TECHNICAL PROGRESS REPORT

A. SUMMARY

Progress under AEC Research Contract AT(11-1) 1472 entitled "Digital Computer Analysis and Display of the Radioisotope Scan" in calendar year 1969 is summarized below.

1. A computer program for performing two dimensional Fast Fourier Transforms of radioisotope scans and carrying out the inversion of the transforms was developed.
   a. Methods of using these transforms to accomplish differential and band pass filtering of scans were developed.
   b. Methods of using these transforms to enhance scan resolution by deconvolution with a collimator response function were developed.
   c. Evaluation of the results of applying these procedures to scans of phantoms and patients' organs, although not complete, is well underway.

2. In cooperation with the Martin Marietta Corporation we began developing a method of using the latest theories of optical processing to accomplish the same types of band pass and differential filtering and resolution enhancement with an optical bench (filtered laser beam) that we have been performing with the computer in the past. This approach promises to offer simplicity, economy and clinically valuable improvement of the scan.

3. In cooperation with the IBM Corporation an interface connecting our Dynapix scanner to our IBM 1800 computer was designed and built.
   a. A program system which allows on-line recording of data from the Dynapix at the same time other Nuclear Medicine functions are being carried out was written. It has not yet been debugged and tested.

4. An on-line computer program system for general use in the Nuclear Medicine Laboratory developed previously was greatly improved.
   a. Scans are now recorded and processed automatically under keyboard control by the computer.
   b. Our library of computer-assisted-instruction Nuclear Medicine courses was expanded.
   c. A new version of our inventory control program was written which assists technologists greatly in record keeping and dose calculation.
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d. A method of transferring scans recorded by the computer onto magnetic tape for permanent storage was further perfected and a large number of normal and abnormal scans have been recorded and stored.

e. Previously we were able to plot isodose contours and perspective views of scans on an X-Y plotter. A program was developed which allows these same plots to be displayed on a cathode ray tube located next to the scanner.

f. Programs which accomplish linear and non-linear regression analysis of disappearance curves were improved. Programs for analysis of Rose Bengal excretion tests, renograms, and for determination of glomerular filtration rates were written.

g. Several other programs for use by technologists and secretaries with the or-line computer to analyze, store and report patient tests were developed.

5. Documentation of many of the computer programs developed under AEC(11-1) 1472 was written and widely distributed in response to requests for copies from all parts of the world.

6. Perhaps the most important accomplishment was the organization of an impressive group of scientists who are devoting much thought and effort on a volunteer basis to our project.

B. MATHEMATICAL PROCESSING OF THE RADIOISO TOPE SCAN

The data acquired in the process of recording a radioisotope scan results from several factors: (1) the distribution of the radioisotope within the patient; (2) the background radiation; (3) fluctuations in the radioactive count due to the random process of radioisotope decay; and (4) distortion resulting from the scanning system itself, principally the collimator.

We are attempting to improve the diagnostic accuracy and clinical usefulness of scans by using mathematical analysis to eliminate the latter three of these factors. We began by making an obviously false assumption, that is, that the radioactivity is distributed in the focal plane of the collimator. It is our hope that later we can work with the three dimensional distribution of this activity, but for the present this simplification is necessary. In addition, we can ignore the background radiation outside of the patient in most clinical scanning situations, since this is relatively very low. In Figure 1 we see the idealized profile of the scan of a liver with a small centrally located lesion ($A_S$). The profile of a collimator response function to a point source is also idealized as the function $C_S$. It can be shown mathematically that if we disregard the random fluctuation introduced by the radioisotope decay process, the idealized recorded scan profile ($O_S$) is the result of the convolution of $C_S$ and $A_S$. 
SPATIAL DOMAIN

Convolution

\[ O(s) = \int_{-\infty}^{\infty} A(s) \cdot C(s - s_t) \, ds_t \]

Transformation to frequency domain

\[ O(\omega) = A(\omega) \cdot C(\omega) \]

