MICHIGAN STATE UNIVERSITY

CYCLOTRON LABORATORY

X-RAY ATTENUATION THROUGH THE ROD ARRAY OF THE CANCER THERAPY COLLIMATOR: A GEOMETRIC APPROACH

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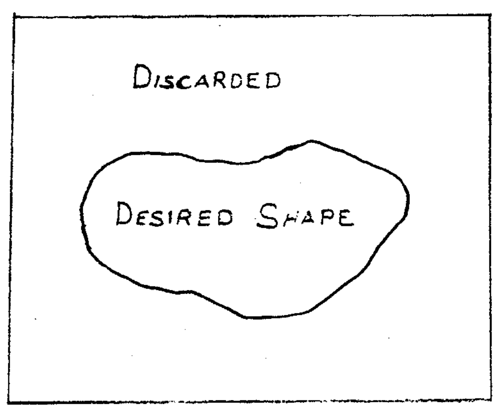
CONTENTS

I. Present Process of X-ray Collimation

The desired result of radiation therapy is the destruction of diseased tissue while healthy tissue is allowed to remain intact to the degree needed to regenerate. Because an individual tumor has it's own unique shape, it follows that the radiation field shape needed for one patient will not at all resemble that needed for another. Technicians need a method of shaping the beam that will arrive at the tumor.

A. Block Casting

At the present time a technique called block casting is the dominant method of achieving the proper beam shape. In this process, the technician places the patient on a picture taking x-ray simulation machine that reproduces the radiation source and patient positions that will be used in treatment. A picture of the diseased area is then taken, which shows the position and shape of the tumor. From this picture the technician can then shape a stryrofoam mold by attaching one end of a "hot wire" to the radiation source position, place the styrofoam blank in the collimator position between source and patient and use the other end of the tightly pulled wire to trace along the x-ray picture.



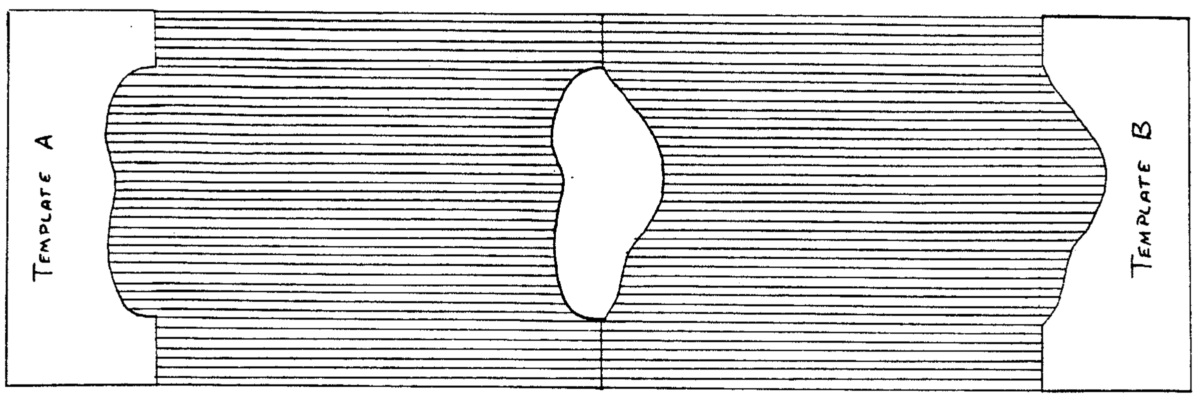
STYROFOAM BLANK

The outer cut-off section of the styrofoam (that now resembles the finished blocks) is then discarded and only the inner section is used in the casting process. The finished blocks are made from a lead

II. Rod Array Collimator to Shape the Field

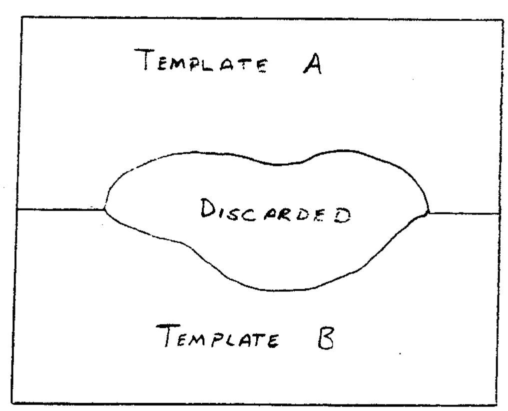
A. How does it work?

