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The benchmark experiments of the TRIGA Mark-II reactor in the ICSBEP handbook have been analyzed with the Monte Carlo code MVP using the cross section libraries based on JENDL-3.3, JENDL-3.2 and ENDF/B-VI.8. The MCNP calculations have been also performed with the ENDF/B-VI.6 library for comparison between the MVP and MCNP results. For both cores labeled 132 and 133, which have different core configurations, the ratio of the calculated to the experimental results (C/E) for k_{eff} obtained by the MVP code is 0.999 for JENDL-3.3, 1.003 for JENDL-3.2, and 0.998 for ENDF/B-VI.8. For the MCNP code, the C/E values are 0.998 for both Core 132 and 133. All the calculated results agree with the reference values within the experimental uncertainties. The results obtained by MVP with ENDF/B-VI.8 and MCNP with ENDF/B-VI.6 differ only by 0.02% for Core 132, and by 0.01% for Core 133.

Keywords: TRIGA, ICSBEP, MVP, MCNP, JENDL-3.2, JENDL-3.3, ENDF/B-VI, Benchmark, Critical Experiment.

※ Visiting researcher from Institute of Nuclear Science and Technology, Bangladesh Atomic Energy Commission

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モンテカルロコードMVPを用いたTRIGA MARK-II ベンチマーク IEU-COMP-THERM-003の解析

日本原子力研究所東海研究所エネルギーシステム研究部
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(2004年1月29日受理)

ICSBEPハンドブックに掲載されているTRIGA Mark-II炉心のベンチーマーク実験を核データライブラリーJENDL-3.3, JENDL-3.2及びENDF/B-VI.8とモンテカルロコードMVPを用いて解析した。また、MVPコードとMCNPコードの比較のためにENDF/B-VI.6を用いたMCNPの計算も行った。炉心構成の異なる炉心132及び133についてMVPコード及びJENDL-3.3、JENDL-3.2、ENDF/B-VI.8を用いて得られたC/E値はそれぞれ0.999、1.003、0.998であった。MCNPコードを用いて得られたC/E値は炉心132と133について共に 0.998 であった。すべての結果は実験値と実験誤差の範囲内で一致した。MVP とENDF/B-VI.8及びMCNPとENDF/B-VI.6を用いて得られた結果は炉心132については0.02%、炉心133については0.01%の差異しか見られなかった。

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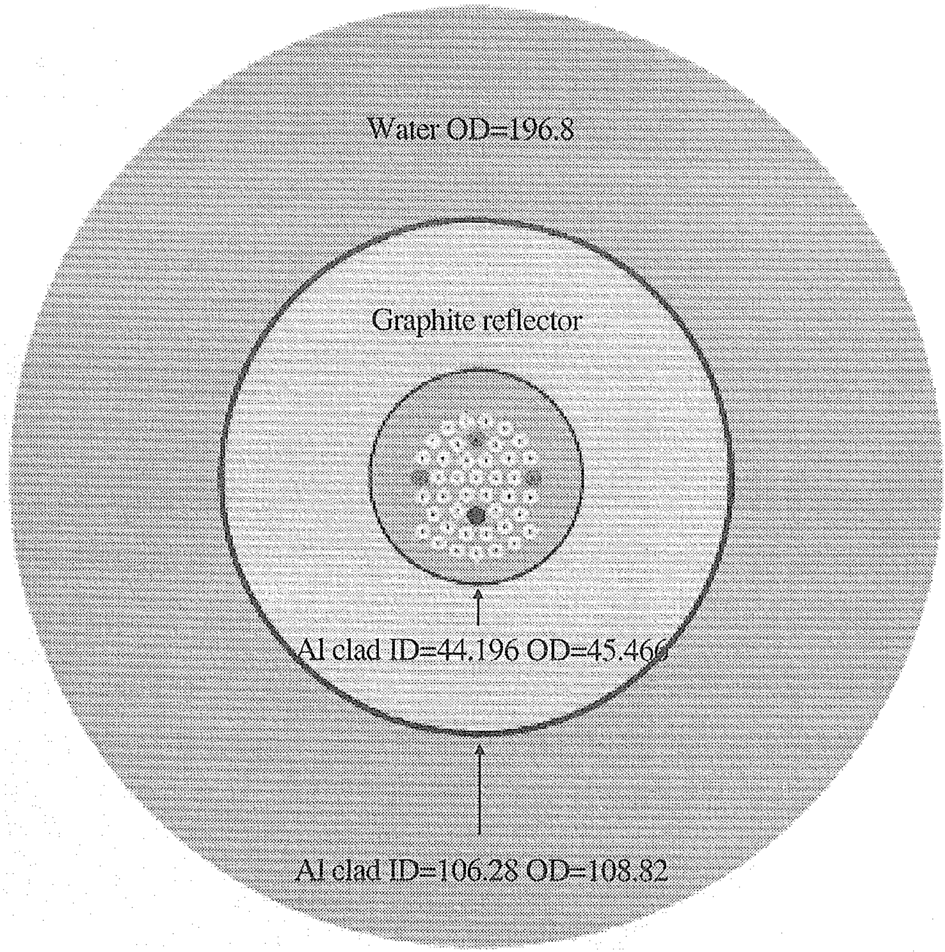
1. Introduction

In this study, two critical benchmark experiments[2] (Identification number: IEU-COMP-THERM-003) of the TRIGA Mark II reactor in Ljubljana, Slovenia, which were performed as a part of startup test of the reactor after reconstruction and upgrading in 1991, have been analyzed by using the continuous-energy Monte Carlo code MVP[1] with different evaluated nuclear data libraries. The core configurations of the critical experiments differed only in the positions of outermost fuel elements. The fuel is a homogeneous mixture of uranium and zirconium hydride. The standard stainless steel-clad fuel elements with 12 wt.% uranium of 20% enrichment (uranium is 20 wt.% of ^{235}U) were used. The analyses have been done using the cross section libraries based on JENDL-3.3[3], JENDL-3.2[4] and ENDF/B-VI release 8 (ENDF/B-VI.8). The same calculations have been revised with MCNP5[5] using the library ENDF/B-VI release 6 (ENDF/B-VI.6), as there is an error in the reported input of MCNP for the benchmark experiment. Cell calculations for a fuel rod have also been performed with the codes MVP and MCNP5 using the libraries generated from ENDF/B-VI.8 and ENDF/B-VI.6, respectively.

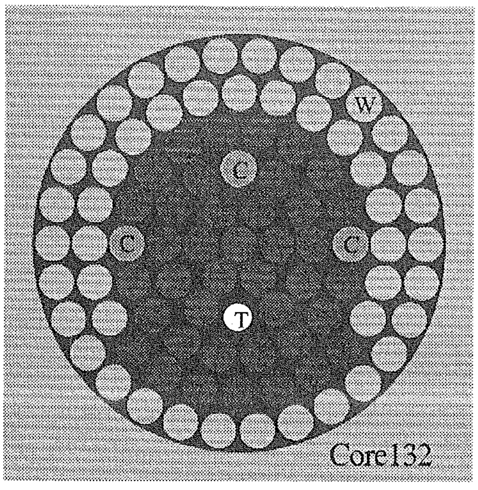
2. MVP Calculation Geometry

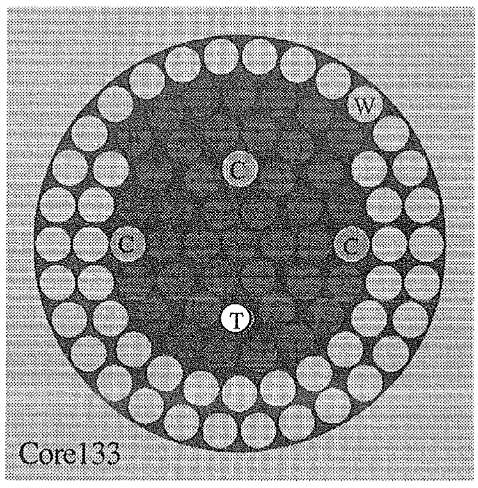
2.1 Full-Core Model

There are 91 locations for fuel and control elements in the core. Elements are arranged in six concentric rings, A, B, C, D, E, and F specified in Table 1. The core labeled 132 had 7 fuel elements in the E ring placed on the same side as the transient rod, while Core 133 had them placed on the opposite side (Fig. 1.a). As the pitch of the fuel locations in the core are not regular, so unit cell lattices have been defined for the fuel rod, control rod, and water column for the vacant positions of the core, and located at the corresponding positions repeatedly using different frames. The core arrangements, materials and dimensions of reflector, fuel elements, control rods, and transient rod are given in Tables 2, 3.a-c, and Figures 1.a, b, 2.a-c. Material compositions for the fuel elements, control rods, transient rod, claddings, reflector, water and air are given in Table 4.



