ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

ARGONNE CODE CENTER:
BENCHMARK PROBLEM BOOK

La Grange Inst. dlt.
1506706

Prepared by the
Computational Benchmark Problems Committee of the
MATHEMATICS AND COMPUTATION DIVISION
OF THE AMERICAN NUCLEAR SOCIETY

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ANL-7416 Supplement 2

This publication is the second supplement to, and revision of, ANL-7416, originally published in February 1968, with Supplement 1 issued in December 1972.

Supplemental and replacement pages contained in this publication are as follows:

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INSERTED

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PAGES TO BE
REMOVED

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COMMENT

Revised page

Revised pages

Revised page

Supplemental pages
containing Source
Situations 8 through
15 with accompanying
Benchmark Problems
and Benchmark Problem
Solutions

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PREFACE

This book is an outgrowth of activities of the Computational Benchmark Problems Committee of the Mathematics and Computation Division of the American Nuclear Society. This is the second supplement of the original benchmark book which was first published in February, 1968 and contained computational benchmark problems in four different areas. Supplement No. 1, which was published in December, 1972, contained corrections to the original benchmark book plus additional problems in three new areas. The current supplement, Supplement No. 2, contains problems in eight additional new areas.

The objectives of computational benchmark work and the procedures used by the committee in pursuing the objectives are outlined in the original edition of the benchmark book (ANL-7416, February, 1968). The members of the committee who have made contributions to Supplement No. 2 are listed below followed by the contributors to the earlier editions of the benchmark book.

ANL-7416, Supplement No. 2 (June 1977)

D. F. Biron (GAAA-France)
P. T. Choong (GE)
G. W. Cunningham (ORNL)
H. L. Dodds, Jr. (U. of Tenn.), Chairman
V. J. Esposito (W-NES)
E. Finnemann (KWU)
T. B. Fowler (ORNL)
E. L. Fuller (EPRI)
M. V. Gregory (SRL)
K. Koebke (KWU)
S. A. Kusneriuk (AECL-CRNL)
S. Langenbuch (GRS-Munich)
E. R. Lee (CE)
A. Leonard (NASA-Ames)
S. K. Loyalka (U. of Mo.)
A. N. Mallen (SRL)
C. T. McDaniel (GE-San Jose)
F. N. McDonnell (AECL-CRNL)
D. A. Meneley (Ontario Hydro)
B. Micheelsen (RISØ-Denmark)
I. Misfeldt (RISØ-Denmark)
C. D. Morgan (B&W)
A. Nero (EPRI)
F. J. Rahn (EPRI)
D. B. Selby (ORNL)
R. G. Steinke (LASL)
D. R. Vondy (ORNL)
M. R. Wagner (KWU)
B. A. Weate (GA)
W. Werner (GRS-Munich)
W. A. Wittkopf (B&W)
B. A. Zolotar (EPRI)

ANL-7416, Supplement No. 1 (December 1972)

R. Breen (BAPL)
R. H. Brogli (GGA)
H. L. Dodds, Jr. (SRL)
E. L. Fuller (ANL)
H. Greenspan (ANL)
B. A. Hutchins (GE-San Jose)
D. Meneley (Ontario Hydro), Chairman
W. H. Rhyne (NFS)
D. Vondy (ORNL)
M. R. Wagner (Siemens)

ANL-7416, Original Edition (February 1968)

R. Blaine (AI)
R. Froehlich (GGA)
H. Greenspan (ANL)
K. Lathrop (GGA)
W. Turner (KAPL)
D. Vondy (ORNL)
E. Wachspress (KAPL), Chairman

Constraints

Boundary conditions

Approximations and simplifications

3. Configuration

Description

Reduction from source situation, if applicable

Sketch

4. Data

5. Specific Problems of Interest

Reference problem

Other problems

6. Expected Results

Primary results

Auxiliary results

7. Summary of Available Solutions

Most accurate known solution with the estimated accuracy

Other solutions

8. Documentation of Solutions

References

Sufficient data on techniques to enable duplication of results

Computer characteristics, including essential hardware and software data for the program with which the problem was solved, and significant figures carried in the computation

Solution details

Rigid adherence to any form might hinder rather than aid the specification of benchmark problems. For this reason, format guidelines rather than standard forms have been presented for general use.

IV. BENCHMARK PROBLEMS

Source Situations

1. Small Spherical Critical Experiment
2. A High-temperature Gas-cooled Reactor Configuration
3. An Analytical Two-dimensional Multigroup Diffusion Problem
4. A Simple Highly Nonseparable Reactor
5. Two-dimensional Isolated Source in an Absorbing Medium
6. Infinite Slab Reactor Model
7. Monoenergetic Point Reactor Model
8. Two-dimensional (R-z) Reactor Model
9. Multi-dimensional (Hex-z) HTGR Model
10. PWR Thermal Hydraulics--Flow Between Two Channels With Different Heat Fluxes
11. Multi-dimensional (x-y-z) LWR Model
12. Neutron Transport in a Cylindrical 'Black' Rod
13. Neutron Transport in a BWR Rod Bundle
14. Multi-dimensional (x-y-z) BWR Model
15. Neutronic Depletion Benchmark Problems

BENCHMARK PROBLEM SOLUTION

Identification: 7-A2-2

Benchmark Problem ID.7-A2

Date Submitted: May 1971

By: W. H. Köhler and
R. T. Perry (Texas A&M)
(Name and Organization)

Date Accepted: January 1973

By: D. A. Meneley (Ontario Hydro)
(Name and Organization)Descriptive Title: AIREK3¹ Finite-difference Solution with Constant Heat
Removal

Mathematical Model: See Ref. 1.

Pertinent Features of Solution Methods: See Solution ID.7-A1-3

Computer: IBM 360/65

Date Solved: May 1971

at: Texas A&M

Program: AIREK3

Reference

1. L. R. Blue and M. Hoffman, Generalized Program for the Numerical Solution of Space Independent Reactor Kinetics Equations,
Atomics International Document AMTD-131 (1963).

Results

Period of power density oscillation = 0.817 sec

Maximum power density = 6558 w/cm³

Temperature rise per period = 408.07°C

BENCHMARK SOURCE SITUATION

Identification: 8

Date Submitted: January 1973 By: H. L. Dodds, Jr. (U. of Tenn.)

Date Adopted: June 1977 By: E. L. Fuller (EPRI)
W. Werner (GRS-Munich)

Descriptive Title: *Two-Dimensional (R-z) Reactor Model*

Suggested Function: Test two-dimensional neutron kinetics solutions

Reactor Configuration:

Note: All Dimensions
in Centimeters

BENCHMARK PROBLEM

Identification: 8-A1 Source Situation ID.8
 Date Submitted: January 1973 By: H. L. Dodds, Jr. (U. of Tenn.)
 Date Accepted: June 1977 By: E. L. Fuller (EPRI)
 W. Werner (GRS-Munich)
 Descriptive Title: *Delayed Supercritical Transient; Two-Dimensional, Two-Group Neutron Diffusion Problem in Thermal Reactor*

Reduction of Source Situation:

1. Two-dimensional (r-z), two-group diffusion theory
2. Six delayed neutron precursor groups

$$\begin{aligned} \nabla \cdot D_1(\bar{r}, t) \nabla \phi_1(\bar{r}, t) - \Sigma_1(\bar{r}, t) \phi_1(\bar{r}, t) + (1-\beta) \left[v \Sigma_{f_1}(\bar{r}, t) \cdot \right. \\ \left. \phi_1(\bar{r}, t) + v \Sigma_{f_2}(\bar{r}, t) \phi_2(\bar{r}, t) \right] + S_1(\bar{r}, t) \\ + \sum_{i=1}^6 \lambda_i C_i(\bar{r}, t) = \frac{1}{V_1} \frac{\partial}{\partial t} \phi_1(\bar{r}, t) \end{aligned}$$

$$\begin{aligned} \nabla \cdot D_2(\bar{r}, t) \nabla \phi_2(\bar{r}, t) - \Sigma_2(\bar{r}, t) \phi_2(\bar{r}, t) + \Sigma_{1 \rightarrow 2}(\bar{r}, t) \phi_1(\bar{r}, t) \\ + S_2(\bar{r}, t) = \frac{1}{V_2} \frac{\partial}{\partial t} \phi_2(\bar{r}, t) \end{aligned}$$

$$\begin{aligned} \beta^i \left[v \Sigma_{f_1}(\bar{r}, t) \phi_1(\bar{r}, t) + v \Sigma_{f_2}(\bar{r}, t) \phi_2(\bar{r}, t) \right] - \lambda_i C_i(\bar{r}, t) \\ = \frac{\partial}{\partial t} C_i(\bar{r}, t), \quad i=1, \dots, 6 \end{aligned}$$

with zero flux boundary conditions on external surfaces
and steady state initial conditions.

Data:

Initial Two-Group Constants

Region	Group i	D_i (cm)	Σ_i^* (cm ⁻¹)	$v\Sigma_{f_i}$ (cm ⁻¹)	Σ_{1+2} (cm ⁻¹)
1,15	1	1.0684+0	2.8-2	0	2.6-2
	2	0.32051+0	3.3-3	0	-
2,14	1	1.3495+0	1.201-2	0	1.2-2
	2	8.7032-1	1.9-2	0	-
3,4,11	1	1.3052+0	1.0475-2	1.1776-3	8.0351-3
	2	8.8857-1	1.3063-2	1.3268-2	-
5,12	1	1.3052+0	1.0475-2	1.1776-3	8.0351-3
	2	8.8857-1	1.2623-2	1.3268-2	-
6,13	1	1.3052+0	1.0475-2	1.1776-3	8.0351-3
	2	8.8857-1	1.2183-2	1.3268-2	-
7,8	1	1.3052+0	1.0475-2	1.1776-3	8.0351-3
	2	8.8857-1	1.3453-2	1.3268-2	-
9	1	1.3052+0	1.0475-2	1.1776-3	8.0351-3
	2	8.8857-1	1.2973-2	1.3268-2	-
10	1	1.3052+0	1.0475-2	1.1776-3	8.0351-3
	2	8.8857-1	1.2933-2	1.3268-2	-
16	1	1.2997+1	1.0470-2	1.2875-3	7.9061-3
	2	8.7951-1	1.3065-2	1.4246-2	-

Additional parameters for all regions are $V_1 = 10^7$ cm/sec,

$V_2 = 2.2 \times 10^5$ cm/sec,

$S_1 = S_2 = 0.0$

$$* \Sigma_1 = \Sigma_{c_1} + \Sigma_{f_1} + \Sigma_{1+2}$$

$$\Sigma_2 = \Sigma_{c_2} + \Sigma_{f_2}$$

Additional Data:

Delayed Neutron Data

Type	β	λ (sec ⁻¹)
1	2.47-4	1.27-2
2	1.394-3	3.17-2
3	1.222-3	1.15-1
4	2.645-3	3.11-1
5	8.32-4	1.40+0
6	1.69-4	3.87+0

Initiating Perturbation:

In Regions 3 and 7,

$$\frac{\Sigma_2(t)}{\Sigma_2(0)} = \begin{cases} 1 + 0.03 t, & t \leq 1 \\ 1.03, & t > 1 \end{cases}$$

where t = time (sec).

In Region 11,

$$\frac{\Sigma_2(t)}{\Sigma_2(0)} = \begin{cases} 1 - 0.03 t, & t \leq 1 \\ 0.97, & t > 1 \end{cases}$$

The initial configuration is made critical by dividing the production cross sections by k_{eff} , and the initial precursor concentrations are in equilibrium with the initial critical flux distribution.

Expected Primary Results:

1. Total power versus time
2. Time-dependent group flux distributions

Possible Additional Results:

1. Sensitivity of solution to time-step size
2. Power density averaged over height versus radial position, i.e.,

$$\frac{\frac{1}{N} \sum_{\text{all } j} \int_{V_{ij}} (\Sigma_{f_1} \phi_1 + \Sigma_{f_2} \phi_2) dv}{\sum_{\text{all } j} \int_{V_{ij}} dv} \quad \text{versus } r_i$$

for $i = 1, \dots, \text{NPX}$ and $j = 1, \dots, \text{NPY}$

where V_{ij} = mesh volume element ij

NPX = number of radial mesh points

NPY = number of axial mesh points

N = normalization constant (arbitrary)

3. Power density averaged over radius versus axial position, i.e.,

$$\frac{\frac{1}{N} \sum_{\text{all } i} \int_{V_{ij}} (\Sigma_{f_1} \phi_1 + \Sigma_{f_2} \phi_2) dv}{\sum_{\text{all } i} \int_{V_{ij}} dv} \quad \text{versus } Z_j$$

for $i = 1, \dots, \text{NPX}$ and $j = 1, \dots, \text{NPY}$

Solutions:

1. Direct finite-difference method: 8-A1-1, 8-A1-3
2. Flux factorization method: 8-A1-2

BENCHMARK PROBLEM SOLUTION

Identification: 8-A1-1 Benchmark Problem ID.8-A1
Date Submitted: January 1973 By: H. L. Dodds, Jr. (U. of Tenn.)
Date Accepted: June 1977 By: E. L. Fuller (EPRI)
W. Werner (GRS-Munich)
Descriptive Title: *Direct Finite-Difference Solution with*
TWØDTA^{1,2}

Mathematical Model: A 5-point difference approximation with mesh points located at mesh interval boundaries is used for the leakage operator in the neutron diffusion equations². The time dependence is approximated by backward differences.

Computer: IBM-360, Model 195

Code: TWØDTA¹ (single-precision)

Date Solved: January 1973 at Savannah River Laboratory

References:

1. H. L. Dodds, J. W. Stewart, and C. E. Bailey, "Comparison of the Quasistatic and Direct Methods for Two-Dimensional Thermal Reactor Dynamics," *Trans. Am. Nucl. Soc.* 15(2), 786 (1972).
2. Y. B. Yasinsky, M. Natelson, and L. A. Hageman, *TWIGL -- A Program to Solve the Two-Dimensional, Two-Group, Space-Time Neutron Diffusion Equations with Temperature Feedback*, WAPD-TM-743, Bettis Atomic Power Laboratory (1968).

Results: This solution as well as solutions 8-A1-2 and 8-A1-3 are for a fixed spatial mesh ($\Delta r = 8$ cm, 30 intervals and $\Delta Z = 18.75$ cm, 28 intervals). However, different size time steps were used in order to evaluate the temporal discretization error.

Initial $k_{\text{eff}} = 0.866901$.

Although the value of k_{eff} resulting from solution of the eigenvalue problem is 0.867053, the value of k_{eff} actually used in the transient calculation to divide the production cross sections is 0.866901, which is determined by requiring that the unperturbed reactor exhibit a steady state transient behavior.

Exhibit A: Total power (relative to initial value) versus time as a function of Δt .

Exhibit B: Group 1 and Group 2 relative flux distributions at 0.0, 1.0, and 4.0 sec for $\Delta t = 0.001$ sec. Zero flux values on the external surfaces are not tabulated.

Exhibit C: Power density averaged over height versus radial position, i.e.,

$$\frac{\frac{1}{N} \sum_{\text{all } j} \int_{V_{ij}} (\Sigma_{f1} \phi_1 + \Sigma_{f2} \phi_2) dv}{\sum_{\text{all } j} \int_{V_{ij}} dv} \quad \text{versus } r_i$$

for $i = 1, \dots, \text{NPX}$ and $j = 1, \dots, \text{NPY}$

where V_{ij} = mesh volume element ij

NPX = number of radial mesh points

NPY = number of axial mesh points

N = normalization constant (arbitrary)

Exhibit D: Power density averaged over radius versus axial position, i.e.,

$$\frac{\frac{1}{N} \sum_{\text{all } i} \int_{V_{ij}} (\Sigma_{f_1} \phi_1 + \Sigma_{f_2} \phi_2) dv}{\sum_{\text{all } i} \int_{V_{ij}} dv} \text{ versus } Z_j$$

for $i = 1, \dots, \text{NPX}$ and $j = 1, \dots, \text{NPY}$

Exhibit E: Plot of data presented in Exhibit C.

Exhibit F: Plot of data presented in Exhibit D.

EXHIBIT A

Total Power Versus Time as Function of Time-Step Size

Time (sec)	Δt (sec)					
	0.001	0.005	0.05	0.2	0.5	1.0
0	1.000	1.000	1.000	1.000	1.000	1.0
0.2	1.039	1.038	1.040	1.043		
0.4	1.108	1.107	1.110	1.113		
0.6	1.209	1.209	1.211	1.217		
0.8	1.360	1.359	1.364	1.373		
1.0	1.596	1.595	1.604	1.623	1.661	1.723
1.2	1.752	1.750	1.749	1.744		
1.4	1.828	1.825	1.828	1.826		
1.6	1.895	1.892	1.895	1.896		
1.8	1.960	1.957	1.960	1.961		
2.0	2.027	2.020	2.023	2.025	2.037	2.078
3.0	2.335	2.329	2.336	2.338	2.351	2.393
4.0	2.659	2.652	2.660	2.663	2.678	2.724
CPU* Time (sec)	3057	727	219	110	85	62

* IBM-360, Model 195

Relative Flux in Group 1 at Time = 0.0 sec

	Radial Mesh Point Number																			
Axial Mesh Point Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
4	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.19	0.18
5	0.18	0.17	0.15	0.14	0.12	0.11	0.09	0.07	0.04	0.02										
6	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.64	0.64	0.64	0.64	0.64	0.64	0.63	0.63	0.61	0.59	
7	0.57	0.54	0.50	0.45	0.40	0.34	0.28	0.21	0.14	0.07										
8	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.02	1.01	0.99	0.96
9	0.92	0.87	0.80	0.73	0.64	0.55	0.45	0.34	0.23	0.11										
10	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.35	1.33	1.30	1.26
11	1.21	1.14	1.06	0.96	0.85	0.73	0.60	0.45	0.30	0.15										
12	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.60	1.58	1.54	1.49
13	1.43	1.35	1.25	1.13	1.00	0.86	0.70	0.53	0.36	0.18										
14	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.77	1.76	1.73	1.69	1.64
15	1.57	1.49	1.37	1.24	1.09	0.94	0.77	0.58	0.39	0.19										
16	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.85	1.85	1.83	1.80	1.75	1.69
17	1.61	1.51	1.40	1.26	1.12	0.97	0.80	0.61	0.41	0.20										
18	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.88	1.88	1.88	1.88	1.88	1.87	1.86	1.84	1.81	1.76	1.69
19	1.60	1.50	1.38	1.25	1.11	0.96	0.80	0.61	0.41	0.20										
20	1.91	1.91	1.91	1.91	1.91	1.91	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.89	1.88	1.85	1.81	1.76	1.69
21	1.60	1.50	1.38	1.25	1.11	0.96	0.80	0.61	0.41	0.20										
22	1.92	1.92	1.92	1.92	1.91	1.91	1.91	1.91	1.91	1.91	1.90	1.90	1.90	1.90	1.89	1.88	1.87	1.85	1.82	

EXHIBIT B (Continued)

Relative Flux in Group 2 at Time = 0.0 sec

Radial Mesh Point Number																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
5	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
6	0.13	0.13	0.12	0.12	0.10	0.09	0.08	0.06	0.05	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
7	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
8	0.36	0.36	0.32	0.29	0.25	0.21	0.17	0.13	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.58	0.55	0.51	0.46	0.41	0.34	0.27	0.20	0.13	0.07	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
10	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
11	0.76	0.73	0.67	0.61	0.53	0.45	0.36	0.27	0.16	0.09	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
12	0.98	0.98	0.90	0.90	0.90	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
13	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
14	0.98	0.93	0.87	0.76	0.69	0.58	0.46	0.34	0.23	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
16	1.00	0.94	0.87	0.79	0.69	0.59	0.47	0.36	0.24	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12
18	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
19	0.98	0.93	0.87	0.78	0.69	0.58	0.46	0.34	0.23	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
21	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
22	0.76	0.73	0.67	0.62	0.53	0.45	0.36	0.27	0.16	0.09	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
23	0.58	0.55	0.51	0.46	0.41	0.34	0.27	0.20	0.13	0.07	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
24	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
25	0.36	0.36	0.32	0.29	0.25	0.21	0.17	0.13	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	0.58	0.55	0.51	0.46	0.41	0.34	0.27	0.20	0.13	0.07	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
27	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
28	0.76	0.73	0.67	0.61	0.53	0.45	0.36	0.27	0.16	0.09	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

EXHIBIT B (Continued)

