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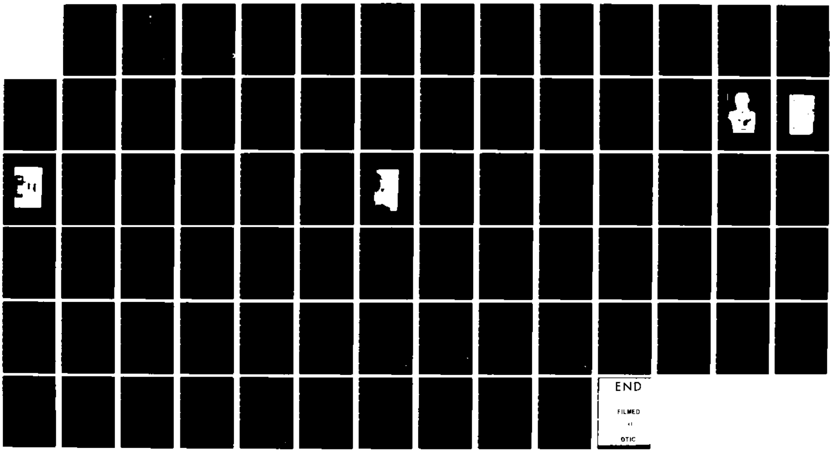

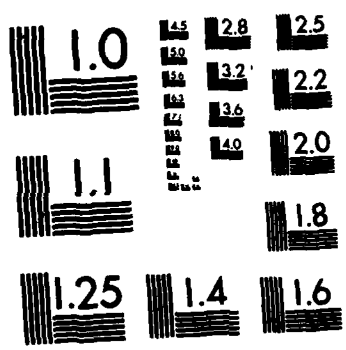

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COMPUTER DESIGNED COMPENSATION FILTERS FOR USE IN RADIATION THERAPY

:HESIS

AFIT/GEP/PH/82D-14 Richard Higgins Jr.

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY (ATC)
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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

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Master of Science

by

Richard Higgins Jr., B.S.

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Graduate Engineering Physics

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Richard Higgins Jr.

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Abstract

A computer program was written in the MUMPS language to design filters for use in cancer radiotherapy. The filter corrects for patient surface irregularities and allows homogeneous dose distribution with depth in the patient. The program does not correct for variations in the density of the patient.

The program uses data available from the software in Computerized Medical Systems Inc.'s Radiation Treatment Planning package. External contours of General Electric CAT scans are made using the RTP software. The program uses the data from these external contours in designing the compensation filters. The program is written to process from 3 to 31, 1cm thick, CAT scan slices.

The output from the program can be in one of two different forms. The first option will drive the probe of a CMS Water Phantom in three dimensions as if it were the bit of a routing machine. Thus a routing machine constructed to run from the same output that drives the Water Phantom probe would produce a three dimensional filter mold. The second option is a listing of thicknesses for an array of aluminum blocks to filter the radiation. The size of the filter array is 10 inches by 10 ~~inches~~. The Printronix printer provides an array of blocks 1/2 ~~inch~~ by 1/2 inch with the thickness in millimeters printed inside each block.

COMPUTER DESIGNED COMPENSATION FILTERS

FOR USE IN RADIATION THERAPY

I. Introduction

Surface irregularities of cancer patients make radiation therapy more difficult. The surface irregularities cause the treatment beam to pass through different amounts of tissue to reach the depth of the tumor. The beam is attenuated more in the regions where it has passed through more tissue. This causes a skewing of the isodose curves which cause difficulty in treatment planning (Ref 1,2,3,4,6,8). The patient can be made to approach the ideal of a flat surface orthogonal to the beam by the introduction of a filter to compensate for tissue deficits at the patient's surface.

The tissue compensator cannot be placed directly on the patient's surface because the electrons emitted from the compensator would burn the patient's skin during treatment. The tissue compensator must be at least 15 cm from the patient's skin to prevent burning (Ref 3,4). The displacement of the tissue compensator above the patient makes it necessary to reduce the lateral dimensions of the compensation filter to correct for beam divergence (Ref 1,5,6). See Figure 1. The vertical dimension of the filter must be changed by the ratio of the attenuations of the compensator material and the tissue.

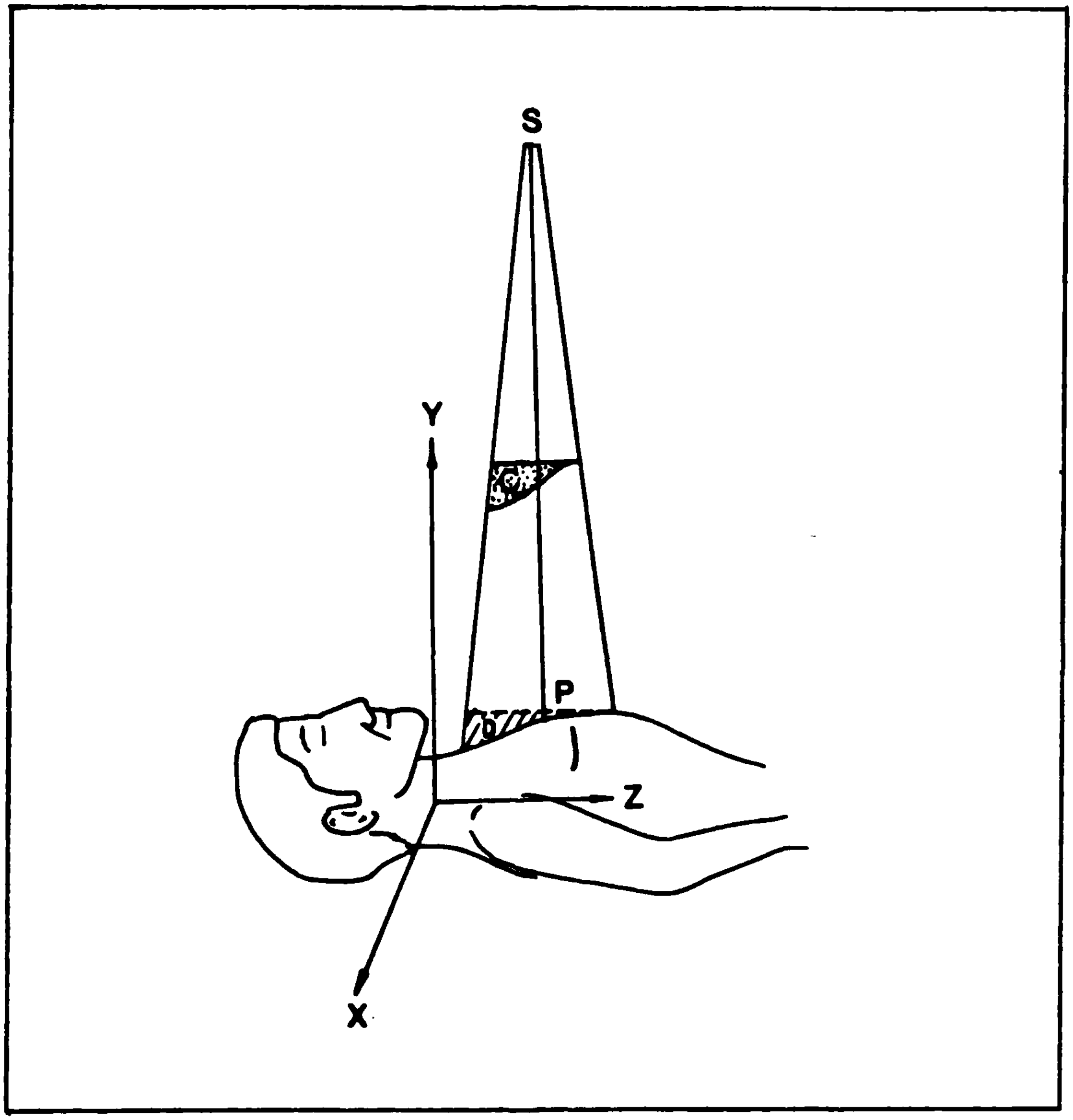

Figure 1. This is an example of the concept of a tissue compensator. S is the radiation source and P is the central axis point. C is the filter for the compensation of the tissue deficit D.

There have been many methods of designing and constructing compensation filters used in the past. Most of these methods were time consuming and uncomfortable for the patient. One such method involved the use of the "rod box" to measure the topography of the patient. This involves clamping the many rods coming out of the box into position so that the rods are touching the patient's surface. Then the comparative lengths of the rods are used in the design of the filter. Another method used a router to carve out a styrofoam filter mold while a pointer connected to the router was run over the surface of the patient (Ref 1).

The idea is to find a way of designing and constructing a compensation filter which is less time consuming and is more comfortable for the patient than current methods. Cancer patients routinely undergo computerized axial tomography (CAT) prior to treatment. These CAT scans could be used for computer-designed compensation filters using the data available from the Computerized Medical Services Inc.'s (CMS) Radiation Treatment Planning software.

Problem

The problem undertaken in this study was to use the CMS computer facilities available at the Wright-Patterson AFB Medical Center to design a compensation filter. The computer would use the external contours of the CAT scans to do this. The primary aim was to set up a MUMPS language program to drive the probe of the water phantom as if it were a router bit being used to carve out a styrofoam filter mold (see Appendix A). The secondary aim was to have a hardcopy printout for an aluminum block filter to be used until the routing machine could be built (see Appendix F). The program would also need the versatility to work for various compensation materials.

Scope

The scope involved getting the program to run for a twenty-one slice sequence of CAT scans. The CAT scans imaged the Rando Phantom, a human skeleton encased in tissue equivalent material (see Figure 5). Testing of program output was limited to driving the water phantom probe in what appeared to be the proper manner, geometric evaluation of the filter and film dosimetry using the compensation filter with treatment of the Rando Phantom .

Assumptions

Two major assumptions were made to simplify the problem. The first was that the human body has a uniform density of 1 gm / cm^3 and the second was that effects of scattering by the filter and the filter holder could be ignored.

General Approach

The general approach was to retrieve the position coordinates for the external contours from the CAT scan slices and manipulate this data so it could be used by the routing machine driver routine. Then the data was further manipulated for use in the printout of the two dimensional array that would be used to design the aluminum block filter.

Sequence of presentation

A more detailed analysis of the problem and the development of the program is discussed in the next section. The third section covers the validation of the project. The fourth section discusses conclusions and results. Appendix A contains information concerning the Water Phantom. Since most people lack familiarity with the MUMPS language, a short guide is in Appendix B. Appendix C contains the program documentation. Appendix D contains the program itself. Appendix E contains the aluminum block filter printout .

II. Detailed Analysis and Program Development

The data contained in the stored external contours of the CAT scan slices are in X and Y coordinates for each point on the contour. Each of the X and Y values is an average over the one centimeter thickness of each CAT scan slice. A successive series of these CAT scan slices along the Z axis will be used by the program to design the three dimensional compensation filter (see Figure 2).

The RTP software and the program itself must be copied onto the fixed disc of the disc drive unit. The Master Patient File (MPF) disc must then be placed on the disc drive unit. The General Electric CAT scan slices must be copied from the magnetic tape onto the MPF disc. The CMS software allows this to be done fairly easily. An empty MPF disc has room for only twenty-four CAT scan slices. If more than twenty-three CAT scan slices are to be used in the filter design one must copy only the first twenty-three onto the MPF disc, then external contours are made of these slices using the RTP software. These external contours must be initiated with the light pen located at the bottom of the CAT scan slice (this allows a later simplification of the program). After these contours have been made and stored with their contour descriptions, the CAT scans on the MPF are erased so the remaining CAT scans can now be copied onto the disc and have their external contours generated and stored on the MPF.

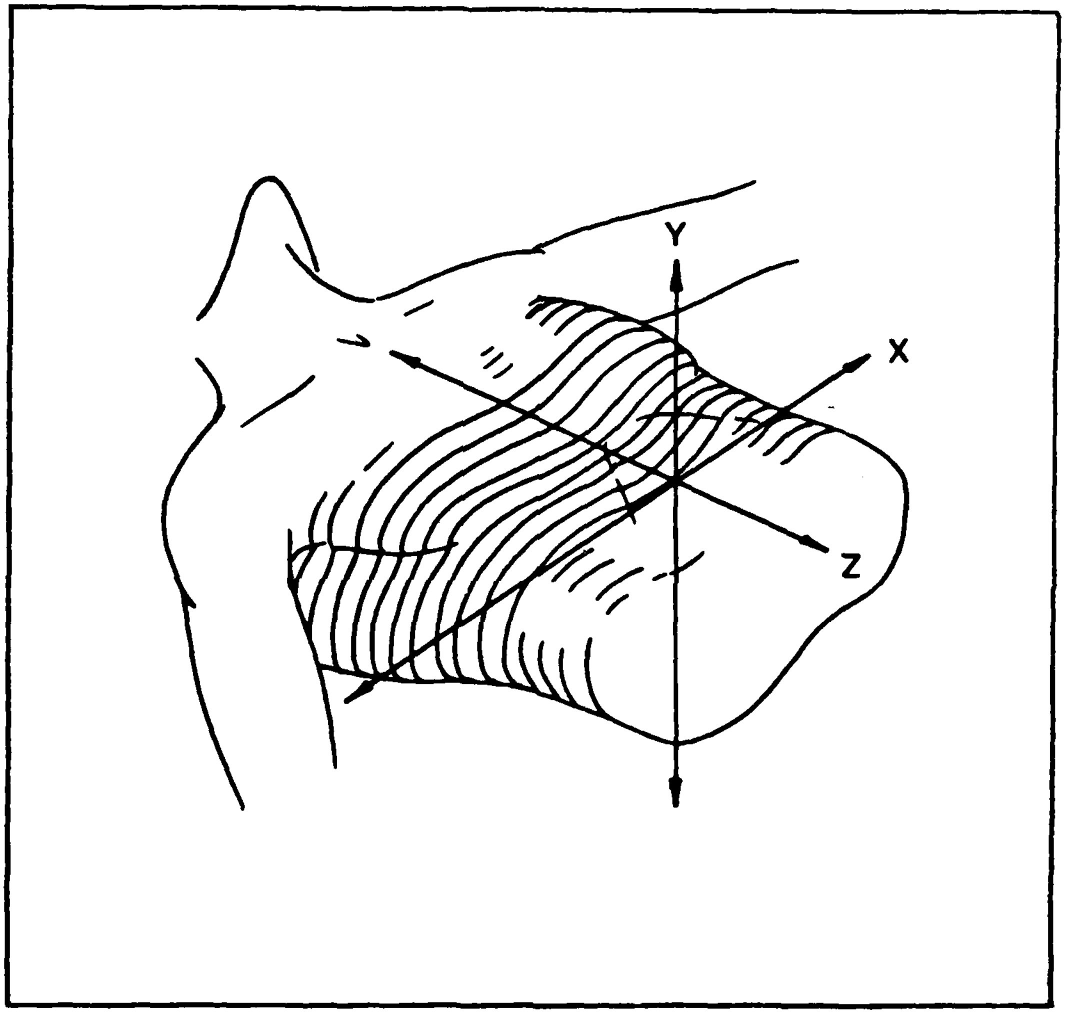

Figure 2. The figure is an example of the treatment area of the patient as a composition of successive CAT scan slices and shows the coordinate axes at the patient.

The X and Y coordinates of the central axis point must be determined. The central axis point is that point directly below the beam source. The coordinates can be found with the existing RTP software. Using the External Beam Planning option a treatment beam is positioned so that it passes through the central axis point. The hardcopy printout of the treatment plan gives the values in millimeters for the X and Y coordinates of the central axis point. These values are used later in the program.

The program must be divided into smaller programs because of the limited size of the buffer in the CMS computer system. Each of these smaller programs calls up the next program in the sequence. The size of the buffer also limits the number of local variables which can be carried along from one linked program to the next. This requires that most variables must have their values stored in global variables on the disc rather than in the buffer. This increases the amount of time necessary to run the program .

Program Development

The first problem to be addressed is the reading of the values for the X and Y coordinates, for each point, on each of the external contours from the MPF disc. First the number of data points contained in the external contour must be read. The program then reads the X and Y coordinates for each of the points. The coordinate system origin is within the CAT scan slice and can be located using the hardcopy printout of the RTP treatment plan. The X and Y values must be converted into units of millimeters and stored in global variables on the disc containing the program. The RTP software stores the X and

Y coordinates in a form that requires division of the value by 16 to convert to units of millimeters. Each external contour is then stored with its X coordinates stored in one global variable and its Y coordinates in another.

