only one type is present in the program at one time. The line contour marks a single point on each scan line at every point at which the successive data values pass up through or down to the commanded level. The area or zone contour (Fig. 1D) intensifies all data points that lie between the commanded level and that level plus a commanded difference. Each type of contour plot may be caused to regress from high

to low count level automatically. The Z-profile is a plot of the count value vs. position for the data points along a commanded scan line (ZX profile, Fig. 1E) or along a commanded column (ZY profile, Fig. 1F). The displayed line is intensified in the intensity map image that accompanies it. This provides a rapid means of examining the quality of the scan data.

Provision is made for the addition of other display modes as their need may arise.

An important feature of the displays is the special marks appearing in them. The landmarks denote the automatically recorded location of small lamps that were attached to strategic points on the patient during the scan (see Fig. 1A). Similar marks are provided by the validator program denoting points that represent statistically valid deviations from the surrounding region. Both types of marks are commanded on or off in the image by typing L. Another type of mark is inserted and moved in the image by the quantitation commands. These points mark the corners of a rectangle whose size and location are keyboard commanded. The program will then provide a sum of data values within, a typeout in array format of these contained points, or a histogram of the data content. Since the points have digital locations, they may be placed similarly in the other image of a pair, or at any desired area in the same image for comparison purpose.

Integration of the point-source response of our system shows that about 50% of the response lies in its very low but very wide skirts, representing extreme scatter and septum penetration. The antiscatter program corrects for this defect. An example of the performance of the antiscatter program is shown in Fig. 3. Figure 3A shows the raw data of a posterior,

gallium-67 scan of a patient's torso. Figure 3B shows the weighted matrix average of the data. Figure 3C shows the result of applying the anti-scatter program. Note the considerable reduction in the scattering haze and the sharpening of the features of the image.

We have found that the multicycle contrast enhancement (MCCE) display provides semiquantitative images that are useful when used with a standard intensity display. Figure 3D shows the data of 3C displayed in the MCCE mode. The region outside the body, of course, contains the lowest count. As one directs his attention along a line from this low-count area toward the high-density area of the liver, he sees that the intensity increases normally and then drops back to zero intensity as the first cycle is completed. This corresponds to an increase of the scaled count of 32 counts. The intensity again brightens through the next 32-count cycle and then drops again to low intensity at the small high-intensity area of the liver. This corresponds to a second range of 32 counts. The high-intensity spot on the liver, therefore, corresponds to a scaled count level of slightly over 64 counts. The intensity value at any point in the image is thus easily determined without the necessity of representing an image by a field of numbers. The high contrast enhancement makes for easy visualization of the normal pattern.

Figure 4 illustrates the performance of the validation program, which calls attention to small but statistically probable deviations that might otherwise be missed by the viewer. A clinician must, of course, judge the biological significance of such deviations. Figure 4A shows the raw scan of a patient with Hodgkin's disease, and clearly there are numerous hot spots. Figure 4B is the averaged version of the same scan. In Fig. 4C

the validator is indicating the areas where the activity deviates from the surrounding average by 1.4 standard deviations or more. In Fig. 4D the threshold deviation is 2 S.D.; the marked areas are therefore fewer in number but of greater significance. Figures 4E and 4F show profiles of one scan line through the hottest spot: the one high in the thorax, just to the left of the midline. In Fig. 4E the points at the top indicate the positions of the picture elements where the count exceeded the threshold deviation (2 S.D.); directly below these dots the lower curve shows the deviating values. Elsewhere in the lower curve the original picture-element counts have been replaced by the ring averages determined by the validator. Figure 4F shows a profile for the same scan line, after the averaging performed for Fig. 4B but without further processing by the validator.

In an image with so many obvious abnormalities, the validator is not needed; however, less obvious deviations are located for examination.

The program described in this paper will be available from our group as ORNL technical memorandum, ORNL-TM-4045.

