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OECD/NEA Committee on Reactor Physics (NEACRP)

3-D NEUTRON TRANSPORT BENCHMARKS

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Abstract

A set of 3-D neutron transport benchmark problems proposed by the Osaka University to NEACRP in 1988 has been calculated by many participants and the corresponding results are summarized in this report. The results of k_{eff}, control rod worth and region-averaged fluxes for the four proposed core models, calculated by using various 3-D transport codes are compared and discussed. The calculational methods used were: Monte Carlo, Discrete Ordinates (Sn), Spherical Harmonics (Pn), Nodal Transport and others. The solutions of the four core models are quite useful as benchmarks for checking the validity of 3-D neutron transport codes.

CONTENTS

List of Contributions

participant	institute		model 1	2	3	4
Ait Abderrahim,A.	SCK/CEN	BELGIUM	*	*	*	
Alcouffe,R.E.	LANL	U.S.A.	*	*	*	
Bryzgalov,V.I.	Kurchatov	U.S.S.R.	*	*		*
Buckel,G.	KFK	GERMANY	*	*	*	
Collins,P.J.	ANL	U.S.A.		*	*	
Fletcher,J.K.	AEA Technology	ENGLAND	*	*	*	*
Kaise,Y.	MAPI	JAPAN	*	*		
Kobayashi,K.	Kyoto Univ.	JAPAN	*			
Lee,S.M.	Indira Gandhi	INDIA	*	*	*	
Landeyro,P.A.	ENEA	ITALY	*	*	*	
Mironovich,Y.N.	FEI	U.S.S.R.				*
Nakagawa,M.	JAERI	JAPAN	*	*	*	*
Palmiotti,G.	CEA	FRANCE	*	*	*	*
Rief,H.	CEC-JRC Ispra	ITALY	*	*	*	
Roy,R.	EP Montreal	CANADA	*	*	*	
Schaefer,R.W.	ANL	U.S.A.		*	*	
Seifert,E.	ZFK	GERMANY	*	*		*
Takeda,T.	Osaka Univ.	JAPAN	*	*	*	*
Wagner,M.R.	Siemens	GERMANY				*
Wehmann,U.	INTERATOM	GERMANY		*	*	*
Yamamoto,T.	PNC JAPAN	JAPAN		*	*	
Yaroslavzeva,L.N	Kurchatov	U.S.S.R.	*	*	*	*

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1. Introduction

This is the final report on the results of the "3–D Neutron Transport Benchmark Problems" proposed from Osaka University to NEACRP in 1988[1]. The purpose of this benchmark proposal was to compare the results of each participant to investigate the accuracy of individual methods, and to set up 3–D neutron transport benchmarks to be used in the future to check the validity of 3–D neutron transport codes.

In this benchmark problem, four models were proposed and twenty two members (twenty organizations) participated.

To discuss the results a working group meeting was held on October 22 and 23, 1990 in Saclay with the sponsorship of OECD–NEA.

At the meeting the method of summarizing the results was discussed and determined in addition to the comparison of the individual calculational results.

It was decided to obtain mean values and standard deviations of k_{eff}, control rod worth, and region–averaged group fluxes for each calculation method; mean values are taken separately for the results obtained in the Sn, Monte–Carlo method, etc. Further, there was a unified opinion about the averaging for the Monte–Carlo method: the inverse of variance should be used as a weight to obtain the mean value.

Also through comparison some errors in calculational results were found, and it was recommended to include the updated results in this final report.

Four calculational benchmark models are illustrated in Chap. 2. In Chap. 3 the convergence criterion and the flux normalization are described.

In Chap. 4 the methods utilized by individual participants are described.

The mean values and standard deviations of k_{eff}, control rod worth and region–averaged group fluxes are shown in Chap. 5.

For the mean value we used the latest contribution from each participant. When a result deviated greatly from other results we excluded it from averaging.

2. Calculational Benchmark Models

The full problem specification of the proposed benchmark cores was described in the NEACRP report A–953 Rev. 1[1], and it is included in Appendix 1 of this report. The simple explanation of the proposed cores is described below.

2. 1. Model 1 (Small LWR)

This core is a model of the Kyoto University Critical Assembly (KUCA). The core

The core calculation is performed in 2 groups. The 2–group cross section set and energy group structure are listed in Appendix 4.

2. 3. Model 3 (Axially heterogeneous FBR)

This core has an internal blanket region as shown in Fig. 3 (1/8 geometry). In this model, 5cm x 5cm x 5cm mesh interval in the 1/8 core model is the reference mesh size. The 4–group cross sections and energy group structure which are used for calculations are given in Appendix 4.

We consider the following three cases :

case 1 : the control rods are inserted

case 2 : the control rods are withdrawn

case 3 : the control rods are replaced with core and/or blanket cells

2. 4. Model 4 (Small FBR with Hexagonal–Z geometry)

This core model is proposed by I. Broeders and E. Kiefhaber of KFK, Germany, and is a model of the KNK–II core(2). This model has a Hexagonal–Z geometry as shown in Fig. 4.

Energy group structure and cross sections in four groups are listed in Appendix 5.

The control rod patterns are considered as follows:

case 1 : the control rods are withdrawn

case 2 : the control rods are half–inserted

case 3 : the control rods are fully–inserted

3. Convergence and Averaging

3. 1. Convergence criteria and flux normalization

The suggested convergence criteria were

$$\Delta\Phi / \Phi < 5 \times 10^{-4}$$

$$\Delta k_{eff} / k_{eff} < 5 \times 10^{-5}.$$

Some participants used smaller values.

The normalization of fluxes is

$$\sum_g \int_V dr \ \nu \Sigma_{fg}(r) \, \Phi_g(r) = 1$$

3. 2 Mean values

The average method used for Monte–Carlo results are as below.

$$x = \sum_i \frac{x_i}{\sigma_i^2} \Big/ \sum_i \frac{1}{\sigma_i^2},$$

$$\frac{1}{\sigma^2} = \sum_i \frac{1}{\sigma_i^2},$$

where x = mean value

x_i = individual Monte–Carlo results

σ_i^2 = variance of individual result x_i

σ^2 = variance of the mean.

The averages of all Monte–Carlo results are calculated. However, to obtain reference solutions the averages of Monte–Carlo results excluding results calculated with perturbation Monte–Carlo codes, and results which are obviously different from the reference solutions are calculated.

The conventional mean values and standard deviations are used for the other methods since they do not have uncertainly estimates.

4. Method Description

We describe the methods used by participants briefly.

VIM code(3)

The Monte–Carlo code "VIM" calculations are one of the codes used at ANL (Schaefer and Fanning) for the benchmark calculation. Usually, the VIM calculatios are performed with continuous energy, and it uses ENDF/B cross section data. However, it was modified to use the given set of multigroup cross sections. No variance reduction techniques were used. A batch

KENO-IV code[6]

Landeyro estimated Models 1, 2 and 3 with the Monte-Carlo code "KENO-IV". All calculations were performed with 480 batches of 1,000 neutrons.

GMVP code[7]

The Monte-Carlo code "GMVP" was used by Nakagawa for all the benchmark problems. Number of histories for Model 1 is 2 million, and 1 million for Models 2, 3 and 4.

MOCA code[8]

Wehmann estimated Models 2, 3 and 4 with the Monte-Carlo code "MOCA". Each case was calculated by the history of 150 neutrons during 12,000 generations, thus by 1.8 million histories.

OMEGA code[9]

Seifert used the perturbation Monte-Carlo code "OMEGA" and calculated Models 1, 2 and 4. Number of histories is 200,000 for Model 1, and 150,000 for Model 2 and 4.

TRITAC code[10]

The TRITAC which uses the discrete ordinates method was developed at Osaka University. This code is based on the three-dimensional diffusion synthetic acceleration method.

Buckel, Lee, Yamamoto, and Takeda used the TRITAC code for this benchmark problem.

Takeda calculated with reference mesh intervals and half mesh intervals for Models 1 and 2, and calculated with the order S_4 and S_8 for all models.

Yamamoto calculated Models 2 and 3 with S_4 and S_8 discrete ordinates.

Buckel calculated Models 1, 2 and 3 with S_4, S_8 and S_{16} discrete ordinates.

Lee calculated Models 1, 2 and 3 with S_4 and S_8 discrete ordinates.

THREEDANT code[11]

THREEDANT is the three–dimensional neutron transport calculation code using the discrete ordinates method and based on the ONEDANT–TWODANT system. In this code the three–dimensional DSA method is adopted for the acceleration, further the DSA equation is accelerated by Chebychev technique and is inverted using a three–dimensional multigrid technique.

Alcouffe used this code for the benchmark calculation, and he calculated with reference mesh intervals for S_4, S_8, S_{12} and S_{16} solutions and with half mesh intervals for S_8 solution.

JAR–SN code[12]

This code is for solving multigroup two– or three–dimensional transport equation with rectangular or hexagonal space meshes. The calculations are carried out for a whole reactor and symmetry angle 60° (for hexagonal geometry).

Yaloslavzeva used this code and calculated S_2, S_4 and S_8 solutions with reference mesh intervals.

ENSEMBLE–K code[13]

This Sn code was used by Kaise to calculated Models 1 and 2. S_4 solutions were given for each case.

MARK–PN code[14]

Fletcher calculated the benchmark problem with the MARK–PN code which employs an expansion of the flux in spherical harmonics. Eigenvalues are quoted for P_1 to P_7 and other results are taken from the P_7 case.

Fletcher also calculated with half mesh intervals and estimated the zero mesh k_{eff} by extrapolation. He calculated Model 4 with the triangular–Z geometry.

PLXYZ code[15]

Kobayashi calculated Model 1 with the PLXYZ code, and he gave P_1, P_3 and P_5 results. Further, he estimated the $P_{infinity}$ eigenvalue by extrapolation. He calculated with a fine mesh (30cmx30cmx30cm).

DIF3D code[16]

Collins (ANL) used the nodal transport theory (NTT) and nodal diffusion theory (NDT) method, as implemented in the DIF3D code, to calculate Models 2 and 3.

The polynomial approximation to the flux direction of solution was quaratic for NTT and cubic for NDT. The quadratic polynomial approximation to the transverse leakage was made

Coarse mesh rebalancing with asymptotic source extrapolation was used to accelerate the outer

Combination method (CCRR code)[18]

Palmiotti used the CCRR code, which is a the combination method of 3–D diffusion and 2–D transport.

The 3–D transport effect is estimated by R–Z transport calculation, R–Z diffusion calculation and 3–D diffusion calculation by

$$K_{3D}^{TR} = K_{RZ}^{TR} \times \frac{K_{3D}^{DIF}}{K_{RZ}^{DIF}}$$

The diffusion values are extrapolated to zero mesh.

Synthesis method (DOT3.5 code)[19]

Synthesis method and DOT3.5 code are used by Ait Abderrahim.

Synthesis method is a combination of 2–D transport theory and 1–D transport theory, and a 3–D synthesized flux Φ(x,y,z) is obtained by weighting the plane flux map Φ(x,y) by axial function f(z):

$$\Phi(x,y,z) = \Phi(x,y) \times f(z)$$

This f(z) is derived by using 2–D transport (r,z), (x,z) or (y,z) calculations and 1–D transport (r), (x) or (y) calculations.

$$f(z) = \left[\begin{array}{c} \dfrac{\Phi(r,z)}{\Phi(r)} \\ \dfrac{\Phi(x,z)}{\Phi(x)} \\ \dfrac{\Phi(y,z)}{\Phi(y)} \end{array} \right.$$

depending on the model considered.

CMEZ code[20]

Mironovich used this code to calculate Model 4. This code uses the combination method of 3–D diffusion and 2–D (R–Z and triangular) and 1–D (cylinder) transport correction, which is indicated as follows:

$$K_{3D}^{TR} = K_{3D}^{DIF} + (K_{RZ}^{TR} - K_{RZ}^{DIF}) + (K_{TRI}^{TR} - K_{TRI}^{DIF}) + (K_{R}^{TR} - K_{R}^{DIF})$$

3–D collision probability transport code "DRAGON"[21]

Roy used this code to calculate the benchmark problems, and this code can treat, in addition to purely Cartesian geometries, mixed cylindrical–Cartesian region, for example, a finite cylinder inserted inside a cube.

Extrapolated values in Pn and Sn method

In Pn and Sn methods, zero mesh k_{eff} is obtained by the following extrapolation.

$$\Delta k = k(\text{zero mesh interval}) - k(Nx,Ny,Nz)$$
$$= A / Nx^2 + B / Ny^2 + C / Nz^2$$

where Nx, Ny and Nz are number of the mesh on each axis.

Also $S_{infinity}$ values are estimated by

$$\Delta k = k(S_{infinity}) - k(Sn)$$
$$= D / n \cong E / N^2$$

where N is the number of discrete ordinates directions.

5. Benchmark results

Mean values and standard deviations of k_{eff} and control rod worth are listed in Tables 4 to 7 for each method and for each model. The same results are shown in Figs. 5 to 19.

All results of k_{eff} and control rod worth contributed from all participants are listed in Tables 8 to 23.

Average values of region–averaged group fluxes are listed in Tables 24 to 33.

The region–averaged fluxes from all participants are listed in Tables 34 to 73.

Fig. 20 shows the spatial mesh effect on k_{eff} for rod–in and rod–out cases of Model 1.

5. 1. Model 1: Small LWR Core

Table 4 lists the mean values and standard deviations of k_{eff} and control rod worth, and Tables 24 and 25 gives the region–averaged fluxes. In the Monte–Carlo method the standard deviation of k_{eff} is ~0.0005Δk, and the relative standard deviation of control rod worth is about 4%. The standard deviations of the region–averaged fluxes are very small.

In the case of the Sn method, k_{eff} and the control rod worth scatter very little compared with those in the Monte–Carlo method. It should be mentioned, however, that the angular quadrature effect and the spatial mesh effect are relatively large. k_{eff} by S_4 calculation differs from that by S_8 calculation by 0.0006Δk in the rod–out case and 0.0002Δk in the rod–in case. In the rod–out case, a void region is present at the control rod position, and this makes the angular quadrature effect significant. The spatial mesh effect on k_{eff} is shown in Fig. 20 as a function of the square inverse of the mesh interval. It is seen that the spatial mesh effect is relatively large in the rod–in case; this is opposite to the angular quadrature effect. The reason for this is that a fine mesh calculation is necessary to treat the flux depression adequately around the control rod. The S_8 results in Table 4 have been corrected for the mesh effect, and are in close agreement with the Monte–Carlo results. The differences in k_{eff} and in the control rod worth are within 1.5σ, where σ is the exact Monte–Carlo standard deviation. Nakagawa used two million histories for each calculation in Model 1, and his Monte–Carlo results are more close to the S_8 results. (see Table 8) The region–averaged fluxes are also close to the Monte–Carlo results, difference being within 1% in all regions and in all energy groups.

In the Pn method, the standard deviations are rather large. Fletcher evaluated the mesh effect by calculating k_{eff} with normal mesh interval of 1.0 cm and with half mesh interval of 0.5 cm, and by extrapolating to the zero mesh interval. His k_{eff} values in the P_7 calculation are 0.9772 for case 1 and 0.9638 for case 2, giving the control rod worth of 1.42×10^{-2}. The spatial mesh effect on k_{eff} is large, i. e., 0.0044Δk in case 1, and 0.0024Δk in case 2. Even after the correction, however, the difference from the Monte–Carlo results remains large, particularly for k_{eff} for the rod–in cases. The standard deviation of region–averaged fluxes shown in Tables 24 and 25 is rather large especially in the thermal group in the reflector regions. The difference of the thermal fluxes from the Monte–Carlo results is large; about 8% in the void region. The same tendency is seen also for the rod–in case.

5. 2. Model 2: Small FBR Core

Table 5 lists the mean values and standard deviations of k_{eff} and control rod worth, and Tables 26 and 27 lists the region–averaged fluxes.

The standard deviation of Monte–Carlo k_{eff} are about half those of Model 1. The small standard deviation is due to the fact that the thermal neutron flux is small compared to that in Model 1 and there is no need to follow neutron histories down to thermal low energy range. For the region–averaged fluxes the standard deviation is very small except for the 4th group flux; the maximum standard deviation of the flux is seen at the sodium filled control rod position region of about 1.5%.

For Sn methods, a good agreement is observed for k_{eff} between the S_4 and S_8 calculations and the angular quadrature effect is smaller than that in Model 1 because of the nearly isotopic angular flux distributions in fast reactors. The spatial mesh effect was investigated by Alcouffe, Yamamoto, and Takeda. The difference between S_8 calculations with 5cm x 5cm x 5cm mesh intervals and 2.5cm x 2.5cm x 2.5cm mesh intervals is rather small, though the difference is a little dependent on the codes utilized. For example, Alcouffe reported the difference is −0.0001, and −0.0002Δk for cases 1 and 2, respectively. The agreement of k_{eff} and control rod worth with the exact Monte–Carlo results is very good. The k_{eff} difference is less than 0.0003Δk. The region–averaged group fluxes also agree well with the Monte–Carlo results.

For the P_7 method the k_{eff} difference from the Monte–Carlo results is ~0.006Δk for both cases, and the control rod worth relative difference is ~3%. These results are the mesh corrected ones. The core flux is about 2% smaller and the blanket flux is 5% larger in the first group.

Collins calculated with the nodal transport method, and the difference of k_{eff} from the Monte–Carlo is about 0.002Δk.

5. 3. Model 3: Axially Heterogeneous FBR Core

Table 6 lists the mean values and standard deviations of k_{eff} and the control rod worth, and Tables 28, 29 and 30 the region–averaged fluxes. The control rod worth is the change in $1/k_{eff}$ from case 1 to case 2 and the control rod position worth is the change in $1/k_{eff}$ from case 2 to case 3.

For the Monte–Carlo results the standard deviation of k_{eff} is small and close to the results of Model 2. For the region–averaged fluxes, the standard deviation is largest in the 4th energy group but is always less than 1% for the ~~for the~~ Monte–Carlo average.

For the Sn method, the tendencies of the angular quadrature sensitivity in cases 1, 2 and 3 are the same, i. e., the S_4 and S_8 k_{eff} difference is about 0.0006Δk for all cases. The S_8 calculation is in good agreement with the Monte–Carlo calculation for cases 2 and 3; for case 1 the S_4 k_{eff} is even closer to the Monte–Carlo one than the S_8 k_{eff}. But for TRITAC solutions calculated by Buckel, Yamamoto, and Takeda, S_8 average k_{eff} results were 0.9708, 1.0007 and 1.0214 for cases 1, 2, 3 and 3.08E–02 for control rod worth, respectively, and these values are rather close to the Monte–Carlo results. Furthermore, Monte–Carlo averages obtained from Wehmann's and Schaefer's results were 0.9707, 1.0005, 1.0214 and 3.08E–02 for cases 1, 2, 3 k_{eff} and control rod worth, respectively, and these results are in good agreement with the TRITAC solutions descrived above. The fluxes in the core, blanket, and control rod position regions agree with the Monte–Carlo results within 1%. The flux discrepancy in the control rod is between 1%~2%.

For the Pn results, the k_{eff} and control rod worth differences from the Monte–Carlo ones

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are large even in the R calculation; especially the control rod worth is relatively underestimated

For hexagonal–Z geometry, the Sn method can suffer from large spatial truncation errors. In the contrast, the nodal transport method has sufficient spatial accuracy.

6. Conclusions

The four models were calculated by Monte–Carlo method, Sn method, Pn method, nodal transport theory and other methods. The exact Monte–Carlo solutions, which were obtained from Monte–Carlo results excluding the perturbation Monte–Carlo ones and results with large errors, were used as reference solutions.

For XYZ geometry (Models 1, 2 and 3), a good agreement was seen between the calculational results by the Monte–Carlo method and the Sn method for k_{eff}, control rod worth and region–averaged group fluxes. For the Pn method a rather large discrepancy from the Monte–Carlo solutions was seen. For hexagonal–Z geometry (Model 4), the Sn method was not accurate. The Pn and the nodal transport methods produced results which were in good agreement with Monte–Carlo method.

We have established the 3–D neutron transport benchmarks, and this benchmark report will be useful for the development of 3–D neutron transport calculation codes in the future.

Acknowledgement

In summarizing the results we got kind comment from many participants. Furthermore, we asked many participants for a large number of numerical results, and they kindly agreed to send us the results in spite of the laborious work. We want to express our great appreciation for this kind cooperation, and want to note this report is cooperative effort of all participants.

Furthermore, we want to express our appreciation to Dr. Sartori for the kind arrangement of the working group and for the nice suggestion for summarizing this report.

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Table 1 List of participants
Model 1

participant	institute	method
P.A.Landeyro	ENEA	Monte-Carlo
H.Rief	CEC-JRC Ispra	Monte-Carlo
E.Seifert	ZFK	Monte-Carlo
V.I.Bryzgalov	Kurchatov	Monte-Carlo
M.Nakagawa	JAERI	Monte-Carlo
G.Palmiotti	DRP/SPRC-CEN/CADARACHE	Spherical Harmonics & Sn & Synthesis
J.K.Fletcher	AEA Technorogy	Spherical Harmonics
K.Kobayashi	Kyoto Univ.	Spherical Harmonics
R.Alcouffe	LANL	Sn
S.M.Lee	IGCAR Kalpakkam	Sn
L.N.Yaroslavzeva	Kurchatov	Sn
G.Buckel	KFK	Sn
T.Takeda	Osaka Univ.	Sn
H.Ait Abderrahim	SCK/CEN	Synthesis
R.Roy	EP Montreal	Collision probability

Model 2

participant	Institute	method
V.I.Bryzgalov	Kurchatov	Monte-Carlo
H.Rief	CEC-JRC Ispra	Monte-Carlo
P.A.Landeyro	ENEA	Monte-Carlo
U.Wehmann	INTERATOM	Monte-Carlo
E.Seifert	ZFK	Monte-Carlo
R.W.Schaefer	ANL	Monte-Carlo
M.Nakagawa	JAERI	Monte-Carlo
J.K.Fletcher	AEA Technology	Spherical Harmonics
R.Alcouffe	LANL	Sn
G.Buckel	KFK	Sn
L.N.Yaroslavzeva	Kurchatov	Sn
S.M.Lee	IGCAR Kalpakkam	Sn
T.Yamamoto	PNC	Sn
Y.Kaise	MAPI	Sn
T.Takeda	Osaka Univ.	Sn
P.J.Collins	ANL	Nodal Transport
H.Ait Abderrahim	SCK/CEN	Synthesis
G.Palmiotti	DRP/SPRC-CEN/CADARACHE	Synthesis
R.Roy	EP Montreal	Collion probability

Table 1 (contd)
Model 3

participant	Institute	method
H.Rief	CEC-JRC Ispra	Monte-Carlo
P.A.Landeyro	ENEA	Monte-Carlo
U.Wehmann	INTERATOM	Monte-Carlo
R.W.Schaefer	ANL	Monte-Carlo
M.Nakagawa	JAERI	Monte-Carlo
J.K.Fletcher	AEA Technology	Spherical Harmonics
R.Alcouffe	LANL	Sn
L.N.Yaroslavzeva	Kurchatov	Sn
S.M.Lee	IGCAR Kalpakkam	Sn
G.Buckel	KFK	Sn
T.Yamamoto	PNC	Sn
T.Takeda	Osaka Univ.	Sn
P.J.Collins	ANL	Nodal Transport
H.Ait Abderrahim	SCK/CEN	Synthesis
G.Palmiotti	DRP/SPRC-CEN/CADARACHE	Synthesis
R.Roy	EP Montreal	Collision probability

Model 4

participant	Institute	method
V.I.Bryzgalov	Kurchatov	Monte-Carlo
U.Wehmann	INTERATOM	Monte-Carlo
E.Seifert	ZFK	Monte-Carlo
M.Nakagawa	JAERI	Monte-Carlo
J.K.Fletcher	AEA Technology	Spherical Harmonics
G.Palmiotti	DRP/SPRC-CEN/CADARACHE	Spherical Harmonics
L.N.Yaroslavzeva	Kurchatov	Sn
T.Takeda	Osaka Univ.	Sn
M.R.Wagner	Siemens	Nodal Transport
Y.N.Mironovich	FEI	Synthesis

Table 2 List of codes used for the benchmark problems

participant	code	method
H.Ait Abderrahim	DOT3.5	Combination of 2-D transport and 1-D transport
R.E.Alcouffe	THREEDANT	Sn method
G.Buckel	TRITAC	Sn method
V.I.Bryzgalov	MCU	Monte-Carlo method
P.J.Collins	DIF3D	Nodal Transport and Diffusion method
J.K.Fletcher	MARK/PN	Spherical Harmonics method
Y.Kaise	ENSEMBLE-K	Sn method
K.Kobayashi	PLXYZ	Spherical Harmonics method
P.A.Landeyro	KENO IV	Monte-Carlo method
S.M.Lee	TRITAC	Sn method
Y.N.Mironovich	CMEZ	Combination method with extrapolation to zero mesh (CMEZ)
M.Nakagawa	GMVP	Monte-Carlo method
G.Palmiotti	MARK/PN	Spherical Harmonics method
	TRITAC	Sn method
	CCRR	Combination of 3-D diffusion and 2-D transport
H.Rief	KENEUR	Monte-Carlo method
R.Roy	DRAGON	The Collision Probability technique ~~and R-Z) transport calculation~~
R.W.Schaefer	VIM	Monte-Carlo method
E.Seifert	OMEGA	Monte-Carlo method
T.Takeda	TRITAC	Sn method
	HEX-Z1 & 2	Sn calculation with Hexagonal geometory
U.Wehmann	MOCA	Monte-Carlo method
M.R.Wagner	HEXNODE	Nodal method with Hexagonal geometry
T.Yamamoto	TRITAC	Sn method
L.N.Yaroslavzeva	JSP-SN	Sn method

Table 3 List of computer used for the benchmark problems

participant	institute	computer
H.Ait Abderrahim	SCK/CEN	IBM4381 Model Q
R.E.Alcouffe	LANL	CRAY YMP 8128
V.I.Brizgalov	Kurchatov	
G.Buckel	KFK	MVS/SP2.1 with JES3
P.J.Collins	ANL	CRAY XMP14
J.K.Fletcher	AEA Technology	VAX3200, DEC3100, CRAY2
Y.Kaise	MAPI	CRAY YMP2116
K.Kobayashi	Kyoto Univ.	FACOM VP400E
P.A.Landeyro	ENEA	IBM 3090
S.M.Lee	Indira Gandhi	ND 570
Y.N.Mironovich	FEI	ES 1061
M.Nakagawa	JAERI	FACOM VP100
G.Palmiotti	CEA	IBM 9370
H.Rief	CEC/JRC Ispra	PC-based Transputer board T800
R.Roy	EP-Montrael	IBM 3090
R.W.Schaefer	ANL	CRAY XMP14
E.Seifert	ZFK	VAX 11/780
T.Takeda	Osaka Univ.	ACOS 2000
M.R.Wagner	Siemens	CDC 990
U.Wehmann	Interatom	CD CYBER
T.Yamamoto	PNC	FACOM M780 10S
L.N.Yaroslavzeva	Kurchatov	ES 1066

Table 4 Average k_{eff} and control rod worth of Model 1

method	case 1	case 2	CR-worth
Exact Monte-Carlo			
	0.9780	0.9624	1.66E-02
	±0.0006	±0.0006	±0.09E-02
Monte-Carlo	0.9778	0.9624	1.64E-02
	±0.0005	±0.0005	±0.07E-02
Pn	0.9766	0.9630	1.45E-02
	±0.0006	±0.0008	±0.22E-02
S4	0.9766	0.9622	1.54E-02
	±0.0002	±0.0002	±0.01E-02
S8	0.9772	0.9623	1.58E-02
	±0.0001	±0.0001	±0.00E-02
CCRR	0.9759	0.9622	1.46E-02
DOT3.5	0.9836	0.9628	2.23E-02

Table 5 Average k_{eff} and control rod worth of Model 2

method	case 1	case 2	CR-worth
Exact Monte-Carlo			
	0.9732	0.9594	1.47E-02
	±0.0002	±0.0002	±0.03E-02
Monte-Carlo	0.9731	0.9589	1.48E-02
	±0.0002	±0.0002	±0.03E-02
Pn	0.9794	0.9647	1.56E-02
S4	0.9735	0.9594	1.51E-02
	±0.0001	±0.0001	±0.01E-02
S8	0.9734	0.9593	1.52E-02
	±0.0002	±0.0002	±0.01E-02
DIF3D(NTT)	0.9714	0.9572	1.54E-02
CCRR	0.9742	0.9596	1.56E-02

