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UCRL-51860

A PINHOLE FOR PRODUCING A CLOSE-IN IMAGE OF AN EXTENDED 14-MeV NEUTRON SOURCE

Stephen M. Matthews

MASTER

July 1, 1975

Prepared for U.S. Energy Research & Development
Administration under contract No. W-7405-Eng-48

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Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy \$ ____*; Microfiche \$2.25

<u>* Pages</u>	<u>NTIS Selling Price</u>
1-50	\$4.00
51-150	\$5.45
151-325	\$7.60
326-500	\$10.60
501-1000	\$13.60

LAWRENCE LIVERMORE LABORATORY
University of California Livermore, California 94550

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A PINHOLE FOR PRODUCING A CLOSE-IN IMAGE OF AN EXTENDED 14-MeV NEUTRON SOURCE

Abstract

In pulsed-neutron pinhole imaging experiments it is desirable to produce images of extended 14-MeV neutron sources close to the source itself to minimize time-of-flight distortions. "Close" means that the thickness of the pinhole barrier is not negligible in comparison with the distance from the source to the image plane.

A pinhole assembly capable of producing close-in images of extended 14-MeV

neutron sources has been designed and used in a number of experiments. A computer program has been devised to predict the performance of the pinhole by calculating the distribution of neutrons incident on the image plane from a neutron point source in the source plane. The calculation of the image-plane neutron distribution takes into account edge penetration through the barrier and is a function both of the neutron mean free path in the barrier material and of the system geometry.

1. The Basic Problem

A SIMPLE PINHOLE IMAGE

Consider the problem of producing a radiation image of an extended 14-MeV neutron source on an image plane located 3 m from the source, with a spatial resolution of 1 mm at the source and a magnification of 2:1. What is the nature of the required pinhole imaging system? The pinhole must be located one-third of the way between the source and the image plane (screen) for the magnification to be 2:1. The magnification of any pinhole image is given by

$$M = \frac{Z_s}{Z_o}, \quad (1)$$

where Z_s is the distance from the pinhole to the image plane and Z_o is the

distance from the source to the pinhole. The spatial resolution of the image is

$$R = d \left(1 + \frac{1}{M} \right), \quad (2)$$

where d is the pinhole diameter and M is the image magnification.

The resolution R calculated in Eq. (2) is the separation between two point sources on the source plane that image as two tangential circles on the image screen. Both Eqs. (1) and (2) are strictly valid only for a pinhole made in an infinitesimally thin barrier that is opaque to the incident radiation. Such barriers do not exist for 14-MeV neutrons.

FINITE-THICKNESS BARRIERS, PIPE FACTOR, AND IMAGE RESOLUTION

To produce a neutron image with reasonable contrast, the pinhole must be made in a barrier that is relatively opaque to neutrons (see Fig. 1). Therefore the barrier must have a finite thickness. This requirement gives rise to a difficulty. The images formed by a pinhole through a thick barrier are different for source points near the axis and for source points far from the axis.

Consider a uniform plane source that is imaged as a circle by a pinhole in a finite-thickness barrier. This image is brightest in the center and becomes pro-

gressively dimmer off the pinhole axis due to increased pinhole eclipsing. The ratio of the brightness of such an image at any given point to the brightness of the image on the pinhole axis is called the "pipe factor." The pipe factor is unity at the intersection of the pinhole axis and image plane but decreases for points on the image plane with increasing distance from the pinhole axis. There exists a circle on the image plane centered on the pinhole axis at which the pipe factor becomes equal to zero. This circle defines the image penumbra. The circle on the source plane that is imaged as the image penumbra is called the source penumbra. No image can be formed of source points lying outside

Fig. 1. Poorly designed close-imaging system.

or on the source penumbra because for these points the effective pinhole eclipsing is total. The size of the source penumbra depends on the geometry involved. The system shown in Fig. 1 has a source-penumbra diameter of 0.696 cm.

It is apparent that, for a barrier of finite thickness, the image resolution calculated in Eq. (2) is valid only on the pinhole axis and is a worst case. For source points away from the pinhole axis, the image resolution becomes better with decreasing pipe factor because the effective pinhole aperture is decreased.

NONOPAQUE BARRIERS

It is impossible to construct a pinhole barrier that is completely opaque to 14-MeV neutrons since the mean free path of a 14-MeV neutron is on the order of a few centimeters, even in the materials that are most opaque to neutrons. Furthermore, no matter how thick the barrier, there will be neutron transmission through the front and rear rims of the pinhole. This "lip penetration" degrades the image resolution from that calculated by Eq. (2).

What is a good material to use for a pinhole barrier for producing 14-MeV neutron images? A reasonable first choice could be iron. It is easily available, is relatively opaque to 14-MeV neutrons, and has been used extensively for neutron collimators.¹ The first consideration in designing a pinhole barrier is its thickness. If the barrier is too thin, the

image contrast will be low since the resultant image will be superimposed on a uniform background of neutrons that have penetrated the barrier. The maximum possible image contrast (i.e., the intensity ratio of the brightest part of the image to the darkest part) can be no greater than the reciprocal of the neutron transmission through the barrier. To produce a 14-MeV neutron image with a contrast ratio of at least 100, the barrier must have a maximum neutron transmission of 1%. Such a barrier must be at least 4.6 mean free paths thick, which is, for iron, 21.3 cm. This barrier is shown in Fig. 1 and will produce the neutron image described earlier--that is, an image located 3 m from the source, with a spatial resolution of 1 mm and a magnification of 2:1.

THE PINHOLE BARRIER SYSTEM OF FIG. 1

We assume that Eqs. (1) and (2) hold approximately for the finite-thickness case. Equation (2) shows that the pinhole diameter should be 0.67 mm to produce the 1-mm resolution. Equation (1) indicates that the barrier should be placed 1 m from the source and 2 m from the image screen. However, it is unclear what this means since the barrier has a finite thickness. We locate the barrier as shown in Fig. 1, with the front of the pinhole exactly 1 m from the source plane. Simple geometry shows that the source penumbra has a diameter of only 0.696 cm. The source can be no larger than 0.696 cm in diameter and in fact must be significantly smaller than this because a point source imaged with a zero pipe factor can hardly be considered satisfactory. Such a pinhole is useless for imaging sources of interest because the

¹Edward M. Lent, Collimation of Fast Neutrons, UCRL-50857, April 20, 1970.

maximum viewable diameter of the source is not much greater than the resolution. Furthermore, the resolution will be greater than 1 mm because pinhole lip penetration has not been accounted for. The contrast ratio will not even be 100 but will be approximately 15 since the barrier transmission was determined by using the total neutron cross section--a value that is correct only for good geometry. The small distance between the barrier and the image plane necessitates a worst case calculation, made with the inelastic cross section to determine the barrier transmission.

The system described in Fig. 1 presents two principal problems:

1. The barrier is much too thick to provide a source penumbra giving a large enough view of the source plane.
2. The barrier is too thin to provide a good contrast ratio in the bad geometry required to obtain close-in images.

It is the necessity of obtaining the image close to the source that renders the above pinhole system inappropriate. This barrier would work well in producing an image with 2:1 magnification at, say, 300 m from the source. Lip penetration remains a problem in both cases but is tolerable provided the pipe factor and contrast ratio are improved.

A BETTER CHOICE FOR A PINHOLE BARRIER

Figure 2 shows a better design for obtaining close-in images. As in Fig. 1, the pinhole diameter is 0.067 cm, but the effective barrier thickness, for source-penumbra considerations, is only 5 cm instead of 21.3 cm. The source-penumbra diameter is increased by a factor of

3.95. Furthermore, the contrast ratio is considerably improved. The tapered hole through the main part of the barrier is the cone of revolution that defines the penumbra and has its apex on the pinhole axis midway between the two pinhole lips. Therefore the bulk of the barrier does not collimate neutrons or enter into the source-penumbra calculation, but it does contribute to barrier opacity. The total barrier thickness of 80 cm shown in Fig. 2 is 9.91 inelastic mean free paths for 14-MeV neutrons. The minimum contrast ratio is therefore greater than 2×10^4 . Any neutron that scatters off the inside wall of the front taper ahead of the pinhole cannot pass through the pinhole without making a second scatter.

The price of using the design of Fig. 2 is the increased pinhole lip penetration, which degrades image resolution. In fact, the entire pinhole length of 5 cm is less than one inelastic mean free path in iron for 14-MeV neutrons. Hence the barrier can be easily penetrated in the neighborhood of the pinhole. This is not as bad as it might first appear. The transmission through the barrier drops off exponentially with increasing distance from the pinhole axis, so that the on-axis image resolution behaves as though the image were produced by a pinhole of slightly larger diameter. This can be more than made up for in two ways. First, the pinhole barrier can be moved closer to the source plane. This gives increased magnification and improved resolution [see Eq. (2)] but at the cost of decreased source-penumbra diameter. For the design shown in Fig. 2, a magnification of 2.5:1 would provide 6.7% better image resolution in compar-

Source
planeIron barrier $\lambda = 8.07$ Image
plane

Fig. 2. Better designed close-imaging system.

ison to a 2:1 magnification; however, the source-penumbra diameter would decrease by 13.9%. Second, the pinhole length of only 5 cm (compared to 21.3 in Fig. 1) permits drilling the pinhole in a cylindrical insert of exotic material with a smaller mean free path. We have used inserts made of platinum, which is significantly more opaque to 14-MeV neutrons than is iron. Only a few hundred dollars worth of platinum is needed (even at today's inflated prices) because the insert

is a very small fraction of the total barrier volume.

The ability of a pinhole system to produce a close-in image can be calculated, consistent with the limitations of barrier nonopaqueness and barrier finite thickness discussed earlier, with the programs listed in the appendices. The pinhole barrier system shown in Fig. 2 will be used as a calculational model to demonstrate the programs and to familiarize the reader with them.