Deconvolution

\[ A(\omega) = O(\omega) \cdot C(\omega)^{-1} \]

Transformation to spatial domain

\[ A(\omega) \rightarrow A(s) \]

Figure 1
In other words, in the spacial domain \( \Omega \) (in two dimensions the observed scan) is the result of the double integration of the actual distribution \( A(s) \) convolved with the two dimensional collimator response \( C(g) \). A standard mathematical means of solving convolution integrals is to transform the functions to the frequency domain (Fourier transformation) and carry out a so-called deconvolution, which in this case results in the multiplication of the function \( O(\omega) \), by the inverse of the transform of the collimator response \( C(\omega) \). When the resulting function is transformed back to the spacial domain, the result is the actual distribution of the radioisotope within the patient.

In the past carrying out transforms of this type on radioisotope scans has required so much computer time that it has not been practical. In 1965 however, J. W. Cooley and J. W. Tukey developed a computer method called a fast Fourier transform (1) which allowed the determination of two dimensional Fourier transforms in a fraction of the time previously needed. Until a few months ago, use of these programs was restricted for military reasons. Now they are available and we have modified their program for use in analyzing radioisotope scans.

The scan data itself is recorded on-line using methods previously described (2, 3, 4) using an IBM 1800 computer. The scan data is then transferred to cards or tape and transmitted through a micro-wave link to the University of Colorado’s CDC 6400 computer. A large computer is necessary for these calculations because our scan arrays are about 100 x 90 elements, and in order to run the fast Fourier transform program efficiently, this size array must be expanded so that the dimensions are in powers of 2 --- in other words, in this case, 128 x 128. In addition, analysis of the scans requires the use of complex numbers which means that an array 256 x 128 must be used. In addition, if one wishes to perform a deconvolution of the type discussed above, he must use a similar size array to hold the transform of the collimator response function. Fortunately, our CDC has 170 K\(_s\) central memory and 200 K\(_s\) of extended core so that this is no problem.

The computer program presently in use takes the data which have been transmitted over the micro-wave link, performs a two dimensional Fourier transformation of the collimator response function, takes the transformation of the scan itself, complex divides the second transform by the first, and then takes the inverse transform of the result. It next prints out a contour map of the transformed organ and punches a deck of cards of the result of this inverse transformation for entry back into the IBM 1800. It also prints five pictures of the organ, using various amounts of cut-off and contrast enhancement (4). For an ordinary sized scan this program takes about 30 seconds. To date we have not actually deconvolved scans with a true collimator response function, but have confined ourselves to working with a two dimensional gaussian function which closely corresponds to the collimator response.

If one attempts to do a deconvolution on raw data, it results principally in the amplification of noise. Some type of smoothing or filtering must be introduced first. We have developed and studied a number of means of smoothing scan data using the computer in the past (5, 6). A number of other smoothing processes have also been described by others (8).
Actually, the Fourier transform itself can be used to smooth the scan. This is a technique which is very familiar to engineers who have worked with the numerical analysis of radar signals. We have been fortunate in being assisted in the application of these developments to scans by several individuals - in particular, Mr. Dennis Kirsh, M.S.E.E., who has worked with the analysis of radar signals for several years, and who is from the Martin Marietta Corporation, and Dr. Cathey, a noted authority on the use of optical Fourier transforms in the processing of optical images, and several members of our biometrics division.

If one examines a Fourier transform of a radioisotope scan and uses the square root of the sum of the squares of the real and imaginary coefficients to study the distribution of power at the various frequencies, he will find the highest powers distributed in the corners of the resulting array. These are what engineers call the DC components, and they are the result of the coefficients of the lower frequencies. The coefficients of the higher frequencies are located toward the center. By taking the two dimensional transform of a scan and setting both the real and imaginary coefficients to zero everywhere except within small arcs around the four corners, one eliminates the high frequencies which are principally a result of noise. This type of filter is called a "box car filter" by electrical engineers. By appropriate selection of the frequencies retained, corresponding to the frequency resolution of the scanning system, it is possible to achieve extremely gratifying smoothing of the scan without significant loss of resolution. Examples of this work are shown in Fig. 2, 3 and 4. We have modified our computer program to carry out this box car filtering before applying the deconvolution discussed above. The results of this process are demonstrated in Fig. 5. Preliminary studies on both patient organs and phantoms suggest that this does actually enhance resolution. Much additional work, however, is needed to fully evaluate this, and it is underway.

