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Numerical Procedure To Determine Geometric View Factors for Surfaces Occluded by Cylinders

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SUMMARY

A numerical procedure has been developed to determine geometric view factors between connected infinite strips occluded by any number of infinite circular cylinders. The procedure requires a two-dimensional cross-sectional model of the configuration of interest. The two-dimensional model consists of a convex polygon enclosing any number of circles. Each side of the polygon represents one strip, and each circle represents a circular cylinder. A description and listing of a computer program based on this procedure are included in this report. The program calculates geometric view factors between individual strips and between individual strips and the collection of occluding cylinders.

INTRODUCTION

Most comprehensive thermal analyzers which deal with radiation (such as MITAS (ref. 1)) require, as part of their input, geometric view factors which define the fraction of radiant energy emanating from one surface and intercepted by another. Reliable computer programs (such as CONFAC II (ref. 2)) are available for calculating geometric view factors for many complex configurations, and geometric view factors for simple configurations can be obtained from tables or calculated by hand. However, a simple method is not currently available for calculating geometric view factors for surfaces occluded by multiple arbitrarily located circular cylinders. This configuration is frequently encountered in heater arrays with tubular elements and can be analyzed with sufficient accuracy for many applications by using a two-dimensional model.

This report describes a numerical procedure to determine geometric view factors between connected infinite strips that enclose any number of arbitrarily located circular cylinders. The computer program which performs the computation and its input requirements are described, and a demonstration problem and a listing of the program are included.

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

C	center of tube
C_{V-J}	configuration factor from view point V to region J
D_1, D_2	two endpoints of destination region
$\overline{D_1 D_2}$	destination region
F_{I-J}	geometric view factor from region I to region J

M	distance in x-direction from view point to center of occluding tube
N	distance in y-direction from view point to center of occluding tube
N_{reg}	number of regions
N_{vp}	number of view points in region
$\vec{n}$	vector normal to source region at view point
P_1, P_2	two endpoints of unshadowed portion of destination region
$\overline{P_1P_2}$	unshadowed portion of destination region
r	radius of tube
S_1, S_2	two endpoints of source region
$\overline{S_1S_2}$	source region
T_1, T_2	two points of tangency
V	view point
X, Y	global axis system
X'	line passing through view point parallel to X-axis
Y'	line passing through view point parallel to Y-axis
x, y	global coordinates
α_1	angle formed by normal to source region at view point and $\overline{VP_1}$, measured clockwise
α_2	angle formed by normal to source region at view point and $\overline{VP_2}$, measured counterclockwise
θ_C	angle from X' to $\overline{VC}$
θ_n	angle from X' to $\vec{n}$
θ_{P_1}	angle from X' to $\overline{VP_1}$
θ_{P_2}	angle from X' to $\overline{VP_2}$
θ_{T_1}	angle from X' to $\overline{VT_1}$
θ_{T_2}	angle from X' to $\overline{VT_2}$
$\Delta\theta$	$= \theta_C - \theta_{T_1}$

Subscripts:

D	destination region
S	source region
T	tubes
V	view point

GENERAL DESCRIPTION OF NUMERICAL PROCEDURE

A numerical procedure was developed to compute geometric view factors between connected infinite strips that enclose any number of arbitrarily located circular cylinders. The procedure requires a two-dimensional cross-sectional model of the configuration of interest. The two-dimensional model consists of a convex polygon enclosing any number of circles, hereafter called tubes. Each side of the polygon represents one strip, and the tubes represent the circular cylinders. Any number of strips and cylinders may be defined in the model with no change to the computer program itself, because computer memory is dynamically allocated according to problem size. There is, of course, a maximum number of strips and tubes that may be analyzed within the user's computer memory allotment.

ANALYSIS

The geometric view factors required as input in most comprehensive thermal analyzers may be approximated for many applications by geometric view factors based on a two-dimensional cross-sectional model of the configuration of interest. A typical cross-sectional model of a pentagonal enclosure with three arbitrarily located circular cylinders is illustrated in figure 1. In the two-dimensional analysis, geometric view factors are required from each side of the pentagon to each remaining side and also from each side to the collection of circles. Since a geometric view factor represents the fraction of radiant energy emanating from one region which is intercepted by another, one side of the model must be considered a "source" region while all others are in turn considered "destination" regions. In figure 1, region $\overline{S_1S_2}$ is the source region, region $\overline{D_1D_2}$ is the destination region, and the geometric view factor computed is from $\overline{S_1S_2}$ to $\overline{D_1D_2}$.

The equation for this geometric view factor involves an integration over the source region, which is performed using a closed-form approach when occlusion is not present. In complicated configurations, however, the integration is performed by dividing the source region into a finite number of subregions and averaging the geometric view factors from all subregions. The energy emanating from each of the subregions is considered constant over that subregion, so a representative point, called a view point, at the center of the subregion may be used as the energy source in the computation. The fraction of total energy emanating from this view point which is intercepted by the destination region is called the configuration factor from the point to the region. Hence, the geometric view factor from a source region to a destination region is the average of configuration factors from a finite number of view points spaced evenly along the source region. The number of view points used in computation may be increased to improve the accuracy of the resulting geometric view factor.

When there is no occlusion between source and destination regions, this computation is relatively simple to perform. If no tubes are present in the triangle formed by the view point and the endpoints of the destination region, then the destination region receives all radiant energy cast in its direction from the view point. If tubes are present in the triangle, however, the tubes intercept a fraction of this energy, and the configuration factor to that destination region is proportionately reduced. The triangle formed by the view point and the ends of the destination region is called the look wedge. When occlusions are present, the configuration factor from a view point to the destination region is equal to the sum of the configuration factors from that view point to each unshadowed portion of the destination region. In figure 1, the occluding tubes obscure only the ends of the destination region; therefore, only one unshadowed portion must be considered. An unshadowed portion within a look wedge is always defined by the edges of the look wedge or by lines tangent to occluding tubes from the view point.

To determine which tubes lie inside the look wedge, angles from X' to the lines from the view point to the two points of tangency must be computed. Figure 2 shows the geometry used to compute the angles θ_{T_1} and θ_{T_2} to the tangent lines. In the figure, M represents the distance in the x-direction from V to the center C of the tube, N represents the distance in the y-direction, and r is the radius of the tube. By trigonometric manipulation,

$$\cos \theta_{T_1} = \frac{M\sqrt{M^2 + N^2 - r^2} + rN}{M^2 + N^2}$$

and

$$\cos \theta_{T_2} = \frac{M\sqrt{M^2 + N^2 - r^2} - rN}{M^2 + N^2}$$

These cosines and the corresponding sines are used to compute the two angles. A comparison of the angles defining the look wedge and the angles to the tangent lines of each tube identifies occluding tubes for the look wedge. These angles are then used to define the unshadowed portions of the destination region to which the configuration factors must be computed.

A configuration factor $C_{V-\overline{P_1P_2}}$ from a view point V on a source region to an unshadowed region $\overline{P_1P_2}$ may be computed according to the following formula (ref. 3, p. 141):

$$C_{V-\overline{P_1P_2}} = \frac{1}{2}\left(\sin \alpha_1 + \sin \alpha_2\right)$$

where α_1 and α_2 are angles formed by the normal to the source region at V and lines connecting V and the two ends of region P_1P_2. Angle α_1 is measured clockwise from the normal and α_2 is measured counterclockwise. Figure 3 illustrates the angles necessary for the computation of this configuration factor.

For each view point, configuration factors from the view point to all unshadowed portions of the destination region are summed to obtain the configuration factor C_{V-D} from the view point to the destination region. The mean of configuration factors from all view points in the source region is the geometric view factor F_{S-D} from the source region to the destination region; that is,

$$F_{S-D} = \frac{1}{N_{vp}} \sum_{V=1}^{N_{vp}} C_{V-D}$$

where N_{vp} is the number of view points in the source region. A geometric view factor is computed in a similar manner for every source and destination region within the enclosure. The energy conservation principle dictates that

$$\sum_{D=1}^{N_{reg}} F_{S-D} + F_{S-T} = 1$$

where N_{reg} is the number of regions defined in the polygonal model. Therefore, the view factor F_{S-T} from the source region to the collection of occluding tubes may also be calculated.

This analysis may be generalized for nonconvex arrangements of regions. In this case, the possibility of occluding regions as well as occluding tubes must be taken into consideration, but the concept of summation of configuration factors to unshadowed regions remains the same.

IMPLEMENTATION OF NUMERICAL PROCEDURE

Computer Program

Program VIEWFAC computes geometric view factors according to the analysis just described. It was written in FORTRAN Extended 4.6 language for a Control Data CYBER computer under network operating system (NOS) 1.2. The program occupies 22076 octal locations in memory, and additional memory is required for the storage of arrays of problem-related data. The dynamic allocation of blank common allows the user to specify memory requirements as a function of the problem size according to the following formula:

$$(\text{Memory required})_8 \approx 22076_8 + \Big((\text{No. of regions})^2 + 5(\text{No. of regions} + \text{No. of tubes})\Big)_8$$

A simplified flow chart of program VIEWFAC is shown in figure 4. Input data required by the program are (1) the number of regions and tubes in the model, (2) coordinates of the endpoints of each region, (3) the number of subregions into which each region is to be divided, (4) coordinates of each tube center, and (5) the radius of each tube. Details of data input are given in appendix A, and a listing of the program is presented in appendix B. The program prints out the input data, computed geometric view factors, and also an area-weighted geometric view factor (AF), which may be used to check reciprocity within the model.

Many check cases were used to verify the computer program; two of them are shown in figure 5. The reciprocity between regions was demonstrated with the check case shown in figure 5(a) in which there were no occluding tubes present. The check case in figure 5(b) verified the detection of an occluding tube and the subsequent computation of configuration factors to unoccluded subregions. These cases are simple enough to be analyzed with a hand calculator in order to check the values generated by the program.

Demonstration Problem

The problem chosen to demonstrate the use of program VIEWFAC is one configuration of a quartz-lamp radiant heater currently in use in thermal structures research at the Langley Research Center. (See fig. 6.) The heater consists of an array of quartz lamps. The arrangement of the lamps - number of lamps, distance between lamps, and number of rows of lamps - may be varied according to the particular application. In the demonstration problem, 41 pairs of lamps were arranged in a single row, and a cross section of half of the symmetric array (41 lamps) was modeled for the analysis.

The area surrounding the array was divided into regions. The purpose of the heater analysis was to determine the heat flux uniformity near the ends of the array; therefore, the area near the end was modeled in more detail. Figure 6(a) shows the region definitions, and figure 6(b) shows the position of the row of lamps between the upper and lower regions. Region 22, located along the line of symmetry, actually represented the half of the heater which was not modeled for analysis. In the demonstration problem, all regions were divided into 10 subregions, except regions 10 and 20 which were divided into 120 subregions because of their longer length. A listing of program input and output for this problem is included in appendix C.

Figure 7 shows the effect of occlusion by the tubes on the geometric view factors from a typical lower region, region 4, to upper regions. The difference in the values with and without occlusion is a measure of the amount of energy intercepted by the tubes between region 4 and the upper regions.

For each region I,

$$\left(\text{Area}_{I}\right)\left(\text{View Factor}_{I\text{-Lamps}}\right) = \left(\text{Area}_{\text{Lamps}}\right)\left(\text{View Factor}_{\text{Lamps-}I}\right)$$

Therefore, the geometric view factors from each region to the lamps are also an indication of the amount of radiant energy that each region receives from the lamps. A comparison of these values indicated that the amount of radiant energy received from the lamps near the end of the heater was significantly less than that received nearer the center line. These results are shown graphically in figure 8.

CONCLUDING REMARKS

A numerical procedure has been developed to determine geometric view factors between connected infinite strips occluded by any number of infinite, arbitrarily located, circular cylinders. A description of the procedure, a listing of the computer program based on this procedure, and a discussion of a demonstration problem are given. Taking into account possible occlusion by the cylinders, the computer program calculates the geometric view factors between the individual strips. The program also calculates the geometric view factors between the individual strips and the collection of occluding cylinders.

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APPENDIX A

INPUT REQUIRED FOR PROGRAM VIEWFAC

The input data for program VIEWFAC are defined in this appendix. The list-directed read capability of FORTRAN is used for all input; therefore, data values on each card must be separated by commas or blanks and may be positioned anywhere within the 80 columns. Real-type data values must contain a decimal point. A data value must be input for every variable read; a blank card or field does not cause variables to be set to zero.

Input cards are of the following five types and must appear in the order discussed:

The configuration card contains one value (NCONFIG, an integer-type variable) which specifies the number of configurations to be analyzed. For each configuration, a set of the following four types of cards must be input.

The title card contains up to 80 characters describing the configuration to be analyzed. This card may be blank but must be present.

The problem-size card contains two values (NREG and NTUBE, integer-type variables) specifying the number of regions and tubes to be defined in this configuration. If no tubes are present in the configuration, a zero may be input for NTUBE.

A region-definition card must be input for each region defined in the configuration. Each card contains five values:

(1) The x-coordinate of the first endpoint of the region (REGX1, a real-type variable).

(2) The y-coordinate of the first endpoint of the region (REGY1, a real-type variable).

(3) The x-coordinate of the second endpoint of the region (REGX2, a real-type variable).

(4) The y-coordinate of the second endpoint of the region (REGY2, a real-type variable).