II. PINHOLE Program and How It Works

THE GEOMETRY

The PINHOLE program is used to calculate the image-producing ability of a pinhole system. It has been used in a number of experiments in which close-in neutron images were measured and found to be in agreement with the PINHOLE program prediction.

The PINHOLE program is a ray-tracing computer program that works for any pinhole system of the general type shown in

Fig. 3. A source plane, an image plane, a pinhole and a barrier are so defined by the program that the source and image planes are parallel to each other and perpendicular to the pinhole axis. A rectangular coordinate system is so defined that the pinhole axis is the Z-axis and the origin is at the center of the pinhole, midway between the front and rear lips. The $Z = 0$ plane is the center plane of the pinhole barrier, which is assumed to be infinite in extent and to have a thickness T

Fig. 3. Geometry for PINHOLE program.

such that the front and rear walls of the barrier are the planes $Z = -T/2$ and $Z = +T/2$, respectively.

The pinhole itself is given a radius R and a length D that is less than T , such that the front and rear lips are circles of radius R lying in the $Z = -D/2$ and $Z = +D/2$ planes, respectively. The penumbra cone is defined as the cone swept out by a line passing through the origin and both pinhole lips. No barrier material is contained within the pinhole or penumbra cone. The penumbra cone intersects the source and image planes at the source penumbra and image penumbra. The source plane is the plane $Z = -Z_0$ and the image plane is the plane $Z = Z_a$. The barrier material is assigned a neutron mean free path λ .

THE IMAGE SCREEN

The geometry and barrier material are defined in the program by setting the symbols defined above equal to numerical lengths in centimeters. The image screen is defined by choosing a rectangular area anywhere on the image plane. This is done by specifying two X values, $X_{s \text{ max}}$ and $X_{s \text{ min}}$, and two Y values, $Y_{s \text{ max}}$ and $Y_{s \text{ min}}$, which define the screen borders. The screen can be placed anywhere on the image plane and can be of arbitrary size. The screen does not have to be symmetric about the Z -axis. The only requirement in defining the screen is that $X_{s \text{ min}} < X_{s \text{ max}}$ and $Y_{s \text{ min}} < Y_{s \text{ max}}$.

LOCATION OF THE POINT SOURCE

The last item to be defined is the location of the neutron source. This source is assumed to be an isotropic

unit point source located on the source plane either on the Z -axis or at any positive position on the X -axis inside the source penumbra. It is assumed to emit isotropically a total of one particle that has the specified mean free path in the barrier material. The location of the point source is defined by inserting values for the parameters **START**, **FINISH**, and **DELTA** into the program. A sample problem is worked out for the pinhole barrier system of Fig. 2.

THE DYNAMICS OF THE PINHOLE PROGRAM

When all the parameters have been specified, the screen is broken into an 800×800 matrix of equal-area rectangular elements, each element having an area $\Delta A = \Delta X \Delta Y$ such that

$$\Delta X = \frac{X_{s \text{ max}} - X_{s \text{ min}}}{800}$$

and

$$\Delta Y = \frac{Y_{s \text{ max}} - Y_{s \text{ min}}}{800}.$$

The total distance S_{ij} from the point source on the source plane to the center of the element area ΔA_{ij} on the image screen is calculated. Also, the distance W_{ij} , which is the portion of S_{ij} that passes through barrier material, is determined. These distances are identified in Fig. 3. The PINHOLE program calculates both S_{ij} and W_{ij} using equations that arise from mathematics no more sophisticated than elementary high school trigonometry. Both S_{ij} and W_{ij} are functions of the input geometric parameters and the position of ΔA_{ij} on the image screen.

Once S_{ij} and W_{ij} are calculated, the following equations are evaluated. First, τ_{ij} , the transmission coefficient from the point source through the barrier to the element ΔA_{ij} is found from

$$\tau_{ij} = \exp \left(- \frac{W_{ij}}{\lambda} \right). \quad (3)$$

The cosine of the angle between the normal to the screen and the ray S_{ij} from the point source to the element ΔA_{ij} is determined. This is given by

$$\cos \theta_{ij} = \frac{Z_o + Z_s}{S_{ij}}. \quad (4)$$

Notice that in Eq. (4) and everywhere through the program the distance Z_o is used as a positive number, even though it measures a length to the left, or negative, side of the Z-axis as defined in Fig. 3. This is because it is convenient to enter Z_o into the program as a positive length. This convention does not apply to the other parameters. The intensity I_{ij} of the unit point source incident on the element ΔA_{ij} of the screen is calculated by

$$I_{ij} = \frac{\tau_{ij}}{4\pi(S_{ij})^2} \cos \theta_{ij}. \quad (5)$$

A DO loop in the program repeats the calculation of I_{ij} for each of the 800×800 matrix elements ΔA_{ij} on the screen.

PINHOLE PROGRAM OUTPUTS

The calculation produces a two-dimensional image-intensity profile of the unit point source. This profile has a mesh of 800×800 , which is fine enough for most applications. The output for the profile is in the form of a contour

plot over the screen dimensions. Five contour levels are plotted at 99, 50, 25, 10, and 1% of the maximum intensity on the screen. The maximum intensity $I_{\max}$ is determined by the equation

$$I_{\max} = \frac{1}{4\pi(S_{\max})^2} \cos \theta_{\max}, \quad (6)$$

where $S_{\max}$ is the straight-line distance from the point source through the origin to screen and $\theta_{\max}$ is the angle that $S_{\max}$ makes with the screen normal.

In addition to the contour plot of the screen intensity level, the PINHOLE program gives a list of calculated values and input geometrical factors. These are described below.

Integral

This term is used to calculate the total number of particles incident on the chosen screen. It is found by summing over all the I_{ij} values of Eq. (5) and multiplying the sum by ΔA :

$$\text{integral} = \Delta A \sum_{i,j}^{800,800} I_{ij}. \quad (7)$$

The integral is of particular importance for neutron image sampling of an extended source. In this case the PINHOLE calculation is performed with a screen reduced in size to that of an individual neutron detector. The calculation is then repeated with the detector fixed but with the unit point source displaced slightly to a new location on the source plane. The integral resulting from each calculation is the number of neutrons incident on the small detector as a function of position of the point source on the source plane.

The background signal that arises when an extended source is imaged is due to

those neutrons that arrive at the detector by penetrating the barrier material rather than by passing through the pinhole. The background from a given unit point source on the source plane can easily be calculated by using a difference method. A source is placed at the given point, and the difference between two integrals is found. The first integral is calculated from the experimental parameters of the pinhole system and is the total number of neutrons arriving at the detector. The second integral is calculated with the mean free path of the barrier material changed to an infinitesimal value to render the barrier artificially opaque. This second integral is the number of neutrons arriving at the detector by passage through the pinhole only. The difference between the two integrals is the background at the given detector position from the given unit point source. An estimated total background from an extended source can be obtained by integrating this kind of background calculation over the source.

Peak Intensity

The peak intensity is the numerical value of $I_{\max}$ calculated in Eq. (6).

Pinhole Radius

The pinhole radius is the value of the input parameter R shown in Fig. 3.

Pinhole Length

The pinhole length is the length designated D in Fig. 3.

Barrier Thickness

The barrier thickness is the value T shown in Fig. 3.

Neutron Mean Free Path

This parameter is the neutron mean free path in the barrier material.

Radius of Source Penumbra

The source penumbra has been defined earlier. A point source located outside the source penumbra cannot be imaged by the pinhole. The program calculates this radius by using the equation

$$R_{sp} = 2R(Z_o/D). \quad (8)$$

Source Plane to Front of Pinhole

This is the distance l_1 of the front pinhole lip from the source plane. It is given by

$$l_1 = Z_o - D/2. \quad (9)$$

Front of Pinhole to Image Plane

This is the distance l_2 between the front pinhole lip and the image plane. It is given by the equation

$$l_2 = Z_s + D/2. \quad (10)$$

Image Magnification

The magnification M is given by the equation

$$M = l_2/l_1, \quad (11)$$

where l_1 and l_2 are found from Eqs. (9) and (10). Equation (11) is most nearly correct only for an opaque barrier. However, it does provide a fairly close approximation to the real expected magnification, which is actually a slowly

varying function over the image plane. The magnification calculated by Eq. (11) is also useful when checking the imaging properties of the pinhole barrier system with a light source.

Image Resolution

This is the resolution determined by Eq. (2) using the value of M calculated by Eq. (11). This resolution is correct only for an opaque barrier. The true image resolution must take into account barrier penetration and pinhole lip penetration. This can be determined by a special variation of the PINHOLE program called GRID, which can calculate the image of a number of unit point sources placed side by side.

Time-of-Flight Constant

The purpose of placing the pinhole close to the source is to keep neutron time-of-flight distortions at a minimum. The time-of-flight constant is the time-of-flight spreading of a 14-MeV neutron signal with an energy spread of 1 MeV. The value comes from the simple classical relation

$$\frac{\Delta E}{E} = 2 \frac{\Delta t}{t}, \quad (12)$$

where

$$\Delta E = 1 \text{ MeV}$$

$$E = 14 \text{ MeV}$$

$$t = \text{flight time of a 14-MeV neutron over the distance } Z_o + Z_s$$

$$\Delta t = \text{the time-of-flight constant.}$$

THE PINI SUBROUTINE

The PINI subroutine performs a calculation similar to the PINHOLE calculation but in one dimension. The output consists of several plots, the most important being the unit point source image intensity along the X-axis of the screen.

The PINI subroutine divides the X-axis of the screen into 800 linear increments and then calculates the total distance along each ray connecting the unit point source with each linear element on the X-axis of the screen. The length of that part of each ray passing through the barrier is also calculated. The intensity profile along the X-axis of the screen is then calculated by an equation analogous to Eq. (5) and plotted as a function of position along the screen in the X-direction. Both the intensity and the log of the intensity are plotted.

