NRC-94-007

Westinghouse Electric Corporation
Commercial Nuclear Fuel Division
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February 11, 1994

U. S. Nuclear Regulatory Commission
Charles J. Haughney, Chief 6H3
Storage and Transport Systems Branch
Division of Industrial and Medical Nuclear Safety, IMNS
11555 Rockville Pike
Rockville, MD 20852

Subject: Docket 71-5450: Application for Approval of Packaging, RCC Shipping Containers.

Gentlemen:

The Westinghouse Electric Corporation hereby submits six (6) copies of an application for approval of packaging of fissile radioactive material (RCC Shipping Containers) -- package identification number USA/5450/AF.

If you have any questions concerning this submittal, please write to me at the above address; telephone (803) 776-2610, extension 3426; or fax (803) 695-3964.

C. F. Sanders

C. F. Sanders, Manager
Nuclear Material Management & Product Records

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APPLICATION DETAILS

February 11, 1994

1. The shipments shall consist of Westinghouse-designed 14x14 OFA fuel assemblies.

2. The fuel stack will consist of 144 inches (nominal) of UO_2 enriched to 4.95% (nominal) ^{235}U, with the top six inches of the fuel made of annular pellets; the middle 132 inches of fuel made of solid pellets; and the bottom six inches of fuel made of annular pellets. Figure 1 shows the annular pellet; Figure 2 shows the fuel stack in the rod. The solid pellets are the same length and OD as the annular pellets.

3. All parameters for this fuel are the same as those listed in Certificate of Compliance 5450, Paragraph 5.b.iii, column 1, except that the top and bottom six inches of the fuel stack has annular pellets; due to the smaller amount of UO_2 in the annular pellets, the maximum ^{235}U per fuel assembly is reduced from 22.1 to 21.6 kgs. The weight difference was calculated using the formula

$$W_{new} = (W_s + W_a(\frac{N_a}{N_s}))W_{old}$$

where

W_{new} = the new maximum ^{235}U weight per assembly with annular blankets,

W_s = the portion of the stack which is solid pellets, or 11/12 of the stack,

W_a = the portion of the stack which is annular pellets, or 1/12 of the stack,

N_a = the nominal weight of one annular pellet, or 0.0107 lbs.,

N_s = the nominal weight of one solid pellet, or 0.0143 lbs., and

W_{old} = the maximum ^{235}U weight per assembly with all solid pellets.

4. Figure 3 illustrates the KENO model used for the HAC.

5. Reactivity differences are discussed in a following page.

6. Clamping frames are positioned at each grid, and the 14x14 OFA assembly has seven (7) grids. Figure 4 illustrates the positions of the clamping frame arms along the assembly's

length.

7. The configuration of the 14x14 OFA assembly is as follows:

Pellet OD	0.3444 in. nominal
Rod OD	0.4000 in. nominal
Clad thickness	0.0225 in. minimum
^{235}U/assembly	18.5 kgs. maximum