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PHOTO 2715-72

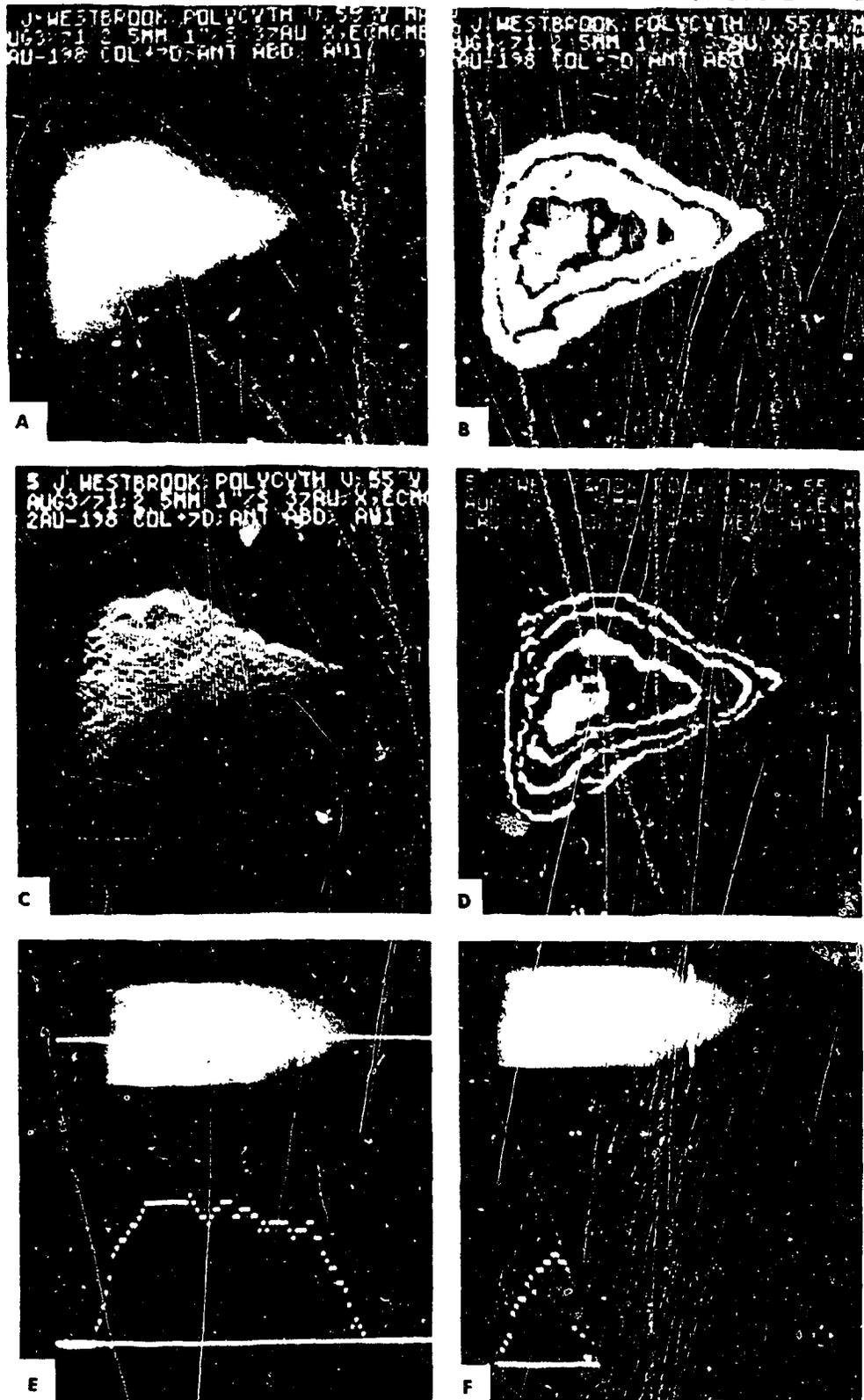


FIG. 1. Six types of display available with this program. The standard intensity map with optional landmarks is shown in (A). The multicycle enhancement image is shown in (B). The isometric view appears in (C), and the area contour is shown in (D). Figures (E) and (F) are examples of the X- and Y-line profile display, with the line being displayed below marked as a high-intensity line in the intensity map above.