Table 6 Average k_{eff} and control rod worth of Model 3

method	case 1	case 2	case 3	CR-worth	CRP-worth
Exact Monte-Carlo					
	0.9709	1.0005	1.0214	3.05E-02	2.03E-02
	±0.0002	±0.0002	±0.0002	±0.03E-02	±0.00E-02
Monte-Carlo	0.9708	1.0005	1.0214	3.06E-02	2.03E-02
	±0.0002	±0.0002	±0.0002	±0.03E-02	±0.00E-02
Pn	0.9772	1.0040	1.0247	2.74E-02	2.01E-02
S4	0.9710	1.0012	1.0218	3.11E-02	2.02E-02
	±0.0005	±0.0003	±0.0003	±0.04E-02	±0.02E-02
S8	0.9704	1.0006	1.0213	3.11E-02	2.03E-02
	±0.0004	±0.0004	±0.0005	±0.03E-02	±0.02E-02
DIF3D(NTT)	0.9695	0.9996	1.0209	3.10E-02	2.10E-02
CCRR	0.9673	0.9968		3.06E-02	

Table 7 Average k_{eff} and control rod worth of Model 4

method	case 1	case 2	case 3	CR-worth
Exact Monte-Carlo				
	1.0951	0.9833	0.8799	2.23E-01
	±0.0004	±0.0004	±0.0003	±0.01E-01
Monte-Carlo	1.0951	0.9833	0.8799	2.23E-01
	±0.0004	±0.0004	±0.0003	0.01E-01
Pn	1.0942	0.9834	0.8819	2.20E-01
	±0.0015	±0.0055	±0.0100	±0.12E-01
S8	1.0887	0.9875	0.8927	2.02E-01
	±0.0043	±0.0061	±0.0110	±0.10E-01
HEXNOD(NT)	1.0889	0.9783	0.8748	2.25E-01
CMEZ	1.094	0.980	0.881	2.21E-01
	±0.002	±0.004	±0.002	±0.30E-01

Table 8 Individual results of k_{eff} and control rod worth of Model 1 (Monte-Carlo method)

	case 1	case 2	CR-worth
Bryzgalov	0.975	0.961	1.494E-02
	±0.002	±0.002	±0.302E-02
Rief	0.9780	0.9627	1.625E-02
	±0.00080	±0.00084	±0.120E-02
	0.9781	0.9628	1.619E-02
	±0.00080	±0.00084	±0.120E-02
Landeyro	0.97946	0.96253	1.796E-02
	±0.00135	±0.00138	±0.205E-02
Seifert	0.9773	0.9620	1.63E-02
	±0.0022	±0.0022	±0.31E-02
Nakagawa	0.9776	0.9624	1.62E-02
	±0.00069	±0.00071	±0.102E-02

Table 9 Individual results of k_{eff} and control rod worth of Model 1 (Pn method)

	case 1	case 2	CR-worth
Palmiotti			
PN=7	0.97310	0.96131	1.260E-02
Fletcher			
PN=1	0.92831	0.93111	-3.237E-03
PN=3	0.96994	0.96033	1.032E-02
PN=5	0.97224	0.96125	1.175E-02
PN=7	0.97277	0.96137	1.218E-02
PN=7(half mesh)	0.97607	0.96316	1.373E-02
PN=7(zero mesh)	0.97717	0.96375	1.424E-02
Kobayashi			
PN=1	0.9234	0.9298	-7.454E-03
PN=3	0.9713	0.9608	1.125E-02
PN=5	0.9743	0.9617	1.345E-02
PN inf*	0.9760	0.9622	1.469E-02

* Extrapolated value

Table 10 Individual results of k_{eff} and control rod worth of Model 1 (Sn method)

		case 1	case 2	CR-worth
Palmiotti				
S8		0.97711	0.96230	1.575E-02
Buckel				
Diffusion		0.92771	0.93113	-3.949E-02
S4		[illegible]	[illegible]	[illegible]
S8		0.97713	0.96231	1.576E-02
S16		[illegible]	[illegible]	[illegible]
Lee				
S8		0.97729	0.96250	1.572E-02
Alcouffe				
S4		0.97670	0.96236	1.526E-02
S8		0.97714	0.96236	1.572E-02
S12		0.97721	0.96231	1.585E-02
S16		0.97723	0.96228	1.590E-02
S8(half mesh)		0.97719	0.96246	1.566E-02
Yaroslavzeva				
Dif.	(1.0cm)	0.89998	0.91952	-2.36E-02
S2	(5.0cm)	0.97689	0.95755	2.06E-02
	(2.5cm)	0.97825	0.96116	1.82E-02
	(1.0cm)	0.97861	0.96207	1.76E-02
S4	(5.0cm)	0.97227	0.95588	1.76E-02
	(2.5cm)	0.97593	0.96112	1.58E-02
	(1.0cm)	0.97631	0.96198	1.53E-02
S8	(5.0cm)	0.97230	0.95532	1.83E-02
	(2.5cm)	0.97662	0.96138	1.62E-02
	(1.0cm)	0.97711	0.96229	1.58E-02
Kaise				
Dif.		0.92731	0.93039	-3.570E-02
S4		0.9766	0.9619	1.56E-02
Takeda				
S4	(1.0cm)	0.97669	0.96232	1.529E-02
	(0.5cm)	0.97669	0.96224	1.538E-02
S8	(1.0cm)	0.97713	0.96229	1.578E-02
	(0.5cm)	0.97713	0.96238	1.569E-02

Table 11 Individual results of k_{eff} and control rod worth of Model 1 (Other methods)

		case 1	case 2	CR-worth
Ait Abderrahim				
DOT3.5(Synthesis)		0.98365	0.96283	2.229E-02
Palmiotti				
CCRR*		0.97589	0.96221	1.457E-02
CCRR**		0.96328	0.94794	1.680E-02
Roy				
DRAGON	IC1	0.94840	0.92522	2.642E-02
	IC2	1.07864	1.05591	1.995E-02
	IC3	1.13533	1.11519	1.590E-02
	CP1	0.89430	0.87435	2.551E-02
	CP2	1.00645	0.98724	1.934E-02
	LAGR2	0.93220	0.93657	-3.725E-02
	LAGR3	0.92832	0.93259	-4.930E-03
	MCFD2	0.92466	0.92838	-4.343E-03
	MCFD3	0.92864	0.93230	-4.221E-03

* : Combination of 3D diffusion and 2D transport 'BISTRO'
** : Used transport equivalent cross-section
IC1 : The first IC solution ; considered 5x5x5 cm^3 block
IC2 : The first IC solution ; considered 2.5x2.5x2.5 cm^3 block
IC3 : The first IC solution ; considered 1x1x1 cm^3 block
CP1 : no used IC techniqe ; considered 5x5x5 cm^3 block
CP2 : no used IC techniqe ; considered 2.5x2.5x2.5 cm^3 block
LAGR2 : the variational collocation method on diffusion equation with quadratic Lagrange polynomials expansion.
LAGR3 : the variational collocation method on diffusion equation with cubic Lagrange polynomials expansion.

Table 12 Individual results of k_{eff} and control rod worth of Model 2 (Monte-Carlo method)

	case 1	case 2	CR-worth
Wehmann	0.97298 ±0.000315	0.95919 ±0.000326	1.478E-02 ±0.049E-02
Schaefer	0.97344 ±0.000363	0.95988 ±0.000384	1.451E-02 ±0.057E-02
Rief	0.9732 ±0.00047	0.9591	1.511E-02 ±0.063E-02
Landeyro	0.97285 ±0.00079	0.95922 ±0.00077	1.461E-02 ±0.118E-02
Bryzgalov	0.9707 ±0.0012	0.9530 ±0.0007	1.913E-02 ±0.781E-02
Seifert	0.9729 ±0.0015	0.9575 ±0.0016	1.65E-02 ±0.22E-02
Nakagawa	0.9732 ±0.00048	0.9593 ±0.00042	1.49E-02 0.066E-02

Table 13 Individual results of k_{eff} and control rod worth of Model 2 (Pn method)

	case 1	case 2	CR-worth
Fletcher			
PN=1	0.97854	0.96475	1.461E-02
PN=3	0.98297	0.96982	1.372E-02
PN=5	0.98304	0.96991	1.377E-02
PN=7	0.98305	0.96993	1.377E-02
PN=7(half mesh)	0.98021	0.96597	1.504E-02
PN=7(zero mesh)	0.97936	0.96465	1.556E-02

Table 14 Individual results of k_{eff} and control rod worth of Model 2 (Sn method)

	case 1	case 2	CR-worth
Buckel			
Dif.	0.95460	0.93806	1.847E-02
S4	0.97321	0.95923	1.498E-02
S8	0.97341	0.95925	1.516E-02
S16	0.97345	0.95927	1.518E-02
Alcouffe			
S4	0.97348	0.95936	1.511E-02
S8	0.97348	0.95931	1.517E-02
S12	0.97348	0.95930	1.518E-02
S16	0.97348	0.95930	1.519E-02
S8(half mesh)	0.97360	0.95954	1.506E-02
Lee			
S8	0.97311	0.95899	1.513E-02
Yaroslavzeva			
Dif.	0.96494	0.95224	1.38E-02
S2	0.97344	0.95900	1.55E-02
S4	0.97359	0.95939	1.52E-02
S8	0.97347	0.95924	1.52E-02
Yamamoto			
S4	0.97344	0.95927	1.518E-02
S8	0.97345	0.95922	1.524E-02
Kaise			
Dif.	0.97058	0.95742	1.416E-02
S4	0.9736	0.9594	1.520E-02
Takeda			
S4(5.0cm)	0.97361	0.95961	1.498E-02
(2.5cm)	0.97341	0.95934	1.507E-02
S8(5.0cm)	0.97361	0.95956	1.504E-02
(2.5cm)	0.97339	0.95928	1.511E-02

Table 15 Individual results of k_{eff} and control rod worth of Model 2 (Other methods)

	case 1	case 2	CR-worth
Palmiotti			
CCRR*	0.97422	0.95961	1.563E-02
CCRR**	0.96839	0.95394	1.564E-02
Collins			
DIF3D NDT	0.96911	0.95435	1.596E-02
NTT	0.97143	0.95716	1.535E-02
Roy			
DRAGON IC1	0.99451	0.97878	1.616E-02
IC2	0.95558	0.94031	1.699E-02

* : Combination of 3D diffusion and 2D transport
** : Used transport equicvalent cross-section
NDT : Nodal Diffusion Theory
NTT : Nodal Transport Theory
IC1 : The first IC solution; considered 5x5x5 cm^3 blook
IC2 : The first IC solution; considered 2.5x2.5x2.5 cm^3 blook

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Table 16 Individual results of k_{eff} and control rod worth of Model 3 (Monte-Carlo method)

	case 1	case 2	case 3	CR-worth	CRP-worth
Wehmann	0.97059 ±0.000306	1.00063 ±0.000296	1.02131 ±0.000298	3.093E-02 ±0.044E-02	2.024E-02 ±0.00049E-02
Rief	0.96767 ±0.0014	0.99721		3.0612E-02 ±0.0605E-02	
Schaefer	0.97089 ±0.000317	1.00059 ±0.000343	1.02142 ±0.000341	3.057E-02 ±0.048E-02	2.039E-02 ±0.00047E-02
Landeyro	0.97169 ±0.00069	1.00068 ±0.00075	1.02091 ±0.00072	2.9814E-02 ±0.105E-02	1.980E-02 ±0.102E-02
Nakagawa	0.9712 ±0.00054	0.9998 ±0.00065	1.0216 ±0.00058	2.94E-02 ±0.086E-02	2.13E-02 ±0.086E-02

Table 17 Individual results of k_{eff} and control rod worth of Model 3 (Pn method)

	case 1	case 2	case 3	CR-worth	CRP-worth
Fletcher					
PN=1	0.97072	0.99876	1.02036	2.892E-02	2.119E-02
PN=3	0.96844	1.00375	1.02457	3.633E-02	2.024E-02
PN=5	0.97712	1.00399	1.02469	2.739E-02	2.012E-02
PN=7	0.97716	1.00402	1.02470	2.738E-02	2.009E-02
PN=3(half mesh)	0.97298	1.00177	1.02277	2.954E-02	2.049E-02

Table 18 Individual results of k_{eff} and control rod worth of Model 3 (Sn method)

	case 1	case 2	case 3	CR-worth	CRP-worth
Alcouffe					
S4	0.97060	1.00129	1.02184	3.158E-02	2.009E-02
S8	0.96999	1.00080	1.02142	3.174E-02	2.017E-02
S12	0.96991	1.00073	1.02134	3.176E-02	2.017E-02
S16	0.96987	1.00070	1.02133	3.177E-02	2.018E-02
S8(half mesh)	0.97035	1.00091		3.147E-02	
Buckel					
Diff.	0.95267	0.98667	1.00865	3.6169E-02	2.208E-02
S4	0.97147	1.00133	1.02197	3.0703E-02	2.017E-02
S8	0.97084	1.00083	1.02146	3.0857E-02	2.019E-02
S16	0.97076	1.00076	1.02142	3.0886E-02	2.021E-02
Yaroslavzeva					
Dif.	0.96850	0.99643	1.01853	2.89E-02	2.178E-02
S2	0.95817	0.99768	1.01846	4.13E-02	2.045E-02
S4	0.97087	1.00139	1.02192	3.14E-02	2.006E-02
S8	0.97025	1.00067	1.02117	3.13E-02	2.006E-02
Lee					
S4	0.9700	1.0005	1.0212	3.143E-02	2.026E-02
S8	0.9697	0.9996	1.0202	3.085E-02	2.020E-02
Yamamoto					
S4	0.97135	1.00121	1.02183	3.070E-02	2.016E-02
S8	0.97076	1.00071	1.02135	3.083E-02	2.019E-02
Takeda					
S4	0.97142	1.00127	1.02189	3.069E-02	2.015E-02
S8	0.97081	1.00077	1.02140	3.084E-02	2.018E-02

Table 19 Individual results of k_{eff} and control rod worth of Model 3 (Other methods)

	case 1	case 2	case 3	CR-worth	CRP-worth
Collins					
DIF3D NDT	0.96481	0.99569	1.01769	3.214E-02	2.171E-02
NTT	0.96951	0.99955	1.02091	3.100E-02	2.093E-02
Palmiotti					
CCRR*	0.96135	0.99478	1.01697	3.496E-02	2.193E-02
CCRR**	0.96733	0.99684		3.060E-02	
Roy					
DRAGON IC1	0.98547	1.01854	1.03208	3.396E-02	1.288E-02

NDT : Nodal Diffusion Theory
NTT : Nodal Transport Theory
* : Combination of 3D diffusion and 2D transport
** : Used transport equicvalent cross-section
IC1 : The first IC solution; considered 5x5x5 cm^3 blook

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Table 20 Individual results of k_{eff} and control rod worth of Model 4 (Monte-Carlo method)

	case 1	case 2	case 3	CR-worth
Wehmann	1.09515 ±0.000395	0.98340 ±0.000394	0.88001 ±0.000375	2.232E-01 ±0.0059E-01
Bryzgalov	1.096 ±0.002	0.981 ±0.002	0.878 ±0.002	2.265E-01 ±0.031E-01
Seifert	1.0960 ±0.0023	0.9860 ±0.0021	0.8806 ±0.0019	2.232E-01 ±0.030E-01
Nakagawa	1.0947 ±0.00086	0.9825 ±0.0014	0.8794 ±0.00084	2.236E-01 ±0.012E-01

Table 21 Individual results of k_{eff} and control rod worth of Model 4 (Pn method)

	case 1	case 2	case 3	CR-worth
Palmiotti				
PN=1	1.07860	0.97071	0.87217	2.194E-01
PN=3		0.98863		
PN=5	1.09563	0.98889		
PN=7	1.09570	0.98892	0.89203	2.084E-01
Fletcher				
PN=1	1.07860	0.97071	0.87217	2.194E-01
PN=3	1.09558	0.98863	0.89166	2.088E-01
PN=5	1.09563	0.98892	0.89201	2.083E-01
PN=7	1.09570	0.98892	0.89203	2.084E-01
PN=7(half mesh)	1.09347	0.98060	0.87678	2.260E-01
PN=7(zero mesh)	1.09273	0.97782	0.87170	2.320E-01

Table 22 Individual results of k_{eff} and control rod worth of Model 4 (Sn method)

	case 1	case 2	case 3	CR-worth
Yaroslavzeva				
Dif.	1.09588	1.00727	0.93773	1.539E-01
S2	1.10670	0.99785	0.91897	1.846E-01
S4	1.09323	0.99418	0.90415	1.913E-01
S8	1.09303	0.99359	0.90360	1.918E-01
Takeda				
S4*	1.08438	0.98214	0.88132	2.125E-01
S4**	1.08879	0.97198	0.85842	2.465E-01
S8*	1.08436	0.98145	0.88179	2.119E-01

* : calculated by HEX-Z1 code
** : calculated by HEZ-Z2 code

Table 23 Individual results of k_{eff} and control rod worth of Model 4 (Other methods)

	case 1	case 2	case 3	CR-worth
Mironovich				
CMEZ(Synthesis)	1.094	0.980	0.881	2.21E-01
	±0.002	±0.004	±0.002	±0.30E-01
Wagner				
HEXNOD DT 12	1.07715	0.96130	0.85293	2.4405E-01
20	1.07667	0.96082	0.85293	2.4363E-01
NT 12	1.08919	0.97851	0.87465	2.2521E-01
20	1.08890	0.97830	0.87484	2.2470E-01

CMEZ : Combination method code
DT : Diffusion theory
NT : Nodal transport theory, with DP_1 approximation at node interfaces
12 & 20 : Number of axial layer

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Table 24 Region-averaged fluxes of Model 1, case1 (Method-averaged values)

method		core	reflector	void
Exact Monte-Carlo				
	1G	4.7509E-03	5.9251E-04	1.4500E-03
		.10%	.21%	.47%
	2G	8.6998E-04	9.1404E-04	9.7406E-04
		.12%	.23%	.63%
Monte-Carlo	1G	4.7835E-03	5.9722E-04	1.4529E-03
		.06%	.08%	.21%
	2G	8.7841E-04	9.2036E-04	9.7684E-04
		.08%	.11%	.34%
Pn	1G	4.7472E-03	5.9439E-04	1.4096E-03
		1.22%	.92%	.19%
	2G	8.6452E-04	9.2059E-04	9.0113E-04
		1.21%	3.44%	3.62%
Sn	1G	4.7650E-03	5.9361E-04	1.4453E-03
		.03%	.10%	.06%
	2G	8.7162E-04	9.1520E-04	9.6997E-04
		.02%	.24%	.09%
DOT3.5(Synthesis)				
	1G	4.6082E-03	6.2502E-04	1.7341E-03
	2G	8.7682E-04	1.1900E-03	1.3088E-03

Table 25 Region-averaged fluxes of Model 1, case 2 (Method-averaged values)

method		core	reflector	CR
Exact Monte-Carlo				
	1G	4.9125E-03	5.9109E-04	1.2247E-03
		.10%	.21%	.48%
	2G	8.6921E-04	8.7897E-04	2.4604E-04
		.13%	.23%	.72%
Monte-Carlo	1G	4.9006E-03	5.8989E-04	1.2264E-03
		.06%	.08%	.21%
	2G	8.6814E-04	8.8012E-04	2.4615E-04
		.08%	.10%	.35%
Pn	1G	4.8581E-03	5.8854E-04	1.1996E-03
		1.91%	1.82%	.08%
	2G	8.6003E-04	8.8412E-04	2.4257E-04
		2.07%	3.41%	2.99%
Sn	1G	4.8968E-03	5.8980E-04	1.2218E-03
		.03%	.10%	.14%
	2G	8.6751E-04	8.8074E-04	2.4538E-04
		.02%	.31%	.18%
DOT3.5(Synthesis)				
	1G	4.7795E-03	6.2157E-04	1.3707E-03
	2G	8.7145E-04	1.1227E-03	2.9764E-04

Table 26 Region-averaged fluxes of Model 2, case 1 (Method-averaged values)

method		core	radial blanket	axial blanket	CRP
Exact Monte-Carlo					
	1G	4.2814E-05	3.3252E-06	5.1850E-06	2.5344E-05
		.06%	.18%	.27%	.33%
	2G	2.4081E-04	3.0893E-05	4.6912E-05	1.6658E-04
		.05%	.10%	.14%	.18%
	3G	1.6411E-04	3.2834E-05	4.6978E-05	1.2648E-04
		.06%	.10%	.16%	.23%
	4G	6.2247E-06	2.0473E-06	3.7736E-06	6.9840E-06
		.20%	.34%	.46%	.17%
Monte-Carlo	1G	4.2817E-05	3.3249E-06	5.1835E-06	2.5362E-05
		.06%	.17%	.26%	.32%
	2G	2.4083E-04	3.0878E-05	4.6902E-05	1.6678E-04
		.05%	.10%	.13%	.18%
	3G	1.6409E-04	3.2817E-05	4.6959E-05	1.2652E-04
		.06%	.10%	.15%	.22%
	4G	6.2214E-06	2.0487E-06	3.7578E-06	6.9834E-06
		.19%	.33%	.43%	.17%
Pn	1G	4.2370E-05	3.5595E-06	5.4492E-06	2.5130E-05
	2G	2.3926E-04	3.5354E-05	5.3696E-05	1.6795E-04
	3G	1.6679E-04	4.0261E-05	5.7551E-05	1.3187E-04
	4G	6.2855E-06	2.6785E-05	5.0063E-06	7.9182E-06
Sn	1G	4.2815E-05	3.3494E-06	5.2125E-06	2.5559E-05
		.02%	.05%	.08%	.04%
	2G	2.4072E-04	3.1192E-05	4.7407E-05	1.6696E-04
		.05%	.02%	.05%	.01%
	3G	1.6405E-04	3.3091E-05	4.7324E-05	1.2677E-04
		.02%	.10%	.15%	.04%
	4G	6.2113E-06	2.0582E-06	3.7513E-06	6.9202E-06
		.05%	.16%	.21%	.18%
DIF3D(NTT)	1G	4.2766E-05	3.4022E-06	5.2868E-06	2.5584E-05
	2G	2.4059E-04	3.1169E-05	4.7367E-05	1.6646E-04
	3G	1.6406E-04	3.3012E-05	4.7206E-05	1.2653E-04
	4G	6.2147E-06	2.0559E-06	3.7529E-06	6.9475E-06
DOT3.5(Synthesis)					
	1G	4.0369E-05	3.2489E-06	4.9696E-06	2.5241E-05
	2G	2.3970E-04	3.1736E-05	4.7186E-05	1.7317E-04
	3G	1.7128E-04	3.4866E-05	4.8817E-05	1.3650E-04
	4G	6.5905E-06	2.2119E-06	3.8902E-06	7.3544E-06

Table 27 Region-averaged fluxes of Model 2, case 2 (Method-averaged values)

method		core	radial blanket	axial blanket	CRP	CR
Exact Monte-Carlo						
	1G	4.3482E-05	3.3176E-06	5.2209E-06	2.5902E-05	1.6556E-05
		.06%	.18%	.27%	.46%	.54%
	2G	2.4171E-04	3.0438E-05	4.6772E-05	1.6779E-04	9.1050E-05
		.05%	.10%	.14%	.25%	.26%
	3G	1.6200E-04	3.2126E-05	4.6190E-05	1.2551E-04	5.1815E-05
		.06%	.11%	.16%	.31%	.30%
	4G	6.0438E-06	2.0016E-06	3.6287E-06	7.0648E-06	1.1073E-06
		.21%	.34%	.45%	1.79%	1.00%
Monte-Carlo	1G	4.3481E-05	3.3192E-06	5.2210E-06	2.5869E-05	1.6571E-05
		.06%	.17%	.25%	.43%	.51%
	2G	2.4172E-04	3.0440E-05	4.6788E-05	1.6778E-04	9.1096E-05
		.05%	.09%	.13%	.23%	.25%
	3G	1.6201E-04	3.2116E-05	4.6174E-05	1.2536E-04	5.1824E-05
		.06%	.10%	.15%	.29%	.28%
	4G	6.0430E-06	2.0018E-06	3.6247E-06	6.9227E-06	1.1095E-06
		.20%	.32%	.42%	1.47%	.92%
Pn	1G	4.2725E-05	3.5250E-06	5.5024E-06	2.5396E-05	
	2G	2.3884E-04	3.4677E-05	5.2212E-05	1.6799E-05	
	3G	1.6194E-04	3.9126E-05	5.9001E-05	1.2961E-05	
	4G	6.0935E-06	2.5970E-06	4.8751E-06	7.7209E-06	
Sn	1G	4.3464E-05	3.3347E-06	5.2749E-06	2.6013E-05	1.6744E-05
		.02%	.06%	.06%	.14%	.11%
	2G	2.4169E-04	3.0754E-05	4.7341E-05	1.6785E-04	9.2440E-05
		.02%	.02%	.04%	.14%	.15%
	3G	1.6200E-04	3.2343E-05	4.6583E-05	1.2497E-04	5.2449E-05
		.02%	.06%	.10%	.15%	.18%
	4G	6.0328E-06	2.0036E-06	3.6481E-06	6.6805E-06	1.1052E-06
		.04%	.12%	.16%	.14%	1.81%
DIF3D(NTT)	1G	4.3417E-05	3.3879E-06	5.3511E-06	2.5960E-05	1.7191E-05
	2G	2.4158E-04	3.0740E-05	4.7299E-05	1.6676E-04	9.3279E-05
	3G	1.6202E-04	3.2271E-05	4.6468E-05	1.2430E-04	5.2752E-05
	4G	6.0301E-06	2.0007E-06	3.6463E-06	6.6650E-06	1.1395E-06
DOT3.5(Synthesis)						
	1G	4.0586E-05	3.2201E-06	5.0115E-06	2.4621E-05	1.0541E-05
	2G	2.4060E-04	3.1473E-05	4.7463E-05	1.6816E-04	5.2711E-05
	3G	1.7036E-04	3.4478E-05	4.8779E-05	1.3020E-04	2.5986E-05
	4G	6.4812E-06	2.1828E-06	3.8776E-06	6.8899E-06	3.9622E-07

Table 28 Region-averaged fluxes of Model 3, case 1 (Method-averaged values)

method	core	internal blanket	radial blanket	axial blanket	CRP	CR
Exact Monte-Carlo						
1G	2.0334E-05	1.2562E-05	1.5888E-06	2.9405E-06	1.2230E-05	1.2150E-05
	.06%	.35%	.36%	.23%	.20%	.45%
2G	1.1501E-04	1.1237E-04	1.6736E-05	3.0115E-05	8.6309E-05	6.7771E-05
	.04%	.20%	.22%	.12%	.11%	.22%
3G	8.2784E-05	1.1931E-04	2.1521E-05	3.5408E-05	7.5128E-05	3.9699E-05
	.05%	.22%	.22%	.13%	.12%	.25%
4G	3.4093E-06	7.4318E-06	1.7973E-06	3.7516E-06	5.3074E-06	8.6717E-07
	.19%	.65%	.56%	.32%	.43%	.83%
Monte-Carlo						
1G	2.0334E-05	1.2552E-05	1.5903E-06	2.9405E-06	1.2233E-05	1.2116E-05
	.06%	.34%	.36%	.23%	.20%	.45%
2G	1.1501E-04	1.1232E-04	1.6749E-05	3.0113E-05	8.6332E-05	6.7576E-05
	.04%	.20%	.22%	.12%	.11%	.22%
3G	8.2782E-05	1.1923E-04	2.1532E-05	3.5406E-05	7.5154E-05	3.9637E-05
	.05%	.22%	.22%	.13%	.12%	.25%
4G	3.4093E-06	7.4326E-06	1.7995E-06	3.7519E-06	5.3099E-06	8.6972E-07
	.19%	.63%	.56%	.32%	.43%	.83%
Pn						
1G	2.0391E-05	1.1947E-05	1.5541E-06	2.8687E-06	1.3244E-05	1.2624E-05
2G	1.1513E-04	1.0971E-04	1.6582E-05	3.0770E-05	9.2081E-05	6.8328E-05
3G	8.2809E-05	1.1888E-04	2.1690E-05	3.7543E-05	7.7626E-05	7.9238E-05
4G	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sn						
1G	2.0377E-05	1.2598E-05	1.6067E-06	2.9599E-06	1.2244E-05	1.2347E-05
	.02%	.08%	.04%	.35%	.59%	.08%
2G	1.1495E-04	1.1260E-04	1.6799E-05	3.0253E-05	8.6200E-05	6.8586E-05