MedCyc Corp. is developing a new collimator design which uses a honeycomb array of eighth in. tungsten rods to shape the x-ray field. This rod array works in the "contour gauge" method where a shaped template applied with force to one end of the moveable rods causes the same shape to be re-created on the other rod end. Using two sets of rods allows a full 360 degrees to be shaped.

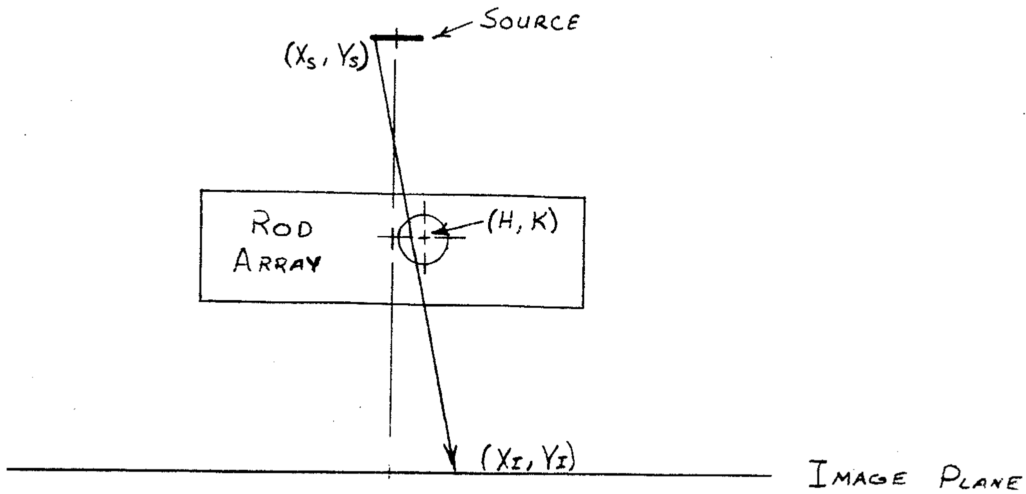


ROD COLLIMATOR TOP VIEW

This new type collimator can be fitted to existing accelerators in use today. The template shaping process is the same hot wire method used presently to make styrofoam molds for block casting. The major difference is that the portion of styrofoam previously cut off and disposed of is now used as the shaping template.



STYROFOAM BLANK



The equation for the line from source point to image point is found by taking their X & Y coordinates:

$$(Y - Y_S) = Y_S - Y_I / X_S - X_I (X - X_S)$$

$$Y = M(X - X_S) + Y_S$$

Next, the equation for the circle that will represent the position of the rod circumference is found by taking the standard equation for a circle. Then the line equation is substituted into it as a Y-value.