The calculation is then repeated with the mean free path of 14-MeV neutrons in the barrier material changed from its entered value to a very small number to represent an almost perfectly opaque material. A plot is made of the screen intensity function for an opaque barrier, and this is superimposed over the plot of the intensity function calculated with the real barrier. This superposition immediately reveals the effects of pinhole lip penetration on the image.

Each of the 800 rays traced by the PINI subroutine has its barrier entrance and exit coordinates graphed on an X,Z plot. The plot of these points forms an outline of the pinhole barrier.

THE EXTRA OPTION OF THE PINI SUBROUTINE

The PINI subroutine contains an option for calculating the effect of increasing the thickness at the rear of the barrier with extra material of the same mean free path as the original barrier, as shown in Fig. 4. This option is exercised by entering a value for the parameter EXTRA in the parameter entrance part of the program. Indeed, some numerical value of this

dimension that is greater than or equal to zero but less than $Z_s - T/2$ must be entered or the program will not run. The contour plot of the PINHOLE program assumes a barrier of thickness T only. However, the PINI subroutine is run through twice, the first pass with the barrier thickness set equal to T , as shown in Fig. 3, and the second pass with the barrier set equal to $T + \text{EXTRA}$, as shown in Fig. 4.

Source
plane

Image
plane

Fig. 4. Illustration of EXTRA option.

III. A Sample Problem

THE PINHOLE AND GRID PROGRAMS

The pinhole barrier system shown in Fig. 2 is calculated as a sample problem using the complete PINHOLE and GRID programs, which are listed in Appendices I and II. The GRID program performs essentially the same calculations as the PINHOLE program but allows the simultaneous imaging of two or more unit point sources. This is quite useful in checking image resolution since the distance separating the sources can be reduced until they cannot be individually imaged. When this occurs, the limit of resolution has been reached.

In both the PINHOLE and GRID programs there are 14 parameters that must be entered or the programs will not run. All the parameters are entered in the beginning of the program after the CALL CRTID card, as listed in Appendices I and II.

PINHOLE PROGRAM

The sample problem consists of imaging four unit point sources with the barrier system of Fig. 2. The first parameter is pinhole radius, which is 0.033 cm. A card is punched out with the entry

$$R = 0.033 \quad (\text{entry 1})$$

and inserted into the deck as shown in Appendix I. Each of the other parameters is entered by punching its values on computer cards and entering the cards into the deck as shown below and in Appendix I. All dimensions entered into the PINHOLE and GRID programs must be in centimeters.

The pinhole length as shown in Fig. 2 is 5 cm. Therefore a card is punched

$$D = 5. \quad (\text{entry 2})$$

The pinhole barrier thickness of the iron barrier is 80 cm:

$$T = 80. \quad (\text{entry 3})$$

The mean free path of radiation in barrier material is 8.07 cm:

$$AVFP = 8.07 \quad (\text{entry 4})$$

The source plane distance from center of barrier is 102.5 cm:

$$ZO = 102.5 \quad (\text{entry 5})$$

Note that this parameter is entered as a positive number, even though the source plane is at $Z = -102.5$.

The image plane distance from center of barrier is 197.5 cm:

$$ZS = 197.5 \quad (\text{entry 6})$$

The ZS entry above defines the image plane, but not the screen position on the image plane. A rectangular screen of any size may be placed anywhere on the image plane inside or outside the penumbra. The screen does not have to be centered on the pinhole axis. For the purpose of this sample calculation we shall choose a square screen 5.2 cm on a side and centered on the pinhole axis. The edges of such a screen are obviously at $X = \pm 2.6$ cm and

$Y = \pm 2.6$ cm. This screen is defined by entering the screen's edge values as follows:

XSMAX = 2.6	(entry 7)
XSMIN = -2.6	(entry 8)
YSMAX = 2.6	(entry 9)
YSMIN = -2.6	(entry 10)

A unit point source is placed on the source plane at the origin or on the positive X-axis inside the source penumbra. When the calculation is completed, it is usually convenient to move the source to a new location and repeat the calculation with the other parameters fixed. We shall illustrate how this is done by first placing a source at the origin and then moving it 0.4 cm and repeating the entire calculation. This is repeated each time moving the source point by 0.4 cm from its previous location until the source point arrives at $X = 1.2$ cm. The calculation is then terminated.

The START position of the source point is the origin of the source plane. This is specified by the entry

START = 0. (entry 11)

We desire the calculation to FINISH, or terminate, when the source arrives at $X = 1.2$ cm:

FINISH = 1.2 (entry 12)

The point source is to be moved by 0.4 cm for each successive calculation. We specify this with the entry

DELTA = 0.4 (entry 13)

These START, FINISH, and DELTA entries will produce four separate calculations with the geometry defined earlier. The unit point source will be located at $X = 0.$, $X = 0.4$, $X = 0.8$, and $X = 1.2$. A complete calculation on the LLL-7600 takes approximately 30 seconds of computer time per source point.

The EXTRA option as defined earlier must be entered for the program to run, even though it is used only in the one-dimensional calculations of the PINI subroutine. This parameter is defined in Fig. 4. We shall choose an EXTRA barrier thickness of 40 cm additional to be added to the rear of the 80-cm barrier, bringing the total barrier to a thickness of 120 cm. This is done by entering

EXTRA = 40. (entry 14)

The two-dimensional output of the PINHOLE program does not recognize EXTRA and its calculations use only the 80-cm barrier. Then the PINI subroutine performs one-dimensional calculations using first the 80-cm barrier and then a barrier of $(80 + 40)$ cm.

PINHOLE PROGRAM OUTPUT

We obtain four sets of output from the sample calculation since four separate positions of the unit point source were entered. The output resulting from the first calculation with the unit point source on the origin of the source plane is shown in Figs. 5a through 5j.

The contour plot of Fig. 5a is the intensity profile on the screen chosen. The computer has picked a coordinate system in which the screen appears to be a 6-cm

Fig. 5a. Contour plot of screen for sample problem with point source at $X = 0$.

square, but the calculation is extended only over the 5.2-cm-square screen used as input to the program. The results show contours at the 99, 50, 25, 10, and 1% intensity levels. The contours appear as circles centered about the origin of the image plane, as would be expected for an on-axis point source. The lower right cor-

ner of the figure shows the point source is at $X = 0$, cm, which is the origin of the source plane.

A listing of the input and calculated parameters appears in Fig. 5b. The integral of $1.41 \text{ E-}07$ counts is the number of neutrons incident on the chosen screen from an on-axis unit point source that emits

(text continues p. 20)

PINHOLE IMAGE INTENSITY FROM UNIT POINT SOURCE

INTEGRAL	1.41E-07 COUNTS
PEAK INTENSITY	8.84E-07 COUNTS / SQ CM
PINHOLE RADIUS	0.033 CENTIMETERS
PINHOLE LENGTH	5.00
SOURCE PENUMBRA RADIUS	1.35
BARRIER THICKNESS	80.00
NEUTRON MEAN FREE PATH	8.07
SOURCE PLANE TO FRONT OF PINHOLE	100.00
FRONT OF PINHOLE TO IMAGE PLANE	200.00
IMAGE MAGNIFICATION	2.00
IMAGE RESOLUTION	0.10
T.O.F. CONSTANT	2.05 NS / MEV
	PT SOURCE AT 0. CM

Fig. 5b. Data listing for sample problem with point source at $X = 0$.

Fig. 5c. One-dimensional linear intensity on screen.

Fig. 5d. One-dimensional log intensity on screen.

Fig. 5e. Point-source image produced with opaque and nonopaque barriers showing lip penetration.

Fig. 5f. X,Z plot of ray entrance and exit points through barrier.

Fig. 5g. Linear intensity on screen using EXTRA option.

Fig 5h. Log intensity on screen using EXTRA option.

Fig. 5i. Pinhole lip penetration with EXTRA option.

Fig. 5j. Ray entrance and exit points through barrier with EXTRA option, X,Z plot.

isotropically over 4π . The peak intensity of 8.84×10^{-7} counts cm^{-2} is the value I_{max} of Eq. (6) and is the value on which the contours of Fig. 5a are based. The remainder of the listing consists of the input parameters and the calculated parameters described earlier.

Figures 5a and 5b are the only two figures that are direct output from the PINHOLE program. The rest of the figures (Figs. 5c-5j) result from the PINI subroutine. Figure 5c is a linear one-dimensional intensity plot across the X-axis of the screen resulting from the unit point source at $X = 0$ cm on the source plane. The log of the intensity is shown in Fig. 5d. Figure 5e shows the result of a linear superposition of two intensity plots; one is a repeat of the linear plot described earlier, and the other is the result of a calculation using an infinitesimal mean free path in the barrier material. The effect of barrier penetration is clearly apparent in Fig. 5e.

An X,Z plot of the entrance and exit points through the pinhole barrier of the rays traced from the point source to the screen is shown in Fig. 5f. These points clearly outline the pinhole barrier.

Figures 5g through 5j are repeats of Figs. 5c through 5f with the EXTRA barrier thickness added. It is clear from the plots that in this example the EXTRA thickness of 40 cm added to the rear of the barrier has very little effect on the linear intensity of the image, but it does reduce the background by approximately two orders of magnitude.

The above described output is the complete output from the program for a unit

point source at a designated position. This calculation used about 30 seconds of LLL-7600 computer time. The point source is moved to $X = 0.4$ cm on the source plane, and the entire calculation is repeated. This process is continued until the point source arrives at $X = 1.2$ cm on the source plane, moving in steps of 0.4 cm, after which the calculation is terminated.

We shall not show all the data obtained for each source point but only the contour plots (Figs. 6a-6c), the data listing (Figs. 7a-7c), and the one-dimensional intensity plots showing the effects of barrier penetration (Figs. 8a-8c).

CONTOUR PLOTS

As the point source moves in the positive X-direction on the source plane, the image moves in the negative X-direction on the screen. The image movement is approximately twice the source movement. This is characteristic of a pinhole camera with a magnification of 2:1. As the source is moved further off axis, the resulting image becomes less and less circular.