Table 29 Region-averaged fluxes of Model 3, case 2 (Method-averaged values)

method	core	internal blanket	radial blanket	axial blanket	CRP
Exact Monte-Carlo					
1G	1.9859E-05	1.2267E-05	1.5266E-06	2.8785E-06	1.2522E-05
	.06%	.32%	.39%	.24%	.19%
2G	1.1439E-04	1.1272E-04	1.6168E-05	2.9877E-05	8.8832E-05
	.04%	.21%	.23%	.13%	.10%
3G	8.4521E-05	1.2240E-04	2.0996E-05	3.5685E-05	7.7412E-05
	.05%	.21%	.22%	.13%	.12%
4G	3.5472E-06	7.7910E-06	1.7728E-06	3.8246E-06	5.3470E-06
	.19%	.64%	.54%	.33%	.42%
Monte-Carlo					
1G	1.9859E-05	1.2267E-05	1.5266E-06	2.8785E-06	1.2522E-05
	.06%	.32%	.39%	.24%	.19%
2G	1.1439E-04	1.1272E-04	1.6168E-05	2.9877E-05	8.8832E-05
	.04%	.21%	.23%	.13%	.10%
3G	8.4521E-05	1.2240E-04	2.0996E-05	3.5685E-05	7.7412E-05
	.05%	.21%	.22%	.13%	.12%
4G	3.5472E-06	7.7910E-06	1.7728E-06	3.8246E-06	5.3470E-06
	.19%	.64%	.54%	.33%	.42%
Pn					
1G	1.9932E-05	1.1774E-05	1.4835E-06	2.8004E-06	
2G	1.1465E-04	1.1041E-04	1.6070E-05	3.0601E-05	
3G	8.4426E-05	1.2213E-04	2.1299E-05	3.7848E-05	
4G	3.5258E-06	7.8906E-06	1.8178E-06	4.2348E-06	
Sn					
1G	1.9868E-05	1.2384E-05	1.5260E-06	2.8798E-06	1.2575E-05
	.05%	.25%	.55%	.31%	.36%
2G	1.1437E-04	1.1321E-04	1.6236E-05	3.0022E-05	8.8972E-05
	.04%	.28%	.58%	.34%	.39%
3G	8.4481E-05	1.2309E-04	2.1114E-05	3.5792E-05	7.7302E-05
	.06%	.39%	.83%	.36%	.50%
4G	3.5423E-06	7.7809E-06	1.7745E-06	3.8238E-06	5.2992E-06
	.09%	.45%	1.11%	.41%	.58%
DIF3D(NTT)					
1G	1.9825E-05	1.2609E-05	1.5534E-06	2.9106E-06	1.2641E-05
2G	1.1430E-04	1.1377E-04	1.6217E-05	3.0111E-05	8.9197E-05
3G	8.4534E-05	1.2346E-04	2.0952E-05	3.5856E-05	7.7653E-05
4G	3.5481E-06	7.8077E-06	1.7495E-06	3.8289E-06	5.3470E-06

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Table 30 Region-averaged fluxes of Model 3, case 3 (Method-averaged values)

method	core	internal blanket	radial blanket	axial blanket
Exact Monte-Carlo				
1G	1.9033E-05	1.1875E-05	1.3718E-06	2.7276E-06
	.06%	.35%	.38%	.24%
2G	1.1026E-04	1.0838E-04	1.4703E-05	2.8409E-05
	.04%	.21%	.22%	.13%
3G	8.0177E-05	1.1672E-04	1.9121E-05	3.3614E-05
	.05%	.22%	.23%	.13%
4G	3.1958E-06	7.0366E-06	1.6164E-06	3.5169E-06
	.19%	.67%	.57%	.33%
Monte-Carlo				
1G	1.9033E-05	1.1875E-05	1.3718E-06	2.7276E-06
	.06%	.35%	.38%	.24%
2G	1.1026E-04	1.0838E-04	1.4703E-05	2.8409E-05
	.04%	.21%	.22%	.13%
3G	8.0177E-05	1.1672E-04	1.9121E-05	3.3614E-05
	.05%	.22%	.23%	.13%
4G	3.1958E-06	7.0366E-06	1.6164E-06	3.5169E-06
	.19%	.67%	.57%	.33%
Pn				
1G	1.9106E-05			2.6435E-06
2G	1.1046E-04			2.8839E-05
3G	8.0112E-04			3.5362E-05
4G	3.1694E-06			3.8573E-06
Sn				
1G	1.9048E-05	1.1920E-05	1.3751E-06	2.7272E-06
	.05%	.28%	.65%	.35%
2G	1.1023E-04	1.0858E-04	1.4805E-05	2.8423E-05
	.04%	.32%	.68%	.39%
3G	8.0153E-05	1.1679E-04	1.9327E-05	3.3655E-05
	.06%	.43%	.99%	.39%
4G	3.1862E-06	7.0488E-06	1.6244E-06	3.5175E-06
	.08%	.49%	1.29%	.42%
DIF3D(NTT)				
1G	1.9007E-05	1.2097E-05	1.3955E-06	2.7486E-06
2G	1.1017E-04	1.0901E-04	1.4753E-05	2.8450E-05
3G	8.0215E-05	1.1713E-04	1.9129E-05	3.3663E-05
4G	3.1913E-06	7.0760E-06	1.5970E-06	3.5173E-06
DOT3.5(Synthesis)				
1G	1.8530E-05	4.5322E-06	2.7072E-06	2.3309E-06
2G	1.0458E-04	4.3552E-05	2.8030E-05	2.3692E-05
3G	7.7395E-05	5.4533E-05	3.6439E-05	2.9089E-05
4G	3.2295E-06	3.8575E-06	3.1295E-06	3.2220E-06

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Table 31 Region-averaged fluxes of Model 4, case 1 (Method-averaged values)

method	test zone	axial blanket	driver with moderator	CRP
Exact Monte-Carlo				
1G	1.3499E-04	3.5243E-05	6.3396E-05	5.2497E-05
	.11%	.24%	.09%	.11%
2G	1.0856E-04	4.9804E-05	4.9993E-05	5.0666E-05
	.14%	.23%	.08%	.12%
3G	3.0770E-05	2.6203E-05	2.8215E-05	2.2637E-05
	.24%	.35%	.10%	.20%
4G	3.8749E-06	1.2749E-05	1.4486E-05	1.0366E-05
	.44%	.32%	.11%	.34%
Monte-Carlo				
1G	1.3499E-04	3.5243E-05	6.3396E-05	5.2497E-05
	.11%	.24%	.09%	.11%
2G	1.0856E-04	4.9804E-05	4.9993E-05	5.0666E-05
	.14%	.23%	.08%	.12%
3G	3.0770E-05	2.6203E-05	2.8215E-05	2.2637E-05
	.24%	.35%	.10%	.20%
4G	3.8749E-06	1.2749E-05	1.4486E-05	1.0366E-05
	.44%	.32%	.11%	.34%
Pn				
1G	1.3246E-04	3.8626E-05	6.3676E-05	5.3900E-05
2G	1.0884E-04	5.3507E-05	4.8661E-05	5.1974E-05
3G	3.1356E-05	2.7845E-05	2.7724E-05	2.3449E-05
4G	3.9845E-06	1.2776E-05	1.4261E-05	1.1151E-05
Sn				
1G	1.3435E-05	3.5410E-05	6.6393E-05	5.4226E-05
2G	1.0791E-04	4.9618E-05	5.1327E-05	5.1474E-05
3G	3.0289E-05	2.5893E-05	2.8424E-05	2.2143E-05
4G	3.2917E-06	1.1649E-05	1.4341E-05	9.2927E-06
HEXNOD(NT)				
1G	1.3317E-04	3.5860E-05	6.5622E-05	5.2673E-05
2G	1.0741E-04	4.9930E-05	5.0333E-05	5.0610E-05
3G	3.0910E-05	2.6255E-05	2.8358E-05	2.2703E-05
4G	3.9903E-06	1.2073E-05	1.4532E-05	1.0527E-05

Table 32 Region-averaged fluxes of Model 4, case 2 (Method-averaged values)

method	test zone	axial blanket	driver with moderator	CRP	CR
Exact Monte-Carlo					
1G	1.4695E-04	3.7122E-05	7.0291E-05	1.1866E-04	4.4354E-05
	.10%	.22%	.08%	.14%	.17%
2G	1.1251E-04	4.8758E-05	5.1347E-05	1.0031E-04	3.5773E-05
	.12%	.21%	.09%	.16%	.18%
3G	2.6560E-05	2.2353E-05	2.7720E-05	3.6997E-05	7.7894E-06
	.24%	.35%	.10%	.27%	.32%
4G	2.4518E-06	8.6671E-06	1.3952E-05	1.1076E-05	4.8143E-07
	.35%	.59%	.12%	.48%	.43%
Monte-Carlo					
1G	1.4695E-04	3.7122E-05	7.0291E-05	1.1866E-04	4.4354E-05
	.10%	.22%	.08%	.14%	.17%
2G	1.1251E-04	4.8758E-05	5.1347E-05	1.0031E-04	3.5773E-05
	.12%	.21%	.09%	.16%	.18%
3G	2.6560E-05	2.2353E-05	2.7720E-05	3.6997E-05	7.7894E-06
	.24%	.35%	.10%	.27%	.32%
4G	2.4518E-06	8.6671E-06	1.3952E-05	1.1076E-05	4.8143E-07
	.35%	.59%	.12%	.48%	.43%
Pn					
1G	1.4619E-04	4.0153E-05	6.9230E-05	1.1947E-04	4.5836E-05
2G	1.1202E-04	5.1692E-05	5.0327E-05	9.9713E-05	3.6277E-05
3G	2.6725E-05	2.3587E-05	2.7600E-05	3.7225E-05	1.2536E-05
4G	2.6008E-06	9.2026E-06	1.3969E-05	1.1472E-05	3.8632E-06
Sn					
1G	1.4946E-04	3.7525E-05	7.1443E-05	1.2547E-04	4.7178E-05
2G	1.1226E-04	4.8811E-05	5.2295E-05	1.0395E-05	3.7692E-05
3G	2.5243E-05	2.2012E-05	2.7650E-05	3.6876E-05	8.1131E-06
4G	2.0788E-06	8.4655E-06	1.3793E-05	9.1418E-06	4.9955E-07
HEXNOD(NT)					
1G	1.4733E-04	3.7583E-05	7.0620E-05	1.1912E-04	4.4890E-05
2G	1.1149E-04	4.8760E-05	5.1532E-05	9.9954E-05	3.5967E-05
3G	2.6463E-05	2.2502E-05	2.7810E-05	3.7343E-05	7.7973E-06
4G	2.5308E-06	8.7327E-06	1.3965E-05	1.1241E-05	6.2915E-07

Table 33 Region-averaged fluxes of Model 4, case 3 (Method-averaged values)

method		test zone	axial blanket	driver with moderator	CR
Exact Monte-Carlo					
	1G	1.4983E-04	4.0660E-05	7.4993E-05	9.5471E-05
		.11%	.24%	.10%	.10%
	2G	1.1677E-04	5.1828E-05	5.1904E-05	6.9316E-05
		.14%	.23%	.10%	.11%
	3G	2.1823E-05	2.3632E-05	2.6958E-05	1.3437E-05
		.29%	.36%	.11%	.21%
	4G	1.1663E-06	9.8501E-06	1.3391E-05	9.5265E-07
		.41%	.43%	.13%	.40%
Monte-Carlo					
	1G	1.4983E-04	4.0660E-05	7.4993E-05	9.5471E-05
		.11%	.24%	.10%	.10%
	2G	1.1677E-04	5.1828E-05	5.1904E-05	6.9316E-05
		.14%	.23%	.10%	.11%
	3G	2.1823E-05	2.3632E-05	2.6958E-05	1.3437E-05
		.29%	.36%	.11%	.21%
	4G	1.1663E-06	9.8501E-06	1.3391E-05	9.5265E-07
		.41%	.43%	.13%	.40%
Pn					
	1G	1.6004E-04	4.3773E-05	7.4091E-05	9.6475E-05
	2G	1.1445E-04	5.5105E-05	5.1229E-05	6.8633E-05
	3G	2.1475E-05	2.4826E-05	2.7126E-05	1.2895E-05
	4G	1.2197E-07	1.0372E-05	1.3616E-05	8.2098E-07
Sn					
	1G	1.6885E-04	4.1747E-05	7.6295E-05	1.0559E-04
	2G	1.1766E-04	5.2949E-05	5.2631E-05	7.5813E-05
	3G	1.9566E-05	2.3442E-05	2.6580E-05	1.4578E-05
	4G	9.8209E-05	9.5603E-06	1.3210E-05	7.8467E-07
HEXNOD(NT)					
	1G	1.6465E-04	4.1097E-05	7.5255E-05	9.6537E-05
	2G	1.1640E-04	5.2117E-05	5.2147E-05	6.9708E-05
	3G	2.1815E-05	2.3668E-05	2.7023E-05	1.3615E-04
	4G	1.1923E-05	9.7162E-06	1.3396E-05	1.0023E-06

Table 34 Individual results of region-averaged fluxes of Model 1, case 1 (Monte-Carlo method)

		core	reflector	void
Rief	1G	4.8010E-03	5.9845E-04	1.4536E-03
		.07%	.09%	.23%
	2G	8.7918E-04	9.2268E-04	9.7804E-04
		.10%	.13%	.41%
Landeyro	1G	4.6924E-03	5.9318E-04	1.4528E-03
		.26%	.42%	1.17%
	2G	8.6762E-04	9.1387E-04	9.5522E-04
		.36%	.52%	1.35%
Bryzgalov	1G	4.7774E-03	5.9795E-04	1.4462E-03
	2G	8.7487E-04	9.1795E-04	9.6410E-04
Seifert	1G	4.763E-03	5.916E-04	
		.25%	.35%	
	2G	8.707E-03	9.177E-04	
		.40%	.50%	
Nakagawa	1G	4.7617E-03	5.9227E-04	1.4495E-03
		.11%	.25%	.51%
	2G	8.7029E-04	9.1408E-04	9.7954E-04
		.13%	.25%	.71%

Table 35 Individual results of region-averaged fluxes of Model 1, case 1 (Pn method)

		core	reflector	void
Palmiotti	1G	4.8277E-03	6.0181E-04	
	2G	8.6979E-04	9.5267E-04	
Kobayashi	1G	4.6949E-03	5.9248E-04	1.4122E-03
	2G	8.7392E-04	8.7744E-04	8.6851E-04
Fletcher	1G	4.7191E-03	5.8890E-04	1.4069E-03
	2G	8.4987E-04	9.3166E-04	9.3375E-04

Table 36 Individual results of region-averaged fluxes of Model 1, case 1 (Sn method)

		core	reflector	void
Alcouffe	1G	4.7652E-03	5.9387E-04	1.4458E-03
	2G	8.7174E-04	9.1554E-04	9.7080E-04
Buckel	1G	4.7643E-03	5.9434E-04	1.4462E-03
	2G	8.7142E-04	9.1637E-04	9.7147E-04
Lee	1G	4.7635E-03	5.9391E-04	1.4447E-03
	2G	8.7180E-04	9.1813E-04	9.6989E-04
Yaroslavzeva	1G	4.7657E-03	5.9356E-04	1.4460E-03
	2G	8.7173E-04	9.1233E-04	9.6951E-04
Takeda	1G	4.7666E-03	5.9265E-04	1.4441E-03
	2G	8.7152E-04	9.1398E-04	9.6902E-04

Table 37 Individual results of region-averaged fluxes of Model 1, case 1 (Other methods)

	core	reflector	void
Ait Abderrahim (Synthesis method)			
1G	4.6082E-03	6.2502E-04	1.7341E-03
2G	8.7682E-04	1.1900E-03	1.3088E-03

Table 38 Individual results of region-averaged fluxes of Model 1, case 2
(Monte Carlo method)

		core	reflector	CR
Rief	1G	4.8956E-03	5.8970E-04	1.2268E-03
		.07%	.09%	.23%
	2G	8.6766E-04	8.8044E-04	2.4618E-04
		.10%	.12%	.40%
Landeyro	1G	5.0450E-03	5.9458E-04	1.2228E-03
		.35%	.48%	1.20%
	2G	8.7717E-04	8.8548E-04	2.4477E-04
		.40%	.54%	1.61%
Bryzgalov	1G	4.9428E-03	5.9313E-04	1.2289E-03
	2G	8.7097E-04	8.8658E-04	2.4350E-04
Seifert	1G	4.898E-03	5.895E-04	
		.24%	.32%	
	2G	8.665E-04	8.798E-04	
		.37%	.47%	
Nakagawa	1G	4.9002E-03	5.9030E-04	1.2251E-03
		.11%	.23%	.52%
	2G	8.6825E-04	8.7749E-04	2.4636E-04
		.14%	.26%	.80%

Table 39 Individual results of region-averaged fluxes of Model 1, case 2
(Pn method)

		core	reflector	CR
Palmiotti	1G	4.9822E-03	6.0216E-04	
	2G	8.7425E-04	9.2214E-04	
Kobayashi	1G	4.8333E-03	5.8741E-04	1.2006E-03
	2G	8.7088E-04	8.4836E-04	2.4984E-04
Fletcher	1G	4.7587E-03	5.7605E-04	1.1987E-03
	2G	8.3494E-04	8.8185E-04	2.3531E-04

Table 40 Individual results of region-averaged fluxes of Model 1, case 2 (Sn method)

		core	reflector	CR
Alcouffe	1G	4.8971E-03	5.9011E-04	1.2217E-03
	2G	8.6761E-04	8.8094E-04	2.4538E-04
Buckel	1G	4.8973E-03	5.9048E-04	1.2247E-03
	2G	8.6726E-04	8.8205E-04	2.4604E-04
[redacted]				
	2G	8.6768E-04	8.8428E-04	2.4546E-04
Yaroslavzeva	1G	4.8963E-03	5.8954E-04	1.2215E-03
	2G	8.6764E-04	8.7705E-04	2.4511E-04
Takeda	1G	4.8986E-03	5.8896E-04	1.2202E-03
	2G	8.6748E-04	8.7958E-04	2.4488E-04

Table 41 Individual results of region-averaged fluxes of Model 1, case 2 (Other methods)

		core	reflector	CR
Ait Abderrahim (Synthesis method)				
	1G	4.7795E-03	6.2157E-04	1.3707E-03
	2G	8.7145E-04	1.1227E-03	2.9764E-04

Table 42 Individual results of region-averaged fluxes of Model 2, case 1 (Monte-Carlo method)

		core	radial blanket	axial blanket	CRP
Wehmann	1G	4.2856E-05	3.3368E-06	5.2104E-06	2.5260E-05
		.10%	.25%	.39%	.44%
	2G	2.4070E-04	3.0916E-05	4.6860E-05	1.6634E-04
		.08%	.14%	.21%	.23%
	3G	1.6396E-04	3.2869E-05	4.7032E-05	1.2634E-04
		.09%	.14%	.22%	.29%
	4G	6.2360E-06	2.0574E-06	3.7802E-06	6.9860E-06
		.27%	.45%	.65%	.17%
Schaefer	1G	4.2782E-05	3.2999E-06	5.1315E-06	2.5485E-05
		.10%	.30%	.50%	.56%
	2G	2.4083E-04	3.0920E-05	4.6919E-05	1.6767E-04
		.08%	.19%	.25%	.34%
	3G	1.6431E-04	3.2820E-05	4.6973E-05	1.2703E-04
		.11%	.19%	.32%	.45%
	4G	6.2192E-06	2.0305E-06	3.7824E-06	6.8697E-06
		.38%	.64%	.90%	1.65%
Rief	1G	4.2879E-05	3.3210E-06	5.1726E-06	2.5647E-05
		.29%	.64%	.74%	1.30%
	2G	2.4127E-04	3.0723E-05	4.6825E-05	1.6975E-04
		.24%	.32%	.39%	.69%
	3G	1.6379E-04	3.2614E-05	4.6763E-05	1.2690E-04
		.29%	.36%	.50%	.81%
	4G	6.1745E-06	2.1054E-06	3.6652E-06	6.8475E-06
		.76%	2.13%	1.15%	2.62%
Landeyro	1G	4.2699E-05	3.0467E-06	5.2269E-06	2.5646E-05
		.43%	2.69%	1.16%	7.59%
	2G	2.4094E-04	2.8905E-05	4.7284E-05	1.6817E-04
		.31%	1.07%	.57%	2.89%
	3G	1.6385E-04	3.0786E-05	4.6955E-05	1.2818E-04
		.32%	.88%	.52%	2.97%
	4G	6.1870E-06	1.9160E-06	3.7539E-06	6.7842E-06
		.84%	2.32%	1.43%	7.89%
Nakagawa	1G	4.2807E-05	3.3539E-06	5.1963E-06	2.5319E-05
		.15%	.44%	.70%	1.28%
	2G	2.4096E-04	3.0898E-05	4.6907E-05	1.6482E-04
		.11%	.22%	.36%	.60%
	3G	1.6420E-04	3.2933E-05	4.6845E-05	1.2587E-04
		.15%	.25%	.37%	.74%
	4G	6.2032E-06	2.0633E-06	3.7464E-06	6.8105E-06
		.59%	.88%	1.28%	2.84%

Table 43 Individual results of region-averaged fluxes of Model 2, case 1 (Pn method)

		core	radial blanket	axial blanket	CRP
Fletcher	1G	4.2370E-05	3.5595E-06	5.4492E-06	2.5130E-05
	2G	2.3926E-04	3.5354E-05	5.3696E-05	1.6795E-04
	3G	1.6679E-04	4.0261E-05	5.7551E-05	1.3187E-04
	4G	6.2855E-06	2.6785E-05	5.0063E-06	7.9182E-06

Table 44 Individual results of region-averaged fluxes of Model 2, case 1 (Sn method)

		core	radial blanket	axial blanket	CRP
Buckel	1G	4.2809E-05	3.3531E-06	5.2136E-06	2.5553E-05
	2G	2.4065E-04	3.1195E-05	4.7403E-05	1.6697E-04
	3G	1.6403E-04	3.3074E-05	4.7289E-05	1.2675E-04
	4G	6.2105E-06	2.0562E-06	3.7468E-06	6.9127E-06
Lee	1G	4.2831E-05	3.3494E-06	5.2123E-06	2.5562E-05
	2G	2.4099E-04	3.1199E-05	4.7412E-05	1.6700E-04
	3G	1.6399E-04	3.3074E-05	4.7292E-05	1.2670E-04
	4G	6.2060E-06	2.0562E-06	3.7470E-06	6.9108E-06
Alcouffe	1G	4.2816E-05	3.3488E-06	5.2092E-06	2.5558E-05
	2G	2.4068E-04	3.1187E-05	4.7387E-05	1.6693E-04
	3G	1.6405E-04	3.3077E-05	4.7294E-05	1.2676E-04
	4G	6.2117E-06	2.0576E-06	3.7484E-06	6.9175E-06
Yaroslavzeva	1G	4.2808E-05	3.3498E-06	5.2206E-06	2.5579E-05
	2G	2.4064E-04	3.1197E-05	4.7459E-05	1.6697E-04
	3G	1.6411E-04	3.3162E-05	4.7480E-05	1.2688E-04
	4G	6.2169E-06	2.0655E-06	3.7685E-06	6.9478E-06
Yamamoto	1G	4.2817E-05	3.3477E-06	5.2093E-06	2.5553E-05
	2G	2.4071E-04	3.1185E-05	4.7387E-05	1.6695E-04
	3G	1.6408E-04	3.3078E-05	4.7295E-05	1.2677E-04
	4G	6.2120E-06	2.0570E-06	3.7485E-06	6.9169E-06
Takeda	1G	4.2812E-05	3.3476E-06	5.2097E-06	2.5551E-05
	2G	2.4067E-04	3.1187E-05	4.7393E-05	1.6694E-04
	3G	1.6404E-04	3.3079E-05	4.7296E-05	1.2674E-04
	4G	6.2107E-06	2.0570E-06	3.7486E-06	6.9157E-06

Table 45 Individual results of region-averaged fluxes of Model 2, case 1 (Other methods)

		core	radial blanket	axial blanket	CRP
Collins (Nodal method)					
NDT	1G	4.2456E-05	3.6576E-06	5.7219E-06	2.7095E-05
	2G	2.4006E-04	3.1971E-05	4.8594E-05	1.6791E-04
	3G	1.6407E-04	3.3490E-05	4.7806E-05	1.2638E-04
	4G	6.2262E-06	2.0755E-06	3.7736E-06	6.7763E-06
NTT	1G	4.2766E-05	3.4022E-06	5.2868E-06	2.5584E-05
	2G	2.4059E-04	3.1169E-05	4.7367E-05	1.6646E-04
	3G	1.6406E-04	3.3012E-05	4.7206E-05	1.2653E-04
	4G	6.2147E-06	2.0559E-06	3.7529E-06	6.9475E-06
Ait Abderrahim (Synthesis method)					
	1G	4.0369E-05	3.2489E-06	4.9696E-06	2.5241E-05
	2G	2.3970E-04	3.1736E-05	4.7186E-05	1.7317E-04
	3G	1.7128E-04	3.4866E-05	4.8817E-05	1.3650E-04
	4G	6.5905E-06	2.2119E-06	3.8902E-06	7.3544E-06

NDT : Nodal Diffusion Theory

NTT : Nodal Transport Theory

Table 46 Individual results of region-averaged fluxes of Model 2, case 2 (Monte-Carlo method)

		core	radial blanket	axial blanket	CRP	CR
Wehmann	1G	4.3516E-05	3.3180E-06	5.2344E-06	2.5823E-05	1.6486E-05
		.10%	.25%	.38%	.61%	.71%
	2G	2.4176E-04	3.0508E-05	4.6836E-05	1.6777E-04	9.0932E-05
		.08%	.14%	.21%	.33%	.36%
	3G	1.6187E-04	3.2239E-05	4.6184E-05	1.2561E-04	5.1472E-05
		.09%	.15%	.23%	.41%	.40%
	4G	6.0436E-06	2.0196E-06	3.6257E-06	6.8304E-04	1.0974E-06
		.28%	.46%	.66%	1.61%	1.36%
Schaefer	1G	4.3470E-05	3.3179E-06	5.1985E-06	2.5884E-05	1.6539E-05
		.10%	.33%	.48%	.84%	1.01%
	2G	2.4180E-04	3.0365E-05	4.6788E-05	1.6738E-04	9.1032E-05
		.09%	.18%	.25%	.47%	.47%
	3G	1.6207E-04	3.2070E-05	4.6102E-05	1.2578E-04	5.2142E-05
		.13%	.20%	.30%	.61%	.56%
	4G	6.0304E-06	1.9749E-06	3.6703E-06	6.9712E-06	1.1092E-06
		.41%	.66%	.84%	2.29%	1.85%
Rief	1G	4.3478E-05	3.3333E-06	5.2216E-06	2.5649E-05	1.6703E-05
		.24%	.53%	.64%	1.21%	1.62%
	2G	2.4189E-04	3.0456E-05	4.6888E-05	1.6776E-04	9.1555E-05
		.21%	.30%	.35%	.61%	.83%
	3G	1.6203E-04	3.2030E-05	4.6085E-05	1.2449E-04	5.1903E-05
		.23%	.31%	.38%	.75%	.85%
	4G	6.0369E-06	2.0029E-06	3.6044E-06	6.6635E-06	1.1229E-06
		.60%	.83%	1.04%	2.57%	2.44%
Landeyro	1G	4.3504E-05	3.1025E-06	5.1761E-06	2.5896E-05	1.6451E-05
		.46%	2.54%	1.23%	7.77%	9.48%
	2G	2.4155E-04	2.8586E-05	4.6152E-05	1.6451E-04	9.0813E-05
		.36%	1.02%	.53%	2.88%	2.97%
	3G	1.6149E-04	3.0275E-05	4.6402E-05	1.2489E-04	5.2261E-05
		.32%	.90%	.54%	2.70%	2.97%
	4G	6.0737E-06	1.8828E-06	3.6373E-06	6.7440E-06	1.0790E-06
		.90%	2.58%	1.46%	7.85%	9.36%
Nakagawa	1G	4.3428E-05	3.3233E-06	5.2382E-06	2.6290E-05	1.6919E-05
		.15%	.45%	.70%	1.26%	1.48%
	2G	2.4153E-04	3.0470E-05	4.6847E-05	1.6877E-04	9.1556E-05
		.10%	.21%	.36%	.63%	.70%
	3G	1.6241E-04	3.2065E-05	4.6242E-05	1.2467E-04	5.2444E-05
		.15%	.25%	.38%	.83%	.75%
	4G	6.0565E-06	2.0015E-06	3.5505E-06	7.0249E-06	1.1415E-06
		.53%	.89%	1.22%	3.23%	2.48%

Table 47 Individual results of region-averaged fluxes of Model 2, case 2 (Pn method)

		core	radial blanket	axial blanket	CRP	CR
Fletcher	1G	4.2725E-05	3.5250E-06	1.1977E-04	2.5396E-05	3.5036E-05
	2G	2.3884E-04	3.4677E-05	5.3188E-05	1.6799E-05	1.8825E-04
	3G	1.6194E-04	3.9126E-05	5.6267E-05	1.2961E-05	1.0502E-04
	4G	6.0935E-06	2.5970E-06	4.8485E-06	7.7209E-06	2.1114E-06