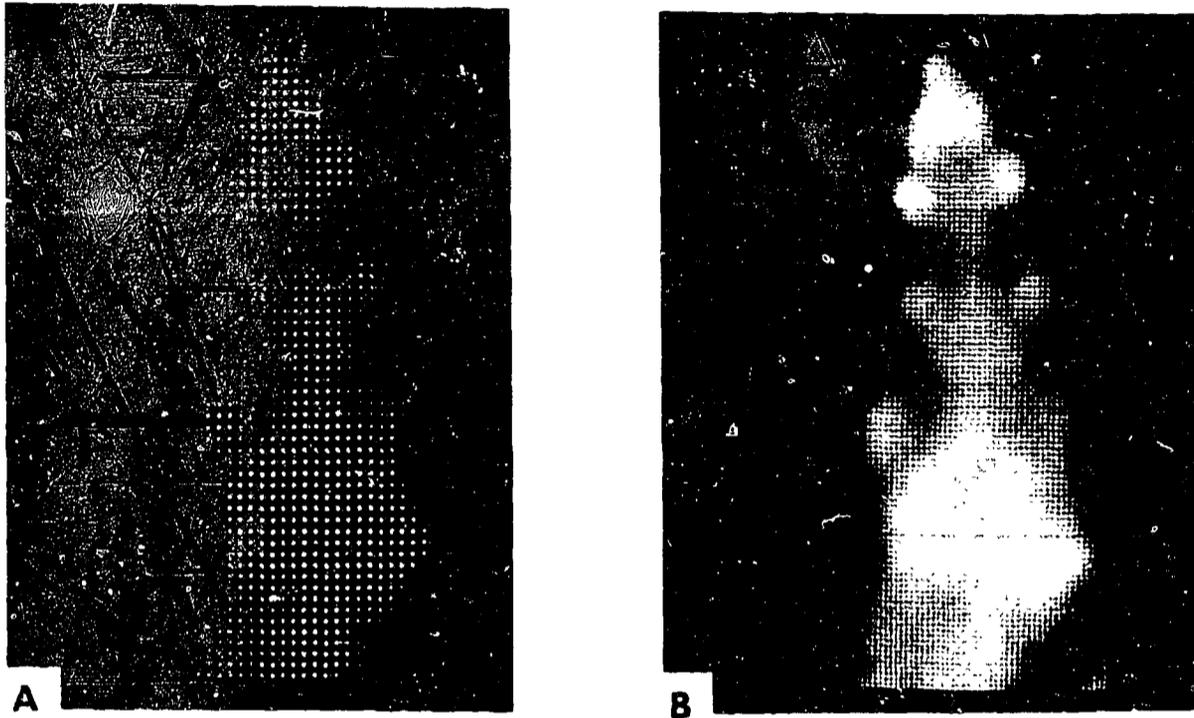


FIG. 2. The effect of interpolation during display. The image in (A) contains 4071 displayed points without interpolation, while that in (B), using the same data in core, contains 16,146 displayed points. The subject imaged is a 280 g rat with a 0.28 mCi dose of Ga-67, scanned after 24 hours. Despite the fact that (B) contains no more information than (A), it is much easier to interpret.