Relative Flux in Group 1 at Time = 1.0 sec

Radial Mesh Point Number

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
4	0.23	0.23	0.23	0.24	0.24	0.24	0.25	0.25	0.25	0.25	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.24
5	0.73	0.73	0.74	0.74	0.75	0.77	0.78	0.79	0.80	0.81	0.81	0.82	0.83	0.83	0.83	0.84	0.83	0.83	0.81	0.79
6	1.18	1.18	1.19	1.20	1.22	1.24	1.26	1.28	1.29	1.31	1.32	1.33	1.34	1.34	1.35	1.35	1.35	1.34	1.31	1.27
7	1.58	1.58	1.59	1.60	1.63	1.65	1.68	1.70	1.72	1.74	1.75	1.77	1.78	1.79	1.80	1.80	1.79	1.77	1.74	1.69
8	1.89	1.93	1.91	1.93	1.95	1.98	2.02	2.04	2.07	2.09	2.10	2.12	2.13	2.14	2.15	2.15	2.14	2.12	2.07	2.01
9	2.12	2.13	2.14	2.16	2.19	2.22	2.26	2.29	2.31	2.33	2.35	2.37	2.38	2.39	2.40	2.40	2.38	2.35	2.30	2.23
10	2.26	2.26	2.27	2.30	2.33	2.36	2.40	2.43	2.46	2.48	2.49	2.51	2.52	2.53	2.53	2.53	2.51	2.47	2.41	2.33
11	2.35	2.35	2.36	2.39	2.42	2.45	2.49	2.52	2.54	2.57	2.58	2.59	2.60	2.61	2.61	2.60	2.58	2.54	2.47	2.37
12	2.44	2.45	2.46	2.48	2.51	2.55	2.58	2.61	2.64	2.66	2.67	2.68	2.69	2.69	2.69	2.68	2.65	2.60	2.53	2.42
13	2.55	2.56	2.57	2.59	2.62	2.66	2.69	2.72	2.75	2.76	2.77	2.78	2.78	2.78	2.77	2.74	2.68	2.60	2.49	
14	2.68	2.69	2.70	2.72	2.75	2.79	2.83	2.85	2.87	2.89	2.89	2.90	2.90	2.89	2.88	2.87	2.83	2.77	2.68	2.57
15	2.85	2.85	2.87	2.89	2.92	2.95	2.98	3.01	3.02	3.03	3.04	3.04	3.03	3.02	3.00	2.98	2.94	2.87	2.78	2.66
16	3.06	3.06	3.07	3.09	3.12	3.15	3.18	3.20	3.21	3.21	3.21	3.20	3.18	3.17	3.14	3.11	3.06	2.99	2.89	2.76
17	3.23	3.23	3.24	3.25	3.27	3.30	3.32	3.34	3.35	3.35	3.34	3.33	3.32	3.31	3.30	3.26	3.20	3.11	3.00	2.87
18	3.67	3.67	3.67	3.68	3.69	3.70	3.70	3.70	3.69	3.67	3.64	3.61	3.57	3.52	3.47	3.40	3.33	3.23	3.11	2.96
19	3.89	3.89	3.89	3.89	3.89	3.88	3.87	3.85	3.82	3.79	3.75	3.70	3.65	3.59	3.52	3.44	3.34	3.23	3.11	2.96
20	3.78	3.77	3.77	3.76	3.75	3.74	3.72	3.69	3.66	3.62	3.57	3.52	3.46	3.40	3.32	3.23	3.14	3.03	2.91	2.77
21	3.32	3.32	3.32	3.31	3.30	3.28	3.26	3.23	3.20	3.16	3.11	3.06	3.01	2.95	2.88	2.80	2.71	2.61	2.51	2.39
22	2.59	2.59	2.58	2.57	2.56	2.55	2.53	2.51	2.48	2.45	2.41	2.37	2.32	2.27	2.22	2.15	2.09	2.01	1.93	1.84
23	1.63	1.63	1.63	1.62	1.62	1.61	1.59	1.58	1.56	1.54	1.52	1.49	1.46	1.43	1.39	1.35	1.31	1.26	1.21	1.15
24	0.52	0.52	0.51	0.51	0.51	0.51	0.50	0.50	0.49	0.49	0.48	0.47	0.46	0.45	0.44	0.42	0.41	0.40	0.38	0.36
25	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.07
26	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Axial Mesh Point Number

Relative Flux in Group 2 at Time = 1.0 sec

Radial Mesh Point Number

[illegible]

EXHIBIT 3 (Continued)

Relative Flux in Group 1 at Time = 4.0 sec

Axial Mesh Point Number	Radial Mesh Point Number																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
4	0.37	0.38	0.38	0.38	0.39	0.39	0.40	0.40	0.41	0.41	0.41	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.41	0.39
5	1.18	1.18	1.19	1.20	1.22	1.24	1.26	1.27	1.29	1.30	1.31	1.32	1.33	1.34	1.35	1.35	1.35	1.33	1.31	1.27
6	1.91	1.91	1.92	1.94	1.97	2.00	2.03	2.06	2.09	2.11	2.13	2.14	2.16	2.17	2.18	2.19	2.18	2.16	2.12	2.06
7	2.54	2.55	2.56	2.59	2.63	2.67	2.71	2.75	2.78	2.81	2.84	2.86	2.88	2.89	2.91	2.91	2.90	2.87	2.81	2.73
8	3.06	3.07	3.09	3.12	3.16	3.21	3.26	3.31	3.35	3.38	3.41	3.43	3.45	3.47	3.48	3.49	3.48	3.43	3.36	3.26
9	3.13	3.13	3.14	3.16	3.19	3.23	3.28	3.33	3.38	3.43	3.47	3.50	3.53	3.56	3.59	3.61	3.62	3.62	3.56	3.46
10	3.67	3.69	3.70	3.74	3.79	3.85	3.91	3.96	4.00	4.03	4.06	4.09	4.10	4.12	4.12	4.10	4.03	3.93	3.79	3.62
11	3.83	3.84	3.86	3.90	3.95	4.01	4.07	4.12	4.16	4.20	4.22	4.24	4.26	4.27	4.27	4.24	4.23	4.15	4.04	3.88
12	4.01	4.02	4.04	4.08	4.13	4.19	4.25	4.30	4.34	4.37	4.39	4.41	4.42	4.42	4.42	4.40	4.36	4.28	4.15	3.98
13	4.22	4.22	4.25	4.28	4.33	4.39	4.45	4.50	4.54	4.57	4.59	4.60	4.60	4.60	4.59	4.57	4.52	4.43	4.29	4.11
14	4.46	4.47	4.49	4.53	4.58	4.64	4.70	4.74	4.78	4.80	4.81	4.82	4.81	4.81	4.79	4.76	4.70	4.60	4.45	4.26
15	4.76	4.77	4.79	4.83	4.88	4.94	4.99	5.03	5.06	5.07	5.08	5.07	5.06	5.04	5.02	4.98	4.91	4.80	4.64	4.43
16	5.14	5.15	5.17	5.20	5.25	5.30	5.35	5.38	5.39	5.40	5.39	5.37	5.35	5.32	5.28	5.22	5.14	5.01	4.84	4.62
17	5.63	5.63	5.65	5.67	5.71	5.75	5.78	5.80	5.80	5.79	5.76	5.73	5.68	5.63	5.57	5.49	5.39	5.25	5.06	4.82
18	6.24	6.24	6.25	6.26	6.27	6.29	6.29	6.28	6.26	6.23	6.18	6.12	6.05	5.97	5.87	5.76	5.63	5.46	5.25	5.01
19	6.73	6.73	6.74	6.75	6.76	6.77	6.77	6.76	6.74	6.71	6.68	6.63	6.57	6.50	6.41	6.30	6.17	6.01	5.79	5.54
20	7.45	7.45	7.46	7.47	7.48	7.49	7.49	7.48	7.46	7.43	7.40	7.36	7.30	7.23	7.14	7.03	6.89	6.71	6.47	6.21
21	8.45	8.45	8.46	8.47	8.48	8.49	8.49	8.48	8.46	8.43	8.40	8.36	8.30	8.23	8.14	8.03	7.89	7.71	7.47	7.21
22	9.70	9.70	9.71	9.72	9.73	9.74	9.74	9.73	9.71	9.68	9.65	9.61	9.56	9.50	9.41	9.30	9.16	8.97	8.73	8.47
23	11.21	11.21	11.22	11.23	11.24	11.25	11.25	11.24	11.22	11.19	11.16	11.12	11.07	11.01	10.92	10.81	10.67	10.47	10.21	9.95
24	13.01	13.01	13.02	13.03	13.04	13.05	13.05	13.04	13.02	12.99	12.96	12.92	12.87	12.81	12.72	12.61	12.47	12.27	12.01	11.75
25	15.11	15.11	15.12	15.13	15.14	15.15	15.15	15.14	15.12	15.09	15.06	15.02	14.97	14.91	14.82	14.71	14.57	14.37	14.11	13.85
26	17.51	17.51	17.52	17.53	17.54	17.55	17.55	17.54	17.52	17.49	17.46	17.42	17.37	17.31	17.22	17.11	16.97	16.77	16.51	16.25
27	20.21	20.21	20.22	20.23	20.24	20.25	20.25	20.24	20.22	20.19	20.16	20.12	20.07	20.01	19.92	19.81	19.67	19.47	19.21	18.95

EXHIBIT B (Continued)

Relative Flux in Group 2 at Time = 4.0 sec

Radial Mesh Point Number

Axial Mesh Point Number

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
3	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07
4	0.27	0.27	0.27	0.28	0.28	0.28	0.29	0.29	0.30	0.30	0.30	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.30	0.29
5	0.71	0.71	0.71	0.72	0.73	0.75	0.77	0.78	0.79	0.80	0.81	0.81	0.82	0.82	0.83	0.84	0.84	0.84	0.82	0.80
6	1.14	1.14	1.15	1.16	1.18	1.21	1.24	1.26	1.27	1.29	1.30	1.31	1.32	1.33	1.34	1.35	1.36	1.35	1.32	1.29
7	1.52	1.52	1.53	1.55	1.57	1.61	1.65	1.67	1.70	1.71	1.73	1.74	1.75	1.76	1.78	1.80	1.80	1.79	1.75	1.71
8	1.83	1.83	1.84	1.86	1.89	1.94	1.98	2.01	2.04	2.06	2.08	2.09	2.10	2.12	2.13	2.15	2.16	2.14	2.10	2.04
9	2.05	2.06	2.07	2.09	2.13	2.18	2.22	2.26	2.28	2.31	2.32	2.34	2.35	2.36	2.38	2.40	2.40	2.38	2.33	2.26
10	2.17	2.18	2.19	2.21	2.25	2.30	2.35	2.38	2.41	2.43	2.45	2.46	2.48	2.49	2.50	2.52	2.52	2.49	2.43	2.35
11	2.25	2.12	1.96	1.78	1.56	1.32	1.07	0.81	0.54	0.27	2.52	2.54	2.55	2.55	2.56	2.58	2.58	2.54	2.47	2.38
12	2.26	2.12	1.96	1.77	1.56	1.33	1.09	0.83	0.55	0.28	2.62	2.63	2.64	2.65	2.65	2.66	2.66	2.62	2.54	2.44
13	2.35	2.35	2.37	2.39	2.43	2.48	2.53	2.57	2.59	2.61	2.74	2.75	2.75	2.75	2.75	2.76	2.76	2.71	2.63	2.52
14	2.47	2.47	2.49	2.51	2.55	2.60	2.65	2.69	2.71	2.73	2.87	2.88	2.88	2.87	2.87	2.88	2.87	2.81	2.72	2.61
15	2.38	2.23	2.05	1.85	1.64	1.40	1.14	0.87	0.58	0.29	3.03	3.03	3.02	3.02	3.01	3.01	2.99	2.93	2.84	2.71
16	2.61	2.62	2.63	2.65	2.69	2.75	2.80	2.83	2.85	2.87	3.22	3.21	3.20	3.18	3.17	3.16	3.14	3.07	2.96	2.83
17	2.47	2.31	2.12	1.91	1.69	1.44	1.18	0.90	0.60	0.30	3.45	3.43	3.40	3.37	3.35	3.33	3.29	3.21	3.10	2.96
18	2.79	2.79	2.81	2.83	2.87	2.92	2.97	3.00	3.02	3.03	3.77	3.73	3.69	3.64	3.59	3.54	3.47	3.37	3.24	3.10
19	2.57	2.39	2.20	1.98	1.75	1.50	1.22	0.93	0.62	0.31	3.96	3.91	3.85	3.79	3.71	3.63	3.53	3.41	3.28	3.14
20	3.01	3.02	3.03	3.05	3.08	3.14	3.19	3.21	3.22	3.23	3.79	3.73	3.67	3.60	3.52	3.43	3.33	3.21	3.08	2.95
21	2.67	2.49	2.29	2.06	1.82	1.55	1.27	0.96	0.65	0.32	4.02	4.01	4.01	4.00	3.99	3.97	3.95	3.92	3.88	3.84
22	3.31	3.31	3.32	3.34	3.36	3.41	3.45	3.47	3.47	3.46	4.28	4.24	4.20	4.13	4.05	3.96	3.86	3.74	3.61	3.48
23	2.79	2.60	2.39	2.15	1.89	1.61	1.31	0.99	0.67	0.33	4.42	4.12	4.12	4.11	4.11	4.10	4.09	4.07	4.04	4.00
24	3.75	3.77	3.77	3.78	3.79	3.81	3.83	3.83	3.82	3.80	4.82	4.75	4.75	4.75	4.74	4.74	4.73	4.71	4.67	4.63
25	2.94	2.75	2.53	2.28	1.99	1.68	1.35	1.02	0.68	0.34	5.02	4.81	4.59	4.36	4.13	3.89	3.65	3.41	3.17	2.93
26	4.12	4.12	4.12	4.11	4.11	4.10	4.09	4.07	4.04	4.00	5.24	5.04	4.82	4.59	4.36	4.13	3.89	3.65	3.41	3.17
27	2.99	2.81	2.59	2.33	2.03	1.69	1.34	1.01	0.67	0.33	5.42	5.24	5.04	4.82	4.59	4.36	4.13	3.89	3.65	3.41
28	4.02	4.01	4.01	4.00	3.99	3.97	3.95	3.92	3.88	3.84	5.62	5.44	5.24	5.04	4.82	4.59	4.36	4.13	3.89	3.65
29	2.81	2.64	2.43	2.18	1.90	1.58	1.25	0.94	0.62	0.31	5.82	5.64	5.44	5.24	5.04	4.82	4.59	4.36	4.13	3.89
30	3.54	3.54	3.54	3.53	3.51	3.49	3.47	3.44	3.40	3.36	6.02	5.84	5.64	5.44	5.24	5.04	4.82	4.59	4.36	4.13
31	2.42	2.28	2.09	1.88	1.64	1.36	1.08	0.80	0.53	0.26	6.22	6.04	5.84	5.64	5.44	5.24	5.04	4.82	4.59	4.36
32	2.76	2.76	2.76	2.75	2.73	2.72	2.70	2.67	2.64	2.61	6.42	6.24	6.04	5.84	5.64	5.44	5.24	5.04	4.82	4.59
33	1.46	1.75	1.61	1.44	1.26	1.05	0.83	0.62	0.41	0.20	6.62	6.44	6.24	6.04	5.84	5.64	5.44	5.24	5.04	4.82
34	1.76	1.75	1.75	1.74	1.74	1.72	1.71	1.69	1.67	1.65	6.82	6.64	6.44	6.24	6.04	5.84	5.64	5.44	5.24	5.04
35	1.17	1.10	1.01	0.91	0.79	0.66	0.52	0.39	0.26	0.13	7.02	6.84	6.64	6.44	6.24	6.04	5.84	5.64	5.44	5.24
36	0.66	0.66	0.66	0.65	0.65	0.65	0.64	0.63	0.63	0.62	7.22	7.04	6.84	6.64	6.44	6.24	6.04	5.84	5.64	5.44
37	0.43	0.43	0.37	0.33	0.29	0.24	0.19	0.15	0.10	0.05	7.42	7.24	7.04	6.84	6.64	6.44	6.24	6.04	5.84	5.64
38	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15	7.62	7.44	7.24	7.04	6.84	6.64	6.44	6.24	6.04	5.84
39	0.11	0.10	0.09	0.08	0.07	0.06	0.05	0.04	0.02	0.01	7.82	7.64	7.44	7.24	7.04	6.84	6.64	6.44	6.24	6.04
40	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	8.02	7.84	7.64	7.44	7.24	7.04	6.84	6.64	6.44	6.24
41	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.00	8.22	8.04	7.84	7.64	7.44	7.24	7.04	6.84	6.64	6.44
42	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	8.42	8.24	8.04	7.84	7.64	7.44	7.24	7.04	6.84	6.64
43	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	8.62	8.44	8.24	8.04	7.84	7.64	7.44	7.24	7.04	6.84

EXHIBIT C

Relative Power Density Averaged Over Height
Versus Radial Position*

<u>Radius, cm.</u>	<u>t = 0 sec.</u>	<u>t = 1 sec.</u>	<u>t = 4 sec.</u>
0	1.504	2.405	4.028
8	1.504	2.408	4.031
16	1.504	2.414	4.042
24	1.504	2.426	4.062
32	1.503	2.444	4.090
40	1.503	2.470	4.133
48	1.503	2.494	4.172
56	1.502	2.507	4.192
64	1.502	2.512	4.199
72	1.501	2.512	4.197
80	1.500	2.507	4.187
88	1.500	2.497	4.170
96	1.500	2.487	4.147
104	1.499	2.469	4.119
112	1.500	2.452	4.089
120	1.506	2.436	4.061
128	1.503	2.409	4.013
136	1.481	2.355	3.922
144	1.444	2.281	3.798
152	1.393	2.190	3.645
160	1.333	2.086	3.470
168	1.257	1.960	3.261
176	1.162	1.807	3.004
184	1.051	1.630	2.710
192	0.926	1.432	2.381
200	0.815	1.258	2.091
208	0.682	1.052	1.748
216	0.516	0.794	1.320
224	0.345	0.531	0.882
232	0.172	0.264	0.438
240	0.0	0.0	0.0

* $\Delta t = 0.001$ sec.

EXHIBIT D

Power Density Averaged Over Radius Versus Axial Position*

<u>Height,** cm.</u>	<u>t = 0 sec.</u>	<u>t = 1 sec.</u>	<u>t = 4 sec.</u>
0	0.0	0.0	0.0
18.75	0.0	0.0	0.0
37.50	0.0	0.0	0.0
56.25	0.0	0.0	0.0
75.00	0.117	0.153	0.247
93.75	0.645	0.843	1.362
112.50	1.035	1.358	2.195
131.25	1.367	1.802	2.917
150.00	1.619	2.151	3.488
168.75	1.777	2.385	3.877
187.50	1.822	2.412	4.046
206.25	1.815	2.520	4.123
225.00	1.816	2.582	4.244
243.75	1.817	2.659	4.394
262.50	1.817	2.752	4.570
281.25	1.817	2.859	4.774
300.00	1.816	2.984	5.007
318.75	1.815	3.128	5.273
337.50	1.822	3.313	5.605
356.25	1.776	3.390	5.753
375.00	1.619	3.196	5.437
393.75	1.367	2.765	4.713
412.50	1.035	2.130	3.635
431.25	0.645	1.341	2.291
450.00	0.117	2.442	4.171
468.75	0.0	0.0	0.0
487.50	0.0	0.0	0.0
506.25	0.0	0.0	0.0
525.00	0.0	0.0	0.0

* $\Delta t = 0.001$ sec.

** Height is measured from the top of the reactor.

EXHIBIT E

Plot of Data Presented in Exhibit C

EXHIBIT F
Plot of Data Presented in Exhibit D

BENCHMARK PROBLEM SOLUTION

Identification:	8-A1-2	Benchmark Problem:	ID.8-A1
Date Submitted:	January 1973	By:	H. L. Dodds, Jr. (U. of Tenn.)
Date Accepted:	June 1977	By:	E. L. Fuller (EPRI) W. Werner (GRS-Munich)
Descriptive Title:	<i>Flux Factorization Solution with TWODQD.</i> ¹		

Mathematical Model: A 5-point difference approximation with mesh points located at mesh interval boundaries is used for the leakage operator in the neutron diffusion equations. The improved quasistatic method described in Reference 2 is used to solve the time-dependent problem.

Pertinent Features of the Method: The total flux is factored into the product of a space-energy-time dependent shape function and a purely time-dependent amplitude function. The resulting set of coupled equations are solved iteratively (see Ref. 1 for details).

Computer: IBM-360, Model 195

Code: TWØDQD¹ (single precision)

Date Solved: January 1973 at Savannah River Laboratory

References:

1. H. L. Dodds, "Accuracy of the Quasistatic Method for Two-Dimensional Thermal Reactor Transients with Feedback," *Nucl. Sci. Eng.* 59, 271 (1976).

2. D. A. Meneley, G. K. Leaf, A. J. Lindeman, T. A. Daly, and W. T. Sha, "A Kinetics Model for Fast Reactor Analysis in Two Dimensions," *Dynamics of Nuclear Systems*, pp 433-500, D. Hetrick, Ed., The University of Arizona Press, Tucson, Arizona (1972).

Results:

Uniform mesh with $\Delta r = 8$ cm (30 intervals) and $\Delta t = 18.75$ cm (28 intervals).

Initial $k_{\text{eff}} = 0.866901$ (taken from Benchmark Problem Solution 8-A1-1).

Exhibit A: Total power (relative to initial value) versus time as a function of Δt .

Exhibit B: Group 1 and Group 2 relative flux distributions at 0.0, 1.0, and 4.0 sec for $\Delta t = 0.001$ sec. Zero flux values on the external surfaces are not tabulated.

Exhibit C: Power density averaged over height versus radial position, i.e.,

$$\frac{\frac{1}{N} \sum_{\text{all } j} \int_{V_{ij}} (\Sigma_{f1} \phi_1 + \Sigma_{f2} \phi_2) dv}{\sum_{\text{all } j} \int_{V_{ij}} dv} \quad \text{versus } r_i$$

for $i = 1, \dots, \text{NPX}$ and $j = 1, \dots, \text{NPY}$

where V_{ij} = mesh volume element ij

NPX = number of radial mesh points

NPY = number of axial mesh points

N = normalization constant (arbitrary)

Exhibit D: Power density averaged over radius versus axial position, i.e.,

$$\frac{\frac{1}{N} \sum_{\text{all } i} \int_{V_{ij}} (\Sigma_{f_1} \phi_1 + \Sigma_{f_2} \phi_2) dv}{\sum_{\text{all } i} \int_{V_{ij}} dv} \text{ versus } Z_j$$

for $i = 1, \dots, \text{NPX}$ and $j = 1, \dots, \text{NPY}$

Exhibit E: Plot of data presented in Exhibit C.

Exhibit F: Plot of data presented in Exhibit D.

EXHIBIT A

Total Power Versus Time as a Function of Time-Step Size*

Time (sec)	Δt (sec)					
	0.001	0.005	0.05	0.2	0.5	1.0
0	1.000	1.000	1.000	1.000	1.000	1.000
0.2	1.039	1.039	1.039	1.040		
0.4	1.109	1.109	1.108	1.109		
0.6	1.210	1.210	1.210	1.210		
0.8	1.361	1.361	1.360	1.360		
1.0	1.598	1.598	1.596	1.596	1.605	1.627
1.2	1.753	1.753	1.757	1.745		
1.4	1.829	1.829	1.830	1.821		
1.6	1.896	1.896	1.895	1.888		
1.8	1.960	1.960	1.961	1.965		
2.0	2.024	2.024	2.025	2.014	2.014	2.019
3.0	2.336	2.336	2.337	2.324	2.322	2.328
4.0	2.661	2.661	2.662	2.646	2.642	2.648
CPU** Time (sec)	2898	607	93	84	70	62

* Δt is defined as the time interval between shape calculations. The time interval between inner product calculations (i.e., calculations of reactivity and generation time) is equal to 0.05 sec for the cases with $\Delta t \geq 0.05$ and is equal to Δt for the cases with $\Delta t < 0.05$. A time-step size of 0.001 sec was used for the solution of the amplitude equations in all of the above cases.