Sorting routines must be used to go through the values of the X and Y coordinates. The program requires the maximum X and Y values and the minimum X value for each of the external contours for later operations. The maximum Y values for each of the external contours are sorted to find the maximum Y value out of all the contours.

The maximum Y value is used to shift the Y coordinate system so that Y is equal to zero at the maximum point of the patient surface and all other y values are less than zero. This is necessary for the router driver routine so that the router cuts into the filter mold where there are tissue deficits. The X coordinate system is shifted by subtracting the value for the X coordinate of the central axis point from all the X values. This sets X equal to zero on the central axis (see Figure 3).

The data points of each external contour are accessed and those points which fall below a line drawn from the minimum X to maximum X points are deleted (see Figure 4). The remaining contour coordinates are then stored in ranked order from the maximum X value down to the minimum X value. This enables the router to begin at one end of the filter mold and cut its way to the other end for each CAT scan slice. The router can not follow indentations along the X axis so those must be deleted prior to the router driver routine because the router only

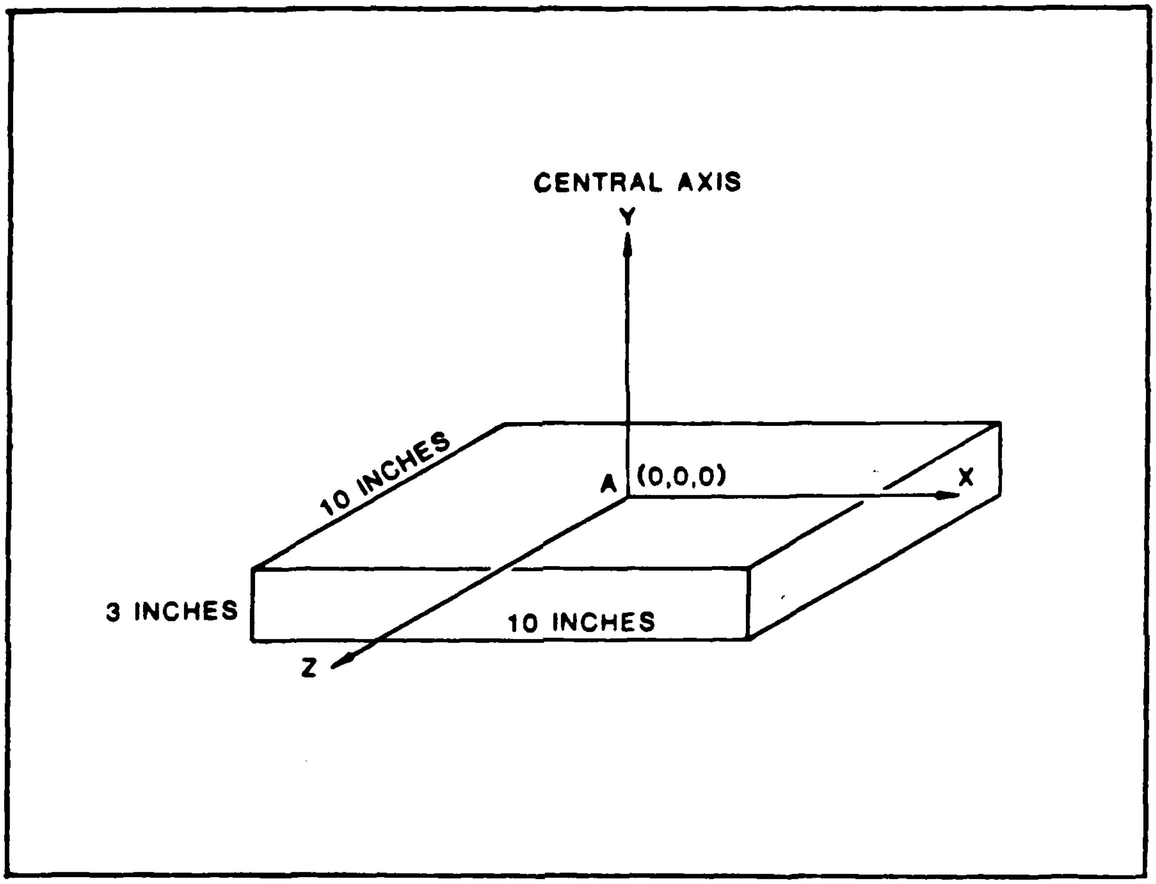

Figure 3. The figure shows the coordinate system at the styrofoam filter block. The dimensions of the filter are 10 inches by 10 inches by 3 inches. Point A is the central axis point at the top of the filter. This is the origin of the coordinate system at the filter.

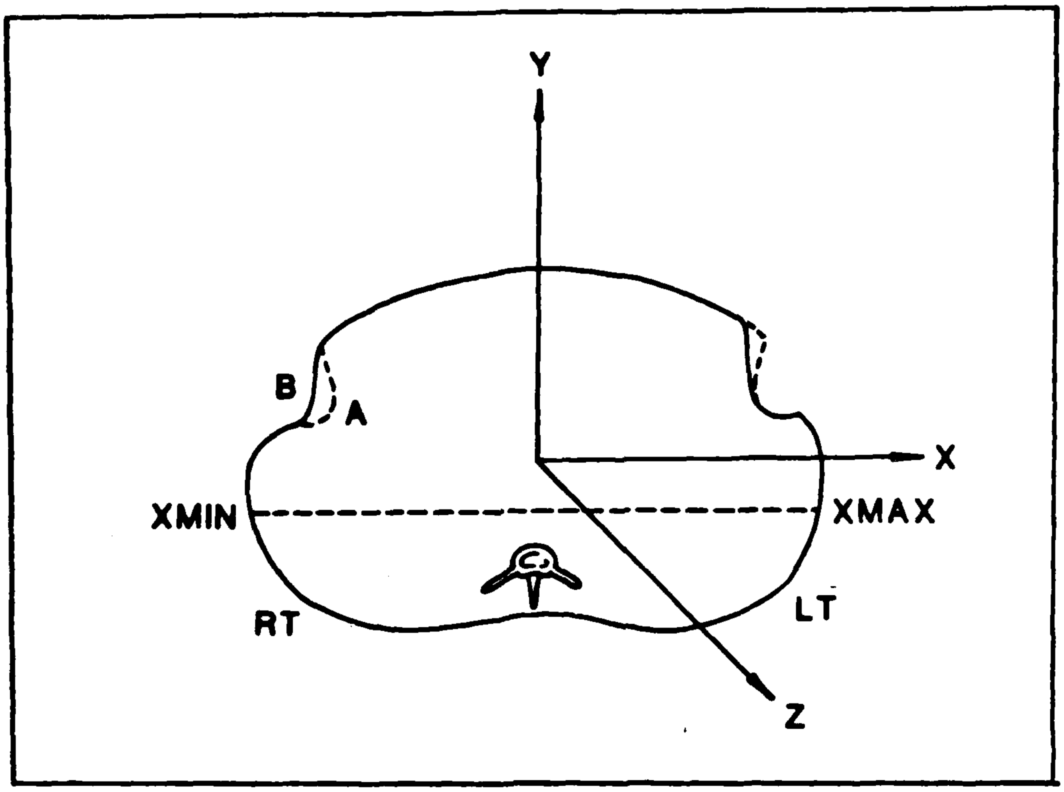

Figure 4. The figure gives an example of the deletion of indentations along the X axis and shows the cutoff line for the points to be deleted on the bottom of the CAT scan external contour. Beginning at point XMAX and moving counter-clockwise, each X coordinate value is compared with the next X value on the contour. If the following X value is not less than the preceeding value it is set equal to the preceeding value and rewritten into the file. This causes indentations similar to A to be replaced with a straight line such as B. This enables the router to track properly over the contour in the X and Y dimensions. When point XMIN is reached the coordinates between XMIN and XMAX are deleted along with their corresponding Y coordinates.

moves in the X and Y dimensions while processing a CAT scan slice. Upon completion, it then increments along the Z axis to the next slice and starts over.

The X coordinate values for the points on each external contour must be trigonometrically reduced for the reduction in lateral dimensions at the filter. The diameter of the source, the distance from the source to the patient at the central axis point, the distance from the source to the filter base and the diameter of the filter base are values used in this calculation. The source is then treated as a virtual point source located at increased source-to-patient and source-to-filter distances, with the original diameter of the source acting as a stop (see Figure 5).

For the new filter holder:

TAN=116.5/651=126.2/D2

D2=126.5*(651/116.5)=707 (D2 is updated source-to-filter base distance)

707-651=56, 800+56=856 (The updated source-to-patient distance)

TAN=126.5/707=R2/856

R2=153mm

This makes 30cm the geometric limitation of the treatment area along the X axis due to the filter holder sides interfering with the beam divergence. This means the maximum number of slices that can be treated with the new filter holder in place is twenty-nine. The size of the treatment area at the patient can be adjusted at the source with the trimmer bars (which limit the treatment beam divergence). This allows the beam divergence to be limited so that it does not contact the sides of the filter holder.

Tangents can now be easily calculated for transposing the X coordinates at the patient to those values needed at the filter.

$$X(filter)=(X(patient)/(856-Y(patient)))*651$$

The Z coordinate values are those arising from the one centimeter thickness of each CAT scan slice. The values along the Z axis must also be reduced to those needed at the compensation filter. Since the reduction depends on the distance from the source to the patient, an average distance for each CAT scan slice must be calculated. This is done by taking one half of the height of the CAT scan slice along the Y axis and adding this to the source to patient distance. The new source-to-patient distance is used in calculating the tangent values used to transpose the Z coordinate values. The one centimeter width of each slice is also transposed for use as the width of the router bit. The Y coordinate values are transposed into the values needed at the filter through division by the compensator tissue ratio. This ratio is the ratio of the attenuations of the compensator and the tissue at 1.25 MeV, the average energy for the photons from the Cobalt 60 Therapy Radiation Source. The body is assumed to be without voids and with a uniform density of 1gm / cm^3.

The router driver routine is set to start with transposed X and Y coordinate data from a CAT scan slice at one end of the treatment area. It begins at the maximum X position for the slice. The router bit width is given and the bit must now be attached. The machine then drives the router bit along the contour given by the X and Y data points. The router bit is then removed and the router then moves to the maximum X position for the next slice. This procedure is repeated until the filter mold is completed.

Since there is no router machine built yet, a hardcopy printout which can be used to make an aluminum block filter is desired. This filter is composed of half inch by half inch blocks of aluminum of different thicknesses stacked to the proper height for each array position. The printout is ten inches by ten inches and is divided into half inch by half inch squares along the X and Z axes (see Appendix E). The Y values that fall within each of the squares are averaged and their mean is printed within the square. The Y value tells one how tall the blocks are to be for that square.

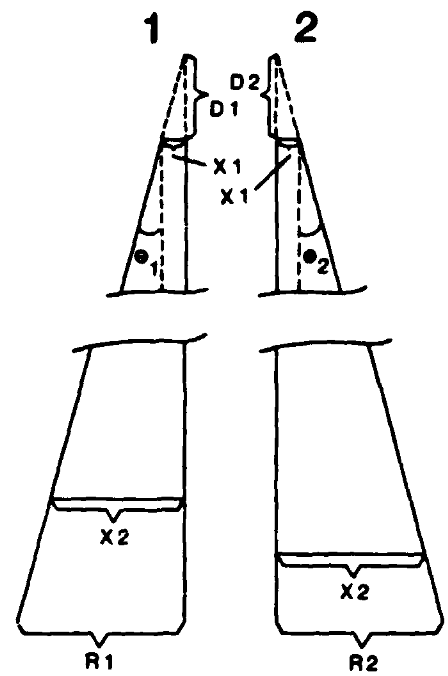

Figure 5. The figure shows how the source will be treated as a virtual point source and the limitation of the maximum treatment beam divergence due to the filter holder itself. Side 1 is an example of the Heustis filter holder. The angle is the maximum half-angle beam divergence, X2 is the half-width of the filter, X1 is the half-width of the source, D1 is the length to be added to the original source-to-patient and source-to-filter distances in order to treat the source as a point source and R1 is the half-width of the patient that can be treated with the holder in place. Side 2 has the new filter holder in place. D2, the half-angle divergence and the half-width at the patient are different from the corresponding values on side 1 because of the different original source-to-filter distances.

III. Validation

The router driver routine cannot be validated quantitatively. The routine does drive the the probe on the water phantom in what appears to be the proper manner. The X and Y coordinates when printed out and the Z coordinates and the width at the filter for each of the CAT scan slices are correct when one works out the geometric transformations done to them.

Early tests of the program used external contours of regular geometric figures of different sizes (tilted squares) which were manually entered using existing CMS software. The program output for these was also validated geometrically.

The program was run using twenty-one CAT scan slices taken of the Rando Phantom. The Rando Phantom is a human skeleton encased in tissue equivalent material (see Figure 6). The hardcopy printout was used to build an aluminum block filter (see Figure 7).The filter needed a special holder in order to be used on the Cobalt 60 machine at the Medical Center. The holder was made out of aluminum at the AFIT machine shop (see Figure 8). The new holder has both a rack for the shadow tray and a rack for the filter. The AFIT machine shop also made the half inch by half inch aluminum blocks in thicknesses of 1, 2, 5, 10, 20 and 30 millimeters. The aluminum blocks were held together using rubber cement so they could be reused.

The phantom was then treated both with and without the filter in place. Film dosimetry was taken during each treatment. The film dosimetry was then evaluated using the CMS computer driven isodensitometer (see Figures 9 and 10). The isodensitometer results show that the filter does compensate for tissue deficits in the patient. The isodensitometer results were not quantitative enough to show how accurately the filter compensated for the missing tissue.

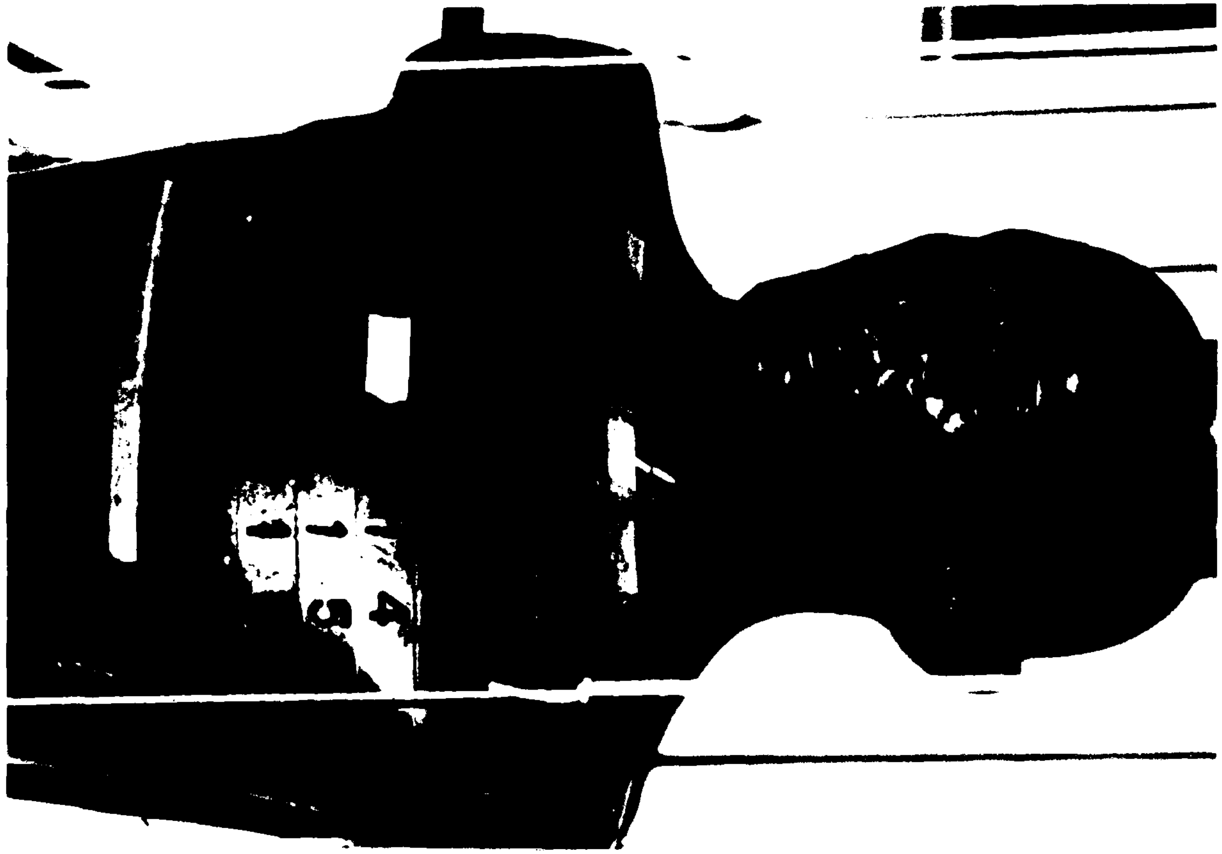

Figure 6. The Rando Phantom is a human skeleton encased in tissue equivalent material. It was used for the CAT scan slices that the program used to generate the compensation filter. The Rando Phantom was also used as the patient in the film dosimetry testing.