When the point source is as far as 0.8 cm from the origin of the source plane, the resultant image is distorted enough to cause a characteristic butterfly distortion at the 50% intensity level. This is the result of asymmetric pinhole lip penetration. At a displacement of 1.2 cm, the contour plot is not large enough to be seen clearly on the chosen screen. This contour can be shown in better detail by rerunning the calculation with a smaller screen centered about the image.

Fig. 6a. Contour plot for sample problem with source at $X = 0.4$.

Fig. 6b. Contour plot for sample problem with source at $X = 0.8$.

Fig. 6c. Contour plot for sample problem with source at $X = 1.2$.

DATA LISTING

The displayed data shown in Figs. 7a, 7b, and 7c indicate that the number of particles arriving on the screen decreases as the source gets closer to the source penumbra. The integral for a source 1.2 cm

off axis is $1.99 \text{ E-}08$ counts compared to $1.41 \text{ E-}07$ counts for an on-axis source. These numbers are, of course, a function of the screen size. Had a smaller screen been chosen--for example, a 2-cm-square screen centered on the origin--then the integral from the on-axis source would have been

PIN-HOLE IMAGE INTENSITY FROM UNIT POINT SOURCE

INTEGRAL	1.89E+07 COUNTS
PEAK INTENSITY	8.0E+07 COUNTS / SQ CM
PIN-HOLE RADIUS	0.133 CENTIMETERS
PIN-HOLE LENGTH	5.00
SOURCE PENUMBRA RADIUS	1.35
SLITTER THICKNESS	80.00
NEUTRON MEAN FREE PATH	0.07
SOURCE PLANE TO FRONT OF PIN-HOLE	100.00
FRONT OF PIN-HOLE TO IMAGE PLANE	200.00
IMAGE MAGNIFICATION	2.00
IMAGE RESOLUTION	0.10
T.O.F. CONSTANT	2.25 NS / MEV
PT SOURCE AT 0.40 CM	

Fig. 7a. Data listing for sample problem with source at $X = 0.4$.

PIN-HOLE IMAGE INTENSITY FROM UNIT POINT SOURCE

INTEGRAL	6.05E+08 COUNTS
PEAK INTENSITY	8.0E+07 COUNTS / SQ CM
PIN-HOLE RADIUS	0.133 CENTIMETERS
PIN-HOLE LENGTH	5.00
SOURCE PENUMBRA RADIUS	1.35
SLITTER THICKNESS	80.00
NEUTRON MEAN FREE PATH	0.07
SOURCE PLANE TO FRONT OF PIN-HOLE	100.00
FRONT OF PIN-HOLE TO IMAGE PLANE	200.00
IMAGE MAGNIFICATION	2.00
IMAGE RESOLUTION	0.10
T.O.F. CONSTANT	2.25 NS / MEV
PT SOURCE AT 0.80 CM	

Fig. 7b. Data listing for sample problem with source at $X = 0.8$.

INTEGRAL	1.99E+08 COUNTS
PEAK INTENSITY	8.46E+07 COUNTS/CM
PINHOLE RADIUS	0.138 CENTIMETERS
PINHOLE LENGTH	5.00
SOURCE PENUMBRA RADIUS	35
BARrier THICKNESS	80.00
NEUTRON MEAN FREE PATH	8.07
SOURCE PLANE TO FRONT OF PINHOLE	100.00
FRONT OF PINHOLE TO IMAGE PLANE	200.00
IMAGE MAGNIFICATION	2.00
IMAGE RESOLUTION	0.10
1.014 CONSTANT	2.0E-05 MEV
OF SOURCE AT 1.00 CM	

Fig. 7c. Data listing for sample problem
with source at X = 1.2.

slightly smaller, and the integral from the point source 1.2 cm off axis would have been substantially smaller since most of the image would have missed the screen.

Notice that the peak intensity would not change in the above example. The peak intensity is not the peak intensity on the screen, but is the $I_{\max}$ of Eq. (6).

ONE-DIMENSIONAL INTENSITY PLOTS

The PINI subroutine plots shown in Figs. 8a, 8b, and 8c show basically the same results displayed in the contour plots. The image becomes narrower and barrier penetration becomes more pronounced as the point source is moved further from the origin of the source plane.

THE GRID PROGRAM

To illustrate the GRID program we again use the system that was calculated in the

previous example; that is, the system shown in Fig. 2 with the EXTRA option set at 40 cm. The geometric parameters are entered in exactly the same way as with the PINHOLE program example, except for the entries that define the point source (see the GRID program listing in Appendix II).

We shall calculate the effect of placing six unit point sources side by side on the X-axis of the source plane, each source separated from its neighbor by 0.2 cm. As with the PINHOLE program, the sources are restricted to the origin or the positive X-axis of the source plane within the source penumbra. The first source will be placed at the origin. This is specified by entering a card

START = 0. (entry 1)

There are to be a total of six sources

Fig. 8a. Pinhole lip penetration for sample problem with source at $X = 0.4$.

Fig. 8b. Pinhole lip penetration for sample problem with source at $X = 0.8$.

Fig. 8c. Pinhole lip penetration for sample problem with source at $X = 1.2$.

each separated by 0.2 cm. Therefore the cards

NUMBER = 6 (entry 2)
DELTA = 0.2 (entry 3)

are entered in the appropriate place as shown in the GRID program listing. All

other entries are the same as with the PINHOLE program. A total of 14 entries must be made or the program will not run. The GRID program will now calculate the image produced by six unit point sources placed along the X-axis of the source plane at $X = 0$, $X = 0.2$, $X = 0.4$, $X = 0.6$, $X = 0.8$, and $X = 1.0$. The entire calcula-

tion of six points in this sample problem has used close to 3 minutes of LLL-7600 computer time.

GRID PROGRAM OUTPUT

The output of the GRID program is very similar to that of the PINHOLE program. Figures 9a, 9b, and 9c show some of the

GRID program output. Figure 9a is the contour plot with contours at 99, 50, 25, 10, and 1% of the peak intensity. The peak intensity value of $1.05 \text{ E-06 counts cm}^{-2}$ listed in Fig. 9b is the peak intensity incident on the screen and is not the value I_{max} of Eq. (6) as in the PINHOLE program output. The integral value shows a total

Fig. 9a. Contour plot using GRID program--sources resolvable.

PINHOLE IMAGE INTENSITY FROM UNIT POINT SOURCES

INTEGRAL	6.40E-07 COUNTS
PEAK INTENSITY	1.05E-08 COUNTS / SQ CM
PINHOLE RADIUS	0.033 CENTIMETERS
PINHOLE THICKNESS	5.30
SOURCE PENUMBRA RADIUS	1.35
BARRIER THICKNESS	80.00
NEUTRON MEAN FREE PATH	8.07
SOURCE PLANE TO FRONT OF PINHOLE	100.00
FRONT OF PINHOLE TO IMAGE PLANE	200.00
IMAGE MAGNIFICATION	2.00
IMAGE RESOLUTION	0.10
T.O.F. CONSTANT	2.05 NS / MEV

6 UNIT POINT SOURCES EACH SEPARATED BY 0.20 CM

Fig. 9b. Data listing from GRID program using six sources.

Fig. 9c. Lip penetration does not destroy image resolution.

of 6.40 E-07 counts incident on the chosen screen from the six isotropically emitting unit point sources. The one-dimensional output shown in Fig. 9c is the result of calculation using both the real barrier and an artificially opaque barrier with the mean free path set equal to an infinitesimal value. Figures 9a, 9b, and 9c show that point sources placed 0.2 cm apart

along the X-axis of the source plane can be resolved fairly well with this system.

We shall now repeat the GRID calculation with 14 unit point sources placed 0.1 cm apart along the X-axis. This is done by changing the entry NUMBER from 6 to 14 and the entry DELTA from 0.2 to 0.1. The results of this calculation are shown in Figs. 10a, 10b, and 10c. The contour plot

Fig. 10a. Contour plot from GRID program shows 14 points that cannot be resolved.

PINHOLE IMAGE INTENSITY FROM UNIT POINT SOURCES

INTEGRAL	1.25E+16 COUNTS
PEAK INTENSITY	1.67E+16 COUNTS 50 CM
PINHOLE RADIUS	0.033 CENTIMETERS
PINHOLE THICKNESS	5.00
SOURCE PENUMBRA RADIUS	1.35
BARRIER THICKNESS	80.00
NEUTRON MEAN FREE PATH	8.07
SOURCE PLANE TO FRONT OF PINHOLE	100.00
FRONT OF PINHOLE TO IMAGE PLANE	200.00
IMAGE MAGNIFICATION	2.00
IMAGE RESOLUTION	0.10
T.O.P. CONSTANT	4.05 NS / MEV

14 UNIT POINT SOURCES EACH SEPARED BY 0.10 CM

Fig. 10b. Data listing from GRID program using 14 source points.

Fig. 10c. Pinhole lip penetration destroys resolution over most of image.

Fig. 10a shows that individual sources cannot be resolved by this system when separated by 0.1 cm and placed near the origin of the source plane. The sources can be resolved near the penumbra because the eclipsing effect of the finite-thickness barrier results in a smaller effective pinhole diameter. Figure 10b shows that the total number of counts reaching the screen has increased to 1.25 E-06 , which is almost double the incident counts when six sources were used. The calculated number of counts does not increase by exactly $7/3$ since the pipe-factor consideration is implicit with-

in the calculation. The peak intensity increased from 1.05 E-06 to 1.67 E-06 counts cm^{-2} mainly as a result of increased *superposition or piling up of images from sources close to the origin of the source plane*. This is precisely the result of a failure of the system to resolve each source individually.

This effect is dramatically illustrated in Fig. 10c, in which the resolution failure near the center of the source plane is seen to result from the pinhole lip penetration effect.

