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MCNP-Model for the OAEP Thai Research Reactor

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MANAGED AND OPERATED BY
LOCKHEED MARTIN ENERGY RESEARCH CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL-27 (3-96)

ORNL/TM-13656

Computational Physics and Engineering Division

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June 1998

Prepared by the
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operated by
LOCKHEED MARTIN ENERGY RESEARCH CORP.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-96OR22464

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ACKNOWLEDGMENT

This work was sponsored by the Office of Arms Control and Nuclear Non-Proliferation of the United States Department of Energy. The work was conducted under the auspices of the

"ARRANGEMENT
FOR THE
EXCHANGE OF TECHNICAL INFORMATION
AND FOR COOPERATION IN THE FIELD OF
PEACEFUL USES OF NUCLEAR ENERGY
BETWEEN
THE OFFICE OF ATOMIC ENERGY FOR PEACE OF THAILAND
AND THE UNITED STATES DEPARTMENT OF ENERGY"

ABSTRACT

An MCNP input was prepared for the Thai Research Reactor, making extensive use of the MCNP geometry's lattice feature that allows a flexible and easy rearrangement of the core components and the adjustment of the control elements.

The geometry was checked for overdefined or undefined zones by two-dimensional plots of cuts through the core configuration with the MCNP geometry plotting capabilities, and by a three-dimensional view of the core configuration with the SABRINA code.

Cross sections were defined for a hypotetical core of 67 standard fuel elements and 38 low-enriched uranium fuel elements - all filled with fresh fuel. Three test calculations were performed with the MCNP4B-code to obtain the multiplicaton factor for the cases with control elements fully inserted, fully withdrawn, and at a working position.

1. INTRODUCTION

At the request of the Office of Atomic Energy for Peace (OAEP) of Thailand, a study to model the TRR-1/M1 reactor at the OAEP with the MCNP Monte Carlo computer code[1] has been performed. The reactor model used in this study corresponds to the TRR-1/M1 reactor loaded with fresh fuel that consists of 67 standard fuel elements and 38 low-enriched uranium fuel (LEU) elements. Neutron multiplication factors, k_{eff}'s, were obtained for three control rod configurations: (1) inserted, (2) fully withdrawn, and (3) at a working position. The values of the calculated k_{eff}'s are reasonable, although they are at the high end due to the assumption of fresh fuel loading.

In modeling the reactor core, the lattice feature of the MCNP geometry has been used extensively, which allows an easy and flexible rearrangement of the core components and provides for the repositioning of the control rods.

The details of the reactor geometry are presented in Sect. 2, and the material data descriptions are given in Sect. 3. The results of the criticality calculations are described in Sect. 4. Appendix A contains plots of two-dimensional (2-D) slices at various elevations of the core and a three-dimensional (3-D) view generated by the program SABRINA. An MCNP input is given in Appendix B.

2. THE REACTOR GEOMETRY

2.1 THE CORE CONFIGURATION

The TRR-1/M1 reactor has a TRIGA Mark III-type reactor core.[2] The core consists of 121 reactor element positions in a hexagonal grid. A core configuration was modeled with 67 standard fuel elements; 38 LEU fuel elements; 5 control rods, including one trim rod; 3 neutron detector elements; and 8 positions for irradiation devices, including the central thimble. The active core is a hexagon with a height of 38.1 cm and a diameter of of about 54 cm. The complete model extends axially to ± 75 cm and radially to 54 cm in order to allow control rod movements in the axial direction and to have sufficient water around the core.

All reactor elements are assumed to be submerged in light water in a rack, which is composed of a 1.5-cm-thick solid aluminum bottom plate positioned at 31 cm below the core midplane and a 2.5-cm-thick aluminum gridplate positioned at 30.5 cm above core midplane. The bottom aluminum plate has penetrations that allow the control rods and the trim rod to move up and down.

A 2.0-cm-thick aluminum safety plate positioned at 69 cm below the core midplane defines the rest position of the completely inserted control rods and the trim rod.

The following sections describe details of the reactor elements, each of which can conveniently be placed as a unit in the input description within a lattice of hexagonals.

2.2 THE FUEL ELEMENTS

Each fuel element is modeled as a rod with a 3.67-cm outer diameter and an overall length of 55.50 cm. The rod consists of a 3.57-cm inner diameter, cylindical stainless steel tube (0.05-cm wall thickness) surrounding a cylinder composed of $U\text{-}ZrH_{1.6}$ fuel in the 38.10-cm central part and 8.7-cm-long graphite plugs at the top and bottom of the rod.

The core consists of two types of fuel elements that differ in the ^{235}U enrichment, but are equivalent in all other respects:

- the standard fuel element with a ^{235}U enrichment of 8.5% and a ^{235}U loading of 38.4 g, and
- the LEU fuel element with a ^{235}U enrichment of 19.7% and a ^{235}U loading of 99.0 g.

2.3 THE CONTROL AND TRIM RODS

The control rods, as well as the trim rod, are designed as neutron absorbers followed by a fuel zone. In the fully inserted position, the neutron- absorbing part is placed in the core; in the fully withdrawn position, the fuel zone is placed in the core and serves as an additional fuel element.

The control and trim rod tubes are of the same diameter and wall thickness as the fuel rods tubes, but have an overall length of 103 cm. The tubes are filled from bottom to top with 9.85

cm water, 38.10 cm standard fuel, 38.10 cm boron carbide, followed by a 16.95-cm-long vacuum zone.

All control rods can be positioned independently within a range from 0 cm to 38 cm using the transformation cards (TR), where the position 0 cm is the fully inserted position and the position 38 cm is the fully withdrawn position.

2.4 THE NEUTRON DETECTOR AND IRRADIATION POSITIONS

The neutron detector positions and all irradiation positions are modeled as empty (voided) stainless steel tubes of the same size as the fuel rod tubes.

3. MATERIAL DATA

The cross-section data were defined assuming fresh fuel, with no burnup and activation of the structural material. If a real core were to be modeled, burnup effects would have to be considered in the cross-sections. To allow different burnup levels of the fuel elements, more fuel rod definitions with different universe numbers would have to be created in the MCNP geometry input.

Among the different available cross-sections, the data recommended in the MCNP4A manual[3] were used. However, for zirconium, the ENDL85 data set was chosen, because it gave more reliable nuclear heating results for other research reactors.[4]

Impurities were included into the macroscopic cross-sections of aluminum (ASTM Al6061) and stainless steel (ASTM SS304).

The U-$ZrH_{1.6}$ fuel was used for both the standard fuel element and the LEU fuel element. A neutron poison of 0.47 wt % erbium was added to the LEU fuel elements. Since no cross-section data were available for erbium, hafnium was used as a substitute with its number density scaled by a factor of 173/105 to compensate for the higher thermal neutron absorption of erbium.[5] To account for temperature effects on the cross-sections, the fuel temperature was assumed to be 700 K. All other materials are assumed to have a temperature of 300 K.

For the graphite cross-sections, a porosity of 20% was taken into account.[6]

In Table 3.1 the number densities of all materials, as used in the criticality test calculations described in Chapter 4, are given.