** IBM-360, Model 195.

Relative Flux in Group 1 at Time = 0.0 sec

Axial Mesh Point Number

[illegible]

EXHIBIT B (Continued)

Relative Flux in Group 2 at Time = 0.0 sec

Axial Mesh Point Number	Radial Mesh Point Number																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03
4	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14
5	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.40	0.39	0.38	0.37
6	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.63	0.63	0.62	0.60
7	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.83	0.83	0.81	0.79
8	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.98	0.96	0.93
9	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.09	1.09	1.08	1.05	1.02
10	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.13	1.13	1.11	1.08	1.04
11	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.11	1.08	1.01
12	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.13	1.11	1.08	1.03
13	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.13	1.11	1.08	1.03
14	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.11	1.08	1.03
15	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.13	1.11	1.08	1.03
16	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.13	1.11	1.08	1.03
17	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.11	1.08	1.03
18	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.13	1.13	1.11	1.04
19	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.09	1.09	1.08	1.05	1.02
20	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.98	0.96	0.93
21	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.83	0.83	0.81	0.79
22	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.63	0.63	0.62	0.60
23	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.40	0.39	0.38	0.37
24	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14
25	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03
26	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
27	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00

Relative Flux in Group 2 at Time = 1.0 sec

		Radial Mesh Point Number																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Axial Mesh Point Number	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
		0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00									
	3	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04
		0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.01									
	4	0.17	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.18
		0.18	0.17	0.15	0.14	0.12	0.10	0.08	0.06	0.04	0.02										
	5	0.44	0.44	0.44	0.45	0.46	0.47	0.48	0.48	0.49	0.50	0.50	0.50	0.51	0.51	0.51	0.52	0.52	0.52	0.51	0.49
		0.48	0.46	0.42	0.38	0.34	0.28	0.22	0.17	0.11	0.06										
	6	0.71	0.71	0.71	0.72	0.73	0.75	0.77	0.78	0.79	0.80	0.80	0.81	0.82	0.82	0.83	0.84	0.84	0.83	0.82	0.80
		0.77	0.73	0.68	0.62	0.54	0.45	0.36	0.27	0.18	0.09										
	7	0.94	0.94	0.95	0.96	0.98	1.00	1.02	1.04	1.05	1.06	1.07	1.08	1.08	1.09	1.10	1.11	1.12	1.11	1.08	1.06
		1.02	0.97	0.90	0.82	0.72	0.60	0.48	0.36	0.24	0.12										
	8	1.13	1.13	1.14	1.15	1.17	1.20	1.23	1.24	1.26	1.27	1.28	1.29	1.30	1.31	1.32	1.33	1.33	1.32	1.29	1.26
		1.22	1.16	1.08	0.97	0.85	0.71	0.57	0.43	0.28	0.14										
	9	1.27	1.27	1.28	1.29	1.31	1.34	1.37	1.39	1.41	1.42	1.43	1.44	1.45	1.46	1.46	1.46	1.46	1.43	1.39	
		1.34	1.28	1.18	1.07	0.94	0.79	0.63	0.47	0.31	0.16										
	10	1.33	1.34	1.35	1.36	1.38	1.41	1.44	1.46	1.48	1.49	1.50	1.51	1.52	1.53	1.53	1.54	1.55	1.53	1.49	1.44
		1.38	1.30	1.20	1.09	0.96	0.81	0.65	0.49	0.33	0.16										
11	1.38	1.38	1.39	1.40	1.42	1.45	1.48	1.51	1.52	1.53	1.54	1.55	1.56	1.56	1.57	1.58	1.58	1.55	1.51	1.45	
	1.38	1.33	1.20	1.08	0.96	0.82	0.67	0.51	0.34	0.17											
12	1.43	1.43	1.44	1.46	1.48	1.51	1.54	1.56	1.58	1.59	1.60	1.60	1.61	1.61	1.61	1.62	1.62	1.59	1.55	1.49	
	1.41	1.32	1.21	1.10	0.97	0.83	0.68	0.52	0.35	0.17											
13	1.49	1.50	1.51	1.52	1.54	1.57	1.61	1.63	1.64	1.65	1.66	1.66	1.67	1.67	1.67	1.67	1.67	1.64	1.59	1.52	
	1.44	1.35	1.24	1.12	0.99	0.85	0.69	0.53	0.35	0.18											
14	1.57	1.58	1.58	1.60	1.62	1.65	1.68	1.70	1.72	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.69	1.64	1.57	
	1.49	1.39	1.28	1.15	1.02	0.87	0.71	0.54	0.36	0.18											
15	1.67	1.67	1.68	1.69	1.71	1.75	1.78	1.80	1.81	1.81	1.82	1.81	1.81	1.81	1.80	1.80	1.79	1.76	1.70	1.63	
	1.54	1.44	1.32	1.19	1.05	0.90	0.73	0.56	0.37	0.19											
16	1.79	1.79	1.80	1.81	1.83	1.87	1.90	1.91	1.92	1.92	1.92	1.91	1.90	1.90	1.89	1.88	1.87	1.83	1.77	1.69	
	1.60	1.49	1.37	1.23	1.09	0.93	0.76	0.58	0.39	0.19											
17	1.96	1.96	1.96	1.97	1.99	2.02	2.04	2.05	2.06	2.05	2.04	2.03	2.02	2.00	1.99	1.98	1.95	1.91	1.84	1.76	
	1.66	1.55	1.42	1.28	1.13	0.96	0.78	0.59	0.40	0.20											
18	2.22	2.22	2.22	2.23	2.23	2.25	2.26	2.26	2.25	2.24	2.22	2.20	2.18	2.15	2.12	2.09	2.05	1.99	1.92	1.84	
	1.74	1.63	1.50	1.35	1.18	1.00	0.80	0.60	0.40	0.20											
19	2.42	2.42	2.42	2.41	2.41	2.41	2.40	2.39	2.37	2.35	2.33	2.30	2.27	2.23	2.19	2.14	2.08	2.01	1.94	1.85	
	1.77	1.66	1.53	1.38	1.20	1.00	0.80	0.60	0.40	0.20											
20	2.35	2.35	2.35	2.34	2.33	2.32	2.31	2.30	2.28	2.25	2.22	2.19	2.15	2.11	2.07	2.01	1.96	1.89	1.82	1.74	
	1.65	1.56	1.43	1.29	1.12	0.93	0.74	0.55	0.37	0.18											
21	2.07	2.07	2.06	2.06	2.05	2.04	2.03	2.01	1.99	1.97	1.94	1.91	1.87	1.83	1.79	1.74	1.69	1.63	1.57	1.50	
	1.43	1.34	1.23	1.11	0.97	0.80	0.64	0.47	0.31	0.16											
22	1.61	1.61	1.61	1.60	1.60	1.59	1.57	1.56	1.54	1.52	1.50	1.48	1.45	1.42	1.38	1.34	1.30	1.25	1.20	1.15	
	1.09	1.03	0.95	0.85	0.74	0.62	0.49	0.36	0.24	0.12											
23	1.02	1.02	1.02	1.02	1.01	1.01	1.00	0.99	0.98	0.96	0.95	0.93	0.91	0.89	0.87	0.85	0.82	0.79	0.76	0.72	
	0.69	0.65	0.59	0.53	0.46	0.39	0.31	0.23	0.15	0.07											
24	0.38	0.38	0.38	0.38	0.38	0.38	0.37	0.37	0.37	0.36	0.35	0.35	0.34	0.33	0.32	0.32	0.31	0.29	0.28	0.27	
	0.25	0.24	0.22	0.20	0.17	0.14	0.11	0.09	0.06	0.03											
25	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	
	0.06	0.06	0.05	0.05	0.04	0.03	0.03	0.02	0.01	0.01											
26	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	
	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00											
27	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00											

EXHIBIT B (Continued)

Relative Flux in Group 1 at Time = 4.0 sec

Axial Mesh Point Number	Radial Mesh Point Number																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
4	0.37	0.38	0.38	0.39	0.39	0.40	0.40	0.40	0.41	0.41	0.41	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.41	0.40
5	1.18	1.18	1.19	1.20	1.22	1.24	1.26	1.27	1.29	1.30	1.31	1.33	1.33	1.34	1.35	1.35	1.35	1.33	1.31	1.27
6	1.91	1.91	1.92	1.94	1.97	2.00	2.03	2.06	2.09	2.11	2.13	2.15	2.16	2.17	2.18	2.19	2.18	2.16	2.12	2.06
7	2.54	2.55	2.57	2.59	2.63	2.67	2.71	2.75	2.79	2.81	2.84	2.86	2.88	2.89	2.91	2.91	2.91	2.87	2.82	2.73
8	3.06	3.07	3.09	3.12	3.16	3.21	3.27	3.31	3.35	3.38	3.41	3.44	3.46	3.47	3.49	3.49	3.48	3.44	3.36	3.26
9	3.44	3.45	3.47	3.51	3.55	3.61	3.67	3.72	3.76	3.79	3.82	3.85	3.87	3.88	3.89	3.90	3.88	3.83	3.74	3.62
10	3.68	3.68	3.70	3.74	3.79	3.85	3.91	3.96	4.00	4.04	4.07	4.09	4.11	4.12	4.13	4.13	4.10	4.04	3.93	3.80
11	3.84	3.84	3.87	3.90	3.95	4.01	4.07	4.12	4.17	4.20	4.23	4.25	4.26	4.27	4.27	4.26	4.23	4.15	4.04	3.88
12	4.01	4.02	4.04	4.08	4.13	4.19	4.25	4.30	4.34	4.37	4.40	4.41	4.42	4.43	4.42	4.41	4.36	4.28	4.15	3.99
13	4.22	4.23	4.25	4.29	4.34	4.40	4.46	4.51	4.54	4.57	4.59	4.60	4.60	4.60	4.59	4.57	4.52	4.43	4.29	4.11
14	4.47	4.47	4.50	4.53	4.58	4.64	4.70	4.75	4.78	4.80	4.82	4.82	4.82	4.81	4.79	4.76	4.70	4.60	4.45	4.26
15	4.77	4.78	4.80	4.83	4.88	4.94	4.99	5.03	5.06	5.08	5.08	5.08	5.07	5.05	5.02	4.98	4.91	4.80	4.64	4.44
16	5.15	5.15	5.17	5.21	5.25	5.30	5.35	5.38	5.40	5.40	5.40	5.38	5.35	5.32	5.28	5.23	5.14	5.02	4.84	4.63
17	5.63	5.64	5.65	5.68	5.71	5.75	5.79	5.80	5.81	5.79	5.77	5.73	5.69	5.63	5.57	5.50	5.39	5.25	5.06	4.83
18	6.24	6.25	6.25	6.28	6.28	6.29	6.30	6.29	6.27	6.23	6.18	6.12	6.05	5.97	5.88	5.77	5.63	5.46	5.25	5.01
19	6.65	6.65	6.65	6.64	6.63	6.62	6.59	6.56	6.52	6.46	6.39	6.31	6.21	6.10	5.98	5.84	5.68	5.49	5.27	5.03
20	7.47	7.46	7.46	7.44	7.42	7.39	7.36	7.31	7.25	7.18	7.10	7.01	6.91	6.79	6.66	6.51	6.34	6.15	5.94	5.71
21	8.11	8.11	8.11	8.10	8.08	8.06	8.03	8.00	7.95	7.89	7.81	7.72	7.62	7.50	7.37	7.22	7.05	6.86	6.65	6.43
22	8.81	8.81	8.81	8.80	8.78	8.76	8.74	8.71	8.68	8.64	8.60	8.55	8.50	8.44	8.37	8.29	8.19	8.07	7.94	7.79
23	9.55	9.55	9.55	9.54	9.52	9.50	9.48	9.45	9.42	9.38	9.34	9.29	9.24	9.18	9.11	9.02	8.91	8.78	8.64	8.49
24	10.33	10.33	10.33	10.32	10.30	10.28	10.26	10.24	10.21	10.18	10.14	10.10	10.05	10.00	9.94	9.86	9.75	9.62	9.48	9.33
25	11.15	11.15	11.15	11.14	11.12	11.10	11.08	11.06	11.04	11.01	10.97	10.93	10.88	10.83	10.77	10.70	10.61	10.50	10.37	10.22
26	12.01	12.01	12.01	12.00	11.98	11.96	11.94	11.92	11.90	11.87	11.83	11.79	11.75	11.70	11.64	11.57	11.48	11.37	11.24	11.09
27	12.91	12.91	12.91	12.90	12.88	12.86	12.84	12.82	12.80	12.77	12.73	12.69	12.65	12.60	12.54	12.47	12.38	12.27	12.14	11.99

Relative Flux in Group 2 at Time = 4.0 sec

Axial Mesh Point Number

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
3	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07
4	0.27	0.27	0.27	0.28	0.28	0.28	0.29	0.29	0.30	0.30	0.30	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.30	0.29
5	0.71	0.71	0.71	0.72	0.73	0.75	0.77	0.78	0.79	0.80	0.81	0.81	0.82	0.82	0.83	0.84	0.84	0.84	0.82	0.80
6	1.14	1.14	1.15	1.16	1.18	1.21	1.24	1.26	1.27	1.29	1.30	1.31	1.32	1.33	1.34	1.35	1.36	1.35	1.32	1.29
7	1.52	1.52	1.53	1.55	1.58	1.61	1.65	1.68	1.70	1.71	1.73	1.74	1.75	1.77	1.78	1.80	1.80	1.79	1.76	1.71
8	1.83	1.83	1.85	1.87	1.90	1.94	1.98	2.02	2.04	2.06	2.08	2.09	2.11	2.12	2.13	2.15	2.16	2.14	2.10	2.04
9	2.05	2.06	2.07	2.09	2.13	2.18	2.23	2.26	2.29	2.31	2.33	2.34	2.35	2.37	2.38	2.40	2.41	2.38	2.33	2.26
10	2.17	2.18	2.19	2.21	2.25	2.30	2.35	2.39	2.41	2.44	2.45	2.47	2.48	2.49	2.50	2.52	2.52	2.49	2.43	2.35
11	2.25	2.25	2.27	2.29	2.33	2.38	2.43	2.46	2.49	2.51	2.53	2.54	2.55	2.56	2.56	2.58	2.58	2.54	2.47	2.38
12	2.35	2.35	2.37	2.39	2.43	2.48	2.53	2.57	2.59	2.61	2.63	2.64	2.64	2.65	2.65	2.67	2.66	2.62	2.54	2.44
13	2.47	2.47	2.49	2.51	2.55	2.60	2.65	2.69	2.71	2.73	2.74	2.75	2.75	2.75	2.76	2.77	2.76	2.71	2.63	2.52
14	2.61	2.62	2.63	2.66	2.69	2.75	2.80	2.83	2.85	2.87	2.88	2.88	2.88	2.88	2.87	2.88	2.87	2.81	2.73	2.61
15	2.79	2.80	2.81	2.83	2.87	2.92	2.97	3.00	3.02	3.03	3.03	3.03	3.03	3.02	3.01	3.01	3.00	2.93	2.84	2.72
16	3.01	3.02	3.03	3.05	3.09	3.14	3.19	3.21	3.22	3.23	3.22	3.21	3.20	3.18	3.17	3.16	3.14	3.07	2.96	2.83
17	3.31	3.31	3.32	3.34	3.37	3.41	3.46	3.47	3.47	3.47	3.45	3.43	3.41	3.38	3.35	3.33	3.29	3.21	3.10	2.96
18	3.77	3.77	3.77	3.78	3.79	3.82	3.83	3.83	3.82	3.80	3.77	3.73	3.69	3.64	3.59	3.54	3.47	3.37	3.25	3.10
19	4.12	4.12	4.12	4.12	4.11	4.10	4.09	4.07	4.04	4.01	3.96	3.91	3.86	3.79	3.71	3.63	3.53	3.42	3.28	3.14
20	4.02	4.02	4.01	4.00	3.99	3.97	3.95	3.92	3.89	3.84	3.79	3.74	3.67	3.60	3.52	3.43	3.33	3.21	3.08	2.95
21	3.55	3.54	3.54	3.53	3.51	3.49	3.47	3.44	3.40	3.36	3.31	3.26	3.20	3.13	3.05	2.97	2.88	2.78	2.66	2.54
22	2.77	2.76	2.76	2.75	2.74	2.72	2.70	2.67	2.64	2.61	2.57	2.54	2.47	2.42	2.36	2.29	2.22	2.14	2.05	1.96
23	1.86	1.79	1.61	1.45	1.26	1.05	0.83	0.62	0.41	0.20	1.63	1.60	1.56	1.53	1.49	1.45	1.40	1.35	1.29	1.23
24	0.66	0.65	0.66	0.65	0.65	0.65	0.64	0.63	0.63	0.62	0.61	0.60	0.58	0.57	0.56	0.54	0.52	0.50	0.48	0.46
25	0.16	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.12	0.12	0.11
26	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.04
27	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

EXHIBIT C

Relative Power Density Averaged Over Height
Versus Radial Position

<u>Radius, cm.</u>	<u>t = 0 sec.</u>	<u>t = 1 sec.</u>	<u>t = 4 sec.</u>
0	1.504	2.408	4.031
8	1.504	2.411	4.035
16	1.504	2.417	4.046
24	1.504	2.429	4.065
32	1.503	2.447	4.093
40	1.503	2.473	4.136
48	1.503	2.497	4.175
56	1.502	2.509	4.195
64	1.502	2.515	4.202
72	1.501	2.514	4.200
80	1.500	2.509	4.190
88	1.500	2.500	4.173
96	1.499	2.487	4.150
104	1.499	2.472	4.122
112	1.500	2.454	4.091
120	1.506	2.439	4.064
128	1.503	2.411	4.016
136	1.481	2.358	3.925
144	1.444	2.284	3.800
152	1.393	2.192	3.647
160	1.333	2.088	3.473
168	1.257	1.962	3.263
176	1.162	1.808	3.006
184	1.051	1.632	2.712
192	0.926	1.434	2.382
200	0.815	1.259	2.093
208	0.682	1.053	1.749
216	0.516	0.795	1.321
224	0.345	0.531	0.882
232	0.172	0.264	0.439
240	0.0	0.0	0.0

* $\Delta t = 0.001$ sec.

EXHIBIT D

Power Density Averaged Over Radius Versus Axial Position*

<u>Height**</u> , cm.	<u>t = 0 sec.</u>	<u>t = 1 sec.</u>	<u>t = 4 sec.</u>
0	0.0	0.0	0.0
18.75	0.0	0.0	0.0
37.50	0.0	0.0	0.0
56.25	0.0	0.0	0.0
75.00	0.117	0.153	0.247
93.75	0.645	0.844	1.363
112.50	1.035	.359	2.196
131.25	1.367	1.804	2.919
150.00	1.619	2.153	3.491
168.75	1.777	2.388	3.879
187.50	1.822	2.484	4.049
206.25	1.815	2.522	4.126
225.00	1.816	2.584	4.247
243.75	1.817	2.662	4.397
262.50	1.817	2.754	4.573
281.25	1.817	2.862	4.777
300.00	1.816	2.987	5.010
318.75	1.815	3.132	5.277
337.50	1.822	3.316	5.609
356.25	1.777	3.393	5.757
375.00	1.619	3.200	5.441
393.75	1.367	2.768	4.716
412.50	1.035	2.133	3.638
431.25	0.645	1.343	2.292
450.00	0.117	0.244	4.174
468.75	0.0	0.0	0.0
487.50	0.0	0.0	0.0
506.25	0.0	0.0	0.0
525.00	0.0	0.0	0.0

* $\Delta t = 0.001$ sec.

** Height is measured from the top of the reactor.

EXHIBIT E

Plot of Data Presented in Exhibit C

EXHIBIT F

Plot of Data Presented in Exhibit D

BENCHMARK PROBLEM SOLUTION

Identification: 8-A1-3 Benchmark Problem ID.8-A1
Date Submitted: June 1976 By: F.N. McDonnell (AECL-CRNL)
Date Accepted: June 1977 By: H.L. Dodds, Jr. (U. of Tenn.)
E. L. Fuller (EPRI)
W. Werner (GRS-Munich)
Descriptive Title: Direct Finite-Difference Solution with ADEP¹
Mathematical Model: The alternating-direction explicit method of solution with an exponential transformation is used. Non-derivative terms are approximated by central averaging.
Computer: CDC-6600
Code: ADEP¹
Date Solved: July 1974 at Chalk River Nuclear Laboratories
Reference: 1. R.S. Denning, "ADEP, One- and Two-Dimensional Few-Group Kinetics Code", BMI-1911(1971).
Results: Uniform Mesh with $\Delta r=8\text{cm}$ (30 intervals) and $\Delta z=18.75\text{ cm}$ (28 intervals) Initial $K_{\text{eff}} = 0.866861$
Exhibit A: Total power (relative to initial value) versus time as a function of Δt .
Exhibit B: Group 1 and Group 2 Relative Flux Distributions at 0.0, 1.0 and 4.0 seconds for $\Delta t=0.0005$ seconds.
Exhibit C: Power Density Averaged over Height vs. Radial Position, i.e.

$$\frac{1}{N} \sum_{\text{all } j} \int_{V_{ij}} (\Sigma_{f_1} \phi_1 + \Sigma_{f_2} \phi_2) dv \text{ versus } r_i$$

for $i=1,\dots,NPX$ and $j=1,\dots,NPY$

where V_{ij} = mesh volume element ij

NPX = number of radial mesh points

NPY = number of axial mesh points

N = normalization constant

- Exhibit D: Power Density Averaged over Radius vs. Axial Position.
- Exhibit E: Plot of data presented in Exhibit C.
- Exhibit F: Plot of data presented in Exhibit D.