Table 48 Individual results of region-averaged fluxes of Model 2, case 2 (Sn method)

		core	radial blanket	axial blanket	CRP	CR
Sn						
Buckel	1G	4.3457E-05	3.3386E-06	5.2773E-06	2.6037E-05	1.6756E-05
	2G	2.4164E-04	3.0762E-05	4.7339E-05	1.6799E-04	9.2460E-05
	3G	1.6198E-04	3.2332E-05	4.6558E-05	1.2507E-04	5.2451E-05
	4G	6.0321E-06	2.0020E-06	3.6437E-06	6.6808E-06	1.1028E-06
Lee	1G	4.3478E-05	3.3349E-06	5.2716E-06	2.6049E-05	1.6728E-05
	2G	2.4176E-04	3.0765E-05	4.7349E-05	1.6809E-04	9.2336E-05
	3G	1.6195E-04	3.2335E-05	4.6566E-05	1.2512E-04	5.2356E-05
	4G	6.0284E-06	2.0022E-06	3.6440E-06	6.6896E-06	1.1478E-06
Alcouffe	1G	4.3469E-05	3.3347E-06	5.2736E-06	2.6008E-05	1.6741E-05
	2G	2.4174E-04	3.0751E-05	4.7336E-05	1.6783E-04	9.2431E-05
	3G	1.6199E-04	3.2336E-05	4.6565E-05	1.2499E-04	5.2454E-05
	4G	6.0356E-06	2.0035E-06	3.6505E-06	6.6850E-06	1.0883E-06
Yaroslavzeva	1G	4.3457E-05	3.3341E-06	5.2810E-06	2.5937E-05	1.6779E-05
	2G	2.4167E-04	3.0751E-05	4.7378E-05	1.6734E-04	9.2733E-05
	3G	1.6206E-04	3.2389E-05	4.6688E-05	1.2456E-04	5.2643E-05
	4G	6.0357E-06	2.0088E-06	3.6599E-06	6.6604E-06	1.0887E-06
Yamamoto	1G	4.3468E-05	3.3334E-06	5.2735E-06	2.6022E-05	1.6737E-05
	2G	2.4170E-04	3.0751E-05	4.7325E-05	1.6791E-04	9.2392E-05
	3G	1.6201E-04	3.2334E-05	4.6562E-05	1.2503E-04	5.2425E-05
	4G	6.0332E-06	2.0027E-06	3.6453E-06	6.6822E-06	1.1026E-06
Takeda	1G	4.3456E-05	3.3325E-06	5.2725E-06	2.6025E-05	1.6721E-05
	2G	2.4164E-04	3.0745E-05	4.7320E-05	1.6796E-04	9.2287E-05
	3G	1.6198E-04	3.2329E-05	4.6559E-05	1.2508E-04	5.2366E-05
	4G	6.0320E-06	2.0024E-06	3.6450E-06	6.6848E-06	1.1012E-06

Table 49 Individual results of region-averaged fluxes of Model 2, case 2 (Other methods)

		core	radial blanket	axial blanket	CRP	CR
Collins (Nodal method)						
NDT	1G	4.3124E-05	3.6414E-06	5.7878E-06	2.7579E-05	1.8609E-05
	2G	2.4104E-04	3.1532E-05	4.8507E-05	1.6873E-04	9.6931E-05
	3G	1.6199E-04	3.2741E-05	4.7050E-05	1.2448E-04	5.4137E-05
	4G	6.0417E-06	2.0203E-06	3.6677E-06	6.5387E-06	1.1539E-06
NTT	1G	4.3417E-05	3.3879E-06	5.3511E-06	2.5960E-05	1.7191E-05
	2G	2.4158E-04	3.0740E-05	4.7299E-05	1.6676E-04	9.3279E-05
	3G	1.6202E-04	3.2271E-05	4.6468E-05	1.2430E-04	5.2752E-05
	4G	6.0301E-06	2.0007E-06	3.6463E-06	6.6650E-06	1.1395E-06
Ait Abderrahim (Synthesis method)						
	1G	4.0586E-05	3.2201E-06	5.0115E-06	2.4621E-05	1.0541E-05
	2G	2.4060E-04	3.1473E-05	4.7463E-05	1.6816E-04	5.2711E-05
	3G	1.7036E-04	3.4478E-05	4.8779E-05	1.3020E-04	2.5986E-05
	4G	6.4812E-06	2.1828E-06	3.8776E-06	6.8899E-06	3.9622E-07

Table 50 Individual results of region-averaged fluxes of Model 3, case 1 (Monte-Carlo method)

		core	internal blanket	radial blanket	axial blanket	CRP	CR
Wehmann	1G	2.0337E-05			2.9519E-06	1.2214E-05	1.2143E-05
		.08%			.34%	.27%	.60%
	2G	1.1493E-04			3.0042E-05	8.6232E-05	6.7910E-05
		.05%			.18%	.14%	.30%
	3G	8.2784E-05			3.5361E-05	7.4894E-05	3.9733E-05
		.06%			.19%	.17%	.33%
	4G	3.4158E-06			3.7495E-06	5.2953E-06	8.6536E-07
		.25%			.46%	.58%	1.12%
Schaefer	1G	2.0333E-05	1.2682E-05	1.5888E-06	2.9332E-06	1.2293E-05	1.2262E-05
		.10%	.45%	.45%	.39%	.37%	.82%
	2G	1.1503E-04	1.1288E-04	1.6672E-05	3.0190E-05	8.6658E-05	6.7618E-05
		.08%	.26%	.29%	.21%	.21%	.43%
	3G	8.2813E-05	1.2015E-04	2.1472E-05	3.5545E-05	7.5453E-05	3.9740E-05
		.11%	.31%	.29%	.24%	.23%	.47%
	4G	3.3997E-06	7.4406E-06	1.8012E-06	3.7477E-06	5.3152E-06	8.7718E-07
		.38%	.91%	.75%	.65%	.83%	1.53%
Rief	1G	2.0426E-05	1.2316E-05	1.6715E-06	2.9411E-06	1.3147E-05	8.7141E-06
		1.09%	1.71%	2.46%	1.52%	3.14%	6.33%
	2G	1.1392E-04	1.1005E-04	1.7474E-05	2.9990E-05	9.2048E-05	5.0708E-05
		1.09%	1.35%	1.57%	1.16%	1.57%	2.79%
	3G	8.1947E-05	1.1648E-04	2.2122E-05	3.5250E-05	7.9808E-05	3.3626E-05
		1.11%	1.35%	1.59%	1.26%	1.57%	2.91%
	4G	3.4075E-06	7.4481E-06	1.8677E-06	3.7606E-06	5.5307E-06	1.7055E-06
		1.78%	2.86%	3.02%	1.80%	3.88%	7.67%
Landeyro	1G	2.0408E-05	1.2391E-05	1.5561E-06	2.9516E-06	1.3482E-05	1.2319E-05
		.70%	1.02%	3.43%	1.01%	8.67%	5.34%
	2G	1.1526E-04	1.1032E-04	1.6744E-05	3.0164E-05	9.3054E-05	6.7769E-05
		.49%	.57%	1.33%	.49%	2.37%	2.28%
	3G	8.2619E-05	1.1845E-04	2.1612E-05	3.5289E-05	7.9089E-05	3.9406E-05
		.48%	.51%	.96%	.44%	1.31%	2.14%
	4G	3.4013E-06	7.2503E-06	1.8329E-06	3.7491E-06	5.5131E-06	8.2001E-07
		1.47%	1.47%	2.23%	.99%	4.27%	8.00%
Nakagawa	1G	2.0325E-05	1.2387E-05	1.5898E-06	2.9191E-06	1.2160E-05	1.1923E-05
		.14%	.66%	.61%	.60%	.53%	1.25%
	2G	1.1522E-04	1.1223E-04	1.6825E-05	3.0148E-05	8.5976E-05	6.7545E-05
		.09%	.38%	.34%	.31%	.26%	.57%
	3G	8.2753E-05	1.1851E-04	2.1582E-05	3.5358E-05	7.5124E-05	3.9477E-05
		.13%	.39%	.35%	.34%	.31%	.72%
	4G	3.4009E-06	7.5432E-06	1.7854E-06	3.7665E-06	5.3233E-06	8.5791E-07
		.50%	1.18%	.93%	.83%	1.05%	2.23%

Table 51 Individual results of region-averaged fluxes of Model 3, case 1 (Pn method)

		core	internal blanket	radial blanket	axial blanket	CRP	CR
Fletcher	1G	2.0391E-05	1.1947E-05	1.5541E-06	2.8687E-06	1.3244E-05	1.2624E-05
	2G	1.1513E-04	1.0971E-04	1.6582E-05	3.0770E-05	9.2081E-05	6.8328E-05
	3G	8.2809E-05	1.1888E-04	2.1690E-05	3.7543E-05	7.7626E-05	7.9238E-05
	4G	3.4015E-06	7.5803E-06	1.8549E-06	4.1841E-06	5.5562E-06	8.3664E-07

Table 52 Individual results of region-averaged fluxes of Model 3, case 1 (Sn method)

		core	internal blanket	radial blanket	axial blanket	CRP	CR
Sn							
Buckel	1G	2.0370E-05	1.2616E-05	1.6069E-06	2.9688E-06	1.2286E-05	1.2367E-05
	2G	1.1491E-04	1.1270E-04	1.6792E-05	3.0325E-05	8.6503E-05	6.8653E-05
	3G	8.2641E-05	1.1967E-04	2.1585E-05	3.5572E-05	7.5041E-05	4.0168E-05
	4G	3.4001E-06	7.4370E-06	1.8070E-06	3.7750E-06	5.2820E-06	8.5711E-07
Lee	1G	2.0381E-05	1.2592E-05	1.6076E-06	2.9639E-06	1.2278E-05	1.2341E-05
	2G	1.1499E-04	1.1255E-04	1.6812E-05	3.0304E-05	8.6462E-05	6.8585E-05
	3G	8.2647E-05	1.1950E-04	2.1633E-05	3.5548E-05	7.4969E-05	4.0112E-05
	4G	3.3990E-06	7.4264E-06	1.8142E-06	3.7746E-06	5.2790E-06	8.5588E-07
Yamamoto	1G	2.0378E-05	1.2593E-05	1.6060E-06	2.9637E-06	1.2278E-05	1.2348E-05
	2G	1.1497E-04	1.1256E-04	1.6795E-05	3.0301E-05	8.6447E-05	6.8629E-05
	3G	8.2674E-05	1.1957E-04	2.1590E-05	3.5556E-05	7.5007E-05	4.0159E-05
	4G	3.4012E-06	7.4323E-06	1.8074E-06	3.7737E-06	5.2816E-06	8.5700E-07
Takeda	1G	2.0380E-05	1.2593E-05	1.6065E-06	2.9637E-06	1.2278E-05	1.2344E-05
	2G	1.1498E-04	1.1257E-04	1.6798E-05	3.0303E-05	8.6466E-05	6.8605E-05
	3G	8.2684E-05	1.1958E-04	2.1590E-05	3.5558E-05	7.5015E-05	4.0147E-05
	4G	3.4015E-06	7.4325E-06	1.8059E-06	3.7741E-06	5.2821E-06	8.5668E-07
Yaroslavzeva	1G	2.0376E-05			2.9394E-06	1.2100E-05	1.2337E-05
	2G	1.1492E-04			3.0033E-05	8.5122E-05	6.8457E-05
	3G	8.2618E-05			3.5197E-05	7.3600E-05	4.0000E-05
	4G	3.3950E-06			3.7331E-06	5.1688E-06	8.4380E-07
Alcouffe	1G	2.0400E-05	1.2622E-05	1.6108E-06	2.9367E-06	1.3523E-05	8.1578E-06
	2G	1.1503E-04	1.1276E-04	1.6832E-05	2.9792E-05	9.4343E-05	4.6970E-05
	3G	8.2608E-05	1.1975E-04	2.1622E-05	3.4512E-05	8.0966E-05	2.8344E-05
	4G	3.3934E-06	7.4501E-06	1.8091E-06	3.6025E-06	5.5393E-06	6.2860E-07

Table 53 Individual results of region-averaged fluxes of Model 3, case 1 (Other methods)

		core	internal blanket	radial blanket	axial blanket	CRP	CR
Collins (Nodal method)							
NDT	1G	2.0115E-05	1.3966E-05	1.7419E-06	3.2283E-06	1.3042E-05	1.3666E-05
	2G	1.1456E-04	1.1596E-04	1.7230E-05	3.1081E-05	8.7301E-05	7.1719E-05
	3G	8.2830E-05	1.2119E-04	2.1886E-05	3.6036E-05	7.5202E-05	4.1396E-05
	4G	3.4165E-06	7.4782E-06	1.8209E-06	3.8115E-06	5.2287E-06	8.9797E-07
NTT	1G	2.0336E-05	1.2802E-05	1.6391E-06	2.9909E-06	1.2304E-05	1.2666E-05
	2G	1.1490E-04	1.1296E-04	1.6829E-05	3.0320E-05	8.6401E-05	6.9125E-05
	3G	8.2713E-05	1.1968E-04	2.1524E-05	3.5528E-05	7.5019E-05	4.0361E-05
	4G	3.4001E-06	7.4302E-06	1.7929E-06	3.7686E-06	5.2973E-06	8.8696E-07

Table 54 Individual results of region-averaged fluxes of Model 3, case 2 (Monte-Carlo method)

		core	internal blanket	radial blanket	axial blanket	CRP
Wehmann	1G	1.9871E-05			2.8903E-06	1.2514E-05
		.08%			.34%	.24%
	2G	1.1430E-04			2.9846E-05	8.8688E-05
		.05%			.18%	.12%
	3G	8.4536E-05			3.5694E-05	7.7475E-05
		.06%			.19%	.15%
	4G	3.5502E-06			3.8334E-06	5.3386E-06
		.25%			.46%	.53%
Schaefer	1G	1.9825E-05	1.2210E-05	1.5211E-06	2.8645E-06	1.2535E-05
		.10%	.41%	.48%	.43%	.32%
	2G	1.1446E-04	1.1257E-04	1.6191E-05	2.9851E-05	8.9100E-05
		.08%	.28%	.30%	.23%	.17%
	3G	8.4592E-05	1.2280E-04	2.0985E-05	3.5725E-05	7.7299E-05
		.10%	.30%	.28%	.25%	.23%
	4G	3.5550E-06	7.8018E-06	1.7691E-06	3.8468E-06	5.3666E-06
		.35%	.88%	.69%	.67%	.75%
Landeyro	1G	1.9926E-05	1.2282E-05	1.5649E-06	2.8571E-06	1.2472E-05
		.80%	1.04%	3.33%	1.00%	9.74%
	2G	1.1452E-04	1.1232E-04	1.6269E-05	2.9980E-05	8.8720E-05
		.52%	.56%	1.25%	.50%	2.40%
	3G	8.4303E-05	1.2152E-04	2.1076E-05	3.5536E-05	7.7347E-05
		.53%	.49%	.98%	.41%	1.81%
	4G	3.5366E-06	7.8277E-06	1.7768E-06	3.7954E-06	5.3234E-06
		1.44%	1.37%	2.16%	.94%	4.30%
Nakagawa	1G	1.9894E-05	1.2392E-05	1.5363E-06	2.8776E-06	1.2583E-05
		.16%	.61%	.68%	.58%	1.61%
	2G	1.1462E-04	1.1322E-04	1.6123E-05	2.9986E-05	8.9118E-05
		.10%	.39%	.38%	.32%	.57%
	3G	8.4317E-05	1.2232E-04	2.1004E-05	3.5687E-05	7.7155E-05
		.14%	.35%	.40%	.35%	.65%
	4G	3.5207E-06	7.7405E-06	1.7794E-06	3.7798E-06	5.3341E-06
		.50%	1.24%	.96%	.90%	1.93%

Table 55 Individual results of region-averaged fluxes of Model 3, case 2 (Pn method)

		core	internal blanket	radial blanket	axial blanket	CRP
Fletcher	1G	1.9932E-05	1.1774E-05	1.4835E-06	2.8004E-06	1.2499E-05
	2G	1.1465E-04	1.1041E-04	1.6070E-05	3.0601E-05	9.0536E-05
	3G	8.4426E-05	1.2213E-04	2.1299E-05	3.7848E-05	8.1381E-05
	4G	3.5258E-06	7.8906E-06	1.8178E-06	4.2348E-06	6.1031E-06

Table 56 Individual results of region-averaged fluxes of Model 3, case 2 (Sn method)

		core	internal blanket	radial blanket	axial blanket	CRP
Buckel	1G	1.9858E-05	1.2419E-05	1.5205E-06	2.8893E-06	1.2614E-05
	2G	1.1432E-04	1.1349E-04	1.6170E-05	3.0109E-05	8.9258E-05
	3G	8.4472E-05	1.2348E-04	2.0996E-05	3.5894E-05	7.7633E-05
	4G	3.5433E-06	7.8079E-06	1.7624E-06	3.8332E-06	5.3233E-06
Lee	1G	1.9885E-05	1.2333E-05	1.5406E-06	2.8787E-06	1.2561E-05
	2G	1.1444E-04	1.1267E-04	1.6398E-05	3.0003E-05	8.8834E-05
	3G	8.4389E-05	1.2227E-04	2.1418E-05	3.5772E-05	7.7057E-05
	4G	3.5361E-06	7.7202E-06	1.8087E-06	3.8302E-06	5.2833E-06
Yamamoto	1G	1.9867E-05	1.2390E-05	1.5213E-06	2.8836E-06	1.2603E-05
	2G	1.1438E-04	1.1331E-04	1.6186E-05	3.0079E-05	8.9199E-05
	3G	8.4503E-05	1.2328E-04	2.1022E-05	3.5869E-05	7.7573E-05
	4G	3.5442E-06	7.7961E-06	1.7644E-06	3.8309E-06	5.3210E-06
Takeda	1G	1.9872E-05	1.2393E-05	1.5216E-06	2.8844E-06	1.2606E-05
	2G	1.1441E-04	1.1335E-04	1.6189E-05	3.0089E-05	8.9228E-05
	3G	8.4529E-05	1.2333E-04	2.1020E-05	3.5879E-05	7.7600E-05
	4G	3.5452E-06	7.7995E-06	1.7626E-06	3.8322E-06	5.3230E-06
Yaroslavzeva	1G	1.9857E-05			2.8631E-06	1.2492E-05
	2G	1.1432E-04			2.9830E-05	8.8341E-05
	3G	8.4513E-05			3.5546E-05	7.6649E-05
	4G	3.5426E-06			3.7925E-06	5.2455E-06
Alcouffe	1G	1.9865E-05	1.2388E-05	1.5218E-06	2.8831E-06	1.2637E-05
	2G	1.1438E-04	1.1330E-04	1.6192E-05	3.0073E-05	8.9872E-05
	3G	8.4507E-05	1.2327E-04	2.1032E-05	3.5866E-05	7.8747E-05
	4G	3.5444E-06	7.7958E-06	1.7662E-06	3.8329E-06	5.4474E-06

Table 57 Individual results of region-averaged fluxes of Model 3, case 2 (Other methods)

		core	internal blanket	radial blanket	axial blanket	CRP
Collins (Nodal method)						
NDT	1G	1.9600E-05	1.3750E-05	1.6464E-06	3.1427E-06	1.3370E-05
	2G	1.1398E-04	1.1676E-04	1.6581E-05	3.0868E-05	8.9978E-05
	3G	8.4679E-05	1.2499E-04	2.1283E-05	3.6368E-05	7.7736E-05
	4G	3.5646E-06	7.8527E-06	1.7750E-06	3.8711E-06	5.2634E-06
NTT	1G	1.9825E-05	1.2609E-05	1.5534E-06	2.9106E-06	1.2641E-05
	2G	1.1430E-04	1.1377E-04	1.6217E-05	3.0111E-05	8.9197E-05
	3G	8.4534E-05	1.2346E-04	2.0952E-05	3.5856E-05	7.7653E-05
	4G	3.5481E-06	7.8077E-06	1.7495E-06	3.8289E-06	5.3470E-06

Table 58 Individual results of region-averaged fluxes of Model 3, case 3 (Monte-Carlo method)

		core	internal blanket	radial blanket	axial blanket
Wehmann	1G	1.9026E-05			2.7286E-06
		.08%			.34%
	2G	1.1024E-04			2.8398E-05
		.05%			.18%
	3G	8.0192E-05			3.3534E-05
		.06%			.19%
	4G	3.2002E-06			3.5022E-06
		.25%			.47%
Schaefer	1G	1.9033E-05	1.1865E-05	1.3748E-06	2.7211E-06
		.11%	.46%	.48%	.42%
	2G	1.1021E-04	1.0818E-04	1.4752E-05	2.8342E-05
		.08%	.28%	.28%	.24%
	3G	8.0203E-05	1.1652E-04	1.9204E-05	3.3609E-05
		.11%	.30%	.30%	.27%
	4G	3.2013E-06	7.0597E-06	1.6128E-06	3.5216E-06
		.40%	.98%	.75%	.67%
Landeyro	1G	1.9012E-05	1.1842E-05	1.3498E-06	2.7965E-06
		.79%	1.08%	3.11%	1.04%
	2G	1.1029E-04	1.0824E-04	1.4644E-05	2.8739E-05
		.51%	.56%	1.37%	.47%
	3G	7.9762E-05	1.1656E-04	1.9003E-05	3.4038E-05
		.49%	.49%	1.02%	.43%
	4G	3.2001E-06	6.8733E-06	1.6084E-06	3.5615E-06
		1.40%	1.31%	2.33%	.99%
Nakagawa	1G	1.9058E-05	1.1903E-05	1.3675E-06	2.7163E-06
		.15%	.60%	.64%	.60%
	2G	1.1042E-04	1.0885E-04	1.4614E-05	2.8416E-05
		.10%	.40%	.39%	.35%
	3G	8.0090E-05	1.1717E-04	1.9000E-05	3.3624E-05
		.14%	.40%	.39%	.35%
	4G	3.1725E-06	7.1613E-06	1.6239E-06	3.5258E-06
		.47%	1.26%	.96%	.84%

Table 59 Individual results of region-averaged fluxes of Model 3, case 3 (Pn method)

		core	internal blanket	radial blanket	axial blanket
Fletcher	1G	1.9106E-05			2.6435E-06
	2G	1.1046E-04			2.8839E-05
	3G	8.0112E-04			3.5362E-05
	4G	3.1694E-06			3.8573E-06

Table 60 Individual results of region-averaged fluxes of Model 3, case 3 (Sn method)

		core	internal blanket	radial blanket	axial blanket
Buckel	1G	1.9038E-05	1.1955E-05	1.3688E-06	2.7368E-06
	2G	1.1017E-04	1.0890E-04	1.4728E-05	2.8516E-05
	3G	8.0140E-05	1.1721E-04	1.9191E-05	3.3758E-05
	4G	3.1865E-06	7.0762E-06	1.6107E-06	3.5258E-06
Lee	1G	1.9063E-05	1.1865E-05	1.3906E-06	2.7255E-06
	2G	1.1028E-04	1.0799E-04	1.4979E-05	2.8400E-05
	3G	8.0060E-05	1.1593E-04	1.9657E-05	3.3637E-05
	4G	3.1813E-06	6.9901E-06	1.6605E-06	3.5255E-06
Yamamoto	1G	1.9047E-05	1.1927E-05	1.3702E-06	2.7314E-06
	2G	1.1023E-04	1.0869E-04	1.4754E-05	2.8486E-05
	3G	8.0174E-05	1.1698E-04	1.9228E-05	3.3730E-05
	4G	3.1876E-06	7.0628E-06	1.6138E-06	3.5231E-06
Takeda	1G	1.9055E-05	1.1933E-05	1.3708E-06	2.7326E-06
	2G	1.1028E-04	1.0874E-04	1.4758E-05	2.8499E-05
	3G	8.0210E-05	1.1704E-04	1.9230E-05	3.3746E-05
	4G	3.1890E-06	7.0663E-06	1.6125E-06	3.5248E-06
Yaroslavzeva	1G	1.9037E-05			2.7096E-06
	2G	1.1017E-04			2.8213E-05
	3G	8.0183E-05			3.3403E-05
	4G	3.1865E-06			3.4882E-06
Alcouffe	1G	1.8954E-05	1.1030E-05	1.3711E-06	2.7244E-06
	2G	1.0982E-04	1.0050E-04	1.4764E-05	2.8414E-05
	3G	8.0006E-05	1.0811E-04	1.9245E-05	3.3653E-05
	4G	3.1964E-06	6.5342E-06	1.6160E-06	3.5169E-06

Table 61 Individual results of region-averaged fluxes of Model 3, case 3 (Other methods)

		core	internal blanket	radial blanket	axial blanket
Collins (Nodal method)					
NDT	1G	1.8826E-05	1.3130E-05	1.4744E-06	2.9509E-06
	2G	1.0989E-04	1.1160E-04	1.5050E-05	2.9080E-05
	3G	8.0313E-05	1.1848E-04	1.9394E-05	3.4095E-05
	4G	3.2039E-06	7.1161E-06	1.6173E-06	3.5531E-06
NTT	1G	1.9007E-05	1.2097E-05	1.3955E-06	2.7486E-06
	2G	1.1017E-04	1.0901E-04	1.4753E-05	2.8450E-05
	3G	8.0215E-05	1.1713E-04	1.9129E-05	3.3663E-05
	4G	3.1913E-06	7.0760E-06	1.5970E-06	3.5173E-06
Ait Abderrahim (Synthesis method)					
	1G	1.8530E-05	4.5322E-06	2.7072E-06	2.3309E-06
	2G	1.0458E-04	4.3552E-05	2.8030E-05	2.3692E-05
	3G	7.7395E-05	5.4533E-05	3.6439E-05	2.9089E-05
	4G	3.2295E-06	3.8575E-06	3.1295E-06	3.2220E-06

Table 62 Individual results of region-averaged fluxes of Model 4, case 1 (Monte-Carlo method)

		test zone	axial blanket	driver with moderator	CRP
Nakagawa	1G	1.360E-04	3.532E-05	6.493E-05	
		.80%	.70%	.34%	
	2G	1.103E-04	5.010E-05	4.996E-05	
		.60%	.57%	.22%	
	3G	3.099E-05	2.590E-05	2.826E-05	
		.56%	.75%	.22%	
	4G	3.873E-06	1.192E-05	1.446E-05	
		.87%	.94%	.26%	
Wehmann	1G	1.3497E-04	3.5233E-05	6.3294E-05	5.2497E-05
		.11%	.25%	.09%	.11%
	2G	1.0847E-04	4.9748E-05	4.9998E-05	5.0666E-05
		.14%	.25%	.09%	.12%
	3G	3.0723E-04	2.6287E-05	2.8204E-05	2.2637E-05
		.26%	.39%	.11%	.20%
	4G	3.8755E-06	1.2875E-05	1.4491E-05	1.0366E-05
		.51%	.34%	.12%	.34%

Table 63 Individual results of region-averaged fluxes of Model 4, case 1 (Pn method)

		test zone	axial blanket	driver with moderator	CRP
Fletcher	1G	1.3246E-04	3.8626E-05	6.3676E-05	5.3900E-05
	2G	1.0884E-04	5.3507E-05	4.8661E-05	5.1974E-05
	3G	3.1356E-05	2.7845E-05	2.7724E-05	2.3449E-05
	4G	3.9845E-06	1.2776E-05	1.4261E-05	1.1151E-05

Table 64 Individual results of region-averaged fluxes of Model 4, case 1 (Sn method)

		test zone	axial blanket	driver with moderator	CRP
Takeda	1G	1.3435E-05	3.5410E-05	6.6393E-05	5.4226E-05
	2G	1.0791E-04	4.9618E-05	5.1327E-05	5.1474E-05
	3G	3.0289E-05	2.5893E-05	2.8424E-05	2.2143E-05
	4G	3.2917E-06	1.1649E-05	1.4341E-05	9.2927E-06

Table 65 Individual results of region-averaged fluxes of Model 4, case 1 (Other methods)

		test zone	axial blanket	driver with moderator	CRP
Wagner (Nodal method)					
NT 20	1G	1.3317E-04	3.5860E-05	6.5622E-05	5.2673E-05
	2G	1.0741E-04	4.9930E-05	5.0333E-05	5.0610E-05
	3G	3.0910E-05	2.6255E-05	2.8358E-05	2.2703E-05
	4G	3.9903E-06	1.2073E-05	1.4532E-05	1.0527E-05