In addition to using the Fourier transform to smooth and enhance the resolution of scans, these transforms can be used to carry out what is called by electrical engineers differential filtering. The basic differential filter viewed in one dimension can be considered a ramp function, which suddenly drops to zero in both the higher and lower frequency regions. We have been applying two dimensional filters of this type to radioisotope scans. To date we have used a modification of the filter just described, in which the DC or lowest frequency terms are kept. As one leaves the corners of the transforms, the next terms are set to zero, then as one proceeds toward the center, the coefficients are multiplied by increasingly large terms and then in the central region the terms are again set to zero. Results with phantoms so far show that this differential filter does, indeed, enlarge lesions and at the same time results in highly satisfactory smoothing. This process, so far, has had the undesirable effect of introducing what electrical engineers call a ripple. This can be seen, for instance, in the normal liver scan as a rather low frequency undulation in activity near a sharp transition in the scan. We are presently working with modifications of the differential filter, which we hope will eliminate this effect. The results of applying differential filters to scans are shown in Fig. 6 and 7.
the application of Fourier transformation to the analysis of radioisotope scans is being pursued in other groups. To my knowledge, the group under Dr. Brownell at the Massachusetts General Hospital and Dr. A. E. Todd-Pokropek at Middlesex Hospital in England are also studying this. Dr. Inuma in Japan, Dr. Nagai in Geneva, and an IBM group working with Dr. Scheer in Heidelberg are also carrying out similar studies. Obviously, much additional work needs to be done in this area. We are vigorously pursuing the study of phantoms with these methods as well as the processing of simulated data. It will take us several more months to assess their value and to clearly define the limits of our ability to enhance resolution and improve the diagnostic accuracy of scans.

C. OPTICAL PROCESSING OF THE RADIOISOTOPE SCAN

It was previously known that when a beam of coherent light such as that emitted by a laser is transmitted through an image and then focused by a lens, that the new image at the focal point of the lens will be the Fourier transform of the original image (7). If this image is then sent through another lens, the resulting image will be the inverse transform. This is called optical processing and the laser and lens systems are called an optical bench. The Martin Marietta Corporation in Denver has such a bench and a group of experts involved in optical processing on several projects. They have been helping us achieve preliminary results in the application of these methods to radioisotope scans. Results show that by modifying the light beam in the focal point of the lens, when it is in the transformed state, interesting changes in the scan can be produced. When a photographic reduction of an ordinary liver scan is used as the original image, a picture of the focal point reveals a very interesting pattern. The pattern is somewhat diamond shaped, with beads of activity dispersed along the vertical and horizontal axes. These are the results of increased power in frequencies related to the spacing between lines in the scan. By simply putting a vertically oriented piece of wire in the transform this line spacing becomes essentially invisible or smoothed out. One difference between the optical transform and the mathematical Fourier transform is that in the former, low frequencies are seen toward the center, while in the latter they are on the periphery. A picture of a two-dimensional mathematical Fourier transform reveals the coefficients of the low frequencies are distributed in the four corners of the array. The optical transform can be reproduced by inverting the quadrants of the mathematical transform bringing the outer corners to the center. By using a piece of metal shim with a tiny hole in the transform image, we believe we have increased the resolution of the eight holes in the standard Picker liver phantom. We have designed several filters which we hope will produce an equivalent effect to the box car and differential filtering described above. To date we have been able to produce smoothing without resolution degradation. We feel our preliminary results are very exciting and certainly warrant vigorous pursuit of this investigation of optical processing.
D. INTERFACE CONNECTING A DYNAPIX SCANNER TO THE IBM 1800 COMPUTER