Table 3.1. Nuclide number densities [atom/(barn cm)] for the materials used in the criticality calculations

Light water (density = 1.00 g/cm^3)	
H	$6.7000 \cdot 10^{-2}$
O	$3.3500 \cdot 10^{-2}$

Stainles steel SS304 (density = 7.87 g/cm^3)	
Cr	$1.4161 \cdot 10^{-2}$
Mn	$8.3717 \cdot 10^{-4}$
Fe	$5.6089 \cdot 10^{-2}$
Ni	$1.0046 \cdot 10^{-2}$
Mo	$2.0929 \cdot 10^{-3}$

Table 3.1 (continued)

Standard fuel (density = 6.11g/cm^3)	
H	$5.5318 \cdot 10^{-2}$
Zr	$3.5849 \cdot 10^{-2}$
U-235	$2.4800 \cdot 10^{-4}$
U-238	$9.8550 \cdot 10^{-4}$

LEU fuel (density = 6.51g/cm^3)	
H	$5.0440 \cdot 10^{-2}$
Zr	$3.4295 \cdot 10^{-2}$
Hf	$6.3186 \cdot 10^{-5}$
U-235	$6.3860 \cdot 10^{-4}$
U-238	$2.5700 \cdot 10^{-2}$

Graphite (density = 1.28g/cm^3)	
C	$6.4240 \cdot 10^{-2}$

Boron carbide (density = 2.50g/cm^3)	
B-10	$2.1780 \cdot 10^{-2}$
B-11	$8.7131 \cdot 10^{-2}$
C	$2.7228 \cdot 10^{-2}$

Aluminum 6061 (density = 2.70g/cm^3)	
Mg	$6.0887 \cdot 10^{-4}$
Al	$5.9305 \cdot 10^{-2}$
Si	$3.5127 \cdot 10^{-4}$
Ti	$1.7164 \cdot 10^{-5}$
Cr	$5.0597 \cdot 10^{-5}$
Mn	$1.4965 \cdot 10^{-5}$
Fe	$1.0010 \cdot 10^{-4}$
Cu	$8.7251 \cdot 10^{-5}$

4. CRITICALITY CALCULATIONS

For the configuration and the cross-section data outlined in the previous chapters, criticality calculations were performed to validate the input. The neutron multiplication factors, k_{eff}'s, were calculated for three control rod configurations: fully inserted, fully withdrawn, and at working position, as defined in Table 4.1. The k_{eff} results are given in Table 4.2.

Table 4.1. Working positions of the control rods and the trim rod as defined for test calculation No. 2.

Control rod No..	Control rod position[a] (cm)
1	1.0
2	0.0
3	18.0
4	36.0
5	27.0

[a] The position 0 cm defines the completely inserted control rod; the position 38 cm defines the completely withdrawn position.

Table 4.2. Multiplication factors (k_{eff}'s) calculated with MCNP4B for three cases of the control rod positions

No.	Control element positions	k_{eff}	Rel. Std. Dev.
1	fully inserted	0.97699	0.00531
2	at working position[a]	1.03173	0.00684
3	fully withdrawn	1.11048	0.00800

[a] as defined in Table 4.1.

The calculated k_{eff} results indicate subcriticality for the fully inserted control rods, slight supercriticality for the partially inserted control rods, and supercriticality for fully withdrawn control rods, all within the expectations. The multiplication factors are at the high end, since the assumption of fresh fuel for all fuel elements means a maximum fissile material content in the core and the absence of neutron poison originating from the fission products. Installations placed around the core, such as beam tubes and irradiation devices, will also have the effect of lowering the multiplication factor.

5. REFERENCES

1. Judith F. Briesmeister, ed., *MCNP – A General Monte Carlo Code N-particle Transport Code Version 4B*, Technical Report LA-12625-M Version 4B, Los Alamos National Laboratory, Los Alamos, N. M., March 1997.

2. Manoon Aramrattana, "Research Reactor Operation and Utilization in Thailand", *Proceedings of First Asian Symposium on Research Reactors*, Yokosuka, Kangawa (Japan), November 1986.

3. Judith F. Briesmeister, ed., *MCNP – A General Monte Carlo Code N-particle Transport Code Version 4A*, Technical Report LA-12625-M Version 4A, Los Alamos National Laboratory, Los Alamos, N. M., November 1993.

4. C. A. Wemple, B. G. Schnitzler, and J. M. Ryskamp, *Neutronic Methods, Models and Applications at the Idaho National Engineeering Laboratory for the Advanced Neutron Source Reactor Three-element Core Design*, Technical Report ORNL/M-4602, Martin Marietta Energy Systems, Inc., August 1995.

5. J. J. Duderstadt and L. J. Hamilton, *Nuclear Reactor Analysis*, John Wiley & Sons, New York, 1976.

6. W. L. Witteman, General Atomics (Triga Group), Personal communication to Nisarut Ruksawin, August 1996.

7. Kenneth A. Van Riper, *SABRINA – User's Guide*, Technical Report LA-UR-93-3696, Los Alamos National Laboratory, Los Alamos, N. M., October 1993.

APPENDIX A
GEOMETRY PLOTTING

APPENDIX A. GEOMETRY PLOTTING

Prior to calculations the geometry was checked for errors due to overdefined or undefined zones. Geometry errors appear in the MCNP plots as areas with dashed surface boundaries. MCNP allows 2-D plots of slices through a geometry; however, for hexagonal lattice geometries, only slices with a normal vector parallel to the axis of the hexagons are permitted.

Typical geometry plots for the Thai Research Reactor are found in Sect. A.2, the color/material map of which is given in Sect. A.1.

A more illustrative 3-D view of the geometry was produced using the SABRINA-code[7] and is presented in Sect. A.3. The colors of these plots are chosen in a way that they match the color map of the MCNP plots.

A.1 COLOR DESCRIPTION OF THE PLOTTING

Material	Color
Light water	Light blue
Stainless steel	Grey
Standard fuel	Magenta
LEU fuel	Red
Graphite reflector	Green
Boron carbide absorber	Yellow
Void	White
Aluminum structures	Blue