$$(X - H)^2 + (Y - K)^2 = R^2$$

$$(X - H)^2 + [M(X - X_S) + Y_S - K]^2 = R^2$$

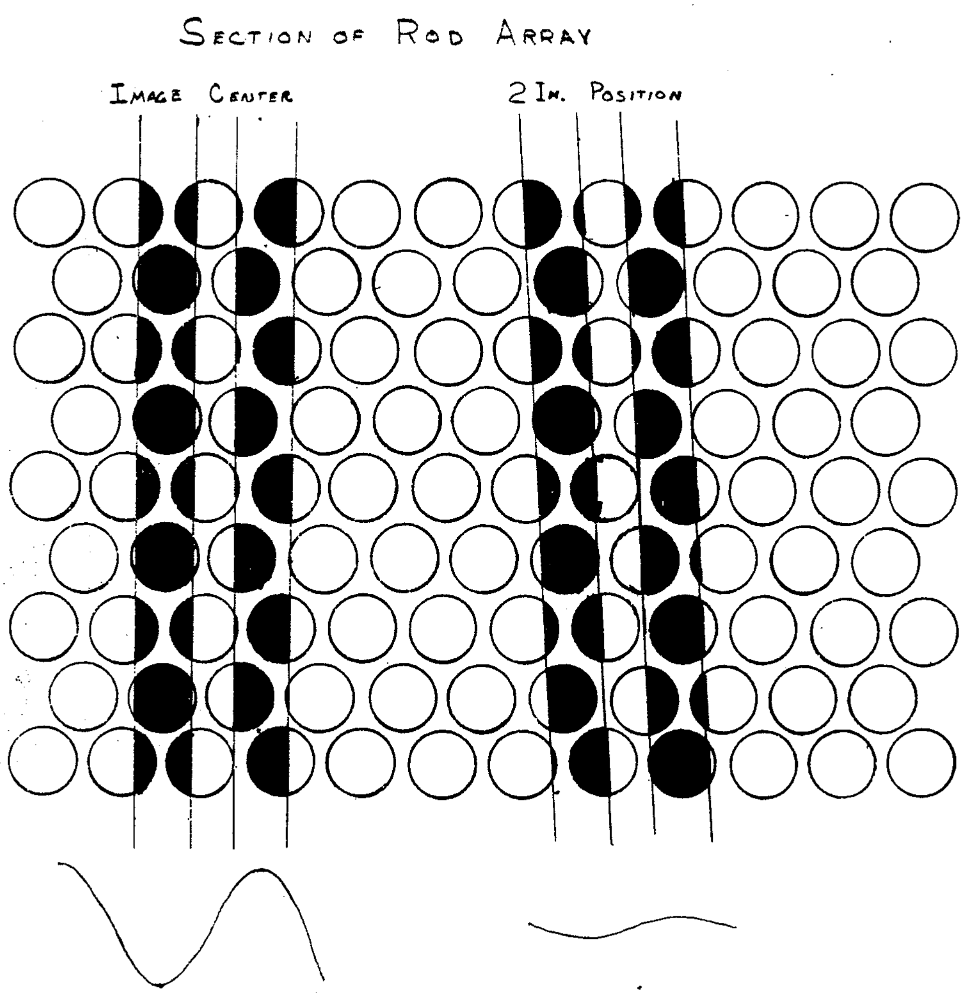
Leaving only X as a variable and then the equation can be put into $ax^2 + bx + c = 0$ form. If the line intersects the circle at more than one point, $b - 4ac > 0$ and the values of $X_i (e=1,2)$ can be found using the quadratic formula. These values can then be substituted into the line equation to get the Y_i-values. The thickness of the rods between these two points can then be found.