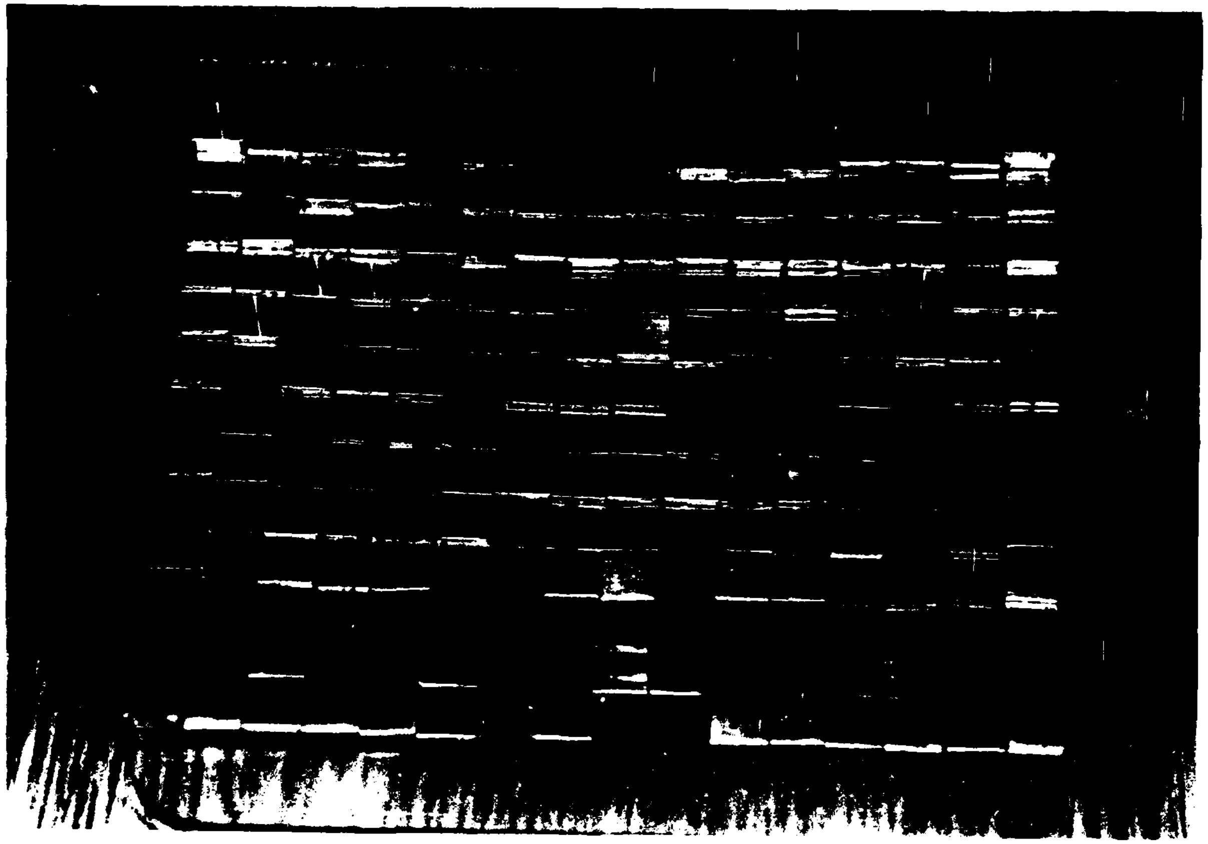

Figure 7. The aluminum block filter for compensation of tissue deficits. This filter was used in the radiation treatment of the Rando Phantom for the film dosimetry testing of the radiation dose.

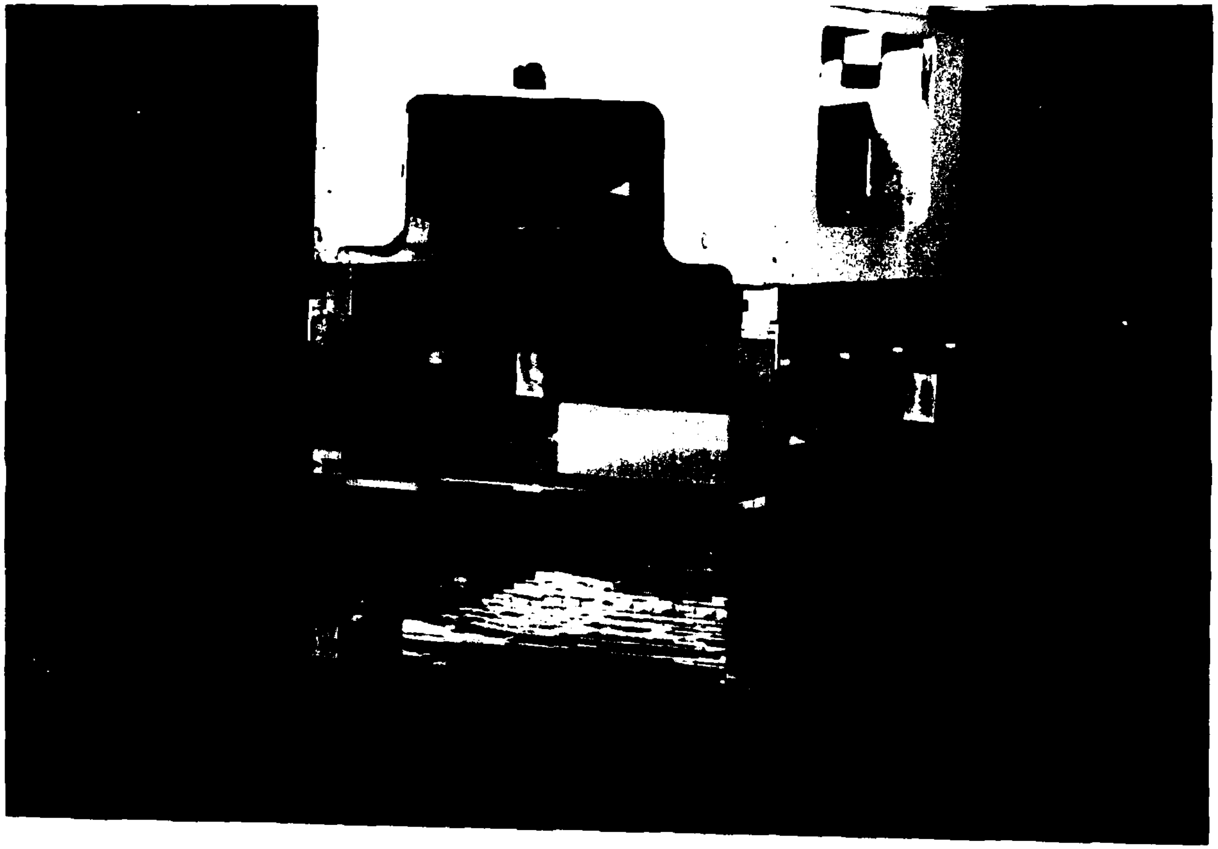

Figure 8. The aluminum filter holder with both the shadow tray of the Heustis holder and a tray for the tissue compensator. The holder was used for the film dosimetry testing both with and without the compensation filter in place.

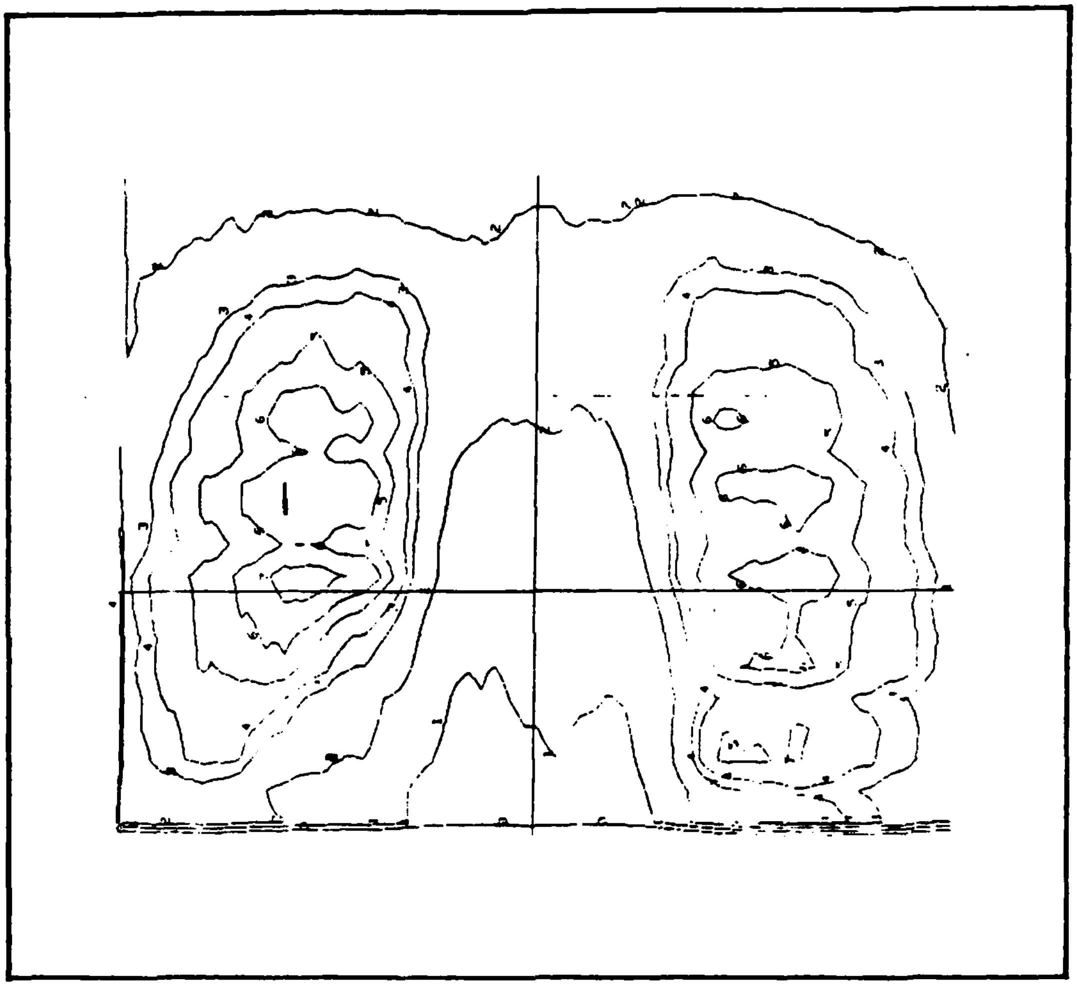

Figure 9. The isodensitometer output from the film dosimetry results for treatment without the compensation filter in place.

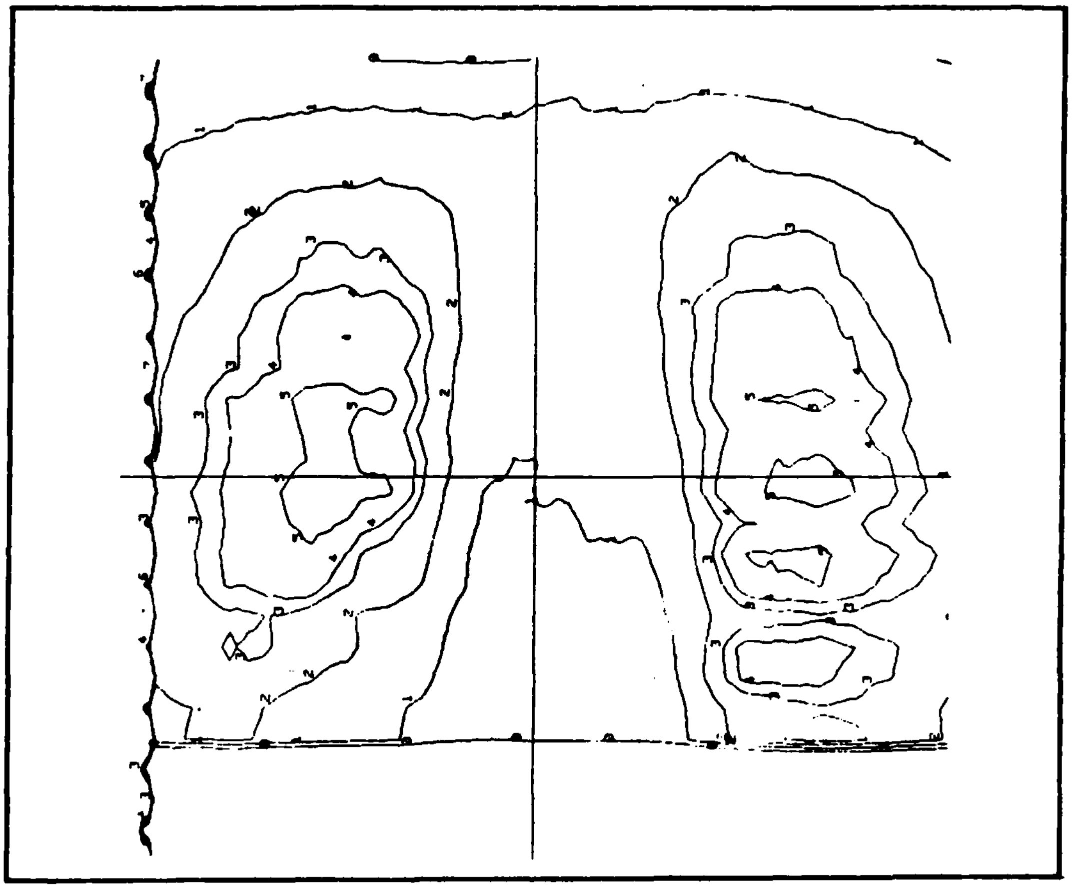

Figure 10. The isodensitometer output from the film dosimetry results for treatment with the compensation filter in place.

IV. Conclusions and recommendations

The computer program designs a compensation filter which is geometrically accurate. The proper reductions in the lateral dimensions do take place. The film dosimetry and the isodensitometer evaluation would give a more accurate picture if the Rando Phantom were not curved on the underneath. This causes the dose to vary in uniformity at the film because some portions of the beam pass through less tissue before exiting the phantom. The problem could be eliminated by using thermoluminescent dosimeters placed within the phantom itself at a uniform depth. The dosimeters would give an accurate picture of the dose distribution. Time constraints prevented the use of these dosimeters. After further verification using the TLD's, the routing machine should be constructed and evaluated.

The program can also be improved. There are three areas where improvements might be made. The first is to attempt to take into account the varying densities of the patient. Contours of areas with a different density from the surrounding tissue can be made using the RTP software. The second area of improvement is to take into account the scattering due to the filter and the filter holder. The third is in decreasing the calculation time of the program.

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Appendix A: The Water Phantom

The CMS water phantom is part of a dosimetry system used for plotting isodose contours. It is a remotely controlled device. The water phantom is capable of moving its probe along any two of its three dimensions. The driver routine in the program will drive the Water Phantom probe first along the X and Z dimensions to its proper position prior to following the transposed contour coordinates of the CAT scan slice. The Water Phantom will the move along the X and Y dimensions as it follows the contour coordinates of the scan slice. This procedure is repeated until all the CAT scan slices have been processed.

Figure 11. A photograph showing the CMS water phantom. A is the water phantom probe mount. The movement of the water phantom probe is used to simulate the movement of the bit of a router machine that would be run by the same driver routine.