Acknowledgment

The author thanks Raymond A. Heinle of LLL-Nevada, who independently produced a

similar computer program, for his many helpful remarks and suggestions.

APPENDIX I

COMPLETE LISTING OF PINHOLE CODE


```

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000196 000196
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000199 000199
000200 000200
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000202 000202
000203 000203
000204 000204

501 LL = LL + 1
CONTINUE
L = L + 1
DO 101 J = 1, 100, 1
YJ = J
YS = YMIN + YJ * DYS
SY(J) = YS
DO 102 I = 1, 100, 1
XI = I
XS = XMIN + XI * DXS
SX(I) = XS
Q11 = (XS-C)/(ZS+Z0)
Q12 = (YS-C)/(ZS+Z0)
Q1 = Q11*(ZS+Z0) + Q12*(Q12)
IF(Q1.EQ.0.)204
Q2 = 2 - C*((XS-C)/(ZS+Z0))
AL1 = AL(HFT)
AL2 = AL(HFD)
AL3 = AL(HFD)
AL4 = AL(HFT)
C = Z0*Z0*Q1 + Q2
G = Z0*Z0*Q1 + Z0*Q2 + C=C
H = B-R2
IF(AL1.LE.FLR2) ,201
Z1 = H
X1 = X(Z1)
Y1 = Y(Z1)
GO TO 200

201 CONTINUE
IF(AL2.GT.R2) ,202
IF(E.EQ.0.) ,210
Z1 = -G/F
X1 = X(Z1)
Y1 = Y(Z1)
GO TO 200

210 CONTINUE
ZA = (-F+SQRT(F*F-4.*E*Q1))/(2.*E)
ZB = (-F-SQRT(F*F-4.*E*Q1))/(2.*E)
IF((-HFT.LT.ZA).AND.(ZA.LT.-HFD)) ,203
Z1 = ZA
X1 = X(Z1)
Y1 = Y(Z1)
GO TO 200

203 CONTINUE
Z1 = ZB
X1 = X(Z1)
Y1 = Y(Z1)
GO TO 200

202 CONTINUE
IF(AL3.GE.R2) ,204
ZA = (-F + SQRT(F*F-4.*Q1*H))/(2.*Q1)
ZB = (-F - SQRT(F*F-4.*Q1*H))/(2.*Q1)
IF((-HFD.LE.ZA).AND.(ZA.LE.HFD)) ,205
Z1 = ZA
X1 = X(Z1)
Y1 = Y(Z1)
GO TO 200

205 CONTINUE
Z1 = ZB
X1 = X(Z1)
Y1 = Y(Z1)
GO TO 200

204 CONTINUE
TRANS = 1
GO TO 300

200 CONTINUE
IF(AL3.LE.R2) ,206
ZA = (-F + SQRT(F*F-4.*Q1*H))/(2.*Q1)
ZB = (-F - SQRT(F*F-4.*Q1*H))/(2.*Q1)
IF((-HFD.LE.ZA).AND.(ZA.LE.HFD)) ,207
Z2 = ZA
X2 = X(Z2)
Y2 = Y(Z2)
GO TO 301

207 CONTINUE
Z2 = ZB
X2 = X(Z2)
Y2 = Y(Z2)
GO TO 301

205 CONTINUE
IF(AL4.LT.FLR2) ,208
ZA = (-F+SQRT(F*F-4.*E*Q1))/(2.*E)
ZB = (-F-SQRT(F*F-4.*E*Q1))/(2.*E)
IF((-HFD.LT.ZA).AND.(ZA.LT.HFT)) ,209
Z2 = ZA
X2 = X(Z2)
Y2 = Y(Z2)
GO TO 301

209 CONTINUE
Z2 = ZB
X2 = X(Z2)
Y2 = Y(Z2)
GO TO 301

206 CONTINUE
Z2 = HFT
X2 = X(Z2)
Y2 = Y(Z2)
GO TO 301

301 CONTINUE
DIS = (X2-X1)*(X2-X1)+(Y2-Y1)*(Y2-Y1)+(Z2-Z1)*(Z2-Z1)
DIS = SQRT(DIS2)