Summary of the CP time requirements.

For this problem ADEP takes ~ 0.25 ms/mesh point/group/time-step.

For $\Delta t = 0.0005$ s the total CP time for the transient is ~ 3400 s of CDC-6600 time.

EXHIBIT ATOTAL POWER VERSUS TIME AS FUNCTION
OF TIME STEP SIZE

Time (s)	$\Delta t(s)$		
	0.0005	0.001	0.005
0.0	1.000	1.000	1.000
0.2	1.041	1.043	1.008
0.4	1.111	1.111	1.061
0.6	1.213	1.212	1.148
0.8	1.365	1.364	1.276
1.0	1.603	1.606	1.466
1.2	1.761	1.767	1.697
1.4	1.838	1.839	1.853
1.6	1.906	1.906	1.963
1.8	1.971	1.971	2.047
2.0	2.035	2.036	2.116
3.0	2.353	2.353	2.405
4.0	2.683	2.683	2.730
CDC-6600 CPU(s)	3400	1700	340

RELATIVE FLUX IN GROUP 1 AT t=0 s

Axial Mesh Point Number

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00
2	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00
3	.04 .03	.04 .03	.04 .03	.04 .03	.04 .02	.04 .02	.04 .02	.04 .01	.04 .01	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00
4	.20 .18	.20 .17	.20 .15	.20 .14	.20 .12	.20 .11	.20 .09	.20 .07	.20 .04	.20 .02	.20 .00	.20 .00	.20 .00	.20 .00	.20 .00	.20 .00	.20 .00	.20 .00	.20 .19	.18 .18
5	.63 .57	.63 .54	.63 .50	.63 .45	.63 .40	.63 .34	.63 .28	.63 .21	.63 .14	.63 .07	.64 .00	.64 .00	.64 .00	.64 .00	.64 .00	.64 .00	.63 .00	.62 .00	.61 .00	.59 .00
6	1.02 .92	1.02 .87	1.02 .80	1.02 .73	1.02 .64	1.02 .55	1.02 .45	1.02 .34	1.02 .23	1.02 .11	1.02 .00	1.02 .00	1.03 .00	1.03 .00	1.03 .00	1.03 .00	1.02 .00	1.01 .00	.99 .00	.96 .00
7	1.35 1.21	1.35 1.14	1.35 1.06	1.35 .96	1.35 .85	1.35 .73	1.35 .60	1.35 .45	1.35 .30	1.35 .15	1.36 .00	1.36 .00	1.36 .00	1.36 .00	1.36 .00	1.36 .00	1.35 .00	1.33 .00	1.30 .00	1.26 .00
8	1.61 1.43	1.61 1.35	1.61 1.25	1.61 1.13	1.61 1.00	1.61 .86	1.61 .70	1.61 .53	1.61 .36	1.61 .18	1.61 .00	1.61 .00	1.61 .00	1.61 .00	1.61 .00	1.61 .00	1.60 .00	1.58 .00	1.54 .00	1.49 .00
9	1.78 1.56	1.78 1.47	1.78 1.36	1.78 1.24	1.78 1.09	1.78 .94	1.78 .77	1.78 .58	1.78 .39	1.78 .19	1.78 .00	1.78 .00	1.78 .00	1.78 .00	1.78 .00	1.77 .00	1.76 .00	1.73 .00	1.69 .00	1.64 .00
10	1.86 1.61	1.86 1.51	1.86 1.39	1.86 1.26	1.86 1.12	1.86 .96	1.86 .74	1.86 .61	1.86 .41	1.86 .20	1.86 .00	1.86 .00	1.86 .00	1.85 .00	1.85 .00	1.84 .00	1.83 .00	1.80 .00	1.75 .00	1.69 .00
11	1.89 1.60	1.89 1.50	1.89 1.38	1.89 1.25	1.89 1.11	1.89 .96	1.89 .80	1.89 .61	1.89 .41	1.88 .20	1.88 .00	1.88 .00	1.88 .00	1.87 .00	1.87 .00	1.86 .00	1.84 .00	1.81 .00	1.76 .00	1.69 .00
12	1.91 1.60	1.91 1.49	1.91 1.38	1.91 1.25	1.91 1.11	1.90 .96	1.90 .80	1.90 .61	1.90 .41	1.90 .20	1.90 .00	1.90 .00	1.89 .00	1.89 .00	1.88 .00	1.88 .00	1.87 .00	1.85 .00	1.81 .00	1.76 .00
13	1.92 1.60	1.92 1.49	1.92 1.37	1.92 1.24	1.92 1.10	1.91 .96	1.91 .79	1.91 .61	1.91 .41	1.91 .20	1.91 .00	1.90 .00	1.90 .00	1.89 .00	1.88 .00	1.87 .00	1.85 .00	1.81 .00	1.76 .00	1.69 .00
14	1.92 1.60	1.92 1.49	1.92 1.37	1.92 1.24	1.92 1.10	1.92 .96	1.91 .79	1.91 .61	1.91 .41	1.91 .20	1.91 .00	1.91 .00	1.90 .00	1.89 .00	1.89 .00	1.87 .00	1.85 .00	1.81 .00	1.76 .00	1.68 .00
15	1.92 1.60	1.92 1.49	1.92 1.37	1.92 1.24	1.92 1.10	1.91 .96	1.91 .79	1.91 .61	1.91 .41	1.91 .20	1.91 .00	1.90 .00	1.90 .00	1.89 .00	1.88 .00	1.87 .00	1.85 .00	1.81 .00	1.76 .00	1.69 .00
16	1.91 1.60	1.91 1.49	1.91 1.38	1.91 1.25	1.91 1.11	1.91 .96	1.90 .80	1.90 .61	1.90 .41	1.90 .20	1.90 .00	1.90 .00	1.89 .00	1.89 .00	1.88 .00	1.87 .00	1.85 .00	1.81 .00	1.76 .00	1.69 .00
17	1.89 1.60	1.89 1.50	1.89 1.38	1.89 1.25	1.89 1.11	1.89 .96	1.89 .80	1.89 .61	1.89 .41	1.88 .20	1.88 .00	1.88 .00	1.88 .00	1.88 .00	1.87 .00	1.86 .00	1.84 .00	1.81 .00	1.76 .00	1.69 .00
18	1.86 1.61	1.86 1.51	1.86 1.40	1.86 1.26	1.86 1.12	1.86 .97	1.86 .80	1.86 .61	1.86 .41	1.86 .20	1.86 .00	1.86 .00	1.86 .00	1.85 .00	1.85 .00	1.84 .00	1.83 .00	1.80 .00	1.75 .00	1.69 .00
19	1.78 1.56	1.78 1.48	1.78 1.37	1.78 1.24	1.78 1.09	1.78 .94	1.78 .77	1.78 .58	1.78 .39	1.78 .19	1.78 .00	1.78 .00	1.78 .00	1.78 .00	1.78 .00	1.77 .00	1.76 .00	1.73 .00	1.69 .00	1.64 .00
20	1.61 1.43	1.61 1.35	1.61 1.25	1.61 1.13	1.61 1.00	1.61 .86	1.61 .70	1.61 .53	1.61 .36	1.61 .18	1.61 .00	1.61 .00	1.61 .00	1.61 .00	1.61 .00	1.61 .00	1.61 .00	1.60 .00	1.58 .00	1.54 .00
21	1.35 1.21	1.35 1.14	1.35 1.06	1.35 .96	1.35 .85	1.35 .73	1.35 .60	1.35 .45	1.35 .30	1.36 .15	1.36 .00	1.36 .00	1.36 .00	1.36 .00	1.36 .00	1.36 .00	1.35 .00	1.33 .00	1.30 .00	1.26 .00
22	1.02 .92	1.02 .87	1.02 .80	1.02 .73	1.02 .64	1.02 .55	1.02 .45	1.02 .34	1.02 .23	1.02 .11	1.02 .00	1.02 .00	1.03 .00	1.03 .00	1.03 .00	1.03 .00	1.03 .00	1.02 .00	1.01 .00	.99 .00
23	.63 .57	.63 .54	.63 .50	.63 .45	.63 .40	.63 .34	.63 .28	.63 .21	.63 .14	.64 .07	.64 .00	.64 .00	.64 .00	.64 .00	.64 .00	.64 .00	.64 .00	.63 .00	.63 .00	.61 .00
24	.20 .18	.20 .17	.20 .15	.20 .14	.20 .12	.20 .11	.20 .09	.20 .07	.20 .04	.20 .02	.20 .00	.20 .00	.20 .00	.20 .00	.20 .00	.20 .00	.20 .00	.20 .00	.19 .00	.18 .00
25	.04 .03	.04 .03	.04 .03	.04 .03	.04 .02	.04 .02	.04 .02	.04 .01	.04 .01	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00	.04 .00
26	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00
27	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00

EXHIBIT B (Cont'd)
RELATIVE FLUX IN GROUP 2 t=0 s

	Radial Mesh Point Number																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
3	.03	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
4	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04
5	.03	.03	.03	.03	.02	.02	.02	.02	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
6	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62
7	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82
8	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98
9	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
10	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12
11	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
12	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
13	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
14	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
15	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
16	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
17	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
18	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12
19	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
20	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98
21	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82
22	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62
23	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39
24	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15
25	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04
26	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
27	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

Axial Mesh Point Number

EXHIBIT B (Cont'd)

RELATIVE FLUX IN GROUP 1 t=1.0 s

	Radial Mesh Point Number																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00
2	.01 .01	.01 .01	.01 .01	.01 .01	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01
3	.05 .05	.05 .04	.05 .04	.05 .04	.05 .03	.05 .03	.05 .02	.05 .02	.05 .01	.05 .01	.05 .05	.05 .05	.05 .05	.05 .05	.05 .05	.05 .05	.05 .05	.05 .05	.05 .05	.05 .05
4	.23 .24	.23 .22	.24 .21	.24 .19	.24 .16	.24 .14	.25 .12	.25 .09	.25 .06	.26 .03	.26	.26	.26	.26	.26	.26	.26	.26	.26	.25
5	.73 .76	.73 .72	.74 .66	.75 .60	.76 .53	.77 .46	.78 .37	.79 .28	.80 .19	.81 .09	.82	.82	.83	.83	.84	.84	.84	.83	.81	.79
6	1.19 1.23	1.19 1.16	1.20 1.08	1.21 .98	1.22 .86	1.24 .74	1.26 .61	1.28 .46	1.30 .31	1.31 .15	1.32	1.33	1.34	1.35	1.36	1.36	1.36	1.34	1.31	1.28
7	1.58 1.63	1.58 1.54	1.59 1.43	1.61 1.29	1.63 1.14	1.66 .98	1.68 .80	1.71 .61	1.73 .41	1.75 .20	1.76	1.77	1.78	1.79	1.80	1.81	1.80	1.78	1.74	1.69
8	1.90 1.94	1.90 1.93	1.91 1.70	1.93 1.54	1.96 1.36	1.99 1.17	2.02 .96	2.05 .72	2.07 .48	2.09 .24	2.11	2.13	2.14	2.15	2.16	2.16	2.15	2.13	2.08	2.02
9	2.13 2.14	2.13 2.02	2.15 1.87	2.17 1.69	2.20 1.50	2.23 1.29	2.26 1.06	2.30 .80	2.32 .54	2.34 .27	2.36	2.37	2.39	2.40	2.40	2.41	2.39	2.36	2.31	2.23
10	2.26 2.23	2.27 2.09	2.28 1.94	2.30 1.75	2.33 1.55	2.37 1.34	2.41 1.10	2.44 .84	2.46 .56	2.48 .28	2.50	2.52	2.53	2.54	2.54	2.54	2.52	2.48	2.42	2.34
11	2.35 2.26	2.36 2.12	2.37 1.95	2.39 1.77	2.42 1.57	2.46 1.36	2.50 1.13	2.53 .86	2.55 .58	2.57 .29	2.59	2.60	2.61	2.62	2.62	2.61	2.59	2.55	2.48	2.38
12	2.45 2.31	2.45 2.16	2.47 1.99	2.49 1.80	2.52 1.60	2.56 1.38	2.59 1.15	2.62 .88	2.65 .59	2.67 .30	2.68	2.69	2.70	2.70	2.70	2.69	2.66	2.61	2.54	2.43
13	2.56 2.37	2.57 2.21	2.58 2.03	2.60 1.84	2.63 1.63	2.67 1.42	2.70 1.17	2.73 .90	2.76 .61	2.77 .30	2.79	2.79	2.80	2.79	2.79	2.78	2.75	2.69	2.61	2.50
14	2.69 2.44	2.70 2.28	2.71 2.09	2.73 1.89	2.77 1.68	2.80 1.45	2.84 1.21	2.86 .92	2.88 .62	2.90 .31	2.91	2.91	2.91	2.90	2.89	2.88	2.84	2.78	2.69	2.58
15	2.86 2.52	2.86 2.35	2.88 2.16	2.90 1.95	2.93 1.73	2.96 1.50	2.99 1.24	3.02 .95	3.04 .64	3.05 .32	3.05	3.05	3.04	3.03	3.02	2.99	2.95	2.88	2.79	2.67
16	3.07 2.61	3.07 2.44	3.08 2.24	3.10 2.02	3.13 1.79	3.16 1.55	3.19 1.28	3.21 .98	3.22 .66	3.22 .33	3.22	3.21	3.20	3.18	3.16	3.12	3.08	3.00	2.90	2.77
17	3.34 2.72	3.34 2.53	3.35 2.32	3.37 2.09	3.39 1.85	3.41 1.60	3.43 1.32	3.44 1.01	3.45 .68	3.44 .34	3.43	3.41	3.38	3.35	3.31	3.27	3.21	3.13	3.01	2.88
18	3.68 2.81	3.69 2.62	3.69 2.41	3.70 2.17	3.70 1.91	3.71 1.65	3.72 1.35	3.72 1.03	3.70 .69	3.68 .34	3.66	3.62	3.58	3.54	3.48	3.42	3.34	3.24	3.12	2.98
19	3.91 2.82	3.91 2.63	3.91 2.42	3.91 2.18	3.90 1.91	3.89 1.64	3.88 1.34	3.86 1.01	3.82 .68	3.81 .34	3.77	3.72	3.67	3.60	3.53	3.45	3.36	3.25	3.12	2.98
20	3.79 2.64	3.79 2.46	3.79 2.26	3.78 2.03	3.77 1.79	3.75 1.53	3.73 1.24	3.71 .94	3.67 .63	3.63 .31	3.59	3.54	3.48	3.41	3.33	3.25	3.15	3.04	2.92	2.79
21	3.34 2.27	3.34 2.12	3.33 1.95	3.32 1.75	3.31 1.54	3.29 1.31	3.27 1.07	3.24 .81	3.21 .54	3.17 .27	3.13	3.08	3.02	2.96	2.89	2.81	2.72	2.62	2.52	2.40
22	2.60 1.74	2.60 1.63	2.59 1.49	2.58 1.34	2.57 1.18	2.56 1.00	2.54 .82	2.52 .62	2.49 .41	2.46 .20	2.42	2.38	2.33	2.28	2.23	2.16	2.09	2.02	1.93	1.84
23	1.64 1.09	1.64 1.02	1.64 .93	1.63 .84	1.62 .71	1.61 .63	1.60 .51	1.58 .39	1.57 .26	1.55 .13	1.52	1.50	1.47	1.43	1.40	1.36	1.31	1.26	1.21	1.15
24	.52 .34	.52 .32	.52 .29	.51 .26	.51 .23	.51 .19	.50 .16	.50 .12	.49 .08	.49 .04	.48	.47	.46	.45	.44	.43	.41	.40	.38	.36
25	.10 .07	.10 .06	.10 .06	.10 .05	.10 .05	.10 .04	.10 .03	.10 .02	.10 .02	.10 .01	.10	.09	.09	.09	.09	.09	.08	.08	.08	.07
26	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .00	.01 .00	.01 .00	.01 .00	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
27	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

EXHIBIT B (Cont'd)
RELATIVE FLUX IN GROUP 2 t=1.0 s

Radial Mesh Point Number

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
2	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
3	.04	.04	.04	.04	.04	.04	.04	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.04
4	.17	.17	.17	.17	.17	.17	.17	.18	.18	.18	.19	.19	.19	.19	.19	.19	.19	.19	.19	.18
5	.44	.44	.44	.45	.46	.47	.48	.49	.49	.50	.50	.50	.51	.51	.52	.52	.52	.52	.51	.50
6	.71	.71	.71	.72	.73	.75	.77	.78	.79	.80	.81	.81	.82	.82	.83	.84	.84	.83	.82	.80
7	.94	.95	.95	.96	.98	1.00	1.02	1.04	1.05	1.06	1.07	1.08	1.09	1.09	1.10	1.11	1.12	1.11	1.09	1.06
8	1.13	1.14	1.14	1.16	1.17	1.20	1.23	1.25	1.26	1.27	1.29	1.29	1.30	1.31	1.32	1.33	1.34	1.34	1.30	1.26
9	1.27	1.27	1.28	1.29	1.31	1.34	1.37	1.39	1.41	1.42	1.44	1.44	1.45	1.46	1.47	1.48	1.48	1.47	1.44	1.39
10	1.34	1.34	1.35	1.36	1.38	1.42	1.45	1.47	1.48	1.50	1.51	1.52	1.52	1.53	1.54	1.55	1.55	1.53	1.49	1.46
11	1.39	1.39	1.40	1.40	1.43	1.46	1.49	1.51	1.53	1.54	1.55	1.56	1.57	1.57	1.58	1.58	1.56	1.52	1.46	1.46
12	1.43	1.44	1.44	1.46	1.48	1.51	1.54	1.57	1.58	1.59	1.60	1.61	1.61	1.62	1.63	1.62	1.60	1.55	1.49	1.49
13	1.50	1.50	1.51	1.52	1.55	1.58	1.61	1.63	1.65	1.66	1.67	1.67	1.67	1.67	1.67	1.68	1.67	1.64	1.59	1.53
14	1.58	1.58	1.59	1.60	1.62	1.66	1.69	1.71	1.72	1.73	1.74	1.74	1.74	1.74	1.74	1.74	1.73	1.70	1.65	1.58
15	1.67	1.68	1.68	1.70	1.72	1.75	1.78	1.80	1.81	1.82	1.82	1.82	1.81	1.81	1.81	1.81	1.80	1.76	1.71	1.63
16	1.80	1.80	1.81	1.82	1.84	1.87	1.90	1.92	1.92	1.93	1.92	1.92	1.91	1.90	1.89	1.89	1.88	1.83	1.77	1.69
17	1.96	1.96	1.97	1.98	2.00	2.02	2.05	2.06	2.06	2.06	2.05	2.04	2.02	2.01	1.99	1.98	1.96	1.91	1.85	1.76
18	2.22	2.22	2.23	2.23	2.24	2.25	2.26	2.26	2.25	2.23	2.21	2.18	2.16	2.13	2.10	2.06	2.00	1.93	1.84	1.74
19	2.42	2.42	2.42	2.42	2.44	2.44	2.44	2.40	2.38	2.36	2.34	2.31	2.27	2.24	2.19	2.14	2.09	2.02	1.94	1.86
20	2.36	2.36	2.35	2.35	2.34	2.33	2.32	2.30	2.28	2.26	2.23	2.20	2.16	2.12	2.07	2.02	1.96	1.90	1.82	1.74
21	2.07	2.07	2.07	2.07	2.06	2.05	2.03	2.02	2.00	1.97	1.94	1.91	1.88	1.83	1.80	1.75	1.70	1.64	1.57	1.50
22	1.62	1.62	1.61	1.61	1.60	1.59	1.58	1.56	1.55	1.53	1.51	1.48	1.45	1.42	1.39	1.35	1.31	1.26	1.21	1.15
23	1.03	1.03	.95	.95	.74	.62	.49	.36	.24	.12										
24	.38	.38	.38	.38	.38	.36	.37	.37	.37	.36	.36	.35	.34	.33	.33	.32	.31	.29	.28	.27
25	.10	.10	.09	.09	.09	.09	.09	.09	.09	.09	.09	.08	.08	.08	.08	.08	.08	.07	.07	.07
26	.04	.04	.04	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03	.03	.03	.03	.03	.03	.03
27	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01