Dimensions in cm





W- vacant position (water); F- fuel element; C- control element; T- transient rod

Figure 1.a Top views of the TRIGA reactor benchmark model

1. Introduction

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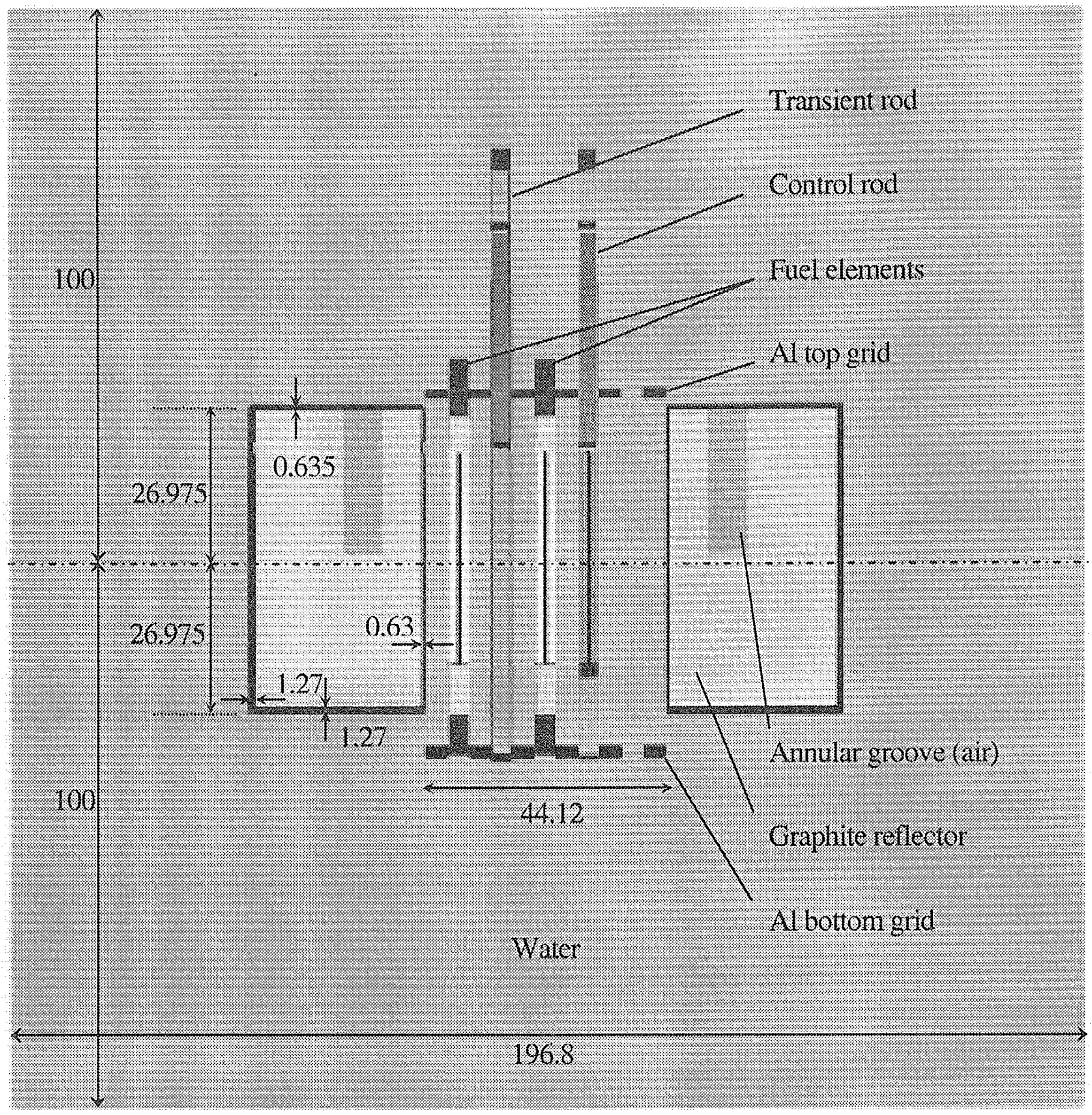

Dimensions in cm

Figure 1.b Side views of the TRIGA reactor benchmark model.

Table 3.b. Dimensions of the control rods

(The core mid plane intersects 36.83 cm above the bottom of the rod.)

Component		Dimension (cm)
Control rod	Outer radius	1.74625
	Element length	111.125
Fuel material	Outer radius	1.666875
	Inner radius	0.3175
	Height	38.10
Zr rod	Radius	0.3175
	Height	38.10
Absorber (B_4C)	Radius	1.666875
	Height	38.10
Cladding (stainless steel)	Thickness	0.0508
	Inner radius	1.69545
Voids (air)-Heights	Top	9.525
	Above absorber	0.47625
	Above fuel	0.79375
	Bottom	13.97
Fittings (stainless steel) –Heights	Bottom	1.27
	Below fuel	2.54
	Above fuel	1.27
	Above absorber	1.27
	Above top void	3.81

Table 3.c. Dimensions of the transient rod

(The core mid plane intersects 36.83 cm above the bottom of the rod.)

Component		Dimension (cm)
Transient rod and guide tube	Element length	111.125
	Outer radius	1.87706
Air follower	Radius	1.51638
	Height	55.40375
Absorber (B_4C)	Radius	1.51638
	Height	38.10
Cladding and guide tube (aluminum)	Outer radius	1.87706
	Inner radius	1.51638
Top void	Height	9.525
Void above absorber (air)	Height	0.47625
Fittings (aluminum)	Bottom	1.27
	Below absorber	1.27
	Above absorber	1.27
	Above top void	3.81

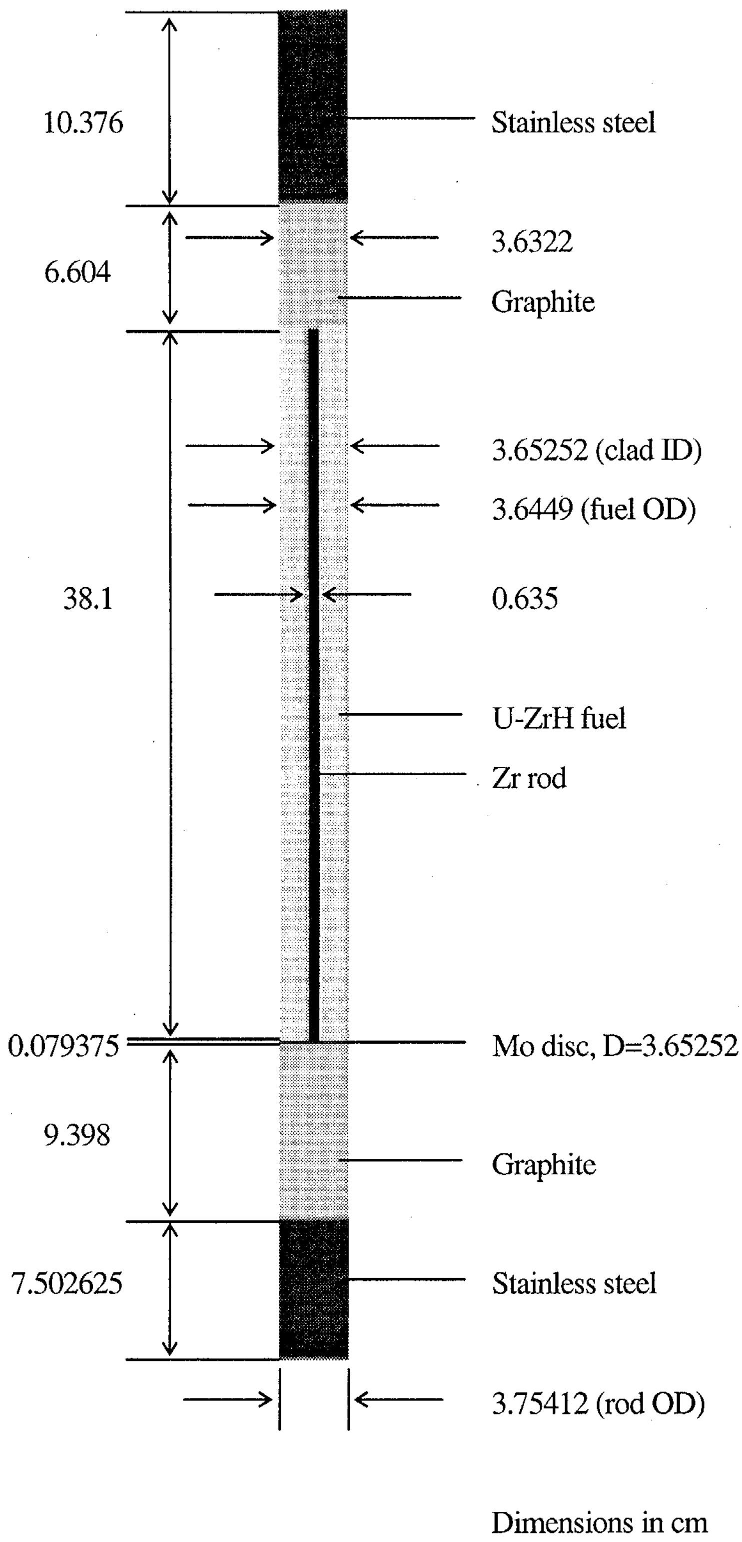

Figure 2.a Fuel element.

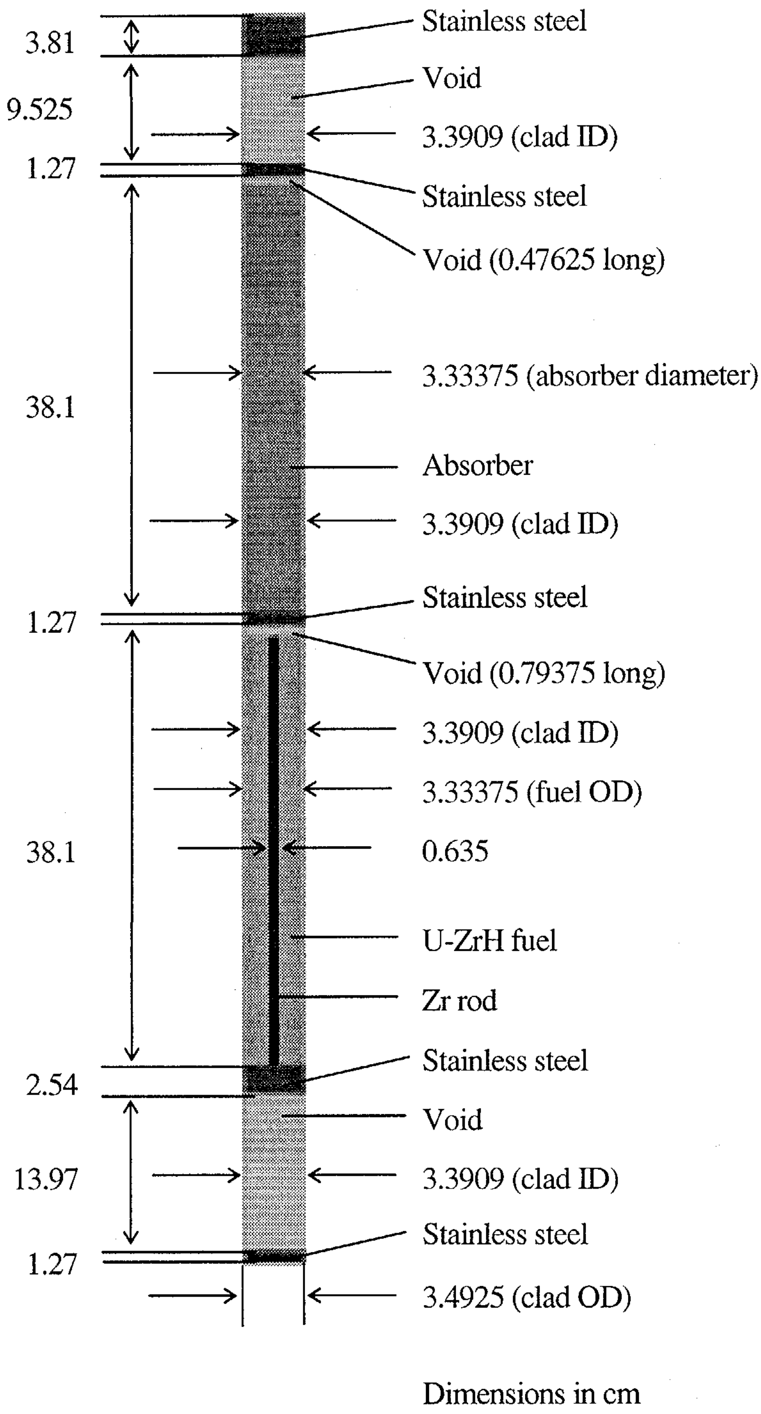

Figure 2.b Fueled-follower control rod.