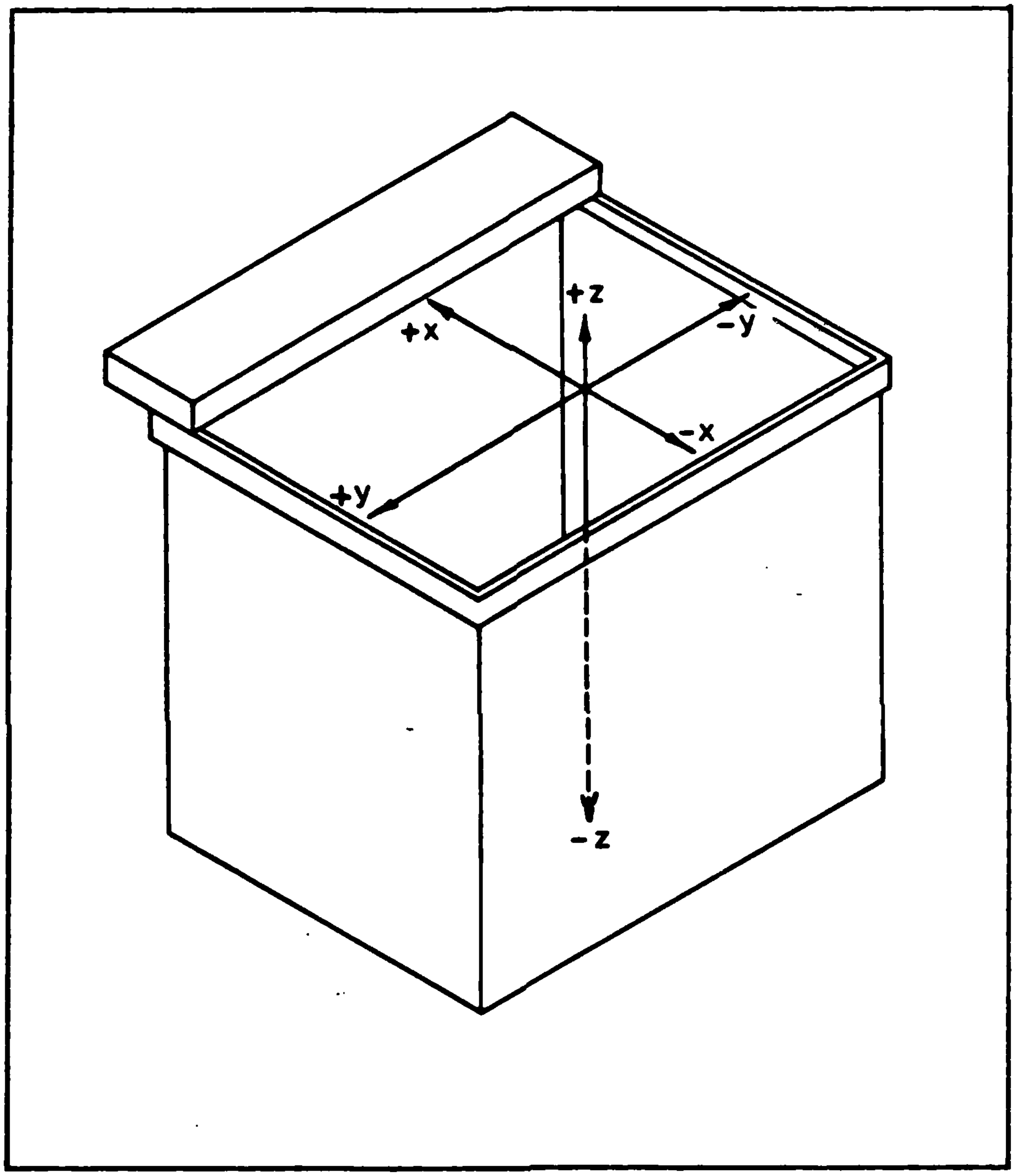
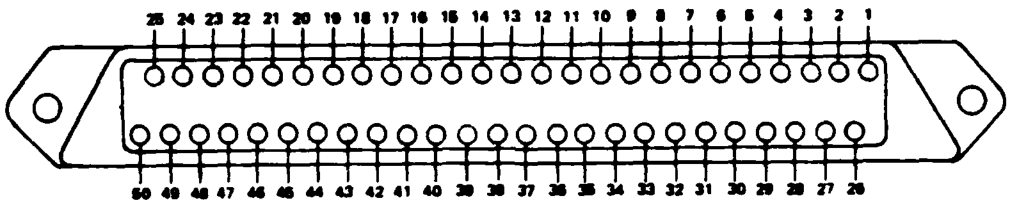


Figure 12. The figure demonstrates the axes of movement for the Water Phantom probe. These X, Y and Z coordinates will be the same as the coordinate system at the filter top previously shown in Figure 3.



CONNECTOR J11

AMPHENOL, 50 PIN "BLUE RIBBON" CONNECTOR			
PIN NUMBER	DESCRIPTION	PIN NUMBER	DESCRIPTION
1	Y MOTOR Ø1	27	Z MOTOR Ø1
2	Y MOTOR Ø1	28	Z MOTOR Ø1
3	Y MOTOR Ø2	29	Z MOTOR Ø2
4	Y MOTOR Ø2	30	Z MOTOR Ø2
5	Y MOTOR Ø3	31	Z MOTOR Ø2
6	Y MOTOR Ø3	32	Z MOTOR Ø3
7	Y MOTOR Ø4	33	Z MOTOR Ø3
8	Y MOTOR Ø4	34	Z MOTOR Ø3
9	X MOTOR Ø1	35	Z MOTOR Ø4
10	X MOTOR Ø1	36	Z MOTOR Ø4
11	X MOTOR Ø2	37	Z MOTOR Ø4
12	X MOTOR Ø2	38	X MAN. +
13	X MOTOR Ø3	39	Z MOTOR
14	X MOTOR Ø3	40	Z MOTOR
15	X MOTOR Ø4	41	Z MOTOR
16	X MOTOR Ø4	42	Z MOTOR
17	Z MAN. -	43	Y MAN. -
20	Z MAN. +	44	Y MAN. +
21	X MAN. -	45	CHASSIS GROUND
22	X MOTOR	46	Y POT
23	X MOTOR	47	X POT
24	Y MOTOR	48	Z POT
25	Y MOTOR	49	+5V DC
26	Z MOTOR Ø1	50	SIG. GROUND

Figure 13. The Water Phantom 50 pin input Connector is shown with a table of the pin functions.

Appendix B: Short Guide to MUMPS

Mathematical Operators:

+	Addition
-	Subtraction
*	Multiplication
/	Division
\	Integer Division
**	Exponentiation

Mathematical Operations

There is no hierarchy of operations. Operations are performed strictly from left to right unless parentheses are used.

Lines with mathematical operations must be preceeded with the SET command. One SET command can be used for more than one mathematical operation.

e.g.

```
S X=(27**2)*4, Y=X*37
```

Arithmetic Comparison Operators:

=	Equal to	'=	Not equal to
<	Less than	'<	Not less than
>	Greater than	'>	Not greater than

Go To Commands

Reset the pointer so that the line label immediately following the Go To command is the next line executed by the program.

e.g.

G LINE2 (Go to LINE2)

Can also be used to reset the pointer so that the next line executed is in another program.

e.g.

G LINE2 PROGRAM2 (Go to LINE2 in program PROGRAM2)

There are also conditional Go To commands.

e.g.

G LINE2:X=5 (Go to LINE2 if X is equal to 2)

If Commands

If the statement is true then the rest of the line is executed, if the statement is not true the pointer drops to the next line without executing the other commands on the line.

e.g.

I X=25 S Y=K G LINE2 (If X equals 25 set Y equal to K and go to LINE2)

Variables

Local variables can be up to 15 alphanumerics.

Arrays

Arrays are subscripted variables. The numeric subscript must have a value between 0 and 8388607. There can be more than one subscript for a variable. String subscripts are also allowed.

Global Arrays

There are multidimensional arrays which allow retrieval and storage outside of the program.

Appendix C: Program Documentation

Program LOAD1

Purpose: To initialize values needed for the operation of the entire linked program.

The program requests the operator to enter the X and Y coordinates of the central axis point, source-to-patient distance, the source-to-filter distance, the number of the CAT scan slice containing the central axis point, the compensator tissue ratio, a zero if the router driver routine is desired, a zero if the filter is on the top rack and the patient ID number. The program then sets N equal to zero. The program then increments N and requests the contour description for the CAT scan slice. This procedure is repeated until all of the descriptions have been entered and assigned an N value. The operator enters a zero if the last description has been entered and the program transfers control to program EXT11.

Programs EXT11 and EXT22

Purpose: To access the data points for the external contours, convert the values into units of millimeters and store them in specific global arrays.

Program EXT11 sets N equal to zero. The value for N is incremented and the program accesses the MPF to retrieve the first block of the file containing the external contour stored under the contour description associated with N. This block of information is placed in file FID. The program now opens file FID3 connected to global ABC(N,"XCOMP") and file FID4 connected to global ABC(N,"YCOMP").

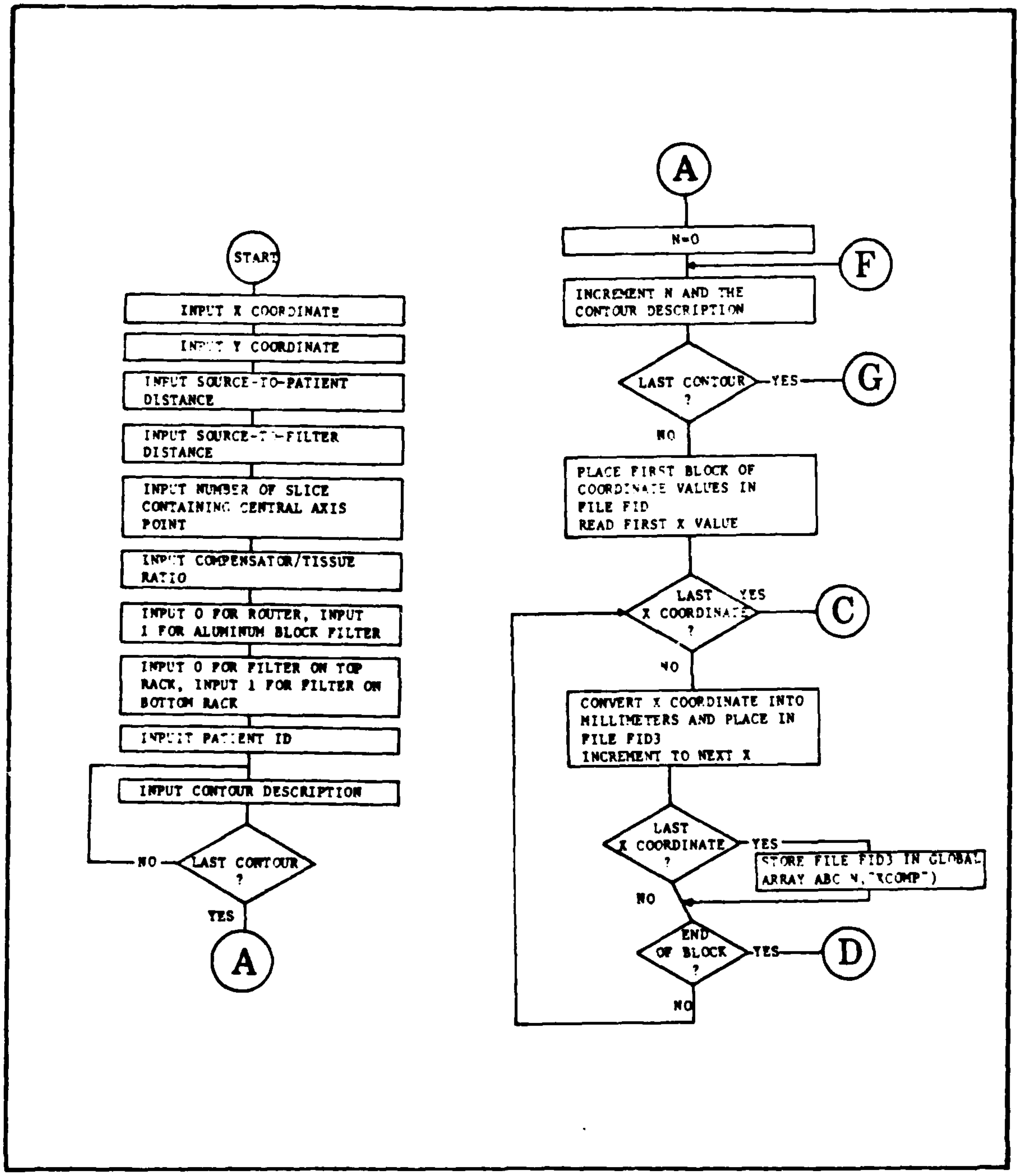


Figure 14. Linked Program Flow Chart (Sheet 1 of 7)

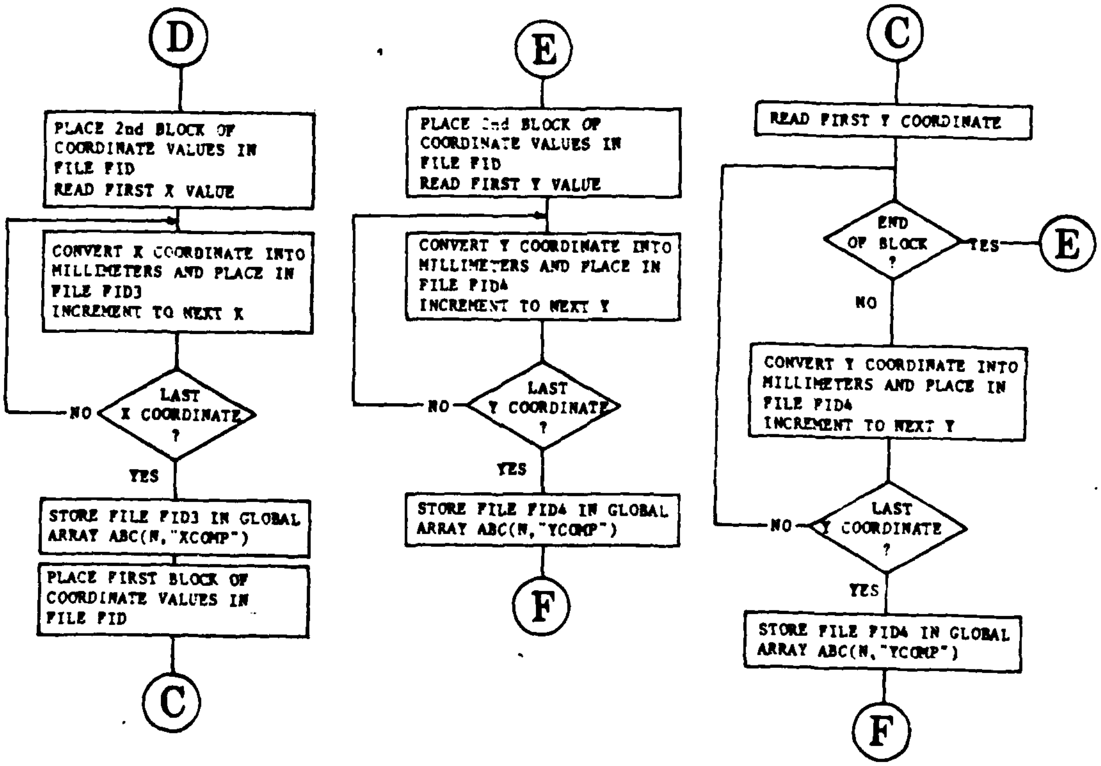


Figure 14. Linked Program Flow Chart (Sheet 2 of 7)