Axial Mesh Point Number

Radial Mesh Point Number

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00
2	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00
3	.08 .08	.08 .07	.08 .07	.08 .06	.08 .05	.08 .05	.08 .04	.08 .04	.08 .02	.08 .01	.08 .00	.08 .00	.08 .00	.08 .00	.08 .00	.08 .00	.08 .00	.08 .00	.08 .00	.08 .00
4	.38 .38	.38 .36	.38 .33	.38 .30	.39 .27	.39 .23	.40 .19	.41 .14	.41 .10	.41 .05	.42 .00	.42 .00	.42 .00	.43 .00	.43 .00	.43 .00	.43 .00	.42 .00	.41 .00	.40 .00
5	1.19 1.23	1.19 1.16	1.20 1.08	1.21 1.08	1.22 1.06	1.25 1.04	1.27 1.01	1.28 1.00	1.30 1.00	1.31 1.00	1.32 1.00	1.34 1.00	1.34 1.00	1.35 1.00	1.36 1.00	1.36 1.00	1.36 1.00	1.34 1.00	1.32 1.00	1.28 1.00
6	1.92 1.99	1.93 1.88	1.94 1.75	1.96 1.60	1.98 1.40	2.02 1.20	2.05 1.08	2.08 1.00	2.10 1.00	2.13 1.00	2.15 1.00	2.16 1.00	2.18 1.00	2.19 1.00	2.20 1.00	2.21 1.00	2.20 1.00	2.18 1.00	2.13 1.00	2.07 1.00
7	2.56 2.64	2.57 2.50	2.58 2.32	2.61 2.10	2.65 1.86	2.69 1.60	2.73 1.31	2.77 1.00	2.81 1.00	2.84 1.00	2.86 1.00	2.88 1.00	2.90 1.00	2.92 1.00	2.93 1.00	2.94 1.00	2.93 1.00	2.90 1.00	2.84 1.00	2.75 1.00
8	3.09 3.15	3.09 2.99	3.11 2.76	3.14 2.51	3.19 2.21	3.27 1.90	3.29 1.56	3.34 1.18	3.38 1.00	3.41 1.00	3.44 1.00	3.46 1.00	3.48 1.00	3.50 1.00	3.51 1.00	3.52 1.00	3.51 1.00	3.46 1.00	3.39 1.00	3.29 1.00
9	3.47 3.49	3.48 3.30	3.50 3.05	3.53 2.77	3.58 2.45	3.64 2.10	3.69 1.72	3.74 1.31	3.79 1.00	3.82 1.00	3.85 1.00	3.88 1.00	3.90 1.00	3.91 1.00	3.92 1.00	3.93 1.00	3.91 1.00	3.86 1.00	3.77 1.00	3.65 1.00
10	3.70 3.65	3.71 3.43	3.73 3.17	3.77 2.87	3.82 2.54	3.88 2.20	3.94 1.81	3.99 1.38	4.03 1.00	4.07 1.00	4.10 1.00	4.12 1.00	4.14 1.00	4.15 1.00	4.16 1.00	4.16 1.00	4.13 1.00	4.07 1.00	3.96 1.00	3.82 1.00
11	3.87 3.72	3.87 3.48	3.90 3.21	3.93 2.91	3.98 2.58	4.04 2.24	4.10 1.85	4.16 1.42	4.20 1.00	4.23 1.00	4.26 1.00	4.28 1.00	4.29 1.00	4.30 1.00	4.30 1.00	4.30 1.00	4.26 1.00	4.19 1.00	4.07 1.00	3.91 1.00
12	4.04 3.81	4.05 3.56	4.07 3.28	4.11 2.97	4.16 2.63	4.22 2.29	4.28 1.89	4.33 1.45	4.37 1.00	4.41 1.00	4.43 1.00	4.45 1.00	4.46 1.00	4.46 1.00	4.46 1.00	4.44 1.00	4.40 1.00	4.32 1.00	4.19 1.00	4.02 1.00
13	4.25 3.93	4.26 3.67	4.28 3.37	4.32 3.05	4.37 2.71	4.43 2.35	4.49 1.95	4.54 1.49	4.58 1.00	4.61 1.00	4.62 1.00	4.64 1.00	4.64 1.00	4.63 1.00	4.61 1.00	4.56 1.00	4.46 1.00	4.33 1.00	4.15 1.00	4.00
14	4.50 4.06	4.51 3.79	4.53 3.49	4.57 3.15	4.62 2.80	4.68 2.42	4.74 2.01	4.78 1.54	4.82 1.00	4.84 1.00	4.86 1.00	4.86 1.00	4.86 1.00	4.85 1.00	4.83 1.00	4.80 1.00	4.74 1.00	4.64 1.00	4.49 1.00	4.30
15	4.80 4.22	4.81 3.94	4.83 3.62	4.87 3.27	4.92 2.90	4.98 2.51	5.04 2.08	5.07 1.59	5.10 1.07	5.12 1.00	5.12 1.00	5.12 1.00	5.10 1.00	5.09 1.00	5.06 1.00	5.02 1.00	4.95 1.00	4.86 1.00	4.68 1.00	4.47
16	5.19 4.40	5.19 4.10	5.21 3.77	5.25 3.40	5.29 3.01	5.34 2.60	5.39 2.16	5.42 1.65	5.44 1.11	5.46 1.00	5.44 1.00	5.42 1.00	5.39 1.00	5.36 1.00	5.32 1.00	5.27 1.00	5.19 1.00	5.06 1.00	4.88 1.00	4.66
17	5.68 4.59	5.68 4.28	5.70 3.92	5.72 3.54	5.77 3.13	5.80 2.70	5.83 2.23	5.85 1.70	5.85 1.14	5.84 1.00	5.81 1.00	5.74 1.00	5.73 1.00	5.68 1.00	5.61 1.00	5.54 1.00	5.44 1.00	5.29 1.00	5.10 1.00	4.87
18	6.29 4.77	6.29 4.45	6.30 4.09	6.31 3.68	6.32 3.24	6.34 2.79	6.35 2.29	6.34 1.74	6.32 1.17	6.28 1.00	6.23 1.00	6.17 1.00	6.10 1.00	6.02 1.00	5.92 1.00	5.81 1.00	5.68 1.00	5.50 1.00	5.29 1.00	5.05
19	6.70 4.79	6.70 4.48	6.70 4.11	6.69 3.75	6.68 3.25	6.67 2.78	6.65 2.27	6.61 1.72	6.57 1.15	6.51 1.00	6.44 1.00	6.36 1.00	6.26 1.00	6.15 1.00	6.03 1.00	5.88 1.00	5.72 1.00	5.53 1.00	5.31 1.00	5.07
20	6.52 4.49	6.51 4.20	6.51 3.85	6.49 3.47	6.47 3.04	6.44 2.60	6.40 2.12	6.36 1.60	6.30 1.07	6.23 1.00	6.15 1.00	6.06 1.00	5.95 1.00	5.83 1.00	5.70 1.00	5.55 1.00	5.38 1.00	5.19 1.00	4.98 1.00	4.75
21	5.75 3.88	5.75 3.62	5.74 3.32	5.72 2.99	5.69 2.62	5.66 2.24	5.62 1.82	5.58 1.37	5.52 1.00	5.45 1.00	5.37 1.00	5.28 1.00	5.18 1.00	5.07 1.00	4.95 1.00	4.81 1.00	4.66 1.00	4.44 1.00	4.30 1.00	4.10
22	4.48 2.98	4.48 2.78	4.47 2.55	4.46 2.29	4.43 2.01	4.41 1.72	4.37 1.40	4.33 1.05	4.28 1.00	4.23 1.00	4.16 1.00	4.09 1.00	4.01 1.00	3.92 1.00	3.82 1.00	3.71 1.00	3.59 1.00	3.46 1.00	3.31 1.00	3.15
23	2.83 1.86	2.83 1.74	2.82 1.59	2.81 1.43	2.80 1.26	2.78 1.07	2.76 1.00	2.73 1.00	2.70 1.00	2.66 1.00	2.62 1.00	2.57 1.00	2.52 1.00	2.46 1.00	2.40 1.00	2.33 1.00	2.25 1.00	2.17 1.00	2.07 1.00	1.97
24	.89 .58	.89 .54	.89 .50	.89 .45	.88 .39	.88 .33	.87 .27	.86 .20	.85 .14	.84 .07	.83 .00	.81 .00	.79 .00	.78 .00	.75 .00	.73 .00	.71 .00	.68 .00	.65 .00	.62
25	.18 .12	.18 .11	.18 .10	.18 .09	.18 .08	.18 .07	.17 .05	.17 .04	.17 .03	.17 .01	.17 .00	.16 .00	.16 .00	.15 .00	.15 .00	.15 .00	.14 .00	.14 .00	.13 .00	.12
26	.03 .02	.03 .02	.03 .01	.03 .01	.03 .01	.03 .01	.03 .01	.02 .01	.02 .01	.02 .00	.02 .00	.02 .00	.02 .00	.02 .00	.02 .00	.02 .00	.02 .00	.02 .00	.02 .00	.02
27	.00 .00	.00 .00	.00 .00	.00 .00	2.26 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00

EXHIBIT B (Cont'd)

RELATIVE FLUX IN GROUP 2 $t=4.0$ s

		Radial Mesh Point Number																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Axial Mesh Point Number	1	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .00	.01 .00	.01 .00	.01 .00	.01 .00	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01 .01	.01	
	2	.03 .03	.03 .02	.03 .02	.03 .02	.03 .03	.03 .02	.03 .01	.03 .01	.03 .01	.03 .01	.03 .03	.03 .03	.03 .03	.03 .03	.03 .03	.03 .03	.03 .03	.03 .03	.03 .03	.03
	3	.07 .07	.07 .07	.07 .06	.07 .05	.07 .05	.07 .04	.07 .03	.07 .03	.08 .02	.08 .01	.08 .08	.08 .08	.08 .08	.08 .08	.08 .08	.08 .08	.08 .08	.08 .08	.07 .07	.07
	4	.27 .24	.27 .27	.27 .25	.28 .23	.28 .26	.29 .17	.29 .14	.30 .10	.30 .07	.30 .05	.31 .31	.31 .31	.31 .31	.31 .31	.31 .31	.31 .31	.31 .31	.31 .31	.31 .31	.30
	5	.71 .78	.72 .74	.72 .69	.73 .62	.74 .55	.76 .46	.77 .37	.79 .27	.80 .18	.81 .09	.81 .81	.82 .82	.82 .83	.83 .84	.84 .85	.85 .85	.85 .84	.84 .83	.83 .81	.81
	6	1.15 1.25	1.15 1.20	1.16 1.11	1.17 1.01	1.17 .88	1.22 .74	1.25 .59	1.27 .44	1.28 .29	1.30 .15	1.31 1.31	1.32 1.32	1.33 1.33	1.34 1.34	1.35 1.36	1.36 1.37	1.36 1.36	1.33 1.33	1.30 1.30	1.30
	7	1.53 1.67	1.53 1.59	1.54 1.48	1.56 1.34	1.59 1.17	1.62 .98	1.66 .78	1.69 .58	1.71 .39	1.73 .19	1.74 1.74	1.76 1.76	1.77 1.77	1.78 1.78	1.79 1.81	1.81 1.82	1.82 1.80	1.77 1.77	1.72 1.72	1.72
	8	1.84 1.99	1.85 1.89	1.86 1.76	1.88 1.59	1.91 1.40	1.95 1.17	2.01 .93	2.03 .70	2.06 .46	2.08 .23	2.09 2.09	2.11 2.11	2.12 2.12	2.13 2.13	2.15 2.17	2.17 2.18	2.16 2.16	2.11 2.11	2.06 2.06	2.06
	9	2.07 2.20	2.07 2.09	2.09 1.94	2.11 1.75	2.14 1.54	2.19 1.29	2.24 1.03	2.28 .77	2.30 .51	2.33 .26	2.34 2.34	2.36 2.36	2.37 2.37	2.38 2.38	2.40 2.42	2.42 2.42	2.42 2.40	2.35 2.35	2.28 2.28	2.28
	10	2.19 2.27	2.19 2.14	2.21 1.98	2.23 1.79	2.27 1.58	2.32 1.33	2.37 1.08	2.40 .81	2.43 .54	2.45 .27	2.47 2.47	2.49 2.49	2.50 2.51	2.51 2.52	2.54 2.54	2.54 2.51	2.45 2.45	2.37 2.37	2.27 2.27	2.27
	11	2.26 2.28	2.27 2.14	2.28 1.97	2.31 1.78	2.34 1.58	2.40 1.35	2.45 1.10	2.48 .83	2.51 .56	2.53 .28	2.55 2.55	2.56 2.56	2.57 2.57	2.58 2.58	2.58 2.60	2.60 2.60	2.56 2.56	2.49 2.49	2.40 2.40	2.40
	12	2.37 2.33	2.37 2.18	2.39 2.01	2.41 1.82	2.45 1.61	2.50 1.37	2.55 1.12	2.59 .85	2.61 .57	2.63 .29	2.65 2.65	2.66 2.66	2.67 2.67	2.67 2.67	2.69 2.69	2.68 2.68	2.54 2.54	2.36 2.36	2.26 2.26	2.26
	13	2.44 2.40	2.49 2.25	2.51 2.07	2.53 1.87	2.57 1.65	2.62 1.41	2.68 1.15	2.71 .88	2.73 .59	2.75 .29	2.76 2.76	2.77 2.77	2.77 2.77	2.77 2.78	2.79 2.79	2.78 2.78	2.73 2.73	2.65 2.65	2.54 2.54	2.54
	14	2.63 2.49	2.64 2.33	2.65 2.14	2.68 1.93	2.71 1.70	2.77 1.46	2.82 1.19	2.85 .91	2.88 .61	2.89 .30	2.90 2.90	2.90 2.90	2.90 2.90	2.90 2.90	2.90 2.89	2.89 2.84	2.75 2.75	2.63 2.63	2.54 2.54	2.54
	15	2.81 2.59	2.82 2.42	2.83 2.22	2.85 2.00	2.89 1.77	2.95 1.51	3.00 1.23	3.03 .96	3.05 .63	3.06 .31	3.06 3.06	3.06 3.05	3.04 3.04	3.03 3.03	3.04 3.02	2.96 2.96	2.86 2.86	2.74 2.74	2.65 2.65	2.65
	16	3.04 2.70	3.04 2.51	3.05 2.31	3.08 2.08	3.11 1.84	3.16 1.57	3.21 1.28	3.24 .97	3.25 .65	3.25 .32	3.25 3.24	3.22 3.21	3.19 3.19	3.19 3.16	3.09 3.09	2.99 2.99	2.85 2.85	2.74 2.74	2.65 2.65	2.65
	17	3.33 2.82	3.34 2.63	3.35 2.41	3.36 2.27	3.39 1.91	3.44 1.63	3.48 1.32	3.50 1.00	3.50 .67	3.49 .33	3.48 3.46	3.43 3.40	3.37 3.36	3.32 3.32	3.24 3.24	3.12 3.12	2.98 2.98	2.88 2.88	2.78 2.78	2.78
	18	3.80 2.97	3.80 2.78	3.80 2.55	3.81 2.30	3.82 2.01	3.85 1.70	3.86 1.36	3.86 1.03	3.85 .69	3.83 .34	3.80 3.76	3.72 3.67	3.62 3.62	3.57 3.50	3.50 3.40	3.27 3.27	3.13 3.13	3.03 3.03	2.93 2.93	2.93
	19	4.16 3.02	4.15 2.84	4.15 2.61	4.15 2.35	4.14 2.05	4.14 1.71	4.12 1.36	4.10 1.02	4.07 .68	4.02 .33	4.00 3.94	3.89 3.82	3.74 3.74	3.66 3.56	3.44 3.44	3.31 3.31	3.17 3.17	3.07 3.07	2.97 2.97	2.97
	20	4.05 2.83	4.05 2.66	4.04 2.45	4.03 2.20	4.02 1.92	4.00 1.60	3.98 1.27	3.95 .95	3.92 .63	3.87 .31	3.82 3.77	3.70 3.63	3.55 3.55	3.46 3.35	3.24 3.24	3.11 3.11	2.97 2.97	2.87 2.87	2.77 2.77	2.77
	21	3.57 2.44	3.57 2.30	3.57 2.11	3.56 1.90	3.54 1.65	3.52 1.37	3.50 1.09	3.47 .81	3.43 .54	3.39 .27	3.34 3.28	3.22 3.15	3.08 2.99	2.90 2.90	2.80 2.80	2.69 2.69	2.56 2.56	2.46 2.46	2.36 2.36	2.36
	22	2.79 1.88	2.79 1.77	2.78 1.62	2.77 1.46	2.76 1.27	2.74 1.05	2.72 .83	2.69 .62	2.66 .41	2.63 .20	2.59 2.54	2.49 2.44	2.38 2.31	2.24 2.24	2.16 2.16	2.07 2.07	1.97 1.97	1.87 1.87	1.77 1.77	1.77
	23	1.77 1.18	1.77 1.11	1.77 1.02	1.76 .92	1.75 .80	1.74 .66	1.73 .52	1.71 .39	1.69 .26	1.67 .13	1.64 1.61	1.58 1.54	1.50 1.50	1.46 1.46	1.41 1.41	1.36 1.36	1.30 1.30	1.24 1.24	1.14 1.14	1.14
	24	.66 .44	.66 .41	.66 .37	.66 .33	.66 .29	.65 .24	.65 .20	.64 .15	.63 .10	.62 .05	.61 .60	.59 .59	.57 .57	.56 .56	.54 .54	.53 .53	.51 .51	.48 .48	.46 .46	.46
	25	.16 .11	.16 .10	.16 .09	.16 .08	.16 .07	.16 .06	.16 .05	.16 .04	.16 .02	.15 .01	.15 .15	.15 .14	.14 .14	.13 .13	.13 .13	.12 .12	.12 .12	.11 .11	.11 .11	.11
	26	.06 .04	.06 .04	.06 .03	.06 .03	.06 .03	.06 .02	.06 .02	.06 .01	.06 .01	.06 .00	.06 .06	.06 .06	.05 .05	.05 .05	.05 .05	.05 .05	.05 .05	.04 .04	.04 .04	.04
27	.02 .01	.02 .01	.02 .01	.02 .01	.02 .01	.02 .01	.02 .01	.02 .00	.02 .00	.02 .00	.02 .02	.02 .02	.02 .02	.02 .02	.02 .02	.02 .02	.02 .02	.02 .02	.02 .02	.02	

EXHIBIT CRELATIVE POWER DENSITY (AVERAGED OVER HEIGHT)
VS. RADIAL POSITION*

<u>Radius, cm</u>	<u>t=0 s</u>	<u>t=1 s</u>	<u>t=4 s</u>
0	1.504	2.414	4.062
8	1.504	2.417	4.065
16	1.504	2.424	4.077
24	1.504	2.436	4.096
32	1.503	2.453	4.125
40	1.503	2.480	4.168
48	1.502	2.504	4.208
56	1.502	2.516	4.227
64	1.501	2.522	4.235
72	1.501	2.521	4.231
80	1.500	2.516	4.223
88	1.499	2.507	4.206
96	1.498	2.494	4.183
104	1.498	2.479	4.154
112	1.499	2.461	4.123
120	1.505	2.446	4.096
128	1.502	2.418	4.047
136	1.480	2.365	3.956
144	1.443	2.290	3.830
152	1.392	2.199	3.676
160	1.32	2.094	3.500
168	1.256	1.968	3.289
176	1.162	1.814	3.030
184	1.051	1.637	2.734
192	0.925	1.438	2.402
200	0.815	1.263	2.110
208	0.682	1.056	1.763
216	0.516	0.798	1.332
224	0.345	0.533	0.889
232	0.172	0.265	0.442
240	0.0	0.0	0.0

* $\Delta t = 0.0005$ s

EXHIBIT DRELATIVE POWER DENSITY (AVERAGED OVER RADIUS)
VS. AXIAL POSITION*

<u>Height**</u>	<u>t=0 s</u>	<u>t=1 s</u>	<u>t=4 s</u>
0	0.0	0.0	0.0
18.75	0.0	0.0	0.0
37.50	0.0	0.0	0.0
56.25	0.0	0.0	0.0
75.00	0.118	0.154	0.250
93.75	0.646	0.848	1.375
112.50	1.037	1.365	2.216
131.25	1.369	1.811	2.946
150.00	1.622	2.163	3.524
168.75	1.780	2.398	3.916
187.50	1.826	2.469	4.088
206.25	1.820	2.534	4.167
225.00	1.821	2.597	4.290
243.75	1.822	2.676	4.442
262.50	1.822	2.770	4.621
281.25	1.822	2.879	4.829
300.00	1.821	3.006	5.066
318.75	1.820	3.153	5.338
337.50	1.827	3.341	5.678
356.25	1.781	3.421	5.832
375.00	1.623	3.227	5.514
393.75	1.370	2.792	4.780
412.50	1.038	2.152	3.688
431.25	0.647	1.355	2.324
450.00	0.118	0.247	0.423
468.75	0.0	0.0	0.0
487.50	0.0	0.0	0.0
506.25	0.0	0.0	0.0
525.00	0.0	0.0	0.0

* $\Delta t = 0.0005 \text{ s}$

** Height is measured from top of the reactor

BENCHMARK SOURCE SITUATION

Identification: 9

Date Submitted: June 1976

By: R. G. Steinke (LASL)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)

M. R. Wagner (KWU)

Descriptive Title: Multi-dimensional (Hex-z) HTGR Model

Suggested Function: Test multigroup solutions in hexagonal (triangular) geometry

Configuration: Three-dimensional configuration having six-fold rotational symmetry in the x-y plane (three figures)

Figure 1. A-Y Plane Diagram of the Top Half of the Reactor.
 (The composition letter and column number of each hexagon block in the sixty degree rotational symmetry sector are given in their upper and lower halves.)

Figure 3. Axial Plant Cut #2 Diagram (The composition letter of each hexagon block in the sixty degree rotational symmetry sector is shown in the diagram. The composition letters and column numbers are for the counter-clockwise rotated face of the cut.)

Boundary Condition: Vacuum boundary condition on outside surface.

Composition: Fuel temperature = 1150°K. Moderator and poison temperature = 1050°K.

Composition Letter		A	B	C	D	E	F	G	H
Composition Description		Controlled Core Top Half	Uncontrolled Core Top Half	Regular Core Top Half	Buffer One Side Top Half	Buffer Two Sides Top Half	Buffer Three Sides Top Half	Radial Reflector	Bottom Reflector
Concentration†	Th-232	1.83-4	1.83-4	3.22-4	3.43-4	3.55-4	3.68-4	0.0	0.0
	U-235	1.21-5	1.21-5	2.13-5	1.92-5	1.79-5	1.66-5	0.0	0.0
	U-238	7.60-7	7.60-7	1.34-6	1.20-6	1.12-6	1.04-6	0.0	0.0
	C	5.49-2	5.49-2	6.15-2	6.15-2	6.15-2	6.15-2	8.93-2	7.26-2
	B(nat)	1.60-3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	B-10	0.0	0.0	4.00-7	4.00-7	4.00-7	4.00-7	0.0	0.0
Composition Letter		I	J	K	L	M	N	P	Q
Composition Description		Controlled Core Bottom Half	Uncontrolled Core Bottom Half	Regular Core Bottom Half	Buffer One Side Bottom Half	Buffer Two Sides Bottom Half	Buffer Three Sides Bottom Half	Controlled Top Reflector	Un-Controlled Top Reflector
Concentration†	Th-232	1.49-4	1.49-4	2.88-4	3.16-4	3.33-4	3.50-4	0.0	0.0
	U-235	8.41-6	8.41-6	1.62-5	1.51-5	1.44-5	1.38-5	0.0	0.0
	U-238	5.27-7	5.27-7	1.02-6	9.48-7	9.05-7	8.62-7	0.0	0.0
	C	5.05-2	5.05-2	6.19-2	6.17-2	6.17-2	6.17-2	6.74-2	6.74-2
	B(nat)	1.60-3	0.0	0.0	0.0	0.0	0.0	1.60-3	0.0
	B-10	0.0	0.0	4.00-7	4.00-7	4.00-7	4.00-7	0.0	0.0

† Units of 10^{24} atoms/cm³.