FIGURE 1

ENRICHED ANNULAR AXIAL BLANKET PELLET

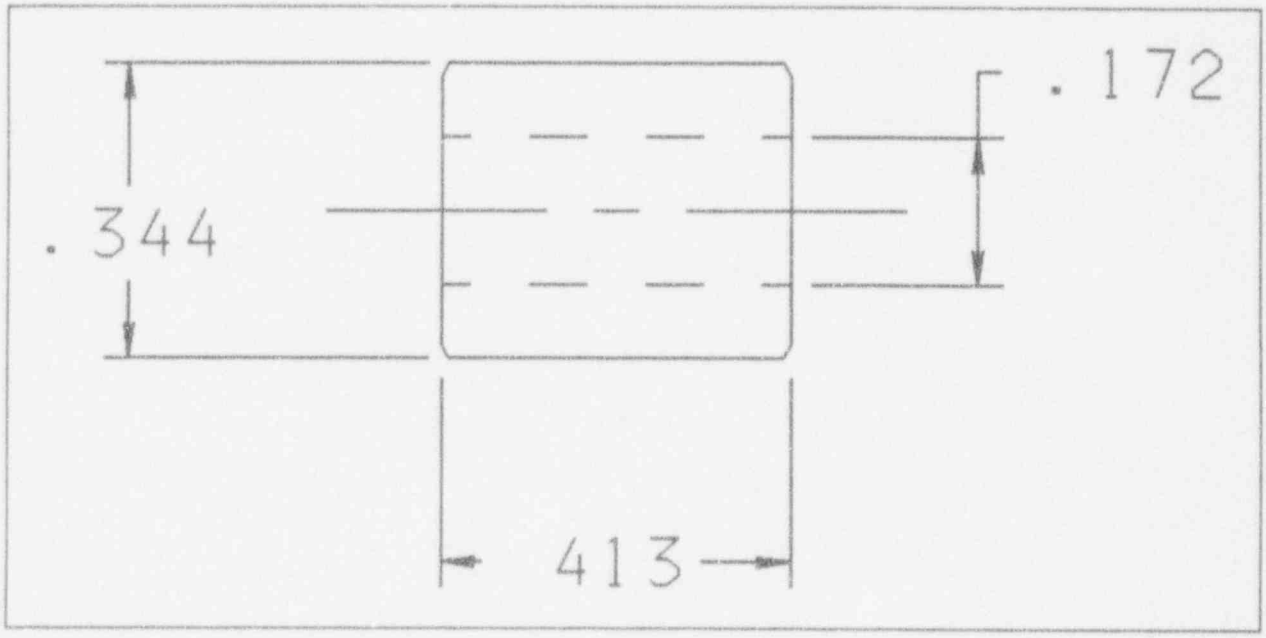


FIGURE 2

PRAIRIE ISLAND 2 14X14 OFA FUEL STACK

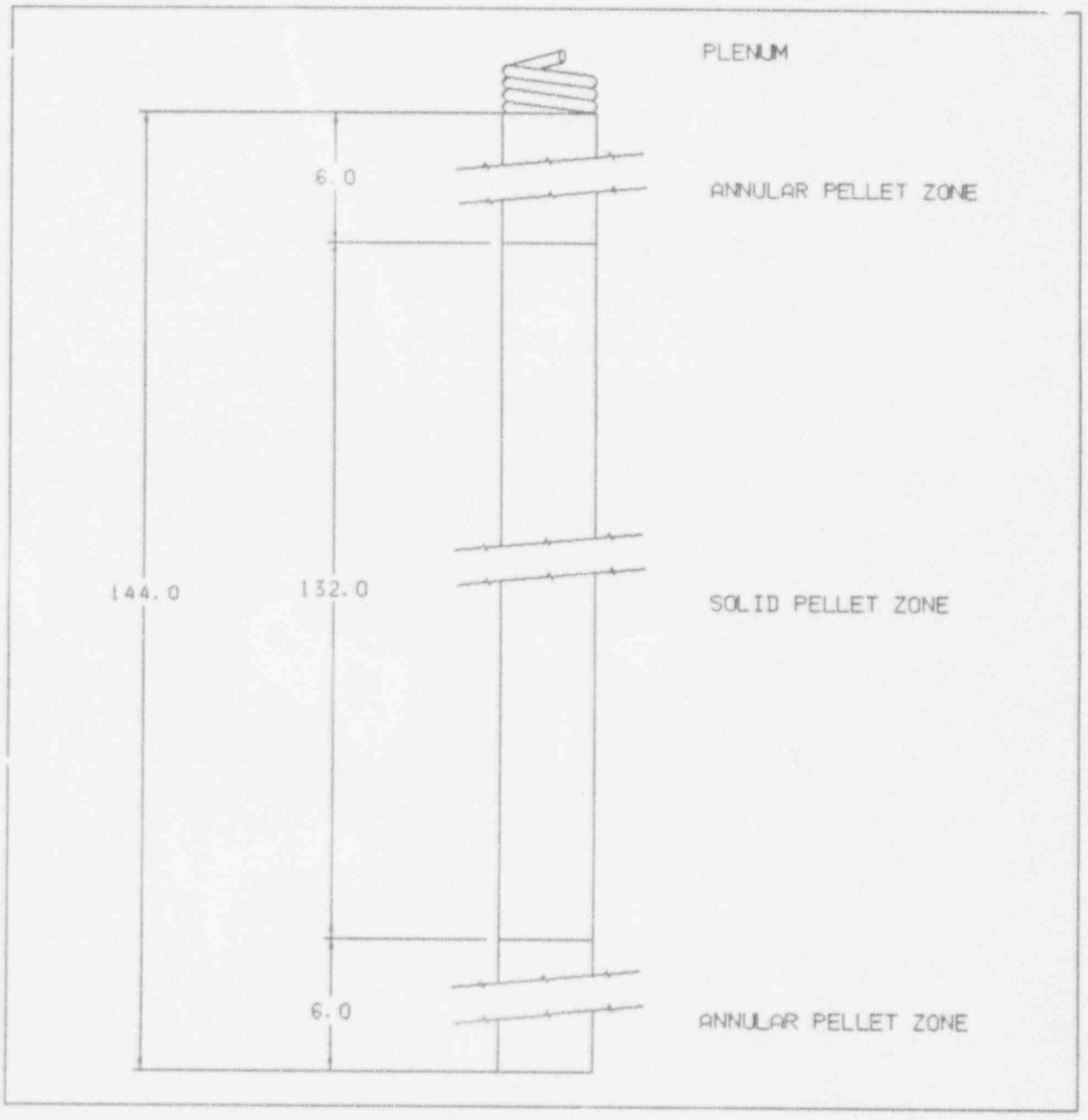


FIGURE 3

KENO MODEL OF FUEL ASSEMBLY WITHIN CONTAINER FOR SQUARE LATTICE FUEL

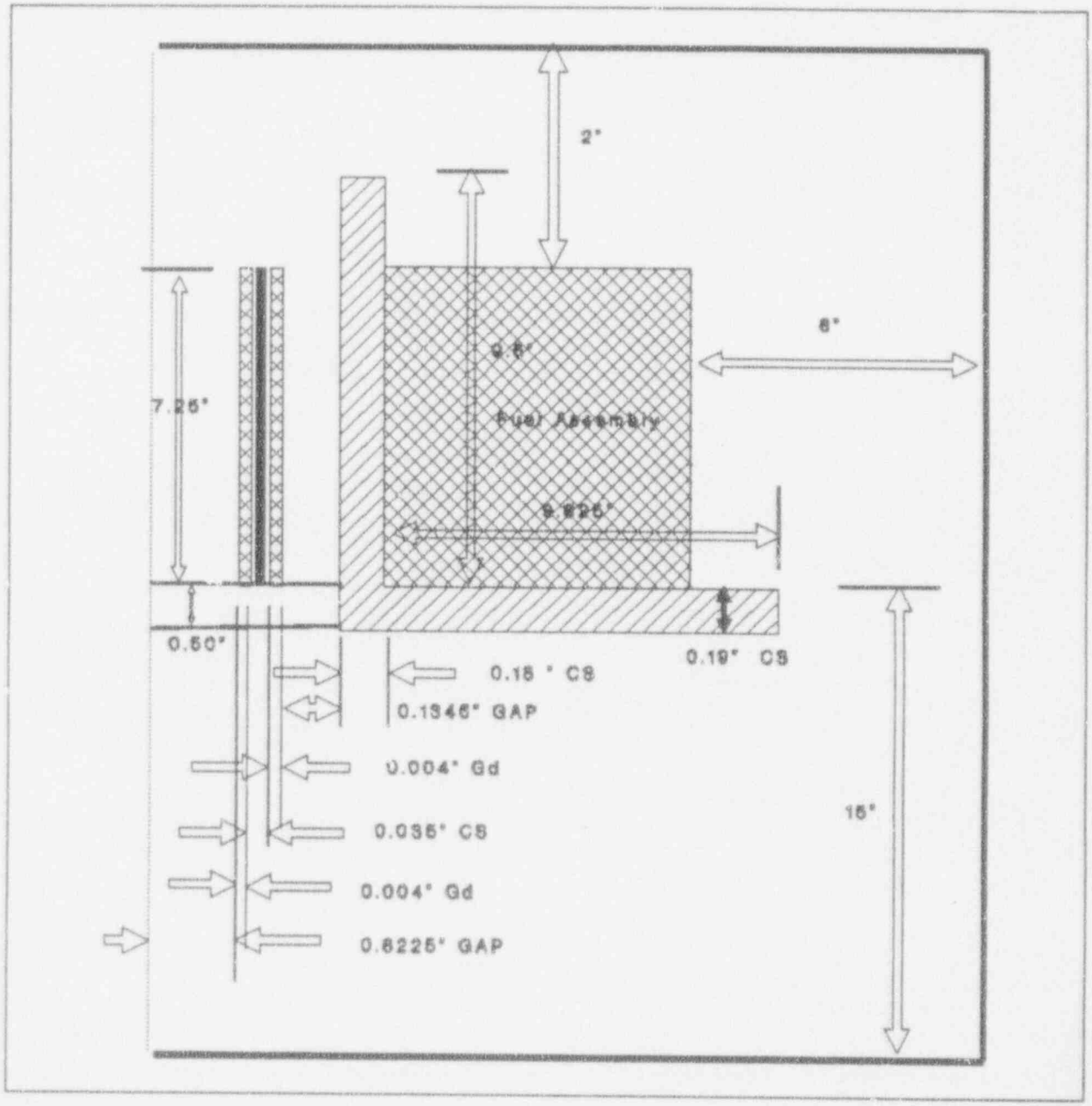
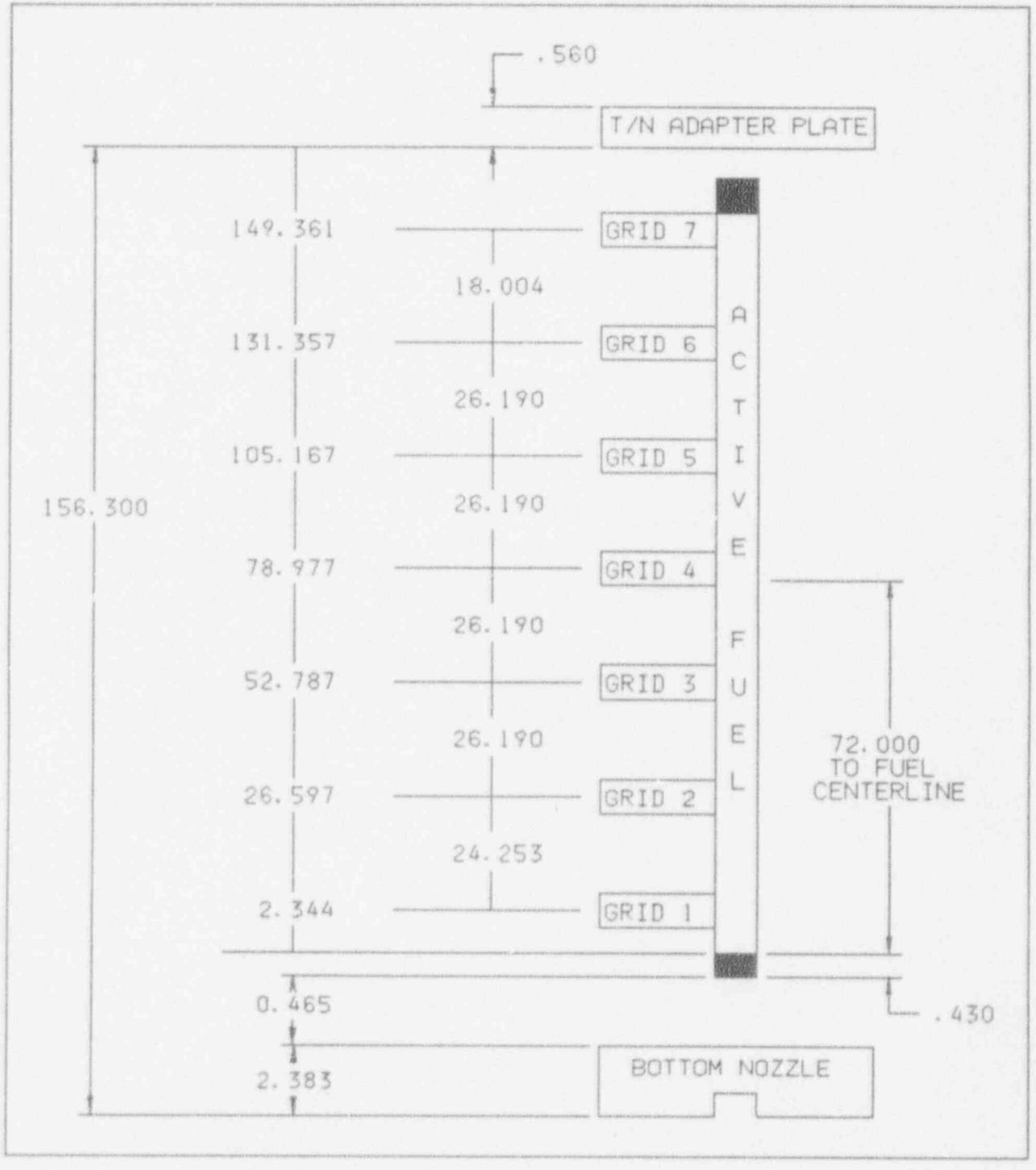


FIGURE 4

GRID (CLAMPING FRAME ARM) SPACING
14X14 OFA ASSEMBLY



REACTIVITY DIFFERENCES

Calculations have been performed using the KENO Va criticality code to evaluate the reactivity of the Westinghouse RCC shipping container when loaded with NSP 14x14 OFA fuel assemblies. The NSP assemblies include six inch, enriched, annular axial blankets on both the top and bottom ends of the active fuel zone. Fuel assembly enrichment was assumed to be 5.0 wt% for both the solid center pellets and the annular axial blanket pellets.