A.2 MCNP GEOMETRY PLOTS

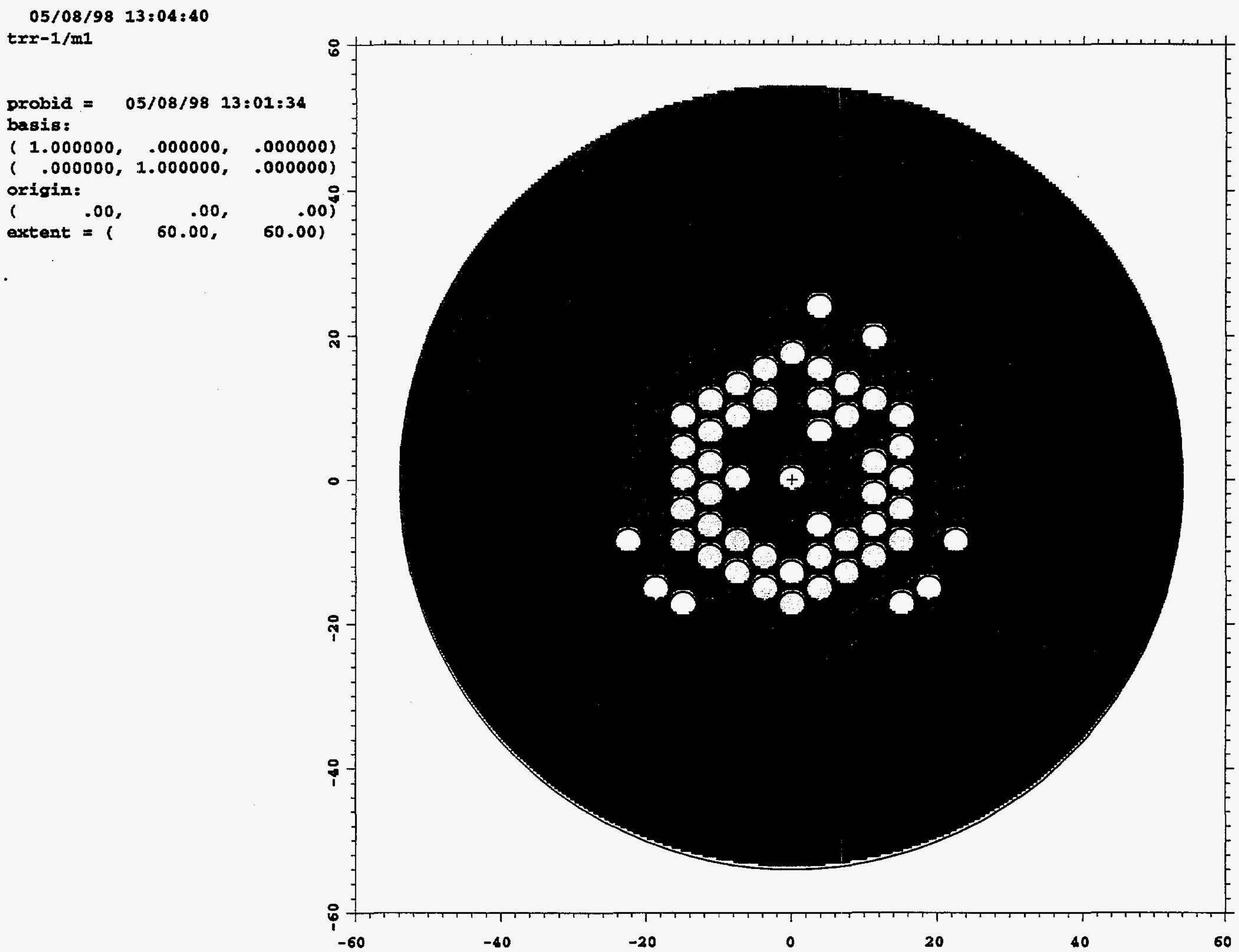

Fig. A.1. THAIRR: X-Y cut of the full geometry in the core midplane (the color map is described in Sect. A.1).

```
05/08/98 13:09:44
trr-1/m1

probid =   05/08/98 13:07:56
basis:
( 1.000000,  .000000,  .000000)
(  .000000, 1.000000,  .000000)
origin:
(      .00,       .00,   -69.50)
extent = (    30.00,     30.00)
```

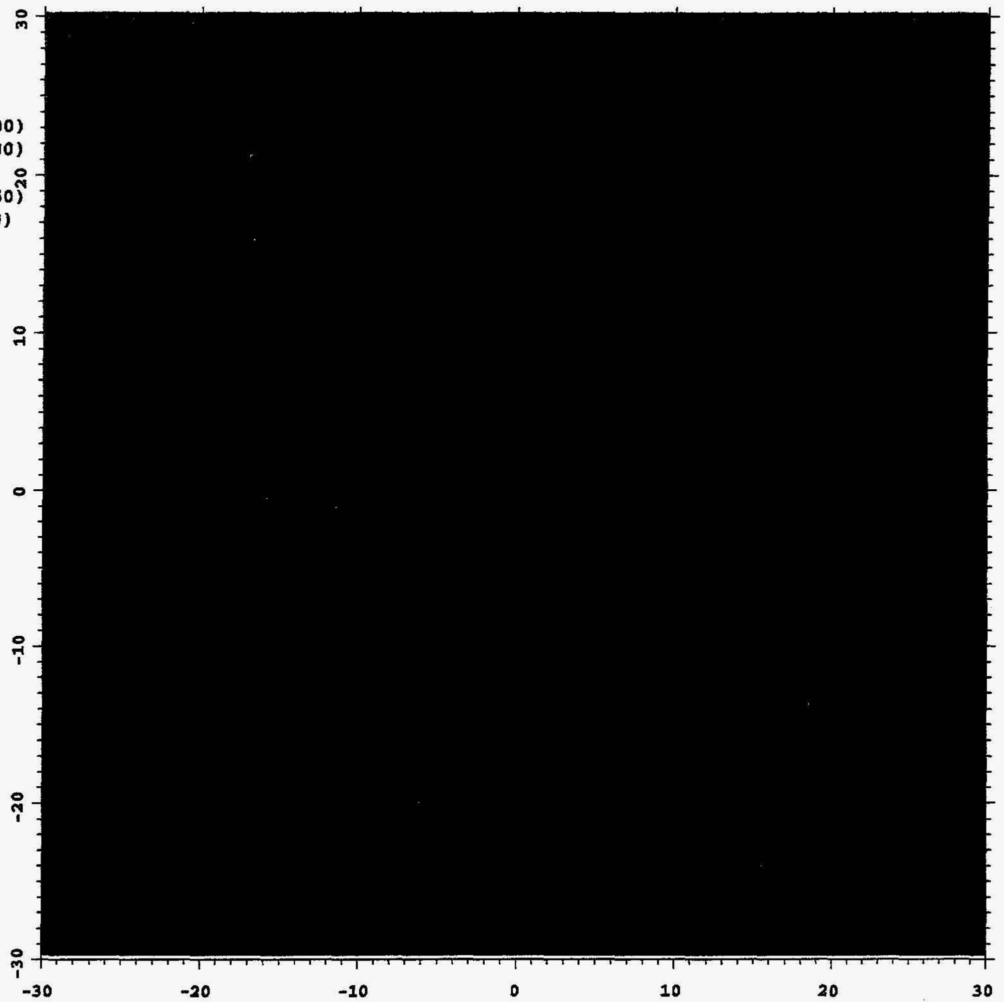

Fig. A.2. THAIRR: X-Y cut through the safety plate at a level 69.50 cm below the core midplane (the color map is described in Sect. A.1).

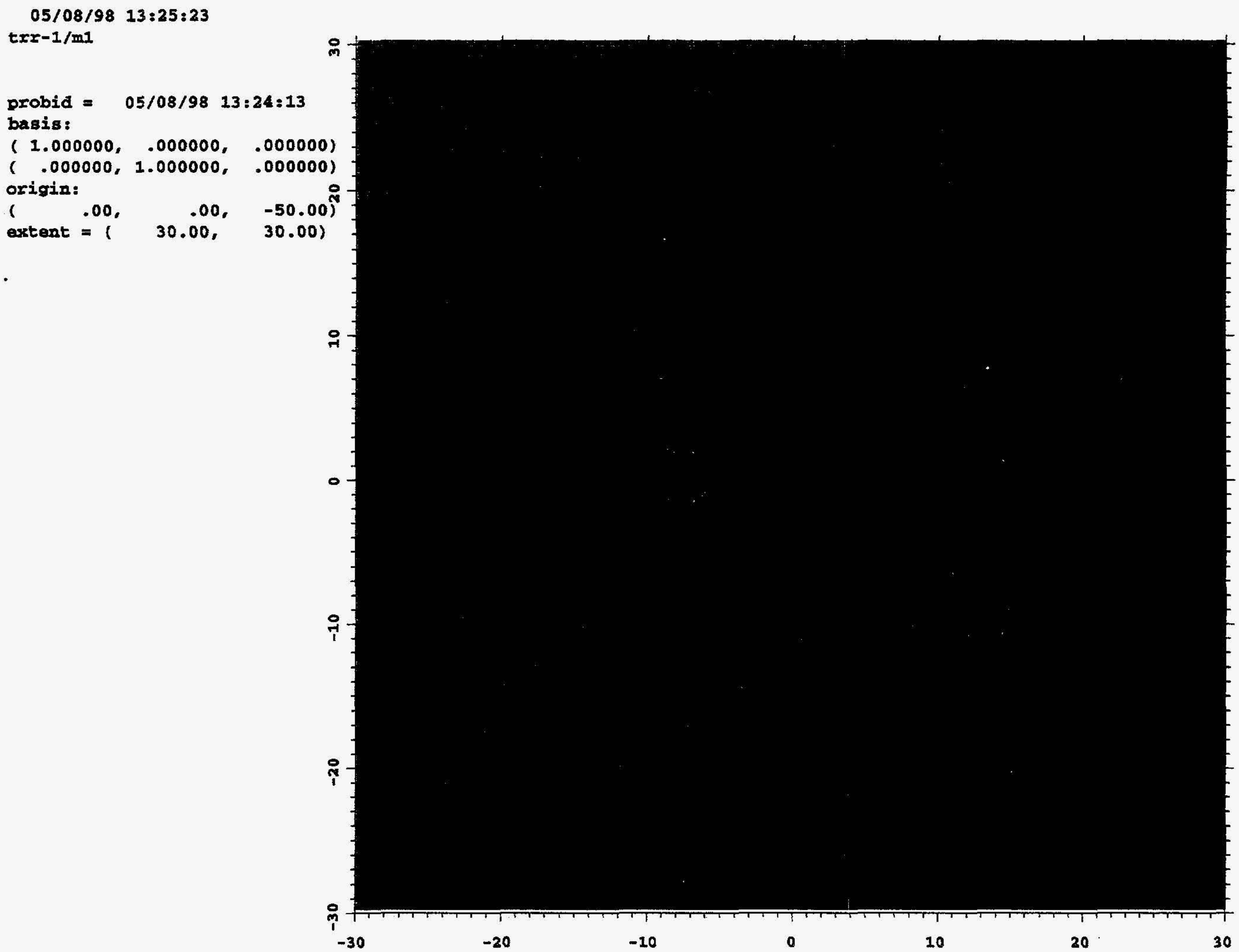

Fig. A.3. THAIRR: X-Y cut through the water region at a level 50.00 cm below the core midplane (the color map is described in Sect. A.1).