NT : Nodal Transport

20 : Number of axial layers

Table 66 Individual results of region-averaged fluxes of Model 4, case 2 (Monte-Carlo method)

		test zone	axial blanket	driver with moderator	CRP	CR
Nakagawa	1G	1.491E-04	3.683E-05	7.001E-05		
		.23%	.44%	.14%		
	2G	1.131E-04	4.876E-05	5.108E-05		
		.22%	.39%	.44%		
	3G	2.651E-05	2.250E-05	2.774E-05		
		.52%	.71%	.23%		
	4G	2.477E-06	8.547E-06	1.399E-05		
		1.26%	1.29%	.27%		
Wehmann	1G	1.4648E-04	3.7218E-05	7.0408E-05	1.1866E-04	4.4354E-05
		.11%	.25%	.09%	.14%	.17%
	2G	1.1227E-04	4.8757E-05	5.1358E-05	1.0031E-04	3.5773E-05
		.14%	.25%	.09%	.16%	.18%
	3G	2.6574E-05	2.2307E-05	2.7716E-05	3.6997E-05	7.7894E-06
		.27%	.40%	.11%	.27%	.32%
	4G	2.4498E-06	8.7007E-06	1.3943E-05	1.1076E-05	4.8143E-07
		.36%	.67%	.13%	.48%	.43%

Table 67 Individual results of region-averaged fluxes of Model 4, case 2 (Pn method)

		test zone	axial blanket	driver with moderator	CRP	CR
Fletcher	1G	1.4619E-04	4.0153E-05	6.9230E-05	1.1947E-04	4.5836E-05
	2G	1.1202E-04	5.1692E-05	5.0327E-05	9.9713E-05	3.6277E-05
	3G	2.6725E-05	2.3587E-05	2.7600E-05	3.7225E-05	1.2536E-05
	4G	2.6008E-06	9.2026E-06	1.3969E-05	1.1472E-05	3.8632E-06

Table 68 Individual results of region averaged fluxes of Model 4, case 2

(Sn method)

		test zone	axial blanket	driver with moderator	CRP	CR
Takeda	1G	1.4946E-04	3.7525E-05	7.1443E-05	1.2547E-04	4.7178E-05
	2G	1.1226E-04	4.8811E-05	5.2295E-05	1.0395E-05	3.7692E-05
	3G	2.5243E-05	2.2012E-05	2.7650E-05	3.6876E-05	8.1131E-06
	4G	2.0788E-06	8.4655E-06	1.3793E-05	9.1418E-06	4.9955E-07

Table 69 Individual results of region-averaged fluxes of Model 4, case 2
(Other methods)

		test zone	axial blanket	driver with moderator	CRP	CR
Wagner						
NT 20	1G	1.4733E-04	3.7583E-05	7.0620E-05	1.1912E-04	4.4890E-05
	2G	1.1149E-04	4.8760E-05	5.1532E-05	9.9954E-05	3.5967E-05
	3G	2.6463E-05	2.2502E-05	2.7810E-05	3.7343E-05	7.7973E-06
	4G	2.5308E-06	8.7327E-06	1.3865E-05	1.1241E-05	6.3915E-07

Table 70 Individual results of region-averaged fluxes of Model 4, case 3 (Monte-Carlo method)

	test zone	axial blanket	driver with moderator	CR
Nakagawa 1G	1.672E-04	4.103E-05	7.454E-05	9.586E-05
	.92%	.72%	.41%	.28%
2G	1.177E-04	5.243E-05	5.171E-05	6.962E-05
	.77%	.66%	.32%	.34%
3G	2.188E-05	2.380E-05	2.698E-05	1.344E-05
	.87%	.78%	.36%	.47%
4G	1.174E-06	9.733E-05	1.340E-05	9.728E-07
	1.73%	1.23%	.40%	.95%
Wehmann 1G	1.4963E-04	4.0616E-05	7.5020E-05	9.5412E-05
	.11%	.25%	.10%	.11%
2G	1.1674E-04	5.1744E-05	5.1923E-05	6.9278E-05
	.14%	.25%	.10%	.12%
3G	2.1816E-05	2.3588E-05	2.6956E-05	1.3436E-05
	.31%	.40%	.12%	.23%
4G	1.1658E-06	9.7430E-06	1.3390E-05	9.4854E-07
	.42%	.43%	.14%	.44%

Table 71 Individual results of region-averaged fluxes of Model 4, case 3 (Pn method)

	test zone	axial blanket	driver with moderator	CR
Fletcher 1G	1.6004E-04	4.3773E-05	7.4091E-05	9.6475E-05
2G	1.1445E-04	5.5105E-05	5.1229E-05	6.8633E-05
3G	2.1475E-05	2.4826E-05	2.7126E-05	1.2895E-05
4G	1.2197E-07	1.0372E-05	1.3616E-05	8.2098E-07

Table 72 Individual results of region-averaged fluxes of Model 4, case 3 (Sn method)

		test zone	axial blanket	driver with moderator	CR
Takeda	1G	1.6885E-04	4.1747E-05	7.6295E-05	1.0559E-04
	2G	1.1766E-04	5.2949E-05	5.2631E-05	7.5813E-05
	3G	1.9566E-05	2.3442E-05	2.6580E-05	1.4578E-05
	4G	9.8209E-05	9.5603E-06	1.3210E-05	7.8467E-07

Table 73 Individual results of region-averaged fluxes of Model 4, case 3 (Other methods)

		test zone	axial blanket	driver with moderator	CR
Wagner					
NT	1G	1.6465E-04	4.1097E-05	7.5255E-05	9.6537E-05
	2G	1.1640E-04	5.2117E-05	5.2147E-05	6.9708E-05
	3G	2.1815E-05	2.3668E-05	2.7023E-05	1.3615E-04
	4G	1.1923E-05	9.7162E-06	1.3396E-05	1.0023E-06

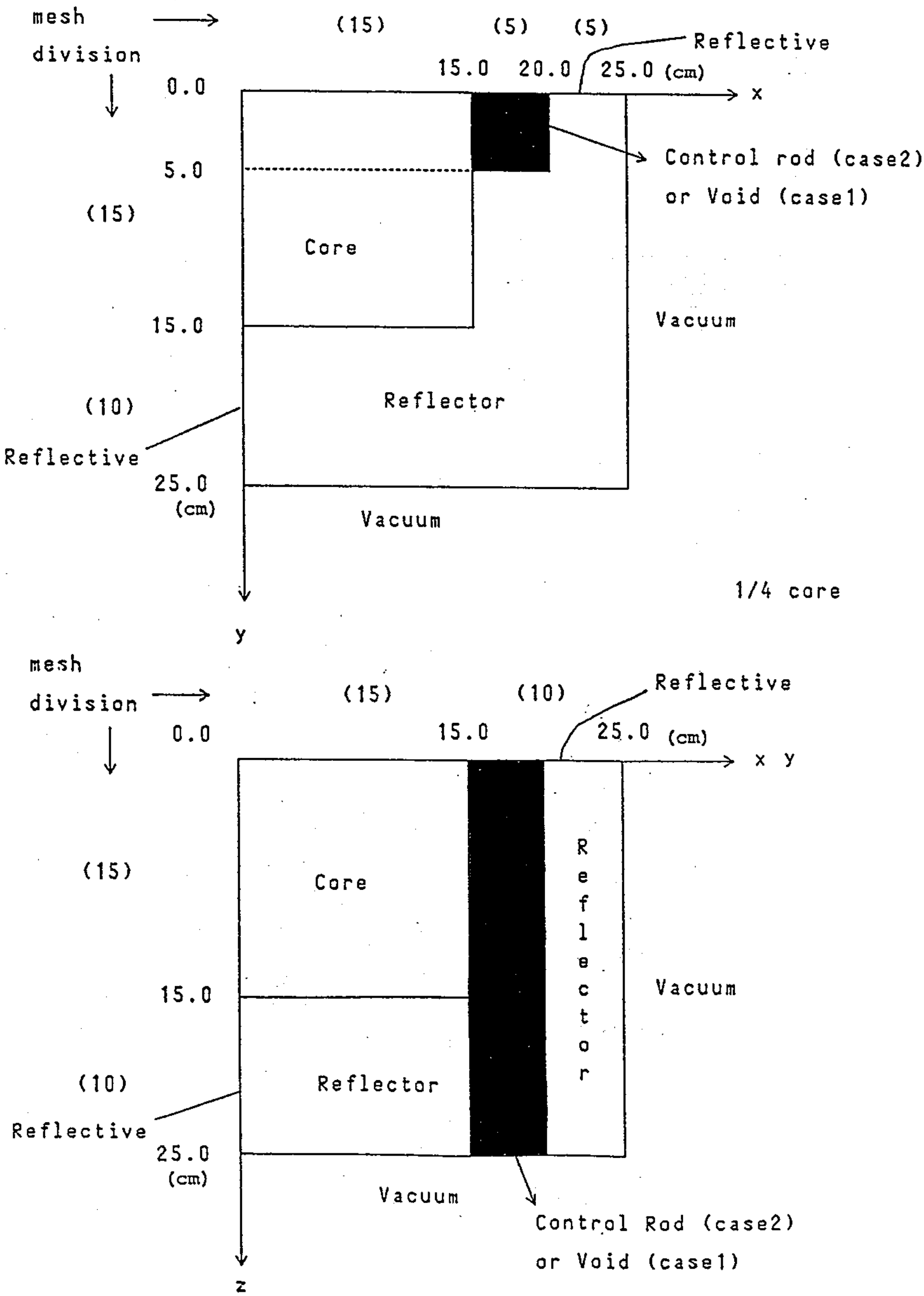


Fig. 1 Core configuration of Model 1

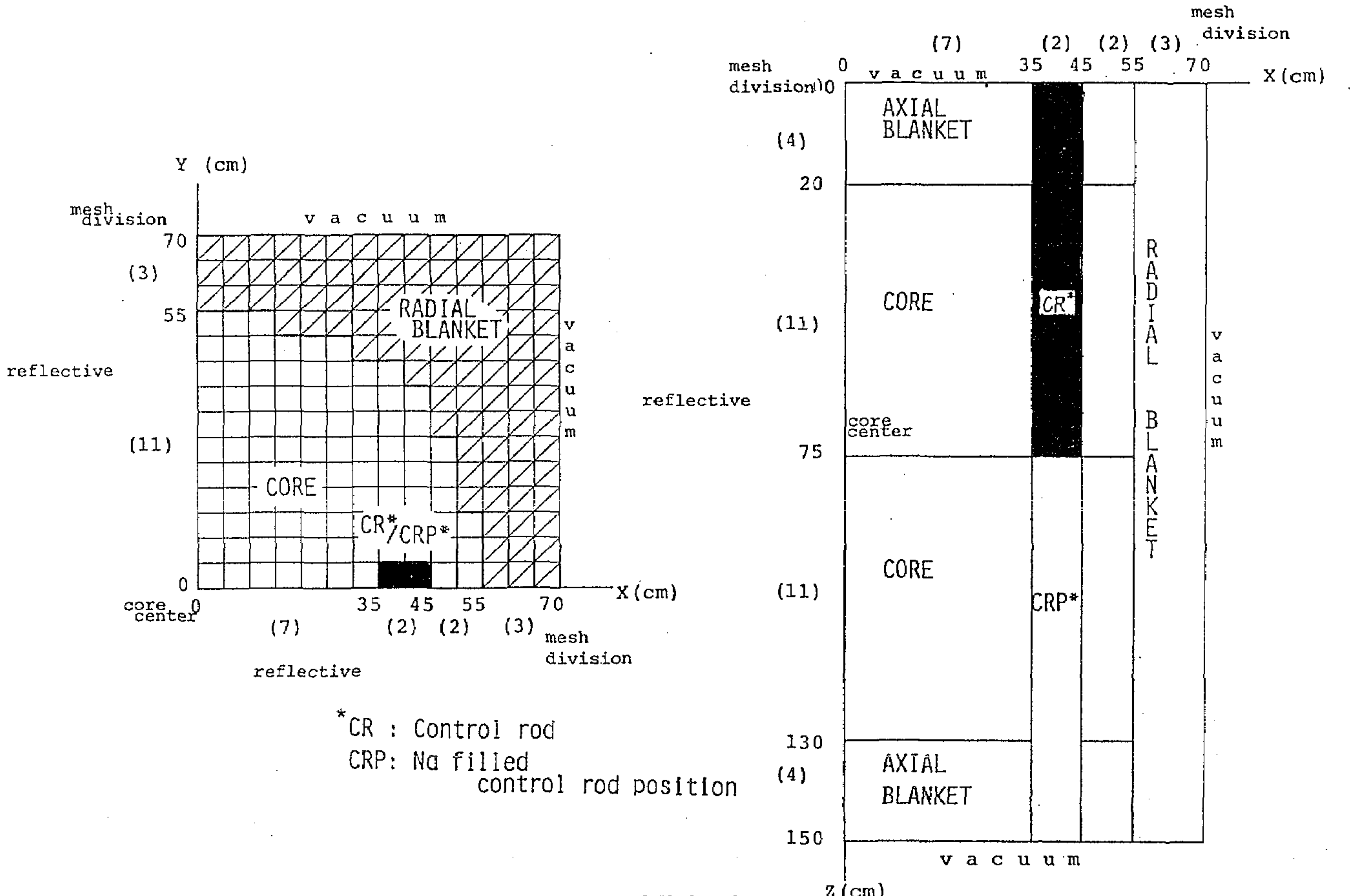


Fig. 2 Core configuration of Model 2

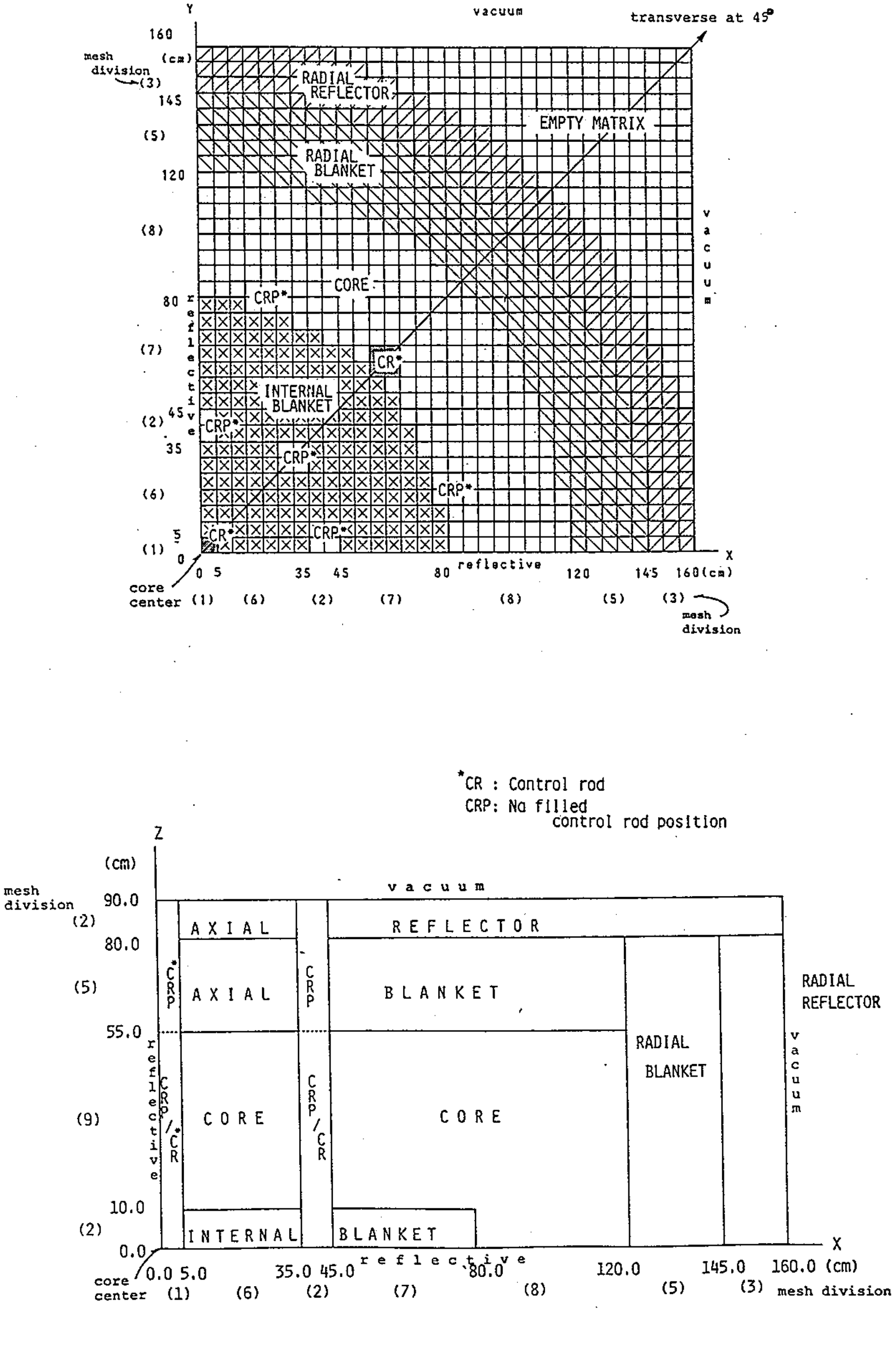
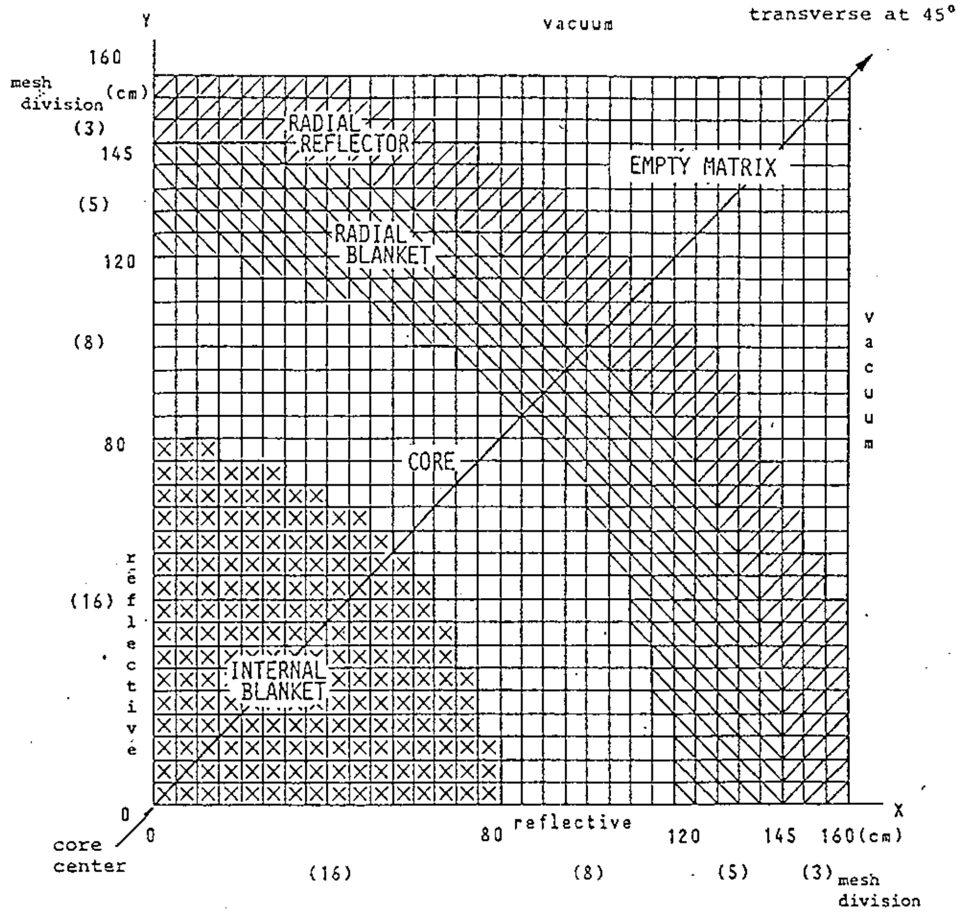


Fig. 3a Core configuration of Model 3

94260078



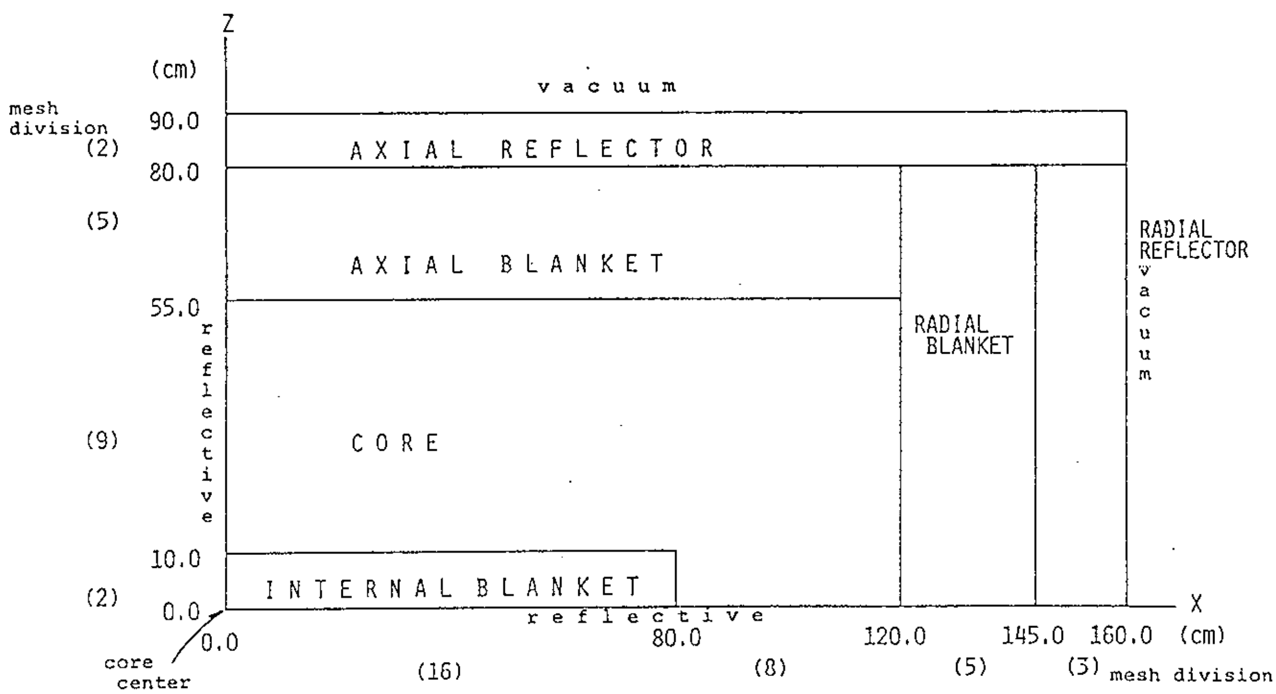


Fig. 3b Core configuration of Model 3

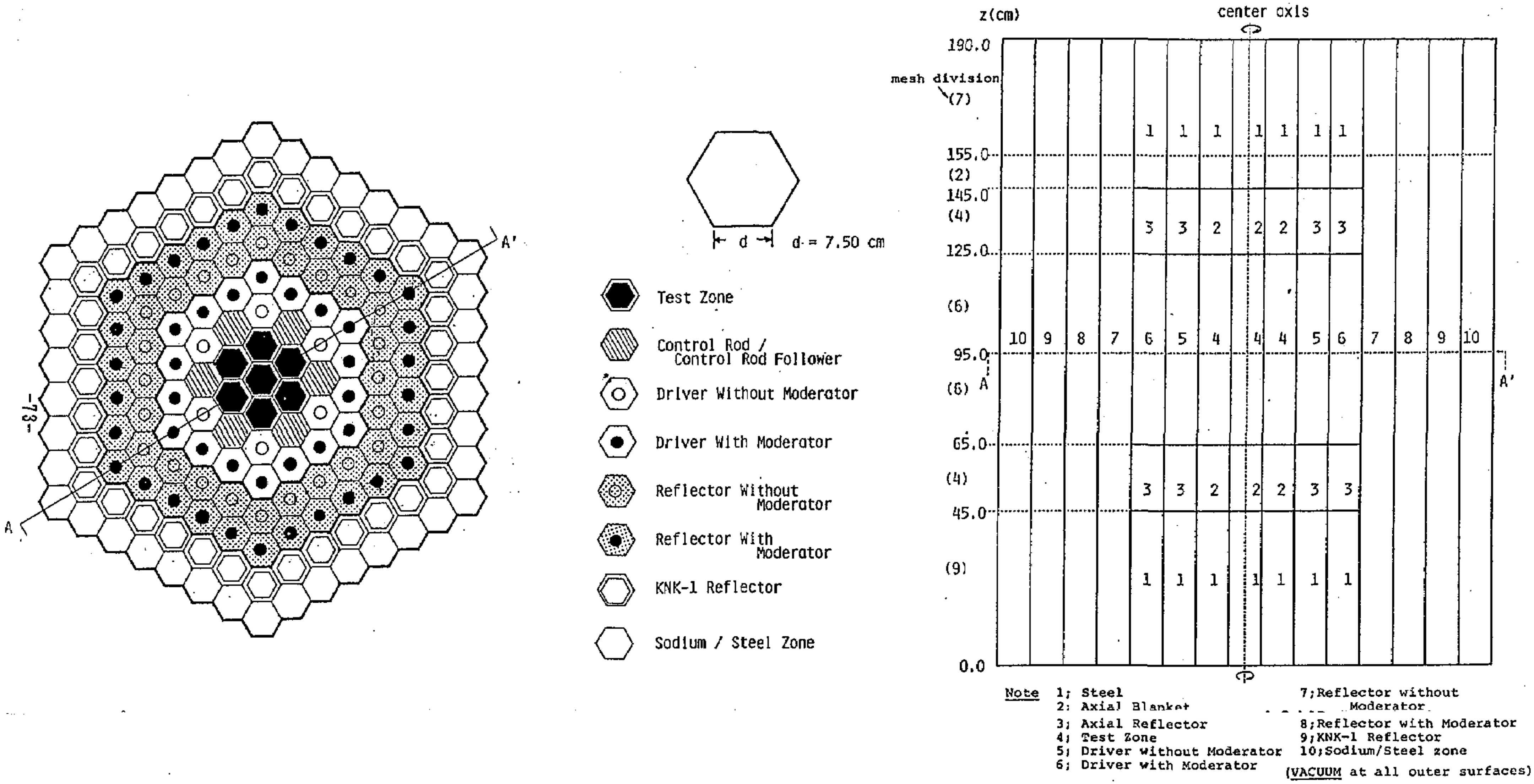
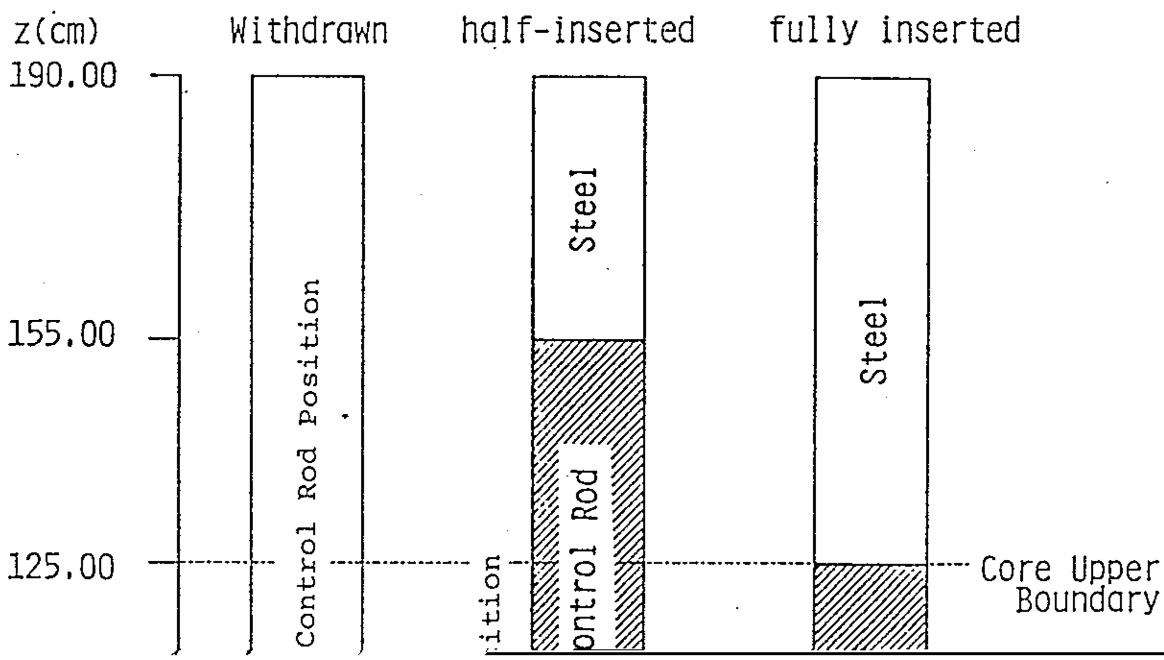