Five cases were modeled. Table A describes each case and the resultant reactivity. The KENO decks for each of the five cases are listed in Tables B through F. The water density at which optimum moderation occurs, 0.02 g/cm^3, was determined by making multiple KENO runs. The data from these runs are presented in Figure 4. All cases were modeled under the Hypothetical Accident Condition (HAC) scenario.

Case 1 evaluates the RCC cask reactivity under the same bases and assumptions applied to all previous Westinghouse cask evaluations - namely, that the insides of the fuel rods are dry and are not subject to the water which is assumed to flood the open areas within the cask. The model is three-dimensional and does not take into account any of the cask materials of construction.

Case 2 is identical to the first, except that the water is assumed also to penetrate into the inside of each fuel rod and flood the pellet-to-clad gap areas and the annulus of the annular blanket pellets.

Case 3 is a two-dimensional model. Assumptions modeled are as follows: the entire pellet stack is solid, there is optimum moderation around the assembly, the inside of the rod remains dry, and approximately 50% of the materials of construction are taken into account.

Case 3* was originally analyzed in 1985 (Table 8, Page 19-20, dated 12/20/85) and is included here for reference. It assumes a solid pellet stack, full density water around the assembly, no water inside the rod, and no container construction materials taken into account. It is also a two-dimensional model.

Case 4 is again a three-dimensional model. It is identical to Case 2 except that partial density water around the assembly is postulated. Full density water is assumed to be inside the rod in the annulus and pellet-to-clad gap.

Case 5 is also three-dimensional, and is identical to Case 4 except that the pellet stack is assumed to be solid along its entire length.

Note the ΔK_{eff} between Cases 1 and 2, and between Cases 4 and 5. This increase in reactivity is on the order of the uncertainty of KENO (≈ 0.005). Comparing Cases 1 and 2, we can see

that introducing water inside the rod containing annular pellets does not significantly increase reactivity. Comparing Cases 4 and 5, we see that introducing annular pellets at reduced water density also does not significantly increase reactivity. Comparing Cases 1 and 5, and Cases 2 and 4, shows that the effect of reducing water density from full density to optimum moderation outside the rods produces a slightly larger ΔK which is less than 0.012. However, comparing Cases 3 and 3*, we see that even taking into account optimum moderation, inclusion of the package materials of construction into the model results in a significant decrease ($\Delta K \approx .14$) in reactivity for a solid pellet model.

It has been demonstrated that while introduction of annular pellets, and flooding the annulus, resulted in a small increase in reactivity, and introduction of optimum moderation resulted in a slightly larger increase in reactivity, it is also shown that taking package materials of construction into consideration results in a decrease in reactivity which is an order of magnitude less than the previously discussed increases. From this, we infer that by inclusion of the package materials of construction in the model, at optimum moderation, would result in K_{eff} significantly less than 0.95, and therefore, that the acceptance criterial for criticality are satisfied.

TABLE A

KENO CASES FOR 14X14 OFA FUEL ASSEMBLY

CASE Nº	MODEL	PELLET CONFIG	OUTSIDE ROD MODERATOR DENSITY	INSIDE ROD MODERATOR DENSITY	K_{eff}	1-σ	95/95-K	ΔK
1	3D	SOLID/ANN	1.00	0.0	0.92487	0.00490	0.94126	0.0052
2	3D	SOLID/ANN	1.00	1.0	0.93107	0.00425	0.94646	
3	2D[1]	SOLID	0.02	0.0	0.79181	0.00401	0.80683	0.1399
3*	2D	SOLID	1.00	0.0	0.93231	0.00359	0.94677	
4	3D	SOLID/ANN	0.02	1.0	0.94439	0.00376	0.95909	0.0049
5	3D	SOLID	0.02	1.0	0.94007	0.00335	0.95411	

1. Model includes additional metal components.

FIGURE 5

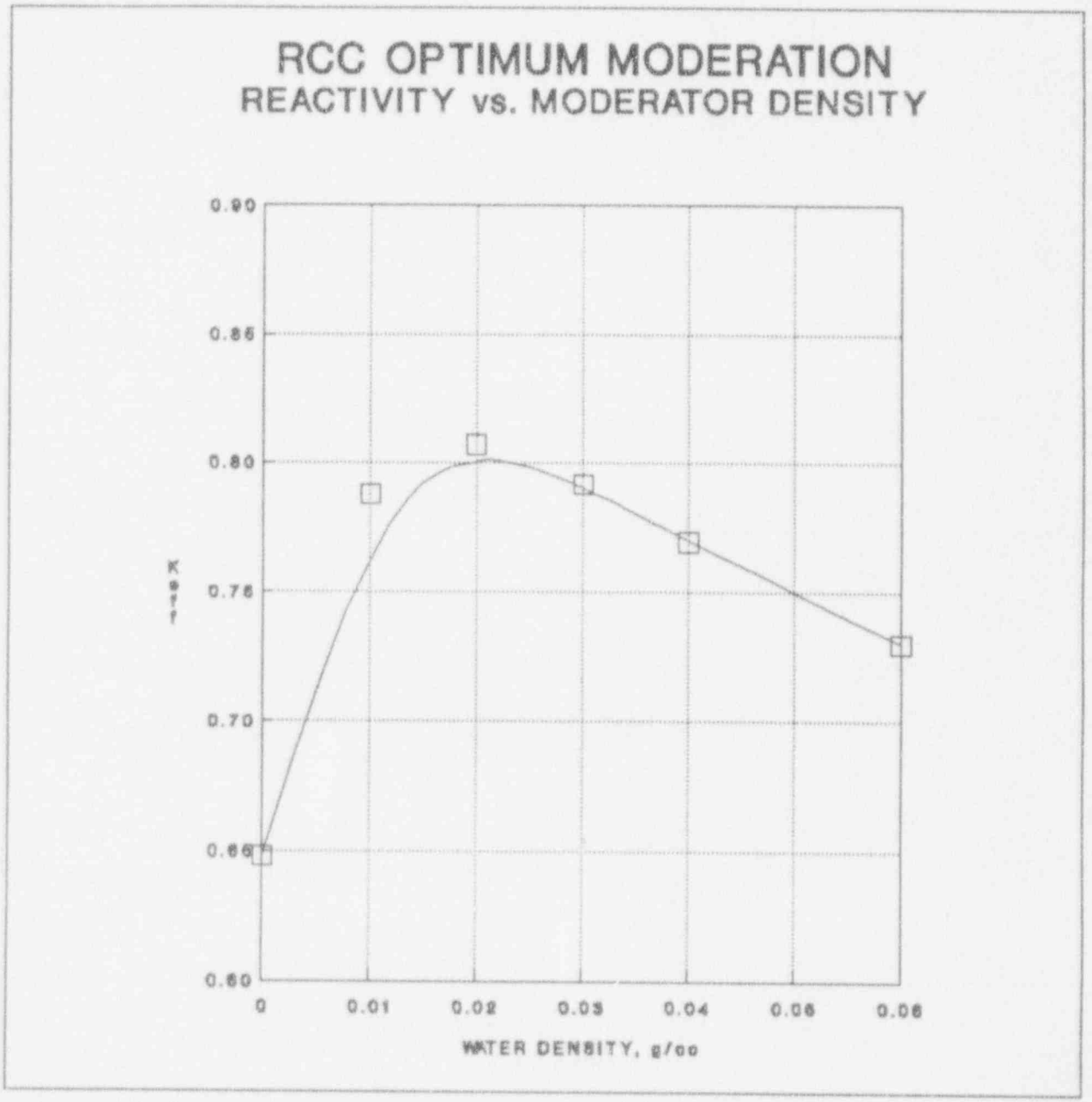
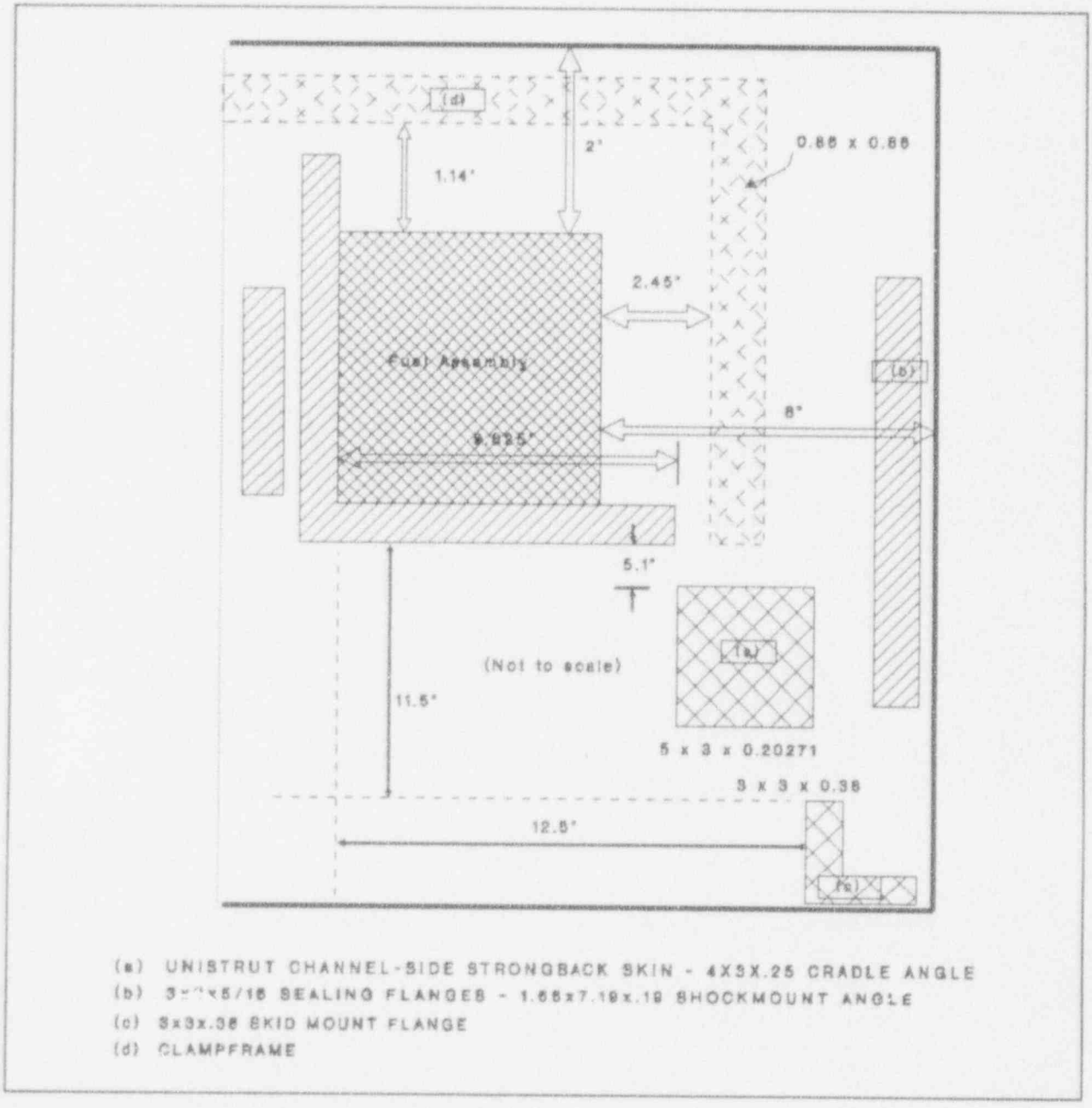