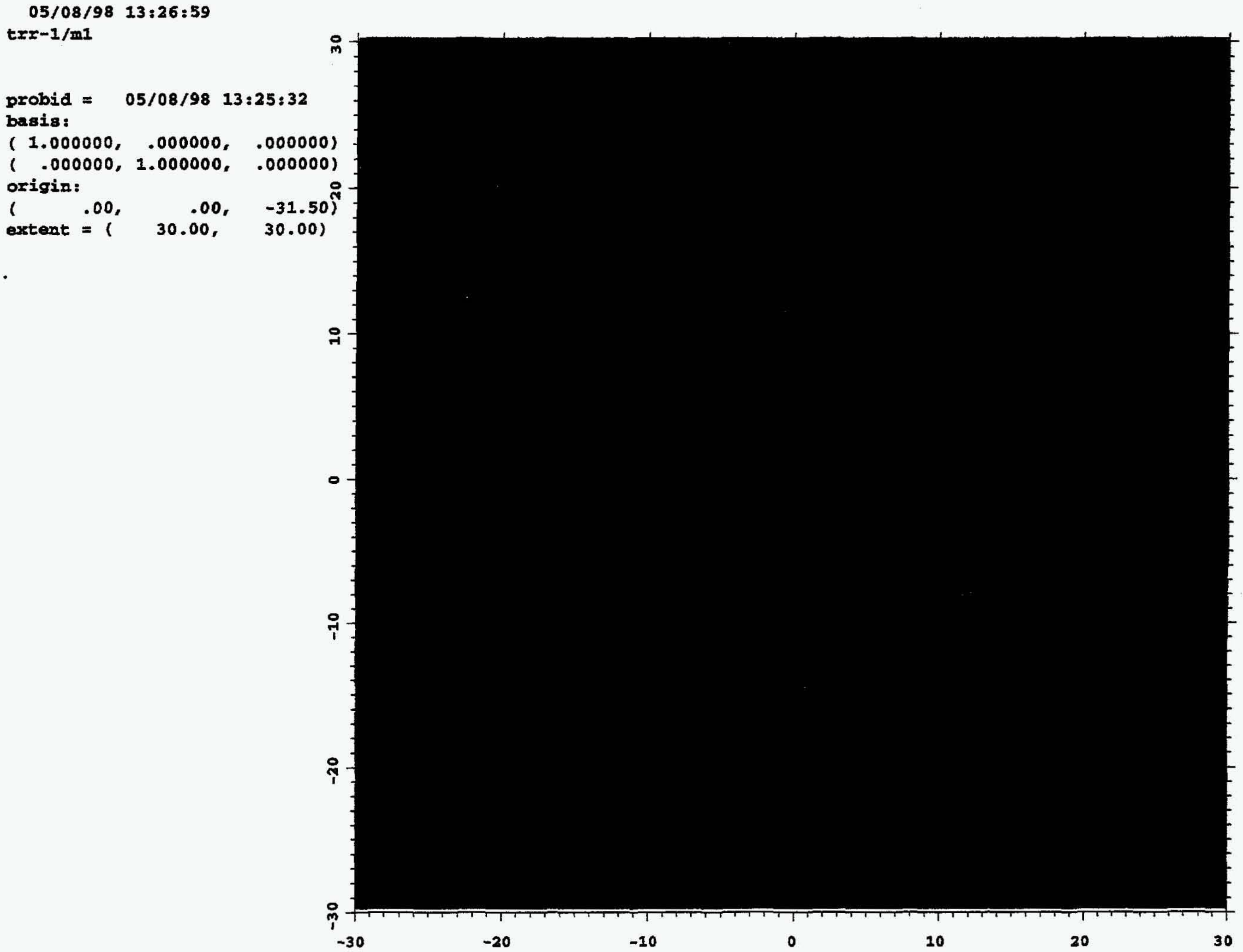

Fig. A.4. THAIRR: X-Y cut through the bottom grid plate at a level 31.50 cm below the core midplane (the color map is described in Sect. A.1).

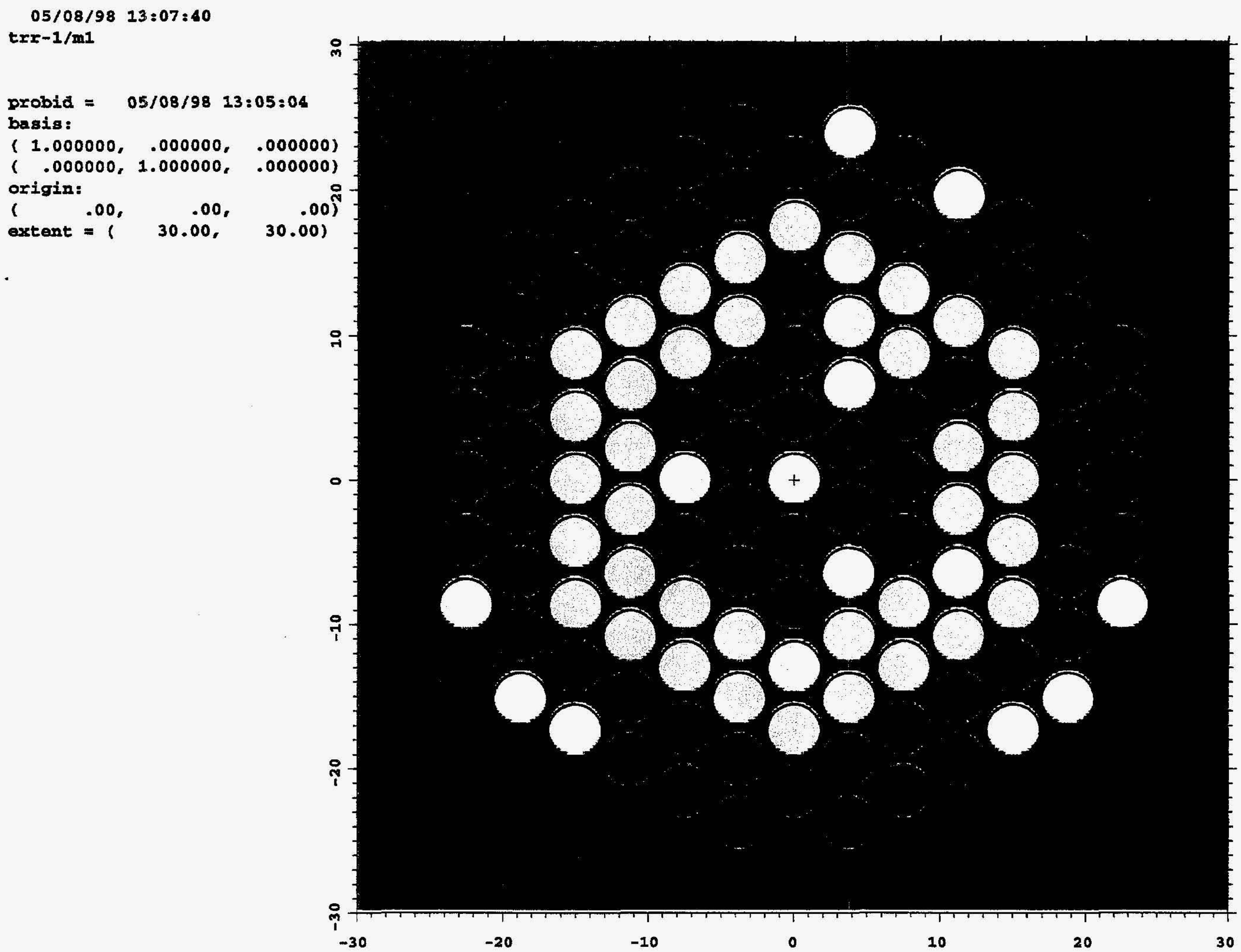

Fig. A.5. THAIRR: X-Y cut of the core region in the core midplane (the color map is described in Sect. A.1).