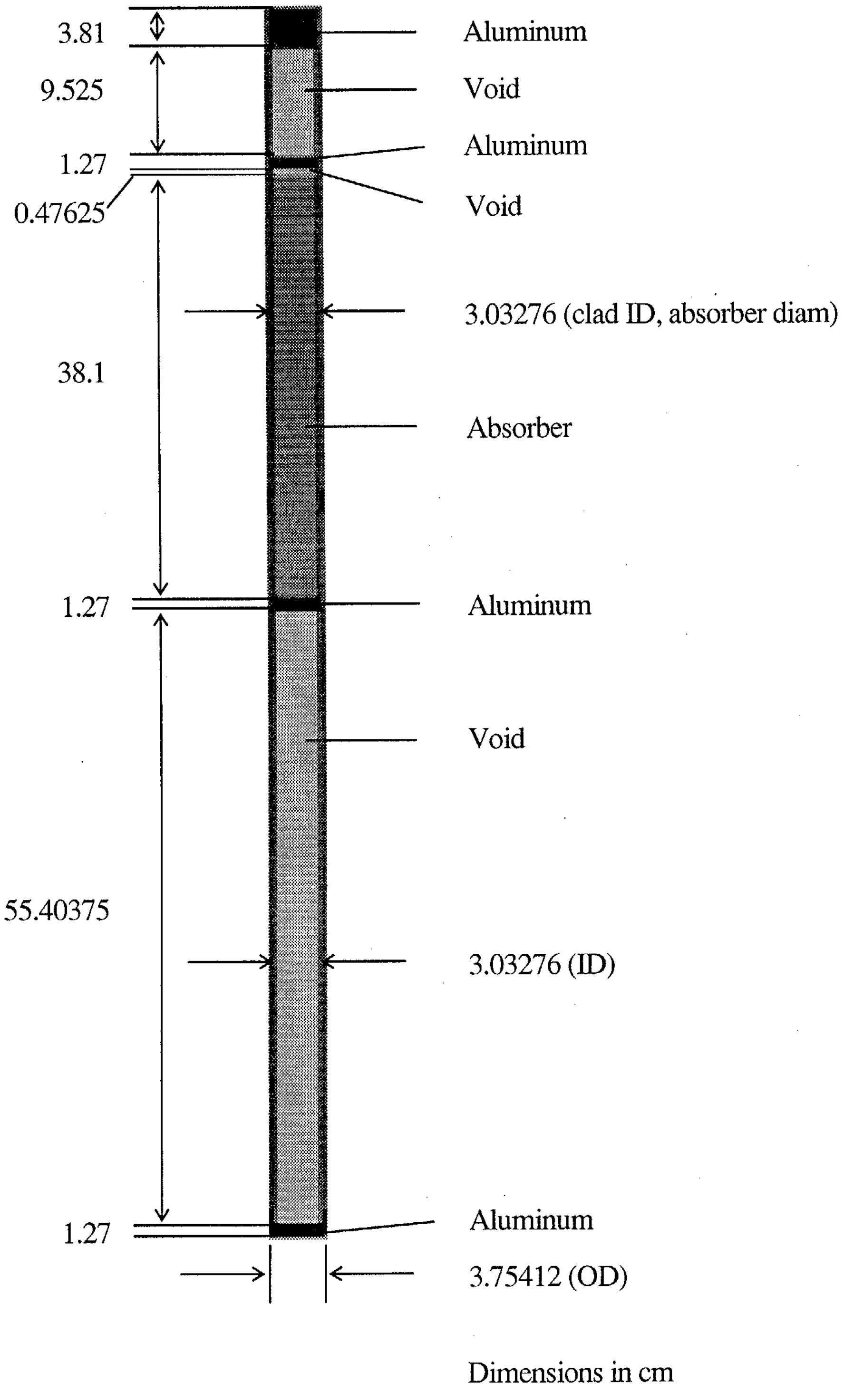

Figure 2.c Transient rod and guide tube.

Table 4. Material composition

Material	Component	Atom density (atoms/barn-cm)
Fuel elements (U-ZrH)	H	5.5253e-02
	Zr	3.4530e-02
	^{238}U	1.4625e-03
	^{235}U	3.6801e-04
Control rods (U-ZrH)	H	5.6284e-02
	Zr	3.5175e-02
	^{238}U	1.4898e-03
	^{235}U	3.7487e-04
Zr rod	Zr	4.2843e-02
Absorber (B_4C)	^{10}B	2.1443e-02
	^{11}B	8.6310e-02
	C	2.7355e-02
Element cladding, steel ends of rods and fittings (stainless steel)	Fe	5.6860e-02
	Cr	1.7360e-02
	Ni	8.0948e-03
	Mn	1.7295e-03
	Si	3.3831e-03
	C	3.1643e-04
	P	6.1353e-05
	S	5.9256e-05
Reflector cladding, grids, transient rod (aluminum)	^{27}Al	6.0262e-02
Supporting disc in fuel element	Mo	6.4025e-02
Graphite	^{12}C	8.0221e-02
Water	H	6.6689e-02
	O	3.3344e-02
Void regions (air)	N	4.3479e-05
	O	1.0868e-05

2.2 Cell Calculation Model

A cell calculation model has been set up to investigate the characteristics of the Zr-H fuel. Both in MVP and MCNP, isotropic boundary reflection is considered for the fuel cell calculation using the same fuel dimension (Figure 3) and composition as in the TRIGA benchmark model (Table 3.a).

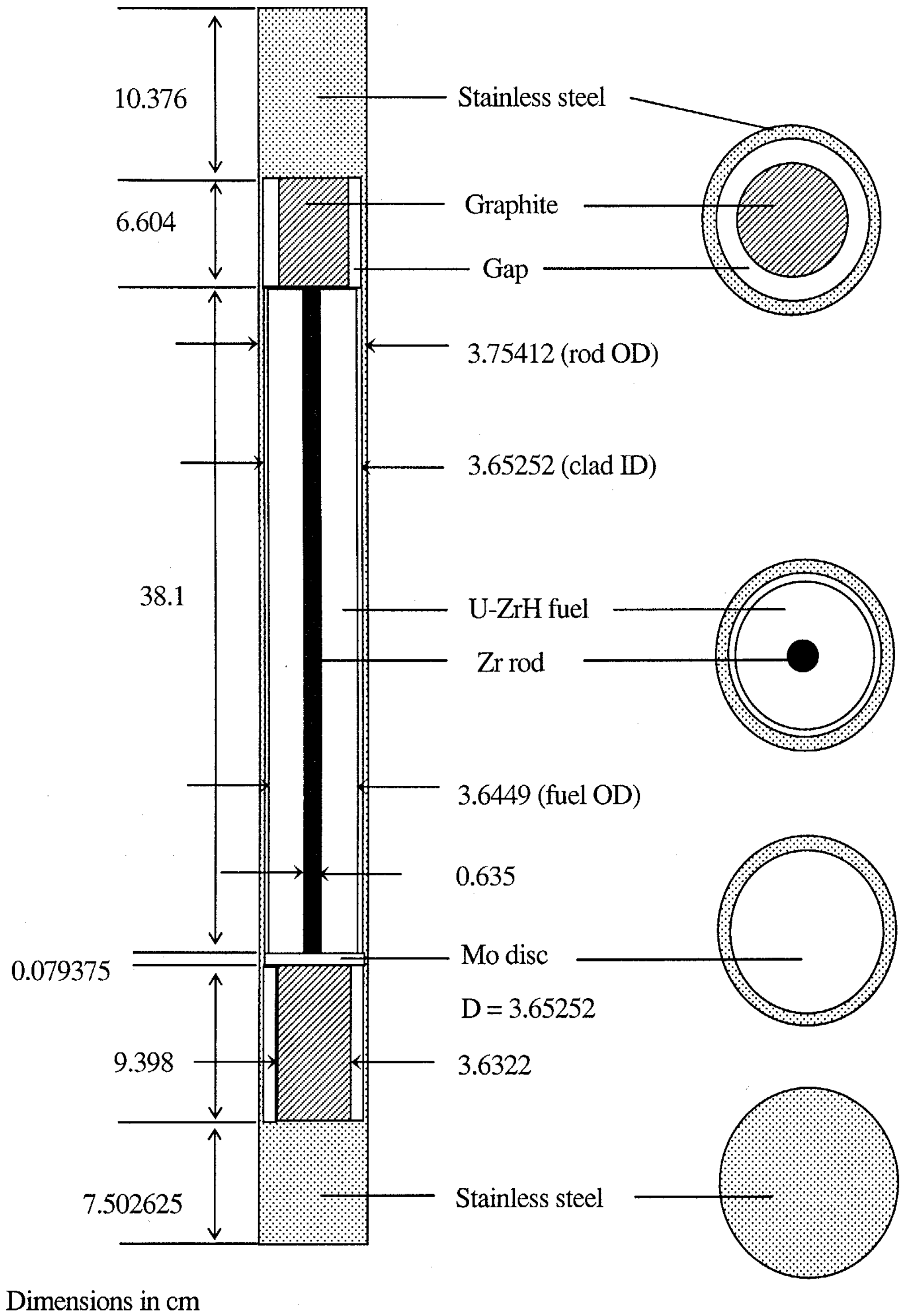

Figure 3. Longitudinal and cross-sectional view of the fuel rod for cell calculation