Fig. 4a Core configuration of Model 4


z(cm)
Withdrawn
half-inserted
fully inserted
190.00
155.00
125.00
Steel
Steel
Control Rod Position
ontrol Rod
ition
Core Upper
Boundary

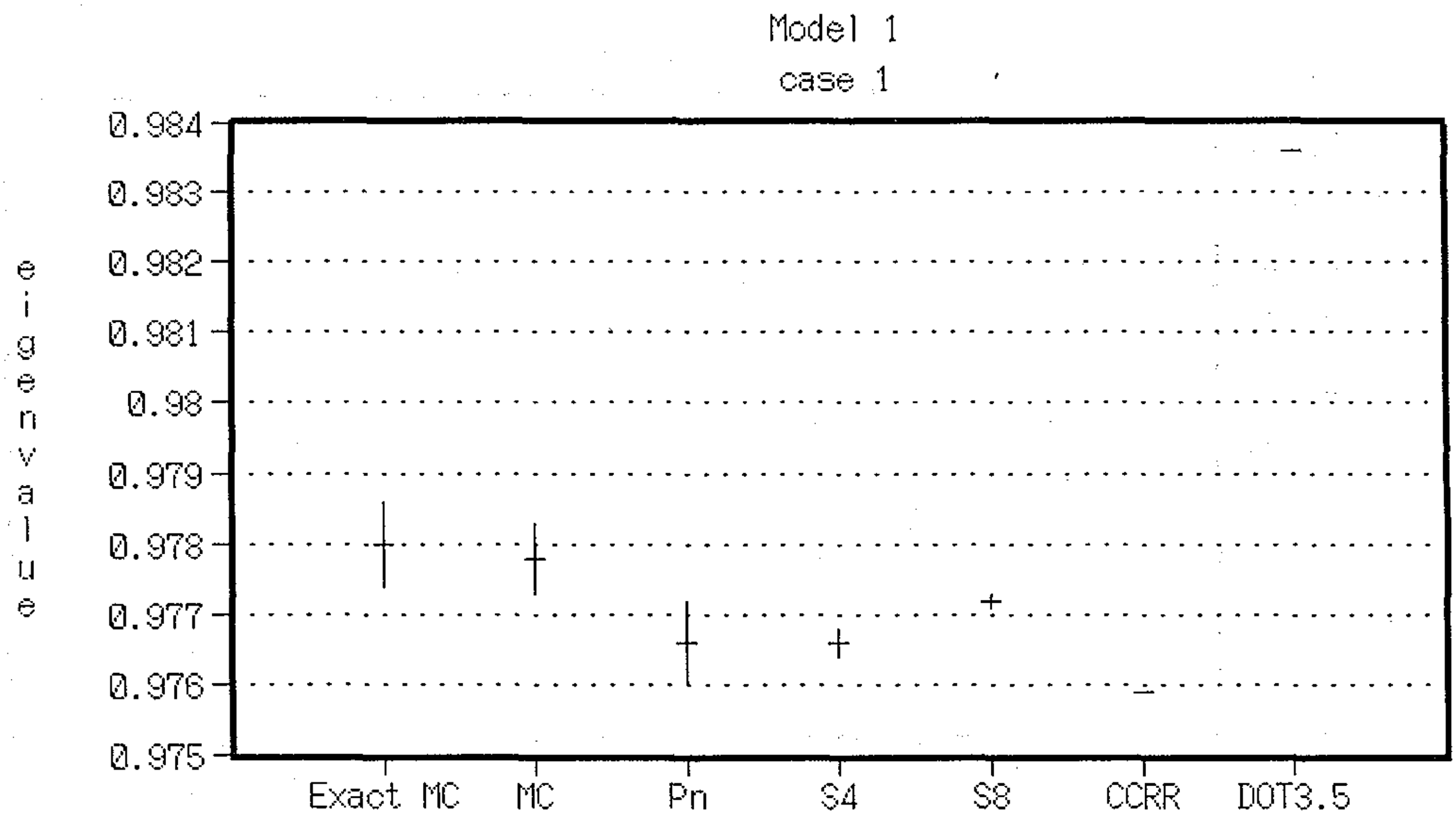


Fig. 5 Average k_{eff} of Model 1, case 1

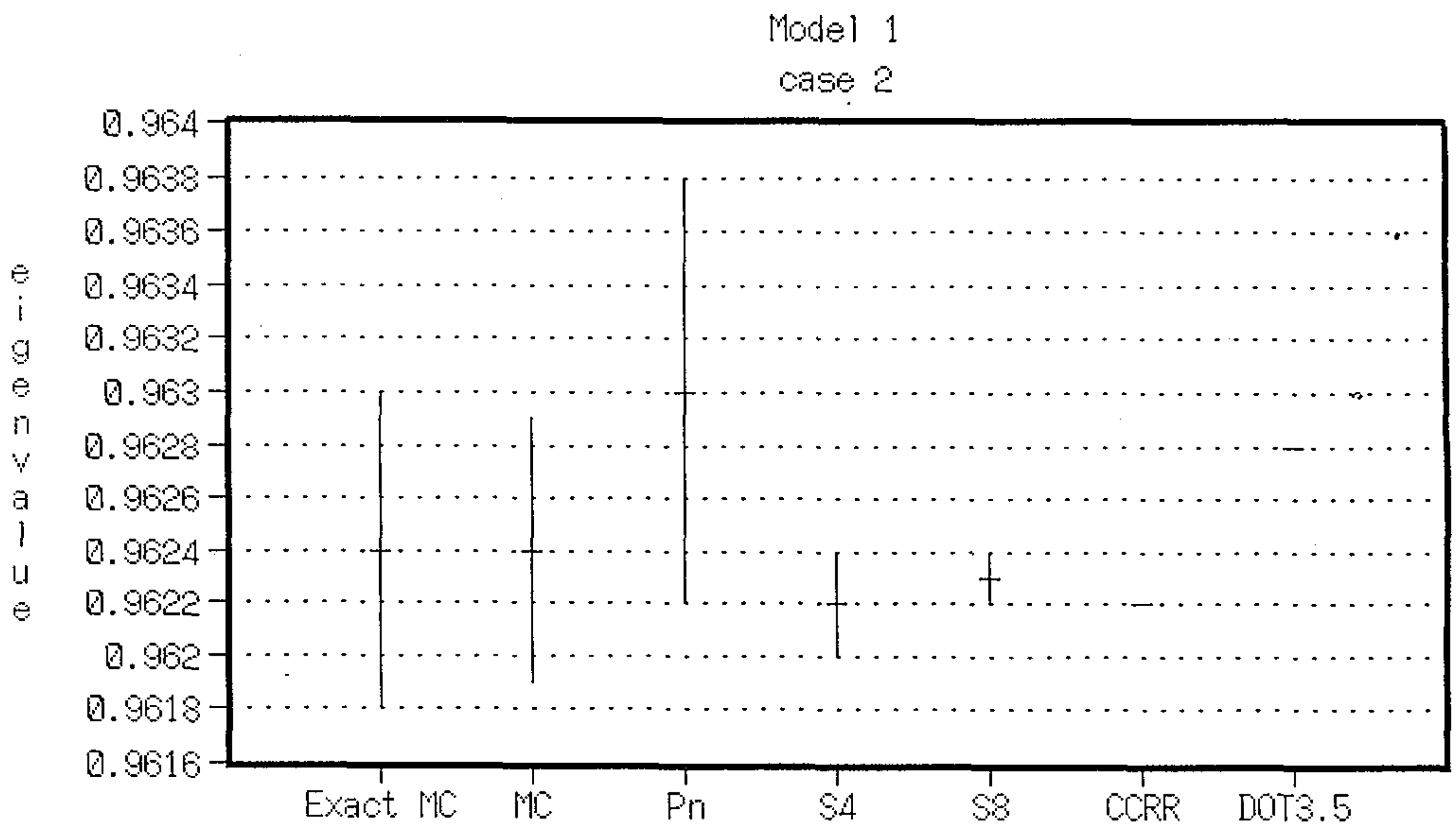


Fig. 6 Average k_{eff} of Model 1, case 2

94260082

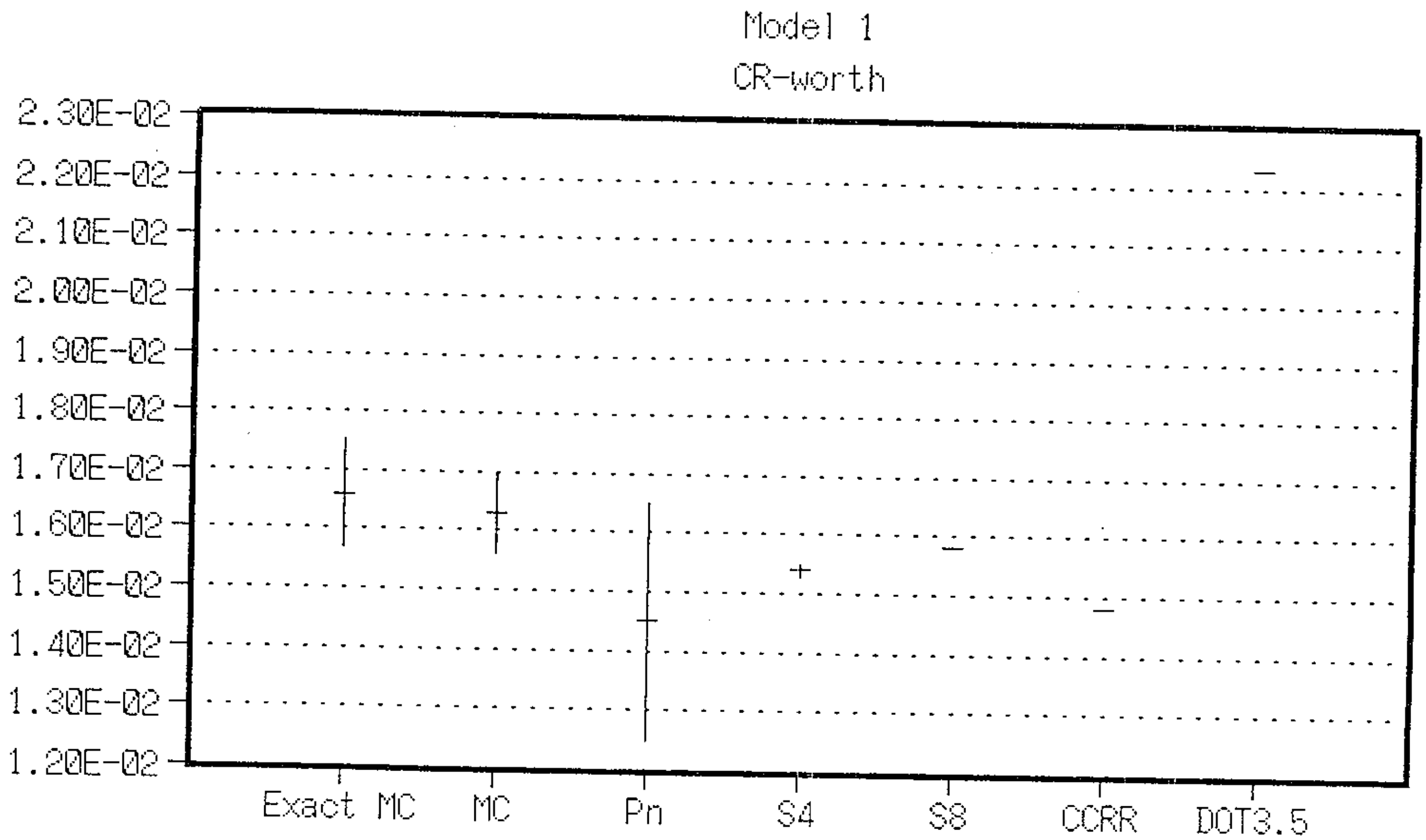


Fig. 7 Average control rod worth of Model 1

94260083

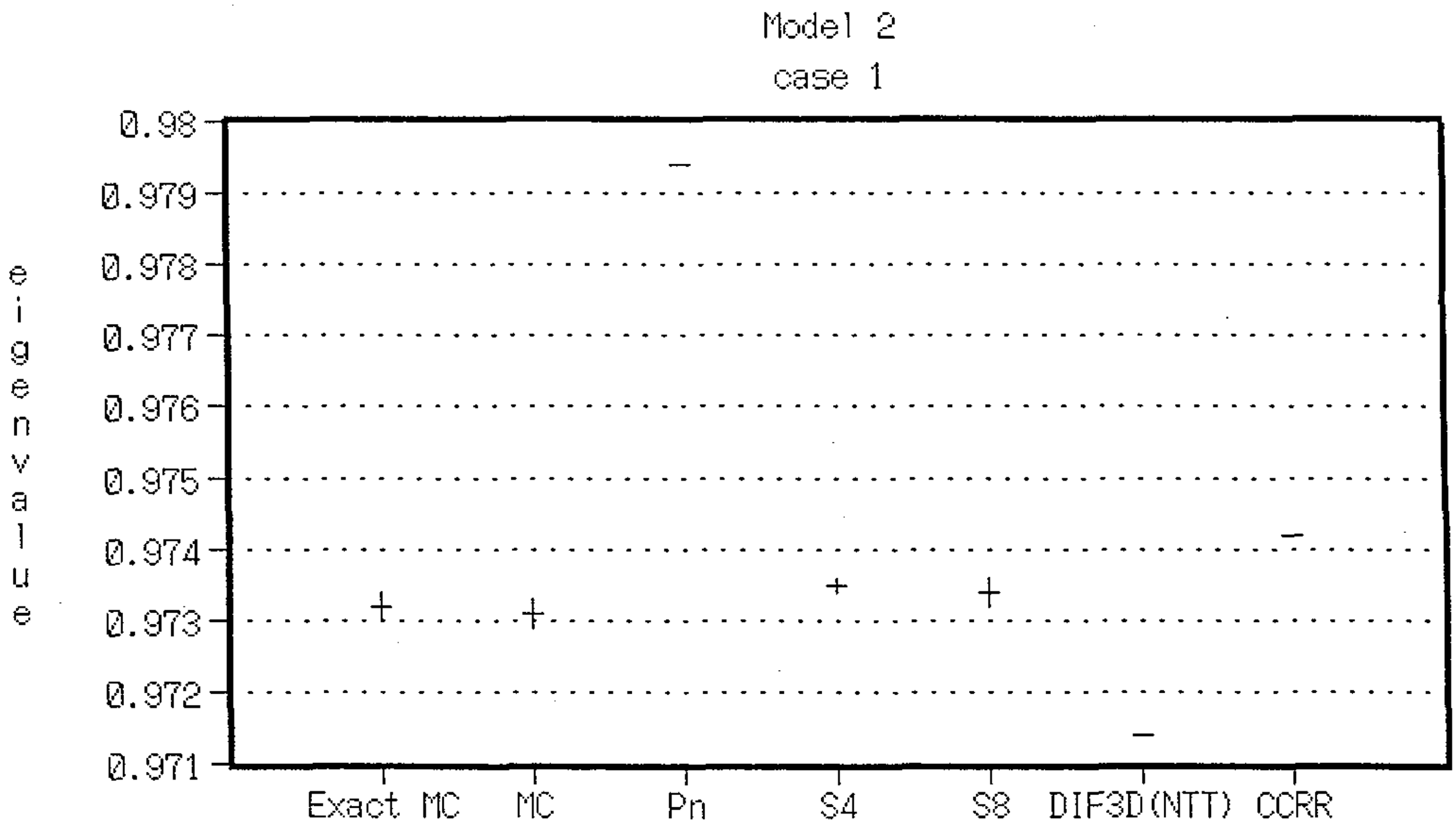


Fig. 8 Average k_{eff} of Model 2, case 1

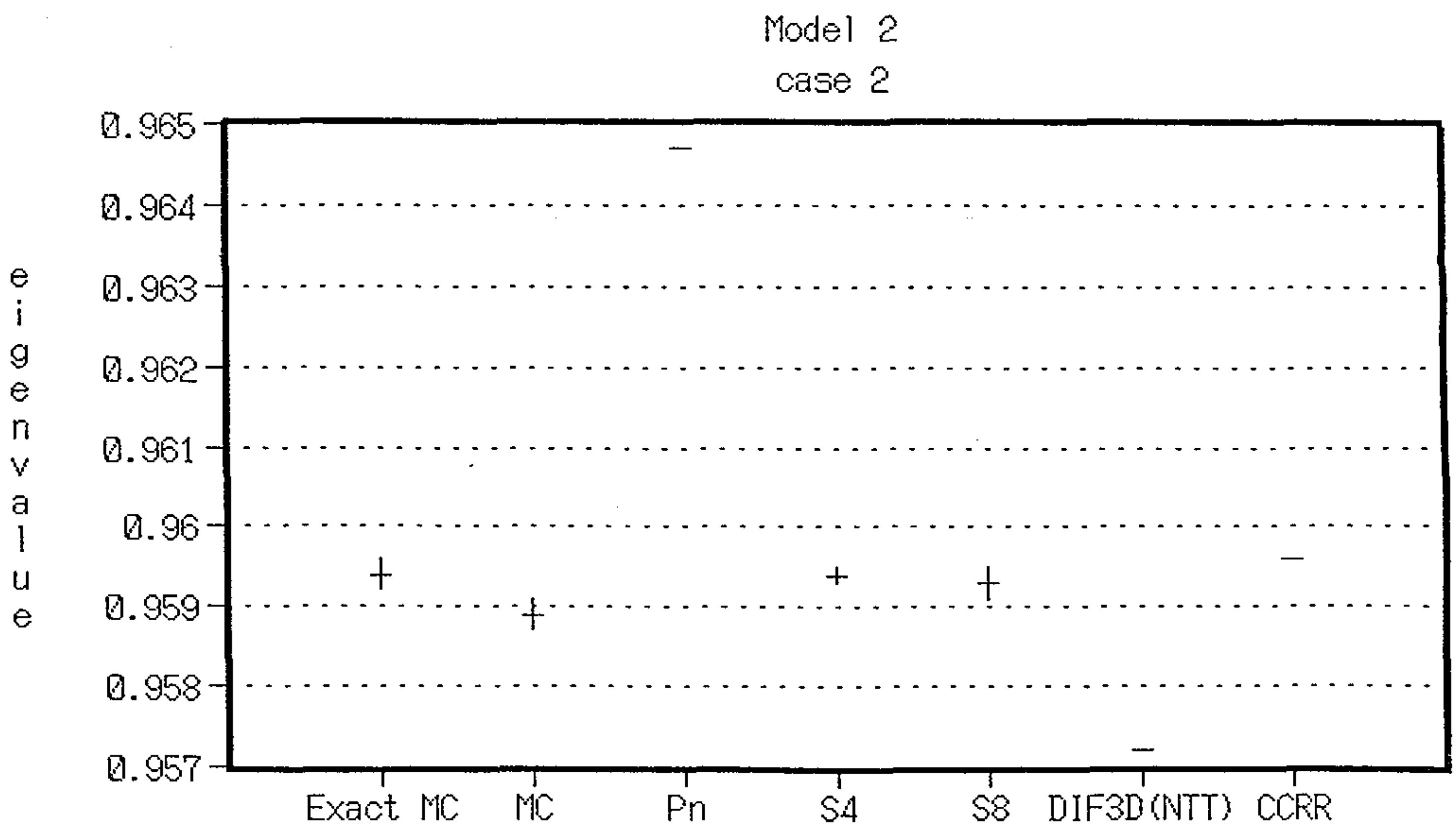


Fig. 9 Average k_{eff} of Model 2, case 2

94260084

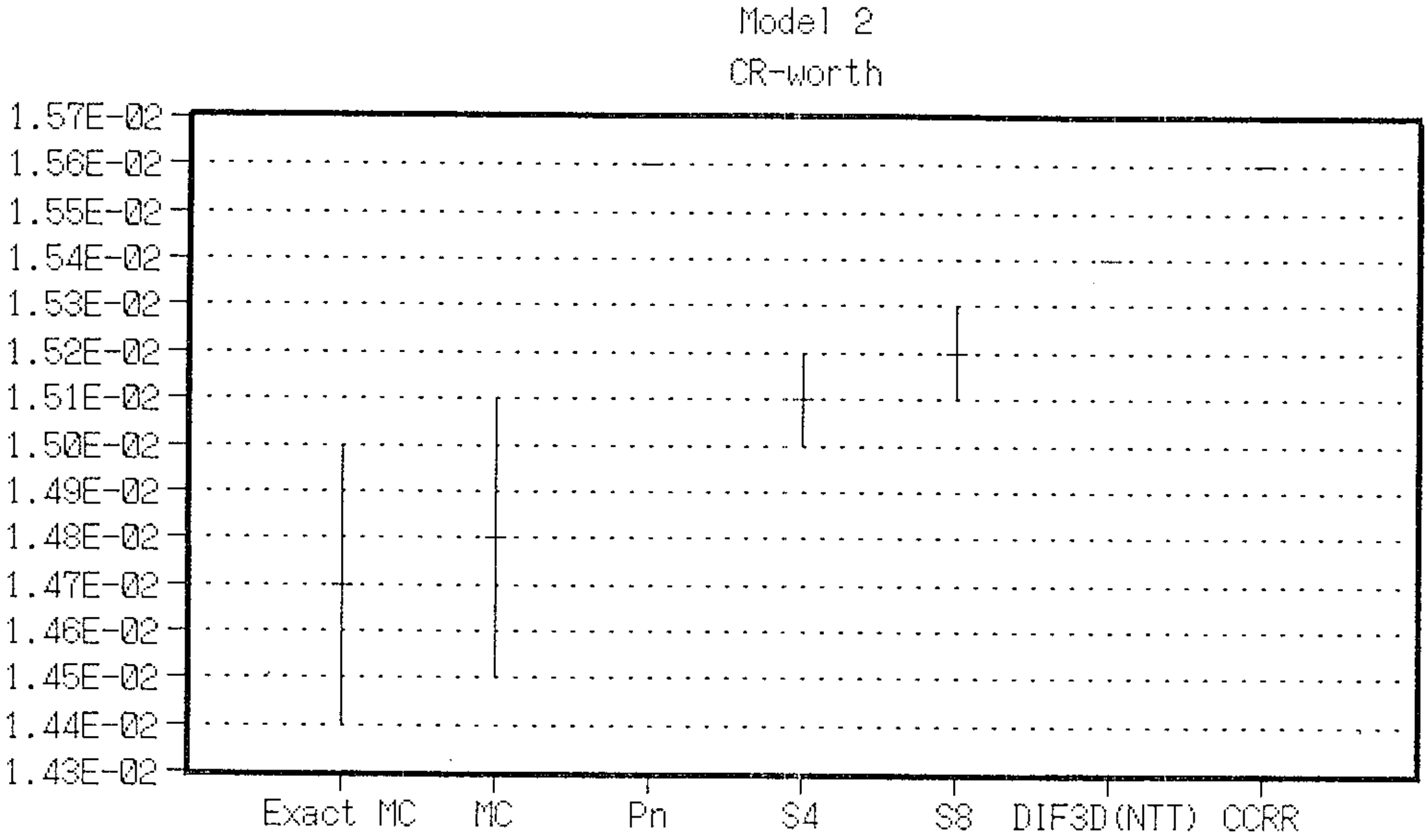


Fig. 10 Average control rod worth of Model 2

94260085

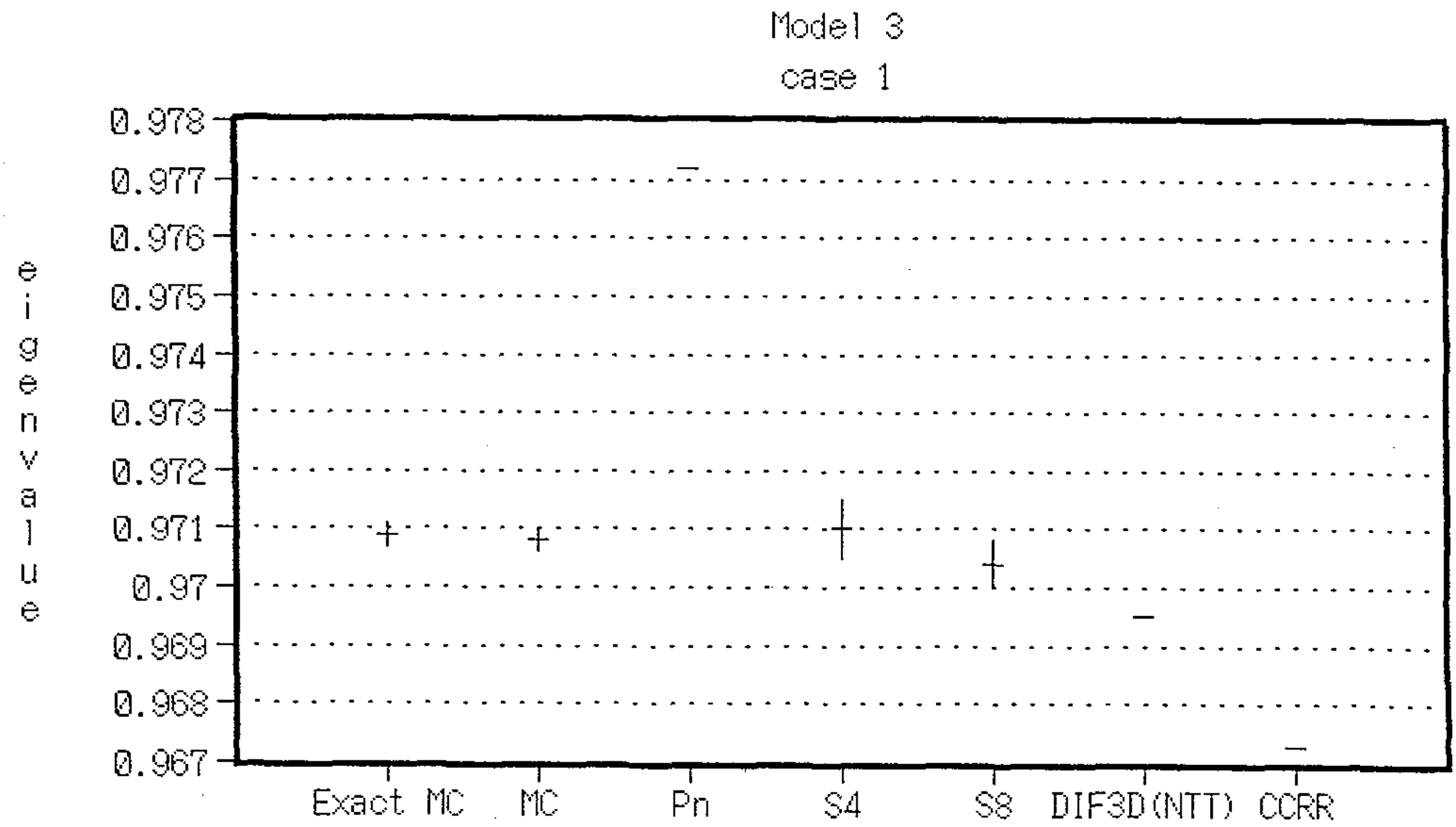


Fig. 11 Average k_{eff} of Model 3, case 1

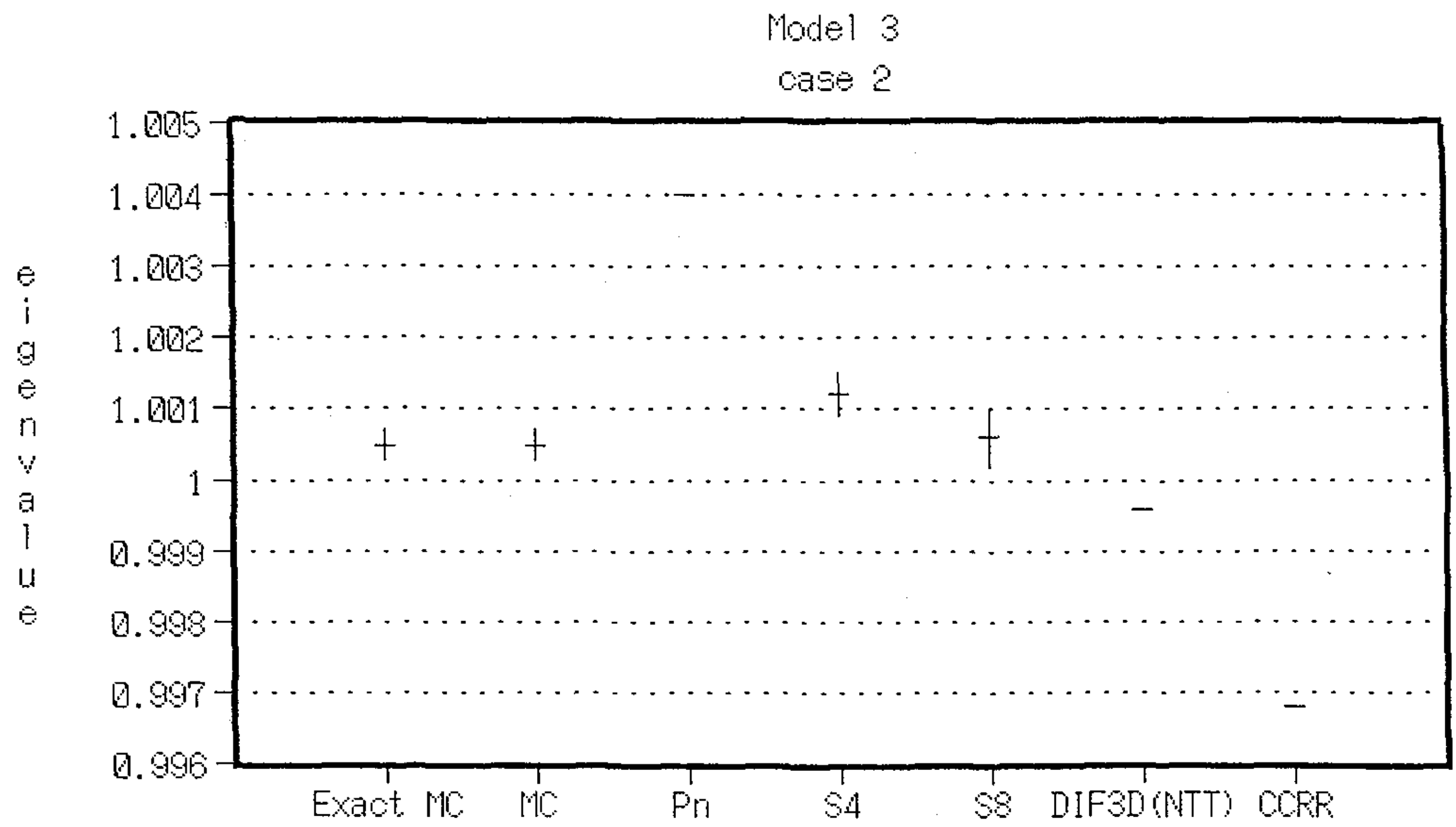


Fig. 12 Average k_{eff} of Model 3, case 2

94260086

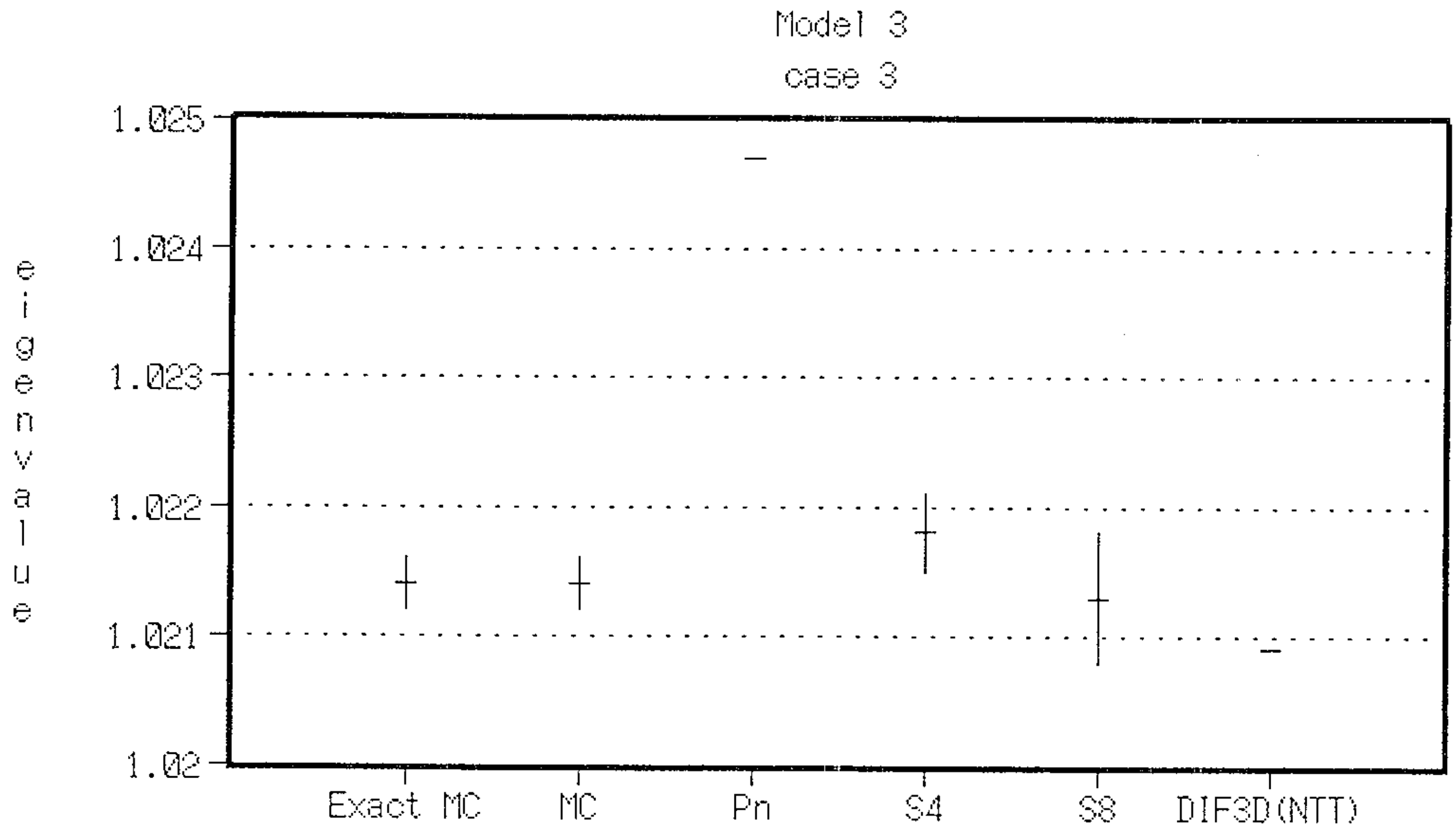


Fig. 13 Average k_{eff} of Model 3, case 3

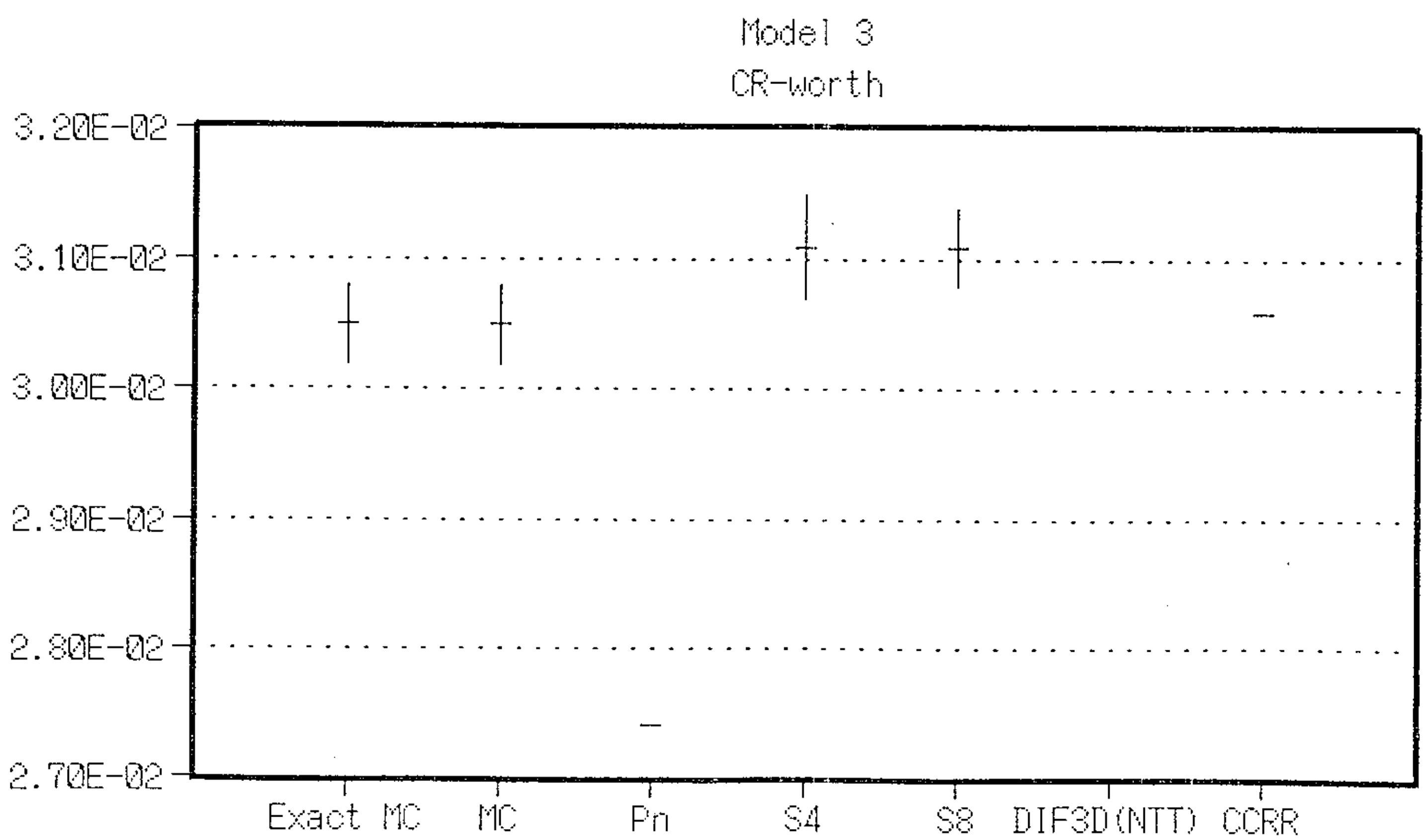


Fig. 14 Average control rod worth of Model 3

94260087

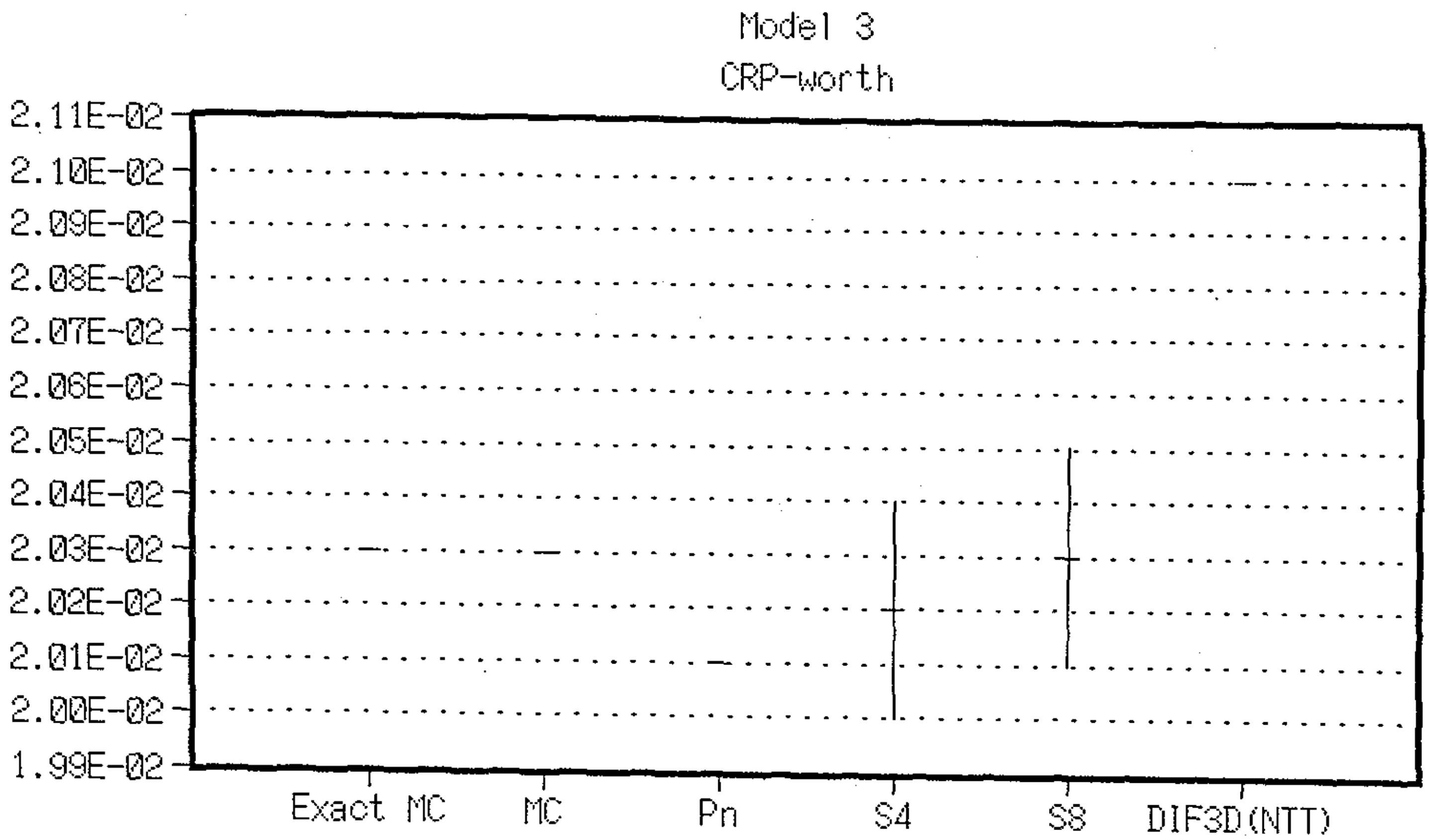


Fig. 15 Average control rod position worth of Model 3

94260088

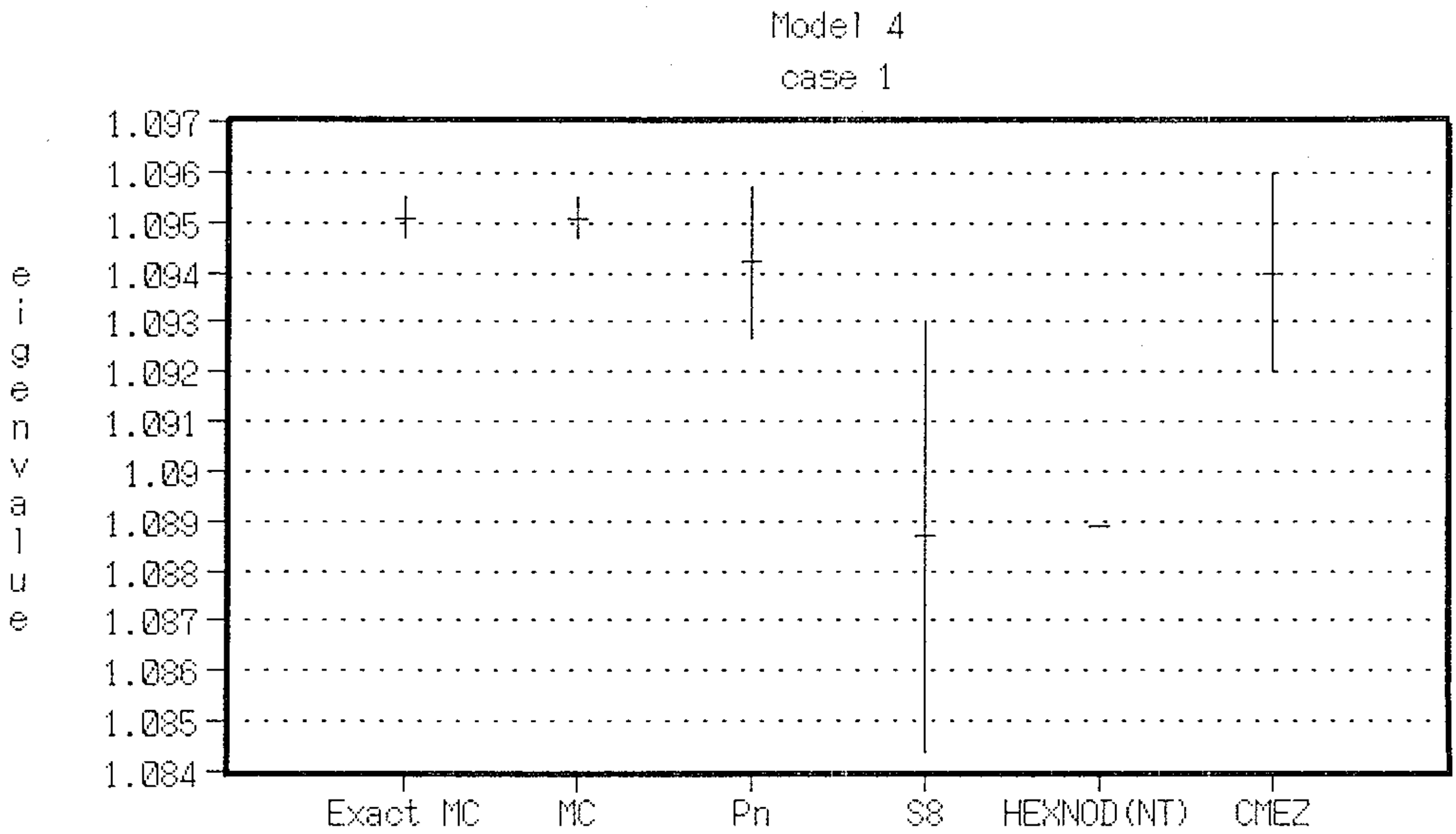


Fig. 16 Average k_{eff} of Model 4, case 1

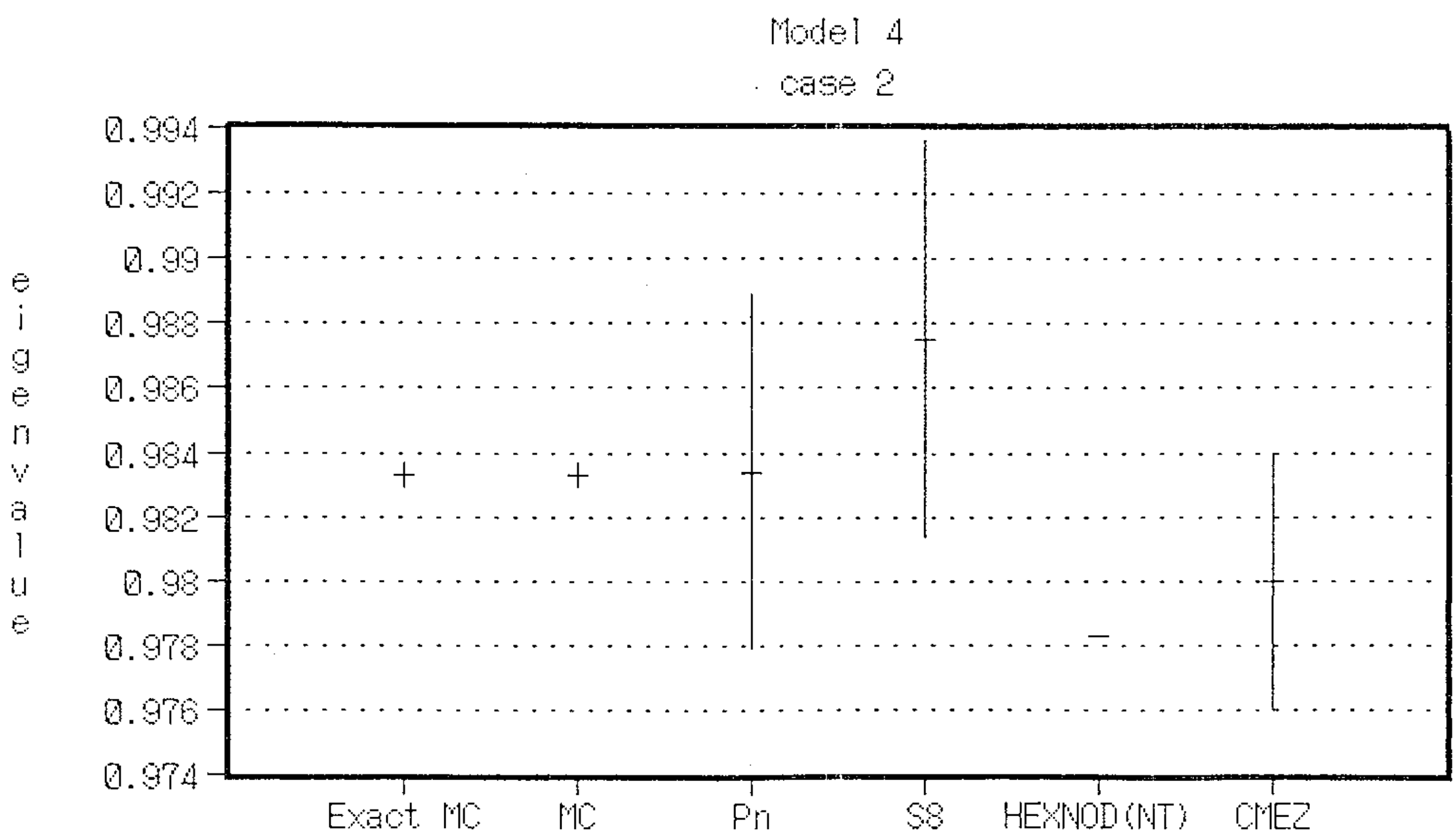


Fig. 17 Average k_{eff} of Model 4, case 2

94260089

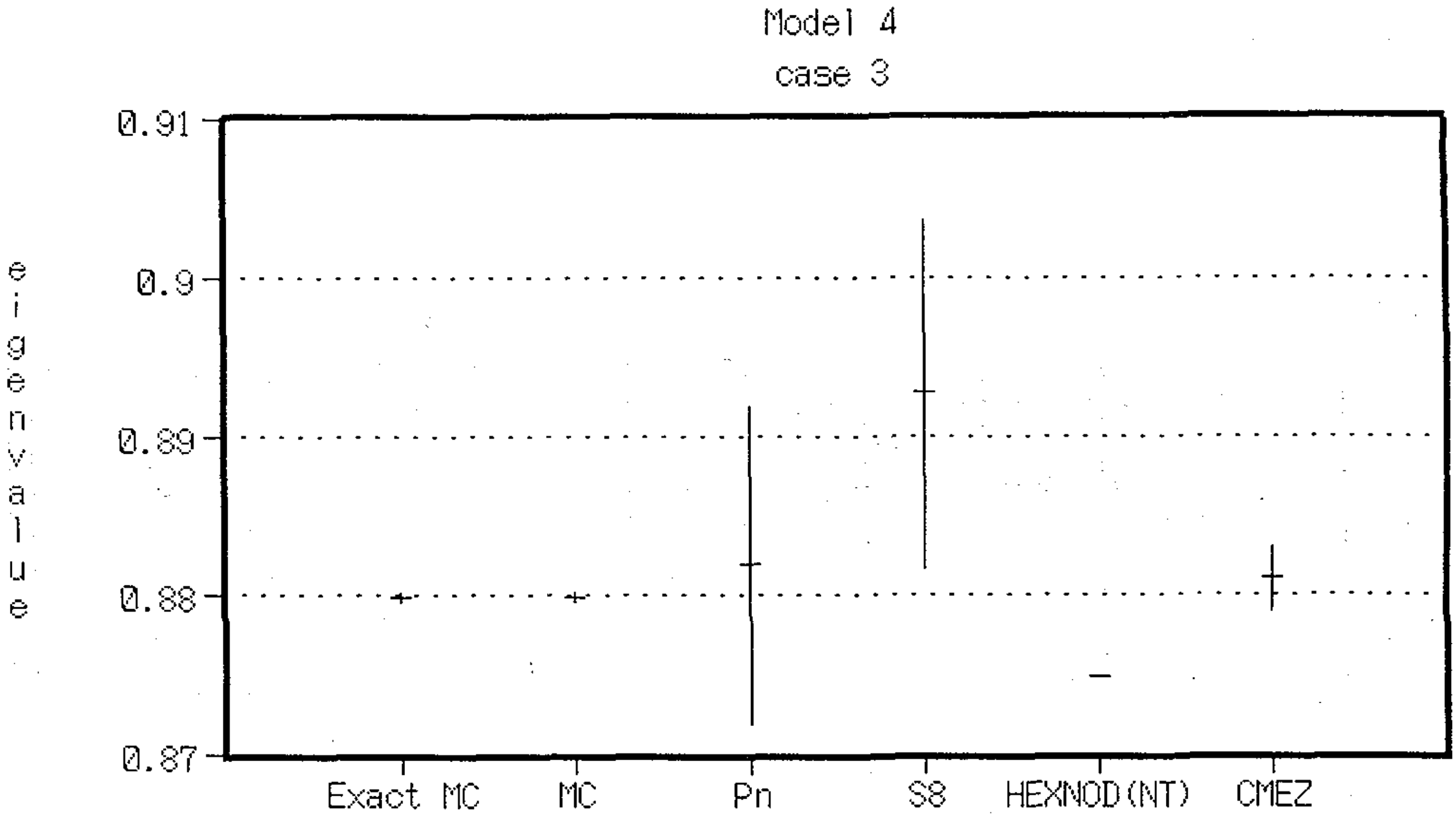


Fig. 18 Average k_{eff} of Model 4, case 3

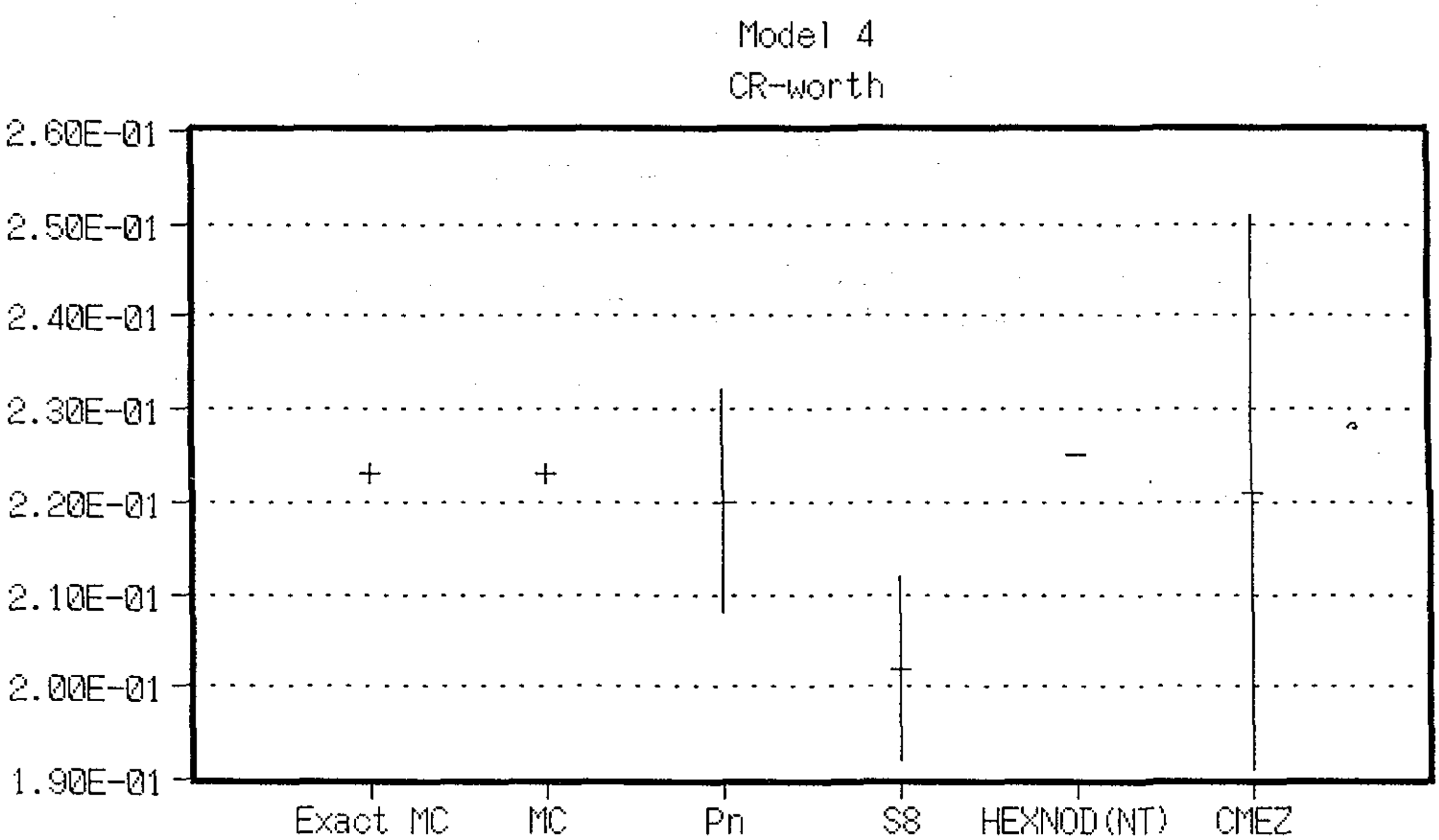


Fig. 19 Average control rod worth of Model 4

94260090

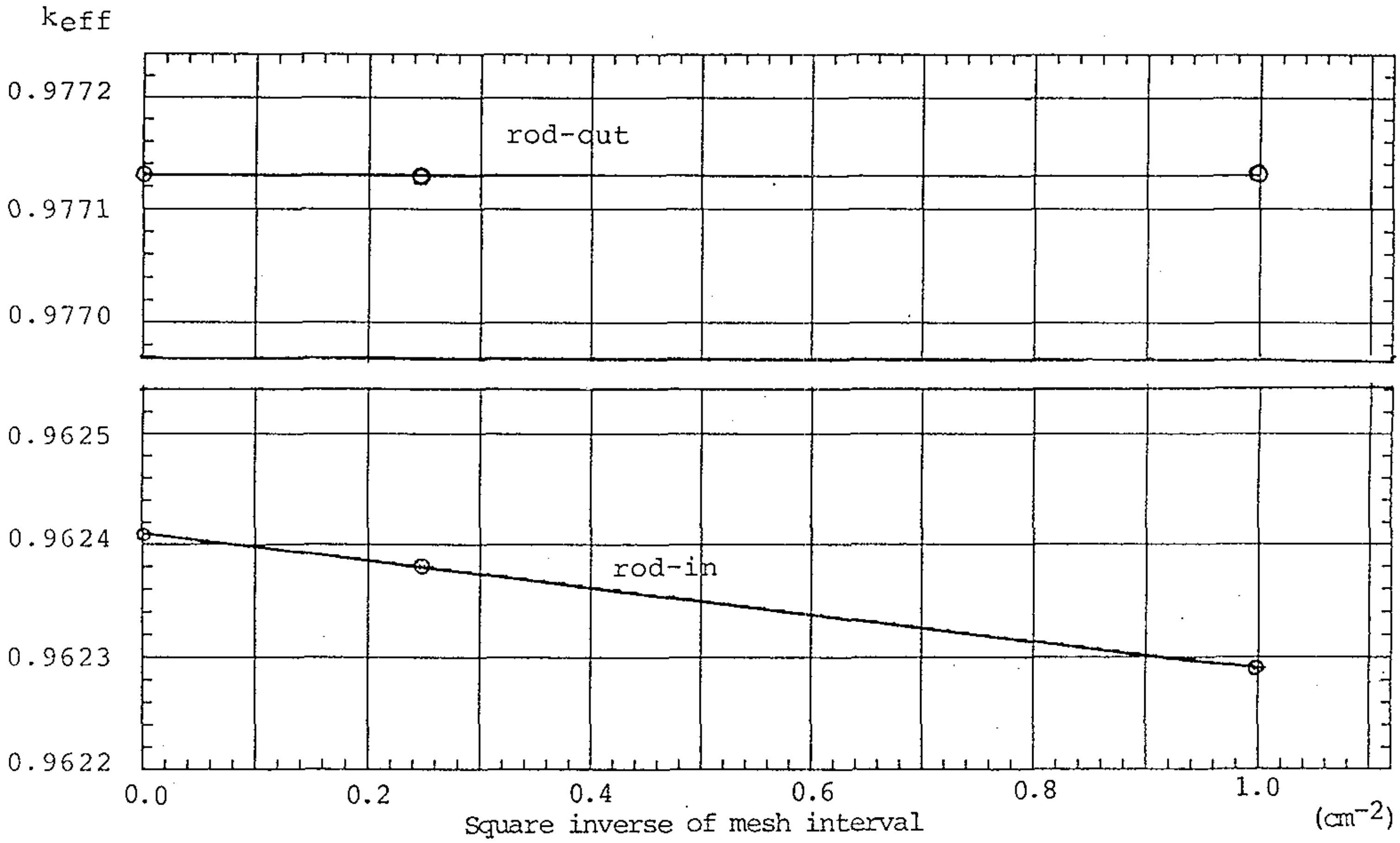


Fig. 20 Spatial mesh effect on k_{eff} for rod-in and rod-out cases of Model 1

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Appendix 1 : "Specifications of calculational benchmark models"

Calculational method

Any calculational methods are acceptable. Not only the direct 3–D treatment such as the 3–D Sn, 3–D nodal transport and Monte–Carlo method, but also the combined use of 1–D and 2–D (XY, Hexagonal, Triangular and RZ) transport calculations can be used.

The following conditions are recommended to use:

1) Flux normalization

The total production of the whole reactor is normalized to unity.

$$\sum_g \int_V dr\, \nu\, \Sigma_{f\,g}(r)\, \Phi_g(r) = 1$$

2) Isotropic scattering

The P_1 scattering effect is included by using the transport cross section instead of total cross section.

3) Multigroup cross sections

The few–group cross sections are given in order to remove the effect of the difference between participants.

The cross section $\Sigma_{t\,g}$ (transport cross section), $\Sigma_{s\,g\rightarrow g'}$ (scattering cross section), $\nu\Sigma_{f\,g}$ (production cross section), χ_g (fission spectrum) are used as in the conventional manner, assuming that χ_g is not space dependent:

$$\Omega \text{ grad } \Phi_g(r,\Omega) + \Sigma_{t\,g}(r)\, \Phi_g(r,\Omega) = \frac{1}{4\pi} \sum_{g'} \Sigma_{s\,g\rightarrow g'}(r) \int_V d\Omega\, \Phi_g(r,\Omega)$$

$$+ \frac{\chi^g}{4\pi\, k_{eff}} \sum_{g'} \nu\Sigma_{f\,g}(r) \int_V d\Omega\, \Phi_g(r,\Omega)$$

The absorption cross section satisfies the relation

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$$\Sigma_{a\,g} = \Sigma_{t\,g} - \sum_{g'} \Sigma_{s\,g \to g'}$$

which means that (n,2n) or (n,3n) processes are not taken into account.

4) The examples of the mesh sizes are given for each calculational model; participants may take their appropriate angle and space meshes. S_4 or S_8 quadrature set will be used at Osaka University (Appendix 2). If possible, it is desirable to calculate the solution extrapolated to fine mesh and $S_{infinity}$ solutions.

The convergence criterion (relative difference between successive iterations) used at Osaka University is as follows;

Inner iteration : $\Delta\Phi / \Phi < 5x10^{-4}$

Outer iteration : $\Delta k / k < 5x10^{-5}$

All participants are requested to supply information on resources used in their computations, e.g. CPU time, core storage, computer type, etc.. Additional information so as to specify clearly how their computations were run are also requested. For example, Monte–Carlo submittals should include information on variance reduction techniques used in the Monte–Carlo runs, and numbers of histories per generation and number of generations.

Calculational model

We consider the following four reactor cores. Participants may choose as many reactor cores as they wish out of the reactor cores provided.

Model 1 (Small LWR)

This core is similar to Kyoto University Critical Assembly (KUCA). The main features are as follows:

Polyethylene moderated

93 w/o enriched U–Al alloy & natural U metal plates

Average ^{235}U enrichment 9.6 w/o, $V_M / V_F = 1.5$

1 / 8 core dimension : X x Y x Z = 15cm x 15cm x 15cm (Fig. 1)

The mesh size used at Osaka University for reference calculation is 1cm x 1cm x 1cm. The control rods are located at core/reflector boundary as shown in Fig. 1.

We consider the following tow cases;

case 1 : The control rod position is empty (void)

case 2 : The control rod is inserted as shown in Fig. 1

It has been found that the control rod worth becomes negative when one utilizes diffusion calculations. Then the transport effect is very strong for control rod worth. The 2–group cross sections are given in Appendix 2.

Required solutions

a) k_{eff} for the two cases, and control rod worth defined by

$$\left.\frac{1}{k_{eff}}\right|_{\text{case 2}} - \left.\frac{1}{k_{eff}}\right|_{\text{case 1}}$$

b) Region–averaged fluxes

Two–group fluxes averaged in the core region, reflector region, control rod or void region.

c) Region–averaged reaction rates

Production and absorption rates in the core and the reflector regions, and the neutron leakage rates from the two regions in each group.

d) Energy group wise flux distributions

Distributions of mesh–averaged flux for the reference mesh (1cm x 1cm x 1cm) is appropriate. The following distributions are required:

1) along X–axis (0.0<X<25.0, 0.0<Y<1.0) on the (0.0<Z<1.0) plane.

2) along Y–axis (0.0<X<1.0, 0.0<Y<25.0) on the (0.0<Z<1.0) plane.

3) along the Z–axis (0.0<X<1.0, 0.0<Y<1.0, 0.0<Z<25.0)

Model 2 (Small FBR)

The core geometry (quarter core) is shown in Fig. 2. The reference mesh size used at Osaka University is 5cm x 5cm x 5cm.

We consider the cases without control rod (case 1; control rod position is filled with Na) and with control rod half–inserted. (case 2) The core calculation is performed in 4–groups. The 4–group cross sections and energy group structure are listed in Appendix 4.

Required solutions

a) k_{eff} for the two cases ; control rod worth

b) Region–averaged reaction rates

Production, absorption and leakage rates in the core, radial blanket, axial blanket, Na filled control rod positions and control rod regions in each group.

c) ^{238}U capture, ^{238}U fission and ^{239}Pu fission rate distributions along X and Y axes at the core midplane rates for the reference mesh size (5cm x 5cm x 5cm) are appropriate, i.e., (0.0<X<70.0, 0.0<Y<5.0) for X–axis, and (0.0<X<5.0, 0.0<Y<70.0) for Y–axis. ^{238}U capture, ^{238}U fission and ^{239}Pu fission macroscopic cross sections are listed below.