The 10 crystal rectilinear scanner made by Picker Nuclear and known as the Dynapix is in many ways ideally suited for on-line digital computer recording of its output. The output of each crystal is already available on 6-bit scalers. For financial reasons we were previously unable to build an interface to transfer data from our Dynapix scanner to our computer. We, therefore, approached the IBM Corporation which has a special fund designed to cooperate in developments of this type with universities. They kindly agreed to help us build this piece of equipment. Their engineers assisted us in developing circuit designs which would accept the particular timing and voltage output by the Dynapix and transfer them on-line in a form compatible with the digital in­puts to our IBM 1800 computer and generate the necessary process interrupts to allow this on-line data acquisition in a form compatible with the software that we had developed previously. This interface was completed and installed in December of 1969. We have now completed the rather extensive software development needed to actually acquire the data in the computer in a manner which would not interfere with other functional uses of the computer by the Nuclear Medicine and Central Laboratories of the hospital. Because the digital inputs were only installed in our computer in January of 1970, we have not yet been able to test these programs and debug them. This work will be proceeding in the near future. Figure 10 is a picture of this new interface.

The Dynapix interface uses 24 digital inputs and one process interrupt on the IBM 1800 computer. The digital inputs are divided into three groups. The X position uses four bits giving incremental values of 0 to 255. The Y position is recorded on 8 bits broken into two groups of four, one of those groups containing the line number from 0 to 15 and the second group containing the crystal number from 0 to 10. The counts which are recorded on 6 bit registers give incremental values from 0 to 60. The process interrupt which causes the computer to read the digital input is generated at the same time that the counts are dumped on to the memo-scope of the Dynapix. The 10 crystals are always scanned sequentially.

On the display panel of the interface are nixie lights which display the status of the 24 digital inputs, the process interrupt, off and on condition, and a separate enabling switch which inactivates the signal going to the computer.

E. AN ON-LINE COMPUTER PROGRAMMING SYSTEM FOR GENERAL USE IN THE NUCLEAR MEDICINE LABORATORY

Details of progress in this area are presented in an attached document entitled: "An On-Line Computer System for the Nuclear Medicine Laboratory". This manuscript has been accepted for publication in the Journal of Nuclear Medicine.
F. DOCUMENTATION OF COMPUTER PROGRAMS

We have had requests from all over the world for copies of the computer programs developed in this project. Mr. Groome has developed documentation of our inventory and computer-assisted instruction programs. We have made arrangements for a private company, Datametrics Computing Center, 1117 Pearl Street, Boulder, Colorado, to distribute this documentation and the programs at cost. Copies of this documentation are enclosed.

G. SIGNIFICANT STAFF AND OTHER CHANGES

Mr. David Groome, who has contributed greatly to the systems programming work on our project in the past, began working only part-time as of January 1, 1970. He will continue to work on systems programs such as the package which will allow processing of data from the Dynapix in the future. We are now recruiting for a person to take his place. During 1969 the Division of Nuclear Medicine moved into a new remodeled research area with 1800 sq. ft. of space. This contains a large room especially designed for a computer with supplemented air conditioning and a computer floor. There is also a large area for data recording in which we have our research scanner. In addition, we have "hot" and "cold" chemistry laboratories and a counting room.

Perhaps the most important accomplishment in 1969 was the organization of an impressive group of scientists who are devoting much thought and effort on a volunteer basis to our project. In particular, we are receiving a great deal of help from the University of Colorado Medical Center's Division of Biometrics. This Division is headed by Strother Walker, Ph.D., who has many years experience in all sorts of biostatistics. His two principal assistants are Philip Archer, Ph.D., and Frank Briese, Ph.D. Both individuals have unusual experience in numerical analysis. There are also several other members of his Division who will be able to provide some support to our project. The University of Colorado has a large cyclotron located on the Boulder Campus. Several physicists at this installation have begun to assist us in developing a cooperative program which should result in greatly strengthening our project. Several engineers and mathematicians from the Martin Marietta Corporation of Denver are also giving us valuable voluntary support.