BENCHMARK PROBLEM

Identification: 9-A1

Source Situation ID.9

Date Submitted: June 1976

By: R. G. Steinke (LASL)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
M. R. Wagner (KWU)Descriptive Title: Few-Group, Two-Dimensional Hexagonal
Geometry HTGR Problem

Reduction of Source Situation:

1. Diffusion theory.
2. Four energy groups ($G=4$) with single group downscatter.
3. Two-dimensional hexagonal (triangular) geometry with zero axial leakage; top half of the core horizontal plane (Figure 1 of Source Situation).
4. Zero flux boundary condition on the outside surface.

The few-group diffusion equations to be solved are

$$-\nabla \cdot D^g \nabla \phi^g + \Sigma_r^g \phi^g - \Sigma_s^{g-1 \rightarrow g} \phi^{g-1} = (\chi^g / K_{eff}) \sum_{g'=1}^G \nu \Sigma_f^{g'} \phi^{g'} ; \quad g=1,2,\dots,G=4$$

where

$$\Sigma_r^g = \Sigma_c^g + \Sigma_f^g + \Sigma_s^{g \rightarrow g+1} , \quad \Sigma_s^{G \rightarrow G+1} = 0$$

and the usual cross section definitions apply.

Additional Data:

Fission Spectrum $\chi^1=0.9675, \chi^2=0.0325, \chi^3=0.0, \chi^4=0.0$

Energy Group Intervals

<u>Energy Group Number</u>	<u>Energy Interval, eV</u>
1	1.83+5 to 1.49+7
2	1.76+1 to 1.83+5
3	2.38 to 1.76+1
4	0.0 to 2.38

Macroscopic Cross Sections

Composition A (Controlled Core)

Group g	D^g	Σ_c^g	Σ_f^g	$\nu\Sigma_f^g$	$\Sigma_s^{g \rightarrow g+1}$
1	2.65+0	1.98-4	2.25-5	5.58-5	1.09-2
2	1.37+0	4.55-3	1.49-4	3.61-4	3.28-3
3	1.34+0	9.12-3	4.08-4	9.88-4	2.04-2
4	1.31+0	8.93-3	1.97-3	4.76-3	

Composition B (Uncontrolled Core)

Group g	D^g	Σ_c^g	Σ_f^g	$\nu\Sigma_f^g$	$\Sigma_s^{g \rightarrow g+1}$
1	2.65+0	3.61-5	2.25-5	5.58-5	1.09-2
2	1.37+0	7.69-4	1.49-4	3.61-4	3.28-3
3	1.34+0	4.28-4	4.08-4	9.88-4	2.04-2
4	1.31+0	8.70-4	1.97-3	4.76-3	

Composition C (Regular Core)

Group g	D^g	Σ_c^g	Σ_f^g	$\nu\Sigma_f^g$	$\Sigma_s^{g \rightarrow g+1}$
1	2.35+0	5.82-5	3.95-5	9.83-5	1.23-2
2	1.21+0	1.36-3	2.62-4	6.36-4	3.67-3
3	1.19+0	8.41-4	7.18-4	1.74-3	2.28-2
4	1.16+0	1.89-3	3.46-3	8.39-3	

Composition D (Buffer Core; One Side On Core-Reflector Interface)

Group g	D^g	Σ_c^g	Σ_f^g	$\nu\Sigma_f^g$	$\Sigma_s^{g \rightarrow g+1}$
1	2.35+0	6.08-5	3.76-5	9.31-5	1.23-2
2	1.21+0	1.43-3	2.36-4	5.73-4	3.67-3
3	1.19+0	7.77-4	6.47-4	1.57-3	2.28-2
4	1.16+0	1.87-3	3.12-3	7.56-3	

Composition E (Buffer Core; Two Sides on Core-Reflector Interface)

Group g	D^g	Σ_c^g	Σ_f^g	$\nu\Sigma_f^g$	$\Sigma_s^{g \rightarrow g+1}$
1	2.35+0	6.23-5	3.63-5	8.97-5	1.23-2
2	1.21+0	1.46-3	2.20-4	5.34-4	3.67-3
3	1.19+0	7.38-4	6.03-4	1.46-3	2.28-2
4	1.16+0	1.86-3	2.91-3	7.05-3	

Composition F (Buffer Core; Three Sides On Core-Reflector Interface)

Group g	D^g	Σ_c^g	Σ_f^g	$\nu\Sigma_f^g$	$\Sigma_s^{g \rightarrow g+1}$
1	2.35+0	6.40-5	3.51-5	8.65-5	1.23-2
2	1.21+0	1.50-3	2.04-4	4.95-4	3.67-3
3	1.19+0	6.99-4	5.59-4	1.36-3	2.28-2
4	1.16+0	1.85-3	2.70-3	6.54-3	

Composition G (Radial Reflector)

Group g	D^g	Σ_c^g	Σ_f^g	$\nu\Sigma_f^g$	$\Sigma_s^{g \rightarrow g+1}$
1	1.64+0	1.39-5	0.0	0.0	1.77-2
2	8.50-1	2.18-6	0.0	0.0	5.33-3
3	8.32-1	1.97-5	0.0	0.0	3.31-2
4	8.21-1	1.06-4	0.0	0.0	

Expected Primary Results:

1. Fundamental eigenvalue: K_{eff} .
2. Number of power iterations and computation time for the diffusion calculation versus mesh size.
3. Fundamental eigenvector: Fission rate density and group fluxes
 - a. Hexagon averaged values
(There are 72 unique hexagon columns)
 - b. Radial traverses along axial plane cuts #1 and #2
(See Figure 1 of the Source Situation)

Note: Normalize the core average fission rate density to one fission per cm^3 per second

Possible Additional Results:

1. Neutron balance for each composition type and the core.
2. Change hexagon column 1 from Composition A (Controlled Core) to Composition B (Uncontrolled Core) and report the above.

Best Solution Available:

Solutions Available:

1. Finite difference: 9-A1-1, 9-A1-2, 9-A1-3

Identification: 9-A1-1	Benchmark Problem ID.9-A1
Date Submitted: June 1976	By: R. G. Steinke (LASL)
Date Accepted: June 1977	By: H. L. Dodds, Jr. (U. of Tenn.) M. R. Wagner (KWU)

Descriptive Title: Discrete Few-Group, Two-Dimensional Hexagonal Geometry HTGR Problem

1. Equilateral triangle grid network overlay with mesh lines coinciding with composition interfaces; mesh lines connect mesh points forming a interface centered mesh.
2. Seven-point difference equations with a finite difference first derivative leakage approximation midway between mesh points.

1. One line successive over-relaxation with one inner per outer iteration.
2. Coarse mesh rebalance with concentric ring mesh lines becoming coarse mesh points.
3. Periodic asymptotic flux extrapolation.

Type of Program: Two-Dimensional, Triangular Mesh, Multigroup Diffusion-Depletion Program

Machine Language Contents: None

Computer: UNIVAC 1108

Hardware Used: 64K of central core and 2 drums with 40K of available storage each

Operating System: UNIVAC 1108 EXEC-8 Operating System, Level 31

Significant Figures Carried: Equivalent of eight decimals

Convergence Criteria: Maximum relative flux change less than 10^{-5}

References: W. R. Davison, "BUG180/HTGR, A Two-Dimensional, Triangular Mesh, Multigroup Diffusion-Burnup Code for Use in the Design of 180° Rotationally Symmetric HTGR Cores," General Atomic Report GA-A12674 (April, 1975)

J. P. Dorsey, R. Froehlich and F. Todt, "BUG-2/BUGTRI, Two Dimensional Multigroup Burnup Codes for Rectangular and Hexagonal Geometry," USAEC Report GA-8272, Gulf General Atomic Inc. (August, 1969).

Primary Results:

Mesh Description	Coarse	Fine	Very Fine
Equivalent Number of Mesh Points/Column	3	12	48
Distance Between Mesh Points	20.9 cm	10.45 cm	5.225 cm
Number of Spatial Mesh Points (1/2 core calculation plane)	682	2644	10411
K_{eff} Fundamental Eigenvalue	1.116716	1.117766	1.118149
Number of Power Iterations	55	112	460
Computer Time for Diffusion Calculation (UNIVAC 1108)	1.92 min	13.27 min	160.9

TABLE I
COLUMN AVERAGED FISSION DISTRIBUTION (FISSIONS/CM**3/SEC)
[NORMALIZED TO A CORE AVERAGE VALUE OF ONE]

Column Number	Equivalent No. Points/Column		
	3	12	48
1	0.3798	0.3755	0.3745
2	0.9988	1.0497	1.0655
3	0.7781	0.8207	0.8338
4	1.1891	1.2247	1.2349
5	1.2358	1.2777	1.2902
6	1.2183	1.2662	1.2806
7	1.2450	1.2906	1.3043
8	1.1999	1.2404	1.2522
9	1.2147	1.2470	1.2562
10	0.7442	0.7638	0.7695
11	1.1766	1.1692	1.1665
12	1.1328	1.1431	1.1455
13	1.1938	1.2149	1.2207
14	1.1565	1.1761	1.1812
15	1.1522	1.1551	1.1552
16	1.1802	1.1699	1.1663
17	0.3494	0.3374	0.3339
18	0.8565	0.8673	0.8703
19	0.9093	0.9284	0.9338
20	0.9547	0.9879	0.9977
21	0.9665	1.0048	1.0162
22	0.9419	0.9702	0.9785
23	0.8859	0.9007	0.9048
24	0.7534	0.7280	0.7206
25	1.0347	0.9833	0.9688
26	1.1301	1.1012	1.0928
27	1.1038	1.0702	1.0605
28	0.9614	0.9063	0.8907
29	0.6444	0.6412	0.6404
30	0.9144	0.8673	0.8541
31	0.9867	0.9557	0.9467
32	1.0122	1.0052	1.0028
33	1.0913	1.0852	1.0830
34	1.1010	1.0745	1.0668
35	0.9778	0.9306	0.9174
36	0.6438	0.6409	0.6402
37	0.9128	0.8654	0.8520
38	1.0073	0.9696	0.9587
39	1.1131	1.0972	1.0921
40	1.0477	1.0454	1.0441
41	1.0215	1.0056	1.0008
42	0.9655	0.9256	0.9141

TABLE II

ENERGY GROUP 1 COLUMN AVERAGED FLUX DISTRIBUTION (NEUTRONS/CM**2/SEC)

Column Number	Equivalent No. Points/Column			Column Number	Equivalent No. Points/Column		
	3	12	48		3	12	48
1	127.487	130.467	131.571	37	99.857	102.062	102.886
2	169.477	177.610	180.096	38	139.999	139.480	139.360
3	192.456	195.194	195.811	39	176.456	175.431	175.043
4	190.694	196.893	198.719	40	168.092	168.487	168.502
5	197.946	205.378	207.624	41	158.103	157.898	157.768
6	195.498	203.746	206.268	42	119.647	120.815	121.286
7	199.456	207.498	209.956	43	32.988	27.041	25.275
8	192.469	199.484	201.577	44	29.975	24.738	23.167
9	194.486	200.315	202.026	45	0.091	0.045	0.036
10	184.114	181.724	180.763	46	0.004	0.002	0.001
11	188.270	187.914	187.734	47	0.102	0.050	0.040
12	181.688	183.837	184.395	48	1.888	1.174	1.010
13	191.270	195.396	196.563	49	1.501	0.925	0.796
14	185.564	189.254	190.268	50	0.046	0.023	0.018
15	184.492	185.603	185.840	51	0.003	0.001	0.001
16	188.861	188.077	187.763	52	1.933	1.195	1.027
17	117.302	117.231	117.318	53	0.068	0.036	0.030
18	145.454	146.977	147.331	54	1.406	0.878	0.759
19	154.324	157.142	157.879	55	29.795	24.603	23.027
20	161.897	167.061	168.536	56	33.718	27.583	25.740
21	163.888	169.879	171.627	57	2.052	1.263	1.085
22	159.772	164.108	165.329	58	0.099	0.050	0.040
23	150.443	152.554	153.094	59	2.916	1.818	1.569
24	121.409	120.178	119.863	60	0.098	0.052	0.042
25	128.329	128.996	129.290	61	1.438	0.895	0.772
26	175.705	173.944	173.353	62	30.155	24.877	23.273
27	168.044	166.420	165.866	63	46.225	38.484	36.057
28	105.662	107.535	108.239	64	16.055	12.869	11.964
29	148.656	144.791	143.503	65	0.434	0.262	0.222
30	99.858	102.107	102.960	66	2.510	1.561	1.348
31	137.426	137.510	137.583	67	0.073	0.038	0.031
32	160.448	160.549	160.507	68	0.470	0.279	0.235
33	174.857	174.823	174.745	69	16.760	13.403	12.446
34	169.649	168.309	167.865	70	44.385	37.012	34.691
35	120.082	120.997	121.388	71	15.960	12.800	11.901
36	148.546	144.738	143.446	72	0.423	0.257	0.218

TABLE III

ENERGY GROUP 2 COLUMN AVERAGED FLUX DISTRIBUTION (NEUTRONS/CM**2/SEC)

Column Number	Equivalent No. Points/Column			Column Number	Equivalent No. Points/Column		
	3	12	48		3	12	48
1	300.333	304.512	305.987	37	242.102	236.049	233.903
2	400.118	419.325	425.254	38	328.335	322.002	319.904
3	477.028	493.012	497.895	39	412.029	408.999	407.844
4	450.989	464.459	468.348	40	395.369	395.725	395.537
5	467.542	483.798	488.645	41	367.883	366.146	365.415
6	462.360	480.653	486.177	42	286.128	280.217	278.192
7	471.125	488.822	494.168	43	123.002	112.662	109.970
8	455.166	470.547	475.060	44	111.047	101.982	99.616
9	459.397	471.908	475.505	45	1.936	1.357	1.220
10	456.012	458.782	459.454	46	0.138	0.092	0.082
11	442.440	440.924	440.231	47	2.084	1.483	1.340
12	429.499	433.584	434.539	48	18.657	15.004	14.078
13	451.722	460.248	462.583	49	14.418	11.531	10.809
14	438.792	446.404	448.408	50	0.957	0.690	0.626
15	435.249	436.919	437.129	51	0.113	0.074	0.065
16	443.297	440.890	439.911	52	18.311	14.752	13.846
17	276.273	273.583	272.811	53	1.265	0.963	0.887
18	342.622	346.500	347.458	54	12.916	10.523	9.924
19	364.185	370.932	372.745	55	106.484	97.978	95.785
20	382.115	394.286	397.813	56	121.157	110.948	108.305
21	386.798	400.901	405.067	57	19.707	15.808	14.820
22	377.108	387.353	390.288	58	1.951	1.402	1.271
23	354.832	360.000	361.370	59	25.807	21.038	19.826
24	298.208	291.403	289.166	60	1.752	1.339	1.236
25	303.332	295.934	293.453	61	13.443	10.925	10.293
26	404.874	399.906	398.235	62	109.435	100.609	98.312
27	385.236	380.106	378.379	63	156.395	146.005	143.242
28	253.497	246.472	244.008	64	67.041	59.843	58.020
29	360.212	356.679	355.579	65	5.436	4.306	4.020
30	242.011	236.008	233.907	66	21.944	17.822	16.785
31	323.761	318.614	316.899	67	1.348	1.009	0.926
32	376.045	375.586	375.217	68	6.004	4.659	4.320
33	410.546	409.863	409.450	69	69.155	61.584	59.654
34	392.528	388.299	386.873	70	148.324	138.497	135.861
35	284.604	278.153	275.986	71	66.417	59.328	57.526
36	360.225	356.786	355.662	72	5.225	4.150	3.877

TABLE IV

ENERGY GROUP 3 COLUMN AVERAGED FLUX DISTRIBUTION (NEUTRONS/CM**2/SEC)

Column Number	Equivalent No. Points/Column			Column Number	Equivalent No. Points/Column		
	3	12	48		3	12	48
1	41.557	41.106	40.938	37	36.986	35.847	35.458
2	59.312	62.355	63.308	38	49.545	48.477	48.129
3	72.274	74.904	75.709	39	61.747	61.266	61.085
4	67.710	69.725	70.306	40	59.282	59.338	59.310
5	70.201	72.617	73.338	41	55.147	54.832	54.706
6	69.416	72.155	72.981	42	43.459	42.393	42.038
7	70.739	73.372	74.167	43	19.982	18.513	18.134
8	68.336	70.638	71.312	44	18.035	16.740	16.406
9	68.979	70.835	71.368	45	0.357	0.253	0.228
10	69.076	69.694	69.856	46	0.026	0.017	0.015
11	66.357	66.117	66.010	47	0.384	0.276	0.250
12	64.474	65.085	65.226	48	3.317	2.708	2.553
13	67.823	69.080	69.424	49	2.560	2.079	1.957
14	65.875	67.012	67.310	50	0.177	0.129	0.117
15	65.330	65.567	65.595	51	0.021	0.014	0.012
16	66.465	66.095	65.945	52	3.247	2.658	2.506
17	38.225	36.929	36.498	53	0.232	0.179	0.165
18	50.732	51.478	51.682	54	2.285	1.893	1.793
19	53.977	55.152	55.484	55	17.235	16.028	15.721
20	56.654	58.642	59.232	56	19.609	18.166	17.797
21	57.352	59.629	60.315	57	3.498	2.850	2.684
22	55.908	57.607	58.108	58	0.359	0.261	0.237
23	52.572	53.511	53.777	59	4.553	3.776	3.576
24	45.304	44.153	43.775	60	0.322	0.249	0.230
25	45.911	44.619	44.197	61	2.382	1.967	1.862
26	60.526	59.732	59.468	62	17.755	16.498	16.174
27	57.583	56.738	56.456	63	25.093	23.705	23.343
28	38.595	37.314	36.880	64	11.079	9.994	9.720
29	54.485	54.033	53.889	65	0.980	0.787	0.738
30	36.969	35.837	35.455	66	3.869	3.196	3.025
31	48.895	48.005	47.714	67	0.248	0.187	0.173
32	56.377	56.297	56.238	68	1.084	0.852	0.793
33	61.556	61.443	61.378	69	11.410	10.269	9.979
34	58.783	58.087	57.855	70	23.763	22.445	22.097
35	43.159	42.003	41.625	71	10.971	9.904	9.633
36	54.497	54.058	53.910	72	0.942	0.758	0.711

TABLE V

ENERGY GROUP 4 COLUMN AVERAGED FLUX DISTRIBUTION (NEUTRONS/CM**2/SEC)

Column Number	Equivalent No. Points/Column			Column Number	Equivalent No. Points/Column		
	3	12	48		3	12	48
1	160.031	157.568	156.977	37	310.827	293.927	289.190
2	244.130	256.652	260.552	38	286.048	274.672	271.413
3	341.745	361.548	367.650	39	275.689	271.413	270.069
4	293.305	302.064	304.576	40	258.643	257.937	257.567
5	304.946	315.239	318.304	41	254.113	249.740	248.433
6	300.461	312.254	315.792	42	299.644	286.607	282.885
7	307.195	318.393	321.771	43	454.841	454.438	454.208
8	295.961	305.925	308.830	44	430.889	428.974	428.383
9	299.747	307.672	309.949	45	135.792	134.117	133.818
10	326.863	336.509	339.303	46	23.879	25.180	25.717
11	290.630	288.658	287.963	47	119.032	119.114	119.511
12	279.437	281.953	282.522	48	326.682	320.576	318.844
13	294.552	299.720	301.121	49	270.981	266.622	265.438
14	285.239	290.047	291.288	50	64.011	65.081	65.688
15	284.390	285.027	285.048	51	21.220	22.125	22.553
16	291.580	288.868	287.950	52	273.495	271.312	270.817
17	147.231	141.568	139.959	53	49.381	51.802	52.804
18	209.415	212.078	212.801	54	172.251	174.529	175.694
19	222.260	227.001	228.332	55	375.071	376.922	377.647
20	233.378	241.597	244.022	56	423.292	424.833	425.296
21	236.287	245.725	248.554	57	319.434	314.816	313.523
22	230.257	237.251	239.299	58	89.721	90.636	91.319
23	216.547	220.212	221.241	59	295.692	295.769	295.894
24	349.138	336.969	333.499	60	54.350	57.276	58.462
25	321.527	304.684	299.973	61	176.904	179.588	180.874
26	281.396	273.613	271.363	62	382.784	386.177	387.319
27	275.975	266.842	264.241	63	407.756	415.035	417.364
28	327.565	307.905	302.401	64	339.528	341.048	341.597
29	286.889	285.636	285.398	65	106.924	109.309	110.510
30	311.415	294.656	289.991	66	274.640	273.104	272.731
31	279.963	270.602	267.916	67	49.266	51.541	52.500
32	250.525	248.577	247.899	68	146.943	147.262	147.801
33	269.550	267.859	267.275	69	371.097	368.875	368.236
34	274.363	267.172	265.108	70	397.364	401.382	402.772
35	304.073	288.562	284.238	71	334.560	335.637	336.022
36	286.561	285.503	285.273	72	103.093	105.235	106.329