RCC OPTIMUM MODERATION
REACTIVITY vs. MODERATOR DENSITY
0.90
0.85
0.80
0.75
0.70
0.65
0.60
K eff
0
0.01
0.02
0.03
0.04
0.05
0.06
WATER DENSITY, g/cc

FIGURE 6

KENO MODEL OF SQUARE LATTICE ASSEMBLY WITHIN CONTAINER UTILIZED IN OPTIMUM MODERATION EVALUATION



(a) UNISTRUT CHANNEL-SIDE STRONGBACK SKIN - 4X3X.25 CRADLE ANGLE
(b) 3x[illegible]x5/16 SEALING FLANGES - 1.66x7.19x.19 SHOCKMOUNT ANGLE
(c) 3x3x.38 SKID MOUNT FLANGE
(d) CLAMPFRAME

TABLE B: KENO CASE 1

```
CASE 1).

TITLE-CASK WITH 14X14 OFA 5.00 W/O ASSEMBLY

READ PARAMETERS
  TME=6.0   RUN=YES   PLT=YES
  GEN=900   NPG=300   NSK=005   LIB=41
  XS1=YES   NUB=YES
END PARAMETERS

READ MIXT  SCT=2
MIX= 1
' SOLID UO2 PELLET 5.00 W/O (96.5% TD, 0% DISH)
        1192235     0.0011942
        1192238     0.022404
         118016     0.047196
MIX= 2
' SOLID ZIRC FUEL ROD CLADDING
        2140302     0.043326
MIX= 3
' ANNULAR UO2 PELLET 5.00 W/O (96.5% TD)
        2292235     0.0011942
        2292238     0.022404
         228016     0.047196
MIX= 4
' ANNULAR ZIRC FUEL ROD CLADDING
        3240302     0.043326
MIX= 5
' H2O AT 1.00 G/CC
         31001     0.066854
         38016     0.033427
MIX= 6
'  CARBON STEEL FOR STRONGBACK & SHELL
         36012     4.728898E-4
        315031     5.807008E-5
        316032     6.642906E-5
        325055     3.877064E-4
        326000     8.420119E-2
MIX= 7
'  GADOLINIA OXIDE ABSORBER (0.02 GM GD2O3/CM2 @ 0.01016 CM THICKNESS)
```

```
         48016    9.810529E-3
        464152    1.308071E-5
        464154    1.373474E-4
        464155    9.679722E-4
        464156    1.347313E-3
        464157    1.026835E-3
        464158    1.622008E-3
        464160    1.425792E-3
MIX= 8
'  CARBON STEEL SHEET FOR GD ABSORBER
         56012    4.728898E-4
        515031    5.807008E-5
        516032    6.642906E-5
        525055    3.877064E-4
        526000    8.420119E-2
END MIXT

READ GEOMETRY
UNIT 1
COM=" 14X14 OFA FUEL ROD - ENRICHED REGION"
CYLINDER   1 1   0.437388  167.64  0.0
CYLINDER   0 1   0.44628   167.64  0.0
CYLINDER   2 1   0.50800   167.64  0.0
CUBOID     5 1 4P0.70612   167.64  0.0
UNIT 2
COM=" 14X14 OFA GUIDE TUBE - ENRICHED REGION"
CYLINDER   5 1   0.62484   167.64  0.0
CYLINDER   2 1   0.66802   167.64  0.0
CUBOID     5 1 4P0.70612   167.64  0.0
UNIT 3
COM=" 14X14 OFA INSTRUMENT TUBE - ENRICHED REGION"
CYLINDER   5 1   0.44704   167.64  0.0
CYLINDER   2 1   0.50673   167.64  0.0
CUBOID     5 1 4P0.70612   167.64  0.0
UNIT 4
COM=" 14X14 OFA FUEL ROD - BLANKET REGION"
CYLINDER   0 1   0.218694   15.24  0.0
CYLINDER   3 1   0.437388   15.24  0.0
CYLINDER   0 1   0.44628    15.24  0.0
CYLINDER   4 1   0.50800    15.24  0.0
CUBOID     5 1 4P0.70612    15.24  0.0
UNIT 5
COM=" 14X14 OFA GUIDE TUBE - BLANKET REGION"
```

```
CYLINDER    5  1    0.62484    15.24  0.0
CYLINDER    2  1    0.66802    15.24  0.0
CUBOID      5  1  4P0.70612    15.24  0.0
UNIT 6
COM=" 14X14 OFA INSTRUMENT TUBE - BLANKET REGION"
CYLINDER    5  1    0.44704    15.24  0.0
CYLINDER    2  1    0.50673    15.24  0.0
CUBOID      5  1  4P0.70612    15.24  0.0
UNIT 7
COM=" BOTTOM EDGE OF CS STRONGBACK "
CUBOID      6  1  24.95550  0.0       0.0      -0.45720  182.88  0.0
UNIT 8
COM=" VERTICAL EDGE OF CS STRONGBACK "
CUBOID      6  1   0.0      -0.45720  24.13000  -0.45720  182.88  0.0
UNIT 9
COM=" GADOLINIA ABSORBER PANEL "
CUBOID      8  1   0.04445  -0.04445  18.41500   0.0      182.88  0.0
CUBOID      7  1   0.05461  -0.05461  18.41500   0.0      182.88  0.0
GLOBAL
UNIT 10
COM=" 14X14 OFA ASSEMBLY IN CASK "
ARRAY 1  0.0       0.0       0.0
REPLICATE  5  1  20.32000  2.99720  5.08000  38.10000  15.24  0.0  1
HOLE 7   0.0       0.0       0.0
HOLE 8   0.0       0.0       0.0
HOLE 9   -0.85344   0.81280   0.0
REPLICATE  6  1   0.22606   0.0    0.22606   0.22606  0.22606  0.0  1
END GEOM

READ ARRAY
ARA=1 NUX=14 NUY=14 NUZ=2 COM=" 14x14 OFA ASSEMBLY "
LOOP
 1   1  14   1     1  14   1     1   1   1
 2   3  12   3     3  12   9     1   1   1
 2   3  12   9     6   9   3     1   1   1
 2   5  10   5     5  10   5     1   1   1
 3   7   7   1     8   8   1     1   1   1
 4   1  14   1     1  14   1     2   2   1
 5   3  12   3     3  12   9     2   2   1
 5   3  12   9     6   9   3     2   2   1
 5   5  10   5     5  10   5     2   2   1
 6   7   7   1     8   8   1     2   2   1
END LOOP
```

```
END ARRAY

READ BOUNDS
ALL=SPECULAR
END BOUNDS

READ PLOT
 TTL='BOX SLICE THROUGH ASSEMBLY ARRAY - SOLID PELLETS'
 PIC=BOX
 NCH='0.GIHVA*'
 XUL= 0.0    YUL= 19.77136 ZUL= 60.0
 XLR= 19.77136 YLR= 0.0    ZLR= 60.0
 UAX=1.0   VDN=-1.0  NAX=130
END
 TTL='BOX SLICE THROUGH ASSEMBLY ARRAY - ANNULAR PELLETS'
 PIC=BOX
 NCH='0.GIHVA*'
 XUL= 0.0    YUL= 19.77136 ZUL= 6.0
 XLR= 19.77136 YLR= 0.0    ZLR= 6.0
 UAX=1.0   VDN=-1.0  NAX=130
END
 TTL='MAT SLICE THROUGH ASSEMBLY ARRAY - SOLID PELLETS'
 PIC=MAT
 NCH='0.ZWSGS'
 XUL= 0.0    YUL= 19.77136 ZUL= 60.0
 XLR= 19.77136 YLR= 0.0    ZLR= 60.0
 UAX=1.0   VDN=-1.0  NAX=130
END
 TTL='MAT SLICE THROUGH ASSEMBLY ARRAY - ANNULAR PELLETS'
 PIC=MAT
 NCH='0.ZWSGS'
 XUL= 0.0    YUL= 19.77136 ZUL= 6.0
 XLR= 19.77136 YLR= 0.0    ZLR= 6.0
 UAX=1.0   VDN=-1.0  NAX=130
END
 TTL='BOX SLICE THROUGH CASK MODEL '
 PIC=BOX
 NCH='0.GIHVA*'
 XUL= -2.99720 YUL= 30.15742 ZUL= 60.0
 XLR= 40.31742 YLR=-38.32606 ZLR= 60.0
 UAX=1.0   VDN=-1.0  NAX=130
END
 TTL='MAT SLICE THROUGH CASK MODEL '
```

```
 PIC=MAT
 NCH='0.ZWSGS'
 XUL= -2.99720 YUL= 30.15742 ZUL= 60.0
 XLR= 40.31742 YLR=-38.32606 ZLR= 60.0
 UAX=1.0   VDN=-1.0   NAX=130
END
 TTL='BOX SLICE THROUGH GD ABSORBER '
 PIC=BOX
 NCH='0.GIHVA*'
 XUL= -2.99720 YUL= 20.00000 ZUL= 60.0
 XLR=  0.65000 YLR= -2.00000 ZLR= 60.0
 UAX=1.0   VDN=-1.0   NAX=130
END
 TTL='MAT SLICE THROUGH GD ABSORBER '
 PIC=MAT
 NCH='0.ZWSGS'
 XUL= -2.99720 YUL= 20.00000 ZUL= 60.0
 XLR=  0.65000 YLR= -2.00000 ZLR= 60.0
 UAX=1.0   VDN=-1.0   NAX=130
END PLOT

END DATA
/EOF
```