(5) The number of subregions into which the region is to be divided (IDELREG, an integer-type variable). A view point is automatically located at the midpoint of each subregion during the computation of the configuration factor for the region.

Either end of the region may be designated the first end. The x- and y-coordinates of the endpoints are relative to a global origin defined by the user for the entire configuration.

A tube-definition card must be input for each tube defined in the configuration. Each card contains three values:

(1) The x-coordinate of the center of the tube (TUBX, a real-type variable).

(2) The y-coordinate of the center of the tube (TUBY, a real-type variable).

(3) The radius of the tube (TUBRAD, a real-type variable).

The x- and y-coordinates at the center of the tube are also relative to the global origin defined by the user. If NTUBE is input as zero on the problem-size card, no tube-definition cards should be input.

A listing of input for a demonstration problem is contained in appendix C.

APPENDIX B

LISTING OF PROGRAM VIEWFAC

```
      PROGRAM VIEWFAC(INPUT,OUTPUT)
C
C  THIS PROGRAM CALCULATES VIEW FACTORS FROM ONE REGION
C   TO ANOTHER WHEN THE SECOND SURFACE MAY BE OCCLUDED
C   BY ONE OR MORE ROUND OBJECTS
C
      COMMON /CON/ PI
      COMMON /POINTER/ KREGX1,KREGY1,KREGX2,KREGY2,KDELREG,KTUBX,KTUBY,
     .  KTUBRAD,KTUBIN,KVFRE
      COMMON /LIMITS/ NCONFIG,NREG,NTUBE,TITLE(8)
      COMMON ICORE(1)
      DIMENSION CORE(1)
      EQUIVALENCE (CORE,ICORE)
C
C CALCULATE CONSTANTS
      PI=ACOS(-1.)
C
C CONFIGURATION CASE LOOP
      READ *,NCONFIG
      DO 100 I=1,NCONFIG
      CALL PROBSIZ
      CALL INPUT (CORE(KREGX1),CORE(KREGY1),CORE(KREGX2),CORE(KREGY2),
     .  ICORE(KDELREG),CORE(KTUBX),CORE(KTUBY),CORE(KTUBRAD))
      CALL FACTOR (CORE(KREGX1),CORE(KREGY1),CORE(KREGX2),CORE(KREGY2),
     .  ICORE(KDELREG),CORE(KTUBX),CORE(KTUBY),CORE(KTUBRAD),
     .  CORE(KTUBIN),CORE(KVFRE),NREG,NTUBE)
      CALL PRINT (CORE(KVFRE),NREG,CORE(KREGX1),CORE(KREGY1),
     .  CORE(KREGX2),CORE(KREGY2))
  100 CONTINUE
C
      STOP
      END
```

APPENDIX B

```
      SUBROUTINE FACTOR (REGX1,REGY1,REGX2,REGY2,IDELREG,TUBX,TUBY,
     .   TUBRAD,TUBIN,VFRE,NREG,NTUBE)
C
C  THIS SUBROUTINE CALCULATES VIEW FACTORS FROM EACH REGION TO
C   ALL OTHER REGIONS
C
      DIMENSION VFRE(NREG,1)
      DIMENSION REGX1(1),REGX2(1),REGY1(1),REGY2(1),TUBX(1),TUBY(1)
      DIMENSION IDELREG(1)
      DIMENSION TUBRAD(1)
      DIMENSION TUBIN(3,1)
C
C LOOP ON SOURCE REGION
      DO 300 ISREG=1,NREG
      NVP=IDELREG(ISREG)
C
C LOOP ON DESTINATION REGION
      DO 200 IDREG=1,NREG
C
C DO NOT COMPUTE VF FROM ELEMENT TO ITSELF
      VFRE(ISREG,IDREG)=0.
      IF (IDREG.EQ.ISREG) GOTO 200
      VFVPSUM=0.
C
C LOOP ON VIEW POINT
      DO 100 IVP=1,NVP
C
C FIND COORDINATES OF CURRENT VIEW POINT IN SOURCE REGION
C  AND ANGLE TO NORMAL OF SOURCE REGION
      CALL VPINFO (REGX1(ISREG),REGY1(ISREG),REGX2(ISREG),REGY2(ISREG),
     .   NVP,IVP,XP,YP,SNORM)
C
C FIND ANGLES FROM VIEW POINT TO ENDS OF DESTINATION REGION
      CALL LOOKWDG (XP,YP,REGX1(IDREG),REGY1(IDREG),REGX2(IDREG),
     .   REGY2(IDREG),ANG1,ANG2)
C
C CHECK IF VIEW POINT AND DESTINATION REGION ARE COLINEAR
      IF (ANG2-ANG1.LE.1.E-10) GOTO 200
C
C IDENTIFY TUBES IN LOOK WEDGE, COMPUTE ANGLES TO THEM, AND ORDER THEM
      CALL TUBID (XP,YP,ANG1,ANG2,TUBX,TUBY,TUBRAD,TUBIN,NTUBIN)
C
C  TEST FOR TOTAL OCCLUSION FROM THIS VIEW POINT
      IF (NTUBIN.LE.NTUBE) GOTO 50
      VFVPVAL=0.
      GOTO 60
C
C COMPUTE VIEW FACTOR CONTRIBUTION FROM CURRENT VIEW POINT
   50 CALL VFVP (TUBIN,VFVPVAL,NTUBIN,ANG1,ANG2,SNORM)
   60 VFVPSUM=VFVPSUM+VFVPVAL
  100 CONTINUE
      VFRE(ISREG,IDREG)=VFVPSUM/FLOAT(NVP)
  200 CONTINUE
  300 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE INPUT (REGX1,REGY1,REGX2,REGY2,IDELREG,TUBX,TUBY,
     .  TUBRAD)
C
C  THIS SUBROUTINE DEFINES AND PRINTS CONFIGURATIONS OF
C   REGIONS AND TUBES
C
      COMMON /LIMITS/ NCONFIG,NREG,NTUBE,TITLE(8)
      DIMENSION REGX1(1),REGX2(1),REGY1(1),REGY2(1),TUBX(1),TUBY(1)
      DIMENSION IDELREG(1)
      DIMENSION TUBRAD(1)
C
C REGION DEFINITION
      DO 10 I=1,NREG
      READ *, REGX1(I),REGY1(I),REGX2(I),REGY2(I),IDELREG(I)
   10 CONTINUE
C
C TUBE DEFINITION
      IF (NTUBE.EQ.0) GOTO 25
      DO 20 I=1,NTUBE
      READ *, TUBX(I),TUBY(I),TUBRAD(I)
   20 CONTINUE
C
C PRINT
   25 PRINT 1000
 1000 FORMAT (1X,27HCONFIGURATION DEFINITION:  ,
     .  //28X,4HEND1,36X,4HEND2,19X,10HNO. REGION /
     . 2X,8HREG. NO.,7X,8HX-COORD.,12X,8HY-COORD.,
     . 12X,8HX-COORD., 12X,8HY-COORD.,
     . 6X,10HINCREMENTS /)
      DO 30 I=1,NREG
      PRINT 1001,I,REGX1(I),REGY1(I),REGX2(I),REGY2(I),IDELREG(I)
 1001 FORMAT (3X,I5,5X,F15.5,5X,F15.5,5X,F15.5,5X,F15.5,5X,I5)
   30 CONTINUE
      IF (NTUBE.EQ.0) GOTO 50
      PRINT 1002
 1002 FORMAT (/28X, 6HCENTER /2X, 8HTUBE NO.,7X,8HX-COORD.,12X,
     .  8HY-COORD.,13X,6HRADIUS/)
      DO 40 I=1,NTUBE
      PRINT 1003,I,TUBX(I),TUBY(I),TUBRAD(I)
 1003 FORMAT (3X,I5,5X,F15.5,5X,F15.5,5X,F15.5)
   40 CONTINUE
C
   50 RETURN
      END
```

APPENDIX B

```
      SUBROUTINE LOCATE (XP,YP,TX,TY,TRAD,ANGT1,ANGT2)
C
C THIS SUBROUTINE COMPUTES THE ANGLES FROM THE CURRENT VIEW POINT TO
C  THE CURRENT TUBE RADIUS
C
      COMMON /CON/ PI
C
C COMPUTE COSINES
      DISTX=TX-XP
      DISTY=TY-YP
      DISTX2=DISTX*DISTX
      DISTY2=DISTY*DISTY
      TRAD2=TRAD*TRAD
      RAD=SQRT(DISTX2+DISTY2-TRAD2)
C  TEST FOR TUBE TOUCHING VIEW POINT
      IF (RAD.LT.(1.E-10)) GOTO 10
      TERM1=(DISTX*RAD)/(DISTX2+DISTY2)
      TERM2=(TRAD*DISTY)/(DISTX2+DISTY2)
      COST1=TERM1+TERM2
      COST2=TERM1-TERM2
      SINT1=(DISTY-TRAD*COST1)/RAD
      SINT2=(DISTY+TRAD*COST2)/RAD
C
C COMPUTE ANGLES
      ANGT1=ACOS(COST1)
      ANGT2=ACOS(COST2)
      IF (SINT1.LT.0.) ANGT1=PI+PI-ANGT1
      IF (SINT2.LT.0.) ANGT2=PI+PI-ANGT2
      GOTO 20
C
C  IF TUBE IS TOUCHING VIEW POINT, SET BOTH ANGLES=0.
   10 ANGT1=0.
      ANGT2=0.
      GOTO 30
C
C ORDER ANGLES
   20 IF (ANGT1.LT.ANGT2) RETURN
      DUM=ANGT1
      ANGT1=ANGT2
      ANGT2=DUM
C
C  CHECK FOR ANGLE ASTRIDE X AXIS
      IF ((ANGT2-ANGT1).LT.PI) GOTO 30
      DUM=ANGT2
      ANGT2=PI+PI+ANGT1
      ANGT1=DUM
C
   30 RETURN
      END
```

```
      SUBROUTINE LOOKWDG(XP,YP,X1,Y1,X2,Y2,ANG1,ANG2)
C
C THIS SUBROUTINE CALCULATES THE ANGLES FORMING THE
C  LOOK WEDGE FROM THE CURRENT VIEW POINT TO THE DESTINATION ELEMENT
C
      COMMON /CON/ PI
C
C ANGLE TO FIRST EDGE
      DELX=X1-XP
      DELY=Y1-YP
      DENOM=SQRT(DELX*DELX+DELY*DELY)
      COS1=DELX/DENOM
      SIN1=DELY/DENOM
      ANG1=ACOS(COS1)
      IF (SIN1.LT.0.) ANG1=PI+PI-ANG1
C
C ANGLE TO SECOND EDGE
      DELX=X2-XP
      DELY=Y2-YP
      DENOM=SQRT(DELX*DELX+DELY*DELY)
      COS2=DELX/DENOM
      SIN2=DELY/DENOM
      ANG2=ACOS(COS2)
      IF (SIN2.LT.0.) ANG2=PI+PI-ANG2
C
C ORDER ANGLES
      IF (ANG1.LT.ANG2) GOTO 10
      DUM=ANG1
      ANG1=ANG2
      ANG2=DUM
C
C  CHECK FOR ANGLE ASTRIDE X AXIS
   10 IF ((ANG2-ANG1).LT.PI) RETURN
      DUM=ANG2
      ANG2=PI+PI+ANG1
      ANG1=DUM
C
      RETURN
      END
```

APPENDIX B

```
      SUBROUTINE PRINT (VFRE,NREG,REGX1,REGY1,REGX2,REGY2)
C
C THIS SUBROUTINE PRINTS VIEW FACTORS FROM EACH REGION TO ALL OF THE
C  OTHERS, AND TO THE TUBES
C
      DIMENSION REGX1(1),REGX2(1),REGY1(1),REGY2(1)
      DIMENSION VFRE(NREG,1)
C
      PRINT 1000
 1000 FORMAT (1H1)
      DO 200 ISREG=1,NREG
      PRINT 1001,ISREG
 1001 FORMAT (/1X,25HVIEW FACTORS FROM REGION ,I3)
      SAREA=SQRT(((REGX1(ISREG)-REGX2(ISREG))**2)+((REGY1(ISREG)-
     .  REGY2(ISREG))**2))
      SUM=0.
      DO 100 IDREG=1,NREG
      AF=SAREA*VFRE(ISREG,IDREG)
      PRINT 1002,IDREG,VFRE(ISREG,IDREG),AF
 1002 FORMAT (5X,10HTO REGION ,I3,2H= ,F8.5,6H,   AF= ,F15.5)
      SUM=SUM+VFRE(ISREG,IDREG)
  100 CONTINUE
      AFS=SAREA*SUM
      VFTUB=1.-SUM
      AFT=VFTUB*SAREA
      PRINT 1003,SUM,AFS,VFTUB,AFT
 1003 FORMAT (5X,18HTO ALL ELEMENTS =  ,F9.5,6H   AF= ,F15.5/
     . 5X,11HTO TUBES = ,F8.5,7H,   AF= ,F15.5)
  200 CONTINUE
C
      RETURN
      END
```