```

[illegible]

```

1=C*AT** C-166D
000001 000307
000002 000318
000003 000309
000004 000310
000005 000311
000006 000312
1=C*AT** C-166D
000001 000313
000002 000314
000003 000315
000004 000316
000005 000317
000006 000318
1=C*AT** C-166D
000001 000319
000002 000320
000003 000321
000004 000322
000005 000323
000006 000324
1=C*AT** C-166D
000001 000325
000002 000326
000003 000327
000004 000328
000005 000329
000006 000330
000001 000331
000002 000332
000003 000333
000004 000334
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000004 000394

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BOX 364 04.14.41 06/07U 1975
FUNCTION AL(2)
CODE ANALYSIS
COMMON Z(1000), Q1, Q2, C, XS, YS, ZS, XSMIN, XSMAX, R, D, T, AVFP, ZP, ZDP, EXTRA
AL = (Z+Z0) * (Z+Z0) * Q1 + (Z+Z0) * Q2 + C+D
RETURN
END

BOX 364 04.14.41 06/07U 1975
FUNCTION X(2)
CODE ANALYSIS
COMMON Z(1000), Q1, Q2, C, XS, YS, ZS, XSMIN, XSMAX, R, D, T, AVFP, ZP, ZDP, EXTRA
X = (Z+Z0) * (XS-5)/(ZS+Z0) + C
RETURN
END

BOX 364 04.14.41 06/07U 1975
FUNCTION Y(2)
CODE ANALYSIS
COMMON Z(1000), Q1, Q2, C, XS, YS, ZS, XSMIN, XSMAX, R, D, T, AVFP, ZP, ZDP, EXTRA
Y = (Z+Z0) * YS / (ZS+Z0)
RETURN
END

BOX 364 04.14.41 06/07U 1975
SUBROUTINE PINI
CODE ANALYSIS
DIMENSION Z(1000), B(1000), S(1000), SS(1000)
DIMENSION XAT(1000), XKN(1000), ZZT(1000), ZZN(1000)
COMMON Z(1000), Q1, Q2, C, XS, YS, ZS, XSMIN, XSMAX, R, D, T, AVFP, ZP, ZDP, EXTRA
TANFI = 2. * R/D
R1 = -R
EX = 0.
L = 0
GO TO 19
19 CONTINUE
EX = EXTRA
29 CONTINUE
L = L + 1
X1 = T * TANFI / 2.
X2 = (EX + T/2.) * TANFI
X3 = -X1
X4 = -X2
110 DO I = 1, 1000, 1
Z1(I) = 0.
B1(I) = 0.
S1(I) = 0.
SS(I) = 0.
XAT(I) = 0.
XKN(I) = 0.
ZZT(I) = 0.
ZZN(I) = 0.
1 CONTINUE
I = 0
TNMIN = (XSMIN - C) / (Z0 + ZS)
TNMAX = (XSMAX - C) / (Z0 + ZS)
STEP = (TNMAX - TNMIN) / 800.
DO 101 TANTH = TNMIN, TNMAX, STEP
I = I + 1
XFR = (Z0 - T/2.) * TANTH + C
XNT = (Z0 - D/2.) * TANTH + C
XLVP = (Z0 + D/2.) * TANTH + C
XRE = (Z0 + EX + T/2.) * TANTH + C
IF (XFR .GE. X1) , 2
ZIN = -T/2.
XIN = XFR
GO TO 20
2 CONTINUE
IF (XENT .GE. R) , 3
ZIN = -(Z0 * TANTH + C) / (TANTH + TANFI)
XIN = -ZIN * TANFI
GO TO 20
3 CONTINUE
IF (XLVP .GE. R) , 4
ZIN = (R - C) / TANTH - Z0
XIN = R
GO TO 20
4 CONTINUE
IF (XLVP .GE. RM) , 5
GO TO 21
5 CONTINUE
IF (XENT .GE. RM) , 6
ZIN = -(R + C) / TANTH - Z0
XIN = RM
GO TO 20
6 CONTINUE
IF (XFR .GE. X3) , 7
ZIN = (Z0 * TANFI + C) / (TANFI - TANTH) - Z0
XIN = ZIN * TANFI
GO TO 20
7 CONTINUE
ZIN = -T/2.
XIN = (Z0 - T/2.) * TANTH + C
20 CONTINUE
IF (XRE .GE. X2) , 8

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000071 000095 Z0) = EX + Y/2.
000072 000096 C0) = C * (Z0 + Z0T) * TANTH
000073 000097 CO) = Z0
000074 000098 C0) = C * (Z0 + Z0T) * TANTH
000075 000099 Z0T = (C * Z0 + TANH) / (TANF - TANH)
000076 000100 Z0T = Z0T * TANF
000077 000101 GO TO 22
000078 000102 9 CONTINUE
000079 000103 IF (ALV * CE, RM)
000080 000104 Z0T = (R - C) / TANH * Z0
000081 000105 X0T = R
000082 000106 GO TO 22
000083 000107 10 CONTINUE
000084 000108 IF (X0 - GE, X0)
000085 000109 Z0T = -(Z0 * TANTH + C) / (TANF + TANTH)
000086 000110 X0T = -Z0T * TANF
000087 000111 GO TO 22
000088 000112 11 CONTINUE
000089 000113 Z0T = EX + Y/2.
000090 000114 X0T = XRE
000091 000115 22 CONTINUE
000092 000116 ZT = SQRT((Z0T-XH)*(X0T-XH)+(Z0T-ZIN)*(Z0T-ZIN))
000093 000117 GO TO 104
000094 000118 21 CONTINUE
000095 000119 Z2 = 0.
000096 000120 GO TO 104
000097 000121 104 CONTINUE
000098 000122 Z(1) = Z2
000099 000123 B(1) = C * (ZS + Z0) * TANTH
000100 000124 YV = B(1) * C
000101 000125 AFF = .0000000001
000102 000126 TRANS = EXPF(-Z(1)/AVFP)
000103 000127 TRASS = EXPF(-Z(1)/AFF)
000104 000128 DIST2 = YV * YV * (Z0 + ZS) * (Z0 + ZS)
000105 000129 DIST = SQRT(DIST2)
000106 000130 S(1) = TRANS * (Z0 + ZS) / (12.56636 * DIST2 * DIST)
000107 000131 SS(1) = TRASS * (Z0 + ZS) / (12.56636 * DIST2 * DIST)
000108 000132 X0T(1) = X0T
000109 000133 XMIN(1) = XIN
000110 000134 Z2T(1) = Z0T
000111 000135 ZZN(1) = ZIN
000112 000136 301 CONTINUE
000113 000137 YMIN = XSMIN
000114 000138 YMAX = XSMAX
000115 000139 CALL CARTHM(1, SMIN, SMAX, S, 1)
000116 000140 CALL FRAME
000117 000141 CALL MAPS(YMIN, YMAX, 0, SMAX)
000118 000142 CALL SETORT(B, S, 1)
000119 000143 CALL TRACE(B, S, 1)
000120 000144 CALL SETCH(1, 15, 1, 0, 1, 1)
000121 000145 CALL CRTBCD(16HINTENSITY - COUNTS / SQ CH)
000122 000146 CALL SETCH(10, 1, 1, 0, 1, 0)
000123 000147 CALL CRTBCD(21HX AXIS OF SCREEN - CM)
000124 000148 CALL SETCH(57, 1, 1, 0, 1, 0)
000125 000149 CALL CRTBCD(21HPT SOURCE AT, 0) CM)
000126 000150 CALL SETCH(69, 1, 1, 0, 1, 0) CM)
000127 000151 WRITE(100, 301) C
000128 000152 301 FORAT(F5.2)
000129 000153 FORMT(F5.1)
000130 000154 IF (L.EQ. 1) 501
000131 000155 CALL SETCH(57, 2, 1, 0, 1, 0)
000132 000156 CALL CRTBCD(16H EXTRA = CM)
000133 000157 CALL SETCH(69, 2, 1, 0, 1, 0)
000134 000158 WRITE(100, 500) EXTRA
000135 000159 501 CONTINUE
000136 000160 CALL FRAME
000137 000161 CALL MAPS(YMIN, YMAX, SMIN, SMAX)
000138 000162 CALL SETORT(B, S, 1, 0)
000139 000163 CALL TRACE(B, S, 1)
000140 000164 CALL SETCH(1, 15, 1, 0, 1, 1)
000141 000165 CALL CRTBCD(16HINTENSITY - COUNTS / SQ CH)
000142 000166 CALL SETCH(10, 1, 1, 0, 1, 0)
000143 000167 CALL CRTBCD(21HX AXIS OF SCREEN - CM)
000144 000168 CALL SETCH(57, 1, 1, 0, 1, 0)
000145 000169 CALL CRTBCD(21HPT SOURCE AT, 0) CM)
000146 000170 CALL SETCH(69, 1, 1, 0, 1, 0)
000147 000171 WRITE(100, 301) C
000148 000172 IF (L.EQ. 1) 502
000149 000173 CALL SETCH(57, 2, 1, 0, 1, 0)
000150 000174 CALL CRTBCD(16H EXTRA = CM)
000151 000175 CALL SETCH(69, 2, 1, 0, 1, 0)
000152 000176 WRITE(100, 502) EXTRA
000153 000177 502 CONTINUE
000154 000178 CALL FRAME
000155 000179 CALL MAPS(YMIN, YMAX, 0, SMAX)
000156 000180 CALL SETORT(B, S, 1, 0)
000157 000181 CALL TRACE(B, S, 1)
000158 000182 CALL SETCH(1, 15, 1, 0, 1, 1)
000159 000183 CALL CRTBCD(16HINTENSITY - COUNTS / SQ CH)
000160 000184 CALL SETCH(10, 1, 1, 0, 1, 0)
000161 000185 CALL CRTBCD(21HX AXIS OF SCREEN - CM)
000162 000186 CALL SETCH(57, 1, 1, 0, 1, 0)
000163 000187 CALL CRTBCD(16HBACKSCATTER RADIATION)
000164 000188 CALL SETCH(69, 1, 1, 0, 1, 0)
000165 000189 CALL CRTBCD(21HPT SOURCE AT, 0) CM)
000166 000190 CALL SETCH(69, 1, 1, 0, 1, 0)
000167 000191 WRITE(100, 301) C
000168 000192 IF (L.EQ. 1) 503
000169 000193 CALL SETCH(57, 2, 1, 0, 1, 0)
000170 000194 CALL CRTBCD(16H EXTRA = CM)
000171 000195 CALL SETCH(69, 2, 1, 0, 1, 0)
000172 000196 WRITE(100, 503) EXTRA
000173 000197 503 CONTINUE

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000173	000197	CALL CRTBCD (16)EXTRA =
000174	000488	CALL SETCH (66, 2, 1, 0, 1, 0)
000175	000489	WRITE (100, 500) EXTRA
000176	000500	503 CONTINUE
000177	000501	CALL FNAME
000178	000502	A1 = -1.1 * T/2.
000179	000503	A2 = 1.1 * (T/2. + EX)
000180	000504	A3 = 1.1 * X2
000181	000505	CALL MAPS (A1, A2, -A3, A3)
000182	000506	CALL SETCRT (ZZN, XXT, 1) 0)
000183	000507	CALL POINTS (ZZN, XXT, 1)
000184	000508	CALL SETCRT (ZZT, XXT, 1) 0)
000185	000509	CALL POINTS (ZZT, XXT, 1)
000186	000510	CALL SETCH (1, 15, 1, 0, 1, 1)
000187	000511	CALL CRTBCD (8)X - Axis)
000188	000512	CALL SETCH (10, 1, 1, 0, 1, 0)
000189	000513	CALL CRTBCD (8)Z - Axis)
000190	000514	CALL SETCH (67, 1, 1, 0, 1, 0)
000191	000515	CALL CRTBCD (16)X - Axis)
000192	000516	IF (L EQ 1) 504
000193	000517	CALL SETCH (87, 2, 1, 0, 1, 0)
000194	000518	CALL CRTBCD (16)X - Axis)
000195	000519	CALL SETCH (88, 2, 1, 0, 1, 0)
000196	000520	WRITE (100, 500) EXTRA
000197	000521	504 CONTINUE
000198	000522	IF (L EQ 1) 18,
000199	000523	RETURN
000200	000524	END

APPENDIX II

COMPLETE LISTING OF GRID CODE

```

1*CHAT* C-1880      BCK S84      34 49 45      06/07U      1975
000001 000001      PROGRAM GRID      (TAPE3, TAPE100)
000002 000002      CODE ANALYSIS
000003 000003      DIMENSION SX(100), SY(100), S(100,100), CT(5)
000004 000004      COMMON Z0,01,02,C,XS,Y3,ZS,XSMIN,XSMAX,C,D,AVFP,XP,XL,PATRA
000005 000005      COMMON CSTART,PRES,YRES,SHAX
000006 000006      CALL CRTID (ZHOR,1,1)
000007 000007
000008 000008
000009 000009
000010 000010      UNIT POINT SOURCES PLOTTED MORE THAN ONE AT A TIME
000011 000011
000012 000012      THIS IS A METRIC CODE. ALL DIMENSIONS MUST BE IN CENTIMETERS.
000013 000013      1. PARAMETERS MUST HAVE VALUES ENTERED BELOW
000014 000014      SEE USPL REPORT 51860 WHICH HAS DIRECTIONS FOR USING THIS CODE
000015 000015
000016 000016      PINHOLE RADIUS
000017 000017      R = 0.033
000018 000018
000019 000019      PINHOLE LENGTH
000020 000020      D = 5.
000021 000021
000022 000022      PINHOLE BARRIER THICKNESS
000023 000023      T = 80.
000024 000024
000025 000025      MEAN FREE PATH OF RADIATION IN BARRIER MATERIAL
000026 000026      AVFP = 4.07
000027 000027
000028 000028      SOURCE PLANE DISTANCE FROM CENTER OF PINHOLE BARRIER
000029 000029      Z0 = 102.6
000030 000030
000031 000031      IMAGE PLANE DISTANCE FROM CENTER OF PINHOLE BARRIER
000032 000032      ZS = 197.5
000033 000033
000034 000034      IMAGE SCREEN DEFINITION
000035 000035
000036 000036      MAXIMUM AND MINIMUM "X" VALUES (X EDGES) OF SCREEN
000037 000037      XSMAX = 2.6
000038 000038      XSMIN = -2.6
000039 000039
000040 000040      MAXIMUM AND MINIMUM "Y" VALUES (Y EDGES) OF SCREEN
000041 000041      YSMAX = 2.6
000042 000042      YSMIN = -2.6
000043 000043
000044 000044      UNIT POINT SOURCE LOCATIONS ON "X" AXIS OF SOURCE PLANE
000045 000045      SOURCES CONFINED TO (0 LE X LT RADIUS OF SOURCE PENUMBRA)
000046 000046
000047 000047      THE NUMBER OF UNIT POINT SOURCES AND THE DISTANCE BETWEEN THEM ARE
000048 000048      ENTERED BELOW.
000049 000049
000050 000050      "X" POSITION OF SOURCE NEAREST TO PINHOLE AXIS
000051 000051      START = 0.
000052 000052
000053 000053      THE NUMBER OF UNIT POINT SOURCES TO BE ENTERED
000054 000054      NUMBER = 8
000055 000055
000056 000056      SEPARATION BETWEEN POINT SOURCES ON "X" AXIS OF SOURCE PLANE
000057 000057      DELTA = 0.2
000058 000058
000059 000059      ADDITIONAL THICKNESS ADDED TO REAR OF PINHOLE BARRIER
000060 000060      PINI SUBROUTINE ONLY
000061 000061      EXTRA = 40.
000062 000062
000063 000063
000064 000064
000065 000065
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000101 000101
000102 000102