Additions to the staff of our Division of Nuclear Medicine are to be recruited. Dr. Thomas Ryerson, a radiologist with a background as a practicing aeronautical engineer, will join us in July, 1970, and we have offered a position as my Associate to Dr. Ralph Gorten of Durham, North Carolina. Dr. Gorten is well known for his investigations in computer analysis of radioisotope scans.

All of these individuals working on this project together should greatly strengthen our program in coming years.
BIBLIOGRAPHY


2. Brown, D.W., Groome, D.S., Cleaveland, J.D., Trow, R.S., and Lee, J.I. An on-line computer system for the Nuclear Medicine Laboratory (accepted for publication in Journal of Nuclear Medicine.)


Figure 2. A normal liver scan smoothed with a "boxcar" filter after Fourier transformation.
Figure 3. Original data from a transplanted liver known to have an infarction in the left lobe.
Figure 4. The same liver shown in figure 3. Fourier transformation followed by 'boxcar' filtering and inversion has resulted in smoothing without degradation of resolution.
Figure 5. Picker thyroid phantom after "boxcar" filtering followed by deconvolution with a collimator response function.
Figure 6. The liver shown in figure 3 after operating on the Fourier transform with a differential filter. The lesion appears bigger but the flat part of the normal right lobe appears to show decreased radioactivity since the derivative here is zero.
Figure 7. Picker thyroid phantom operated upon as described in figure 6.
Figure 8. Optical Fourier transform of a Picker liver phantom scanned with an Anger Camera.
Figure 9A  Picker liver phantom recorded on Anger Camera.

Figure 9B  Photograph reproduced in 9A has been optically processed. Results to date are poor but with better filters we believe the method has great promise.
Figure 10. The IBM - University of Colorado Medical Center Dynapix to computer interface.
AN ON-LINE COMPUTER SYSTEM FOR THE NUCLEAR MEDICINE LABORATORY

Donald W. Brown, M. D., David S. Groome, James D. Cleaveland, Richard S. Trow, and Jong Il Lee

*From the University of Colorado Medical Center, 4200 E. 9th Ave, Denver, Colo. This work was supported in part by US Atomic Energy Commission Research Contract AT(ll-1)1472 and National Heart Institute Research Grant HE09112-05
For several years, we have been evaluating the role of the digital computer in Nuclear Medicine.\(^1\,2\,3\,4\) These studies have centered around:

1. Scanning
2. Computer-assisted instruction
3. Automatic control of the radioisotope inventory
4. Permanent storage and immediate recall of clinical reports
5. Improvement in the reliability and ease of interpretation of function studies

We have concluded that in the future the digital computer will become as important to Nuclear Medicine as the sodium iodide crystal is today and can predict that nearly all Nuclear Medicine laboratories will soon be equipped with computers designed for on-line processing of many types of data including scans.

The equipment used in these studies centers around an IBM 1800 computer with a 32,000 word memory, 3 changeable magnetic disk drives, each disk storing 512,000 words, and 2 magnetic tape units. In addition, there is a card-reader punch, a moderately fast line printer, and an X-Y plotter. Several typewriters and typewriter keyboards attached to the computer are distributed through the laboratories. We have just added a storage oscilloscope which is located next to the scanner, and an interface connects a 5" rectilinear scanner to the computer. The computer uses fixed 16-bit words and operates with a multi-programming operating system (MPX). The Nuclear Medicine laboratory and the hospital's Central Laboratory share this computer and a program system* has been developed which allows a number of Nuclear Medicine functions to be carried on at the same time the computer is monitoring and processing laboratory results from 22 auto-analyzers. Two or three of the following can be carried out simultaneously:

- Scan data can be recorded
- Scans printed out
- Computer assisted instruction carried on
- X-Y plots drawn
- Fortran programs can be compiled and executed through the card-reader
- Inventory and patient record programs can be executed
- Analog simulator and statistical programs requiring large amounts of core are run in off hours.