APPENDIX B

```
      SUBROUTINE PROBSIZ
C
C  THIS SUBROUTINE DEFINES THE SIZE OF THE PROBLEM
C   AND FIXES POINTERS TO BEGINNING LOCATIONS OF THE
C   ARRAYS NEEDED FOR COMPUTATIONS
C
      COMMON /POINTER/ KREGX1,KREGY1,KREGX2,KREGY2,KDELREG,KTUBX,KTUBY,
     .  KTUBRAD,KTUBIN,KVFRE
      COMMON /LIMITS/ NCONFIG,NREG,NTUBE,TITLE(8)
C
C CASE TITLE
      READ 1000, TITLE
 1000 FORMAT (8A10)
      PRINT 1001, (TITLE(I),I=1,8)
 1001 FORMAT (1H1,7HCASE:  ,8A10/1X,5H-----,//)
C
C LIMITS
      READ *,NREG,NTUBE
      PRINT 1002,NREG,NTUBE
 1002 FORMAT (1X,16HNO. OF REGIONS= ,I5,/1X,14HNO. OF TUBES= ,I5//)
C
C ARRAY POINTERS FOR DYNAMIC CORE ALLOCATION
      KREGX1=1
      KREGY1=KREGX1+NREG
      KREGX2=KREGY1+NREG
      KREGY2=KREGX2+NREG
      KDELREG=KREGY2+NREG
      KTUBX=KDELREG +NREG
      KTUBY=KTUBX+NTUBE
      KTUBRAD=KTUBY+NTUBE
      KTUBIN=KTUBRAD+NTUBE
      KVFRE=KTUBIN+(NTUBE*3)
C
      RETURN
      END
```

APPENDIX B

```
      SUBROUTINE RSORT (NROW,NCOL,ISC,B)
C
C  THIS SUBROUTINE PERFORMS A KEY BUBBLE SORT,
C   ORDERING THE COLUMNS IN INCREASING ORDER
C   ACCORDING TO THE VALUES IN A KEY ROW
C
      DIMENSION B(NROW,NCOL)
C
C  TEST FOR TRIVIAL CASE OF ONE COLUMN
      IF (NCOL.EQ.1) RETURN
C
C  SORT
      NSRT=NCOL-1
      DO 100 I=1,NSRT
      IEND=NCOL+1-I
      DO 50 J=2,IEND
      ITEST=J-1
      IF (B(ISC,J).GE.B(ISC,ITEST)) GOTO 50
      DO 20 K=1,NROW
      SAVE=B(K,J)
      B(K,J)=B(K,ITEST)
      B(K,ITEST)=SAVE
   20 CONTINUE
   50 CONTINUE
  100 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE SUMMER (VFVPVAL,ANG1,ANG2,SNORM)
C
C  THIS SUBROUTINE SUMS SINES OF ANGLES FORMED BY THE
C   NORMAL TO THE SOURCE REGION AND THE EDGES OF THE
C   DESTINATION REGION
C
      COMMON /CON/ PI
C
      IF ((ANG1.LE.SNORM).AND.(ANG2.GE.SNORM)) GOTO 10
C
C  NORMAL LIES OUTSIDE TWO ANGLES
      PHI1=ABS(ANG1-SNORM)
      PHI2=2.*PI-ABS(ANG2-SNORM)
      GOTO 20
C
C  NORMAL LIES BETWEEN TWO ANGLES
   10 PHI1=ABS(ANG1-SNORM)
      PHI2=ABS(ANG2-SNORM)
C
   20 SINTERM=SIN(PHI1)+SIN(PHI2)
      VFVPVAL=VFVPVAL+.5*ABS(SINTERM)
C
      RETURN
      END
```

```
      SUBROUTINE TUBID (XP,YP,ANG1,ANG2,TUBX,TUBY,TUBRAD,TUBIN,NTUBIN)
C
C THIS SUBROUTINE IDENTIFIES TUBES IN THE CURRENT LOOK WEDGE AND SORTS
C  THEM ACCORDING TO THEIR POSITION IN THE WEDGE
C
      COMMON /LIMITS/ NCONFIG,NREG,NTUBE,TITLE(8)
      COMMON /CON/ PI
      DIMENSION TUBIN(3,1)
      DIMENSION TUBRAD(1)
      DIMENSION TUBX(1),TUBY(1)
C
C IDENTIFY TUBES IN THE LOOK WEDGE
      NTUBIN=0
      IF (NTUBE.EQ.0) GOTO 20
      DO 10 ITUBE=1,NTUBE
      CALL LOCATE (XP,YP,TUBX(ITUBE),TUBY(ITUBE),TUBRAD(ITUBE),ANGT1,
     .  ANGT2)
C
C  TEST FOR TOTAL OCCLUSION
      IF ((ANGT1.EQ.ANGT2).AND.(ANGT1.EQ.0.)) GOTO 15
C
C  ADJUST FOR ONE OR MORE ANGLES ASTRIDE X AXIS
      IF ((ANG2.GE.(PI+PI)).AND.(ANGT1.LT.(ANG2-(PI+PI))))GOTO 2
      IF ((ANG2.LT.(PI+PI)).AND.(ANGT2.GT.(PI+PI))) GOTO 3
      GOTO 5
C
C  LOOK WEDGE ASTRIDE X AXIS, TUBE IS IN WEDGE BUT NOT ASTRIDE
    2 ANGT1=PI+PI+ANGT1
      ANGT2=PI+PI+ANGT2
      GOTO 5
C
C  TUBE ASTRIDE X AXIS, LOOK WEDGE NOT ASTRIDE
    3 ANGT1=0.
      ANGT2=ANGT2-(PI+PI)
C
C  COMPARE ANGLES AND LOAD TABLE OF OCCLUDING TUBES
    5 IF (ANGT1.GT.ANG2) GOTO 10
      IF (ANGT2.LT.ANG1) GOTO 10
      NTUBIN=NTUBIN+1
      TUBIN(1,NTUBIN)=ITUBE
      TUBIN(2,NTUBIN)=ANGT1
      TUBIN(3,NTUBIN)=ANGT2
   10 CONTINUE
C
C SORT TABLE OF TUBES AND ANGLES
      IF (NTUBIN.LE.1) GOTO 20
      CALL RSORT (3,NTUBIN,2,TUBIN)
      GOTO 20
C
C  TOTAL OCCLUSION DUE TO TUBE TOUCHING VIEW POINT.
C  SET NTUBIN.LT.NTUBE TO FLAG THIS.
   15 NTUBIN=NTUBE+1
C
   20 RETURN
      END
```

APPENDIX B

```
      SUBROUTINE VFVP (TUBIN,VFVPVAL,NTUBIN,ANG1,ANG2,SNORM)
C
C THIS SUBROUTINE COMPUTES THE CONTRIBUTION OF THE CURRENT VIEW POINT
C  TO THE VIEW FACTOR FROM THE CURRENT SOURCE REGION TO THE CURRENT
C  DESTINATION REGION
C
      DIMENSION TUBIN(3,1)
C
C  INITIALIZE SUM
      VFVPVAL=0.
C
C EXAMINE EACH TUBE IN LOOK WEDGE
      IF (NTUBIN.NE.0) GOTO 10
      CALL SUMMER (VFVPVAL,ANG1,ANG2,SNORM)
      GOTO 200
   10 DO 100 IT=1,NTUBIN
      ANGT1=TUBIN(2,IT)
      ANGT2=TUBIN(3,IT)
      IF ((ANGT1.LE.ANG1).AND.(ANGT2.LE.ANG1)) GOTO 100
      IF ((ANGT1.LE.ANG1).AND.(ANGT2.GE.ANG2)) GOTO 200
      IF ((ANGT1.GT.ANG1).AND.(ANGT2.LT.ANG2)) GOTO 50
      IF ((ANGT1.LE.ANG1).AND.(ANGT2.LT.ANG2)) GOTO 60
      IF ((ANGT1.GT.ANG1).AND.(ANGT2.GE.ANG2)) GOTO 70
C
C TUBE IS TOTALLY WITHIN LOOK WEDGE
   50 CALL SUMMER (VFVPVAL,ANG1,ANGT1,SNORM)
      ANG1=ANGT2
      GOTO 100
C
C TUBE OCCLUDES FIRST PART OF LOOK WEDGE
   60 ANG1=ANGT2
      GOTO 100
C
C TUBE OCCLUDES LAST PART OF LOOK WEDGE
   70 CALL SUMMER (VFVPVAL,ANG1,ANGT1,SNORM)
      GOTO 200
  100 CONTINUE
C  ADD IN CONTRIBUTION FROM LAST PART OF LOOK WEDGE
      CALL SUMMER (VFVPVAL,ANG1,ANG2,SNORM)
C
  200 RETURN
      END
```

APPENDIX B

```
      SUBROUTINE VPINFO (X1,Y1,X2,Y2,NVP,IVP,XP,YP,SNORM)
C
C THIS SUBROUTINE COMPUTES THE X-Y COORDINATES OF THE CURRENT VIEW POINT
C
      COMMON /CON/ PI
C
      IF (IVP.NE.1) GOTO 100
C
C  COMPUTE ANGLE TO NORMAL OF SOURCE REGION
      DELX=X2-X1
      DELY=Y2-Y1
      IF (DELY.EQ.0.) GOTO 10
      TANORM=-DELX/DELY
      SNORM=ATAN(TANORM)
      IF (SNORM.LE.0.) SNORM=PI+SNORM
      GOTO 20
   10 SNORM=PI*.5
C
C COMPUTE X-Y INCREMENT FOR NEW VIEW POINT ON FIRST PASS THROUGH
C  SUBROUTINE
   20 XINC=(X2-X1)/FLOAT(NVP)
      YINC=(Y2-Y1)/FLOAT(NVP)
      XP=X1+XINC*.5
      YP=Y1+YINC*.5
      RETURN
C
  100 XP=XP+XINC
      YP=YP+YINC
C
      RETURN
      END
```

APPENDIX C

DEMONSTRATION PROBLEM

In this appendix, the input required and the printout generated by program VIEWFAC is given for a demonstration problem. The problem is a quartz-lamp radiant heater consisting of an array of 41 pairs of lamps. A two-dimensional model of the heater is shown in figure 6.

A closed area around the lamps was divided into 22 regions. Geometric view factors were computed from each region to each other region, from each region to all other regions, and from each region to the lamps. The view factors were required as input to the MITAS thermal analyzer (ref. 1) used to determine the heat flux near the edges of the heater.

This problem required 23535 octal memory locations and 93.315 seconds of execution time on a Control Data CYBER 173 computer system.

Program Input

Configuration card: 1

Title card: QUARTZ LAMP RADIANT HEATER, 2-TUBE CONFIGURATION

Problem-size card: 22 41

Region-definition cards:

```
0.    0.     .75 0.     10
0.75 0.    1.95 0.     10
1.95 0.    3.15 0.     10
3.15 0.    4.35 0.     10
4.35 0.    5.55 0.     10
5.55 0.    6.75 0.     10
6.75 0.    7.95 0.     10
7.95 0.    9.15 0.     10
9.15 0.   10.35 0.     10
10.35  0.   24.75   0.   120
0.     2.38    .75   2.38  10
0.75   2.38  1.95   2.38  10
1.95   2.38  3.15   2.38  10
3.15   2.38  4.35   2.38  10
4.35   2.38  5.55   2.38  10
5.55   2.38  6.75   2.38  10
6.75   2.38  7.95   2.38  10
7.95   2.38  9.15   2.38  10
9.15   2.38 10.35   2.38  10
10.35  2.38  24.75  2.38  120
0.    0.    0.    2.38  10
24.75  0.   24.75   2.38  10
```

Tube-definition cards:

.53700000	1.62700000	.12300000
.96300000	1.62700000	.12300000
1.73700000	1.62700000	.12300000
2.16300000	1.62700000	.12300000
2.93700000	1.62700000	.12300000
3.36300000	1.62700000	.12300000
4.13700000	1.62700000	.12300000
4.56300000	1.62700000	.12300000
5.33700000	1.62700000	.12300000
5.76300000	1.62700000	.12300000
6.53700000	1.62700000	.12300000
6.96300000	1.62700000	.12300000
7.73700000	1.62700000	.12300000
8.16300000	1.62700000	.12300000
8.93700000	1.62700000	.12300000
9.36300000	1.62700000	.12300000
10.13700000	1.62700000	.12300000
10.56300000	1.62700000	.12300000
11.33700000	1.62700000	.12300000
11.76300000	1.62700000	.12300000
12.53700000	1.62700000	.12300000
12.96300000	1.62700000	.12300000
13.73700000	1.62700000	.12300000
14.16300000	1.62700000	.12300000
14.93700000	1.62700000	.12300000
15.36300000	1.62700000	.12300000
16.13700000	1.62700000	.12300000
16.56300000	1.62700000	.12300000
17.33700000	1.62700000	.12300000
17.76300000	1.62700000	.12300000
18.53700000	1.62700000	.12300000
18.96300000	1.62700000	.12300000
19.73700000	1.62700000	.12300000
20.16300000	1.62700000	.12300000
20.93700000	1.62700000	.12300000
21.36300000	1.62700000	.12300000
22.13700000	1.62700000	.12300000
22.56300000	1.62700000	.12300000
23.33700000	1.62700000	.12300000
23.76300000	1.62700000	.12300000
24.53700000	1.62700000	.12300000

APPENDIX C

Program Output

CASE: QUARTZ LAMP RADIANT HEATER, 2-TUBE CONFIGURATION

NO. OF REGIONS= 22
NO. OF TUBES= 41

CONFIGURATION DEFINITION:

END1

REG. NO.	X-COORD.	Y-COORD.
1	0.00000	0.00000
2	.75000	0.00000
3	1.95000	0.00000
4	3.15000	0.00000
5	4.35000	0.00000
6	5.55000	0.00000
7	6.75000	0.00000
8	7.95000	0.00000
9	9.15000	0.00000
10	10.35000	0.00000
11	0.00000	2.38000
12	.75000	2.38000
13	1.95000	2.38000
14	3.15000	2.38000
15	4.35000	2.38000
16	5.55000	2.38000
17	6.75000	2.38000
18	7.95000	2.38000
19	9.15000	2.38000
20	10.35000	2.38000
21	0.00000	0.00000
22	24.75000	0.00000

END2 X-COORD.	Y-COORD.	NO. REGION INCREMENTS
.75000	0.00000	10
1.95000	0.00000	10
3.15000	0.00000	10
4.35000	0.00000	10
5.55000	0.00000	10
6.75000	0.00000	10
7.95000	0.00000	10
9.15000	0.00000	10
10.35000	0.00000	10
24.75000	0.00000	120
.75000	2.38000	10
1.95000	2.38000	10
3.15000	2.38000	10
4.35000	2.38000	10
5.55000	2.38000	10
6.75000	2.38000	10
7.95000	2.38000	10
9.15000	2.38000	10
10.35000	2.38000	10
24.75000	2.38000	120
0.00000	2.38000	10
24.75000	2.38000	10