PHOTO 3907-72

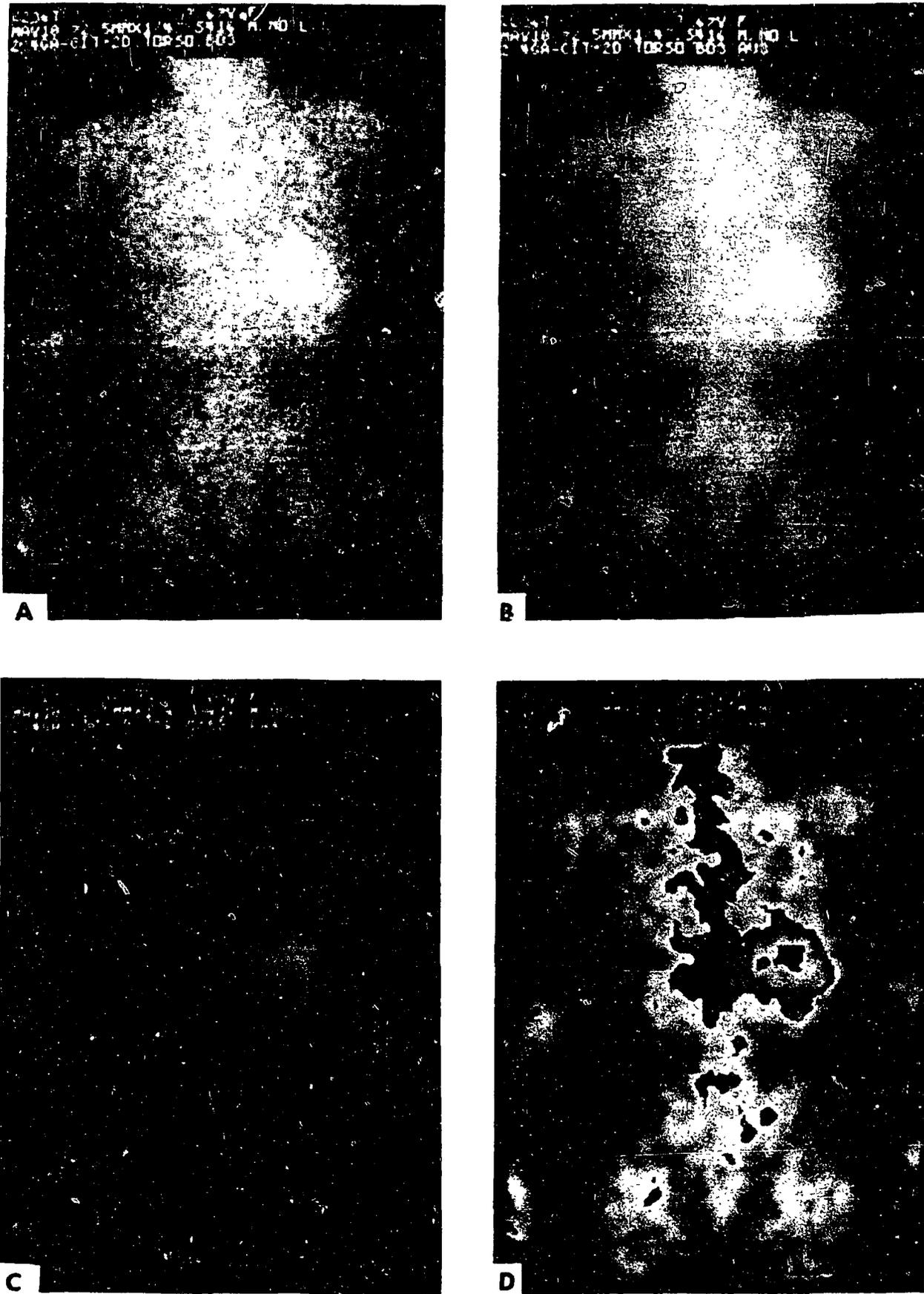


FIG. 3. An example of the correction for scatter and septum penetration. The images are from a Ga-67 scan of a 67 year old female having pseudo-lymphoma. The raw data is shown in (A). Figure (B) is the same data averaged with a 7 x 7-element weighted averager. Note the improved smoothness of the data, but also the generally hazy background throughout the image. Figure (C) is the same data as (B) corrected for scatter and septum penetration. Notice the decrease in the hazy background due to scatter and septum penetration, the elimination of counts outside of the body area, and the higher peaks and lower valleys. Figure (D) is the multicycle contrast enhancement display of the data of (C).