TABLE C: KENO CASE 2

```
CASE 2).

TITLE-CASK WITH 14X14 OFA 5.00 W/O ASSEMBLY

READ PARAMETERS
  TME=7.0   RUN=YES   PLT=YES
  GEN=900   NPG=310   NSK=005   LIB=41
  XS1=YES   NUB=YES
END PARAMETERS

READ MIXT  SCT=2
MIX= 1
' SOLID UO2 PELLET 5.00 W/O (96.5% TD, 0% DISH)
        1192235     0.0011942
        1192238     0.022404
         118016     0.047196
MIX= 2
' H2O AT 1.00 G/CC IN SOLID PELLET GAP
         231001     0.066854
         238016     0.033427
MIX= 3
' SOLID ZIRC FUEL ROD CLADDING
       2140302     0.043326
MIX= 4
' H2O AT 1.00 G/CC IN BLANKET FUEL ANNULUS
         151001     0.066854
         158016     0.033427
MIX= 5
' ANNULAR UO2 PELLET 5.00 W/O (96.5% TD)
        2292235     0.0011942
        2292238     0.022404
         228016     0.047196
MIX= 6
' H2O AT 1.00 G/CC IN ANNULAR PELLET GAP
         341001     0.066854
         348016     0.033427
MIX= 7
' ANNULAR ZIRC FUEL ROD CLADDING
        3240302     0.043326
MIX= 8
```

```
' H2O AT 1.00 G/CC
        31001    0.066854
        38016    0.033427
MIX= 9
'  CARBON STEEL FOR STRONGBACK & SHELL
        36012    4.728898E-4
       315031    5.807008E-5
       316032    6.642906E-5
       325055    3.877064E-4
       326000    8.420119E-2
MIX= 10
'  GADOLINIA OXIDE ABSORBER (0.02 GM GD2O3/CM2 @ 0.01016 CM THICKNESS)
        48016    9.810529E-3
       464152    1.308071E-5
       464154    1.373474E-4
       464155    9.679722E-4
       464156    1.347313E-3
       464157    1.026835E-3
       464158    1.622008E-3
       464160    1.425792E-3
MIX= 11
'  CARBON STEEL SHEET FOR GD ABSORBER
        56012    4.728898E-4
       515031    5.807008E-5
       516032    6.642906E-5
       525055    3.877064E-4
       526000    8.420119E-2
END MIXT

READ GEOMETRY
UNIT 1
COM=" 14X14 OFA FUEL ROD - ENRICHED REGION"
CYLINDER   1  1   0.437388  167.64  0.0
CYLINDER   2  1   0.44628   167.64  0.0
CYLINDER   3  1   0.50800   167.64  0.0
CUBOID     8  1  4P0.70612   167.64  0.0
UNIT 2
COM=" 14X14 OFA GUIDE TUBE - ENRICHED REGION"
CYLINDER   8  1   0.62484   167.64  0.0
CYLINDER   3  1   0.66802   167.64  0.0
CUBOID     8  1  4P0.70612   167.64  0.0
UNIT 3
COM=" 14X14 OFA INSTRUMENT TUBE - ENRICHED REGION"
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CYLINDER    8  1    0.44704   167.64  0.0
CYLINDER    3  1    0.50673   167.64  0.0
CUBOID      8  1  4P0.70612   167.64  0.0
UNIT 4
COM=" 14X14 OFA FUEL ROD - BLANKET REGION"
CYLINDER    4  1    0.218694   15.24  0.0
CYLINDER    5  1    0.437388   15.24  0.0
CYLINDER    6  1    0.44628    15.24  0.0
CYLINDER    7  1    0.50800    15.24  0.0
CUBOID      8  1  4P0.70612    15.24  0.0
UNIT 5
COM=" 14X14 OFA GUIDE TUBE - BLANKET REGION"
CYLINDER    8  1    0.62484    15.24  0.0
CYLINDER    3  1    0.66802    15.24  0.0
CUBOID      8  1  4P0.70612    15.24  0.0
UNIT 6
COM=" 14X14 OFA INSTRUMENT TUBE - BLANKET REGION"
CYLINDER    8  1    0.44704    15.24  0.0
CYLINDER    3  1    0.50673    15.24  0.0
CUBOID      8  1  4P0.70612    15.24  0.0
UNIT 7
COM=" BOTTOM EDGE OF CS STRONGBACK "
CUBOID      9  1   24.95550   0.0       0.0      -0.45720  182.88  0.0
UNIT 8
COM=" VERTICAL EDGE OF CS STRONGBACK "
CUBOID      9  1    0.0      -0.45720  24.13000  -0.45720  182.88  0.0
UNIT 9
COM=" GADOLINIA ABSORBER PANEL "
CUBOID     11  1    0.04445  -0.04445  18.41500   0.0      182.88  0.0
CUBOID     10  1    0.05461  -0.05461  18.41500   0.0      182.88  0.0
GLOBAL
UNIT 10
COM=" 14X14 OFA ASSEMBLY IN CASK "
ARRAY 1   0.0       0.0       0.0
REPLICATE   8  1   20.32000   2.99720  5.08000  38.10000  15.24  0.0  1
HOLE 7    0.0       0.0       0.0
HOLE 8    0.0       0.0       0.0
HOLE 9   -0.85344   0.81280   0.0
REPLICATE   9  1    0.22606   0.0     0.22606   0.22606  0.22606  0.0  1
END GEOM

READ ARRAY
ARA=1 NUX=14 NUY=14 NUZ=2 COM=" 14x14 OFA ASSEMBLY "
```

```
LOOP
 1  1 14  1    1 14  1    1  1  1
 2  3 12  3    3 12  9    1  1  1
 2  3 12  9    6  9  3    1  1  1
 2  5 10  5    5 10  5    1  1  1
 3  7  7  1    8  8  1    1  1  1
 4  1 14  1    1 14  1    2  2  1
 5  3 12  3    3 12  9    2  2  1
 5  3 12  9    6  9  3    2  2  1
 5  5 10  5    5 10  5    2  2  1
 6  7  7  1    8  8  1    2  2  1
END LOOP
END ARRAY

READ BOUNDS
ALL=SPECULAR
END BOUNDS

READ PLOT
  TTL='BOX SLICE THROUGH ASSEMBLY ARRAY - SOLID PELLETS'
  PIC=BOX
  NCH='0.GIHVA*'
  XUL=  0.0     YUL= 19.77136 ZUL= 60.0
  XLR= 19.77136 YLR=  0.0     ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='BOX SLICE THROUGH ASSEMBLY ARRAY - ANNULAR PELLETS'
  PIC=BOX
  NCH='0.GIHVA*'
  XUL=  0.0     YUL= 19.77136 ZUL= 6.0
  XLR= 19.77136 YLR=  0.0     ZLR= 6.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='MAT SLICE THROUGH ASSEMBLY ARRAY - SOLID PELLETS'
  PIC=MAT
  NCH='0.ZWSGS'
  XUL=  0.0     YUL= 19.77136 ZUL= 60.0
  XLR= 19.77136 YLR=  0.0     ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='MAT SLICE THROUGH ASSEMBLY ARRAY - ANNULAR PELLETS'
  PIC=MAT
  NCH='0.ZWSGS'
```

```
  XUL= 0.0     YUL= 19.77136 ZUL= 6.0
  XLR= 19.77136 YLR= 0.0     ZLR= 6.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='BOX SLICE THROUGH CASK MODEL '
  PIC=BOX
  NCH='0.GIHVA*'
  XUL= -2.99720 YUL= 30.15742 ZUL= 60.0
  XLR= 40.31742 YLR=-38.32606 ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='MAT SLICE THROUGH CASK MODEL '
  PIC=MAT
  NCH='0.ZWSGS'
  XUL= -2.99720 YUL= 30.15742 ZUL= 60.0
  XLR= 40.31742 YLR=-38.32606 ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='BOX SLICE THROUGH GD ABSORBER '
  PIC=BOX
  NCH='0.GIHVA*'
  XUL= -2.99720 YUL= 20.00000 ZUL= 60.0
  XLR= 0.65000 YLR= -2.00000 ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='MAT SLICE THROUGH GD ABSORBER '
  PIC=MAT
  NCH='0.ZWSGS'
  XUL= -2.99720 YUL= 20.00000 ZUL= 60.0
  XLR= 0.65000 YLR= -2.00000 ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END PLOT

END DATA
/E0F
```