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TUBE NO.	CENTER X-COORD.	Y-COORD.	RADIUS
1	.53700	1.62700	.12300
2	.96300	1.62700	.12300
3	1.73700	1.62700	.12300
4	2.16300	1.62700	.12300
5	2.93700	1.62700	.12300
6	3.36300	1.62700	.12300
7	4.13700	1.62700	.12300
8	4.56300	1.62700	.12300
9	5.33700	1.62700	.12300
10	5.76300	1.62700	.12300
11	6.53700	1.62700	.12300
12	6.96300	1.62700	.12300
13	7.73700	1.62700	.12300
14	8.16300	1.62700	.12300
15	8.93700	1.62700	.12300
16	9.36300	1.62700	.12300
17	10.13700	1.62700	.12300
18	10.56300	1.62700	.12300
19	11.33700	1.62700	.12300
20	11.76300	1.62700	.12300
21	12.53700	1.62700	.12300
22	12.96300	1.62700	.12300
23	13.73700	1.62700	.12300
24	14.16300	1.62700	.12300
25	14.93700	1.62700	.12300
26	15.36300	1.62700	.12300
27	16.13700	1.62700	.12300
28	16.56300	1.62700	.12300
29	17.33700	1.62700	.12300
30	17.76300	1.62700	.12300
31	18.53700	1.62700	.12300
32	18.96300	1.62700	.12300
33	19.73700	1.62700	.12300
34	20.16300	1.62700	.12300
35	20.93700	1.62700	.12300
36	21.36300	1.62700	.12300
37	22.13700	1.62700	.12300
38	22.56300	1.62700	.12300
39	23.33700	1.62700	.12300
40	23.76300	1.62700	.12300
41	24.53700	1.62700	.12300

```
VIEW FACTORS FROM REGION   1
     TO REGION    1=  0.00000,   AF=          0.00000
     TO REGION    2=  0.00000,   AF=          0.00000
     TO REGION    3=  0.00000,   AF=          0.00000
     TO REGION    4=  0.00000,   AF=          0.00000
     TO REGION    5=  0.00000,   AF=          0.00000
     TO REGION    6=  0.00000,   AF=          0.00000
     TO REGION    7=  0.00000,   AF=          0.00000
     TO REGION    8=  0.00000,   AF=          0.00000
     TO REGION    9=  0.00000,   AF=          0.00000
     TO REGION   10=  0.00000,   AF=          0.00000
     TO REGION   11=   .09347,   AF=           .07010
     TO REGION   12=   .11781,   AF=           .08836
     TO REGION   13=   .03160,   AF=           .02370
     TO REGION   14=   .02465,   AF=           .01848
     TO REGION   15=   .00544,   AF=           .00408
     TO REGION   16=   .00004,   AF=           .00003
     TO REGION   17=   .00052,   AF=           .00039
     TO REGION   18=  0.00000,   AF=          0.00000
     TO REGION   19=  0.00000,   AF=          0.00000
     TO REGION   20=  0.00000,   AF=          0.00000
     TO REGION   21=   .42307,   AF=           .31731
     TO REGION   22=   .00097,   AF=           .00072
     TO ALL ELEMENTS =     .69756   AF=             .52317
     TO TUBES =    .30244,   AF=           .22683

VIEW FACTORS FROM REGION   2
     TO REGION    1=  0.00000,   AF=          0.00000
     TO REGION    2=  0.00000,   AF=          0.00000
     TO REGION    3=  0.00000,   AF=          0.00000
     TO REGION    4=  0.00000,   AF=          0.00000
     TO REGION    5=  0.00000,   AF=          0.00000
     TO REGION    6=  0.00000,   AF=          0.00000
     TO REGION    7=  0.00000,   AF=          0.00000
     TO REGION    8=  0.00000,   AF=          0.00000
     TO REGION    9=  0.00000,   AF=          0.00000
     TO REGION   10=  0.00000,   AF=          0.00000
     TO REGION   11=   .04681,   AF=           .05617
     TO REGION   12=   .15461,   AF=           .18553
     TO REGION   13=   .09126,   AF=           .10951
     TO REGION   14=   .03202,   AF=           .03842
     TO REGION   15=   .01981,   AF=           .02377
     TO REGION   16=   .00371,   AF=           .00446
     TO REGION   17=   .00050,   AF=           .00060
     TO REGION   18=   .00032,   AF=           .00039
     TO REGION   19=  0.00000,   AF=          0.00000
     TO REGION   20=  0.00000,   AF=          0.00000
     TO REGION   21=   .24667,   AF=           .29600
     TO REGION   22=   .00105,   AF=           .00126
     TO ALL ELEMENTS =     .59676   AF=             .71611
     TO TUBES =    .40324,   AF=           .48389
```

```
VIEW FACTORS FROM REGION   3
    TO REGION   1=  0.00000,  AF=        0.00000
    TO REGION   2=  0.00000,  AF=        0.00000
    TO REGION   3=  0.00000,  AF=        0.00000
    TO REGION   4=  0.00000,  AF=        0.00000
    TO REGION   5=  0.00000,  AF=        0.00000
    TO REGION   6=  0.00000,  AF=        0.00000
    TO REGION   7=  0.00000,  AF=        0.00000
    TO REGION   8=  0.00000,  AF=        0.00000
    TO REGION   9=  0.00000,  AF=        0.00000
    TO REGION  10=  0.00000,  AF=        0.00000
    TO REGION  11=   .02955,  AF=         .03546
    TO REGION  12=   .09126,  AF=         .10951
    TO REGION  13=   .15461,  AF=         .18553
    TO REGION  14=   .09126,  AF=         .10951
    TO REGION  15=   .03202,  AF=         .03842
    TO REGION  16=   .01981,  AF=         .02377
    TO REGION  17=   .00371,  AF=         .00446
    TO REGION  18=   .00050,  AF=         .00060
    TO REGION  19=   .00032,  AF=         .00039
    TO REGION  20=  0.00000,  AF=        0.00000
    TO REGION  21=   .10253,  AF=         .12303
    TO REGION  22=   .00117,  AF=         .00140
    TO ALL ELEMENTS =    .52674  AF=            .63209
    TO TUBES =   .47326,  AF=          .56791

VIEW FACTORS FROM REGION   4
    TO REGION   1=  0.00000,  AF=        0.00000
    TO REGION   2=  0.00000,  AF=        0.00000
    TO REGION   3=  0.00000,  AF=        0.00000
    TO REGION   4=  0.00000,  AF=        0.00000
    TO REGION   5=  0.00000,  AF=        0.00000
    TO REGION   6=  0.00000,  AF=        0.00000
    TO REGION   7=  0.00000,  AF=        0.00000
    TO REGION   8=  0.00000,  AF=        0.00000
    TO REGION   9=  0.00000,  AF=        0.00000
    TO REGION  10=  0.00000,  AF=        0.00000
    TO REGION  11=   .01852,  AF=         .02222
    TO REGION  12=   .03202,  AF=         .03842
    TO REGION  13=   .09126,  AF=         .10951
    TO REGION  14=   .15461,  AF=         .18553
    TO REGION  15=   .09126,  AF=         .10951
    TO REGION  16=   .03202,  AF=         .03842
    TO REGION  17=   .01981,  AF=         .02377
    TO REGION  18=   .00371,  AF=         .00446
    TO REGION  19=   .00050,  AF=         .00060
    TO REGION  20=   .00032,  AF=         .00039
    TO REGION  21=   .04889,  AF=         .05867
    TO REGION  22=   .00130,  AF=         .00156
    TO ALL ELEMENTS =    .49423  AF=            .59307
    TO TUBES =   .50577,  AF=          .60693
```

```
VIEW FACTORS FROM REGION   5
    TO REGION    1=  0.00000,   AF=         0.00000
    TO REGION    2=  0.00000,   AF=         0.00000
    TO REGION    3=  0.00000,   AF=         0.00000
    TO REGION    4=  0.00000,   AF=         0.00000
    TO REGION    5=  0.00000,   AF=         0.00000
    TO REGION    6=  0.00000,   AF=         0.00000
    TO REGION    7=  0.00000,   AF=         0.00000
    TO REGION    8=  0.00000,   AF=         0.00000
    TO REGION    9=  0.00000,   AF=         0.00000
    TO REGION   10=  0.00000,   AF=         0.00000
    TO REGION   11=   .00043,   AF=          .00052
    TO REGION   12=   .01981,   AF=          .02377
    TO REGION   13=   .03202,   AF=          .03842
    TO REGION   14=   .09126,   AF=          .10951
    TO REGION   15=   .15461,   AF=          .18553
    TO REGION   16=   .09126,   AF=          .10951
    TO REGION   17=   .03202,   AF=          .03842
    TO REGION   18=   .01981,   AF=          .02377
    TO REGION   19=   .00371,   AF=          .00446
    TO REGION   20=   .00083,   AF=          .00099
    TO REGION   21=   .03069,   AF=          .03682
    TO REGION   22=   .00147,   AF=          .00176
    TO ALL ELEMENTS =     .47791  AF=             .57350
    TO TUBES =    .52209,   AF=          .62650

VIEW FACTORS FROM REGION   6
    TO REGION    1=  0.00000,   AF=         0.00000
    TO REGION    2=  0.00000,   AF=         0.00000
    TO REGION    3=  0.00000,   AF=         0.00000
    TO REGION    4=  0.00000,   AF=         0.00000
    TO REGION    5=  0.00000,   AF=         0.00000
    TO REGION    6=  0.00000,   AF=         0.00000
    TO REGION    7=  0.00000,   AF=         0.00000
    TO REGION    8=  0.00000,   AF=         0.00000
    TO REGION    9=  0.00000,   AF=         0.00000
    TO REGION   10=  0.00000,   AF=         0.00000
    TO REGION   11=   .00050,   AF=          .00060
    TO REGION   12=   .00371,   AF=          .00446
    TO REGION   13=   .01981,   AF=          .02377
    TO REGION   14=   .03202.   AF=          .03842
    TO REGION   15=   .09126,   AF=          .10951
    TO REGION   16=   .15461,   AF=          .18553
    TO REGION   17=   .09126,   AF=          .10951
    TO REGION   18=   .03202,   AF=          .03842
    TO REGION   19=   .01981,   AF=          .02377
    TO REGION   20=   .00454,   AF=          .00545
    TO REGION   21=   .01744,   AF=          .02092
    TO REGION   22=   .00167,   AF=          .00200
    TO ALL ELEMENTS =     .46865  AF=             .56237
    TO TUBES =    .53135,   AF=          .63763
```

```
VIEW FACTORS FROM REGION   7
    TO REGION    1=  0.00000,   AF=          0.00000
    TO REGION    2=  0.00000,   AF=          0.00000
    TO REGION    3=  0.00000,   AF=          0.00000
    TO REGION    4=  0.00000,   AF=          0.00000
    TO REGION    5=  0.00000,   AF=          0.00000
    TO REGION    6=  0.00000,   AF=          0.00000
    TO REGION    7=  0.00000,   AF=          0.00000
    TO REGION    8=  0.00000,   AF=          0.00000
    TO REGION    9=  0.00000,   AF=          0.00000
    TO REGION   10=  0.00000,   AF=          0.00000
    TO REGION   11=   .00032,   AF=           .00039
    TO REGION   12=   .00050,   AF=           .00060
    TO REGION   13=   .00371,   AF=           .00446
    TO REGION   14=   .01981,   AF=           .02377
    TO REGION   15=   .03202,   AF=           .03842
    TO REGION   16=   .09126,   AF=           .10951
    TO REGION   17=   .15461,   AF=           .18553
    TO REGION   18=   .09126,   AF=           .10951
    TO REGION   19=   .03202,   AF=           .03842
    TO REGION   20=   .02435,   AF=           .02922
    TO REGION   21=   .01179,   AF=           .01415
    TO REGION   22=   .00190,   AF=           .00229
    TO ALL ELEMENTS =    .46356  AF=              .55628
    TO TUBES =    .53644,  AF=           .64372

VIEW FACTORS FROM REGION   8
    TO REGION    1=  0.00000,   AF=          0.00000
    TO REGION    2=  0.00000,   AF=          0.00000
    TO REGION    3=  0.00000,   AF=          0.00000
    TO REGION    4=  0.00000,   AF=          0.00000
    TO REGION    5=  0.00000,   AF=          0.00000
    TO REGION    6=  0.00000,   AF=          0.00000
    TO REGION    7=  0.00000,   AF=          0.00000
    TO REGION    8=  0.00000,   AF=          0.00000
    TO REGION    9=  0.00000,   AF=          0.00000
    TO REGION   10=  0.00000,   AF=          0.00000
    TO REGION   11=  0.00000,   AF=          0.00000
    TO REGION   12=   .00032,   AF=           .00039
    TO REGION   13=   .00050,   AF=           .00060
    TO REGION   14=   .00371,   AF=           .00446
    TO REGION   15=   .01981,   AF=           .02377
    TO REGION   16=   .03202,   AF=           .03842
    TO REGION   17=   .09126,   AF=           .10951
    TO REGION   18=   .15461,   AF=           .18553
    TO REGION   19=   .09126,   AF=           .10951
    TO REGION   20=   .05637,   AF=           .06764
    TO REGION   21=   .00860,   AF=           .01032
    TO REGION   22=   .00220,   AF=           .00264
    TO ALL ELEMENTS =    .46067  AF=              .55280
    TO TUBES =    .53933,  AF=           .64720
```

```
VIEW FACTORS FROM REGION   9
    TO REGION    1=  0.00000,  AF=         0.00000
    TO REGION    2=  0.00000,  AF=         0.00000
    TO REGION    3=  0.00000,  AF=         0.00000
    TO REGION    4=  0.00000,  AF=         0.00000
    TO REGION    5=  0.00000,  AF=         0.00000
    TO REGION    6=  0.00000,  AF=         0.00000
    TO REGION    7=  0.00000,  AF=         0.00000
    TO REGION    8=  0.00000,  AF=         0.00000
    TO REGION    9=  0.00000,  AF=         0.00000
    TO REGION   10=  0.00000,  AF=         0.00000
    TO REGION   11=  0.00000,  AF=         0.00000
    TO REGION   12=  0.00000,  AF=         0.00000
    TO REGION   13=   .00032,  AF=          .00039
    TO REGION   14=   .00050,  AF=          .00060
    TO REGION   15=   .00371,  AF=          .00446
    TO REGION   16=   .01981,  AF=          .02377
    TO REGION   17=   .03202,  AF=          .03842
    TO REGION   18=   .09126,  AF=          .10951
    TO REGION   19=   .15461,  AF=          .18553
    TO REGION   20=   .14763,  AF=          .17716
    TO REGION   21=   .00654,  AF=          .00785
    TO REGION   22=   .00257,  AF=          .00308
    TO ALL ELEMENTS =    .45898  AF=            .55078
    TO TUBES =   .54102,  AF=         .64922

VIEW FACTORS FROM REGION  10
    TO REGION    1=  0.00000,  AF=         0.00000
    TO REGION    2=  0.00000,  AF=         0.00000
    TO REGION    3=  0.00000,  AF=         0.00000
    TO REGION    4=  0.00000,  AF=         0.00000
    TO REGION    5=  0.00000,  AF=         0.00000
    TO REGION    6=  0.00000,  AF=         0.00000
    TO REGION    7=  0.00000,  AF=         0.00000
    TO REGION    8=  0.00000,  AF=         0.00000
    TO REGION    9=  0.00000,  AF=         0.00000
    TO REGION   10=  0.00000,  AF=         0.00000
    TO REGION   11=  0.00000,  AF=         0.00000
    TO REGION   12=  0.00000,  AF=         0.00000
    TO REGION   13=  0.00000,  AF=         0.00000
    TO REGION   14=   .00003,  AF=          .00039
    TO REGION   15=   .00007,  AF=          .00099
    TO REGION   16=   .00038,  AF=          .00545
    TO REGION   17=   .00203,  AF=          .02922
    TO REGION   18=   .00470,  AF=          .06764
    TO REGION   19=   .01230,  AF=          .17716
    TO REGION   20=   .41086,  AF=         5.91638
    TO REGION   21=   .00236,  AF=          .03393
    TO REGION   22=   .05842,  AF=          .84124
    TO ALL ELEMENTS =    .49114  AF=           7.07239
    TO TUBES =   .50886,  AF=        7.32761
```

```
VIEW FACTORS FROM REGION  11
    TO REGION   1=   .09364,   AF=          .07023
    TO REGION   2=   .07427,   AF=          .05570
    TO REGION   3=   .04768,   AF=          .03576
    TO REGION   4=   .02965,   AF=          .02224
    TO REGION   5=   .00071,   AF=          .00054
    TO REGION   6=   .00080,   AF=          .00060
    TO REGION   7=   .00053,   AF=          .00039
    TO REGION   8=  0.00000,   AF=         0.00000
    TO REGION   9=  0.00000,   AF=         0.00000
    TO REGION  10=  0.00000,   AF=         0.00000
    TO REGION  11=  0.00000,   AF=         0.00000
    TO REGION  12=  0.00000,   AF=         0.00000
    TO REGION  13=  0.00000,   AF=         0.00000
    TO REGION  14=  0.00000,   AF=         0.00000
    TO REGION  15=  0.00000,   AF=         0.00000
    TO REGION  16=  0.00000,   AF=         0.00000
    TO REGION  17=  0.00000,   AF=         0.00000
    TO REGION  18=  0.00000,   AF=         0.00000
    TO REGION  19=  0.00000,   AF=         0.00000
    TO REGION  20=  0.00000,   AF=         0.00000
    TO REGION  21=   .41685,   AF=          .31264
    TO REGION  22=   .00017,   AF=          .00013
    TO ALL ELEMENTS =    .66430  AF=            .49822
    TO TUBES =   .33570,  AF=          .25178

VIEW FACTORS FROM REGION  12
    TO REGION   1=   .07378,   AF=          .08853
    TO REGION   2=   .15467,   AF=          .18561
    TO REGION   3=   .09109,   AF=          .10931
    TO REGION   4=   .03210,   AF=          .03852
    TO REGION   5=   .01987,   AF=          .02385
    TO REGION   6=   .00372,   AF=          .00446
    TO REGION   7=   .00051,   AF=          .00061
    TO REGION   8=   .00032,   AF=          .00038
    TO REGION   9=  0.00000,   AF=         0.00000
    TO REGION  10=  0.00000,   AF=         0.00000
    TO REGION  11=  0.00000,   AF=         0.00000
    TO REGION  12=  0.00000,   AF=         0.00000
    TO REGION  13=  0.00000,   AF=         0.00000
    TO REGION  14=  0.00000,   AF=         0.00000
    TO REGION  15=  0.00000,   AF=         0.00000
    TO REGION  16=  0.00000,   AF=         0.00000
    TO REGION  17=  0.00000,   AF=         0.00000
    TO REGION  18=  0.00000,   AF=         0.00000
    TO REGION  19=  0.00000,   AF=         0.00000
    TO REGION  20=  0.00000,   AF=         0.00000
    TO REGION  21=   .14403,   AF=          .17284
    TO REGION  22=   .00018,   AF=          .00022
    TO ALL ELEMENTS =    .52028  AF=            .62433
    TO TUBES =   .47972,  AF=          .57567
```

```
VIEW FACTORS FROM REGION  13
    TO REGION   1=    .01989,  AF=          .02387
    TO REGION   2=    .09109,  AF=          .10931
    TO REGION   3=    .15467,  AF=          .18561
    TO REGION   4=    .09109,  AF=          .10931
    TO REGION   5=    .03210,  AF=          .03852
    TO REGION   6=    .01987,  AF=          .02385
    TO REGION   7=    .00372,  AF=          .00446
    TO REGION   8=    .00051,  AF=          .00061
    TO REGION   9=    .00032,  AF=          .00038
    TO REGION  10=  0.00000,   AF=        0.00000
    TO REGION  11=  0.00000,   AF=        0.00000
    TO REGION  12=  0.00000,   AF=        0.00000
    TO REGION  13=  0.00000,   AF=        0.00000
    TO REGION  14=  0.00000,   AF=        0.00000
    TO REGION  15=  0.00000,   AF=        0.00000
    TO REGION  16=  0.00000,   AF=        0.00000
    TO REGION  17=  0.00000,   AF=        0.00000
    TO REGION  18=  0.00000,   AF=        0.00000
    TO REGION  19=  0.00000,   AF=        0.00000
    TO REGION  20=  0.00000,   AF=        0.00000
    TO REGION  21=    .05995,  AF=          .07194
    TO REGION  22=    .00021,  AF=          .00025
    TO ALL ELEMENTS =     .47343  AF=             .56811
    TO TUBES =    .52657,  AF=          .63189

VIEW FACTORS FROM REGION  14
    TO REGION   1=    .01543,  AF=          .01851
    TO REGION   2=    .03210,  AF=          .03852
    TO REGION   3=    .09109,  AF=          .10931
    TO REGION   4=    .15467,  AF=          .18561
    TO REGION   5=    .09109,  AF=          .10931
    TO REGION   6=    .03210,  AF=          .03852
    TO REGION   7=    .01987,  AF=          .02385
    TO REGION   8=    .00372,  AF=          .00446
    TO REGION   9=    .00051,  AF=          .00061
    TO REGION  10=    .00032,  AF=          .00038
    TO REGION  11=  0.00000,   AF=        0.00000
    TO REGION  12=  0.00000,   AF=        0.00000
    TO REGION  13=  0.00000,   AF=        0.00000
    TO REGION  14=  0.00000,   AF=        0.00000
    TO REGION  15=  0.00000,   AF=        0.00000
    TO REGION  16=  0.00000,   AF=        0.00000
    TO REGION  17=  0.00000,   AF=        0.00000
    TO REGION  18=  0.00000,   AF=        0.00000
    TO REGION  19=  0.00000,   AF=        0.00000
    TO REGION  20=  0.00000,   AF=        0.00000
    TO REGION  21=    .01857,  AF=          .02228
    TO REGION  22=    .00023,  AF=          .00028
    TO ALL ELEMENTS =     .45970  AF=             .55164
    TO TUBES =    .54030,  AF=          .64836
```

```
VIEW FACTORS FROM REGION  15
    TO REGION   1=    .00342,   AF=         .00411
    TO REGION   2=    .01987,   AF=         .02385
    TO REGION   3=    .03210,   AF=         .03852
    TO REGION   4=    .09109,   AF=         .10931
    TO REGION   5=    .15467,   AF=         .18561
    TO REGION   6=    .09109,   AF=         .10931
    TO REGION   7=    .03210,   AF=         .03852
    TO REGION   8=    .01987,   AF=         .02385
    TO REGION   9=    .00372,   AF=         .00446
    TO REGION  10=    .00082,   AF=         .00099
    TO REGION  11=  0.00000,    AF=        0.00000
    TO REGION  12=  0.00000,    AF=        0.00000
    TO REGION  13=  0.00000,    AF=        0.00000
    TO REGION  14=  0.00000,    AF=        0.00000
    TO REGION  15=  0.00000,    AF=        0.00000
    TO REGION  16=  0.00000,    AF=        0.00000
    TO REGION  17=  0.00000,    AF=        0.00000
    TO REGION  18=  0.00000,    AF=        0.00000
    TO REGION  19=  0.00000,    AF=        0.00000
    TO REGION  20=  0.00000,    AF=        0.00000
    TO REGION  21=    .00621,   AF=         .00745
    TO REGION  22=    .00026,   AF=         .00031
    TO ALL ELEMENTS =     .45524  AF=           .54628
    TU TUBES =    .54476,  AF=          .65372

VIEW FACTORS FROM REGION  16
    TO REGION   1=  0.00000,    AF=        0.00000
    TO REGION   2=    .00372,   AF=         .00446
    TO REGION   3=    .01987,   AF=         .02385
    TO REGION   4=    .03210,   AF=         .03852
    TO REGION   5=    .09109,   AF=         .10931
    TO REGION   6=    .15467,   AF=         .18561
    TO REGION   7=    .09109,   AF=         .10931
    TO REGION   8=    .03210,   AF=         .03852
    TO REGION   9=    .01987,   AF=         .02385
    TO REGION  10=    .00454,   AF=         .00545
    TO REGION  11=  0.00000,    AF=        0.00000
    TO REGION  12=  0.00000,    AF=        0.00000
    TO REGION  13=  0.00000,    AF=        0.00000
    TO REGION  14=  0.00000,    AF=        0.00000
    TO REGION  15=  0.00000,    AF=        0.00000
    TO REGION  16=  0.00000,    AF=        0.00000
    TO REGION  17=  0.00000,    AF=        0.00000
    TO REGION  18=  0.00000,    AF=        0.00000
    TO REGION  19=  0.00000,    AF=        0.00000
    TO REGION  20=  0.00000,    AF=        0.00000
    TO REGION  21=    .00397,   AF=         .00476
    TO REGION  22=    .00029,   AF=         .00035
    TO ALL ELEMENTS =     .45333  AF=           .54400
    TO TUBES =    .54667,  AF=          .65600
```

```
VIEW FACTORS FROM REGION  17
    TO REGION   1=    .00032,   AF=          .00038
    TO REGION   2=    .00051,   AF=          .00061
    TO REGION   3=    .00372,   AF=          .00446
    TO REGION   4=    .01987,   AF=          .02385
    TO REGION   5=    .03210,   AF=          .03852
    TO REGION   6=    .09109,   AF=          .10931
    TO REGION   7=    .15467,   AF=          .18561
    TO REGION   8=    .09109,   AF=          .10931
    TO REGION   9=    .03210,   AF=          .03852
    TO REGION  10=    .02441,   AF=          .02930
    TO REGION  11=   0.00000,   AF=         0.00000
    TO REGION  12=   0.00000,   AF=         0.00000
    TO REGION  13=   0.00000,   AF=         0.00000
    TO REGION  14=   0.00000,   AF=         0.00000
    TO REGION  15=   0.00000,   AF=         0.00000
    TO REGION  16=   0.00000,   AF=         0.00000
    TO REGION  17=   0.00000,   AF=         0.00000
    TO REGION  18=   0.00000,   AF=         0.00000
    TO REGION  19=   0.00000,   AF=         0.00000
    TO REGION  20=   0.00000,   AF=         0.00000
    TO REGION  21=    .00214,   AF=          .00256
    TO REGION  22=    .00034,   AF=          .00040
    TO ALL ELEMENTS =     .45236  AF=            .54283
    TO TUBES =    .54764,   AF=          .65717

VIEW FACTORS FROM REGION  18
    TO REGION   1=   0.00000,   AF=         0.00000
    TO REGION   2=    .00032,   AF=          .00038
    TO REGION   3=    .00051,   AF=          .00061
    TO REGION   4=    .00372,   AF=          .00446
    TO REGION   5=    .01987,   AF=          .02385
    TO REGION   6=    .03210,   AF=          .03852
    TO REGION   7=    .09109,   AF=          .10931
    TO REGION   8=    .15467,   AF=          .18561
    TO REGION   9=    .09109,   AF=          .10931
    TO REGION  10=    .05651,   AF=          .06782
    TO REGION  11=   0.00000,   AF=         0.00000
    TO REGION  12=   0.00000,   AF=         0.00000
    TO REGION  13=   0.00000,   AF=         0.00000
    TO REGION  14=   0.00000,   AF=         0.00000
    TO REGION  15=   0.00000,   AF=         0.00000
    TO REGION  16=   0.00000,   AF=         0.00000
    TO REGION  17=   0.00000,   AF=         0.00000
    TO REGION  18=   0.00000,   AF=         0.00000
    TO REGION  19=   0.00000,   AF=         0.00000
    TO REGION  20=   0.00000,   AF=         0.00000
    TO REGION  21=    .00154,   AF=          .00185
    TO REGION  22=    .00039,   AF=          .00047
    TO ALL ELEMENTS =     .45182  AF=            .54219
    TO TUBES =    .54818,   AF=          .65781
```

```
VIEW FACTORS FROM REGION  19
    TO REGION   1=  0.00000,   AF=         0.00000
    TO REGION   2=  0.00000,   AF=         0.00000
    TO REGION   3=   .00032,   AF=          .00038
    TO REGION   4=   .00051,   AF=          .00061
    TO REGION   5=   .00372,   AF=          .00446
    TO REGION   6=   .01987,   AF=          .02385
    TO REGION   7=   .03210,   AF=          .03852
    TO REGION   8=   .09109,   AF=          .10931
    TO REGION   9=   .15467,   AF=          .18561
    TO REGION  10=   .14761,   AF=          .17713
    TO REGION  11=  0.00000,   AF=         0.00000
    TO REGION  12=  0.00000,   AF=         0.00000
    TO REGION  13=  0.00000,   AF=         0.00000
    TO REGION  14=  0.00000,   AF=         0.00000
    TO REGION  15=  0.00000,   AF=         0.00000
    TO REGION  16=  0.00000,   AF=         0.00000
    TO REGION  17=  0.00000,   AF=         0.00000
    TO REGION  18=  0.00000,   AF=         0.00000
    TO REGION  19=  0.00000,   AF=         0.00000
    TO REGION  20=  0.00000,   AF=         0.00000
    TO REGION  21=   .00117,   AF=          .00140
    TO REGION  22=   .00045,   AF=          .00054
    TO ALL ELEMENTS =     .45151   AF=           .54181
    TO TUBES =    .54849,   AF=           .65819

VIEW FACTORS FROM REGION  20
    TO REGION   1=  0.00000,   AF=         0.00000
    TO REGION   2=  0.00000,   AF=         0.00000
    TO REGION   3=  0.00000,   AF=         0.00000
    TO REGION   4=   .00003,   AF=          .00038
    TO REGION   5=   .00007,   AF=          .00099
    TO REGION   6=   .00038,   AF=          .00545
    TO REGION   7=   .00203,   AF=          .02930
    TO REGION   8=   .00471,   AF=          .06782
    TO REGION   9=   .01230,   AF=          .17713
    TO REGION  10=   .41085,   AF=         5.91630
    TO REGION  11=  0.00000,   AF=         0.00000
    TO REGION  12=  0.00000,   AF=         0.00000
    TO REGION  13=  0.00000,   AF=         0.00000
    TO REGION  14=  0.00000,   AF=         0.00000
    TO REGION  15=  0.00000,   AF=         0.00000
    TO REGION  16=  0.00000,   AF=         0.00000
    TO REGION  17=  0.00000,   AF=         0.00000
    TO REGION  18=  0.00000,   AF=         0.00000
    TO REGION  19=  0.00000,   AF=         0.00000
    TO REGION  20=  0.00000,   AF=         0.00000
    TO REGION  21=   .00042,   AF=          .00600
    TO REGION  22=   .03793,   AF=          .54620
    TO ALL ELEMENTS =     .46872   AF=          6.74956
    TO TUBES =    .53128,   AF=          7.65044
```

```
VIEW FACTORS FROM REGION  21
    TO REGION   1=    .13268,   AF=          .31577
    TO REGION   2=    .12517,   AF=          .29789
    TO REGION   3=    .05266,   AF=          .12533
    TO REGION   4=    .02250,   AF=          .05354
    TO REGION   5=    .01599,   AF=          .03807
    TO REGION   6=    .00885,   AF=          .02106
    TO REGION   7=    .00628,   AF=          .01494
    TO REGION   8=    .00468,   AF=          .01113
    TO REGION   9=    .00362,   AF=          .00860
    TO REGION  10=    .01622,   AF=          .03861
    TO REGION  11=    .13071,   AF=          .31108
    TO REGION  12=    .07367,   AF=          .17534
    TO REGION  13=    .02907,   AF=          .06918
    TO REGION  14=    .00929,   AF=          .02210
    TO REGION  15=    .00324,   AF=          .00770
    TO REGION  16=    .00216,   AF=          .00514
    TO REGION  17=    .00119,   AF=          .00283
    TO REGION  18=    .00088,   AF=          .00209
    TO REGION  19=    .00068,   AF=          .00161
    TO REGION  20=    .00300,   AF=          .00715
    TO REGION  21=  0.00000,    AF=         0.00000
    TO REGION  22=    .02213,   AF=          .05267
    TO ALL ELEMENTS =     .66464  AF=          1.58184
    TO TUBES =   .33536,  AF=          .79816

VIEW FACTORS FROM REGION  22
    TO REGION   1=    .00027,   AF=          .00064
    TO REGION   2=    .00047,   AF=          .00111
    TO REGION   3=    .00052,   AF=          .00124
    TO REGION   4=    .00058,   AF=          .00138
    TO REGION   5=    .00065,   AF=          .00156
    TO REGION   6=    .00074,   AF=          .00176
    TO REGION   7=    .00085,   AF=          .00201
    TO REGION   8=    .00098,   AF=          .00232
    TO REGION   9=    .00114,   AF=          .00271
    TO REGION  10=    .35596,   AF=          .84718
    TO REGION  11=    .00007,   AF=          .00016
    TO REGION  12=    .00012,   AF=          .00028
    TO REGION  13=    .00013,   AF=          .00031
    TO REGION  14=    .00015,   AF=          .00035
    TO REGION  15=    .00016,   AF=          .00039
    TO REGION  16=    .00019,   AF=          .00044
    TO REGION  17=    .00021,   AF=          .00051
    TO REGION  18=    .00024,   AF=          .00058
    TO REGION  19=    .00029,   AF=          .00068
    TO REGION  20=    .23101,   AF=          .54980
    TO REGION  21=    .02228,   AF=          .05302
    TO REGION  22=  0.00000,    AF=         0.00000
    TO ALL ELEMENTS =     .61699  AF=          1.46844
    TO TUBES =   .38301,  AF=          .91156
```