$$T = (X_1 - X_2)^2 + (Y_1 - Y_2)^2$$

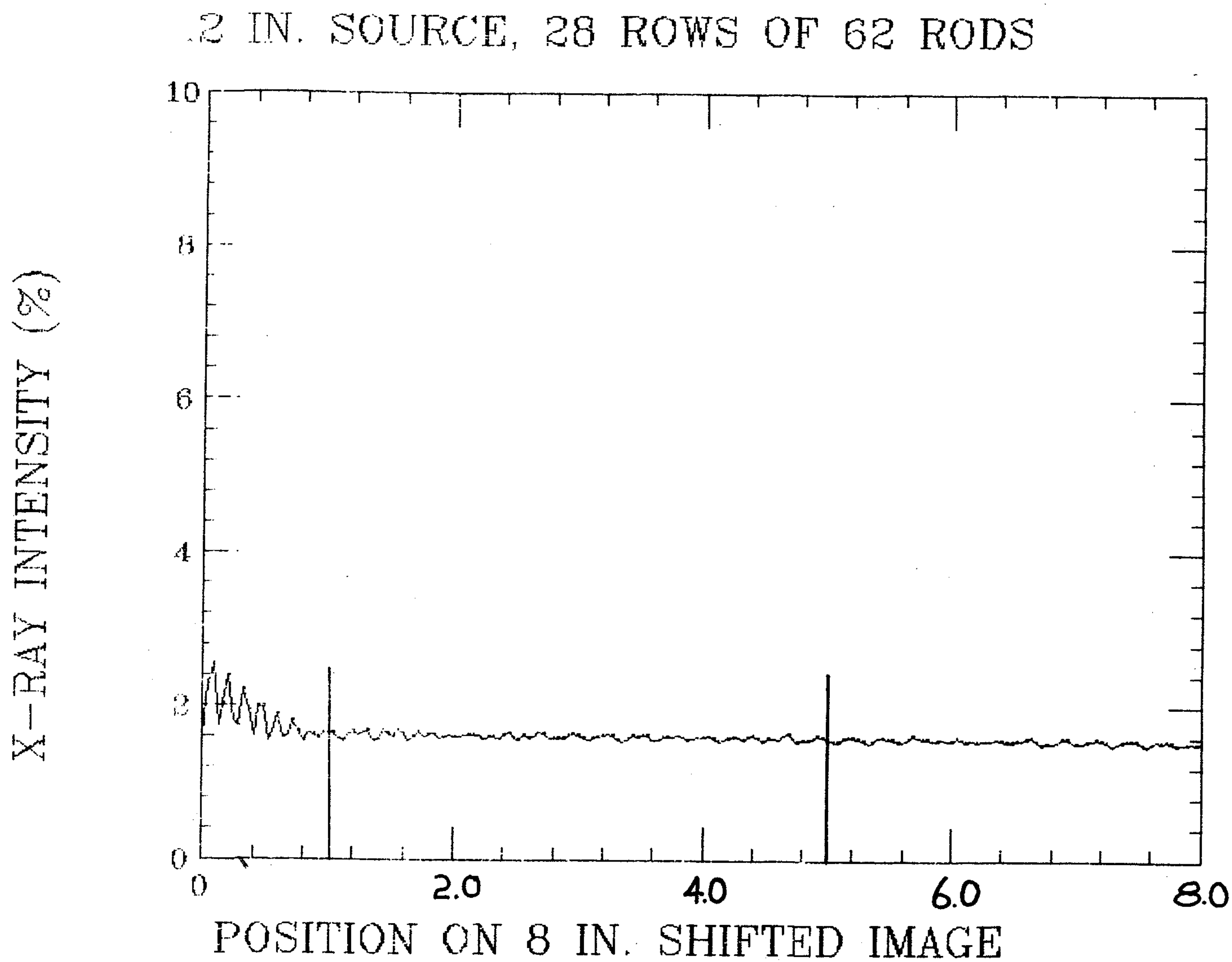
When all rods that intersect the line have been found, the summation of the thicknesses are taken and the percent of maximum intensity from that source point to that image point is:

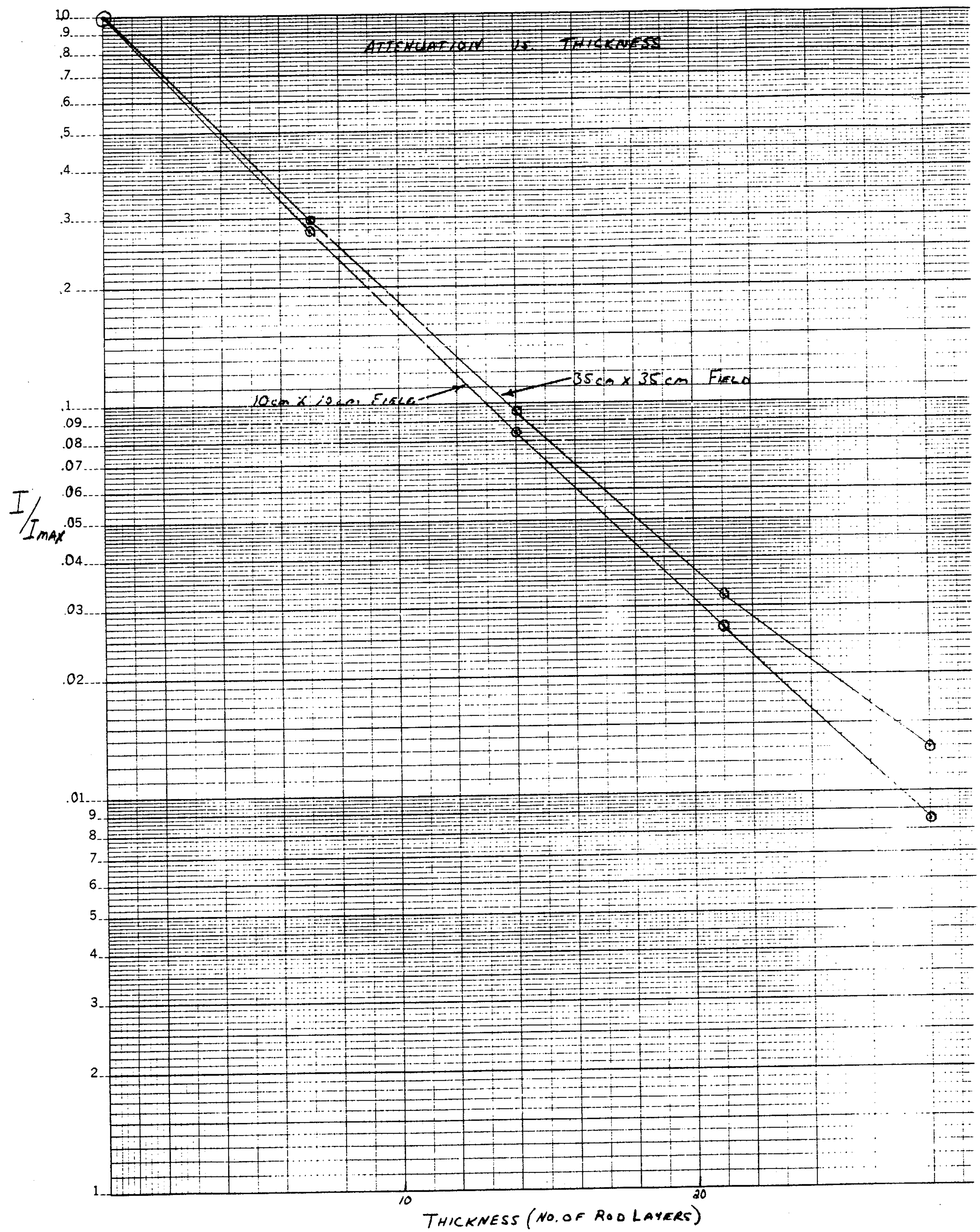
center image point, calculated intensities have a min. to max. difference of .94 %, while at the 1.5 in. position intensities vary by only .12 %.