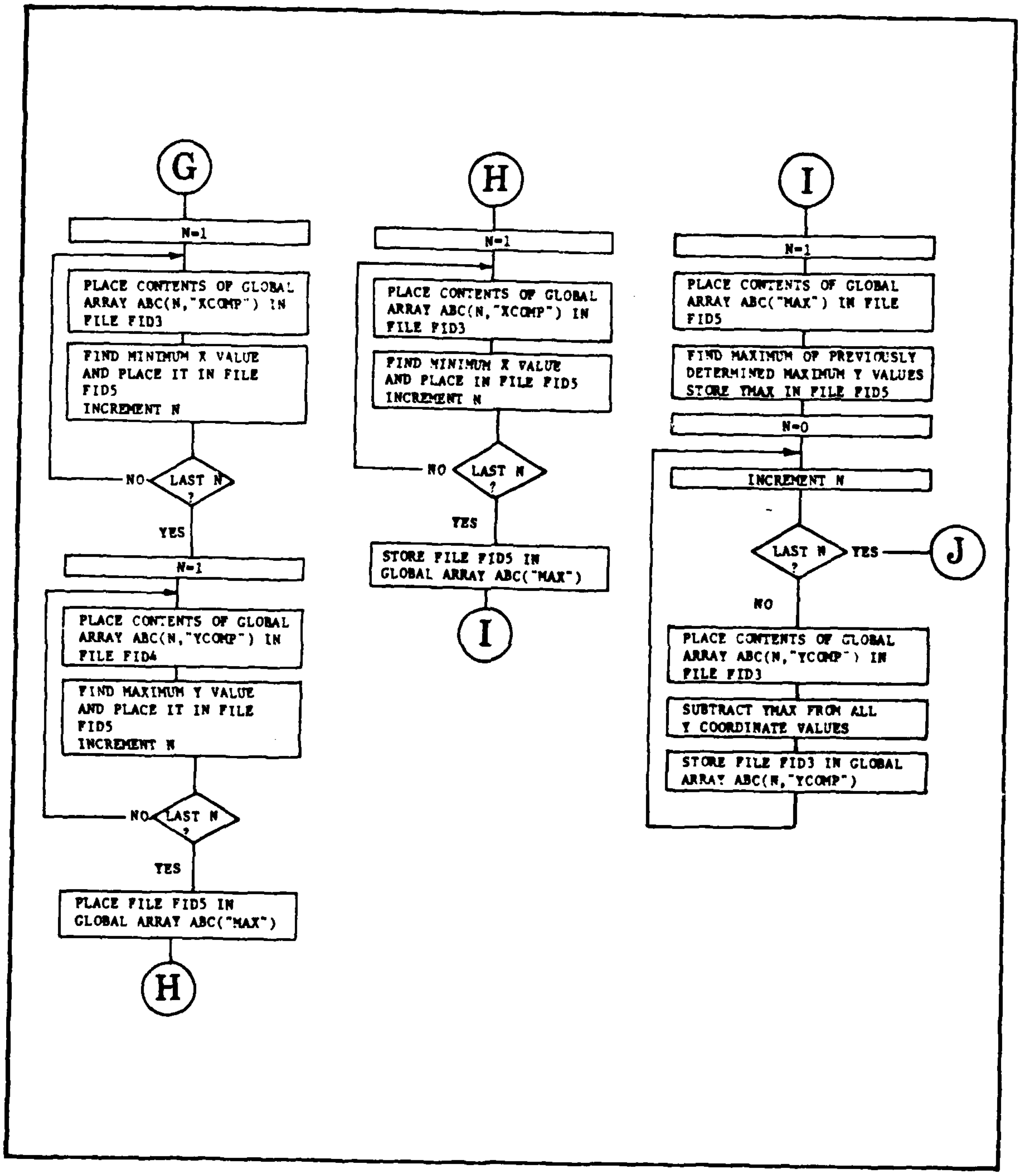


Figure 14. Linked Program Flow Chart (Sheet 3 of 7)

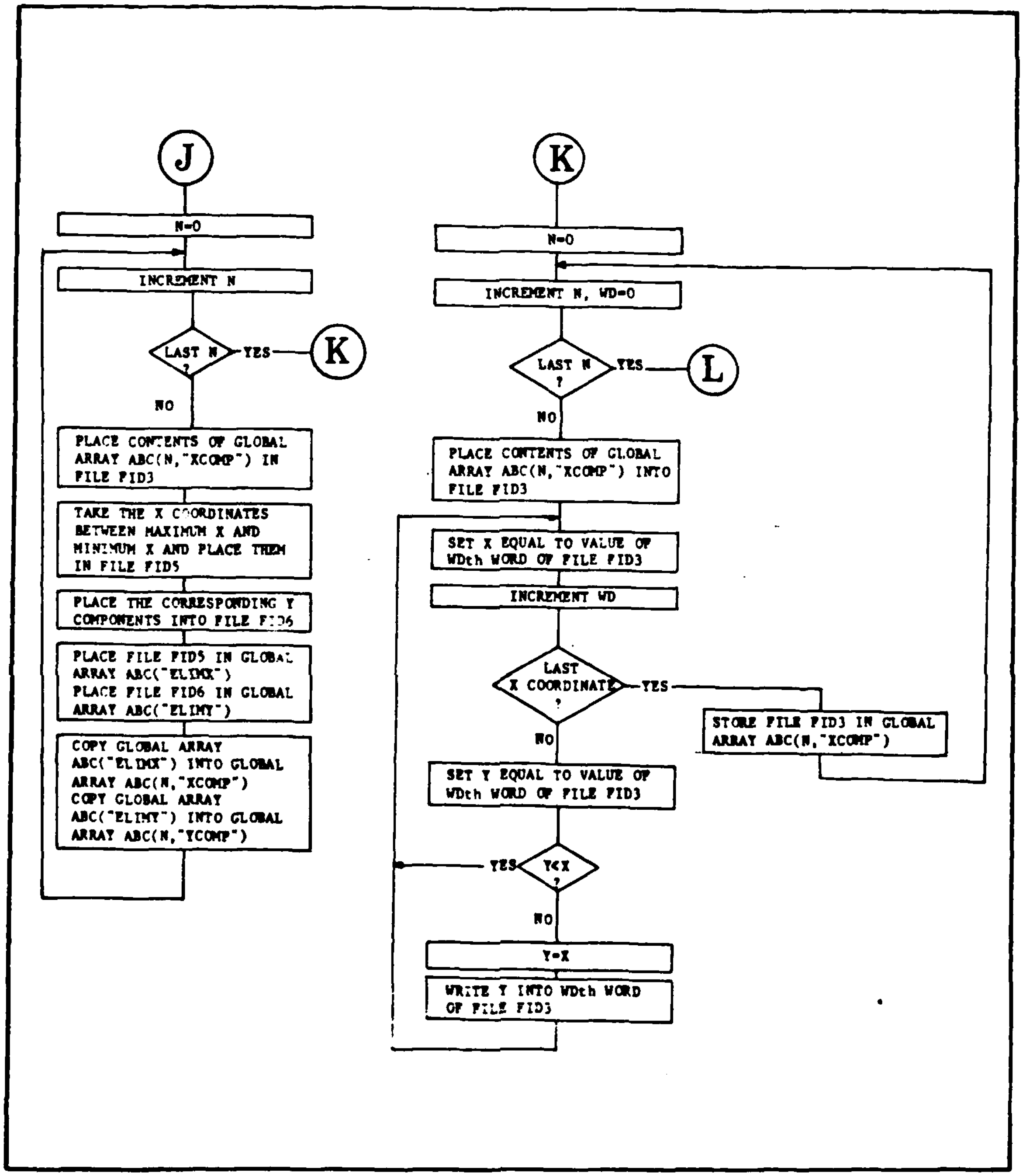


Figure 14. Linked Program Flow Chart (Sheet 4 of 7)

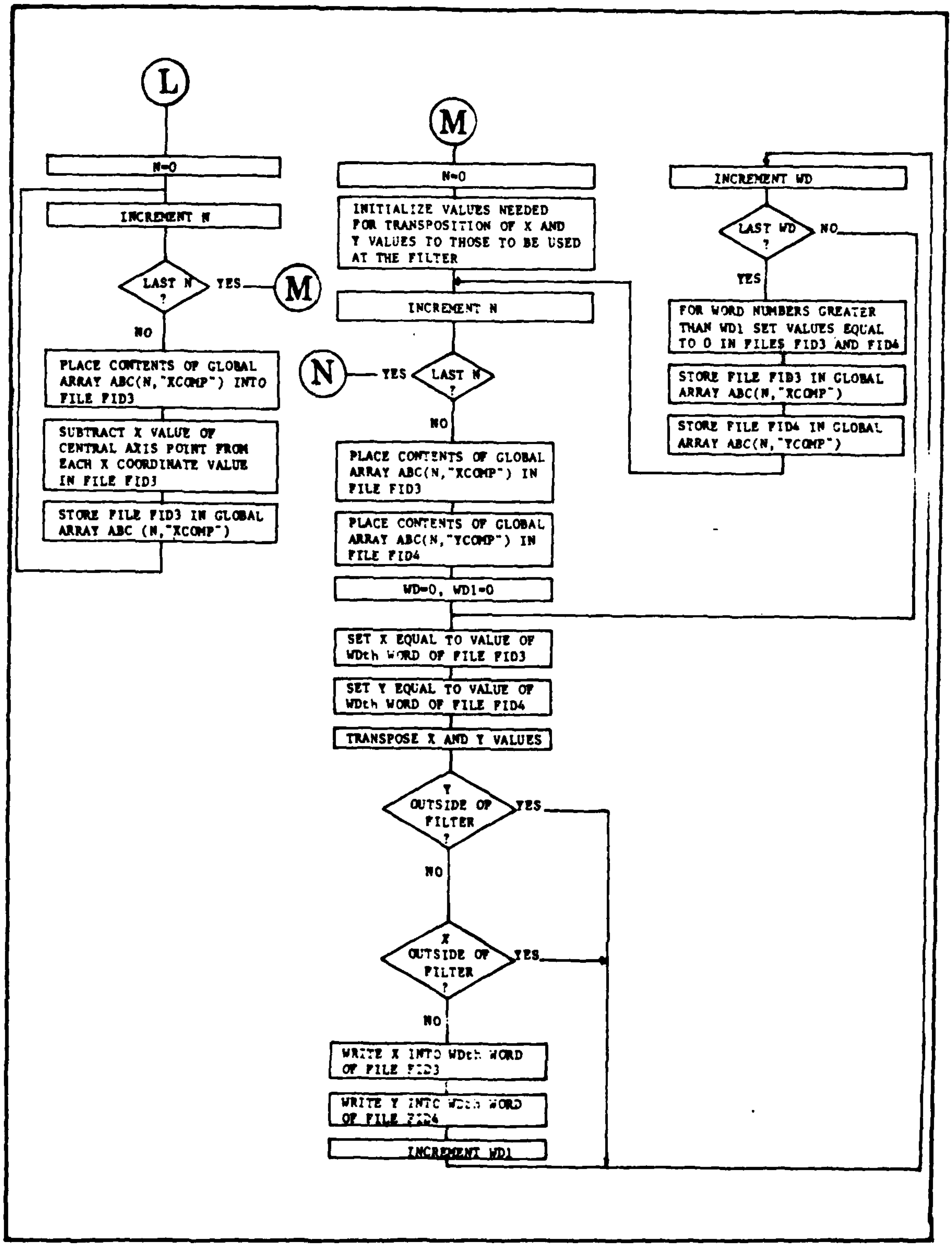


Figure 14. Linked Program Flow Chart (Sheet 5 of 7)

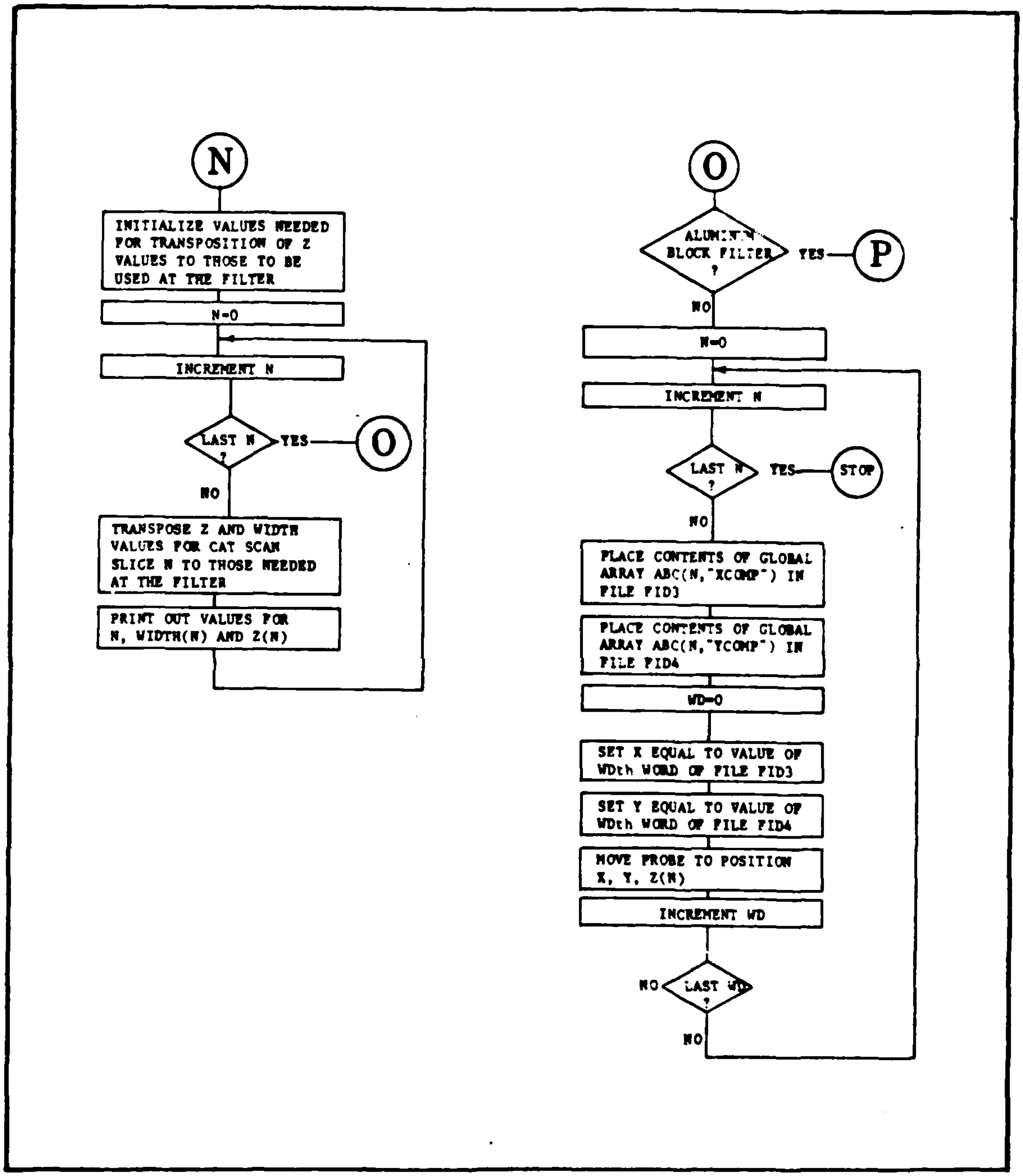


Figure 14. Linked Program Flow Chart (Sheet 6 of 7)

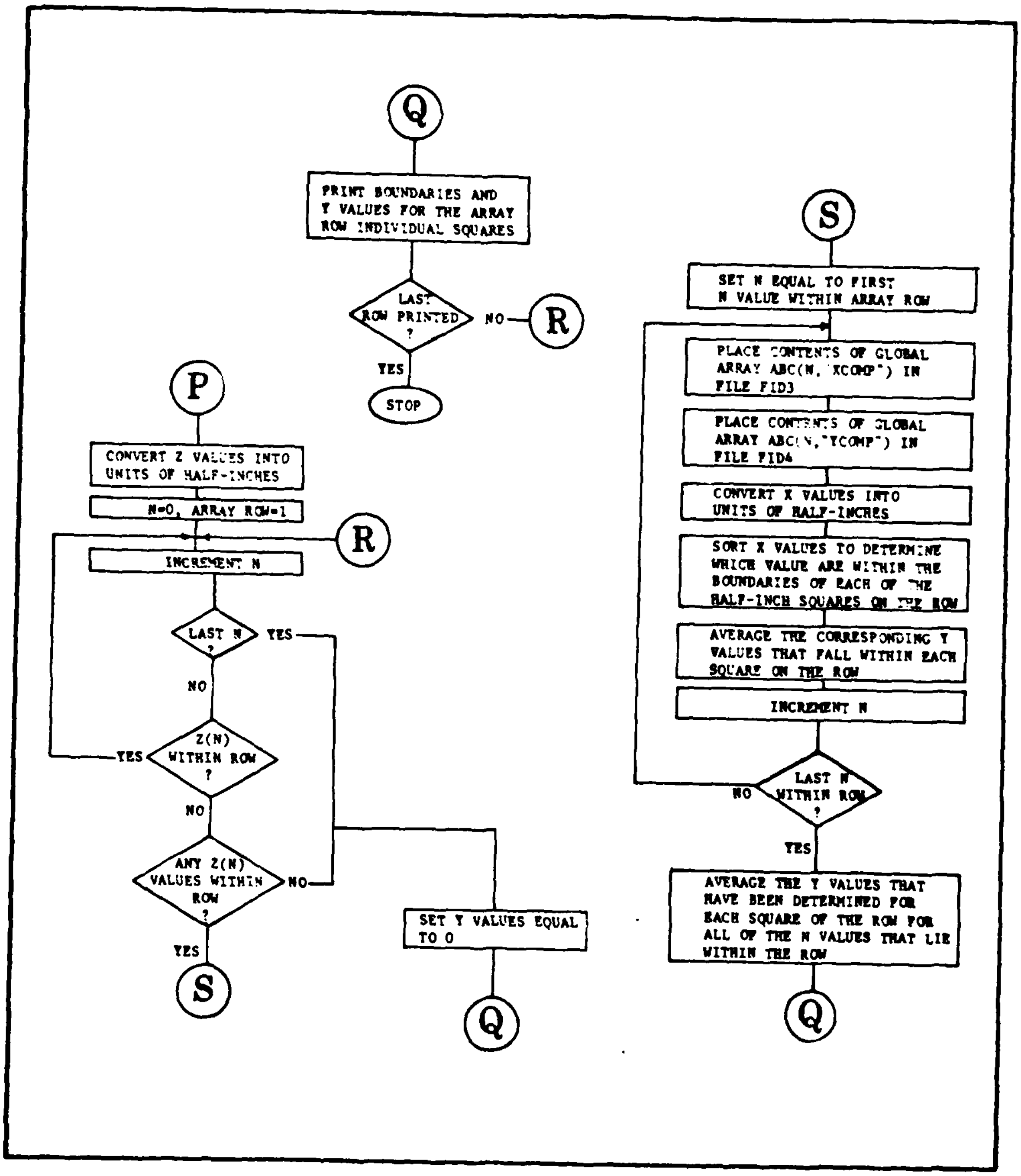


Figure 14. Linked Program Flow Chart (Sheet 7 of 7)

The number of contour points for the external contour is read from file FID at the WDth word location. R(N) is set equal to the number of contour points. RK is set equal to ((2*R(N))+7). This is to be used as a limiting value since it will give the location of the last data point of the external contour.