3. Calculated Results and Discussions

3.1 MVP Results

In each of the MVP calculations for the TRIGA benchmark model, the first 100 batches were skipped and followed by 2,000 active batches with 10,000 particles per batch. The water temperatures were 23.5°C and 22.5°C for Core 132 and Core 133, respectively. For all other cross section data the temperature was 20.0°C. Results were obtained by using the MVP code with the cross section data libraries based on JENDL-3.3, JENDL-3.2 and ENDF/B-VI.8.* Other than the isotopic cross-section data, the natural elements were used for the input when available in the libraries. MVP libraries used based on JENDL-3.3 has been produced with three types of thermal scattering data for ZrH from the free gas model, ENDF/B-VI and ENDF/B-III. The libraries based on JENDL-3.2 have been produced with two types of thermal scattering data from the free gas model and ENDF/B-III. And the libraries based on ENDF/B-VI.8 have been produced from the free gas model and ENDF/B-VI. The data above thermal energy region are the same as those of the free gas model for all libraries.

Table 6. Results of the k_{eff} values for benchmark model calculations

Case \ Core	Core 132	Core 133
Benchmark Model	1.00060 ± 0.0056 [a]	1.00460 ± 0.0056 [a]
MVP (JENDL-3.3)	0.99910 ± 0.0002 [b]	1.00360 ± 0.0002 [b]
MVP (JENDL-3.2)	1.00333 ± 0.0002 [b]	1.00752 ± 0.0002 [b]
MVP (ENDF/B-VI.8)	0.99831 ± 0.0002 [b]	1.00270 ± 0.0002 [b]

(a) As reported in reference 2. (b) The statistical uncertainty of 1 standard deviation is shown.

* Due to the unavailability of the thermal scattering data for ZrH, the MVP calculation with the JEFF-3.0 library has not been performed.

Table 7. C/E for the k_{eff} values for benchmark model calculations

Case \ Core	Core 132	Core 133
MVP (JENDL-3.3)	0.999 ± 0.006 [(a)]	0.999 ± 0.006 [(a)]
MVP (JENDL-3.2)	1.003 ± 0.006 [(a)]	1.003 ± 0.006 [(a)]
MVP (ENDF/B-VI.8)	0.998 ± 0.006 [(a)]	0.998 ± 0.006 [(a)]

(a) A standard deviation includes both statistical and model uncertainties.

The calculated k_{eff} and C/E values for the benchmark model geometry are given in Tables 6 and 7. In both Core 132 and 133, all the calculated results agree with the experimental value within the experimental uncertainty. (In this report, the experimental value means the benchmark model k_{eff} value corrected for geometrical simplification.) In particular, the JENDL-3.3 result is in very good agreement with the experimental one. However, the JENDL-3.2 result overestimates the experimental result by ~0.3%. This is the same trend as the results of the other benchmark calculations.[6)] The dependence of the k_{eff} values on U-235 enrichment was reported in reference 6, and it was found that the k_{eff} value obtained with JENDL-3.3 underestimates the experimental one for the cores with relatively lower U-235 enrichments, while it overestimates for the cores with highly U-235 enrichments. Around 10 wt.% enrichment of U-235, JENDL-3.3 gives the better result.

3.2 Revised MCNP Results

MCNP calculations have been performed with MCNP5 and the library based on ENDF/B-VI release 6. The input data used is the MCNP input data attached in the benchmark report with a modification because there is a mistake in the original input data. The outer radius of the control rod is 1.74625cm but it is specified as 1.714625cm in the input data. In the MCNP calculation the number of histories was 8,800,000 with 4,000 per batch, skipping 100 batches.

Table 8. Results of the k_{eff} values with the MCNP code

Case / Core	MCNP (ENDF/B-VI)	MCNP (ENDF/B-VI.6) (Revised)	Difference (%)
Core 132	$0.99940 \pm 0.0002^{(a)}$	$0.99813 \pm 0.0003^{(b)}$	0.13
Core 133	$1.00420 \pm 0.0002^{(a)}$	$1.00259 \pm 0.0003^{(b)}$	0.16

(a) As reported in reference 2. (b) The statistical uncertainty of 1 standard deviation is shown.

Table 9. C/E for the k_{eff} values with the MCNP code

Core / Case	Core 132	Core 133
MCNP (ENDF/B-VI.6) (Revised)	$0.998 \pm 0.006^{(a)}$	$0.998 \pm 0.006^{(a)}$

(a) A standard deviation includes both statistical and model uncertainties.

Table 8 shows the results of the original and the modified cases. Table 9 shows the C/E values for k_{eff} obtained by MCNP with ENDF/B-VI release 6. The revised results are lower than the original ones by 0.13% and 0.16% and agree with the experimental value within the experimental uncertainty. The differences between the results obtained by using MVP with ENDF/B-VI.8 and MCNP with ENDF/B-VI.6 are 0.02% and 0.01% for Core 132 and 133, respectively. One can compare the MVP and MCNP results because the difference between ENDF/B-VI.6 and -VI.8 doesn't affect the k_{eff} value. No significant difference can be seen between the MVP and MCNP results.

3.3 Results for Cell Calculation

For the fuel cell calculation with MVP, 11,000,000 histories with 10,000 histories per batch skipping 100 batches; on the other hand 8,800,000 histories with 4,000 histories per batch, skipping 100 batches for MCNP were considered. For the cell calculation the results of the k_∞ values (Table 10) obtained by using MVP with ENDF/B-VI.8 and MCNP with ENDF/B-VI .6 differ only 0.04%. This variation is negligible.

Table 10. Results of the k_∞ value for the fuel cell calculations

MVP (ENDF/B-VI.8)	MCNP (ENDF/B-VI.6)	Difference (%)
$1.47450 \pm 0.0001^{(a)}$	$1.47511 \pm 0.0001^{(a)}$	0.04

(a) The statistical uncertainty of 1 standard deviation is shown.

4. Conclusions

In the present study the validation of the Monte Carlo code MVP has been evaluated for the benchmark experiments of the TRIGA reactor using the cross section libraries based on JENDL-3.3, JENDL-3.2 and ENDF/B-VI.8. For both Core 132 and 133, the ratios of the calculated to the experimental results (C/E) are 0.999 for JENDL-3.3, 1.003 for JENDL-3.2, and 0.998 for ENDF/B-VI.8. The MVP results with JENDL-3.3 and ENDF/B-VI.8 are in good agreement with the experimental k_{eff} values, while the result slightly overestimates for JENDL 3.2. All the calculated results agree with the experimental values within the experimental uncertainties. Thus the MVP code is valid with high accuracy for the neutronic analysis of the TRIGA reactor.

We have also performed the benchmark calculations with the MCNP5 code because there is a mistake in the original input data given in Ref. 2. The k_{eff} values obtained from the revised calculation using ENDF/B-VI.6 are found to be 0.99813 and 1.00259 for Core 132 and 133, respectively, which are lower than the original values 0.9994 and 1.0042, respectively. The C/E values are 0.998 for both Core 132 and 133. The calculated results agree with the experimental values within the experimental uncertainties.

We have performed the cell calculations for a fuel rod to compare the MVP and MCNP results. The k_∞ values are found to be 1.47450 for MVP code with the ENDF/B-VI .8 library and 1.47511 for the code MCNP with the ENDF/B-VI .6 library. The variation of the results is negligibly small.

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6) K. Okumura and T. Mori, "Investigation of Dependence of Criticality Evaluation Accuracy on U-235 Enrichment in Light Water Moderated Uranium Fueled Systems", JAERI-Review 2003-023, pp. 59-61 (2003)..