To get a visual idea of why this is happening, the following diagram shows how the thickness varies more in the image center position than the almost non-varying outer regions.



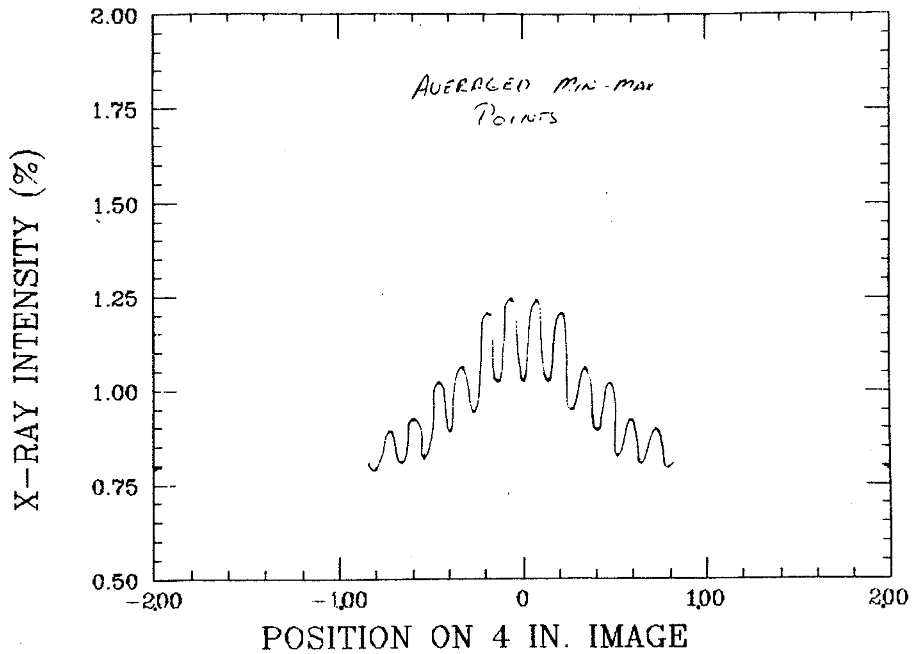
Each of the four rays shown is a cross section of the entire source contribution to an individual image point. Drawn below that are two small sections of the calculated intensities in line with their respective ray directions. In the ray sections corresponding to the center area, it can be seen that the non-shaded areas (corresponding to an absence of absorbing tungsten) is greater above the maximum intensity section of the curve than it is above the minimum intensity section.