The X coordinates of the external contour are accessed first. The accessed data points are divided by 16 which converts the units into millimeters and the results are written into file FID3. If at the end of the first block of data, the limiting value has not been reached, control is transferred to program EXT22 where file FID is closed and the global array of the external contour is reaccessed and file FID is reopened containing the second block of the global array. The limiting value RK is adjusted to provide the proper limit in the second block. When the limiting value of RK is reached, whether in the first or second block, file FID3 is put into the global array ABC(N,"XCOMP"). Control is now transferred to line YRUN in program EXT11 and the Y coordinates are processed in the same manner. After they have all been processed and placed in global array ABC(N,"YCOMP"), control returns to line %1 in program EXT11. Here the value of N is updated for the next external contour. The data points are processed and stored in global arrays and the process repeated until until N reaches the limiting value of N1. Control then passes to the first line of program XYMAX.

Program XYMAX1

Purpose: To find the maximum X coordinate and the maximum Y coordinate for each external contour and place the values in global array ABC("MAX").

First N is set equal to 1. The global array containing the X coordinates of the first external contour is accessed and the values are placed in file FID3. The value at word 0 is read and X is set equal to that value. Y is set equal to the value at word 1. The values of X and Y are compared. If X is greater than or equal to Y, the word number is incremented and Y is set equal to the new value. X and Y are compared again. The process continues until either X is less than Y or the limiting value of R(N) is reached. If X is less than Y, then X is set equal to the value of Y, and the word number is incremented. When the word number reaches the limiting value of R(N) the value of X is the maximum X coordinate for the external contour. The global array ABC("MAX") is now accessed and the value of X is is placed in the array. N is then incremented and the X coordinates of the next external contour are processed in the same manner. After the last external contour has had its X maximum determined, control the transfers to line Y where N is reset to 1 and the same procedure is repeated to find the maximum Y coordinate values for the external contours. After all these have been processed, the files are closed and the unnecessary variables are killed. Control then transfers to line one of program XMIN1

Program XMIN1

Purpose: To find the minimum X coordinate value for each external contour and place those values in global array ABC("MAX").

N is set equal to 1. The global array containing the X coordinates for the first external contour is accessed and the values are placed in file FID3. X is set equal to the value at word 0. Y is set equal to the value at word 1. The values of X and Y are compared. If X is less than or equal to Y, the word number is incremented and Y is set equal to the new value. X and Y are compared again. If X is still less than or equal to Y, the same procedure is followed again. If X is greater than Y, then X is set equal to the value of Y, the word number is incremented and Y is set equal to the new value. This procedure continues until the limiting value of R(N) is reached. At this point, the value of X is the value of the minimum X coordinate. The global array ABC("MAX") is accessed and the value of X is stored within the array. N is then incremented and the next contour is processed the same way. When all the contours have been processed, the files are closed and the unnecessary variables are killed. Control now transfers to the first line in program YMAX1.

Program YMAX1

Purpose: To sort through the previously determined maximum Y coordinate values and find the largest maximum Y value. This value is used to transpose the Y coordinate system so that Y coordinate values are equal to 0 at the maximum Y point.

The global array ABC("MAX") is accessed and its value placed into file FID5. X is set equal to the value of the maximum Y value for the first contour. The word is incremented and Y is set equal to that value. If X is greater than or equal to Y, then the next word value is read from the file and Y is reset to that value. X and Y are recompared, following the same procedure, unless X is less than Y. When X is less than Y, X is reset to the value Y and Y is set equal to the value of the next word in the file. When the value of the last contour has been processed, YMAX is set equal to X, which is the value of the largest Y coordinate of all the contours. YMAX is then stored in global array ABC("MAX").

The global array ABC(N,"YCOMP") is accessed for the first contour. The values are placed into file FID3. Each of these values is read and has the value YMAX subtracted from it and then is replaced into file FID3. After all the Y coordinates have been processed, file FID3 is stored in global array ABC(N,"YCOMP"). N is then incremented. All the Y coordinates for all of the external contours are processed the same way. Then all files are closed and unnecessary variables are killed. Control is transferred to the first line of program ELIM1.

Program ELIM1

Purpose: To eliminate the external contour points which are underneath the patient and therefore are not needed for the filter design.

The program accesses the global array ABC(N,"XCOMP") for the first contour and places it on file FID3. Next the program accesses the global array ABC("MAX") and places those values in file FID4. The minimum X coordinate value is read for the contour being processed and X is set equal to that value. The program then reads the maximum X coordinate value and sets Y equal to it. Z is set equal to the word 0 value of the stored X coordinates. Z is then compared to X and Y. If Z is not equal to either one, then the word number is incremented and Z is reset to the new value. The comparisons are made again. When Z is found to be equal to Y (the maximum X coordinate), MAX1 is set equal to the word number the value of Z was taken from. The word number is then incremented and the comparisons continue in the same manner until Z is found to equal X (the minimum X coordinate), MIN1 is set equal to the value of the word number Z was read from. The word number is then incremented and Z is then recompared with X. When Z is no longer equal to X the control transfers to line L3.

The global array ABC("ELIMX") is accessed and the contents placed in file FID5, global array ABC("ELIMY") is accessed and the contents placed in file FID6. The contents of both files are set equal to 0. The global array ABC(N,"YCOMP") is accessed and the contents placed in file FID7. The word numbers for files FID3 and FID7 are set equal to MAX1 and the word numbers for files FID5 and FID6 are set equal to 0. The value for word MAX1 is read from FID3 and FID7 and written into word 0 in files FID5 and FID6 respectively. The word numbers are incremented and the process repeated until the word number for files FID3 and FID7 reaches the value of MIN1.

After the value of MIN1 has been reached, the files are replaced into the global arrays they originated from. The contents of global array ABC("ELIMX") are copied into global array ABC(N,"XCOMP") and the contents of global array ABC("ELIMY") are copied into global array ABC(N,"YCOMP"). The entire procedure is repeated for each of the external contours. After the last contour has been processed, the files are closed and the unnecessary variables are killed. Control now transfers to the first line in program INDENT.

Program INDENT1

Purpose: To remove indentations of each external contour along the X coordinate axis so the router can properly follow the contours.

The global array ABC(N,"XCOMP")is accessed for the first contour (N=1) and the contents are placed into file FID3. X is set equal to the value from the location of word 0. The word number is incremented and Y is set equal to the new value. If Y is less than X, the word number is incremented and Y is reset to the new value. X and Y are compared again. This procedure continues until Y is greater than X, then Y is set equal to the value of X and the new value for Y is written into file FID3 in the location the previous Y value was read from. The procedure continues until the last word has been read. File FID3 is then placed into the global array ABC(N,"XCOMP"). N is incremented and the next contour is processed. After all contours have been processed, all files are closed, unnecessary variables are killed and control transfers to the first line in program XZERO1.

Program XZERO1

Purpose: To transpose the X coordinate system so that the origin is at the central axis point.

The global array ABC(N,"XCOMP") is accessed for the first contour and the contents placed in file FID3. Each of the X coordinate values is read and has the value of the X component of the central axis point subtracted from it. The modified X coordinate values are then returned to file FID3. When all the coordinate values have been transposed, the file is placed back into global array ABC(N,"XCOMP").

This procedure is repeated for all of the external contours. When the last contour has been processed, the files are closed, unnecessary variables are killed, and control transfers to the first line in program XYTRAN1.

Program XYTRAN1

Purpose: To transpose the X and Y coordinate values at the patient to those needed at the filter.

If the filter is going to be on the bottom rack, the source-to filter distance is updated. Using the half-width of the source, the half width of the filter, the source-to-patient distance and the source-to-filter distance to solve for the tangent of the maximum half-angle beam divergence. This value is used to determine the distance to extend the source-to-patient and source-to-filter distances in order to treat the source as a virtual point source.

The global array ABC(N,"XCOMP") is accessed for the first contour and the values are placed into file FID3. The global array ABC(N,"YCOMP") is accessed and the values are placed into file FID4. X is set equal to the first value of file FID3. Y is set equal to the first value of file FID4. D2 is set equal to the distance (along the Y axis) from the central axis point to the point being processed. D5 is the set equal to the distance (along the y axis) from the virtual source to the the point on the contour being processed. The tangent of the half-angle subtended at the patient's surface in the X coordinate plane from the central axis to the point on the contour is calculated. This tangent value is used to transpose the X coordinate value at the patient to the value to be used at the filter. If the value of the X coordinate at the filter is outside the volume of the filter, then the contour point is deleted and the next set of values for X and Y are processed. The value for the Y coordinate is transposed to that used at the filter through division with the tissue/compensator ratio. D7 is set equal to the distance (along the Y axis) from the source to the top of the filter. The value of the Y coordinate is now compared to the maximum diameter of the filter. If Y is larger than the filter diameter, then the point is deleted and the next set of values for X and Y are read and evaluated in the same way. If both the X and Y coordinates are within the filter volume they are written into files FID3 and FID4 respectively. After all the contour points have been processed, the remaining words in the files are set equal to 0.

The rest of the external contours are processed in the same manner. After the last one is done, all files are closed, unnecessary variables are killed and control transfers to the first line of program ZTRAN1.

Program ZTRAN1

Purpose: To transpose the Z coordinate values, where Z represents the 10 mm thickness of each CAT scan slice along the Z axis.

The global array ABC("MAX") is accessed and placed into file FID5. X1 is set equal to the maximum Y coordinate value (for the first contour), which is read from the file. X1 is divided by the compensator/tissue ratio to transpose the value to the present coordinate system. X1 is divided by 2 and YMAX(N) is set equal to the value. YMAX(N) is used to calculate the width of the router bit for each slice. YMAX1(N) is the value of the maximum depth (along the Y axis for each slice) divided by 2. D2 is set equal to the source-to-patient distance plus the YMAX(N), this allows one transpose the Z coordinates trigonometrically using the values D2, the distance from the source to the midpoint of the patient and D1 the distance from the source to the midpoint of the filter.

The transposed Z values are calculated for the central axis slice first. Calculate the values for the tangents using distance D2 and a pair of Z coordinate values set equal to X and Y (not X and Y coordinates). For the central axis slice these values are 0 and 5. The calculated tangent values are used with the distance D1 to calculate the transposed Z coordinate values X1 and X2. Twice the difference between X2 and X1 is the value assigned to WIDTH(N), which is the width determined for the router bit. For the central axis slice the Z coordinate location for the center of the router bit is Z(N) equal to 0.

This procedure is repeated for the other external contours with the values for X and Y (not X and Y coordinates) incremented by ten after each slice is processed. The WIDTH(N) value is the difference between X2 and X1 (the transposed Z coordinates). The value of Z(N) is equal to the X2 value from the previous slice added to one half the value of the difference between the current values for X2 and X1. After all of the WIDTH(N) and Z(N) values have been calculated for all the slices the unnecessary variables are killed and the file is closed.

The output channel to the printer is opened and the proper title is printed. The values for all the WIDTH(N) and Z(N) are truncated to 3 decimal points and printed. Control transfers to the first line in program WATER1.

<u>Program WATER1</u>

Purpose: To drive the water phantom probe in the same manner as the tip of the router would be driven.

If the value of A is equal to 1, this means the aluminum block filter is to be designed. This causes control to transfer to the first line of program ALUM1. If A is not equal to 1, program WATER1 is followed.

The limiting variables are defined, some of which are accessed from global IDV. The probe of the water phantom is positioned at the center of the coordinate system on the filter block and the operator strikes return to set the origin. The origin is the central axis slice, at the central axis point with Y equal to 0.

N is set equal to 1. The X coordinates of the first slice are accessed and placed into file FID3, the Y coordinates are accessed and placed into file FID4. Z is set equal to Z(N). The first X and Y coordinates are read and the probe will move to the point X,Y,Z(N). The operator must strike return for the probe to be driven along the external contour for the first slice. When completed the operator must strike return to reset the probe position for the next slice to be processed. This procedure is repeated until the last contour has been processed. The program now comes to a stop.

Programs ALUM1, HARD1 and SORTX1

Purpose: To generate a hardcopy design for the aluminum block filter in the form of a two dimensional array. The array is a 10 inch by 10 inch square divided into 1/2 by 1/2 inch squares. Each of the 1/2 inch by 1/2 inch squares is to have printed within it the height in millimeters of the compensating material.

The Z(N) values are converted into units of half-inches. R1 is set equal to the distance between the first slice and the central axis slice, R2 is set equal to the distance between the central axis slice and the last slice. R1 and R2 are raised to the next integer value. R1 is set equal 10 minus R1. R1 is now equal to the number of rows which need no compensation material (up to the midpoint of the filter). The 20 R(K) values are set equal to 0. Control is transferred to the first line in program HARD1.

The output port to the printer is opened and the title and the patient ID are printed out. The top asterisk boundary is printed and the Y(K) values for each 1/2 inch by 1/2 inch square are printed. Control transfers back to line L5 in program ALUM1. The value of R is incremented and control then transfers back to line L1 in program HARD1, where the array row of the filter is printed out with its Y(K) equal to 0 values. This procedure continues until R reaches the limiting value of R1 plus 1. After all the empty rows in the first half of the filter have been output, the calculation of the array rows with non-zero Y(K) values can begin.

Z1 is set equal to the value of R1 minus 10, Z2 is set equal to Z1 plus 1 and Z3 is set equal to R2. A sorting routine is begun to determine which Z(N) values are between Z1 and Z2. NO is the first slice with a Z(N) value between Z1 and Z2, NF is the last slice between Z1 and Z2. Z1 and Z2 are now incremented and control now transfers to the first line in program SORTX1.

The global arrays ABC(N,"XCOMP") and ABC(N,"YCOMP") are accessed and placed into files FID3 and FID4 (for contour NO). The values in FID3 are converted into units of half-inches through division by 12.5. A sorting routine is begun to determine which X coordinates lie within the boundaries of each of the half-inch squares on the array row.

Beginning with X1 set equal to 9 and X2 set equal to 10, the first X coordinate is read (the maximum X coordinate). If X is greater than X2 the point is deleted and the next point is read. If X is less than X2 but not between X1 and X2, then both X1 and X2 are decremented by 1. X is recompared to the new values. When X falls within the boundaries, PO is set equal to the word number the X coordinate was read from. This continues until X no longer lies within the boundaries of X1 and X2. PF is set equal to the word number this X coordinate was read from. Now the corresponding Y coordinate values from locations PO through PF have their values multiplied by a -1 and are averaged together, with Y(N,K) set equal to the mean. The N is the number of the slice the values came from and K is the number of the square the values fall within. Some of the X coordinates make large jumps in value so that they do not fall within the boundaries of one or more squares. These jumps occur where there are flat spots on the contour (where the Y coordinate values don't change). This would cause false values of 0 to be assigned to Y(N,K). The program compensates for this by assigning the previous Y(N,K) value to the squares effected.

This process continues until all the Y components have been assigned to Y(N,K) variables. This is done for CAT scan slices NO through NF. The Y(N,K) values for each K value are averaged and Y(K) is set equal to the result. Control then transfers to line L1 in program HARD1. The asterisk boundary is printed and the Y(K) values are printed in the array row. Control then transfers back to line L5 in program ALUM1.

The next values for variables NO and NF are calculated in the same manner as before. Control transfers to program SORTX1 where the next set of Y(K) values are calculated. Control transfers to program HARD1 where the new row is printed out. This continues until all the contour slices have been processed. The Y(K) values are then reset equal to 0 in program ALUM1 and control transfers back to program HARD1 where the rest of the array rows are printed out. The program then stops.