APPENDIX

MVP input for Core 132 with JENDL-3.3

The pitches of the locations of the core are not regular and the core elements are arranged in a circular fashion. So, in the MVP input six concentric rings and unit cell lattice have been defined for the fuel rod, control rod, and water column for the vacant positions of the core. These unit cells are repeated by using different frames at the corresponding locations in different rings. A sample input of the MVP calculation for Core 132 is given below. To obtain the input for Core 133, the positions of the transient rod and the control rod of the C-ring has to be interchanged in the zone definition part of the geometry block of the following input.

```
TRIGA Mark II Reactor: U(20) - zirconium hydride fuel
rods in water with graphite reflector (JENDL-3.3)(core 132)
*
   NO-RESTART
   LATTICE
   RUSSIAN-ROULETTE  FISSION  EIGEN-VALUE
   NO-EDIT-MACROSCOPIC-DATA(00004000)
   NO-EDIT-MICROSCOPIC-DATA(00004000)
   DYNAMIC-MEMORY(100000000)

%  NG     = 1
%  NHIST  = 10000
%  KBATCH = 2000
%  NSKIP  = 100
%  NBATCH = KBATCH + NSKIP
**********************************************************************
   NGROUP(<NG>)    NMEMO(45)
   ETOP(2.0E+7)    EBOT(1.0E-5)     ETHMAX(4.5)      EWCUT(0.1)
   NPART(<NBATCH*NHIST>)  NHIST(<NHIST>)  NSKIP(<NSKIP>)
   NBANK(<NINT(1.5*NHIST)>) NFBANK(<NINT(1.5*NHIST)>)
   IRAND( 1 )
   TCPU( 355 )
**********************************************************************
% MZR=1, MLEU=2, MFF=3,  MGD=4,  MB4C=5
% MSS=6, MAL=7,  MH2O=8, MAIR=9, MMO=10
% TEMPR   = 273.15 + 20.0
% TEMPW   = 273.15 + 23.5 /* CORE 132
*% TEMPW   = 273.15 + 22.5 /* CORE 133
**************** CROSS SECTION *************************************
$XSEC
* ... isotopic abundance ...
% ZR90=51.45, ZR91=11.22, ZR92=17.15, ZR94=17.38, ZR96=2.80
```

```
*
* Zirconium rod (1)
& IDMAT(<MZR>)
 TEMPMT(<TEMPR>) /* Kelvin
* ZR0000J33( 4.2843E-2 )
% ZRN = 4.2843E-2
 ZR0900J33(<ZR90*ZRN/100>)
 ZR0910J33(<ZR91*ZRN/100>)
 ZR0920J33(<ZR92*ZRN/100>)
 ZR0940J33(<ZR94*ZRN/100>)
 ZR0960J33(<ZR96*ZRN/100>)
*
* fuel element (2)
& IDMAT(<MLEU>)
 TEMPMT(<TEMPR>) /* Kelvin
 H0001ZJ33( 5.5253E-2 )
*
* ZR000ZJ33( 3.4530E-2 )
% ZRFE = 3.4530E-2
 ZR090ZJ33(<ZR90*ZRFE/100>)
 ZR091ZJ33(<ZR91*ZRFE/100>)
 ZR092ZJ33(<ZR92*ZRFE/100>)
 ZR094ZJ33(<ZR94*ZRFE/100>)
 ZR096ZJ33(<ZR96*ZRFE/100>)
*
 U02380J33( 1.4625E-3 )
 U02350J33( 3.6801E-4 )
* contrl rod(3)
& IDMAT(<MFF>)
 TEMPMT(<TEMPR>) /* Kelvin
 H0001ZJ33( 5.6284E-2 )
*
* ZR000ZJ33( 3.5175E-2 )
% ZRCR = 3.5175E-2
 ZR090ZJ33(<ZR90*ZRCR/100>)
 ZR091ZJ33(<ZR91*ZRCR/100>)
 ZR092ZJ33(<ZR92*ZRCR/100>)
 ZR094ZJ33(<ZR94*ZRCR/100>)
 ZR096ZJ33(<ZR96*ZRCR/100>)
*
 U02380J33( 1.4898E-3 )
 U02350J33( 3.7487E-4 )
* Graphite (4)
& IDMAT(<MGD>)
 TEMPMT(<TEMPR>) /* Kelvin
 C0000CJ33( 8.0221E-2 )
* Absorber (B4C) (5)
& IDMAT(<MB4C>)
 TEMPMT(<TEMPR>) /* Kelvin
 B00100J33( 2.1443E-2 )
 B00110J33( 8.6310E-2 )
 C00000J33( 2.7355E-2 )
*
* Stainless Steel(6)
& IDMAT(<MSS>)
```

```
  TEMPMT(<TEMPR>) /* Kelvin
*  FE0000J33( 5.6860E-2 )
% FEN = 5.6860E-2
% FE54=5.90, FE56=91.72, FE57=2.10, FE58=0.28
  FE0540J33(<FE54*FEN/100>)
  FE0560J33(<FE56*FEN/100>)
  FE0570J33(<FE57*FEN/100>)
  FE0580J33(<FE58*FEN/100>)
*
*  CR0000J33( 1.7360E-2 )
% CRN = 1.7360E-2
% CR50=4.345, CR52=83.790, CR53=9.500, CR54=2.365
  CR0500J33(<CR50*CRN/100>)
  CR0520J33(<CR52*CRN/100>)
  CR0530J33(<CR53*CRN/100>)
  CR0540J33(<CR54*CRN/100>)
*
*  NI0000J33( 8.0948E-3 )
% NIN = 8.0948E-3
% NI58=68.077, NI60=26.223, NI61=1.140, NI62=3.634, NI64=0.926
  NI0580J33(<NI58*NIN/100>)
  NI0600J33(<NI60*NIN/100>)
  NI0610J33(<NI61*NIN/100>)
  NI0620J33(<NI62*NIN/100>)
  NI0640J33(<NI64*NIN/100>)
*
  MN0550J33( 1.7295E-3 )
*
* SI0000J33( 3.3831E-3 )
% SIN = 3.3831E-3
% SI28=92.23, SI29=4.67, SI30=3.10
  SI0280J33(<SI28*SIN/100>)
  SI0290J33(<SI29*SIN/100>)
  SI0300J33(<SI30*SIN/100>)
*
  C00000J33( 3.1643E-4 )
*
  P00310J33( 6.1353E-5 )
*
* S00000J33( 5.9256E-5 )
% SNAT = 5.9256E-5
% S32=95.02, S33=0.75, S34=4.21, S36=0.02
  S00320J33(<S32*SNAT/100>)
  S00330J33(<S33*SNAT/100>)
  S00340J33(<S34*SNAT/100>)
  S00360J33(<S36*SNAT/100>)
*
* Aluminium(7)
& IDMAT(<MAL>)
  TEMPMT(<TEMPR>) /* Kelvin
  AL0270J33( 6.0262E-2 )
* Light Water(8)
& IDMAT(<MH2O>)
  TEMPMT(<TEMPW>) /* Kelvin
  H0001HJ33( 6.6689E-2 )
```

```
 O00160J33( 3.3344E-2 )
* Air (9)
& IDMAT(<MAIR>)
 TEMPMT(<TEMPR>) /* Kelvin
 N00140J33( 4.3479E-5 )
 O00160J33( 1.0868E-5 )
*
* MO disc (10)
& IDMAT(<MMO>)
 TEMPMT(<TEMPR>) /* Kelvin
* MO0000J33( 6.4025E-2 )
% MON = 6.4025E-2
% MO092=14.84, MO094= 9.25, MO095=15.92, MO096=16.68
% MO097= 9.55, MO098=24.13, MO100= 9.63
 MO0920J33(<MO092*MON/100>)
 MO0940J33(<MO094*MON/100>)
 MO0950J33(<MO095*MON/100>)
 MO0960J33(<MO096*MON/100>)
 MO0970J33(<MO097*MON/100>)
 MO0980J33(<MO098*MON/100>)
 MO1000J33(<MO100*MON/100>)
END
*************** GEOMETRY ********************************
$GEOM
% HT     =  200.0     /* height of geometry
% Z00    = -100.0     /* position of geometry bottom
% RROD   =   1.87706  /* radius of lattice cell
 /*** parameters for fuel rods
% HTE    =  10.376    /* height of top end
% HTREF  =   6.604    /* height of top reflector
% HFM    =  38.1      /* height of fuel material
% HMD    =   0.079375 /* height of Mo disc
% HLR    =   9.398    /* height of lower reflector
% HBE    =   7.502625 /* height of bottom end
% HFR    =  72.06     /* height of fuel rod
% ZFR00  = -36.03     /* position of fuel rod bottom
% RZR    =  0.3175    /* radius of Zr rod
% RAR    =  1.8161    /* radius of axial reflector (graphite)
% RFM    =  1.82245   /* outer radius of fuel material
% RIC    =  1.82626   /* inner radius of cladding (SS)
% RFR    =  1.87706   /* radius of fuel rod
% HFBW   = ZFR00-Z00  /* height of bottom water below fuel rod
 /*** parameters for control rods
% HCFT   =   3.81     /* height of top fitting
% HCVT   =   9.525    /* height of top void
% HCFAA  =   1.27     /* height of fitting above absorber
% HCVAA  =   0.47625  /* height of void above absorber
% HCA    =  38.10     /* height of absorber
% HCFAF  =   1.27     /* height of fitting above fuel
% HCVAF  =   0.79375  /* height of void above fuel
% HCFM   =  38.10     /* height of fuel material
% HCFBF  =   2.54     /* height of fitting below fuel
% HCVB   =  13.97     /* height of bottom void
% HCFB   =   1.27     /* height of bottom fitting
% HCR    = 111.125    /* height of control rod
```

```
% ZCR00  = -36.83     /* position of control rod bottom
% RCZR   =   0.3175   /* radius of Zr rod
% RCFM   =   1.666875 /* outer radius of fuel material & absorber
% RCIC   =   1.69545  /* inner radius of cladding (SS)
% RCR    =   1.74625  /* radius of control rod
% HCBW   = ZCR00-Z00  /* height of bottom water below control rod
% ZCR01 = HCBW+HCFB  , ZCR02 = ZCR01+HCVB , ZCR03 = ZCR02+HCFBF
% ZCR04 = ZCR03+HCFM , ZCR05 = ZCR04+HCVAF, ZCR06 = ZCR05+HCFAF
% ZCR07 = ZCR06+HCA  , ZCR08 = ZCR07+HCVAA, ZCR09 = ZCR08+HCFAA
% ZCR10 = ZCR09+HCVT
 /*** parameters for transient rods
% HTFT   =   3.81     /* height of top fitting
% HTVT   =   9.525    /* height of top void
% HTFAA  =   1.27     /* height of fitting above absorber
% HTVAA  =   0.47625  /* height of void above absorber
% HTA    =  38.10     /* height of absorber
% HTFBA  =   1.27     /* height of below absorber
% HTAF   =  55.40375  /* height of air follower
% HTFB   =   1.27     /* height of bottom fitting
% HTROD  = 111.125    /* height of transient rod
% ZTR00  = -36.83     /* position of transient rod bottom
% RTIC   =   1.51638  /* inner radius of cladding (Al)
% RTR    =   1.87706  /* radius of transient rod
% HTBW   = ZTR00-Z00  /* height of bottom water below transient rod
% ZTR01 = HTBW+HTFB  , ZTR02 = ZTR01+HTAF , ZTR03 = ZTR02+HTFBA
% ZTR04 = ZTR03+HTA  , ZTR05 = ZTR04+HTVAA, ZTR06 = ZTR05+HTFAA
% ZTR07 = ZTR06+HTVT
 /***
% WPIT   = 100.0      /* dummy pitch
 /***
% RRINGA =  0.0000   /* radial distance of ring A
% RRINGB =  4.0538   /* radial distance of ring B
% RRINGC =  7.9807   /* radial distance of ring C
% RRINGD = 11.9456   /* radial distance of ring D
% RRINGE = 15.9156   /* radial distance of ring E
% RRINGF = 19.8882   /* radial distance of ring F
 /***
% RDAB   = (RRINGA+RRINGB)/2 /* radial distance of midpoint A-B
% RDBC   = (RRINGB+RRINGC)/2 /* radial distance of midpoint B-C
% RDCD   = (RRINGC+RRINGD)/2 /* radial distance of midpoint C-D
% RDDE   = (RRINGD+RRINGE)/2 /* radial distance of midpoint D-E
% RDEF   = (RRINGE+RRINGF)/2 /* radial distance of midpoint E-F
 /*** parameters for grids
% DGRD   = 44.12     /* diameter of bottom & top grids
% THGRD  =  1.905    /* thickness of bottom & top grids
% ZGRDB  = -36.20    /* position of bottom plane of lower grid
% ZGRDT  =  28.88    /* position of bottom plane of top grid
 /***
% RGRD   = DGRD/2     /* radius of bottom & top grids
 /*** parameters for refector
% ORGR   =  53.14    /* outer radius of graphite reflector
% IRGR   =  22.733   /* inner radius of graphite reflector
% HTGR   =  53.95    /* height of graphite reflector
% ORAG   =  36.957   /* outer radius of annular groove
% IRAG   =  29.883   /* inner radius of annular groove
```

```
% HTAG   =  26.124   /* height of annular groove
% THCIN  =   0.635   /* thickness of inner cladding
% THCTP  =   0.635   /* thickness of top cladding
% THCOT  =   1.27    /* thickness of outer cladding
% THCBT  =   1.27    /* thickness of bottom cladding
***** LATTICE DATA *****
 IDLAT(100) /* fuel rod
   LTYP(3) NVLAT( 1 1 1 )
   SZLAT( <WPIT>  0.  <HT> )
   SZHEX( 0. 0. <RROD> <HT> )
   RCELL( 1 1 )
   KLATT( 100 )
   KSLAT( 0 )
 IDLAT(200) /* control rod
   LTYP(3) NVLAT( 1 1 1 )
   SZLAT( <WPIT>  0.  <HT> )
   SZHEX( 0. 0. <RROD> <HT> )
   RCELL( 1 1 )
   KLATT( 200 )
   KSLAT( 0 )
 IDLAT(300) /* transient rod
   LTYP(3) NVLAT( 1 1 1 )
   SZLAT( <WPIT>  0.  <HT> )
   SZHEX( 0. 0. <RROD> <HT> )
   RCELL( 1 1 )
   KLATT( 300 )
   KSLAT( 0 )
 IDLAT(400) /* water
   LTYP(3) NVLAT( 1 1 1 )
   SZLAT( <WPIT>  0.  <HT> )
   SZHEX( 0. 0. <RROD> <HT> )
   RCELL( 1 1 )
   KLATT( 400 )
   KSLAT( 0 )
END
****************** BODY DEFINITION **********************
CYL(   9999  0. 0. -100.0  <HT>  98.4 ) /* tank
*
CYL(    200  0. 0. 0.  0.  <IRGR-THCIN> )
CYL(    201  0. 0. 0.  0.  <IRGR> )
CYL(    202  0. 0. <-HTGR/2-THCBT>  <HTGR+THCBT+THCTP>  <ORGR+THCOT> )