Energy Group	^{238}U capture	^{238}U fission	^{239}Pu fission
1	1.184E-4*	3.101E-3	2.192E-3
2	1.076E-3	2.418E-5	1.917E-3
3	3.858E-3	5.354E-7	2.241E-3
4	9.221E-3	4.543E-6	6.827E-3

* : Read as 1.184×10^{-4}
unit = cm^{-1}

d) Region–averaged group wise fluxes for core, axial blanket, radial blanket, Na filled rod positions and control rod regions.

e) For case 2, radial flux distribution along X–axis on Z = 72.5cm plane near the core midplane. Distributions of mesh–averaged flux for the reference mesh size (5cm x 5cm x 5cm) are appropriate.

Model 3 (Axially heterogeneous FBR)

This core has an internal blanket region as in Fig. 3. Furthermore, both center and off-center control rods will be inserted, so that it is difficult to evaluate the core characteristics by 2-D modeling.

The reference mesh size used at Osaka University is 5cm x 5cm x 5cm. 4–group, 1/8 core calculations will be performed. The cross sections are listed in Appendix 3, which is the same as for the small FBR core, Model 2.

We considered the following three cases:

case 1 : control rods are inserted

case 2 : control rods are withdrawn

case 3 : control rods are replaced with core and/or blanket cells as shown Fig. 3b

Required solutions : all solutions required for the three cases.

a) k_{eff} ; control rod worth obtained from case 1 and case 2, and control rod position worth obtained from case 2 and case 3

b) Region–averaged reaction rates

Production, absorption and leakage rates in the core, internal blanket, radial blanket, axial blanket, Na filled control rod positions and control rod regions.

c) ^{238}U capture, ^{238}U fission and ^{239}Pu fission rate distributions along X–axis and transverse at

45° (see Fig. 3a and 3b) at the Z–plane ($0.0<Z<5.0$). Mesh–averaged values appropriate, i.e. ($0.0<X<160.0$, $0<Y<5.0$) for X–axis. ^{238}U capture, ^{238}U fission and ^{239}Pu fission macroscopic cross sections are the same as given for Model 2.

d) Flux distributions along X–axis and transverse at 45° at ($0.0<Z<5.0$) and ($50.0<Z<55.0$) planes.

e) Region–averaged group wise fluxes for core, axial blanket, radial blanket, internal blanket, Na filled control rod positions and control rod regions.

Model 4 (Small FBR with Hexagonal–Z geometry)

This core model is similar to the KNK–II core proposed by I. Broeders and E. Kiefhaber of KfK, Germany.[2] The core is considered of hexagonal subassemblies; cylindrical model is in general a poor approximation. Furthermore, the transport effect is emphasized due to small size of the core and the local insertion of control rods. Therefore, a three–dimensional hexagonal–Z treatment is necessary.

Energy structure and cross sections in four groups listed in Appendix 5.

The core configurations are shown in Fig. 4a.

The control rod patterns are considered as shown in Fig. 4b; control rod withdrawn (case 1), half inserted (case 2) and fully instead (case 3).

Required solutions

a) k_{eff} for all cases

b) control rod worth

c) subassembly–averaged production rates at core midplane ($95.0<Z<100.0$) for all cases

d) Regio–averaged group fluxes for all regions

Appendix 2 : "Reference angular quadrature sets"

S_4 constants

i	μ_i	η_i	ξ_i	w_i
1	0.30163872	0.90444905	0.30163884	0.041666657
2	0.90444905	0.30163872	0.30163884	0.041666657
3	0.30163872	0.30163872	0.90444905	0.041666657

S_8 constants

i	μ_i	η_i	ξ_i	w_i
1	0.19232747	0.96229947	0.19232748	0.014598559
2	0.57735027	0.79352178	0.19232746	0.011656904
3	0.19232747	0.79352178	0.57735027	0.011656904
4	0.79352178	0.57735027	-0.19232748	0.011656904
5	0.57735027	0.57735027	0.57735027	0.011262900
6	0.19232747	0.57735027	0.79352177	0.011656904
7	0.96229947	0.19232747	0.19232749	0.014598559
8	0.79352178	0.19232747	0.57735027	0.011656904
9	0.57735027	0.19232747	0.79253177	0.011656904
10	0.19232747	0.19232747	0.96229947	0.014598559

Appendix 3 : "2-group cross sections and energy group structure for small LWR"

Group	Energy range (eV) Upper	Lower	Fission Spectrum
1	1.0000E+7	6.8256E-1	1.00000
2	6.8256E-1	1.0000E-5	0.00000

Core

Group	Transport	Absorption	Production
1	2.23775E-01	8.52709E-03	9.09319E-03
2	1.03864E+00	1.58196E-01	2.90183E-01

Scattering Matrix

Group	1-->	2-->
1	1.92423E-01	0.0
2	2.28253E-02	8.80439E-01

Reflector

Group	Transport	Absorption	Production
1	2.50367E-01	4.16392E-04	0.0
2	1.64482E+00	2.02999E-02	0.0

Scattering Matrix

Group	1-->	2-->
1	1.93446E-01	0.0
2	5.65042E-02	1.62452E+00

Control Rod

Group	Transport	Absorption	Production
1	8.52325E-02	1.74439E-02	0.0
2	2.17460E-01	1.82224E-01	0.0

Scattering Matrix

Group	1-->	2-->
1	6.77241E-02	0.0
2	6.45461E-05	3.52358E-02

unit : cm-1

Empty(Void)

Group	Transport	Absorption	Production
1	1.28407E-02	4.65132E-05	0.0
2	1.20676E-02	1.32890E-03	0.0

Scattering Matrix

Group	1-->	2-->
1	1.27700E-02	0.0
2	2.40997E-05	1.07387E-02

Appendix 4 : "4-group cross sections and energy group structure for small FBR and axially heterogeneous FBR"

Group	Energy range (eV) Upper	Lower	Fission Spectrum
1	1.00000E+7	1.35340E+6	0.583319
2	1.35340E+6	8.65170E+4	0.405450
3	8.65170E+4	9.61120E+2	0.011231
4	9.61120E+2	1.00000E-5	0.000000

Core

Group	Transport	Absorption	Production
1	1.14568E-01	7.45551E-03	2.06063E-02
2	2.05177E-01	3.52540E-03	6.10571E-03
3	3.29381E-01	7.80136E-03	6.91403E-03
4	3.89810E-01	2.74496E-02	2.60689E-02

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	7.04326E-02	0.00000E+00	0.00000E+00	0.00000E+00
2	3.47967E-02	1.95443E-01	0.00000E+00	0.00000E+00
3	1.88282E-03	6.20863E-03	3.20586E-01	0.00000E+00
4	0.00000E+00	7.07208E-07	9.92975E-04	3.62360E-01

Axial Reflector

Group	Transport	Absorption	Production
1	1.65612E-01	6.39154E-04	0.00000E+00
2	1.66866E-01	4.06876E-04	0.00000E+00
3	2.68633E-01	1.20472E-03	0.00000E+00
4	8.34911E-01	4.36382E-03	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	1.15653E-01	0.00000E+00	0.00000E+00	0.00000E+00
2	4.84731E-02	1.60818E-01	0.00000E+00	0.00000E+00
3	8.46495E-04	5.64096E-03	2.65011E-01	0.00000E+00
4	0.00000E+00	6.57573E-07	2.41755E-03	8.30547E-01

Radial & Inner Blanket

Group	Transport	Absorption	Production
1	1.19648E-01	7.43283E-03	1.89496E-02
2	2.42195E-01	1.99906E-03	1.75265E-04
3	3.56476E-01	6.79036E-03	2.06978E-04
4	3.79433E-01	1.58015E-02	1.13451E-03

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	6.91158E-02	0.00000E+00	0.00000E+00	0.00000E+00
2	4.04132E-02	2.30626E-01	0.00000E+00	0.00000E+00
3	2.68621E-03	9.57027E-03	3.48414E-01	0.00000E+00
4	0.00000E+00	1.99571E-07	1.27195E-03	3.63631E-01

Radial Reflector

Group	Transport	Absorption	Production
1	1.71748E-01	1.13305E-03	0.00000E+00
2	2.17826E-01	4.90793E-04	0.00000E+00
3	4.47761E-01	1.94500E-03	0.00000E+00
4	7.95199E-01	5.70263E-03	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	1.23352E-01	0.00000E+00	0.00000E+00	0.00000E+00
2	4.61307E-02	2.11064E-01	0.00000E+00	0.00000E+00
3	1.13217E-03	6.27100E-03	4.43045E-01	0.00000E+00
4	0.00000E+00	1.03831E-06	2.77126E-03	7.89497E-01

Axial Blanket

Group	Transport	Absorption	Production
1	1.16493E-01	5.35418E-03	1.31770E-02
2	2.20521E-01	1.48604E-03	1.26026E-04
3	3.44544E-01	5.35300E-03	1.52380E-04
4	3.88356E-01	1.34694E-02	7.87302E-04

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	7.16044E-02	0.00000E+00	0.00000E+00	0.00000E+00
2	3.73170E-02	2.10436E-01	0.00000E+00	0.00000E+00