TABLE D: KENO CASE 3

```
CASE 3).

FECTEAU 14X14 OFA  SHIPPING CONTAINER    OPT MOD  0.02  EXACT MODEL
READ PARAMETERS
  TME=6.0   RUN=YES   PLT=YES
  GEN=900   NPG=300   NSK=005   LIB=41
  XS1=YES   NUB=YES
END PARAMETERS

READ MIXT      SCT=2
MIX= 1
'  UO2 14 OFA PELLET 5.00 W/O (96.5% TD, 0% DISH)
         192235     0.0011942
         192238     0.022404
          18016     0.047196
MIX= 2
'  ZIRC FUEL ROD CLADDING
         240302     0.043326
MIX= 3
'  H2O AT 0.02 G/CC (REFERENCE 1.0 G/CC H=0.066854, O=0.033427)
          31001     0.00133708
          38016     0.00066854
MIX= 4
'  CARBON STEEL FOR STRONGBACK & SHELL
          36012     4.728898E-4
         315031     5.807008E-5
         316032     6.642906E-5
         325055     3.877064E-4
         326000     8.420119E-2
MIX= 5
'  GADOLINIA OXIDE ABSORBER (0.02 GM GD2O3/CM2 @ 0.01016 CM THICKNESS)
          48016     9.810529E-3
         464152     1.308071E-5
         464154     1.373474E-4
         464155     9.679722E-4
         464156     1.347313E-3
         464157     1.026835E-3
         464158     1.622008E-3
         464160     1.425792E-3
MIX= 6
```

```
' CARBON STEEL SHEET FOR GD ABSORBER
        56012     4.728898E-4
       515031     5.807008E-5
       516032     6.642906E-5
       525055     3.877064E-4
       526000     8.420119E-2
     END MIXT
READ GEOM
 UNIT 1      COM='14 OFA FUEL ROD'
  CYLINDER  1 1 0.437388 2P31.75
  CYLINDER  3 1 0.44628  2P31.75
  CYLINDER  2 1 0.50800  2P31.75
  CUBOID    3 1 4P0.70612  2P31.75
 UNIT 2      COM='14 OFA GT OR IT'
  CYLINDER  3 1 0.62484  2P31.75
  CYLINDER  2 1 0.66802  2P31.75
  CUBOID    3 1 4P0.70612  2P31.75
 UNIT 3  ARRAY 1 2R0.0 -31.75  COM='ASSEMBLY ON STRONG BACK'
  CUBOID    3 1 24.9555 0.0 22.86 0.0 2P31.75
  CUBOID    4 1 24.9555 -.4572 22.86 -.4572 2P31.75
 UNIT 4      COM='POISON PLAT BETWEEN ASSEMBLY'
  CUBOID    6 1 .0889 0.0 18.415 0.0 2P31.75
  CUBOID    5 1 .09906 -.01016 18.415 0.0 2P31.75
  CUBOID    3 1 .44069 -2.09931 22.0472 -1.27 2P31.75
  HOLE      8  -2.0993   19.8    0.0
 UNIT 5      COM='REST OF STRONGBACK AND CRADLE'
  CUBOID    3 1 7.1051 0.5149 12.1851 0.5149 2P31.75
  CUBOID    4 1 7.62   0.0    12.70   0.0    2P31.75
 UNIT 6      COM='CONTAINER FLANGES AND BRACKET'
  CUBOID    4 1 1.285  0.0    22.86   0.0    2P31.75
 UNIT 7      COM='SKID ANGLE'
  CUBOID    3 1 7.62   0.9652 7.62    0.9652 2P31.75
  CUBOID    4 1 7.62   0.0    7.62    0.0    2P31.75
 UNIT 8      COM='UNISTRUT CHANNEL ASSEMBLY'
  CUBOID    3 1 1.799  0.0    2.24    0.7398 2P31.75
  CUBOID    4 1 2.539  0.0    2.24    0.0    2P31.75
 UNIT 9      COM='TOP CLAMPING ASSEMBLY'
  CUBOID    4 1 26.21  0.0    2.1     0.0    2P1.05
 UNIT 10     COM='SIDE CLAMPING ASSEMBLY'
  CUBOID    4 1 2.1    0.0    24.23   0.0    2P1.05
 GLOBAL UNIT 14  ARRAY 2 2R0.0 -31.75
  CUBOID    3 1 44.73448 0.0 25.68448 -37.6428 2P31.75
  HOLE      5  28.0  -13.0  0.0
```

```
   HOLE     6  43.0  -15.0  0.0
   HOLE     7  35.0  -37.0  0.0
   HOLE     9  3.00   23.4  0.0
   HOLE    10  29.21  1.27  0.0
   CUBOID    4 1 44.96058 0.0 25.91058 -37.8689 2P31.75
END GEOM
READ ARRAY
 ARA=1 NUX=14 NUY=14 NUZ=1 FILL
 30R1 2 2R1 2 2R1 2 2R1 2 20R1 2 4R1 2 6R1 2
 8R1 2 8R1 2 23R1 2 8R1 2 6R1 2 4R1 2 20R1 2
 2R1 2 2R1 2 2R1 2 30R1    END FILL
 ARA=2 NUX=2 NUY=1 NUZ=1 FILL  4 3   END FILL
END ARRAY
READ BOUN
 ALL=SPEC  END BOUN
READ PLOT
 PIC=UNIT  PLT=YES
 TTL='X-Y SLICE THRU Z=0 TO CONTAINER BOUND FOR 132X132 PRINT'
 XUL=0.0   YUL=32.26058    ZUL=0.0
 XLR=44.96058    YLR=-37.8689    ZLR=0.0
 UAX=1.0     VDN=-1.0     NAX=114  NDN=131  END
 TTL='X-Y SLICE THRU Z=0 TO CONTAINER BOUND FOR 132X132 PRINT'
 PIC=MAT   NCH=' ...*.'
 XUL=0.0   YUL=32.26058    ZUL=0.0
 XLR=44.96058    YLR=-37.8689    ZLR=0.0
 UAX=1.0     VDN=-1.0     NAX=114  NDN=131  END  END PLOT
END DATA
END
/EOF
```