* A simpler TSX version of the scanning portion of this system was originally written by Mr. A. Sprau of the IBM Corporation and is available as a Type III program (1800-17.2.001). Copies of all or any of the programs may be obtained by writing Dr. Brown.
SCANNING

Our interest in digital computers began with an attempt to record rectilinear scan data digitally and improve resolution by the application of numerical analysis and modern statistics — in a sense, applying an inverse transform function which would correct for the distortion caused by the collimator and recording system. At present the scanning system consists of the following: The pulse-height analyzer of a 5" rectilinear scanner is connected to a 8-bit binary scaler. A shaft encoder is attached to the gears of the scanner so that every 0.025 inches of beam traverse, the 12-bit binary output of the shaft encoder is incremented by 1. Using an optional switch selection, at 0.025, 0.05 or 0.1 inches of beam traverse, a "process interrupt" is generated which causes the computer to read the 8-bit binary count and the 7 least significant bits of the shaft encoder and store these along with an 8 millisecond clock reading in the computer's memory. Ends of lines are indicated by making the 8th bit of the position word positive. This "process interrupt" also results in resetting the binary scaler to 0 and the resumption of a new count. When 160 of these triplets of data are recorded in the memory core they are automatically transferred to a disk.

To begin recording a scan, the technologist turns the scanner on and types "START" on the keyboard located next to the scanner. While the scan is being recorded, he enters a code which includes the patient's hospital number, isotope used, date and hour of administration, organ studies, view, and time of the scan. When the scan has been completed, the technologist types "STOP" on the keyboard and the computer then arranges the scan for processing. First it packs two triplets of data into one computer word, correcting for variations in scanner speed. It then picks out the ends of lines, reversing the direction of every other line, and corrects for changes in margins which are
recognized by changes in the bits of the position word. The net effect is a rectangular array of regularly spaced 8-bit counts over the entire area scanned. The packed array is transferred to another section of the disk for more permanent storage along with its identifying code. About 35 routine clinical scans can be stored in the section of disk set aside for this purpose. At the end of each day, all scans recorded are transferred onto magnetic tape for permanent storage. About 1,500 scans can be stored on one role of tape. It is a simple matter to transfer the scans off of tape back into disc storage for processing.

Once a scan is stored on the disk, processing is controlled from the keyboard in a conversational mode. For instance, in order to print a picture of the scan the technologist types "PRINT" along with a few parameters. Depending upon the parameters selected, scans can be printed on the line printer in the computer room or on the typewriter next to the scanner. Various character sets and different amounts of contrast enhancement and background erase can be selected with these parameters. A scan can be printed out while a new scan is being recorded. X-Y plotting of scans using isodose response curves or perspective views can also be selected. "Filtering" or smoothing is carried out by a keyboard command and normally consists of spatial averaging. In addition, one scan may be subtracted from another. For instance, after recording a pancreas scan with $^{75}$Seleno-methionine and a liver scan with $^{113m}$Indium hydroxide and normalizing the two, the liver can be subtracted from the pancreas scan. One scan may also be compared to another. For example, regional pulmonary ventilation-perfusion ratios may be obtained or serial changes in liver lesions resulting from chemotherapy can be objectively displayed. A number of new methods of statistical processing of the scan such
as the iterative correction method described by Nagai et al.\(^{(5,6)}\) are being investigated, but at present are carried out in an off-line mode.

The goals of computer scanning can be summarized as follows: 1) To improve resolution using numerical analysis, modern statistics and the application of inverse transform functions or deconvolutions. 2) Improve the display of the scan making lesions more readily apparent. 3) Subtraction of one scan from another. 4) Comparison of serial scans or rapid sequential scans. 5) Comparison of scans performed with different isotopes. 6) Comparison of a new scan to a norm established for that particular organ, these norms being determined by analysis of a library of normal studies stored on tape. 7) The use of statistical processing to determine the significance of apparent changes. 8) Eventually, to study three dimensional spatial distribution of isotopes and display them in three dimensions.