CYL(    203  0. 0. <-HTGR/2>  <HTGR>  <ORGR> )
CYL(    211  0. 0. <HTGR/2-HTAG>  <HTAG+0.1>  <ORAG> )
CYL(    212  0. 0. 0.  0.  <IRAG> )
*
CYL(    301  0. 0. <ZGRDT>  <THGRD>  <RGRD> ) /* top grid
CYL(    302  0. 0. <ZGRDB>  <THGRD>  <RGRD> ) /* bottom grid
*
 /*** bodies for lattice cell
RHP(     10  0. 0. 0.  <HT>  <WPIT> ) /* dummy frame
 /*** bodies for fuel rod
CYL(     11  0. 0. <HFBW+HBE>  <HLR+HMD+HFM+HTREF>  <RIC> )
CYL(     12  0. 0. 0.  0.  <RAR> )
CYL(     13  0. 0. <HFBW+HBE+HLR+HMD>  <HFM>  <RFM> ) /* fuel material
CYL(     14  0. 0. <HFBW+HBE+HLR>  <HMD>  <RFR> ) /* Mo disk
```

```
CYL(     15  0. 0. 0.  0.  <RZR> ) /* Zr rod
HAF(     16  0. 0. 1.  <-HFBW> )
HAF(     17  0. 0. 1.  <-HFR-HFBW> )
 /*** bodies for control rod
CYL(     20  0. 0. 0.  0.  <RCR> )
CYL(     21  0. 0. <ZCR01>  <ZCR10-ZCR01>  <RCIC> )
CYL(     22  0. 0. 0.  0.  <RCFM> )
CYL(     23  0. 0. 0.  0.  <RCZR> )
HAF(     32  0. 0. 1.  <-ZCR02> )
HAF(     33  0. 0. 1.  <-ZCR03> )
HAF(     34  0. 0. 1.  <-ZCR04> )
HAF(     35  0. 0. 1.  <-ZCR05> )
HAF(     36  0. 0. 1.  <-ZCR06> )
HAF(     37  0. 0. 1.  <-ZCR07> )
HAF(     38  0. 0. 1.  <-ZCR08> )
HAF(     39  0. 0. 1.  <-ZCR09> )
HAF(     40  0. 0. 1.  <-HCBW> )
HAF(     41  0. 0. 1.  <-HCR-HCBW> )
 /*** bodies for transient rod
CYL(     51  0. 0. <ZTR01>  <HTAF>  <RTIC> ) /* air follower
CYL(     52  0. 0. <ZTR03>  <ZTR05-ZTR03>  <RTIC> ) /* absorber+void
CYL(     53  0. 0. <ZTR06>  <HTVT>  <RTIC> ) /* top void
HAF(     54  0. 0. 1.  <-ZTR04> ) /* absorber top
HAF(     55  0. 0. 1.  <-HTBW> )
HAF(     56  0. 0. 1.  <-HTROD-HTBW> )
 /*** bodies for ring separator
CYL(   8001  0. 0. 0.  0.  <RDAB> ) /* A-B
CYL(   8002  0. 0. 0.  0.  <RDBC> ) /* B-C
CYL(   8003  0. 0. 0.  0.  <RDCD> ) /* C-D
CYL(   8004  0. 0. 0.  0.  <RDDE> ) /* D-E
CYL(   8005  0. 0. 0.  0.  <RDEF> ) /* E-F
 /*** bodies for lattice frame
RCL( 1101   0.       0.     <Z00>  0. 0. <HT> <RROD> 1. 0. 0. )
*
RCL( 1201  <RRINGB*COSD(   0)> <RRINGB*SIND(   0)> <Z00>
           0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1202  <RRINGB*COSD( -60)> <RRINGB*SIND( -60)> <Z00>
           0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1203  <RRINGB*COSD(-120)> <RRINGB*SIND(-120)> <Z00>
           0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1204  <RRINGB*COSD(-180)> <RRINGB*SIND(-180)> <Z00>
           0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1205  <RRINGB*COSD(-240)> <RRINGB*SIND(-240)> <Z00>
           0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1206  <RRINGB*COSD(-300)> <RRINGB*SIND(-300)> <Z00>
           0. 0. <HT> <RROD> 1. 0. 0. )
*
RCL( 1301  <RRINGC*COSD(   0)> <RRINGC*SIND(   0)> <Z00>
           0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1302  <RRINGC*COSD( -30)> <RRINGC*SIND( -30)> <Z00>
           0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1303  <RRINGC*COSD( -60)> <RRINGC*SIND( -60)> <Z00>
           0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1304  <RRINGC*COSD( -90)> <RRINGC*SIND( -90)> <Z00>
           0. 0. <HT> <RROD> 1. 0. 0. )
```

```
RCL( 1305  <RRINGC*COSD(-120)> <RRINGC*SIND(-120)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1306  <RRINGC*COSD(-150)> <RRINGC*SIND(-150)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1307  <RRINGC*COSD(-180)> <RRINGC*SIND(-180)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1308  <RRINGC*COSD(-210)> <RRINGC*SIND(-210)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1309  <RRINGC*COSD(-240)> <RRINGC*SIND(-240)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1310  <RRINGC*COSD(-270)> <RRINGC*SIND(-270)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1311  <RRINGC*COSD(-300)> <RRINGC*SIND(-300)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1312  <RRINGC*COSD(-330)> <RRINGC*SIND(-330)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
*
RCL( 1401  <RRINGD*COSD(   0)> <RRINGD*SIND(   0)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1402  <RRINGD*COSD( -20)> <RRINGD*SIND( -20)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1403  <RRINGD*COSD( -40)> <RRINGD*SIND( -40)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1404  <RRINGD*COSD( -60)> <RRINGD*SIND( -60)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1405  <RRINGD*COSD( -80)> <RRINGD*SIND( -80)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1406  <RRINGD*COSD(-100)> <RRINGD*SIND(-100)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1407  <RRINGD*COSD(-120)> <RRINGD*SIND(-120)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1408  <RRINGD*COSD(-140)> <RRINGD*SIND(-140)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1409  <RRINGD*COSD(-160)> <RRINGD*SIND(-160)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1410  <RRINGD*COSD(-180)> <RRINGD*SIND(-180)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1411  <RRINGD*COSD(-200)> <RRINGD*SIND(-200)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1412  <RRINGD*COSD(-220)> <RRINGD*SIND(-220)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1413  <RRINGD*COSD(-240)> <RRINGD*SIND(-240)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1414  <RRINGD*COSD(-260)> <RRINGD*SIND(-260)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1415  <RRINGD*COSD(-280)> <RRINGD*SIND(-280)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1416  <RRINGD*COSD(-300)> <RRINGD*SIND(-300)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1417  <RRINGD*COSD(-320)> <RRINGD*SIND(-320)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1418  <RRINGD*COSD(-340)> <RRINGD*SIND(-340)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
*
RCL( 1501  <RRINGE*COSD(   0)> <RRINGE*SIND(   0)> <Z00>
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          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1502  <RRINGE*COSD( -15)> <RRINGE*SIND( -15)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1503  <RRINGE*COSD( -30)> <RRINGE*SIND( -30)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1504  <RRINGE*COSD( -45)> <RRINGE*SIND( -45)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1505  <RRINGE*COSD( -60)> <RRINGE*SIND( -60)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1506  <RRINGE*COSD( -75)> <RRINGE*SIND( -75)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1507  <RRINGE*COSD( -90)> <RRINGE*SIND( -90)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1508  <RRINGE*COSD(-105)> <RRINGE*SIND(-105)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1509  <RRINGE*COSD(-120)> <RRINGE*SIND(-120)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1510  <RRINGE*COSD(-135)> <RRINGE*SIND(-135)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1511  <RRINGE*COSD(-150)> <RRINGE*SIND(-150)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1512  <RRINGE*COSD(-165)> <RRINGE*SIND(-165)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1513  <RRINGE*COSD(-180)> <RRINGE*SIND(-180)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1514  <RRINGE*COSD(-195)> <RRINGE*SIND(-195)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1515  <RRINGE*COSD(-210)> <RRINGE*SIND(-210)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1516  <RRINGE*COSD(-225)> <RRINGE*SIND(-225)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1517  <RRINGE*COSD(-240)> <RRINGE*SIND(-240)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1518  <RRINGE*COSD(-255)> <RRINGE*SIND(-255)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1519  <RRINGE*COSD(-270)> <RRINGE*SIND(-270)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1520  <RRINGE*COSD(-285)> <RRINGE*SIND(-285)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1521  <RRINGE*COSD(-300)> <RRINGE*SIND(-300)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1522  <RRINGE*COSD(-315)> <RRINGE*SIND(-315)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1523  <RRINGE*COSD(-330)> <RRINGE*SIND(-330)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1524  <RRINGE*COSD(-345)> <RRINGE*SIND(-345)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
*
RCL( 1601  <RRINGF*COSD(   0)> <RRINGF*SIND(   0)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1602  <RRINGF*COSD( -12)> <RRINGF*SIND( -12)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1603  <RRINGF*COSD( -24)> <RRINGF*SIND( -24)> <Z00>
          0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1604  <RRINGF*COSD( -36)> <RRINGF*SIND( -36)> <Z00>
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        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1605  <RRINGF*COSD( -48)> <RRINGF*SIND( -48)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1606  <RRINGF*COSD( -60)> <RRINGF*SIND( -60)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1607  <RRINGF*COSD( -72)> <RRINGF*SIND( -72)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1608  <RRINGF*COSD( -84)> <RRINGF*SIND( -84)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1609  <RRINGF*COSD( -96)> <RRINGF*SIND( -96)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1610  <RRINGF*COSD(-108)> <RRINGF*SIND(-108)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1611  <RRINGF*COSD(-120)> <RRINGF*SIND(-120)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1612  <RRINGF*COSD(-132)> <RRINGF*SIND(-132)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1613  <RRINGF*COSD(-144)> <RRINGF*SIND(-144)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1614  <RRINGF*COSD(-156)> <RRINGF*SIND(-156)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1615  <RRINGF*COSD(-168)> <RRINGF*SIND(-168)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1616  <RRINGF*COSD(-180)> <RRINGF*SIND(-180)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1617  <RRINGF*COSD(-192)> <RRINGF*SIND(-192)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1618  <RRINGF*COSD(-204)> <RRINGF*SIND(-204)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1619  <RRINGF*COSD(-216)> <RRINGF*SIND(-216)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1620  <RRINGF*COSD(-228)> <RRINGF*SIND(-228)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1621  <RRINGF*COSD(-240)> <RRINGF*SIND(-240)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1622  <RRINGF*COSD(-252)> <RRINGF*SIND(-252)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1623  <RRINGF*COSD(-264)> <RRINGF*SIND(-264)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1624  <RRINGF*COSD(-276)> <RRINGF*SIND(-276)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1625  <RRINGF*COSD(-288)> <RRINGF*SIND(-288)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1626  <RRINGF*COSD(-300)> <RRINGF*SIND(-300)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1627  <RRINGF*COSD(-312)> <RRINGF*SIND(-312)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1628  <RRINGF*COSD(-324)> <RRINGF*SIND(-324)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1629  <RRINGF*COSD(-336)> <RRINGF*SIND(-336)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