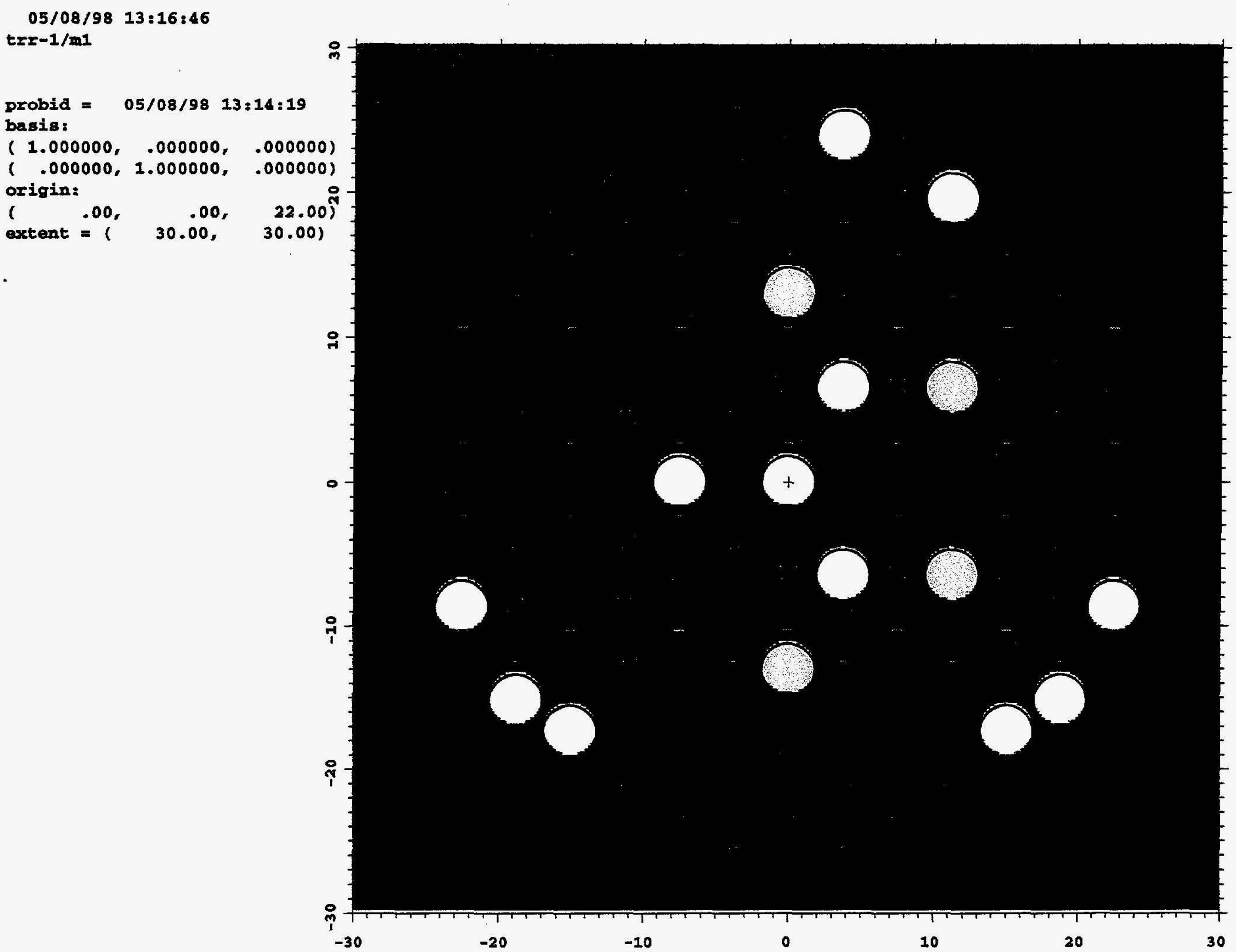

Fig. A.6. THAIRR: X-Y cut through the top graphite zones of the fuel rods at a level 22.00 cm above core midplane (the color map is described in Sect. A.1).

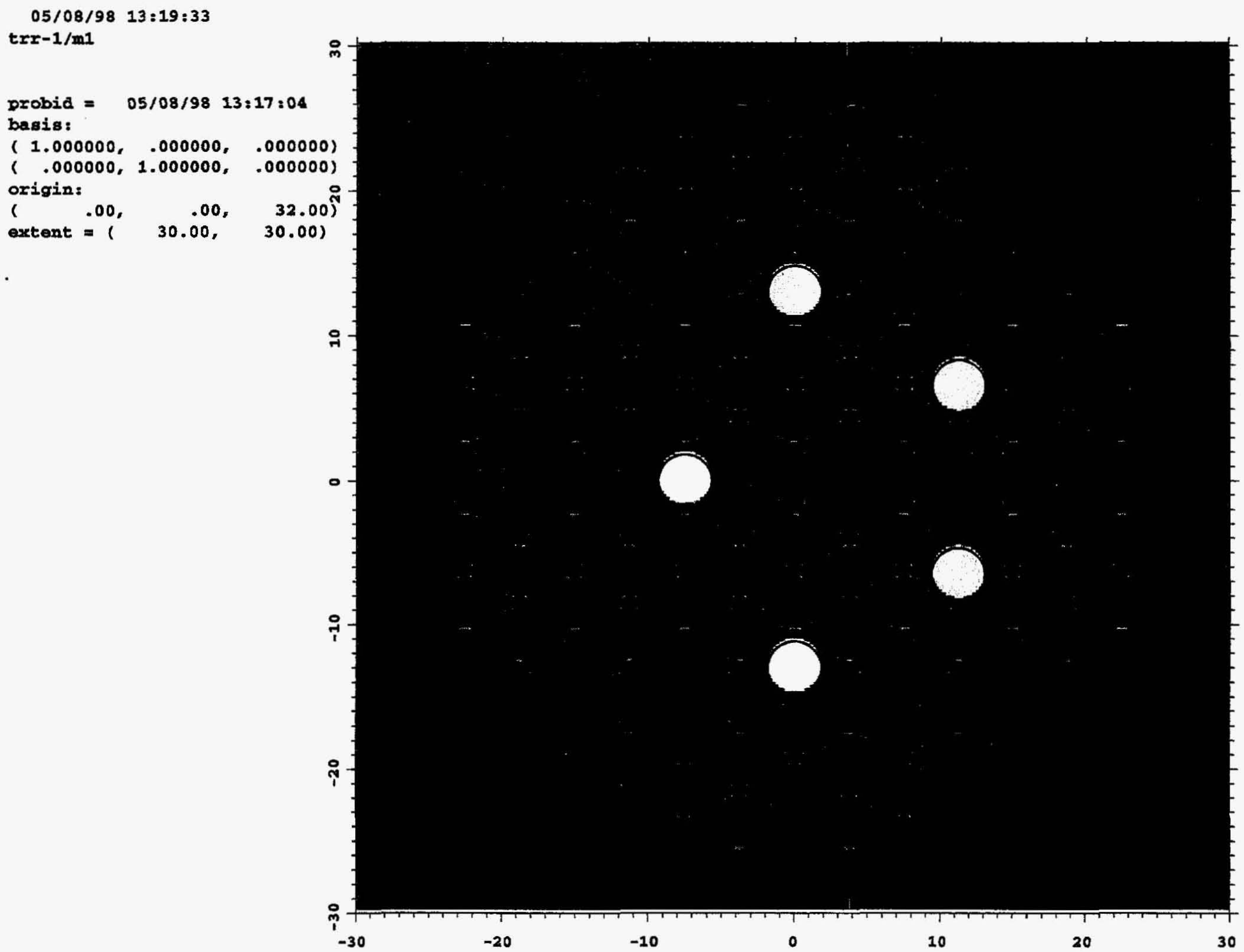

Fig. A.7. THAIRR: X-Y cut through the top grid plate at a level 30.00 cm above the core midplane (the color map is described in Sect. A.1).