REFERENCES

1. Martin Interactive Thermal Analyzer System - Version 1.0. User's Manual. MDS-SPLPD-71-FD238 (REV 3), Martin Marietta Corp., Mar. 1972.

2. Toups, K. A.: A General Computer Program for the Determination of Radiant-Interchange Configuration and Form Factors - CONFAC II. SID-65-1043-2, North American Aviat., Inc., Oct. 1965. (Available as NASA CR-65257.)

3. Sparrow, E. M.; and Cess, R. D.: Radiation Heat Transfer. Augmented Ed. Hemisphere Pub. Corp., c.1978.

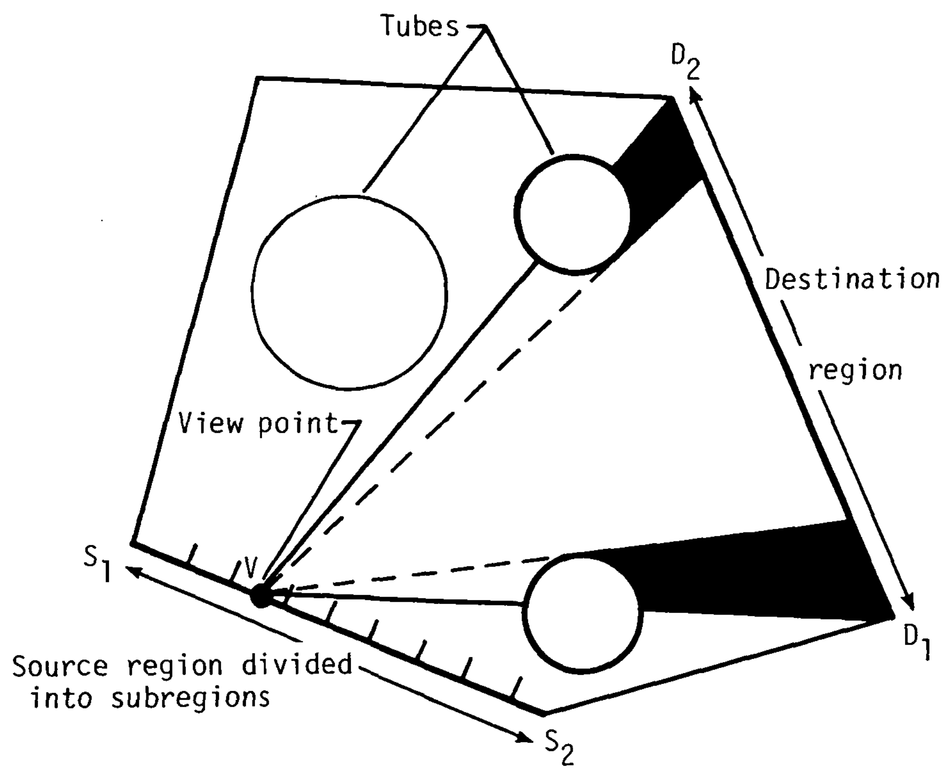


Figure 1.- Typical arrangement of source and destination regions and occluding tubes.

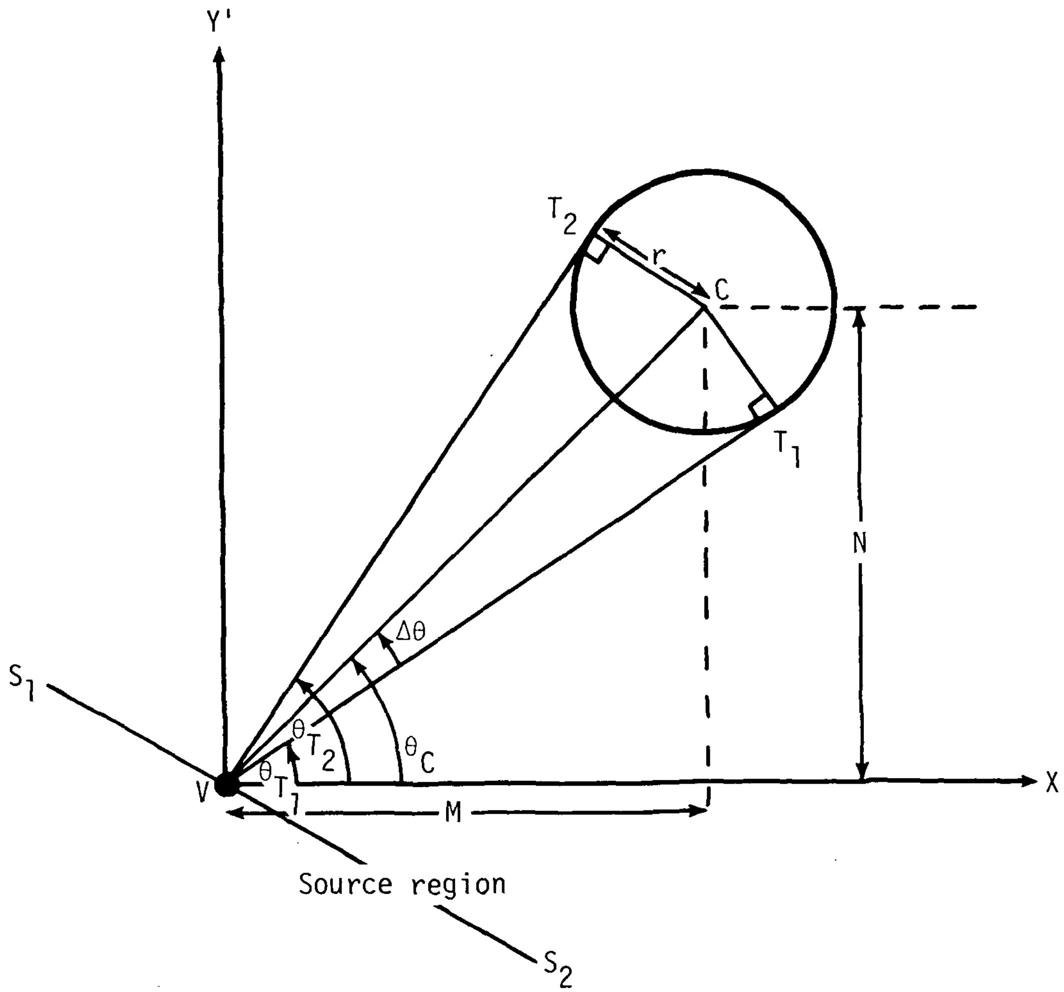


Figure 2.- Geometry used in computation of angles from X' to lines from view point V to points of tangency T_1 and T_2 of tube.