RCL( 1630  <RRINGF*COSD(-348)> <RRINGF*SIND(-348)> <Z00>
        0. 0. <HT> <RROD> 1. 0. 0. )
END
******  ZONE DEFINITIONS  ************
```

```
 ETV      :            : -1000    : -9999
 WATER    : MODERATOR : <MH2O>   :  9999 -200 -202
*
*
 WATER-A  : MODERATOR : <MH2O>   :  9999 -301 -302  8001
      -1101
 WATER-B  : MODERATOR : <MH2O>   :  9999 -301 -302 -8001  8002
      -1201 -1202 -1203 -1204 -1205 -1206
 WATER-C  : MODERATOR : <MH2O>   :  9999 -301 -302 -8002  8003
      -1301 -1302 -1303 -1304 -1305 -1306 -1307 -1308 -1309 -1310
      -1311 -1312
 WATER-D  : MODERATOR : <MH2O>   :  9999 -301 -302 -8003  8004
      -1401 -1402 -1403 -1404 -1405 -1406 -1407 -1408 -1409 -1410
      -1411 -1412 -1413 -1414 -1415 -1416 -1417 -1418
 WATER-E  : MODERATOR : <MH2O>   :  9999 -301 -302 -8004  8005
      -1501 -1502 -1503 -1504 -1505 -1506 -1507 -1508 -1509 -1510
      -1511 -1512 -1513 -1514 -1515 -1516 -1517 -1518 -1519 -1520
      -1521 -1522 -1523 -1524
 WATER-F  : MODERATOR : <MH2O>   :  9999 -301 -302 -8005  200
      -1601 -1602 -1603 -1604 -1605 -1606 -1607 -1608 -1609 -1610
      -1611 -1612 -1613 -1614 -1615 -1616 -1617 -1618 -1619 -1620
      -1621 -1622 -1623 -1624 -1625 -1626 -1627 -1628 -1629 -1630
*
*
 TGRID-A  : TGRID     : <MAL>    :  301  8001
      -1101
 TGRID-B  : TGRID     : <MAL>    :  301 -8001  8002
      -1201 -1202 -1203 -1204 -1205 -1206
 TGRID-C  : TGRID     : <MAL>    :  301 -8002  8003
      -1301 -1302 -1303 -1304 -1305 -1306 -1307 -1308 -1309 -1310
      -1311 -1312
 TGRID-D  : TGRID     : <MAL>    :  301 -8003  8004
      -1401 -1402 -1403 -1404 -1405 -1406 -1407 -1408 -1409 -1410
      -1411 -1412 -1413 -1414 -1415 -1416 -1417 -1418
 TGRID-E  : TGRID     : <MAL>    :  301 -8004  8005
      -1501 -1502 -1503 -1504 -1505 -1506 -1507 -1508 -1509 -1510
      -1511 -1512 -1513 -1514 -1515 -1516 -1517 -1518 -1519 -1520
      -1521 -1522 -1523 -1524
 TGRID-F  : TGRID     : <MAL>    :  301 -8005
      -1601 -1602 -1603 -1604 -1605 -1606 -1607 -1608 -1609 -1610
      -1611 -1612 -1613 -1614 -1615 -1616 -1617 -1618 -1619 -1620
      -1621 -1622 -1623 -1624 -1625 -1626 -1627 -1628 -1629 -1630
*
*
 BGRID-A  : BGRID     : <MAL>   :   302  8001
      -1101
 BGRID-B  : BGRID     : <MAL>   :   302 -8001  8002
      -1201 -1206 -1205 -1204 -1203 -1202
 BGRID-C  : BGRID     : <MAL>   :   302 -8002  8003
      -1301 -1302 -1303 -1304 -1305 -1306 -1307 -1308 -1309 -1310
      -1311 -1312
 BGRID-D  : BGRID     : <MAL>   :   302 -8003  8004
      -1401 -1402 -1403 -1404 -1405 -1406 -1407 -1408 -1409 -1410
      -1411 -1412 -1413 -1414 -1415 -1416 -1417 -1418
 BGRID-E  : BGRID     : <MAL>   :   302 -8004  8005
```

```
      -1501 -1502 -1503 -1504 -1505 -1506 -1507 -1508 -1509 -1510
      -1511 -1512 -1513 -1514 -1515 -1516 -1517 -1518 -1519 -1520
      -1521 -1522 -1523 -1524
 BGRID-F  : BGRID     : <MAL>   :    302 -8005
      -1601 -1602 -1603 -1604 -1605 -1606 -1607 -1608 -1609 -1610
      -1611 -1612 -1613 -1614 -1615 -1616 -1617 -1618 -1619 -1620
      -1621 -1622 -1623 -1624 -1625 -1626 -1627 -1628 -1629 -1630
*
*
 GREF01   : GRCLAD    : <MAL>   : -200  201  202
 GREF02   : GRCLAD    : <MAL>   : -201       202 -203
 GREF03   : GREF      : <MGD>   : -201       203 -211
 GREF04   : GREF      : <MGD>   : -201  212  203  211
 GREF05   : AGROOVE   : <MAIR>  :      -212  203  211
************** PIN CELL ********************
*RING-A
  A0101   : RODA01    : -100    : 1101
*RING-B
  B0101   : RODB01    : -100    : 1201
  B0201   : RODB02    : -100    : 1202
  B0301   : RODB03    : -100    : 1203
  B0401   : RODB04    : -100    : 1204
  B0501   : RODB05    : -100    : 1205
  B0601   : RODB06    : -100    : 1206
*RING-C
  C0101   : RODC01    : -100    : 1301
  C0201   : RODC02    : -100    : 1302
  C0301   : RODC03    : -100    : 1303
  C0401   : RODC04    : -300    : 1304 /* transient
  C0501   : RODC05    : -100    : 1305
  C0601   : RODC06    : -100    : 1306
  C0701   : RODC07    : -100    : 1307
  C0801   : RODC08    : -100    : 1308
  C0901   : RODC09    : -100    : 1309
  C1001   : RODC10    : -200    : 1310 /* control
  C1101   : RODC11    : -100    : 1311
  C1201   : RODC12    : -100    : 1312
*RING-D
  D0101   : RODD01    : -200    : 1401 /* control
  D0201   : RODD02    : -100    : 1402
  D0301   : RODD03    : -100    : 1403
  D0401   : RODD04    : -100    : 1404
  D0501   : RODD05    : -100    : 1405
  D0601   : RODD06    : -100    : 1406
  D0701   : RODD07    : -100    : 1407
  D0801   : RODD08    : -100    : 1408
  D0901   : RODD09    : -100    : 1409
  D1001   : RODD10    : -200    : 1410 /* control
  D1101   : RODD11    : -100    : 1411
  D1201   : RODD12    : -100    : 1412
  D1301   : RODD13    : -100    : 1413
  D1401   : RODD14    : -100    : 1414
  D1501   : RODD15    : -100    : 1415
  D1601   : RODD16    : -100    : 1416
  D1701   : RODD17    : -100    : 1417
```

```
  D1801   : RODD18   : -100    : 1418
*RING-E
  E0101   : RODE01   : -400    : 1501
  E0201   : RODE02   : -400    : 1502
  E0301   : RODE03   : -400    : 1503
  E0401   : RODE04   : -100    : 1504
  E0501   : RODE05   : -100    : 1505
  E0601   : RODE06   : -100    : 1506
  E0701   : RODE07   : -100    : 1507
  E0801   : RODE08   : -100    : 1508
  E0901   : RODE09   : -100    : 1509
  E1001   : RODE10   : -100    : 1510
  E1101   : RODE11   : -400    : 1511
  E1201   : RODE12   : -400    : 1512
  E1301   : RODE13   : -400    : 1513
  E1401   : RODE14   : -400    : 1514
  E1501   : RODE15   : -400    : 1515
  E1601   : RODE16   : -400    : 1516
  E1701   : RODE17   : -400    : 1517
  E1801   : RODE18   : -400    : 1518
  E1901   : RODE19   : -400    : 1519
  E2001   : RODE20   : -400    : 1520
  E2101   : RODE21   : -400    : 1521
  E2201   : RODE22   : -400    : 1522
  E2301   : RODE23   : -400    : 1523
  E2401   : RODE24   : -400    : 1524
*
*RING-F HOLE
  F0101   : RODF01   : -400    : 1601
  F0201   : RODF02   : -400    : 1602
  F0301   : RODF03   : -400    : 1603
  F0401   : RODF04   : -400    : 1604
  F0501   : RODF05   : -400    : 1605
  F0601   : RODF06   : -400    : 1606
  F0701   : RODF07   : -400    : 1607
  F0801   : RODF08   : -400    : 1608
  F0901   : RODF09   : -400    : 1609
  F1001   : RODF10   : -400    : 1610
  F1101   : RODF11   : -400    : 1611
  F1201   : RODF12   : -400    : 1612
  F1301   : RODF13   : -400    : 1613
  F1401   : RODF14   : -400    : 1614
  F1501   : RODF15   : -400    : 1615
  F1601   : RODF16   : -400    : 1616
  F1701   : RODF17   : -400    : 1617
  F1801   : RODF18   : -400    : 1618
  F1901   : RODF19   : -400    : 1619
  F2001   : RODF20   : -400    : 1620
  F2101   : RODF21   : -400    : 1621
  F2201   : RODF22   : -400    : 1622
  F2301   : RODF23   : -400    : 1623
  F2401   : RODF24   : -400    : 1624
  F2501   : RODF25   : -400    : 1625
  F2601   : RODF26   : -400    : 1626
  F2701   : RODF27   : -400    : 1627
```

```
 F2801   : RODF28   : -400    : 1628
 F2901   : RODF29   : -400    : 1629
 F3001   : RODF30   : -400    : 1630
*
#CELL ID(100) TYPE(HEXA) /* fuel rod
 C101   :             :   -999 : -10
 C102   : MODERATOR  :  <MH2O> :  10  16
 C103   : MODERATOR  :  <MH2O> :  10 -17
 C104   : SS         : <MSS > :  10 -16  17 -11
 C103   : VOID       :  <MAIR> :  11 -12 -13 -14
 C104   : REFLECTOR  :  <MGD > :  12 -13 -14
 C105   : MO         : <MMO > :  11  14
 C106   : FUEL       :  <MLEU> :  13 -15
 C107   : ZR         : <MZR > :  13  15
#END CELL
#CELL ID(200) TYPE(HEXA) /* control rod
 C201   :             :   -999 : -10
 C202   : MODERATOR  :  <MH2O> :  10 -20
 C203   : MODERATOR  :  <MH2O> :  10  20  40
 C204   : MODERATOR  :  <MH2O> :  10  20 -41
 C205   : SS         : <MSS > :  10  20 -40  41 -21
 C206   : VOID       :  <MAIR> :  21     -39
 C207   : SS         : <MSS > :  21      39 -38
 C208   : VOID       :  <MAIR> :  21      38 -37
 C209   : VOID       :  <MAIR> :  21 -22  37 -36
 C210   : ABSORBER   :  <MB4C> :  22      37 -36
 C211   : SS         : <MSS > :  21      36 -35
 C212   : VOID       :  <MAIR> :  21      35 -34
 C213   : VOID       :  <MAIR> :  21 -22  34 -33
 C214   : FUEL       :  <MFF > :  22 -23  34 -33
 C215   : ZR         : <MZR > :  23      34 -33
 C216   : SS         : <MSS > :  21      33 -32
 C217   : VOID       :  <MAIR> :  21      32
#END CELL
#CELL ID(300) TYPE(HEXA) /* control rod
 C301   :             :   -999 : -10
 C302   : MODERATOR  :  <MH2O> :  10  55
 C303   : MODERATOR  :  <MH2O> :  10 -56
 C304   : ALUMINUM   :  <MAL > :  10 -55  56 -51 -52 -53
 C305   : VOID       :  <MAIR> :  51
 C306   : VOID       :  <MAIR> :  52 -54
 C307   : ABSORBER   :  <MB4C> :  52  54
 C308   : VOID       :  <MAIR> :  53
#END CELL
#CELL ID(400) TYPE(HEXA) /* water
 C401   :             :   -999 : -10
 C402   : MODERATOR  :  <MH2O> :  10
#END CELL
************* TALLY REGION DATA *********************************
#TALLY REGION
DEFINE @ALL( !* )
$END GEOM
************* Initial Source ( for zero-step )
$SOURCE
*#SOURCE-START
```

```
& NEUTRON
  RATIO( 1.0 )
  @E = #FISSION ( U0235* 0.0253 ) ;
  @(X Y) = #DISC( 0.0 <RRINGE> ) ;
  @Z = #COSINE( <ZFR00> <HFR+ZFR00> ) ;
*#SOURCE-END
$END SOURCE
*
***** energy bin structure *****
   ENGYB( <%ETOP> <%EBOT> )
************* VARIANCE REDUCTION PARAMETERS ************************
%  NR = %NREG, NRG=NR*NG
   WKIL( <NRG>(0.25) )
   WSRV( <NRG>(0.50) )
***** tally region volume *****
   TRVOL(<%NTREG>(1.0)) /* default
************* FISSION NEUTRON GENERATION ****************************
   WGTF( <NR>(1.00) )
*****************************************************************
/
```