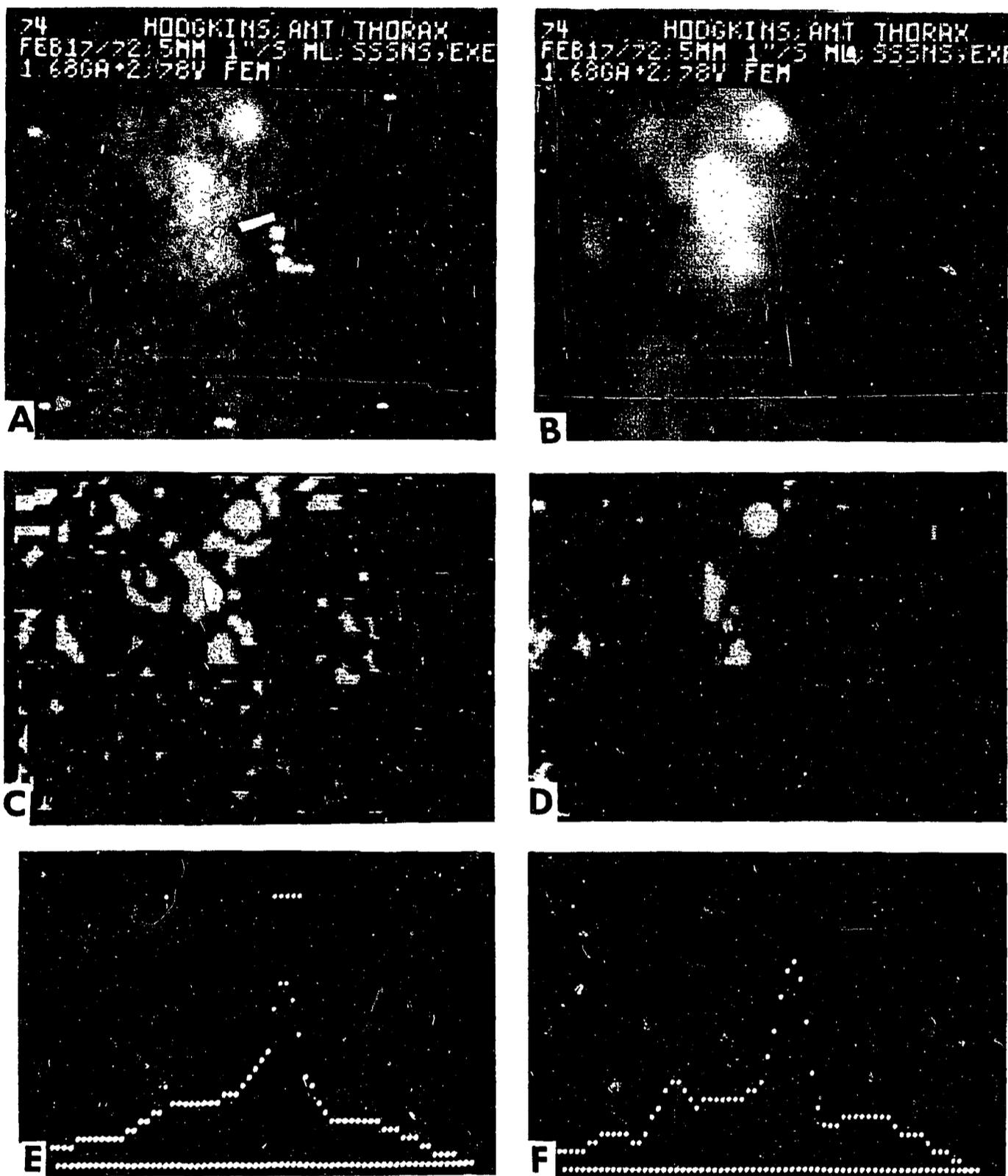


FIG. 4. Results of the use of the validator program. View (A) shows the image of the raw data of a Ga-67 scan of a 78 year old female with Hodgkin's disease. The view in (B) shows the same data averaged by a 7×7 -matrix averager. The view in (C) is the data of (B) after validation with a 1.4 standard-deviation threshold. Too many points exceed the limits and are marked. The data were double-averaged and then validated at 2 standard deviations [view (D)]. In view (E) profiles of one scan line after the validation of (D) are shown. This line passes through the hot spot located high in the thorax just left of the midline. The points at the top indicate the positions of the picture elements where the counts exceed the threshold. Directly below these are the values of these counts retained by the validator. Elsewhere in (E) the original counts have been replaced by the ring average determined by the validator. View (F) shows a profile of the same scan line after averaging [as in (B)] but without validation.