Appendix D: The Linked Program

```
LOAD1(00760)       01 DEC 82  10 05 ID RTP,JWS

%1      ,PROGRAM FOR OPERATOR ENTERED DATA
        R "ENTER VALUE IN MM'S FOR X COMPONENT OF CENTRAL AXIS PT",',X1,'
        R "ENTER VALUE IN MM'S FOR Y COMPONENT OF CENTRAL AXIS PT",',Y1,'
        R "ENTER DISTANCE FROM SOURCE TO CENTRAL AXIS PT",',D1,'
        R "ENTER DISTANCE FROM SOURCE TO BASE OF TOP FILTER",',D2,'
        R "ENTER THE NUMBER OF THE CAT SCAN SLICE CONTAINING THE CENTRAL AXIS PT",',N2,'
        R "ENTER THE COMPENSATOR/TISSUE RATIO",',CTR,'
        R "ENTER 0 FOR ROUTER, ENTER 1 FOR ALUMINUM BLOCK FILTER",',A,'
        R "ENTER 0 IF FILTER ON TOP RACK, 1 IF FILTER ON BOTTOM RACK",',T,'
        R "ENTER PATIENT ID",',PID,'
        S N=0
L1      S N=N+1
        R "ENTER CONTOUR DISCRIPTION, IF LAST SLICE HAS BEEN ENTERED,ENTER 0",',CDES(N),'
        I CDES(N)=0 S N1=N G QUIT
        G L1
QUIT    G %^EXT11
```

Figure 15. The Linked Program (Sheet 1 of 14)

```
E(T11.01198)      01 DEC 82  10 02 ID RTP.JWS   LINKED PROGRAMS

%       .TO ACCESS THE DATA PTS OF UP TO 31 EXTERNAL CONTOURS . CONVERT THEM TO UNITS OF MM'S AND STORE THEM IN GLOBAL ARRAYS
        S N=0
%1      S N=N+1
        I CDES(N)=0 G QUIT^EXT22
        ZC *
        .SUBROUTINES TO OPEN THE FILE WITH THE EXTERNAL CONTOUR DATA AND THE FILES TO STORE THE X & Y COMPONENTS IN MM'S
OT      S I=^IDV("MPF"),DB=$P(I,"^",1),DEV=$P(I,"^",2),UN=$P(I,"^",3) YD DB 2 DSC UN
        YU 2
        S FD=^MPF(PID,"XSEC",CDES(N),"CPNT")
        ZO "CPNT" FID
        S BK=1,WD=6
        ZG FID BK
        YU 1
XCOMP   S FD=^ABC(N,"XCOMP") ZA "XCOMP" 1 CO
        ZO "XCOMP" FID3
YCOMP   S FD=^ABC(N,"YCOMP") ZA "YCOMP" 1 CO
        ZO "YCOMP" FID4
        ZR FID *WD Y,Y IS THE NUMBER OF CONTOUR PTS
        S WD=WD+1
        S R(N)=Y
        .SUBROUTINES TO READ THE EXTERNAL CONTOUR DATA AND CONVERT IT INTO X & Y COMPONENTS AND TO TRANSFER TO BK1 IF EXT DATA IS ON
          MORE THAN ONE BLOCK
XRUN    S J=1
        S RK=(2*R(N))+7
NEXT1   G YRUN WD=RK
        ZR FID *WD L
        S X=L/16
        S W=J-1
        ZW FID3 W X
        S J=J+1,WD=(WD+2)
        I WD=RK ZP FID3 1
        G BK1^EXT22 WD>255 G NEXT1
YRUN    S WD=8
        S J=1
        S RK=(2*R(N))+7
NEXT2   G BK2^EXT22 WD=256
        ZR FID *WD L
        S X=L/16
        S W=J-1
        ZW FID4 W X
        S J=J+1,WD=WD+2
        I WD>RK ZP FID4 1
        G NEW WD>RK G NEXT2
NEW     ZC FID G Q1^EXT22
```

Figure 15. Linked Progams (Sheet 2 of 14)

```
EXT22(01135)      01 DEC 82  10 16 ID RTP.JWS

      .SUBROUTINES TO CHANGE EXTERNAL CONTOUR INFO INTO X & Y COMPONENTS IN BLOCK 2 OF THE EXTERNAL DATA AND TO TRANSFER BACK TO Y
        UN AND FINALLY TO 31
BK    S BK=2,WD=1,RK=RK-256
      ZC FID
CT1   S I=^IDV("MPF"),DB=$P(I,"^",1),DEV=$P(I,"^",2),UN=$P(I,"^",3) YD DB 2 DSC UN
      YU 2
      S FD=^MPF(PID,"XSEC",CDES(N),"CPNT")
      ZO "CPNT" FID2
      ZG FID2 BK
      YU 1
NEX1  ZR FID2 *WD L
      S X=L/16
      S W=J-1
      ZW FID3 W X
      S J=J+1,WD=WD+2
      I WD=RK ZP FID3 1
      G RE1 WD=RK G NEX1
RE1   ZC FID2
      S I=^IDV("MPF"),DB=$P(I,"^",1),DEV=$P(I,"^",2),UN=$P(I,"^",3) YD DB 2 DSC UN
      YU 2
      S FD=^MPF(PID,"XSEC",CDES(N),"CPNT")
      ZO "CPNT" FID
      ZG FID 1
      YU 1
      G YRUN^EXT11
BK2   S BK=2,WD=0,RK=RK-255
      ZC FID
      S I=^IDV("MPF"),DB=$P(I,"^",1),DEV=$P(I,"^",2),UN=$P(I,"^",3) YD DB 2 DSC UN
      YU 2
      S FD=^MPF(PID,"XSEC",CDES(N),"CPNT")
      ZO "CPNT" FID2
      ZG FID2 BK
      YU 1
NEX2  ZR FID2 *WD L
      S X=L/16
      S W=J-1
      ZW FID4 W X
      S J=J+1,WD=WD+2
      I WD=RK ZP FID4 1
      G RE2 WD=RK G NEX2
RE2   ZC FID2
31    ZC * G X1^EXT11
      .TO CALL UP THE NEXT PROGRAM IN THE SEQUENCE
QUIT  K CDES,I,FD,DB,DEV,UN,BK,J,L,X,FID,FID2,FID4,FID3 G %3^XYMAX1
```

Figure 15. Linked Progams (Sheet 3 of 14)

```
(^MAX1 00972)      01 DEC 82  10 02 ID RTP.JWS   LINKED PROGRAMS

%3      ,PROGRAM TO FIND XMAX & YMAX IN EACH EXTERNAL CONTOUR AND PLACE THEM IN FID5
        ZC *
        S N=1
XCOMP   S I=^ABC(N,"XCOMP")
        ZO "XCOMP",FID3
        ZG FID3 1
        S J=0
        S L=1
        ZR FID3 *J X
MAX     ZR FID3 *L Y
        G A X'<Y G B
A       S L=L+1 G C L=R(N) G MAX
B       S X=Y S L=L+1 G C L=R(N) G MAX
C       G ST N=1 G W
ST      S I=^ABC("MAX") ZA "MAX",1 CO
        ZO "MAX",FID5
        ZG FID5 1
        F I=0,1,255 ZW FID5 I 0
        S WD=0
W       ZW FID5 WD X
        S N=N+1,WD=WD+1
        G Y N=N1 ZC FID3 G XCOMP
Y       S N=1
YCOMP   S I=^ABC(N,"YCOMP")
        ZO "YCOMP",FID4
        ZG FID4 1
        S J=0
        S L=1
        ZR FID4 *J X
MAX2    ZR FID4 *L Y
        G A2 X>Y G B2
A2      S L=L+1 G C2 L=R(N) G MAX2
B2      S X=Y S L=L+1 G C2 L=R(N) G MAX2
C2      G ST2 N=1 G W2
ST2     S WD=N1-1
W2      ZW FID5 WD X
        S N=N+1,WD=WD+1
        G Q N=N1 ZC FID4 G YCOMP
Q       S I=^ABC("MAX")
        ZP FID5 1
QUIT    ZC * K X,Y,I,FID3,J,L,FID5,WD,FID4 G %4^XMIN1
```

Figure 15. Linked Progams (Sheet 4 of 14)

```
XMIN1(00499)       01 DEC 82  10 02 ID RTP,JWS   LINKED PROGRAMS

%4       .PROGRAM TO FIND XMIN IN EACH OF THE EXTERNAL CONTOURS AND PLACE IT IN FID5
         ZC *
         S N=1
XCOMP    S I=^ABC(N,"XCOMP")
         ZO "XCOMP" FID3
         ZG FID3 1
         S J=0
         S L=1
         ZR FID3 *J X
MIN      ZR FID3 *L Y
         G A:X'>Y G B
A        S L=L+1 G C:L=R(N) G MIN
B        S X=Y S L=L+1 G C:L=R(N) G MIN
C        G ST:N=1 G W
ST       S WD=2*N1-2
         S I=^ABC("MAX")
         ZO "MAX" FID5
         ZG FID5 1
W        ZW FID5 WD X
         S N=N+1,WD=WD+1
         G QUIT:N=N1 ZC FID3 G XCOMP
QUIT     ZP FID5 1 ZC * K X,Y,I,FID3,J,L,WD,FID5 G %6^YMAX1
```

Figure 15. Linked Progams (Sheet 5 of 14)

```
YMAX1(00743)        01 DEC 82  10:02 ID RTP,JWS    LINKED PROGRAMS

%5      .PROGRAM TO FIND THE HIGHEST POINT ON THE PATIENT SURFACE AND TRANSPOSE THE Y COURDINATES SO THAT Y=0 AT THIS POINT
        S N=1
        S I=^ABC("MAX")
        ZO "MAX",FID5 ZG FID5 1
        S J=N1-1
        S L=N1
        ZR FID5 *J X
R       ZR FID5 *L Y
MAX1    G A1 X>Y G B1
A1      G C1 L=(2*N1-1) S L=L+1 G R
B1      S X=Y G C1 L=(2*N1-1) S L=L+1 G R
C1      S YMAX=X
        K X
WR1     S WD=3*N1-3
        ZW FID5 WD YMAX
        ZP FID5 1
        ;SUBPROGRAM TO TRANSPOSE THE Y COMPONENTS OF EACH EXTERNAL CONTOUR
        S N=0
YCOMPS  S N=N+1 G QUIT N=N1
        S I=^ABC(N,"YCOMP")
        ZO "YCOMP" FID3
        ZG FID3 1
        S J=0
REP     ZR FID3 *J X
        S Y=X-YMAX
WR2     ZW FID3 J Y
        S J=J+1
        G LOOP J=R(N) G REP
LOOP    ZP FID3 1 ZC FID3 G YCOMPS
QUIT    ZC * K I,FID5,J,L,X,Y,FID3 G %7^ELIM1
```

Figure 15. Linked Progams (Sheet 6 of 14)

```
ELIM1(01339)      01 DEC 82   10 02 ID RTP, JWS    LINKED PROGRAMS

%7      ;PROGRAM TO ELIMINATE THOSE PTS BELOW THE XMAX & XMIN PTS UNDER THE PATIENT
        ZC * S N=0
        S WD1=2*N1-2
L1      S N=N+1,G=0 G QUIT N=N1
        S I=^ABC(N,"XCOMP") ZA "XCOMP" 1 CO
        ZO "XCOMP" FID3
        ZG FID3 1
        S I=^ABC("MAX") ZA "MAX" 1 CO
        ZO "MAX",FID4
        ZG FID4 1
        I N>1 S WD1=WD1+1
        ZR FID4 *WD1 X
        S WD2=N-1
        ZR FID4 *WD2 Y
        S WD=0
        ZC FID4
L2      ZR FID3 *WD Z
        I G=1 G S2 Z=X G L3
        G S1 Z=Y G S2 Z=X S WD=WD+1 G L3 WD=R(N) G L2
S1      S MAX1=WD WD=WD+1 G L3 WD=R(N) G L2
S2      S MIN1=WD,G=1,WD=WD+1 G L2
L3      S I=^ABC("ELIMX") ZA "ELIMX" 1 CO
        ZO "ELIMX" FID5
        ZG FID5 1
        S I=^ABC("ELIMY") ZA "ELIMY" 1 CO
        ZO "ELIMY" FID6
        ZG FID6 1
        F I=0 1 255 ZW FID5 1 0
        F I=0 1 255 ZW FID6 I 0
        S I=^ABC(N,"YCOMP") ZA "YCOMP" 1 CO
        ZO "YCOMP" FID7
        ZG FID7 1
        S WD=0,MAX=MAX1
L4      ZR FID3 *MAX X
        ZR FID7 *MAX Y
        ZW FID5 WD X
        ZW FID6 WD Y G L5 MAX=MIN1
        S WD=WD+1,MAX=MAX+1 G L4
L5      S WD(N)=WD ZP FID5 1,FID6 1,FID3 1,FID7 1 ZC FID5,FID6,FID3,FID7
        S I=^ABC("ELIMX") ZA "ELIMX" 1 CO
        ZO "ELIMX" FID5
        S I=^ABC(N,"XCOMP") ZA "XCOMP" 1 CO
        ZO "XCOMP" FID3
        ZX FID5 FID3
        ZC FID3,FID5
        S I=^ABC("ELIMY") ZA "ELIMY" 1 CO
        ZO "ELIMY" FID6
        S I=^ABC(N,"YCOMP") ZA "YCOMP" 1 CO
        ZO "YCOMP" FID4
        ZX FID6 FID4
        ZC FID4,FID6 G L1
QUIT    K I,R,FID3,FID4,G,WD2,X,Y,Z,MAX1,MIN1,FID5,FID6,FID7,MAX G %8^INDENT1
```

Figure 15. Linked Progams (Sheet 7 of 14)

```
INDENT1(00361)     01 DEC 82  10 02 ID RTP.JWS   LINKED PROGRAMS

%8      .PROGRAM TO REMOVE INDENTATIONS IN THE X DIRECTION FROM THE DATA PTS
        ZC * S N=0
L1      S N=N+1.WD=0 G QUIT N=N1
        S I=^ABC(N,"XCOMP") ZA "XCOMP".1 CO
        ZO "XCOMP" FID3
        ZG FID3 1
L2      ZR FID3 *WD X
        S WD=WD+1 G L3 WD=WD(N)
        ZR FID3 *WD Y
        G L2 Y<X G A1
A1      S Y=X ZW FID3 WD Y G L2
L3      ZP FID3 1 ZC FID3 G L1
QUIT    K I,FID3,X,Y G %9^XZERO1
```

```
XZERO1(00345)     01 DEC 82  10 02 ID RTP.JWS   LINKED PROGRAMS

%9      .PROGRAM TO TRANSPOSE X COMPONENTS SO THAT X=0 AT CENTRAL AXIS POINT
        ZC * S N=0
L1      S N=N+1 G QUIT N=N1
        S I=^ABC(N,"XCOMP") ZA "XCOMP".1 CO
        ZO "XCOMP" FID3
        ZG FID3 1
        S WD=0
L2      ZR FID3 *WD X
        S X=X-X1
        ZW FID3 WD X
        S WD=(WD+1) G L3 WD=(WD(N)+1) G L2
L3      ZP FID3 1 ZC * G L1
QUIT    ZC * K I,FID3,X,X1 G %10^XYTRAN1
```