国際単位系（SI）と換算表

表1　SI基本単位および補助単位

量	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表2　SIと併用される単位

名称	記号
分，時，日	min, h, d
度，分，秒	°, ′, ″
リットル	l, L
トン	t
電子ボルト	eV
原子質量単位	u

1 eV=1.60218×10^{-19}J
1 u=1.66054×10^{-27}kg

表3　固有の名称をもつSI組立単位

量	名称	記号	他のSI単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	$m\cdot kg/s^2$
圧力，応力	パスカル	Pa	N/m^2
エネルギー,仕事,熱量	ジュール	J	N·m
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	A·s
電位，電圧，起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	V·s
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	cd·sr
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量等量	シーベルト	Sv	J/kg

表4　SIと共に暫定的に維持される単位

名称	記号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

1 Å=0.1nm=10^{-10}m
1 b=100fm²=$10^{-28}m^2$
1 bar=0.1MPa=10^5Pa
1 Gal=1cm/s²=$10^{-2}m/s^2$
1 Ci=3.7×10^{10}Bq
1 R=2.58×10^{-4}C/kg
1 rad=1cGy=10^{-2}Gy
1 rem=1cSv=10^{-2}Sv

表5　SI接頭語

倍数	接頭語	記号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

（注）

1．表1－5は「国際単位系」第5版，国際度量衡局1985年刊行による。ただし，1 eVおよび1 uの値はCODATAの1986年推奨値によった。
2．表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。
3．bar は，JISでは流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。
4．EC閣僚理事会指令では bar，barnおよび「血圧の単位」mmHgを表2のカテゴリーに入れている。

換　　算　　表

力	N(=10^5dyn)	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘　度　1 Pa·s(N·s/m²)=10 P(ポアズ)(g/(cm·s))
動粘度　1m²/s=10^4St(ストークス)(cm²/s)

圧力	MPa(=10bar)	kgf/cm²	atm	mmHg(Torr)	lbf/in²(psi)
	1	10.1972	9.86923	7.50062×10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
	6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量	J(=10^7 erg)	kgf·m	kW·h	cal(計量法)	Btu	ft·lbf	eV
	1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
	9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
	3.6×10^6	3.67098×10^5	1	8.59999×10^5	3412.13	2.65522×10^6	2.24694×10^{25}
	4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
	1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
	1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
	1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal= 4.18605J（計量法）
　= 4.184J（熱化学）
　= 4.1855J（15℃）
　= 4.1868J（国際蒸気表）

仕事率　1 PS(仏馬力)
　= 75 kgf·m/s
　= 735.499W

放射能	Bq	Ci
	1	2.70270×10^{-11}
	3.7×10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58×10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

（86年12月26日現在）

Analysis of the TRIGA Mark-II Benchmark IEU-COMP-THERM-003 with Monte Carlo Code MVP