.2 IN. SOURCE, 28 ROWS OF 62 RODS
X-RAY INTENSITY (%)
10
8
6
4
2
0
0
2.0
4.0
6.0
8.0
POSITION ON 8 IN. SHIFTED IMAGE


ATTENUATION VS. THICKNESS
35cm x 35cm FIELD
10cm x 10cm FIELD
I/IMAX
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
9
8
7
6
5
4
3
2
1
10
20
THICKNESS (NO. OF ROD LAYERS)

scanning isodensitometer. 2 mm. covers approximately eight calculated image points so eight points were averaged at the central minimums and maximums and these points were hand plotted on the following graph. As can be seen, this curve greatly resembles the experimental curve showing the most symmetry.

0.2 IN. SOURCE, 13 PTS, 28 ROWS OF .125 IN. RODS



The other problem in the original calculated curve is the difference in measured intensity compared to calculated (.8% compared to 1.9%). In an effort to relate the two it was noticed that in the original tests with stacked rods, 8 cm of stacked rods gave .5% transmission. Because of the air spaces between the rods, actual thickness was somewhat less than 8 cm by a factor of .906. A new $T_{1/2}$ was then calculated.

$$8 \text{ cm. } (.906) = 2.85 \text{ in.}$$

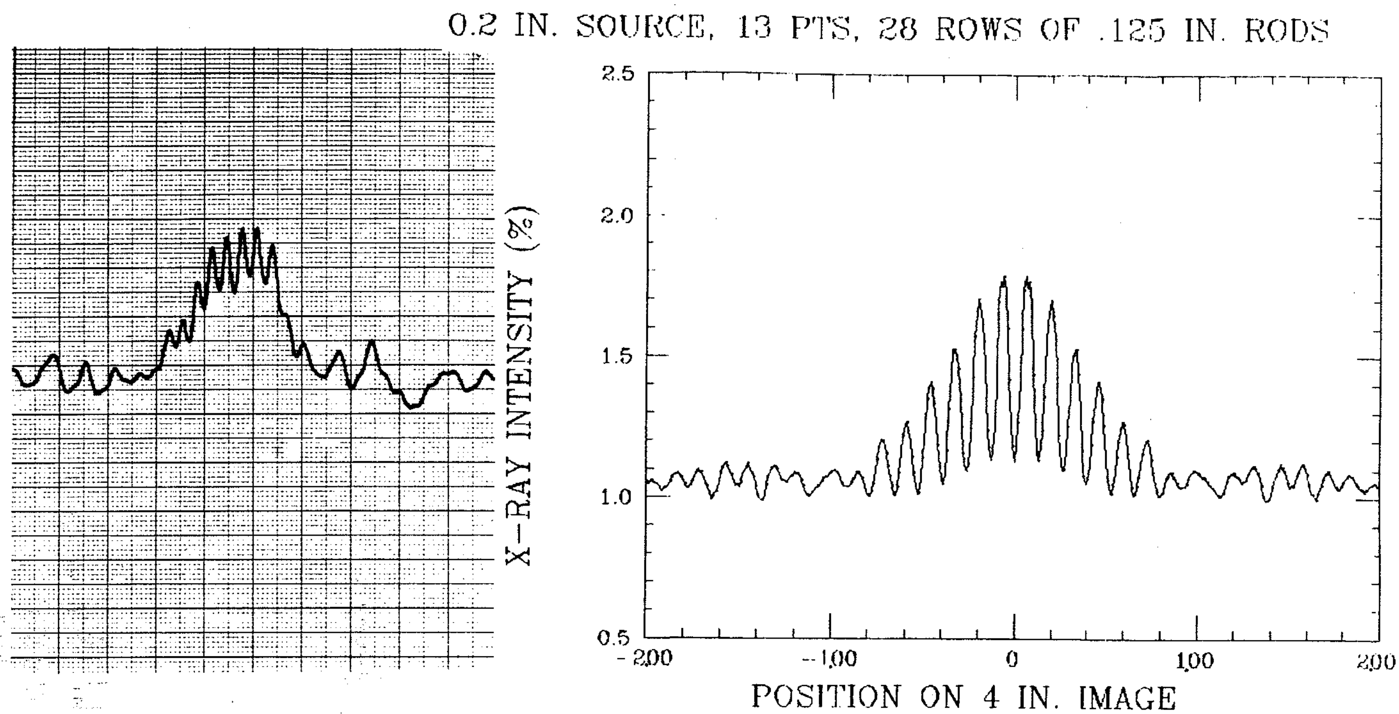
$$I/I = e \; t/T_{1/2}$$

$$.005 = e \; -2.85/T_{1/2}$$

$$\ln .005 = -2.85/T_{1/2}$$

$$T = .539$$

New calculations were then made. The following plots show the experimental profiles compared to the calculated profiles.