3	2.21707E-03	8.59855E-03	3.37506E-01	0.00000E+00
4	0.00000E+00	6.68299E-07	1.68530E-03	3.74886E-01

Control Rod

Group	Transport	Absorption	Production
1	1.84333E-01	5.97638E-03	0.00000E+00
2	3.66121E-01	1.76941E-02	0.00000E+00
3	6.15527E-01	8.82741E-02	0.00000E+00
4	1.09486E+00	4.76591E-01	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	1.34373E-01	0.00000E+00	0.00000E+00	0.00000E+00
2	4.37775E-02	3.18582E-01	0.00000E+00	0.00000E+00
3	2.06054E-04	2.98432E-02	5.19591E-01	0.00000E+00
4	0.00000E+00	8.71188E-07	7.66209E-03	6.18265E-01

Na Filled CRP

Group	Transport	Absorption	Production
1	6.58979E-02	3.10744E-04	0.00000E+00
2	1.09810E-01	1.13062E-04	0.00000E+00
3	1.86765E-01	4.48988E-04	0.00000E+00
4	2.09933E-01	1.07518E-03	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	4.74407E-02	0.00000E+00	0.00000E+00	0.00000E+00
2	1.76894E-02	1.06142E-01	0.00000E+00	0.00000E+00
3	4.57012E-04	3.55466E-03	1.85304E-01	0.00000E+00
4	0.00000E+00	1.77599E-07	1.01280E-03	2.08858E-01

Empty Matrix

Group	Transport	Absorption	Production
1	1.36985E-02	7.49800E-05	0.00000E+00
2	1.69037E-02	3.82435E-05	0.00000E+00
3	3.12271E-02	1.39335E-04	0.00000E+00
4	6.29537E-02	4.95515E-04	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	9.57999E-03	0.00000E+00	0.00000E+00	0.00000E+00
2	3.95552E-03	1.64740E-02	0.00000E+00	0.00000E+00
3	8.80428E-05	3.91394E-04	3.09104E-02	0.00000E+00
4	0.00000E+00	7.72254E-08	1.77293E-04	6.24581E-02

Appendix 5 : "4-group cross sections and energy group structure for small FBR with hexagonal-Z geometry"

Group	Energy range (eV) Upper	Lower	Fission Spectrum
1	1.05000E+7	4.00000E+5	0.908564
2	4.00000E+5	4.64159E+4	0.087307
3	4.64159E+4	2.15443E+3	0.004129
4	2.15443E+3	Thermal	0.000000

Axial Blanket

Group	Transport	Absorption	Production
1	1.40462E-01	1.93752E-03	2.96101E-03
2	2.25534E-01	1.47927E-03	6.56171E-05
3	3.27065E-01	4.72919E-03	1.14630E-04
4	3.41224E-01	9.94260E-03	4.93483E-04

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	1.23805E-01	0.00000E+00	0.00000E+00	0.00000E+00
2	1.45483E-02	2.17260E-01	0.00000E+00	0.00000E+00
3	1.70276E-04	6.78885E-03	3.17948E-01	0.00000E+00
4	9.37083E-07	6.04793E-06	4.38782E-03	3.31281E-01

Driver without Moderator

Group	Transport	Absorption	Production
1	1.40226E-01	7.09892E-03	1.59878E-02
2	2.28245E-01	9.02877E-03	1.64446E-02
3	3.25806E-01	1.72478E-02	2.71451E-02
4	4.18327E-01	5.74211E-02	8.45807E-02

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	1.19887E-01	0.00000E+00	0.00000E+00	0.00000E+00
2	1.30790E-02	2.15213E-01	0.00000E+00	0.00000E+00
3	1.59938E-04	4.00117E-03	3.06885E-01	0.00000E+00
4	1.07166E-06	1.82716E-06	1.67341E-03	3.60906E-01

Test Zone

Group	Transport	Absorption	Production
1	1.24526E-01	7.14117E-03	1.79043E-02
2	2.01025E-01	8.00576E-03	1.59961E-02
3	2.86599E-01	1.45876E-02	2.40856E-02
4	3.68772E-01	4.98120E-02	7.33104E-02

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	1.05964E-01	0.00000E+00	0.00000E+00	0.00000E+00
2	1.12738E-02	1.89370E-01	0.00000E+00	0.00000E+00
3	1.46192E-04	3.64847E-03	2.70207E-01	0.00000E+00
4	9.62178E-07	1.06888E-06	1.80479E-03	3.18960E-01

Axial Reflector

Group	Transport	Absorption	Production
1	1.32933E-01	3.30045E-04	0.00000E+00
2	1.78531E-01	3.36186E-04	0.00000E+00
3	2.83151E-01	8.61269E-04	0.00000E+00
4	4.62167E-01	3.56939E-03	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	1.22995E-01	0.00000E+00	0.00000E+00	0.00000E+00
2	9.41231E-03	1.73095E-01	0.00000E+00	0.00000E+00
3	1.93791E-04	5.09881E-03	2.77194E-01	0.00000E+00
4	1.39307E-06	7.05075E-07	5.09601E-03	4.58598E-01

Driver with Moderator

Group	Transport	Absorption	Production
1	1.41428E-01	4.67223E-03	1.01663E-02
2	2.45394E-01	5.57965E-03	9.46359E-03
3	3.98255E-01	1.32590E-02	1.87325E-02
4	4.35990E-01	6.51184E-02	8.25335E-02

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	1.14337E-01	0.00000E+00	0.00000E+00	0.00000E+00
2	2.09664E-02	2.12006E-01	0.00000E+00	0.00000E+00
3	1.39132E-03	2.67269E-02	3.52093E-01	0.00000E+00
4	6.10281E-05	1.08186E-03	3.29030E-02	3.70872E-01

KNK-1 Reflector

Group	Transport	Absorption	Production
1	1.51644E-01	4.58692E-04	0.00000E+00
2	1.42382E-01	4.59443E-04	0.00000E+00
3	1.65132E-01	1.07883E-03	0.00000E+00
4	8.04845E-01	5.91325E-03	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	1.38427E-01	0.00000E+00	0.00000E+00	0.00000E+00
2	1.23901E-02	1.37502E-01	0.00000E+00	0.00000E+00
3	3.66930E-04	4.41927E-03	1.60722E-01	0.00000E+00
4	1.69036E-06	1.63280E-06	3.33075E-03	7.98932E-01

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Reflector with Moderator

Group	Transport	Absorption	Production
1	1.39164E-01	3.97516E-04	0.00000E+00
2	2.46993E-01	3.02674E-04	0.00000E+00
3	4.52425E-01	1.22034E-03	0.00000E+00
4	5.36256E-01	2.41527E-02	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	1.05911E-01	0.00000E+00	0.00000E+00	0.00000E+00
2	2.96485E-02	1.84820E-01	0.00000E+00	0.00000E+00
3	3.06502E-03	5.91780E-02	3.73072E-01	0.00000E+00
4	1.41697E-04	2.69229E-03	7.81326E-02	5.12103E-01

Sodium / Steel Zone

Group	Transport	Absorption	Production
1	9.65097E-02	2.25039E-04	0.00000E+00
2	9.87095E-02	2.33696E-04	0.00000E+00
3	1.34200E-01	5.39303E-04	0.00000E+00
4	4.12670E-01	3.03759E-03	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	8.83550E-02	0.00000E+00	0.00000E+00	0.00000E+00
2	7.73409E-03	9.52493E-02	0.00000E+00	0.00000E+00
3	1.94719E-04	3.22568E-03	1.30756E-01	0.00000E+00
4	8.89615E-07	7.98494E-07	2.90481E-03	4.09632E-01

Reflector without Moderator

Group	Transport	Absorption	Production
1	1.59346E-01	4.64814E-04	0.00000E+00
2	2.16355E-01	4.76496E-04	0.00000E+00
3	3.48692E-01	1.23810E-03	0.00000E+00
4	6.24249E-01	4.94333E-03	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	1.47969E-01	0.00000E+00	0.00000E-00	0.00000E+00
2	1.06607E-02	2.10410E-01	0.00000E+00	0.00000E+00
3	2.49556E-04	5.46711E-03	3.42085E-01	0.00000E+00
4	1.82565E-06	1.00157E-06	5.36879E-03	6.19306E-01

Control Rod

Group	Transport	Absorption	Production
1	1.39085E-01	8.62218E-03	0.00000E+00
2	2.28152E-01	2.91302E-02	0.00000E+00
3	3.18806E-01	7.40851E-02	0.00000E+00
4	6.27366E-01	3.12550E-01	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	1.17722E-01	0.00000E+00	0.00000E+00	0.00000E+00
2	1.26066E-02	1.94699E-01	0.00000E+00	0.00000E+00
3	1.33314E-04	4.32219E-03	2.44352E-01	0.00000E+00
4	1.08839E-06	1.85491E-07	3.68781E-04	3.14816E-01

Steel

Group	Transport	Absorption	Production
1	9.83638E-02*	2.16042E-04	0.00000E-00
2	1.35140E-01	2.06601E-04	0.00000E+00
3	2.24749E-01	5.56175E-04	0.00000E+00
4	2.83117E-01	2.40965E-03	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	9.06050E-02	0.00000E+00	0.00000E+00	0.00000E+00
2	7.42377E-03	1.30581E-01	0.00000E+00	0.00000E+00
3	1.18163E-04	4.35250E-03	2.19547E-01	0.00000E+00
4	8.25890E-07	3.41675E-07	4.64594E-03	2.80707E-01

Sodium Filled Control Rod Position

Group	Transport	? Absorption	Production
1	7.27587E-02	9.06964E-05	0.00000E+00
2	1.00218E-01	8.04746E-05	0.00000E+00
3	1.60703E-01	1.96101E-04	0.00000E+00
4	1.51576E-01	1.20796E-03	0.00000E+00

Scattering Matrix

Group	1-->	2-->	3-->	4-->
1	6.63634E-02	0.00000E+00	0.00000E-00	0.00000E+00
2	6.23393E-03	9.61236E-02	0.00000E+00	0.00000E-00
3	7.02121E-05	4.01375E-03	1.56016E-01	0.00000E-00
4	4.16388E-07	1.26939E-07	4.49111E-03	1.50368E-01