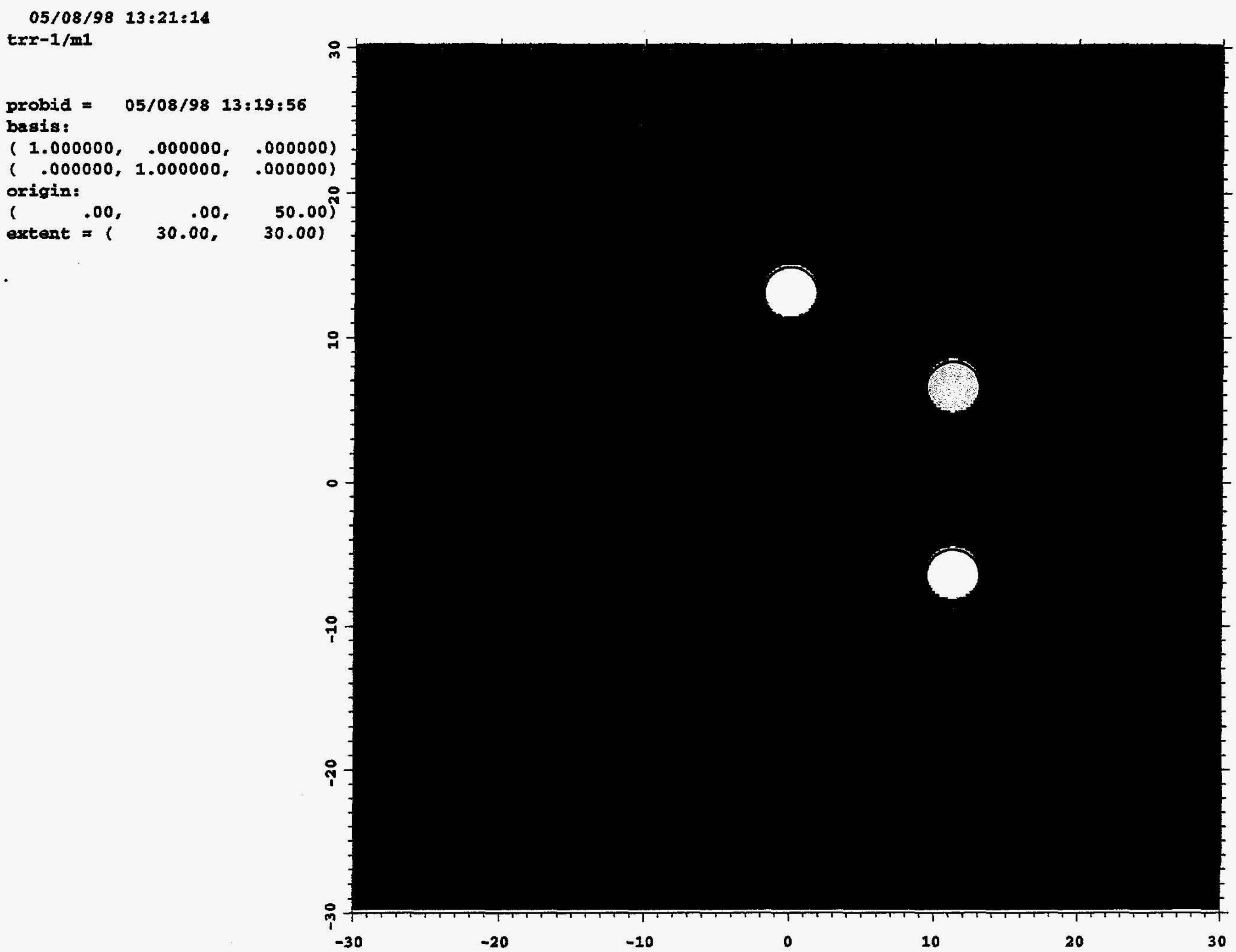

Fig. A.8. THAIRR: X-Y cut through the water zone above the core at a level 50.00 cm above the core midplane (the color map is described in Sect. A.1).

A.3 SABRINA GEOMETRY PLOT

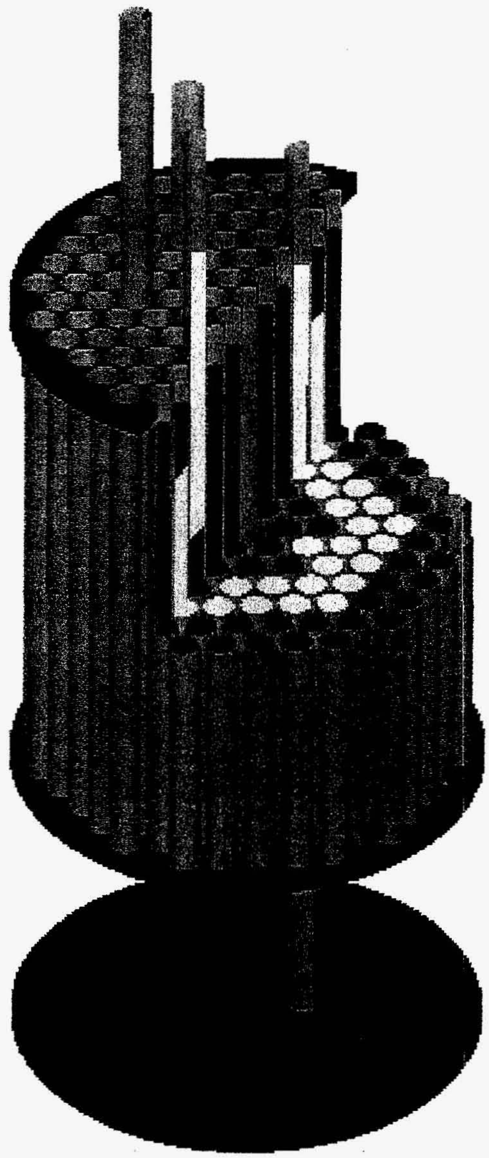

Fig. A.9. THAIRR: 3-D view generated with SABRINA with a cutout in the core midplane (the color map is described in Sect. A.1). The light water is defined transparent to allow a view of the core.