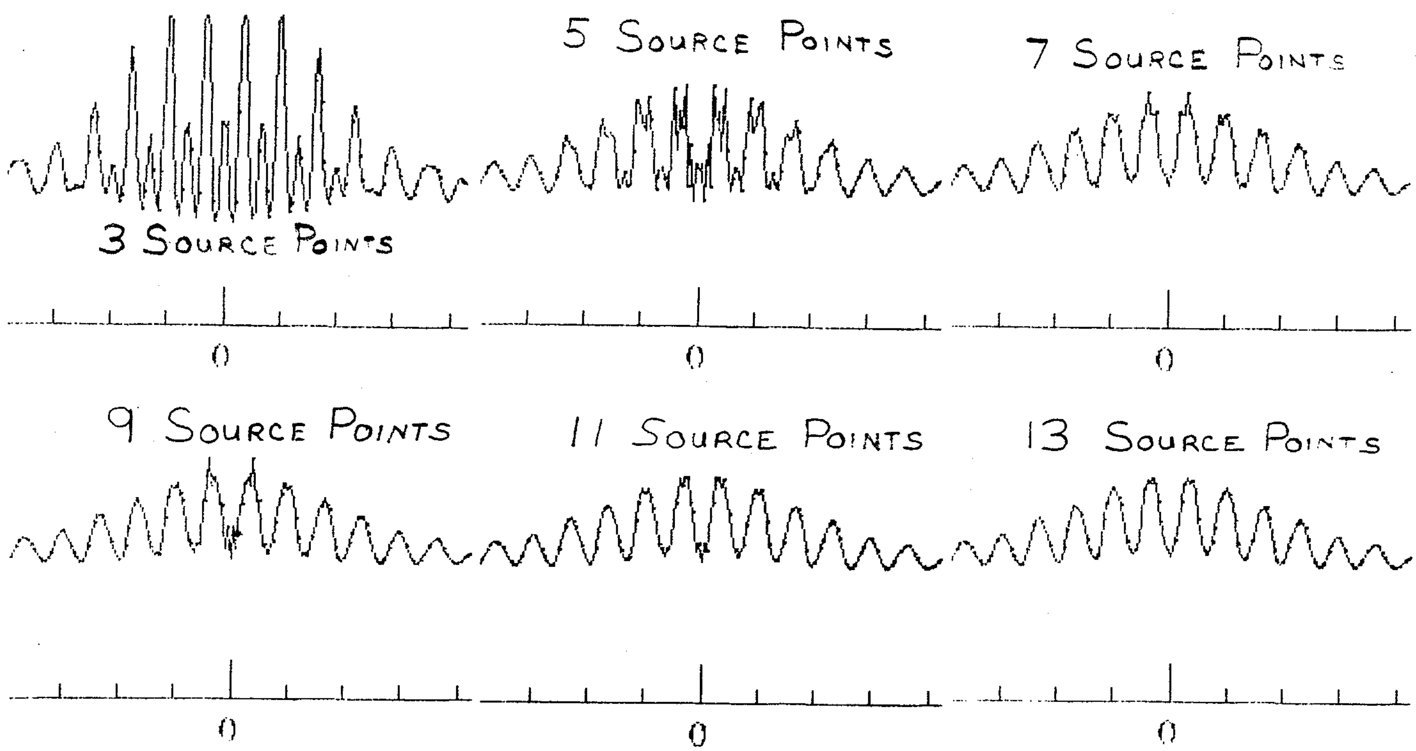


Because of the averaging effect built into the detection equipment used to scan the films, the calculated profiles are probably a closer picture of what is actually the profile shape. There is still the discrepancy in the amount of attenuation but that is now very close to the measured amount. One interesting calculation would entail moving the source off center by 1/4 of a rod diameter or more to see if the non-symmetric effects are seen. Also if three or more field sizes were used in ion chamber measurements instead of just two, a more accurate idea of how photon scatter is affecting the intensity profile could be calculated.