TABLE E: KENO CASE 4

```
CASE 4).

TITLE-CASK 14XOFA 5.0 W/O 0.02 G/CC ANNULAR PELLET

READ PARAMETERS
  TME=6.0   RUN=YES   PLT=YES
  GEN=900   NPG=303   NSK=005   LIB=41
  XS1=YES   NUB=YES
END PARAMETERS

READ MIXT  SCT=2
MIX= 1
' SOLID UO2 PELLET 5.00 W/O (96.5% TD, 0% DISH)
         192235     0.0011942
         192238     0.022404
          18016     0.047196
MIX= 2
' H2O AT 1.00 G/CC IN SOLID PELLET GAP
          31001     0.066854
          38016     0.033427
MIX= 3
' SOLID ZIRC FUEL ROD CLADDING
         240302     0.043326
MIX= 4
' H2O AT 1.00 G/CC IN BLANKET FUEL ANNULUS
          31001     0.066854
          38016     0.033427
MIX= 5
' ANNULAR UO2 PELLET 5.00 W/O (96.5% TD)
         192235     0.0011942
         192238     0.022404
          18016     0.047196
MIX= 6
' H2O AT 1.00 G/CC IN ANNULAR PELLET GAP
          31001     0.066854
          38016     0.033427
MIX= 7
' ANNULAR ZIRC FUEL ROD CLADDING
         240302     0.043326
MIX= 8
```

```
' H2O AT 0.02 G/CC
        31001    0.00133708
        38016    0.00066854
MIX= 9
'  CARBON STEEL FOR STRONGBACK & SHELL
        36012    4.728898E-4
       315031    5.807008E-5
       316032    6.642906E-5
       325055    3.877064E-4
       326000    8.420119E-2
MIX= 10
'  GADOLINIA OXIDE ABSORBER (0.02 GM GD2O3/CM2 @ 0.01016 CM THICKNESS)
        48016    9.810529E-3
       464152    1.308071E-5
       464154    1.373474E-4
       464155    9.679722E-4
       464156    1.347313E-3
       464157    1.026835E-3
       464158    1.622008E-3
       464160    1.425792E-3
MIX= 11
'  CARBON STEEL SHEET FOR GD ABSORBER
        56012    4.728898E-4
       515031    5.807008E-5
       516032    6.642906E-5
       525055    3.877064E-4
       526000    8.420119E-2
END MIXT

READ GEOMETRY
UNIT 1
COM=" 14X14 OFA FUEL ROD - ENRICHED REGION"
CYLINDER    1  1    0.437388  167.64  0.0
CYLINDER    2  1    0.44628   167.64  0.0
CYLINDER    3  1    0.50800   167.64  0.0
CUBOID      8  1  4P0.70612   167.64  0.0
UNIT 2
COM=" 14X14 OFA GUIDE TUBE - ENRICHED REGION"
CYLINDER    8  1    0.62484   167.64  0.0
CYLINDER    3  1    0.66802   167.64  0.0
CUBOID      8  1  4P0.70612   167.64  0.0
UNIT 3
COM=" 14X14 OFA INSTRUMENT TUBE - ENRICHED REGION"
```

```
CYLINDER    8  1    0.44704   167.64  0.0
CYLINDER    3  1    0.50673   167.64  0.0
CUBOID      8  1  4P0.70612   167.64  0.0
UNIT 4
COM=" 14X14 OFA FUEL ROD - BLANKET REGION"
CYLINDER    4  1    0.218694   15.24  0.0
CYLINDER    5  1    0.437388   15.24  0.0
CYLINDER    6  1    0.44628    15.24  0.0
CYLINDER    7  1    0.50800    15.24  0.0
CUBOID      8  1  4P0.70612    15.24  0.0
UNIT 5
COM=" 14X14 OFA GUIDE TUBE - BLANKET REGION"
CYLINDER    8  1    0.62484    15.24  0.0
CYLINDER    3  1    0.66802    15.24  0.0
CUBOID      8  1  4P0.70612    15.24  0.0
UNIT 6
COM=" 14X14 OFA INSTRUMENT TUBE - BLANKET REGION"
CYLINDER    8  1    0.44704    15.24  0.0
CYLINDER    3  1    0.50673    15.24  0.0
CUBOID      8  1  4P0.70612    15.24  0.0
UNIT 7
COM=" BOTTOM EDGE OF CS STRONGBACK "
CUBOID      9  1  24.95550   0.0       0.0      -0.45720  182.88  0.0
UNIT 8
COM=" VERTICAL EDGE OF CS STRONGBACK "
CUBOID      9  1   0.0      -0.45720  24.13000  -0.45720  182.88  0.0
UNIT 9
COM=" GADOLINIA ABSORBER PANEL "
CUBOID     11  1   0.04445  -0.04445  18.41500   0.0      182.88  0.0
CUBOID     10  1   0.05461  -0.05461  18.41500   0.0      182.88  0.0
GLOBAL
UNIT 10
COM=" 14X14 OFA ASSEMBLY IN CASK "
ARRAY 1  0.0       0.0       0.0
REPLICATE  8  1  20.32000   2.99720  5.08000  38.10000  15.24  0.0  1
HOLE 7   0.0       0.0       0.0
HOLE 8   0.0       0.0       0.0
HOLE 9  -0.85344   0.81280   0.0
REPLICATE  9  1   0.22606   0.0    0.22606   0.22606  0.22606  0.0  1
END GEOM

READ ARRAY
ARA=1 NUX=14 NUY=14 NUZ=2 COM=" 14x14 OFA ASSEMBLY "
```

```
LOOP
 1  1 14  1    1 14  1    1  1  1
 2  3 12  3    3 12  9    1  1  1
 2  3 12  9    6  9  3    1  1  1
 2  5 10  5    5 10  5    1  1  1
 3  7  7  1    8  8  1    1  1  1
 4  1 14  1    1 14  1    2  2  1
 5  3 12  3    3 12  9    2  2  1
 5  3 12  9    6  9  3    2  2  1
 5  5 10  5    5 10  5    2  2  1
 6  7  7  1    8  8  1    2  2  1
END LOOP
END ARRAY

READ BOUNDS
ALL=SPECULAR
END BOUNDS

READ PLOT
  TTL='BOX SLICE THROUGH ASSEMBLY ARRAY - SOLID PELLETS'
  PIC=BOX
  NCH='0.GIHVA*'
  XUL=  0.0     YUL= 19.77136 ZUL= 60.0
  XLR= 19.77136 YLR=  0.0     ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='BOX SLICE THROUGH ASSEMBLY ARRAY - ANNULAR PELLETS'
  PIC=BOX
  NCH='0.G!HVA*'
  XUL=  0.0     YUL= 19.77136 ZUL= 6.0
  XLR= 19.77136 YLR=  0.0     ZLR= 6.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='MAT SLICE THROUGH ASSEMBLY ARRAY - SOLID PELLETS'
  PIC=MAT
  NCH='0.ZWSGS'
  XUL=  0.0     YUL= 19.77136 ZUL= 60.0
  XLR= 19.77136 YLR=  0.0     ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='MAT SLICE THROUGH ASSEMBLY ARRAY - ANNULAR PELLETS'
  PIC=MAT
  NCH='0.ZWSGS'
```

```
  XUL=  0.0     YUL= 19.77136 ZUL= 6.0
  XLR= 19.77136 YLR=  0.0     ZLR= 6.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='BOX SLICE THROUGH CASK MODEL '
  PIC=BOX
  NCH='0.GIHVA*'
  XUL= -2.99720 YUL= 30.15742 ZUL= 60.0
  XLR= 40.31742 YLR=-38.32606 ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='MAT SLICE THROUGH CASK MODEL '
  PIC=MAT
  NCH='0.ZWSGS'
  XUL= -2.99720 YUL= 30.15742 ZUL= 60.0
  XLR= 40.31742 YLR=-38.32606 ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='BOX SLICE THROUGH GD ABSORBER '
  PIC=BOX
  NCH='0.GIHVA*'
  XUL= -2.99720 YUL= 20.00000 ZUL= 60.0
  XLR=  0.65000 YLR= -2.00000 ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='MAT SLICE THROUGH GD ABSORBER '
  PIC=MAT
  NCH='0.ZWSGS'
  XUL= -2.99720 YUL= 20.00000 ZUL= 60.0
  XLR=  0.65000 YLR= -2.00000 ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END PLOT

END DATA
/EOF
```