**COMPUTER ASSISTED INSTRUCTION**

There is a severe and worsening shortage of radiologists. Obviously training programs in this field must be expanded, but a partial answer to the problem may lie in the introduction of new teaching methods which can increase the efficiency of the teachers already available. A development of this type is the use of the digital computer as a teaching aid, so called computer-assisted instruction (CAI). For two years we have been using the computer as an aid in teaching nuclear medicine to our residents and technologists. We have now written 14 CAI courses, each of which takes about 20 minutes for the student to carry out. Most of the courses follow widely used programmed instruction techniques and include free-form answers, multiple choice, branching, and reinforcement. Subjects include courses on long acting thyroid stimulator substance, lung scanning, the schilling test, and mathematics for Nuclear
Medicine. It is very easy to learn to write courses for CAI. We have found that a bright resident with no previous exposure to computers can become an effective course writer in about two hours. To date both instructors and students have been pleased with the amount of information learned in these preliminary trials, admittedly, a subjective and probably biased impression. What is needed is an objective evaluation of the effectiveness and efficiency of this form of teaching compared to others, and we are planning such studies. In addition, we are seeking assistance from people outside the medical field who are specialists in the science of learning. Improvement in our results could be achieved by better use of the new knowledge of learning theory. We have learned that, as would be expected, the results achieved by computer-assisted instruction as in all teaching depend greatly upon the skill, wisdom, and language structure with which the material is prepared.

INVENTORY CONTROL

Nuclear Medicine presents a unique problem in inventory control since the inventory decreases whether material is being used or not. We have found it helpful to use the on-line computer system to control our inventory. Four functions are available to the technologist. The function "LIST" results in all shipments in the inventory being listed. This listing includes initial activity and volume, current activity and volume, and the date the shipment was received. The function "SHIP" is used to enter or delete a shipment or to list the hospital number, date of injection and activity and volume given to each patient receiving part of that shipment. A new shipment is entered by typing in the isotope and chemical form, the date of shipment, and activity and volume present at the time of shipment. A number is assigned each new shipment. When a shipment is deleted from the inventory, a list is automatically
typed out for permanent record of each use of the isotope. The function "DOSE" is used to determine the shipment number and volume of isotope to be administered to a patient. The isotope and chemical form desired is entered along with the dose in millicuries per kilogram and the patient's weight. The computer searches the inventory until it finds the oldest shipment with enough activity of the radio-pharmaceutical desired and then prints out the volume the technologist should use and the shipment number. The function "USE" can then be called and if "YES" is entered, the inventory is corrected for the volume specified by the previous use of "DOSE". If a manually calculated dose has been used, this routine can be called to update a shipment's volume and list.

REPORTS

At present we are using our on-line computer to store information on all patient studies conducted in Nuclear Medicine, providing immediate recall of this information. Since 1963, 7,060 patient studies have been carried out and in each instance the patient's name, hospital number, age, sex, date of the examination, and a code indicating the isotope used, the route of administration, the study carried out, the results of the study, and whether the study was of particular interest, and proved or unproved, has been stored on a section of one of the computer's disks. This file is always current. After preparing the reports each morning, a secretary enters new patient information through the keyboard, automatically updating the file. The program for this is simple to use, asking questions of the secretary in a conversational mode, and giving her an opportunity to correct any mistakes before the information is actually entered onto the disk. About once a week the file is transferred to magnetic tape as a back-up, and these reports are also kept on cards so that the
information cannot be permanently lost. Programs are available which allow a search of this file for a particular patient by simply typing in his hospital number or for a particular study or result by typing in the appropriate part of the code referred to above. This system has proved particularly helpful in carrying out retrospective studies. For example, we might ask a resident to review all of the $^{113}$Indium hydroxide colloidal bone marrow scans. By typing in an appropriate code on the keyboard, the computer would search the files and list all of these tests we have performed.