APPENDIX B
THE MCNP INPUT FILE

APPENDIX B. THE MCNP INPUT FILE

```
message:   outp=thairr.o  srctp=thairr.s  runtpe=thairr.r mctal=thairr.m

trr-1/m1 - MCNP INPUT DECK FOR THE THAI RESEARCH REACTOR
c ----------------------------------------------------------------------
c
c   Model of the Triga type OAEP Thai-Research-Reactor
c
c   created March 31, 1998 by Jabo Tang & Franz Gallmeier ORNL, USA
c   for the Office of Atomic Energy for Peace, Thailand
c
c   This model includes:
c     - standard fuel rods (fresh fuel)
c     - LEU fuel rods (fresh fuel)
c     - vacant rods
c     - five control rods positioned independently by TR-cards
c       (fresh fuel & fresh boron carbide)
c     - the bottom and top grid plates
c     - the safety plate
c     - substantial amount of light water about the core
c     - set up for keff calculations
c
c ----------------------------------------------------------------------
c  CELL SPECIFICATION CARDS:
c ----------------------------------------------------------------------
c
c  definition of rods:
c
c      standard fuel rods
 10   3 -6.109  -1 +4 -3                u=1  imp:n=1.0   $ fuel, std
 11   5 -1.28   -1 +3 -5                u=1  imp:n=1.0   $ top reflector
 12   5 -1.28   -1 +6 -4                u=1  imp:n=1.0   $ bottom reflector
 13   1 -1.00   -1 +22 -6               u=1  imp:n=1.0   $ water below bott. refl.
 14   1 -1.00   -1 +5 -24               u=1  imp:n=1.0   $ water above top refl.
 15   2 -7.87   +1 -2 +22 -24           u=1  imp:n=1.0   $ ss304 cladding
 16   7 -2.70      +21 -22              u=1  imp:n=1.0   $ lower grid plate
 17   7 -2.70   +2 +23 -24              u=1  imp:n=1.0   $ upper grid plate
 18   1 -1.00   +2 +22 -23              u=1  imp:n=1.0   $ water outside rod
 19   1 -1.00  (+31 -21):(+24 -32)      u=1  imp:n=1.0   $ water above&below rod
c
c      leu fuel rods
```

```
 20    like 10 but mat=4 rho=-6.508      u=2  imp:n=1.0   $ fuel, std
 21    like 11 but                       u=2  imp:n=1.0   $ top reflector
 22    like 12 but                       u=2  imp:n=1.0   $ bottom reflector
 23    like 13 but                       u=2  imp:n=1.0   $ water below bott. refl.
 24    like 14 but                       u=2  imp:n=1.0   $ water above top refl.
 25    like 15 but                       u=2  imp:n=1.0   $ ss clad
 26    like 16 but                       u=2  imp:n=1.0   $ lower grid plate
 27    like 17 but                       u=2  imp:n=1.0   $ upper grid plate
 28    like 18 but                       u=2  imp:n=1.0   $ water outside rod
 29    like 19 but                       u=2  imp:n=1.0   $ water above&below rod
c
c      vacant rods (ct, rabbit, nd, iit)
 30    like 10 but mat=0                 u=3  imp:n=1.0   $ fuel, std
 31    like 11 but mat=0                 u=3  imp:n=1.0   $ top reflector
 32    like 12 but mat=0                 u=3  imp:n=1.0   $ bottom reflector
 33    like 13 but                       u=3  imp:n=1.0   $ water below bott. refl.
 34    like 14 but                       u=3  imp:n=1.0   $ water above top refl.
 35    like 15 but                       u=3  imp:n=1.0   $ ss clad
 36    like 16 but                       u=3  imp:n=1.0   $ lower grid plate
 37    like 17 but                       u=3  imp:n=1.0   $ upper grid plate
 38    like 18 but                       u=3  imp:n=1.0   $ water outside rod
 39    like 19 but                       u=3  imp:n=1.0   $ water above&below rod
c
c      control rod 1 (movable by tr4)
 40   1 -1.00   -1 +41 -42               u=4  imp:n=1.0   $ water below fuel zone
 41   3 -6.109 -1 +42 -43                u=4  imp:n=1.0   $ fuel zone
 42   6 -2.50   -1 +43 -44               u=4  imp:n=1.0   $ b4c absorber
 43   0         -1 +44 -45               u=4  imp:n=1.0   $ void zone above absorber
 45   2 -7.87    +1 -2 +41 -45           u=4  imp:n=1.0   $ ss clad
 46   1 -1.00      -2 +31 -41            u=4  imp:n=1.0   $ water below control rod
 47   1 -1.00      -2 +45 -32            u=4  imp:n=1.0   $ water above control rod
 48   1 -1.00   (+2 +31 -21):(+2 +22 -23)
               :(+2 +24 -32)             u=4  imp:n=1.0   $ water outside of rod
 49   7 -2.70   (+2 +21 -22):(+2 +23 -24) u=4 imp:n=1.0   $ grid plates
c
c      control rod 2 (movable by tr5)
 50   1 -1.00    -1 +51 -52              u=5  imp:n=1.0   $ water below fuel zone
 51   3 -6.109   -1 +52 -53              u=5  imp:n=1.0   $ fuel zone
 52   6 -2.50    -1 +53 -54              u=5  imp:n=1.0   $ b4c absorber
 53   0         -1 +54 -55               u=5  imp:n=1.0   $ void zone above absorber
 55   2 -7.87    +1 -2 +51 -55           u=5  imp:n=1.0   $ ss clad
 56   1 -1.00      -2 +31 -51            u=5  imp:n=1.0   $ water below control rod
```

```
 57   1 -1.00    -2 +55 -32               u=5  imp:n=1.0   $ water above control rod
 58   1 -1.00   (+2 +31 -21):(+2 +22 -23)
               :(+2 +24 -32)              u=5  imp:n=1.0   $ water outside of rod
 59   7 -2.70   (+2 +21 -22):(+2 +23 -24) u=5 imp:n=1.0   $ grid plates
c
c      control rod 3 (movable by tr6)
 60   1 -1.00    -1 +61 -62               u=6  imp:n=1.0   $ water below fuel zone
 61   3 -6.109   -1 +62 -63               u=6  imp:n=1.0   $ fuel zone
 62   6 -2.50   -1 +63 -64                u=6  imp:n=1.0   $ b4c absorber
 63   0         -1 +64 -65                u=6  imp:n=1.0   $ void zone above absorber
 65   2 -7.87    +1 -2 +61 -65            u=6  imp:n=1.0   $ ss clad
 66   1 -1.00     -2 +31 -61              u=6  imp:n=1.0   $ water below control rod
 67   1 -1.00     -2 +65 -32              u=6  imp:n=1.0   $ water above control rod
 68   1 -1.00   (+2 +31 -21):(+2 +22 -23)
               :(+2 +24 -32)              u=6  imp:n=1.0   $ water outside of rod
 69   7 -2.70   (+2 +21 -22):(+2 +23 -24) u=6  imp:n=1.0   $ grid plates
c
c      control rod 4 (movable by tr7)
 70   1 -1.00    -1 +71 -72               u=7  imp:n=1.0   $ water below fuel zone
 71   3 -6.109   -1 +72 -73               u=7  imp:n=1.0   $ fuel zone
 72   6 -2.50   -1 +73 -74                u=7  imp:n=1.0   $ b4c absorber
 73   0         -1 +74 -75                u=7  imp:n=1.0   $ void zone above absorber
 75   2 -7.87    +1 -2 +71 -75            u=7  imp:n=1.0   $ ss clad
 76   1 -1.00     -2 +31 -71              u=7  imp:n=1.0   $ water below control rod
 77   1 -1.00     -2 +75 -32              u=7  imp:n=1.0   $ water above control rod
 78   1 -1.00   (+2 +31 -21):(+2 +22 -23)
               :(+2 +24 -32)              u=7  imp:n=1.0   $ water outside of rod
 79   7 -2.70   (+2 +21 -22):(+2 +23 -24) u=7  imp:n=1.0   $ grid plates
c
c      control rod 5 (movable by tr8)
 80   1 -1.00    -1 +81 -82               u=8  imp:n=1.0   $ water below fuel zone
 81   3 -6.109   -1 +82 -83               u=8  imp:n=1.0   $ fuel zone
 82   6 -2.50   -1 +83 -84                u=8  imp:n=1.0   $ b4c absorber
 83   0         -1 +84 -85                u=8  imp:n=1.0   $ void zone above absorber
 85   2 -7.87    +1 -2 +81 -85            u=8  imp:n=1.0   $ ss clad
 86   1 -1.00     -2 +31 -81              u=8  imp:n=1.0   $ water below control rod
 87   1 -1.00     -2 +85 -32              u=8  imp:n=1.0   $ water above control rod
 88   1 -1.00   (+2 +31 -21):(+2 +22 -23)
               :(+2 +24 -32)              u=8  imp:n=1.0   $ water outside of rod
 89   7 -2.70   (+2 +21 -22):(+2 +23 -24) u=8  imp:n=1.0   $ grid plates
c
c      empty position
```

```
 90   1  -1.00    +31 -21                u=9  imp:n=1.0   $ water below grid plates
 91   1  -1.00    +22 -23                u=9  imp:n=1.0   $ water between grid plates
 92   1  -1.00    +24 -32                u=9  imp:n=1.0   $ water above grid plates
 93   7  -2.70  (+21 -22):(+23 -24)      u=9  imp:n=1.0   $ grid plates
c
c definition of the core configuration:
 100  0           -11 +13 -12    fill=10      imp:n=1.0   $ window cell
 110  1  -1.00   -301 +302 -303 +304 -305 +306