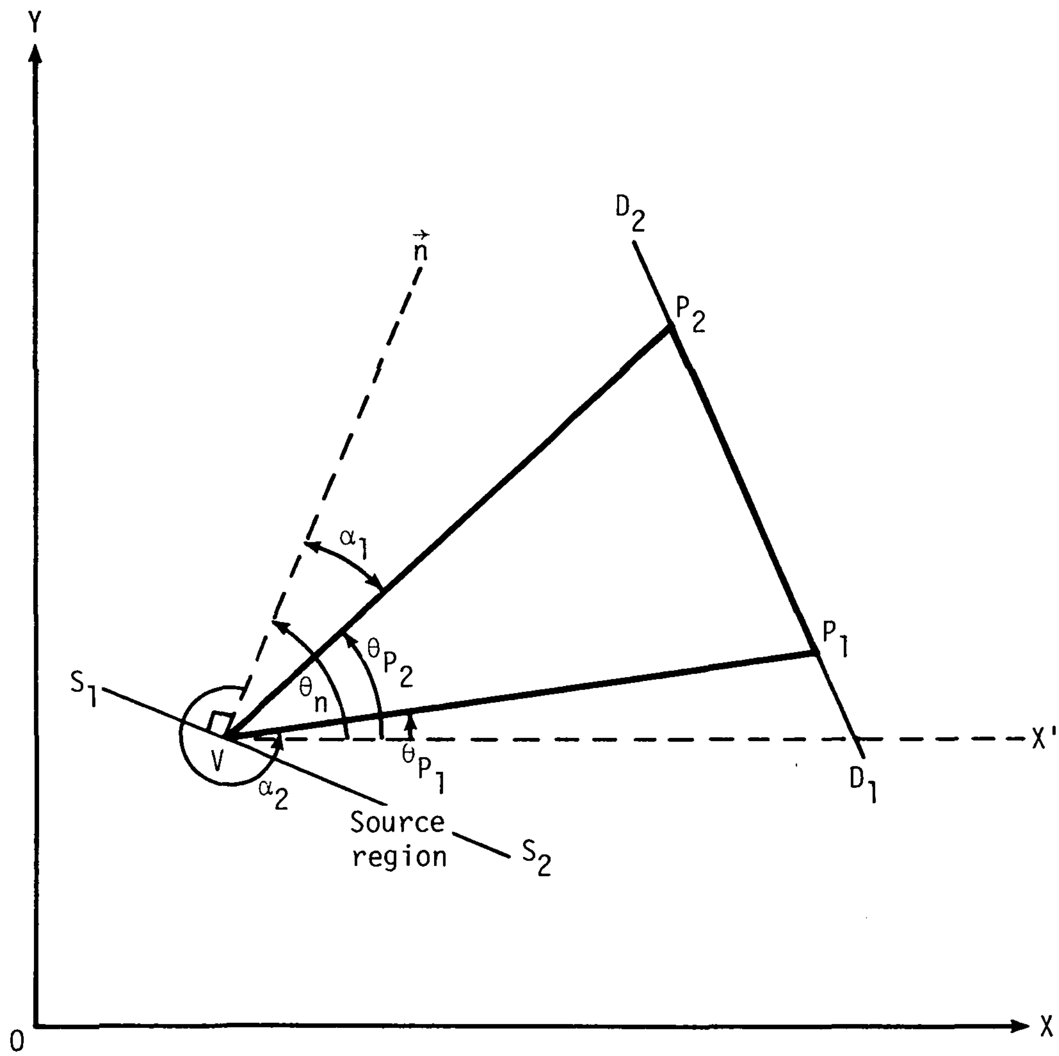


Figure 3.- Angles necessary for computation of configuration factor from view point $\underline{V}$ to unshadowed portion $\overline{P_1P_2}$ of destination region $\overline{D_1D_2}$.

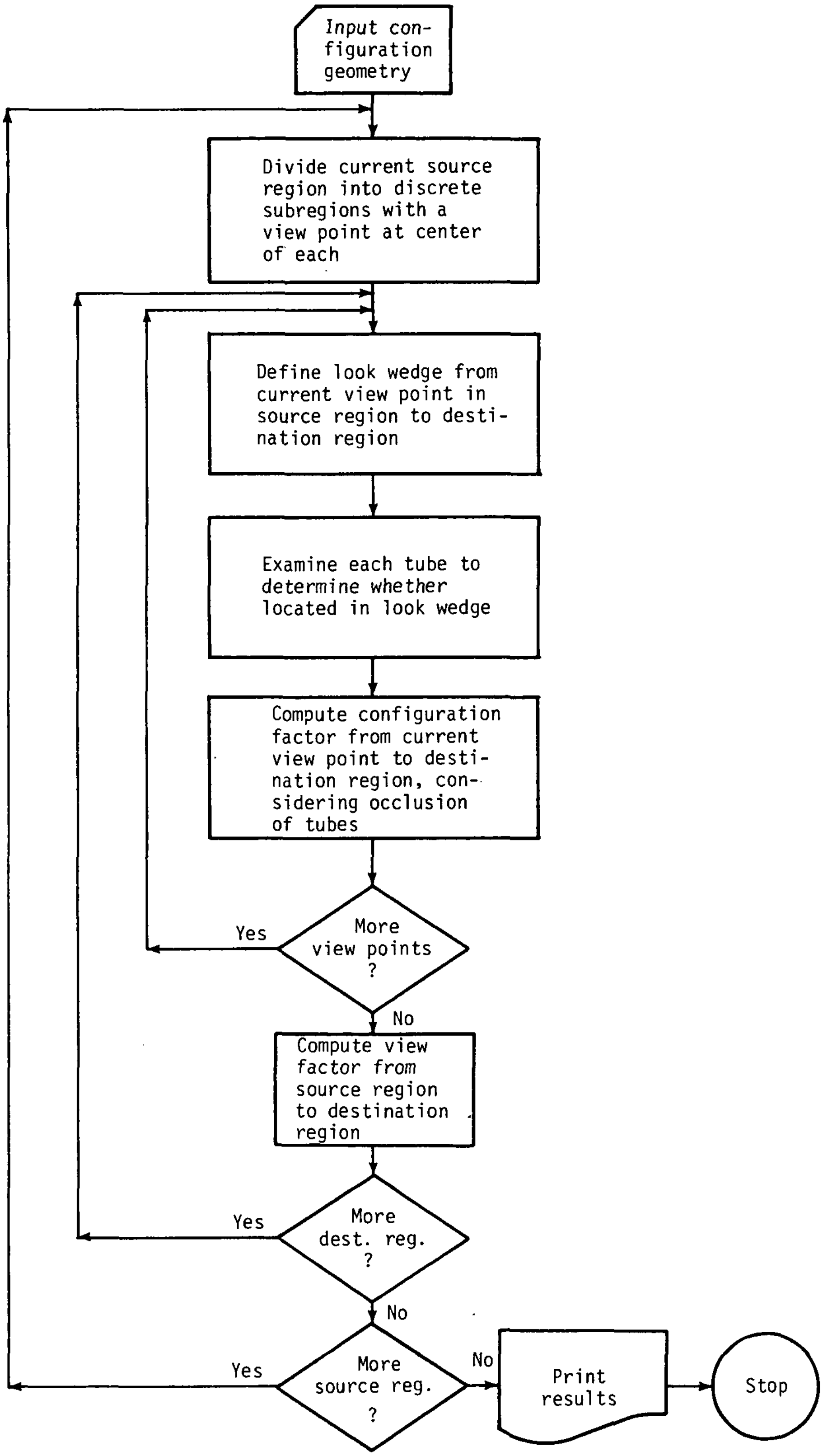
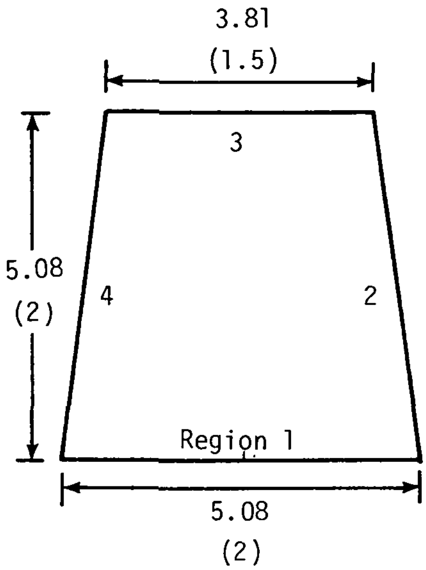


Figure 4.- Simplified flow chart of program VIEWFAC.



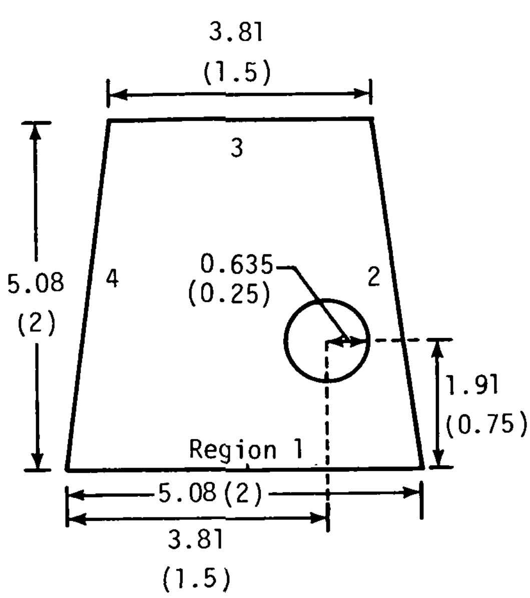

```
VIEW FACTORS FROM REGION   1
    TO REGION   1=  0.00000,   AF=        0.00000
    TO REGION   2=   .33951,   AF=         .67901
    TO REGION   3=   .32099,   AF=         .64198
    TO REGION   4=   .33951,   AF=         .67901
    TO ALL ELEMENTS =    1.00000   AF=        2.00000
    TO TUBES =    .00000,   AF=        .00000

VIEW FACTORS FROM REGION   2
    TO REGION   1=   .33688,   AF=         .67901
    TO REGION   2=  0.00000,   AF=        0.00000
    TO REGION   3=   .21285,   AF=         .42901
    TO REGION   4=   .45027,   AF=         .90754
    TO ALL ELEMENTS =    1.00000   AF=        2.01556
    TO TUBES =    .00000,   AF=        .00000

VIEW FACTORS FROM REGION   3
    TO REGION   1=   .42798,   AF=         .64197
    TO REGION   2=   .28601,   AF=         .42901
    TO REGION   3=  0.00000,   AF=        0.00000
    TO REGION   4=   .28601,   AF=         .42901
    TO ALL ELEMENTS =    1.00000   AF=        1.50000
    TO TUBES =    .00000,   AF=        .00000

VIEW FACTORS FROM REGION   4
    TO REGION   1=   .33688,   AF=         .67901
    TO REGION   2=   .45027,   AF=         .90754
    TO REGION   3=   .21285,   AF=         .42901
    TO REGION   4=  0.00000,   AF=        0.00000
    TO ALL ELEMENTS =    1.00000   AF=        2.01556
    TO TUBES =    .00000,   AF=        .00000
```

(a) No occlusion.