We are using our computer more and more to prepare patient's reports in a form suitable for inclusion in the patient's chart. After performing a thyroid uptake test, or a schilling test in the usual fashion, and calling the appropriate program from the keyboard, the computer obtains appropriate information from the technologist in a conversational mode. This includes such things as the patient's name and hospital number, the dose of isotope administered and background, phantom, sample, and/or patient's counts. The computer then analyzes the data, determines the result, compares it to normal limits and types out a report on the form usually used for reporting patient studies. A physician checks the final results and initials it before it is sent to the ward. (Fig. 1)

Disappearance studies, such as $^{51}$Chromium red blood cell survival tests or platelet survival studies, are also handled in this fashion. The data is subjected to statistical analysis including a linear regression on the logarithms of the sample counts versus time of the sample, thus determining the rate constant and half-time of disappearance, putting confidence limits on the rate constant. The $Y$-intercept is also determined and an analysis of variance is printed out. In addition, two semi-logarithmic $X$-$Y$ plots of the data and the least squares fit are automatically drawn. One of these is small and is laminated to the
clinical report, the other is larger and is kept in the patient's Nuclear Medical folder. (Figs. 2 & 3) Renograms are also processed by the computer. At present, the raw data is recorded at 10 second intervals from both kidneys on punched paper tape. When this data is fed into the computer, two easily interpretable X-Y plots are drawn with the time scale going from left to right and the two renogram curves superimposed for easy comparison. (Fig. 4) Although we have investigated more sophisticated analysis such as polynomial fitting and studying first and second derivatives of the renogram curve, we have not found these helpful as yet in clinical interpretation. At present, the computer prints out the peak time on each side and the time from the peak to half of the peak value. We have found that the renogram normally falls to half of the peak value within 10 minutes after the peak. A physician still dictates the final report which is typed by a secretary and the smaller X-Y plot is laminated to this report to be sent to the ward.

**FUNCTION STUDIES AND SYSTEMS ANALYSIS**

In addition to the thyroid uptake tests, schilling tests, renograms, and disappearance studies discussed above, we are investigating a number of function studies performed routinely in Nuclear Medicine and are confident that we will soon have developed ways of improving their reliability and ease of interpretation using the computer. Many of these studies involve fairly sophisticated mathematical analysis of kinetic models of physiologic systems. Examples would be iron kinetics and the study of calcium metabolism. Studies of this type will become increasingly important and more frequently used in clinical medicine in the future.

As hospital administration becomes more and more complicated, computerized systems analysis of the hospital's operation offers a means of improving
efficiency, reducing costs, spotting weakness in personnel and procedures and predicting future needs. Although Nuclear Medicine is a restricted area of the hospital, we feel that through this same systems analysis approach and linear programming, we can improve many aspects of our service. Our results as yet have not been carried far enough to prove or disprove this belief.

CONCLUSIONS

The studies and techniques reported above demonstrate that the on-line computer can play a broad role in the Nuclear Medicine laboratory. At this time it seems its most important role will be in the analysis and display of the radioisotope scan. It is also useful in computer-assisted instruction, in inventory control, and in the storage, retrieval, and reporting of patient studies. In addition, computer analysis of complicated mathematical models of physiologic systems will probably become a routine part of clinical Nuclear Medicine in the future.
BIBLIOGRAPHY


ILLUSTRATIONS

Figure 1. Computer conversational mode input and output of data from a Schilling Test. The last paragraph is also printed on a report form which is included in the patient's chart.

Figure 2. Analysis of a $^{51}$Chromium Red Blood Cell Survival Test with output of the disappearance half-time and an analysis of variance.

Figure 3. Computer drawn X-Y Plot of data from a $^{51}$Chromium Red Blood Cell Survival Test which is laminated to the report and included in the patient's chart.

Figure 4. Computer drawn Renogram which is laminated to the patient's report and included in his chart.