Figure 15. Linked Progams (Sheet 8 of 14)

```
XYTRAN1(01336)    01 DEC 82  10 02 ID RTP,JWS   LINKED PROGRAMS

%10     ;PROGRAM TO TRANSPOSE X & Y AT THE PATIENT TO VALUES USED AT THE FILTER
        ZC * S N=0
        I T=1 S D2=D2+95
SET     S DS=20 ,SOURCE DIAMETER
        S DFB=253 ,DIAMETER OF FILTER BASE
        S TAN=((DFB-DS)/2)/D2
        S D3=1/(TAN/(DFB/2))
        S D4=D3-D2
        S D5=D1+D4 ,UPDATED SOURCE TO PATIENT DISTANCE
        S D6=D2+D4 ,UPDATED SOURCE TO FILTER BASE DISTANCE
        K D1,D2,D3,D4 DS
        S Y1=Y1-YMAX ,UPDATE Y AT CENTRAL AXIS PT TO PRESENT COORDINATES
L1      S N=N+1 G QUIT N=N1
        S I=^ABC(N,"XCOMP") ZA "XCOMP":1:CO
        ZO "XCOMP":FID3
        ZG FID3 1
        S I=^ABC(N,"YCOMP") ZA "YCOMP":1:CO
        ZO "YCOMP":FID4
        ZG FID4 1
        S WD=0,WD1=0
L2      ZR FID3 *WD X
        ZR FID4 *WD Y
        S D2=Y1-Y
        S D1=D5+D2
        S TAN=X/D1
        S Y=Y/CTR,D7=D6-76 ,D7 IS THE DISTANCE FROM SOURCE TO FILTER TOP
        I T=1 S D7=D6+19
        G NEX1 Y<-76 G ON
NEX1    S WD=WD+1 G STORE WD>WD(N) G L2
ON      S D8=D7-Y
        S X=TAN*D8 G NEX1 X>(DFB/2) G NEX1 X<(-DFB/2)
        ZW FID3 WD1 X
        ZW FID4 WD1 Y G STORE WD=WD(N) S WD=WD+1,WD1=WD1+1 G L2
STORE   I WD1=0 S WD1(N)=0,W=0 F I=W:1:WD(N) ZW FID3 I 0,FID4 I 0
        I WD1=0 D 2 HOM 0 0 W  2,"CTR VALUE IS TOO LOW , NEED MORE ABSORPTIVE COMPENSATOR !",!
        I WD1>0 S WD1(N)=WD1-1,W=WD1-1 F I=W:1:WD(N) ZW FID3 I 0,FID4 I 0
        S I=^ABC(N,"XCOMP") ZP FID3 1
        S I=^ABC(N,"YCOMP") ZP FID4 1
        K WD(N) ZC * G L1
QUIT    K W,D2,D5,D8,I,DFB,Y1,FID3,FID4,WD ZC * G %11^ZTRAN1
```

Figure 15. Linked Progams (Sheet 9 of 14)

```
ZTRAN1(01364)      01 DEC 82  10 02 10 RTP.JWS   LINKED PROGRAMS

%11     .PROGRAM TO TRANSPOSE Z COMPONENTS . Z REPRESENTS THE 10 MM THICKNESS OF EACH CT SCAN
        ZC *
L1      S I=*ABC("MAX") ZA "MAX" 1 CO
        ZO "MAX" FID5
        ZG FID5 1
        S WD=N1-1
        S N=1
L2      ZR FID5 *WD X1
        S YMAX(N)=(X1-YMAX)/CTR/2 .UPDATE YMAX(N) TO PRESENT COORDS
        S YMAX1(N)=(75+(X1-YMAX))*CTR/2
        S N=N+1
        S WD=WD+1 G L3 WD=((2*N1)-2) G L2
L3      S N=N2 .CENTRAL AXIS SLICE
L4      S D1=D7-YMAX(N).D2=D5+YMAX1(N)
        S X=0.Y=5
        S TAN1=X/D2 TAN2=Y/D2
        S X1=TAN1*D1.X2=TAN2*D1.X2(N)=X2.Z(N)=0
        K YMAX(N).YMAX1(N)
        S WIDTH(N)=(X2-X1)*2.N=N+1
        S X=5.Y=15
L6      S D1=D7-YMAX(N).D2=D5+YMAX1(N)
        S W=N-1
        S TAN1=X/D2.TAN2=Y/D2
        S X1=TAN1*D1.X2=TAN2*D1.X2(N)=X2
        K YMAX(N).YMAX1(N)
        S WIDTH(N)=X2-X1.Z(N)=X2(W)+((X2-X1)/2).N=N+1.X=X+10.Y=Y+10 G L7 N=N1 G L6
L7      S N=N2.X=5.Y=15
L8      S N=N-1 G QUIT N=0
        S W=N+1
        S D1=D7-YMAX(N).D2=D5+YMAX1(N)
        S TAN1=X/D2.TAN2=Y/D2
        S X1=TAN1*D1.X2=TAN2*D1.X2(N)=X2
        K YMAX(N).YMAX1(N)
        S WIDTH(N)=X2-X1.Z(N)=-(X2(W)+((X2-X1)/2)).X=X+10.Y=Y+10 G L8
QUIT    K X.X1.X2.Y.D1.D2.D5.D7.W.WD.YMAX.YMAX(N).YMAX1(N).TAN.TAN1.TAN2 ZC *
        O 2 PRT.0 0
        S N=0
        W :2."OUTPUT FROM PROGRAM ZTRAN".!.'
L9      S N=N+1 G L10 N=N1
        S WIDTH(N)=WIDTH(N)*1000\1.Z(N)=Z(N)*1000\1
        S WIDTH(N)=WIDTH(N)/1000.Z(N)=Z(N)/1000
        W :2."N=".N.&3."WIDTH=".WIDTH(N).&3."Z=".Z(N).!
        I A=1 K WIDTH(N)
        G L9
L10     K I.FID5.X2(N) G %12^WATER1
```

Figure 15. Linked Progams (Sheet 10 of 14)

```
WATER1(01440)      01 DEC 82  10 02 ID RTP.JWS    LINKED PROGRAMS

%12     ;PROGRAM TO MOVE WATER PHANTOM PROBE LIKE ROUTER BIT
        G X14^ALUM1 A=1
        CL * S ACM=9,PCD=8,STP=^IDV("WPCAL","STP"),PTOL=^("TOL")
        VM 0 19366 6 D ACM,ACM 4 I,PCD PCD 2 0
        XS ACM 9 ^("X"),ACM 10 ^("Y"),ACM 11 ^("Z"),ACM 22 1
        R #,!!,"POSITION PROBE TO CENTER,STRIKE RETURN TO SET ORIGIN",X
        XS ACM 12 0,ACM 13 0,ACM 14 0,ACM 20 1
        S X=$XS(ACM,2),Y=$XS(ACM,3),Z=$XS(ACM,4)
        XS ACM 12 X,ACM 13 Y,ACM 14 Z
        S CX=0,CY=0,CZ=0
        S N=0
L1      S N=N+1 G QUIT N=N1
        S I=^ABC(N,"XCOMP") ZA "XCOMP" 1:CO
        ZO "XCOMP" FID3
        ZG FID3 1
        S I=^ABC(N"YCOMP") ZA "YCOMP" 1:CO
        ZO "YCOMP" FID4
        ZG FID4 1
        S Z=Z(N),WD=0
L2      ZR FID3 *WD X,FID4 *WD Y
XYZ     S X=X*STP+($S(X)* 5)\1,Y=Y*STP+($S(Y)* 5)\1,Z=Z*STP+($S(Z)* 5)\1
        I CX>X F I=CX -1 X+1 W PCD,*1
        I CX<X F I=CX 1 X-1 W PCD,*2
        I CY<Y F I=CY 1 Y-1 W PCD *8
        I CY>Y F I=CY -1 Y+1 W PCD,*4
        I CZ>Z F I=CZ -1 Z+1 W PCD,*32
        I CZ<Z F I=CZ+1 Z-1 W PCD,*16
        XS ACM 20 1 S CX=$XS(ACM,2)/16*STP\1,CY=$XS(ACM,3)/16*STP\1,CZ=$XS(ACM,4)/16*STP\1
        I $ABS(CX-X)>PTOL'($ABS(CY-Y)>PTOL)',($ABS(CZ-Z)>PTOL) G ERR
        S CX=X,CY=Y,CZ=Z G L3
ERR     W !,POSITION ERROR--OUT OF TOLERANCE!" W X,&2,Y,&2,Z,!,CX,&2,CY,&2,CZ,! G
L3      G L5 WD=0
L4      S WD=WD+1 G L6 WD=WD1(N) G L2
L5      O 2 MOM 0 0
        W 2,"ATTACH ROUTER BIT WITH WIDTH=",WIDTH(N),! R #,!!,"STRIKE RETURN TO CONTINUE",X1,! G XYZ
L6      W 2,"REMOVE ROUTER BIT",! R #,!!,"STRIKE RETURN TO CONTINUE",X2,! ZC * G L1
QUIT    ZC * G
```

Figure 15. Linked Progams (Sheet 11 of 14)

```
ALUM1(00783)       01 DEC 82  10 02 ID RTP,JWS   LINKED PROGRAMS

%14     ; PROGRAM TO OUTPUT DESIGN FOR ALUMINUM BLOCK FILTER
        S N=0,K=20,Z1=0,Z2=0,Z3=1,NO=0,NF=0
L1      S N=N+1
        S Z(N)=Z(N)/12.5 ;Z(N) IN UNITS OF HALF-INCHES
        G L2 N=(N1-1) G L1
L2      S R1=Z(N2)-Z(1),R2=Z(N2)+Z(N)
        S R1=(R1\1)+1,R2=(R2\1)+1
        S R1=10-R1
        S K=0,R=1
L3      S K=K+1
        S Y(K)=0 G L4 K=20 G L3
L4      G %15^HARD1
L5      G L7 K=0 S R=R+1 G L6 R=(R1+1) G L1^HARD1
L6      S N=0,Z1=R1-10,Z2=Z1+1,Z3=R2,W=0,M=0
L7      S N=N+1 G L10 Z1'<Z3 I M=0 G L10 N=N1
L8      I Z(N)'<Z1 S W=W+1 I Z(N)'>Z2 S M=M+1 G FIRST M=1 I N=(N1-1) S NF=N G OUT
        G LAST
FIRST   I M=1 S NO=N,W=1 G L9 N=(N1-1) G NEW
LAST    I W>M S NF=N-1 G OUT
NEW     G L7
L9      I M=1 S NF=N
OUT     S W=0,M=0,Z1=Z1+1,Z2=Z2+1 G %16^SORTX1
L10     S K=0
L11     S K=K+1
        S Y(K)=0 G L12 K=20 G L11
L12     G L1^HARD1
```

Figure 15. Linked Progams (Sheet 12 of 14)

```
HARD1(00913)      01 DEC 82  10 02 ID RTP.JWS   LINKED PROGRAMS

%15    .PROGRAM TO PRINT RESULTS OF PROGRAM ALUM
       S L=0
       O 2 PRT 0 0
       W  2."ALUMINUM BLOCK FILTER FOR PATIENT ",PID,!,!
L1     S L=L+1 G L4 L=21
       W  2,"****************************************************************************************",!
       W  2,"*",Y(1),?5,"*",Y(2),?10,"*",Y(3),?15,"*",Y(4),?20,"*",Y(5),?25,"*",Y(6),?30,"*",Y(7),?35,"*",Y(8)
       W  2,?40,"*",Y(9),?45,"*",Y(10),?50,"*",Y(11),?55,"*",Y(12),?60,"*",Y(13),?65,"*",Y(14),?70,"*",Y(15)
       W  2,?75,"*",Y(16),?80,"*",Y(17),?85,"*",Y(18),?90,"*",Y(19),?95,"*",Y(20),?100,"*",!
L2     W  2,"*",?5,"*",?10,"*",?15,"*",?20,"*",?25,"*",?30,"*",?35,"*",?40,"*",?45,"*",?50,"*"
       W  2,?55,"*",?60,"*",?65,"*",?70,"*",?75,"*",?80,"*",?85,"*",?90,"*",?95,"*",?100,"*",!
L3     S N=NF G L5^ALUM1 Z1'>Z3
L4     W  2,"****************************************************************************************",!
QUIT   K
       ZC * G
```

Figure 15. Linked Progams (Sheet 13 of 14)

```
SORTX1(01352)     01 DEC 82  10 02 ID RTP, JWS   LINKED PROGRAMS

X16     ; PROGRAM TO SORT X AND AVG APPROPRIATE Y VALUES
        S N=(NO-1), X1=9, X2=10
L1      ZC * S N=N+1, K=20 G L7 N=(NF+1)
        S I=^ABC(N, "XCOMP") ZA "XCOMP" 1 CO
        ZO "XCOMP" FID3
        ZG FID3 1
        S I=^ABC(N, "YCOMP") ZA "YCOMP" 1 CO
        ZO "YCOMP" FID4
        ZG FID4 1
        S WD=0, J=0, G=0, U=0, B=0
L2      ZR FID3 *WD X
        S X=(X/12.5)
        G L4 WD'<WD1(N)
        I X>X2 S WD=WD+1 G L4 WD'<WD1(N) G L2
        I X'>X2 S J=J+1 I X'<X1 S G=G+1, B=1 G FIRST G=1 G L3 WD'<(WD1(N)-1)
        G L4 G=0
        G LAST
FIRST   I G=1 S PO=WD, J=1 G L3 WD'<(WD1(N)-1) G NEW
LAST    I G'<1 I J>G S PF=(PO+(G-1)) G L4B
NEW     S WD=WD+1 G L3 WD'<WD1(N) G L2
L3      S PF=WD G L4B
L4      I B=1 I G=0 I K>(U+1) S X1=X1-1, X2=X2-1, J=0, S=K+1, Y(N,K)=Y(N,S), K=K-1 G L2 K'=0 S X1=9, X2=10 G L1
        I B=0 S X1=X1-1, X2=X2-1, J=0, U=U+1, Y(N,K)=0, K=K-1 G L2 K'=0 S X1=9, X2=10 G L1
L4B     S WD=PO, YAVG=0
L5      ZR FID4 *WD Y
        S Y=-Y, Y1=YAVG+Y
        S YAVG=Y1, WD=WD+1 G L6 WD'<(PF+1) G L5
L6      S YAVG=YAVG/((PF+1)-PO)
        S Y(N,K)=YAVG
        S K=K-1, X1=X1-1, X2=X2-1, WD=PF+1, J=0, G=0 G L2 K'=0 S X1=9, X2=10 G L1
L7      S N=NO-1, YAVG=0, Y2=0
L8      S N=N+1 G L9 N=(NF+1)
        S Y=Y(N,K), Y1=YAVG+Y I Y=0 S Y2=Y2+1
        S YAVG=Y1 G L8
L9      S N3=((NF+1)-NO) I Y2'<N3 S N5=1 G L10
        S N5=N3-Y2
L10     S Y(K)=(YAVG/N5)\1
        S K=K-1 G L11 K=0 G L7
L11     S N=NO-1
L12     S N=N+1, K=0 G L14 N=(NF+1)
L13     S K=K+1 G L12 K=21
        K Y(N,K) G L13
L14     G L1 ^HARD1
```

Figure 15. Linked Progams (Sheet 14 of 14)

Appendix E: Printout for Aluminum Block Filter

ALUMINUM BLOCK FILTER FOR PATIENT 0000000000

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	21	20	19	18	17	14	13	12	12	12	14	14	15	18	18	19	23	23	0
17	17	16	15	15	14	13	12	12	12	12	12	12	13	15	15	16	17	17	16
16	15	15	14	12	12	11	11	11	12	11	11	11	12	12	13	13	14	14	15
13	13	12	11	10	10	9	8	8	8	8	8	8	9	9	10	11	11	12	12
12	12	11	10	9	8	7	7	7	7	7	7	7	7	8	9	9	10	11	0
11	10	9	8	8	7	6	5	5	5	5	5	5	6	6	7	8	9	9	9
10	8	7	7	6	5	4	4	3	3	3	4	4	4	5	5	6	7	8	8
10	9	7	6	5	4	3	3	3	3	3	3	3	3	4	5	5	6	7	8
10	8	6	5	4	3	2	2	1	1	1	1	1	2	3	3	5	6	6	9
17	8	6	4	3	2	1	1	0	1	1	1	1	1	1	3	3	6	6	10
17	9	5	4	2	1	0	0	0	0	0	0	0	0	0	1	2	3	7	14
17	10	7	5	3	2	1	1	0	0	1	1	1	1	1	2	3	5	8	17
17	11	7	6	3	3	2	1	1	1	0	0	1	1	1	2	3	5	8	16
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 16. The Printout (reduced) for the Aluminum Block Filter

Vita

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A computer program was written in the MUMPS language to design filters for use in cancer radiotherapy. The filter corrects for patient surface irregularities and allaows homogeneous dose distribution with depth in the patient. The program does not correct for variations in the density of the patient.

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The program uses data available from the software in Computerized Medical Systems Inc.'s Radiation Treatment Planning package. External contours of General Electric CAT scans are made using the RTP software. The program uses the data from these external contours in designing the compensation filters. The program is written to process from 3 to 31, 1 cm thick, CAT scan slices.

The output from the program can be in one of two different forms. The first option will drive the probe of a CMS water phantom in three dimensions as if it wre the bit of a routing machine. Thus a routing machine constructed to run from the same output that drives the water phantom probe would produce a three dimensional filter mold. The second option is a listing of thicknesses for an array of aluminum blocks to filter the radiation. The size of the filter array is 10 inches by 10 inches. The Printronix printer provides an array of blocks 1/2 inch by 1/2 inch with the thickness in millimeters printed inside each block.