*****

CSTART = START
NRES = NUMBER
PRES = DELTA
CALL PINI
TANFI = 2. * R/D
SET = 20 * TANFI
SHAG = (ZS+D/2.) / (Z0-D/2.)
RES = 2.*R*(1.+1./SHAG)
R2 = R*R
FLR = 1 * TANFI/2.
FLR2 = FLR * FLR
HFT = T/2.
HFD = D/2.
OVS = (YSMAX - YSMIN) / 800.
OXS = (XSMAX - XSMIN) / 800.
SIN = 0.
LL = 0
YMIN = YSMIN
XMIN = XSMIN
CALL FRAME
CALL MAPS (XSMIN,XSMAX,YSMIN,YSMAX)
CALL SETCH (1,10,1,0,1,1)
CALL CRTBCD (3/4Y DISTANCE FROM CENTER OF SCREEN - CM)
CALL SETCH (10,2,0,1,0)
CALL CRTBCD (3/4X DISTANCE FROM CENTER OF SCREEN - CM)
CALL SETCH (10,1,1,0,1,0)
WRITE(100,905) NRES
CALL SETCH (14,1,0,1,0)
CALL CRTID (45UNIT POINT SOURCES EACH SEPARATED BY CM)
CALL SETCH (80.,1.,1,0,1,0)

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000205 000205

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      L = 3
      LL = LL + 1
      CONTINUE
      L = L + 1
      DO 10 I = 1, 100, 1
        YJ = J
        YS = YJ * 10 + YJ * 0.5
        SY(J) = YS
        DL = 100
        M = 0
      10 CONTINUE
      M = M + 1
      IF (M.EQ.1) , 501
      C = C * 10
      GO TO 200
501 CONTINUE
      C = C * 10
506 CONTINUE
      CS = ZS + C / 20
      D382 = 20 * ZS + (20 * CS) * CS + CS
      X1 = 1
      SX(1) = X1
      Q11 = (X1 * 8) / (2 * C)
      Q12 = (X1 * 23) / (2 * C)
      IF (Q11.EQ.0) , 204
      Q2 = 2 * C * (Q12 - C) / (2 * C - 1)
      AL1 = AL(HPT)
      AL2 = FLR(HFD)
      AL3 = AL(HFD)
      AL4 = AL(HPT)
      F = C * TANF1 * TANF1
      G = 2 * Z0 * Q1 + Q2
      H = Z0 * Z0 * Q1 + 20 * Q1 + C * C
      IF (AL3.GE.FLR2) , 201
      Z1 = 1
      X1 = X(Z1)
      Y1 = Y(Z1)
      GO TO 200
201 CONTINUE
      IF (AL2.GT.R2) , 202
      IF (E.EQ.0.) , 210
      Z1 = -G/F
      X1 = X(Z1)
      Y1 = Y(Z1)
      GO TO 200
210 CONTINUE
      ZA = (-F + SQRT(F*F-4.*G*H)) / (2.*H)
      ZB = (-F - SQRT(F*F-4.*G*H)) / (2.*H)
      IF ((-HFD.LT.ZA).AND.(C.LT.-HFD)) , 203
      Z1 = ZA
      X1 = X(Z1)
      Y1 = Y(Z1)
      GO TO 200
203 CONTINUE
      Z1 = ZB
      X1 = X(Z1)
      Y1 = Y(Z1)
      GO TO 200
204 CONTINUE
      TRANS = 1
      GO TO 300
200 CONTINUE
      IF (AL3.GE.R2) , 206
      ZA = (-F + SQRT(F*F-4.*G*H)) / (2.*H)
      ZB = (-F - SQRT(F*F-4.*G*H)) / (2.*H)
      IF ((-HFD.LT.ZA).AND.(ZA.LE.HFD)) , 207
      Z2 = ZA
      X2 = X(Z2)
      Y2 = Y(Z2)
      GO TO 301
207 CONTINUE
      Z2 = ZB
      X2 = X(Z2)
      Y2 = Y(Z2)
      GO TO 301
206 CONTINUE
      IF (AL4.LT.FLR2) , 208
      ZA = (-F + SQRT(F*F-4.*G*H)) / (2.*H)
      ZB = (-F - SQRT(F*F-4.*G*H)) / (2.*H)
      IF ((HFD.LT.ZA).AND.(ZA.LT.HPT)) , 209
      Z2 = ZA
      X2 = X(Z2)
      Y2 = Y(Z2)

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[illegible]

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000311 000311 WRITE (100,302) 10F
000312 000312 CALL SETCH (85, 4, 1, 0, 1, 0)
000313 000313 CALL CRTBCD (8HNS / MEV)
000314 000314 CALL SETCH (10, 1, 1, 0, 1, 0)
000315 000315 WRITE (100,305) NRES
000316 000316 CALL SETCH (14, 1, 1, 0, 1, 0)
000317 000317 CALL CRTBCD (XSHUN:1 POINT SOURCES EACH SEPARATED BY CM)
000318 000318 CALL SETCH (80, 1, 1, 0, 1, 0)
000319 000319 WRITE (100,304) PRES, 1, 0, 1, 0)
000320 000320 CALL FRAME
000321 000321 CALL EXIT
000322 000322 END
000323 000323 BOX S64 04.43.45 06/07U 1975
000324 000324 FUNCTION AL(Z)
000325 000325 CODE ANALYSIS
000326 000326 COMMON ZD, Q1, Q2, C, XS, YS, ZS, XSMIN, XSMAX, R, D, T, AVFP, ZP, ZDP, EXTRA
000327 000327 COMMON CSTART, PRES, NRES, SMAX
000328 000328 AL = (Z+Z0) * (Z-Z0) * Q1 + (Z+Z0) * Q2 + C=C
000329 000329 RETURN
000330 000330 END
000331 000331 BOX S64 04.43.45 06/07U 1975
000332 000332 FUNCTION X(Z)
000333 000333 CODE ANALYSIS
000334 000334 COMMON ZD, Q1, Q2, C, XS, YS, ZS, XSMIN, XSMAX, R, D, T, AVFP, ZP, ZDP, EXTRA
000335 000335 COMMON CSTART, PRES, NRES, SMAX
000336 000336 X = (Z+Z0) * (XS-C) / (ZS+Z0) + C
000337 000337 RETURN
000338 000338 END
000339 000339 BOX S64 04.43.45 06/07U 1975
000340 000340 FUNCTION Y(Z)
000341 000341 CODE ANALYSIS
000342 000342 COMMON ZD, Q1, Q2, C, XS, YS, ZS, XSMIN, XSMAX, R, D, T, AVFP, ZP, ZDP, EXTRA
000343 000343 COMMON CSTART, PRES, NRES, SMAX
000344 000344 Y = (Z+Z0) * YS / (ZS+Z0)
000345 000345 RETURN
000346 000346 END
000347 000347 BOX S64 04.43.45 06/07U 1975
000348 000348 SUBROUTINE PINI
000349 000349 CODE ANALYSIS
000350 000350 DIMENSION Z(1000), B(1000), S(1000), SS(1000)
000351 000351 DIMENSION KXT(1000), XNM(1000), ZT(1000), ZZN(1000)
000352 000352 COMMON ZD, Q1, Q2, C, XS, YS, ZS, XSMIN, XSMAX, R, D, T, AVFP, ZP, ZDP, EXTRA
000353 000353 COMMON CSTART, PRES, NRES, SMAX
000354 000354 TANF1 = 2.*R/D
000355 000355 RM = R
000356 000356 EX = 0.
000357 000357 L = 0
000358 000358 GO TO 19
000359 000359 1A CONTINUE
000360 000360 EX = EXTRA
000361 000361 19 CONTINUE
000362 000362 L = L + 1
000363 000363 X1 = T * TANF1/2.
000364 000364 X2 = (EX + T/2.) * TANF1
000365 000365 X3 = -X1
000366 000366 X4 = -X2
000367 000367 110 DO I = 1, 1000, 1
000368 000368 Z(I) = 0.
000369 000369 B(I) = 0.
000370 000370 S(I) = 0.
000371 000371 SS(I) = 0.
000372 000372 KXT(I) = 0.
000373 000373 XNM(I) = 0.
000374 000374 ZT(I) = 0.
000375 000375 ZZN(I) = 0.
000376 000376 1 CONTINUE
000377 000377 I = 0
000378 000378 STEP = (XSMAX - XSMIN) / 800.
000379 000379 DO 101 Y = XSMIN, XSMAX, STEP
000380 000380 I = I + 1
000381 000381 M = 0
000382 000382 32 CONTINUE
000383 000383 M = M + 1
000384 000384 IF (M.EQ.1) , 33
000385 000385 C = CSTART
000386 000386 GO TO 34
000387 000387 33 CONTINUE
000388 000388 C = C + PRES
000389 000389 34 CONTINUE
000390 000390 TANTH = (Y-C) / (Z0 + ZS)
000391 000391 XFR = (Z0 - T/2.) * TANTH + C
000392 000392 XENT = (Z0 - D/2.) * TANTH + C
000393 000393 XLVP = (Z0 + D/2.) * TANTH + C
000394 000394 XRE = (Z0 - EX / T/2.) * TANTH + C
000395 000395 IF (XFR .GE. X1) , 2
000396 000396 ZIN = -T/2.
000397 000397 XIN = XFR.
000398 000398 GO TO 21
000399 000399 2 CONTINUE
000400 000400 IF (XENT .GE. R) , 3
000401 000401 ZIN = -Z0 * TANTH + C / (TANTH + TANF1)
000402 000402 RM = -ZIN * TANF1
000403 000403 GO TO 20
000404 000404 3 CONTINUE
000405 000405 IF (XLVP .GE. R1) , 4
000406 000406 ZIN = (R - C) / TANTH - Z0
000407 000407 XIN = R
000408 000408 GO TO 20
000409 000409 4 CONTINUE
000410 000410 IF (XLPV .GE. RM) , 5
000411 000411 5 CONTINUE
000412 000412 IF (XENT .GE. RM) , 6