TABLE F: KENO CASE 5

```
CASE 5).

TITLE-CASK 14XOFA 5.0 W/O 0.02 G/CC ANNULAR PELLET

READ PARAMETERS
  TME=6.0   RUN=YES   PLT=YES
  GEN=900   NPG=307   NSK=005   LIB=41
  XS1=YES   NUB=YES
END PARAMETERS

READ MIXT  SCT=2
MIX= 1
' SOLID UO2 PELLET 5.00 W/O (96.5% TD, 0% DISH)
         192235     0.0011942
         192238     0.022404
          18016     0.047196
MIX= 2
' H2O AT 1.00 G/CC IN SOLID PELLET GAP
          31001     0.066854
          38016     0.033427
MIX= 3
' SOLID ZIRC FUEL ROD CLADDING
        240302     0.043326
MIX= 4
' H2O AT 1.00 G/CC IN BLANKET FUEL ANNULUS
          31001     0.066854
          38016     0.033427
MIX= 5
' ANNULAR UO2 PELLET 5.00 W/O (96.5% TD)
         192235     0.0011942
         192238     0.022404
          18016     0.047196
MIX= 6
' H2O AT 1.00 G/CC IN ANNULAR PELLET GAP
          31001     0.066854
          38016     0.033427
MIX= 7
' ANNULAR ZIRC FUEL ROD CLADDING
        240302     0.043326
MIX= 8
```

```
' H2O AT 0.02 G/CC
        31001    0.00133708
        38016    0.00066854
MIX= 9
'  CARBON STEEL FOR STRONGBACK & SHELL
        36012    4.728898E-4
       315031    5.807008E-5
       316032    6.642906E-5
       325055    3.877064E-4
       326000    8.420119E-2
MIX= 10
'  GADOLINIA OXIDE ABSORBER (0.02 GM GD2O3/CM2 @ 0.01016 CM THICKNESS)
        48016    9.810529E-3
       464152    1.308071E-5
       464154    1.373474E-4
       464155    9.679722E-4
       464156    1.347313E-3
       464157    1.026835E-3
       464158    1.622008E-3
       464160    1.425792E-3
MIX= 11
'  CARBON STEEL SHEET FOR GD ABSORBER
        56012    4.728898E-4
       515031    5.807008E-5
       516032    6.642906E-5
       525055    3.877064E-4
       526000    8.420119E-2
END MIXT

READ GEOMETRY
UNIT 1
COM=" 14X14 OFA FUEL ROD - ENRICHED REGION"
CYLINDER   1 1   0.437388 167.64 0.0
CYLINDER   2 1   0.44628  167.64 0.0
CYLINDER   3 1   0.50800  167.64 0.0
CUBOID     8 1 4P0.70612  167.64 0.0
UNIT 2
COM=" 14X14 OFA GUIDE TUBE - ENRICHED REGION"
CYLINDER   8 1   0.62484  167.64 0.0
CYLINDER   3 1   0.66802  167.64 0.0
CUBOID     8 1 4P0.70612  167.64 0.0
UNIT 3
COM=" 14X14 OFA INSTRUMENT TUBE - ENRICHED REGION"
```

```
CYLINDER    8  1    0.44704   167.64  0.0
CYLINDER    3  1    0.50673   167.64  0.0
CUBOID      8  1  4P0.70612   167.64  0.0
UNIT 4
COM=" 14X14 OFA FUEL ROD - ENRICHED REGION - REPLACES ANNULAR BLNKT"
CYLINDER    1  1    0.437388  15.24  0.0
CYLINDER    2  1    0.44628   15.24  0.0
CYLINDER    3  1    0.50800   15.24  0.0
CUBOID      8  1  4P0.70612   15.24  0.0
UNIT 5
COM=" 14X14 OFA GUIDE TUBE - BLANKET REGION"
CYLINDER    8  1    0.62484   15.24  0.0
CYLINDER    3  1    0.66802   15.24  0.0
CUBOID      8  1  4P0.70612   15.24  0.0
UNIT 6
COM=" 14X14 OFA INSTRUMENT TUBE - BLANKET REGION"
CYLINDER    8  1    0.44704   15.24  0.0
CYLINDER    3  1    0.50673   15.24  0.0
CUBOID      8  1  4P0.70612   15.24  0.0
UNIT 7
COM=" BOTTOM EDGE OF CS STRONGBACK "
CUBOID      9  1  24.95550  0.0       0.0      -0.45720  182.88  0.0
UNIT 8
COM=" VERTICAL EDGE OF CS STRONGBACK "
CUBOID      9  1   0.0      -0.45720  24.13000  -0.45720  182.88  0.0
UNIT 9
COM=" GADOLINIA ABSORBER PANEL "
CUBOID     11  1   0.04445  -0.04445  18.41500   0.0      182.88  0.0
CUBOID     10  1   0.05461  -0.05461  18.41500   0.0      182.88  0.0
GLOBAL
UNIT 10
COM=" 14X14 OFA ASSEMBLY IN CASK "
ARRAY 1  0.0       0.0       0.0
REPLICATE  8  1  20.32000  2.99720  5.08000  38.10000  15.24  0.0  1
HOLE 7   0.0       0.0       0.0
HOLE 8   0.0       0.0       0.0
HOLE 9   -0.85344   0.81280   0.0
REPLICATE  9  1   0.22606   0.0    0.22606   0.22606  0.22606  0.0  1
END GEOM

READ ARRAY
ARA=1 NUX=14 NUY=14 NUZ=2 COM=" 14x14 OFA ASSEMBLY "
LOOP
```

```
 1  1 14  1   1 14  1   1  1  1
 2  3 12  3   3 12  9   1  1  1
 2  3 12  9   6  9  3   1  1  1
 2  5 10  5   5 10  5   1  1  1
 3  7  7  1   8  8  1   1  1  1
 4  1 14  1   1 14  1   2  2  1
 5  3 12  3   3 12  9   2  2  1
 5  3 12  9   6  9  3   2  2  1
 5  5 10  5   5 10  5   2  2  1
 6  7  7  1   8  8  1   2  2  1
END LOOP
END ARRAY

READ BOUNDS
ALL=SPECULAR
END BOUNDS

READ PLOT
 TTL='BOX SLICE THROUGH ASSEMBLY ARRAY - SOLID PELLETS'
 PIC=BOX
 NCH='0.GIHVA*'
 XUL= 0.0    YUL= 19.77136 ZUL= 60.0
 XLR= 19.77136 YLR= 0.0    ZLR= 60.0
 UAX=1.0   VDN=-1.0  NAX=130
END
 TTL='BOX SLICE THROUGH ASSEMBLY ARRAY - ANNULAR PELLETS'
 PIC=BOX
 NCH='0.GIHVA*'
 XUL= 0.0    YUL= 19.77136 ZUL= 6.0
 XLR= 19.77136 YLR= 0.0    ZLR= 6.0
 UAX=1.0   VDN=-1.0  NAX=130
END
 TTL='MAT SLICE THROUGH ASSEMBLY ARRAY - SOLID PELLETS'
 PIC=MAT
 NCH='0.ZWSGS'
 XUL= 0.0    YUL= 19.77136 ZUL= 60.0
 XLR= 19.77136 YLR= 0.0    ZLR= 60.0
 UAX=1.0   VDN=-1.0  NAX=130
END
 TTL='MAT SLICE THROUGH ASSEMBLY ARRAY - ANNULAR PELLETS'
 PIC=MAT
 NCH='0.ZWSGS'
 XUL= 0.0    YUL= 19.77136 ZUL= 6.0
```

```
  XLR= 19.77136 YLR=  0.0     ZLR= 6.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='BOX SLICE THROUGH CASK MODEL '
  PIC=BOX
  NCH='0.GIHVA*'
  XUL= -2.99720 YUL= 30.15742 ZUL= 60.0
  XLR= 40.31742 YLR=-38.32606 ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='MAT SLICE THROUGH CASK MODEL '
  PIC=MAT
  NCH='0.ZWSGS'
  XUL= -2.99720 YUL= 30.15742 ZUL= 60.0
  XLR= 40.31742 YLR=-38.32606 ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='BOX SLICE THROUGH GD ABSORBER '
  PIC=BOX
  NCH='0.GIHVA*'
  XUL= -2.99720 YUL= 20.00000 ZUL= 60.0
  XLR=  0.65000 YLR= -2.00000 ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END
  TTL='MAT SLICE THROUGH GD ABSORBER '
  PIC=MAT
  NCH='0.ZWSGS'
  XUL= -2.99720 YUL= 20.00000 ZUL= 60.0
  XLR=  0.65000 YLR= -2.00000 ZLR= 60.0
  UAX=1.0    VDN=-1.0   NAX=130
END PLOT

END DATA
/EOF
```