IV. Interesting Aspects of the Array Geometry

The changeable parameters in the computer program allow calculations to be made that involve other source, rod array and image sizes. One interesting change involved making calculations using begins to vary only at the outer edges of the image sample. It may be noticed that this graph is less "spikey" in nature than the .4 in. and 1.0 in. graphs. One explanation for this is that the 3 in. calculations used 31 source positions as compared to 11 in the preceding two.

Another change was used to see how few source points were needed to efficiently give the flowing curve expected from the rod geometry. Calculations were made starting with a .2 in. source with 3 source points, then adding source points by twos until a smooth curve was attained (source positions were easier to calculate if number of source points was limited to an odd amount).



Thirteen source points seems to be the minimum number to use in these calculation. Graphs done with more do not change appreciably although more are needed if a larger source is used.

A listing of the computer program used to calculate the average thicknesses and intensities is attached.

APPENDIX

FORTRAN PROGRAM TO CALCULATE INTENSITY PROFILE

```
      INTENS = EXP( -THICK/.5945)
      IF (I .EQ. 116) PRINT *,'INTENS = ',INTENS,' THICK = ',THICK
      THICK = 0.0
      IINTEN = IINTEN + INTENS
      L = L + 1
      IF ( L .LE. SRCPTS/2) GOTO 20
C     OTHERWISE GET AVERAGE INTENSITY
      I = I + 1
      AVINT(I) = IINTEN/SRCPTS * 100
      IINTEN = 0.0
      PRINT *, 'INTENSITY AT IMAGE POINT ',I,' IS ',AVINT(I),'  %'
      IF (I .LE. IMPTS/2) GOTO 10
C     WRITE RESULTS TO FILE
      J = - IMPTS/2
200   FORMAT ( I4, A2, F9.5 )
37    IF ( J .LE. 0 ) THEN
              AVERAG = AVINT(-(J-1))
              WRITE (08, 200) J,'. ', AVERAG
      ELSE
              AVERAG = AVINT(J+1)
              WRITE (08, 200) J,'. ', AVERAG
              IF (J .GT. IMPTS/2) GOTO 40
      ENDIF
      J = J + 1
      GOTO 37
40    END

C     *****************************************************************
      SUBROUTINE TTHICK( THICK,XCEN,YCEN,RAD,XSRCE,YSRCE,XIMAGE,YIMAGE)
      DOUBLE PRECISION A, B, C, M, YINT, DISC
      REAL X1, Y1, X2, Y2, D
      Y = YSRCE - YIMAGE
      X = XSRCE - XIMAGE
      IF ( X .EQ. 0.0 ) THEN
              A = 1
              B = -2 * YCEN
              C = XSRCE**2 + XCEN**2 + YCEN**2 - RAD**2 - 2 * XSRCE*XCEN
              DISC = B**2 - 4*A*C
              IF (DISC .LE. 0.0) GOTO 50
              Y1 = ( -B + SQRT(DISC))/2
              Y2 = ( -B - SQRT(DISC))/2
              D = Y1 - Y2
              THICK = THICK + D
      ELSE
C             CALCULATE SLOPE
              M = Y/X
              YINT = YIMAG - M * XIMAG
C             CALCULATE COEFICIENTS A, B, C
              A = 1+M*M
              B = -2*XCEN + 2*M*YINT - 2*M*YCEN
              C = XCEN**2 + YINT**2 - 2*YINT*YCEN + YCEN**2 - RAD**2
              DISC = B**2 - 4*A*C
C             CHECK IF LINE INTERSECTS ROD
              IF (DISC .LE. 0.0) GOTO 50
                      X1 = ( -B + SQRT(DISC))/(2*A)
                      X2 = ( -B - SQRT(DISC))/(2*A)
                      Y1 = M*X1 + YINT
                      Y2 = M*X2 + YINT
                      D = SQRT((X1 - X2)**2 + (Y1 - Y2)**2)
                      THICK = THICK + D
```