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VIEW FACTORS FROM REGION   1
    TO REGION   1=  0.00000,   AF=        0.00000
    TO REGION   2=   .22579,   AF=         .45159
    TO REGION   3=   .22651,   AF=         .45303
    TO REGION   4=   .33579,   AF=         .67159
    TO ALL ELEMENTS =     .78810   AF=        1.57621
    TO TUBES =    .21190,   AF=        .42379

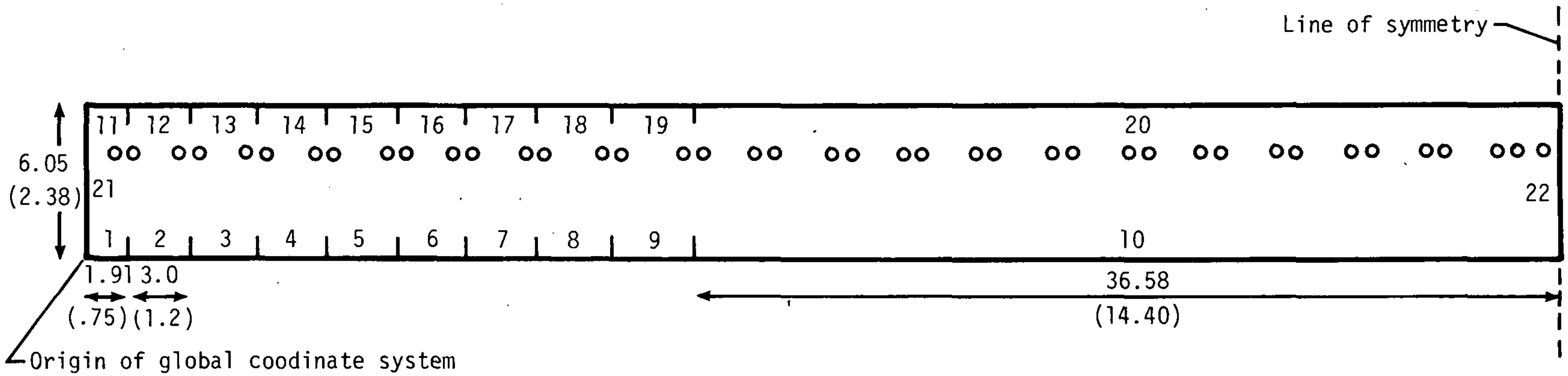
VIEW FACTORS FROM REGION   2
    TO REGION   1=   .22404,   AF=         .45156
    TO REGION   2=  0.00000,   AF=        0.00000
    TO REGION   3=   .18467,   AF=         .37221
    TO REGION   4=   .29904,   AF=         .60274
    TO ALL ELEMENTS =     .70775   AF=        1.42651
    TO TUBES =    .29225,   AF=        .58905

VIEW FACTORS FROM REGION   3
    TO REGION   1=   .30204,   AF=         .45306
    TO REGION   2=   .24815,   AF=         .37223
    TO REGION   3=  0.00000,   AF=        0.00000
    TO REGION   4=   .28601,   AF=         .42901
    TO ALL ELEMENTS =     .83620   AF=        1.25430
    TO TUBES =    .16380,   AF=        .24570

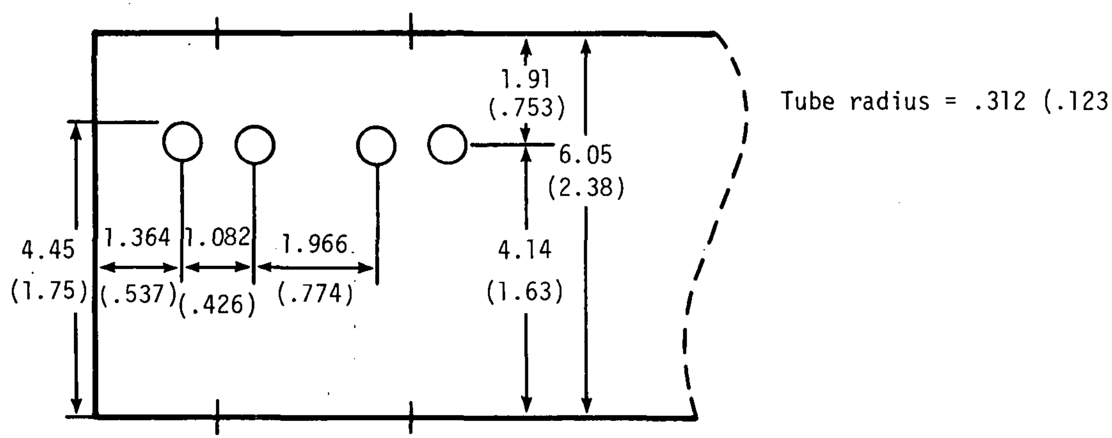
VIEW FACTORS FROM REGION   4
    TO REGION   1=   .33320,   AF=         .67158
    TO REGION   2=   .29903,   AF=         .60271
    TO REGION   3=   .21285,   AF=         .42901
    TO REGION   4=  0.00000,   AF=        0.00000
    TO ALL ELEMENTS =     .84507   AF=        1.70330
    TO TUBES =    .15493,   AF=        .31226
```

(b) Partial occlusion.

Figure 5.- Check cases used to verify program VIEWFAC.



(a) Region definition.



(b) Position of tubes.

Figure 6.- Demonstration problem: Two-dimensional model of quartz-lamp radiant heater. Dimensions shown are centimeters (inches).

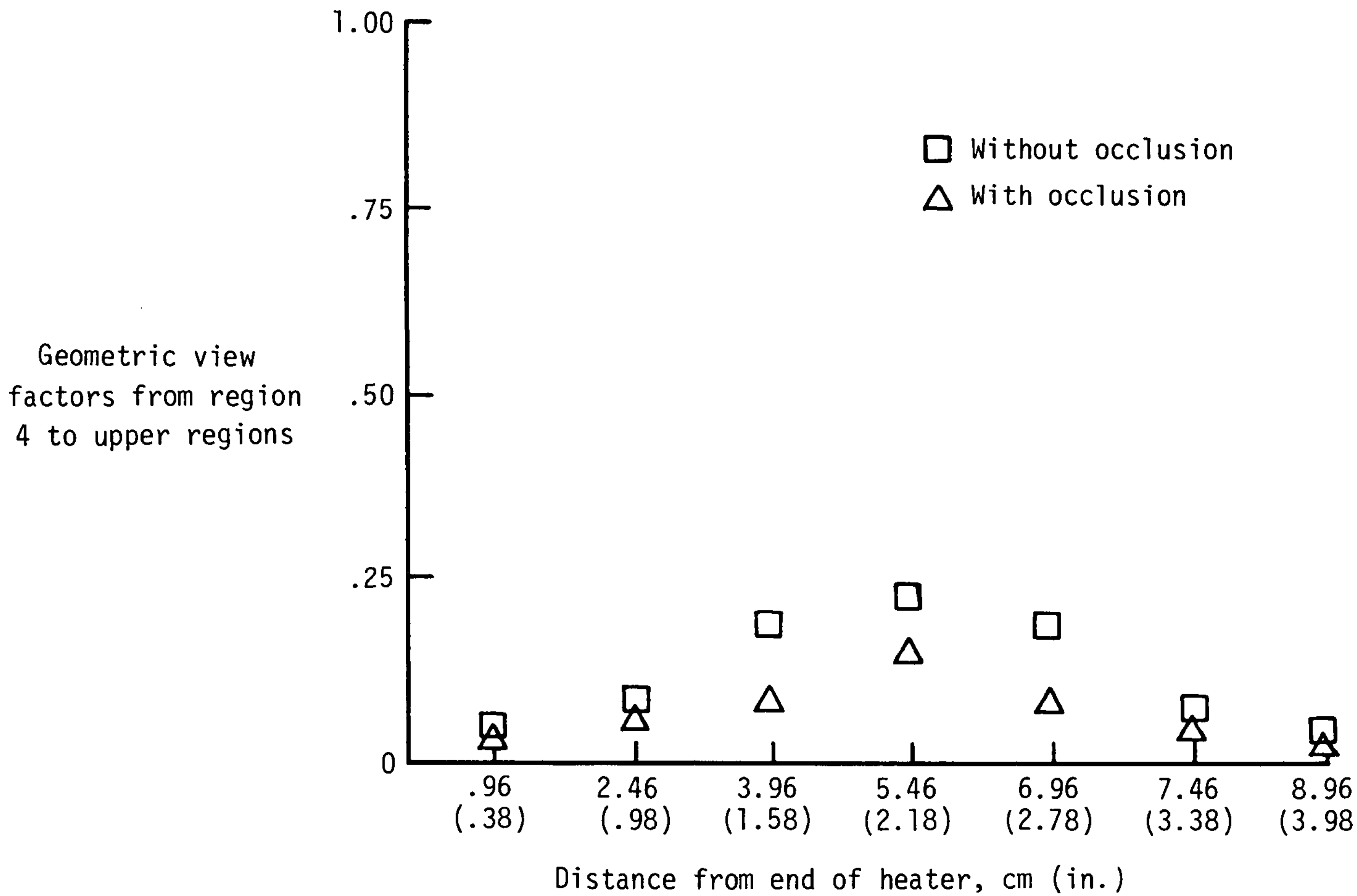


Figure 7.- Demonstration problem: Difference in geometric view factors with and without occlusion by lamps in heater.

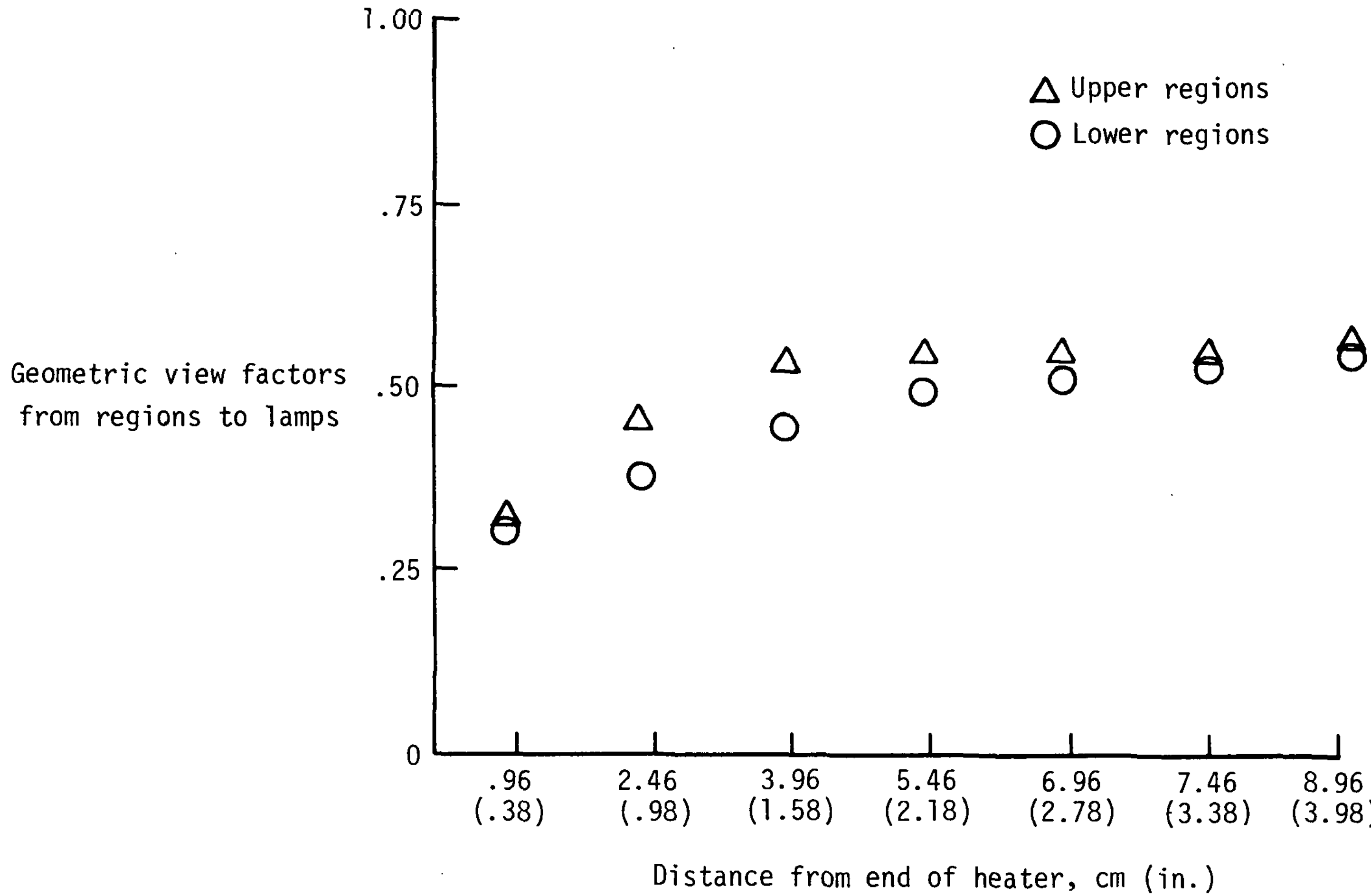


Figure 8.- Demonstration problem: Variation of geometric view factors from regions to lamps near end of heater.

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15. Supplementary Notes

16. Abstract

A numerical procedure has been developed to determine geometric view factors between connected infinite strips occluded by any number of infinite circular cylinders. The procedure requires a two-dimensional cross-sectional model of the configuration of interest. The two-dimensional model consists of a convex polygon enclosing any number of circles. Each side of the polygon represents one strip, and each circle represents a circular cylinder. A description and listing of a computer program based on this procedure are included in this report. The program calculates geometric view factors between individual strips and between individual strips and the collection of occluding cylinders.

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