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000100 000410 ZIN = -(R * C) / TANTH - Z0
000101 000411 MIN = R
000102 000412 GO TO 20
000103 000413 5 CONTINUE
000104 000414 IF (XPR GE. X2) , 7
000105 000415 ZIN = (Z0 * TANTH * C) / (TANFI * TANTH - Z0)
000106 000416 XIN = ZIN * TANFI
000107 000417 GO TO 22
000108 000418 7 CONTINUE
000109 000419 ZIN = T/2
000110 000420 ZIN = (Z0 - T/2) * TANTH - C
000111 000421 20 CONTINUE
000112 000422 IF (XPR GE. X2) , 3
000113 000423 ZOT = EX * T/2
000114 000424 ZOT = C * (Z0 - ZOT) * TANTH
000115 000425 GO TO 22
000116 000426 8 CONTINUE
000117 000427 IF (XPR GE. X2) , 9
000118 000428 ZOT = (C * Z0 * TANTH) / (TANFI - TANTH)
000119 000429 GO TO 22
000120 000430 9 CONTINUE
000121 000431 IF (XPR GE. RH) , 10
000122 000432 ZOT = (R - C) * TANTH - Z0
000123 000433 XOT = R
000124 000434 GO TO 22
000125 000435 10 CONTINUE
000126 000436 IF (XPR GE. X4) , 11
000127 000437 ZOT = -(C * TANTH * C) / (TANFI * TANTH)
000128 000438 XOT = -ZOT * TANFI
000129 000439 GO TO 22
000130 000440 11 CONTINUE
000131 000441 ZOT = EX * T/2
000132 000442 XOT = XRE
000133 000443 22 CONTINUE
000134 000444 ZOT = (ZOT * XIN) * (XOT * XIN) * (ZOT * ZIN) * (ZOT * ZIN)
000135 000445 GO TO 104
000136 000446 20 CONTINUE
000137 000447 ZOT = 0
000138 000448 GO TO 104
000139 000449 10 CONTINUE
000140 000450 ZOT = ZOT * (ZS - Z0) * TANTH
000141 000451 YY = 3(1) - C
000142 000452 APP = .0000000001
000143 000453 TRANS = EXPR(-ZOT) / AVFP
000144 000454 TRASS = EXPR(-ZOT) / AVFP
000145 000455 FIM, EQ 1, 30
000146 000456 DIST2 = YY * YY + (Z0 + ZS) * (Z0 + ZS)
000147 000457 DIST = SQRT(DIST2)
000148 000458 S(1) = TRASS * (Z0 + ZS) / (12.56636 * DIST2 * DIST)
000149 000459 SS(1) = TRASS * (Z0 + ZS) / (12.56636 * DIST2 * DIST)
000150 000460 GO TO 32
000151 000461 30 CONTINUE
000152 000462 DIST2 = YY * YY + (Z0 + ZS) * (Z0 + ZS)
000153 000463 DIST = SQRT(DIST2)
000154 000464 SS(1) = TRASS * (Z0 + ZS) / (12.56636 * DIST2 * DIST) + SS(1)
000155 000465 S(1) = TRASS * (Z0 + ZS) / (12.56636 * DIST2 * DIST) + S(1)
000156 000466 FIM, EQ, NRES , 32
000157 000467 XN(1) = XIN
000158 000468 XN(1) = XIN
000159 000469 ZOT(1) = ZOT
000160 000470 ZN(1) = ZIN
000161 000471 11 CONTINUE
000162 000472 YMIN = XSMIN
000163 000473 YMAX = XSMAX
000164 000474 CALL ARITHMAX (S, 1, 300, 1, 3MIN, 3MAX)
000165 000475 CALL MAP3(YMIN, YMAX, 0, 3MAX)
000166 000476 CALL SETCR (S, 3, 1, 0)
000167 000477 CALL TRACE (B, 5, 1)
000168 000478 CALL SETCR (1, 5, 1, 0, 1, 1)
000169 000479 CALL CRTBCD (2CHINTENSITY - COUNTS / SQ CM)
000170 000480 CALL SETCR (10, 2, 1, 0, 1, 0)
000171 000481 CALL CRTBCD (2HAXIS OF SCRAM - CM)
000172 000482 CALL SETCR (10, 1, 0, 1, 0)
000173 000483 WRITE (100, 302) NRES
000174 000484 CALL SETCR (14, 1, 0, 1, 0)
000175 000485 CALL CRTBCD (40UNIT POINT SOURCES EACH SEPARATED BY CM)
000176 000486 CALL SETCR (150, 2, 1, 0, 1, 0)
000177 000487 WRITE (100, 303) NRES
000178 000488 302 PRINT (1X, 12)
000179 000489 303 PRINT (1X, 12)
000180 000490 304 PRINT (1X, 12)
000181 000491 IF (L EQ. 1) 501
000182 000492 CALL SETCR (C8, 2, 1, 0, 1, 0)
000183 000493 CALL CRTBCD (10EXTRA - CM)
000184 000494 CALL SETCR (76, 2, 1, 0, 1, 0)
000185 000495 WRITE (100, 500) EXTRA
000186 000496 501 CONTINUE
000187 000497 CALL FRAME
000188 000498 CALL MAP3(YMIN, YMAX, 3MIN, 3MAX)
000189 000499 CALL SETCR (B, 5, 1, 0)
000190 000500 CALL TRACE (B, 5, 1)
000191 000501 CALL SETCR (1, 5, 1, 0, 1, 1)
000192 000502 CALL CRTBCD (30HLOG INTENSITY - COUNTS / SQ CM)
000193 000503 CALL SETCR (10, 2, 1, 0, 1, 0)
000194 000504 CALL CRTBCD (2HAXIS OF SCRAM - CM)
000195 000505 CALL SETCR (10, 1, 0, 1, 0)
000196 000506 WRITE (100, 302) NRES
000197 000507 CALL SETCR (14, 1, 0, 1, 0)
000198 000508 CALL CRTBCD (40UNIT POINT SOURCES EACH SEPARATED BY CM)
000199 000509 CALL SETCR (150, 2, 1, 0, 1, 0)
000200 000510 WRITE (100, 303) NRES

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000171 000514 IF (L.EQ. 1) 502
000172 000515 CALL SETCH (8, 2, 1, 0, 1, 0)
000173 000516 CALL CRTBCD (16) EXTRA = CM)
000174 000517 CALL SETCH (76, 2, 1, 0, 1, 0)
000175 000518 WRITE (100, 500) EXTRA
000176 000519 502 CONTINUE
000177 000520 CALL FRAME
000178 000521 CALL SET (MIN, YMAX, 0, SMAX)
000179 000522 CALL SETCT (B, S, 1, 0)
000180 000523 CALL TRACE (B, S, 1, 0)
000181 000524 CALL SETCT (B, S, 1, 0)
000182 000525 CALL TRACE (B, S, 1, 0)
000183 000526 CALL SETCH (1, 18, 1, 0, 1, 1)
000184 000527 CALL CRTBCD (26) HOLE - COUNTS / SQ CM)
000185 000528 CALL SETCH (10, 2, 1, 0, 1, 0)
000186 000529 CALL CRTBCD (16) HOLE OF SCREEN - CM)
000187 000530 CALL SETCH (10, 1, 1, 0, 1, 0)
000188 000531 WRITE (100, 302) NRES
000189 000532 CALL SETCH (14, 1, 1, 0, 1, 0)
000190 000533 CALL CRTBCD (16) HOLE POINT SOURCES EACH SEPARATED BY CM)
000191 000534 CALL SETCH (90, 1, 1, 0, 1, 0)
000192 000535 WRITE (100, 301) PRES
000193 000536 CALL SETCH (68, 1, 1, 0, 1, 0)
000194 000537 CALL CRTBCD (16) BARRIER PENETRATION)
000195 000538 IF (L.EQ. 1) 503
000196 000539 CALL SETCH (68, 2, 1, 0, 1, 0)
000197 000540 CALL CRTBCD (16) EXTRA = CM)
000198 000541 CALL SETCH (76, 2, 1, 0, 1, 0)
000199 000542 WRITE (100, 500) EXTRA
000200 000543 503 CONTINUE
000201 000544 CALL FRAME
000202 000545 A1 = -1.1 * T/2.
000203 000546 A2 = 1.1 * T/2. + EX)
000204 000547 A3 = 1.1 * X2
000205 000548 CALL MAPS (A1, A2, -A2, A3)
000206 000549 CALL SETCT (ZZN, XXN, 1, 0)
000207 000550 CALL POINTS (ZZN, XXN, 1)
000208 000551 CALL SETCT (ZZT, XXT, 1, 0)
000209 000552 CALL POINTS (ZZT, XXT, 1)
000210 000553 CALL SETCH (1, 18, 1, 0, 1, 1)
000211 000554 CALL CRTBCD (8) H - AXIS)
000212 000555 CALL SETCH (10, 1, 1, 0, 1, 0)
000213 000556 CALL CRTBCD (8) H - AXIS)
000214 000557 CALL SETCH (93, 1, 1, 0, 1, 0)
000215 000558 CALL CRTBCD (15) HOLE BARRIER)
000216 000559 IF (L.EQ. 1) 504
000217 000560 CALL SETCH (68, 1, 1, 0, 1, 0)
000218 000561 CALL CRTBCD (16) EXTRA = CM)
000219 000562 CALL SETCH (76, 1, 1, 0, 1, 0)
000220 000563 WRITE (100, 500) EXTRA
000221 000564 504 CONTINUE
000222 000565 IF (L.EQ. 1) 18,
000223 000566 RETURN
000224 000567 END

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