RADIAL TRAVERSES OF THE FISSION RATE DENSITY ALONG CUTS #1 AND #2
IN FIGURE 1 OF THE SOURCE SITUATION

RADIAL TRAVERSE OF THE FOUR GROUP NEUTRON FLUXES
ALONG CUT #1 IN FIGURE 1 OF THE SOURCE SITUATION

RADIAL TRAVERSE OF THE FOUR GROUP NEUTRON FLUXES
ALONG CUT #2 IN FIGURE 1 OF THE SOURCE SITUATION

TABLE VI
NEUTRON BALANCE IN EACH COMPOSITION, THE CORE AND THE CORE-REFLECTOR

Comp. Letter	Energy Group	Points/ Column	Average Neutron Flux	Average Group Source	Reaction Rate Type/Source			
					Fission	Capture	Slowing Down	Normal Leakage
A	1	3	118.757	0.7411	0.00361	0.03173	1.74674	-0.78208
		12	119.121	0.7174	0.00374	0.03288	1.80990	-0.84651
		48	119.354	0.7107	0.00378	0.03325	1.83063	-0.86766
	2	3	279.710	1.3193	0.03159	0.96463	0.6958	-0.69160
		12	278.001	1.3225	0.03132	0.95644	0.68947	-0.67723
		48	277.550	1.3248	0.03122	0.95322	0.68715	-0.67159
	3	3	38.701	0.9174	0.01721	0.38471	0.86055	-0.26247
		12	37.526	0.9118	0.01679	0.37532	0.83953	-0.23165
		48	37.132	0.9104	0.01664	0.37199	0.83209	-0.22072
	4	3	149.059	0.7895	0.37194	1.68598	0.0000	-1.05792
		12	143.854	0.7655	0.37019	1.67808	0.0000	-1.04828
		48						
B	1	3	159.036	1.4859	0.00241	0.00386	1.16665	-0.17292
		12	157.325	1.4973	0.00236	0.00379	1.14527	-0.15143
		48	156.677	1.5010	0.00235	0.00377	1.13776	-0.14387
	2	3	390.337	1.7834	0.03261	0.16831	0.71790	0.08118
		12	391.332	1.7651	0.03303	0.17049	0.72718	0.06930
		48	391.551	1.7582	0.03318	0.17126	0.73046	0.06511
	3	3	59.127	1.2803	0.01884	0.01977	0.94212	0.01928
		12	59.368	1.2836	0.01887	0.01980	0.94355	0.01778
		48	59.428	1.2843	0.01888	0.1980	0.94397	0.01735
	4	3	318.239	1.2062	0.51976	0.22954	0.0000	0.25070
		12	321.233	1.2111	0.52252	0.23076	0.0000	0.24673
		48	322.224	1.2123	0.52361	0.23124	0.0000	0.24516

TABLE VI (Continued)

Comp. Letter	Energy Group	Points/ Column	Average Neutron Flux	Average Group Source	Reaction Rate Type/Source			
					Fission	Capture	Slowing Down	Normal Leakage
C	1	3	175.826	2.2904	0.00303	0.00447	0.94421	0.04829
		12	178.688	2.3147	0.00305	0.00449	0.94954	0.04292
		48	179.491	2.3212	0.00305	0.00450	0.95110	0.04134
	2	3	413.328	2.2396	0.04835	0.25099	0.67732	0.02334
		12	419.373	2.2756	0.04828	0.25063	0.67634	0.02474
		48	421.024	2.2857	0.04826	0.25051	0.67600	0.02523
	3	3	61.822	1.5169	0.02926	0.03428	0.92922	0.00724
		12	62.756	1.5391	0.02928	0.03429	0.92965	0.00678
		48	63.014	1.5452	0.02928	0.03430	0.92982	0.00660
	4	3	268.888	1.4096	0.66003	0.36054	0.0000	-0.02057
		12	271.833	1.4308	0.65734	0.35907	0.0000	-0.01641
		48	272.662	1.4367	0.65664	0.35869	0.0000	-0.01533
D	1	3	138.712	2.0936	0.00249	0.00403	0.81493	0.17855
		12	138.495	2.0196	0.00258	0.00417	0.84347	0.14979
		48	138.471	1.9981	0.00261	0.00421	0.85240	0.14078
	2	3	326.048	1.7765	0.04331	0.26215	0.67357	0.02066
		12	320.308	1.7713	0.04268	0.26859	0.66364	0.03510
		48	318.401	1.7703	0.04245	0.25719	0.66007	0.04029
	3	3	49.220	1.1966	0.02661	0.03196	0.93784	0.00358
		12	48.241	1.1755	0.02655	0.03189	0.93566	0.00590
		48	47.921	1.1685	0.02653	0.03186	0.93503	0.00657
	4	3	283.005	1.1222	0.78681	0.47158	0.0000	-0.25840
		12	272.637	1.0999	0.77337	0.46358	0.0000	-0.23690
		48	269.664	1.0926	0.77004	0.46153	0.0000	-0.23157

TABLE VI (Continued)

Comp. Letter	Energy Group	Points/ Column	Average Neutron Flux	Average Group Source	Reaction Rate Type/Source			
					Fission	Capture	Slowing Down	Normal Leakage
E	1	3	122.686	2.0840	0.00214	0.00367	0.72411	0.27009
		12	123.602	1.9853	0.00226	0.00388	0.76580	0.22806
		48	123.988	1.9572	0.00230	0.00395	0.77922	0.21453
	2	3	291.354	1.5790	0.04059	0.26939	0.67716	0.01285
		12	284.768	1.5870	0.03948	0.26198	0.65854	0.04001
		48	282.543	1.5908	0.03907	0.25921	0.65183	0.04978
	3	3	44.177	1.0693	0.02491	0.03049	0.94197	0.00262
		12	43.005	1.0451	0.02481	0.03037	0.93821	0.00661
		48	42.620	1.0369	0.02478	0.03033	0.93712	0.00776
	4	3	308.414	1.0072	0.89105	0.56954	0.0000	-0.46058
		12	293.284	0.9805	0.87041	0.55635	0.0000	-0.42676
		48	289.032	0.9717	0.86555	0.55324	0.0000	-0.41879
F	1	3	101.792	1.9512	0.00183	0.00334	0.64168	0.35315
		12	103.901	1.8448	0.00198	0.00360	0.69276	0.30166
		48	104.695	1.8147	0.00203	0.00369	0.70963	0.28465
	2	3	245.870	1.3176	0.03807	0.27991	0.68485	-0.00282
		12	239.509	1.3400	0.03646	0.26812	0.65599	0.03943
		48	237.272	1.3487	0.03589	0.26389	0.64565	0.05457
	3	3	37.517	0.9023	0.02324	0.02906	0.94795	-0.00026
		12	36.332	0.8790	0.02311	0.02889	0.94241	0.00560
		48	35.931	0.8708	0.02307	0.02884	0.94079	0.00730
	4	3	316.602	0.8554	0.99935	0.68474	0.0000	-0.68410
		12	298.829	0.8284	0.97400	0.66737	0.0000	-0.64137
		48	293.860	0.8192	0.96850	0.66360	0.0000	-0.63210

TABLE VI (Continued)

Comp Letter	Energy Group	Points/Column	Average Neutron Flux	Average Group Source	Reaction Rate Type/Source			
					Fission	Capture	Slowing Down	Normal Leakage
G	1	3	10.452	0.0000	0.0000	0.0000	0.0000	0.0000
		12	8.474	0.0000	0.0000	0.0000	0.0000	0.0000
		48						
	2	3	41.729	0.1850	0.0000	0.00049	1.20221	-0.20270
		12	37.612	0.1500	0.0000	0.00055	1.33659	-0.33714
		48	36.551	0.1397	0.0000	0.00057	1.39431	-0.39488
	3	3	6.859	0.2224	0.0000	0.00061	1.02080	-0.02140
		12	6.245	0.2005	0.0000	0.00061	1.03112	-0.03173
		48	6.088	0.1948	0.0000	0.00062	1.03430	-0.03492
	4	3	233.029	0.2270	0.0000	0.10880	0.0000	0.89120
		12	233.610	0.2057	0.0000	0.11979	0.0000	0.88021
		48	233.989	0.2015	0.0000	0.12309	0.0000	0.87691
Core	1	3	161.098	2.0995	0.00281	0.00453	0.92868	0.06397
		12	162.988	2.0975	0.00285	0.00459	0.94016	0.05180
		48	163.528	2.0968	0.00286	0.00461	0.94429	0.04824
	2	3	381.416	2.0203	0.04521	0.25825	0.68219	0.01435
		12	384.231	2.0437	0.04507	0.25698	0.67940	0.01854
		48	384.910	2.0504	0.04502	0.25654	0.67839	0.02005
	3	3	57.170	1.3782	0.02721	0.03869	0.93136	0.00274
		12	57.559	1.3885	0.02723	0.03845	0.93084	0.00348
		48	57.652	1.3910	0.02724	0.03837	0.93070	0.00368
	4	3	278.529	1.2836	0.67408	0.40110	0.0000	-0.07518
		12	277.776	1.2925	0.66854	0.39623	0.0000	-0.06477
		48	277.582	1.2946	0.66722	0.39500	0.0000	-0.06222

TABLE VI (Continued)

Comp. Letter	Energy Group	Points/ Column	Average Neutron Flux	Average Group Source	Reaction Rate Type/Source			
					Fission	Capture	Slowing Down	Normal Leakage
Core and Refl.	1	3	97.594	1.2145	0.00281	0.00458	0.99290	-0.00030
		12	97.853	1.2133	0.00285	0.00463	0.99287	-0.00035
		48	97.921	1.2129	0.00286	0.00465	0.99285	-0.00036
	2	3	238.223	1.2466	0.04238	0.24212	0.71472	0.00077
		12	238.115	1.2454	0.04279	0.24396	0.71277	0.00048
		48	238.061	1.2450	0.04289	0.24443	0.71226	0.00042
	3	3	35.962	0.8910	0.02435	0.03468	0.94077	0.00020
		12	35.928	0.8877	0.02464	0.03485	0.94039	0.00013
		48	35.915	0.8868	0.02472	0.03488	0.94030	0.00011
	4	3	259.349	0.8382	0.59711	0.36773	0.0000	0.03516
		12	259.158	0.8348	0.59876	0.36737	0.0000	0.03387
		48	259.205	0.8338	0.59925	0.35730	0.0000	0.03345

BENCHMARK PROBLEM SOLUTION

Identification: 9-A1-2 Benchmark Problem ID.9-A1
Date Submitted: June 1976 By: M. V. Gregory (SRL)
Date Accepted: June 1977 By: H. L. Dodds, Jr. (U. of Tenn.)
 M. R. Wagner (KWU)
Descriptive Title: Discrete Four-Group, Two-Dimensional
 Hexagonal Geometry HTGR Problem

Mathematical Model:

1. Finite difference representation of multigroup neutron diffusion equations.
2. Volume-centered mesh structure. One point per hex - at hexagon center. Three points per hex - at center of each of the three parallelograms making up a hex. Six points per hex - at center of each of the six triangles making up a hex.

Method of Solution:

1. Simultaneous line over-relaxation with two inner iterations per outer iteration.
2. One-group coarse-mesh rebalancing, one coarse-mesh point per collection of seven hexagons.
3. Fission source extrapolation and over-relaxation.
4. Both conventional finite difference and higher order method ("Coarse-Mesh Method," see Ref. 2) solutions presented.

Program Name: GRIMHX

Program Language: FORTRAN-IV

Machine Language Content: None

Program Ancestors: GRIM

Computer: IBM S-360/195

Convergence Criteria: Maximum relative pointwise flux change
and pointwise production change both
less than 10^{-5} .

References

1. H. C. Honeck and J. W. Stewart, "Simultaneous Line Over-Relaxation (SLOR) in Hexagonal Lattice," *Proceedings National Topical Meeting on New Developments in Reactor Physics and Shielding*, Kiamesha Lake, NY, September 12-15, 1972, U. S. Atomic Energy Commission Report CONF-720901 (1972).
2. H. L. Dodds, Jr., H. C. Honeck, and D. E. Hostetler, "Coarse-Mesh Method for Two-Dimensional Mixed-Lattice Diffusion Theory Calculations," *Trans. Am. Nucl. Soc.*, 21, 223 (1975).
3. M. V. Gregory and H. C. Honeck, "Control Algorithms in a Coarse-Mesh Rebalance Framework," *Trans. Am. Nucl. Soc.*, 22, 241 (1975).

PRIMARY RESULTS: FOUR-GROUP, TWO-DIMENSIONAL HEXAGONAL GEOMETRY HIGP PROBLEM
WITH SEVEN CONTROL RODS INSERTED (STANDARD DIFFERENCE CON.)

NUMBER OF MESH POINTS PER COLUMN	1	3	6
DISTANCE BETWEEN MESH POINTS	36.2 CM	18.1 CM	12.067 CM
NUMBER OF SPATIAL MESH POINTS IN THE ONE SIXTH COPE CALCULATION PLANE	72	214	427
NEUTRON MULTIPLICATION CONSTANT K EFF (THE FUNDAMENTAL EIGENVALUE)	1.12725	1.12102	1.12026
NUMBER OF POWER ITERATIONS FOR 1.0-05 POINTWISE FLUX CONVERGENCE	17	18	26
IBM 360/195 COMPUTER TIME FOR THE DIFFUSION CALCULATION	5 SEC	6 SEC	10 SEC
CORE/PERIPHERAL STORAGE (1000 BYTES)	360/80	365/100	375/100

COLUMN AVERAGED FISSION DISTRIBUTION (FISSIONS/CM**3/SEC)
(NORMALIZED TO A CORE AVERAGE VALUE OF ONE)

COLUMN NUMBER	NUMBER OF POINTS/COLUMN	COLUMN NUMBER	NUMBER OF POINTS/COLUMN
	1 3 6		1 3 6
1	.3151 .3609 .3611	22	1.0972 1.0794 1.0043
2	1.2811 1.1582 1.1086	23	.9732 .9386 .9209
3	1.0231 .9011 .8723	24	.6316 .6898 .7028
4	1.3553 1.2825 1.2592	25	.7787 .8913 .9265
5	1.4742 1.3354 1.3191	26	.9955 1.0567 1.0718
6	1.4518 1.3399 1.3140	27	.9517 1.0183 1.0367
7	1.4639 1.3439 1.3360	28	.6821 .8018 .8436
8	1.3915 1.2893 1.2801	29	.6481 .6493 .6442
9	1.3628 1.3057 1.2782	30	.6676 .7785 .8137
10	.8578 .8150 .7897	31	.8242 .8958 .9222
11	1.1272 1.1593 1.1591	32	.9768 .9771 .9943
12	1.1719 1.1655 1.1516	33	1.0541 1.0775 1.0782
13	1.2861 1.2545 1.2347	34	.9777 1.0355 1.0476
14	1.2418 1.2242 1.1941	35	.7420 .8482 .8703
15	1.1520 1.1644 1.1558	36	.6481 .6398 .6442
16	1.1161 1.1574 1.1567	37	.6636 .7652 .8112
17	.2591 .3002 .3169	38	.8167 .9013 .9251
18	.9248 .8933 .8538	39	1.0294 1.0646 1.0754
19	1.0172 .9647 .9529	40	1.0302 1.0726 1.0413
20	1.1357 1.0702 1.0772	41	.9467 .9740 .9905
21	1.1733 1.0754 1.0453	42	.7527 .6431 .8810

ENERGY GROUP 1 COLUMN AVERAGED FLUX DISTRIBUTION (NEUTRONS/CM**2/SEC)

COLUMN NUMBER	NUMBER 1	OF POINTS/COLUMN 3	6	COLUMN NUMBER	NUMBER 1	OF POINTS/COLUMN 3	6
1	121.332	133.395	130.955	37	98.051	103.512	104.837
2	212.785	194.130	186.419	38	128.554	136.493	138.670
3	208.335	196.976	196.541	39	167.233	172.439	173.930
4	220.457	207.751	203.326	40	168.040	167.435	168.839
5	233.386	216.397	213.022	41	152.789	155.853	157.498
6	236.424	216.760	210.388	42	114.927	120.593	122.378
7	238.305	218.344	215.915	43	10.868	17.493	20.489
8	226.431	209.385	206.772	44	9.917	16.026	18.806
9	221.604	210.999	206.277	45	.056	.040	.034
10	174.693	178.089	177.971	46	.004	.002	.001
11	183.237	187.785	187.182	47	.064	.047	.038
12	190.771	188.844	186.033	48	.021	.085	.083
13	209.500	203.463	199.552	49	.601	.645	.674
14	202.287	198.539	193.025	50	.031	.021	.018
15	187.403	188.582	186.597	51	.003	.001	.001
16	181.411	186.846	186.845	52	.806	.882	.865
17	99.786	111.119	114.940	53	.047	.032	.029
18	153.771	149.931	148.842	54	.566	.618	.644
19	169.022	161.796	160.282	55	9.668	15.845	14.586
20	188.477	175.890	172.622	56	10.745	17.607	20.689
21	194.753	180.127	176.297	57	.858	.930	.918
22	182.200	172.520	168.819	58	.061	.046	.038
23	161.755	157.427	155.003	59	1.143	1.244	1.322
24	111.100	117.869	119.030	60	.065	.046	.042
25	119.561	128.533	129.608	61	.584	.647	.657
26	161.048	170.099	171.404	62	9.892	15.939	18.806
27	153.046	162.139	163.956	63	15.143	24.443	29.192
28	101.281	109.172	109.730	64	5.209	8.133	9.609
29	129.077	137.310	139.740	65	.239	.243	.196
30	98.492	105.066	104.976	66	.929	1.188	1.133
31	129.728	126.230	137.531	67	.046	.046	.030
32	152.717	161.069	160.648	68	.245	.253	.205
33	171.904	175.073	174.633	69	5.302	8.416	9.942
34	157.533	165.377	166.392	70	14.321	23.744	29.072
35	113.229	121.309	122.721	71	5.161	8.824	9.567
36	129.068	135.131	139.720	72	.230	.297	.192

ENERGY GROUP 2 COLUMN AVEPAGED FLUX DISTRIBUTION (NEUTRONS/CM**2/SEC)

COLUMN NUMBER	NUMBER 1	OF POINTS/COLUMN 3	6	COLUMN NUMBER	NUMBER 1	OF POINTS/COLUMN 3	6
1	278.663	306.369	302.111	37	215.979	224.871	229.979
2	502.745	458.268	440.346	38	292.722	307.681	314.492
3	548.765	514.049	508.587	39	389.773	400.650	404.710
4	517.950	487.949	478.200	40	393.866	391.631	395.707
5	548.086	507.986	500.406	41	354.416	360.093	364.023
6	555.620	505.086	499.574	42	258.347	267.679	274.052
7	559.713	512.950	507.012	43	65.867	92.629	100.370
8	532.000	492.257	486.292	44	59.561	84.009	90.981
9	520.373	494.860	484.578	45	1.174	1.159	1.124
10	459.927	464.372	460.372	46	.128	.087	.086
11	429.030	439.250	436.256	47	1.296	1.309	1.243
12	448.154	443.518	437.483	48	9.764	11.997	12.453
13	492.045	477.477	468.741	49	7.291	8.915	9.530
14	475.353	466.137	453.994	50	.646	.584	.596
15	439.776	442.116	438.079	51	.097	.069	.067
16	424.469	436.738	437.127	52	9.419	11.720	12.198
17	229.119	255.552	265.139	53	.898	.823	.864
18	362.996	353.696	351.227	54	6.610	8.216	8.819
19	399.298	382.036	378.583	55	56.855	80.837	87.479
20	445.144	415.158	407.592	56	63.937	90.864	98.646
21	459.900	425.227	416.249	57	10.180	12.561	13.065
22	430.370	407.309	398.668	58	1.194	1.246	1.180
23	382.074	371.655	366.073	59	12.981	16.014	17.475
24	268.459	280.239	264.723	60	1.208	1.154	1.109
25	267.909	283.539	267.928	61	6.929	8.785	9.164
26	371.998	390.581	397.459	62	59.014	82.604	89.859
27	351.507	369.687	373.551	63	86.557	119.301	132.015
28	222.521	236.282	239.150	64	34.261	47.135	52.162
29	332.043	348.672	351.880	65	3.189	3.806	3.651
30	216.740	228.342	230.038	66	10.610	15.009	14.735
31	296.099	308.572	312.828	67	.894	1.175	.887
32	370.631	375.428	374.978	68	3.313	3.997	3.851
33	402.565	409.438	408.642	69	34.585	48.305	53.419
34	364.023	380.361	382.922	70	80.837	114.156	124.923
35	253.244	267.517	271.180	71	73.794	51.122	51.695
36	332.181	342.528	352.029	72	3.031	4.533	3.517

ENERGY GROUP 3 COLUMN AVERAGED FLUX DISTRIBUTION (NEUTRONS/CM**2/SEC)

COLUMN NUMBER	NUMBER OF POINTS/COLUMN			COLUMN NUMBER	NUMBER OF POINTS/COLUMN		
	1	3	6		1	3	6
1	35.641	39.765	39.574	37	32.478	33.794	34.663
2	75.314	68.408	65.743	38	43.931	46.120	47.223
3	84.157	78.556	77.559	39	58.354	59.955	60.596
4	77.605	73.199	71.762	40	59.032	58.687	59.372
5	82.197	76.196	75.079	41	53.016	53.848	54.459
6	83.336	76.373	74.968	42	38.836	40.196	41.262
7	83.943	76.946	76.070	43	11.239	15.574	16.729
8	79.791	73.852	72.974	44	10.155	14.110	15.144
9	78.041	74.223	72.706	45	.217	.216	.210
10	70.525	70.952	70.199	46	.024	.016	.016
11	64.297	65.820	65.699	47	.239	.244	.232
12	67.212	66.530	65.647	48	1.756	2.173	2.262
13	73.791	71.615	70.326	49	1.313	1.616	1.729
14	71.294	69.918	68.126	50	.119	.109	.112
15	65.942	66.296	65.717	51	.018	.012	.013
16	63.602	65.440	65.513	52	1.692	2.120	2.213
17	29.302	23.170	34.730	53	.165	.153	.161
18	54.350	52.635	52.400	54	1.188	1.486	1.598
19	59.811	57.095	56.515	55	9.678	13.541	14.519
20	66.689	62.064	60.960	56	10.894	15.238	16.396
21	68.901	63.572	62.155	57	1.831	2.274	2.372
22	64.472	60.685	59.524	58	.220	.232	.270
23	57.220	55.541	54.636	59	2.328	2.892	3.160
24	40.579	42.270	42.950	60	.222	.214	.223
25	40.221	42.477	43.220	61	1.246	1.591	1.662
26	55.579	58.297	58.735	62	10.060	13.864	14.946
27	52.461	55.114	55.690	63	14.682	19.864	21.781
28	33.420	35.445	35.964	64	5.902	8.019	8.818
29	50.713	53.001	53.442	65	.577	.694	.671
30	32.584	34.321	34.674	66	1.904	2.708	2.664
31	44.464	46.378	47.007	67	.163	.213	.165
32	55.512	56.226	56.164	68	.600	.729	.708
33	60.725	61.349	61.243	69	5.952	8.209	9.019
34	54.409	56.823	57.209	70	13.693	18.971	20.572
35	38.021	40.108	40.754	71	5.619	8.692	8.725
36	50.740	52.097	53.472	72	.548	.826	.646