            u=10 imp:n=1.0 lat=2 fill -7:7 -7:7 0:0
       9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
       9 9 9 9 9 9 9 9 1 1 1 3 3 9 9
       9 9 9 9 9 9 1 1 1 1 1 1 1 3 9
       9 9 9 9 9 1 1 2 2 2 2 2 1 1 9
       9 9 9 9 1 1 2 5 2 2 6 2 1 1 9
       9 9 9 3 1 2 2 1 3 1 2 2 1 1 9
       9 9 3 1 2 2 1 1 1 1 2 2 1 1 9
       9 9 1 2 2 1 1 3 1 1 7 2 1 9 9   $ center
       9 3 1 2 2 4 1 1 3 2 2 1 1 9 9
       9 1 1 2 2 1 1 1 2 2 1 1 9 9 9
       9 1 1 2 2 2 2 8 2 1 3 9 9 9 9
       9 1 1 2 2 2 2 2 1 1 9 9 9 9 9
       9 1 1 1 1 1 1 1 3 9 9 9 9 9 9
       9 9 1 1 1 1 1 9 9 9 9 9 9 9 9
       9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
 120  7  -2.70    -11 +14 -13                 imp:n=1.0  $ safety plate
 130  1  -1.00    -101 +102 -103
                 (+11 :-14 :+12)              imp:n=1.0  $ water about the core
 999  0           101:-102:103                imp:n=0    $ system boundary
c ----------------------------------------------------------------------
c  END OF CELL SPECIFICATION CARDS
c ----------------------------------------------------------------------
c  .... a blank line seperates the cell cards from the surface cards ....

c ----------------------------------------------------------------------
c  SURFACE SPECIFICATION CARDS
c ----------------------------------------------------------------------
c fuel rod surface cards
   1    cz  1.815                  $ radius of fuel and graphite
   2    cz  1.865                  $ radius of rod
   3    pz  19.05                  $ top of fuel
   4    pz -19.05                  $ bottom of fuel
   5    pz  27.75                  $ top of graphite
```

```
    6    pz -27.75                        $ bottom of graphite
c core dimension surface cards
   11    cz  27.5                         $ radius of core
   12    pz  73.00                        $ upper core extension
   13    pz -69.00                        $ upper safety plate
   14    pz -70.00                        $ lower safety plate
c grid plates surface cards
   21    pz -32.40                        $ lower grid plate
   22    pz -30.92                        $ lower grid plate
   23    pz  30.49                        $ upper grid plate
   24    pz  33.03                        $ upper grid plate
c general control rod surface cards
   31    pz -120.0                        $ lower extension of geometry
   32    pz 100.0                         $ upper extension of geometry
c control rod 1 surface cards
   41 4  pz -67.00                       $ lower control rod extension
   42 4  pz -57.15                       $ lower end fuel zone
   43 4  pz -19.05                       $ bottom of fuel
   44 4  pz  19.05                       $ top of fuel
   45 4  pz  36.00                       $ upper end void zone
c control rod 2 surface cards
   51 5  pz -67.00                       $ lower control rod extension
   52 5  pz -57.15                       $ lower end fuel zone
   53 5  pz -19.05                       $ bottom of fuel
   54 5  pz  19.05                       $ top of fuel
   55 5  pz  36.00                       $ upper end void zone
c control rod 3 surface cards
   61 6  pz -67.00                       $ lower control rod extension
   62 6  pz -57.15                       $ lower end fuel zone
   63 6  pz -19.05                       $ bottom of fuel
   64 6  pz  19.05                       $ top of fuel
   65 6  pz  36.00                       $ upper end void zone
c control rod 4 surface cards
   71 7  pz -67.00                       $ lower control rod extension
   72 7  pz -57.15                       $ lower end fuel zone
   73 7  pz -19.05                       $ bottom of fuel
   74 7  pz  19.05                       $ top of fuel
   75 7  pz  36.00                       $ upper end void zone
c control rod 5 surface cards
   81 8  pz -67.00                       $ lower control rod extension
   82 8  pz -57.15                       $ lower end fuel zone
   83 8  pz -19.05                       $ bottom of fuel
```

```
   84 8  pz  19.05                    $ top of fuel
   85 8  pz  36.00                    $ upper end void zone
c water surrounding the core
  101    cz  54.0                     $ radius of water outside core
  102    pz -75.0                     $ bottom of water
  103    pz  75.0                     $ top of water
c hexagonal cell
  301    p     1.73205 1 0  4.34
  302    p     1.73205 1 0 -4.34
  303    py    2.17
  304    py   -2.17
  305    p    -1.73205 1 0  4.34
  306    p    -1.73205 1 0 -4.34
c -----------------------------------------------------------------------
c  END OF SURFACE SPECIFICATION CARDS
c -----------------------------------------------------------------------
c  .. a blank line seperates the surface cards from the parameter cards ..

c -----------------------------------------------------
c  TRANSFORMATION CARDS:
c -----------------------------------------------------
c  for positioning the control rods
c    (the positive third entry gives the CR position
c     where the value 0.0 describes the fully inserted
c     CR position)
c
c    CR1 -> universe u=4 -> transformation tr4
c    CR2 -> universe u=5 -> transformation tr5
c    CR3 -> universe u=6 -> transformation tr6
c    CR4 -> universe u=7 -> transformation tr7
c    CR5 -> universe u=8 -> transformation tr8
c -----------------------------------------------------
tr4   0 0  +1.0
tr5   0 0  +9.0
tr6   0 0 +18.0
tr7   0 0 +36.0
tr8   0 0 +27.0
c -----------------------------------------------------
c  END OF TRANSFORMATION CARDS
c -----------------------------------------------------
c
c -----------------------------------------------------------------------
```

```
c  MATERIAL CARDS:
c  -----------------------------------------------------------------------
c        material 1: light water (h2o)  density= 1.00 g/cm**3
m1        1001.50c  0.66667      8016.50c  0.33333
mt1       lwtr.01t
c
c        material 2: cladding (SS304)   density= 7.87 g/cm**3
m2       25055.50c  8.3717-4    26000.55c  5.6089-2    24000.50c  1.4161-2
         28000.50c  1.0046-2    42000.50c  2.0929-3
c
c        material 3: standard fuel      density=6.1091 g/cm**3
m3        1001.50c  5.5318-2    40000.35c  3.5849-2
         92235.50c  2.4800-4    92238.50c  9.8550-4
mt3      h/zr.01t
c
c        material 4: leu fuel           density=6.508 g/cm**3
c         used Hf poison instead of Er poison
c         with an atomic number
c         scaled by the ratio of mic. absorption cross sections (173/105)
m4        1001.50c  5.0440-2    40000.35c  3.4295-2    72000.35c  6.3186-5
         92235.50c  6.3860-4    92238.50c  2.5700-3
mt4      h/zr.01t
c
c        material 5: graphite           density=1.28 g/cm**3
c         20% porosity
m5        6012.50c  6.4240-2
mt5      grph.01t
c
c        material 6: boron carbide (b4c) density 2.50 g/cm**3
m6        5010.50c  2.1780-2     5011.50c  8.7131-2    6012.50c  2.7228-2
c
c        material 7: aluminum 6061      density=2.70 g/cm**3
m7       12000.50c  6.08867-4   13027.50c  5.93050-2   14000.50c  3.51273-4
         22000.50c  1.71637-5   24000.50c  5.05971-5   25055.50c  1.49649-5
         26000.55c  1.00105-4   29000.50c  8.72506-5
c  -----------------------------------------------------------------------
c  END OF MATERIAL CARDS
c  -----------------------------------------------------------------------
c
c  --------------------------------------------------------
c  PARAMETER CARDS
c  --------------------------------------------------------
```

```
tmp    0.060e-6 0.025e-6 8r  0.025e-6 0.060e-6 0.025e-6 8r 0.025e-6 62r
sdef   pos 0 0 0 axs=0 0 1 rad=d1 ext=d2 erg=d3
si1    0 28
si2    20
sp3    -2
kcode  1000 1.0  5  20 5000
mode   n
c  -----------------------------------------------------
c  END OF PARAMETER CARDS
c  -----------------------------------------------------
```

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