ENERGY GROUP 4 COLUMN AVERAGED FLUX DISTRIBUTION (NEUTRONS/CM**2/SEC)

COLUMN NUMBER	NUMBER OF POINTS/COLUMN 1	3	6	COLUMN NUMBER	NUMBER OF POINTS/COLUMN 1	3	6
1	130.114	150.244	150.754	37	221.448	258.084	274.578
2	314.131	283.619	271.299	38	228.954	254.412	262.544
3	459.737	400.035	386.040	39	253.969	262.937	266.602
4	333.842	316.156	310.520	40	253.747	254.694	257.037
5	353.287	329.211	325.747	41	234.020	241.276	245.617
6	357.536	330.371	323.960	42	229.642	259.638	271.616
7	360.573	331.107	329.487	43	433.878	462.374	456.183
8	342.734	317.629	315.641	44	405.593	433.227	429.530
9	335.741	322.078	315.294	45	118.249	130.944	134.798
10	384.019	361.879	349.484	46	27.209	25.401	28.790
11	277.865	286.000	286.047	47	109.063	123.750	123.071
12	288.638	287.312	283.967	48	272.699	308.569	313.759
13	316.755	309.235	304.488	49	228.762	256.934	262.593
14	305.817	301.749	294.396	50	62.076	60.224	69.393
15	283.811	287.130	285.106	51	22.577	21.948	24.907
16	275.167	284.577	285.492	52	237.158	268.889	269.902
17	106.989	124.921	132.312	53	53.564	55.711	57.902
18	226.761	218.707	216.261	54	152.076	182.014	181.318
19	249.418	236.201	233.177	55	367.556	388.927	382.901
20	278.416	257.196	251.411	56	411.769	436.405	429.441
21	287.767	263.350	256.829	57	270.707	307.974	309.827
22	269.865	252.081	245.785	58	93.347	101.514	95.201
23	238.608	229.795	225.343	59	263.247	293.456	296.387
24	290.648	318.870	324.970	60	59.556	62.186	64.204
25	237.498	274.448	286.027	61	167.205	186.140	186.835
26	246.188	262.372	265.842	62	379.284	395.172	393.716
27	235.809	253.029	257.918	63	432.471	435.749	428.411
28	227.569	270.352	285.512	64	320.178	347.270	345.136
29	291.887	290.651	287.750	65	173.000	124.235	116.148
30	222.861	262.614	275.439	66	238.544	273.359	272.002
31	230.973	252.475	260.503	67	52.201	66.985	57.296
32	240.930	246.250	246.637	68	132.922	148.781	151.506
33	259.696	265.671	266.010	69	335.072	365.278	367.925
34	241.930	256.803	260.067	70	408.750	414.311	411.346
35	226.559	261.423	271.566	71	313.305	334.699	339.153
36	291.859	286.535	287.691	72	98.712	121.723	111.672

NEUTRON BALANCE IN EACH COMPOSITION, THE CORE AND THE CORE & REFLECTOR

COMP. LETTER	ENERGY GROUP	POINTS/ COLUMN	AVERAGE NEUTRON FLUX	AVERAGE GROUP SOURCE	REACTION RATE		TYPE/SOURCE	
					FISSION	CAPTURE	SLOWING DOWN	NORMAL LEAKAGE
A	1	1	102.864	.5543	.00418	.03674	2.02769	-1.06361
		3	114.301	.6445	.00399	.03511	1.93307	-.97213
		6	117.227	.6749	.00395	.03439	1.89321	-.93151
	2	1	236.197	1.1398	.03088	.94285	.67968	-.65341
		3	262.811	1.2675	.03089	.94340	.68008	-.65437
		6	270.420	1.3005	.03098	.94614	.69205	-.65918
	3	1	30.208	.7747	.01591	.35560	.79543	-.16694
		3	34.112	.8620	.01615	.36090	.80728	-.18433
		6	35.422	.8870	.01629	.36422	.81469	-.19520
B	4	1	110.293	.6162	.75258	1.59826	.00000	-.95084
		3	128.538	.6959	.76388	1.64946	.00000	-1.01734
		6	134.946	.7226	.36769	1.66765	.00000	-1.03554
	1	1	150.455	1.5738	.00215	.00345	1.04201	-.04762
		3	153.075	1.5351	.00224	.00360	1.08690	-.09275
		6	154.600	1.5186	.00229	.00368	1.10968	-.11564
	2	1	386.275	1.6928	.03410	.17638	.75232	.03712
		3	389.972	1.7201	.03378	.17435	.74363	.04624
		6	391.438	1.7362	.03359	.17338	.73952	.05351
C	3	1	59.343	1.2735	.01901	.01994	.95057	.01047
		3	59.385	1.2791	.01894	.01987	.94712	.01407
		6	59.524	1.2839	.01892	.01984	.94577	.01547
	4	1	343.290	1.2106	.55264	.24671	.00000	.19466
		3	331.594	1.2115	.53922	.23813	.00000	.22265
		6	327.187	1.2143	.53081	.23442	.00000	.23477
	1	1	198.307	2.3993	.00310	.00457	.96535	.02698
		3	183.518	2.3558	.00306	.00453	.95816	.03423
		6	181.571	2.3376	.00307	.00452	.95539	.03702
C	2	1	441.675	2.3968	.04828	.25059	.67623	.02491
		3	429.687	2.3364	.04618	.25012	.67495	.02675
		6	425.417	2.3118	.04821	.25026	.67534	.02619
	3	1	66.169	1.6208	.02931	.03433	.93084	.00552
		3	64.341	1.5770	.02929	.03431	.93026	.00614
		6	63.698	1.5613	.02929	.03431	.93020	.00610
	4	1	283.786	1.5087	.65064	.35552	.00000	-.00636
		3	277.279	1.4670	.65399	.35724	.00000	-.01123
		6	275.029	1.4523	.65523	.35792	.00000	-.01315

NEUTRON BALANCE IN EACH COMPOSITION, THE CORE AND THE CORE & REFLECTOR

COMP. LETTER	ENERGY GROUP	POINTS/ COLUMN	AVERAGE NEUTRON FLUX	AVERAGE GROUP SOURCE	REACTION RATE		TYPE/SOURCE	
					FISSION	CAPTURE	SLOWING DOWN	NORMAL LEAKAGE
D	1	1	129.141	1.7068	.00284	.00460	.93065	.06191
		3	136.361	1.8797	.00273	.00441	.89228	.10059
		6	138.101	1.9377	.00268	.00433	.87663	.11635
	2	1	294.410	1.6458	.04222	.25581	.65652	.04545
		3	308.327	1.7404	.04181	.25334	.65018	.05468
		6	313.660	1.7637	.04197	.25431	.65267	.05105
	3	1	44.197	1.0805	.02647	.03178	.93264	.00912
		3	46.249	1.1316	.02644	.03176	.93188	.00992
		6	47.115	1.1511	.02648	.03180	.93318	.00853
	4	1	229.964	1.0077	.71200	.42675	.00000	-.13875
		3	253.443	1.0545	.74989	.44945	.00000	-.19934
		6	261.523	1.0742	.75958	.45526	.00000	-.21484
E	1	1	115.906	1.5761	.00267	.00458	.90455	.08820
		3	123.478	1.8003	.00249	.00427	.84361	.14963
		6	124.652	1.8733	.00242	.00415	.81846	.17498
	2	1	259.833	1.4786	.03866	.25657	.64493	.05984
		3	272.911	1.5793	.03802	.25230	.63421	.07547
		6	277.720	1.5962	.03828	.25403	.63856	.06913
	3	1	39.026	.9536	.02468	.03020	.93310	.01202
		3	40.927	1.0016	.02464	.03016	.93167	.01354
		6	41.749	1.0192	.02470	.03023	.93391	.01116
	4	1	231.233	.8898	.75623	.48336	.00000	-.23960
		3	265.170	.9331	.82693	.52655	.00000	-.35948
		6	276.410	.9519	.84502	.54012	.00000	-.38514
F	1	1	99.275	1.3955	.00250	.00455	.87495	.11800
		3	105.917	1.6349	.00227	.00415	.79683	.19675
		6	106.514	1.7218	.00217	.00396	.76092	.23295
	2	1	218.413	1.2620	.03514	.25938	.63218	.07430
		3	229.832	1.3577	.03453	.25392	.62126	.09028
		6	233.039	1.3630	.03475	.25553	.62520	.08451
	3	1	32.827	.8016	.02269	.02863	.93373	.01475
		3	34.520	.8435	.02208	.02861	.93311	.01641
		6	35.100	.8553	.02294	.02869	.93573	.01764
	4	1	223.959	.7485	.80791	.55357	.00000	-.76144
		3	263.683	.7871	.80456	.61979	.00000	-.52436
		6	276.493	.8003	.83958	.64379	.00000	-.58736

PRIMARY RESULTS: FOUR-GROUP, TWO-DIMENSIONAL HEXAGONAL GEOMETRY HIGP PROBLEM
WITH SEVEN CONTROL RODS INSERTED (COARSE MESH EQUATION)

NUMBER OF MESH POINTS PER COLUMN	1	3	6
DISTANCE BETWEEN MESH POINTS	36.2 CM	18.1 CM	12.067 CM
NUMBER OF SPATIAL MESH POINTS IN THE ONE SIXTH CORE CALCULATION PLANE	72	214	427
NEUTRON MULTIPLICATION CONSTANT KEFF (THE FUNDAMENTAL EIGENVALUE)	1.11321	1.11735	1.11863
NUMBER OF POWER ITERATIONS FOR $1.0-05$ POINTWISE FLUX CONVERGENCE	26	20	24
IBM 360/195 COMPUTER TIME FOR THE DIFFUSION CALCULATION	8 SEC	7 SEC	10 SEC
COPE/PERIPHERAL STORAGE (1000 BYTES)	360/80	365/100	375/100

COLUMN AVERAGED FISSION DISTRIBUTION (FISSIONS/CM**3/SEC)
(NORMALIZED TO A COPE AVERAGE VALUE OF ONE)

COLUMN NUMBER	NUMBER OF POINTS/COLUMN			COLUMN NUMBER	NUMBER OF POINTS/COLUMN		
	1	3	6		1	3	6
1	.3828	.3801	.3692	22	1.0539	1.0118	.9953
2	1.1995	1.1266	1.0928	23	.9517	.9287	.9159
3	.9224	.8684	.8563	24	.6664	.7047	.7097
4	1.3044	1.2632	1.2496	25	.8654	.9253	.9431
5	1.3710	1.3118	1.3072	26	1.0192	1.0692	1.0772
6	1.3815	1.3137	1.3007	27	.9809	1.0306	1.0473
7	1.3948	1.3180	1.3230	28	.7867	.8405	.8635
8	1.3331	1.2672	1.2690	29	.6296	.6439	.6417
9	1.3163	1.2876	1.2691	30	.7704	.8160	.8324
10	.7999	.7963	.7807	31	.8825	.9165	.9326
11	1.1706	1.1614	1.1603	32	.9878	1.0008	1.0001
12	1.1579	1.1602	1.1490	33	1.0595	1.0796	1.0795
13	1.2537	1.2422	1.2286	34	1.0013	1.0457	1.0570
14	1.2144	1.2137	1.1889	35	.8263	.8809	.8947
15	1.1459	1.1621	1.1549	36	.6298	.6343	.6416
16	1.1223	1.1566	1.1586	37	.7660	.8025	.8300
17	.3246	.3198	.3261	38	.8769	.9241	.9405
18	.9099	.8656	.8799	39	1.0443	1.0704	1.0829
19	.9888	.9523	.9466	40	1.0347	1.0338	1.0470
20	1.0842	1.0297	1.0168	41	.9654	.9808	.9942
21	1.1143	1.0521	1.0375	42	.8369	.8748	.8954

ENERGY GROUP 1 COLUMN AVERAGED FLUX DISTRIBUTION (NEUTRONS/CM**2/SEC)

COLUMN NUMBER	NUMBER 1	OF POINTS/COLUMN 3	5	COLUMN NUMBER	NUMBER 1	OF POINTS/COLUMN 3	6
1	141.792	137.737	132.465	37	102.655	103.900	104.693
2	202.736	190.000	184.301	38	134.585	137.872	139.277
3	202.049	195.438	195.927	39	170.564	173.416	174.392
4	212.076	204.344	201.573	40	169.191	167.499	168.852
5	223.208	212.324	210.930	41	156.398	156.748	157.882
6	224.923	212.168	210.738	42	119.672	121.361	122.416
7	227.175	213.930	213.545	43	17.179	20.507	22.176
8	216.870	205.553	204.788	44	15.979	18.840	20.396
9	213.738	207.793	204.638	45	.020	.027	.028
10	175.293	179.176	178.690	46	.001	.001	.001
11	184.237	180.021	187.286	47	.023	.032	.032
12	188.398	187.698	185.423	48	.621	.788	.610
13	204.355	201.240	198.407	49	.455	.574	.638
14	197.792	196.584	192.005	50	.011	.014	.015
15	186.467	188.010	186.294	51	.001	.001	.001
16	182.271	187.291	187.066	52	.628	.796	.820
17	120.258	116.027	116.515	53	.019	.023	.025
18	154.103	149.591	148.645	54	.445	.557	.612
19	167.186	160.675	159.705	55	16.083	18.876	20.261
20	183.175	173.468	171.387	56	17.474	20.891	22.502
21	188.237	177.270	174.847	57	.650	.831	.865
22	178.092	170.572	167.810	58	.023	.031	.031
23	161.009	156.717	154.626	59	.900	1.129	1.260
24	114.553	118.965	119.461	60	.026	.032	.035
25	125.202	129.726	129.840	61	.453	.580	.623
26	166.274	171.811	172.198	62	16.294	18.930	20.478
27	159.014	163.988	164.835	63	25.177	29.214	31.854
28	106.278	109.746	109.663	64	8.171	9.493	10.370
29	135.604	140.153	141.261	65	.167	.210	.178
30	102.997	105.412	104.804	66	.742	1.083	1.084
31	135.057	137.372	137.915	67	.019	.033	.025
32	160.902	161.478	160.807	68	.170	.219	.185
33	173.427	175.364	174.743	69	8.345	9.841	10.740
34	162.317	160.994	167.069	70	24.226	28.445	30.648
35	118.735	122.361	122.226	71	8.121	10.259	10.318
36	135.604	137.924	141.241	72	.163	.256	.174

ENERGY GROUP 2 COLUMN AVERAGED FLUX DISTRIBUTION (NEUTRONS/CM**2/SEC)

COLUMN NUMBER	NUMBER 1	OF POINTS/COLUMN 3	6	COLUMN NUMBER	NUMBER 1	OF POINTS/COLUMN 3	6
1	322.833	316.465	305.965	37	222.221	226.773	231.358
2	477.128	448.108	435.184	38	302.972	311.225	316.595
3	528.239	506.163	504.412	39	395.916	402.845	405.870
4	497.675	480.177	474.307	40	396.034	391.865	395.912
5	523.080	498.537	495.646	41	360.420	361.988	364.964
6	527.895	498.485	494.273	42	266.028	270.213	275.659
7	532.442	502.777	501.917	43	91.521	102.255	104.824
8	508.893	483.558	481.860	44	83.057	92.818	95.070
9	500.957	487.433	480.879	45	1.125	1.096	1.088
10	458.276	463.650	459.910	46	.090	.074	.078
11	430.672	439.972	438.671	47	1.270	1.246	1.206
12	442.244	441.086	436.286	48	13.101	12.806	12.794
13	478.898	472.359	466.181	49	9.775	9.504	9.815
14	464.152	461.713	451.785	50	.629	.556	.579
15	437.053	440.987	437.549	51	.067	.058	.061
16	427.445	437.972	437.819	52	13.001	12.640	12.593
17	273.803	267.046	270.759	53	.948	.807	.849
18	362.651	352.675	350.668	54	9.203	8.873	9.128
19	393.578	379.125	377.077	55	80.860	89.928	91.628
20	430.898	409.126	404.528	56	90.271	100.896	103.241
21	442.705	418.148	412.633	57	13.738	13.452	13.451
22	419.016	402.386	396.142	58	1.212	1.198	1.150
23	379.058	369.718	365.055	59	18.301	17.359	18.126
24	271.958	282.536	285.868	60	1.299	1.131	1.182
25	275.551	286.505	289.615	61	9.562	9.454	9.470
26	380.313	393.834	395.110	62	83.912	91.777	94.074
27	360.645	373.145	375.344	63	122.360	132.038	138.085
28	228.784	238.815	240.635	64	48.920	52.242	54.657
29	343.240	352.852	353.854	65	4.114	3.989	3.707
30	222.693	230.679	231.418	66	14.990	16.311	15.318
31	304.956	312.236	314.521	67	.936	1.151	.872
32	374.726	376.479	375.414	68	4.219	4.178	3.904
33	405.257	410.199	409.016	69	49.366	53.530	55.959
34	372.023	383.500	384.370	70	115.025	126.246	130.822
35	261.063	270.431	272.094	71	48.383	56.929	54.194
36	343.390	346.446	354.714	72	3.547	4.793	3.577

ENERGY GROUP 3 COLUMN AVERAGED FLUX DISTRIBUTION (NEUTRONS/CM**2/SEC)

COLUMN NUMBER	NUMBER 1	OF POINTS/COLUMN 3	6	COLUMN NUMBER	NUMBER 1	OF POINTS/COLUMN 3	6
1	43.573	41.980	40.528	37	32.915	33.973	34.871
2	71.243	66.846	64.905	38	45.008	46.560	47.519
3	80.427	77.116	76.893	39	58.998	60.222	60.749
4	74.449	72.001	71.169	40	59.165	58.690	59.340
5	78.229	74.741	74.350	41	53.625	54.074	54.581
6	78.975	74.756	74.164	42	39.535	40.497	41.496
7	79.633	75.380	75.278	43	15.609	17.150	17.438
8	76.127	72.513	72.200	44	14.101	15.533	15.785
9	74.919	73.073	72.137	45	.271	.217	.208
10	69.767	70.625	70.020	46	.023	.015	.015
11	64.307	65.889	65.742	47	.306	.247	.231
12	66.157	66.138	65.461	48	2.710	2.431	2.371
13	71.622	70.809	69.930	49	2.032	1.806	1.816
14	69.437	69.221	67.786	50	.152	.110	.111
15	65.345	66.089	65.626	51	.017	.012	.012
16	63.800	65.573	65.599	52	2.676	2.395	2.370
17	36.955	35.432	35.798	53	.226	.158	.162
18	54.111	52.584	52.260	54	1.893	1.682	1.686
19	58.764	56.559	56.232	55	13.697	14.996	15.164
20	64.339	61.056	60.340	56	15.364	16.862	17.118
21	66.101	62.404	61.552	57	2.842	2.553	2.491
22	62.565	60.042	59.086	58	.291	.237	.220
23	56.585	55.154	54.427	59	3.736	3.262	3.341
24	40.347	42.416	43.116	60	.310	.223	.226
25	40.765	42.788	43.451	61	1.978	1.795	1.751
26	56.404	58.684	58.944	62	14.302	15.357	15.611
27	53.772	55.526	55.928	63	20.542	21.842	22.603
28	33.777	35.717	36.169	64	8.637	8.935	9.254
29	51.810	53.480	53.647	65	.884	.765	.696
30	32.980	34.596	34.874	66	3.063	3.079	2.820
31	45.365	46.795	47.249	67	.224	.227	.167
32	55.905	56.340	56.234	68	.907	.802	.734
33	60.512	61.421	61.261	69	8.686	9.136	9.465
34	55.238	57.216	57.416	70	19.204	20.812	21.449
35	38.626	40.432	40.988	71	8.528	9.725	9.171
36	51.849	52.480	53.679	72	.844	.918	.671

ENERGY GROUP 4 COLUMN AVERAGED FLUX DISTRIBUTION (NEUTRONS/CM**2/SEC)

COLUMN NUMBER	NUMBER OF POINTS/COLUMN			COLUMN NUMBER	NUMBER OF POINTS/COLUMN		
	1	3	6		1	3	6
1	159.229	158.717	154.355	37	258.768	271.692	281.350
2	293.438	275.630	267.704	38	247.197	261.227	265.961
3	409.289	384.313	378.359	39	257.642	264.379	267.645
4	321.439	311.454	308.159	40	254.843	255.024	257.275
5	337.857	323.455	322.436	41	238.822	243.055	246.576
6	340.356	323.997	320.713	42	257.603	270.286	276.721
7	343.691	324.768	326.313	43	460.421	473.192	460.691
8	328.495	312.236	312.938	44	451.273	443.999	434.062
9	323.927	317.705	313.069	45	154.081	140.726	139.267
10	354.951	352.467	344.988	46	35.561	27.303	29.742
11	278.693	286.516	286.349	47	141.995	133.007	127.095
12	285.288	286.036	283.344	48	345.996	329.872	323.468
13	308.870	306.256	303.020	49	292.162	275.077	270.841
14	299.165	299.204	293.142	50	81.011	64.757	71.719
15	282.371	286.620	284.906	51	29.527	23.592	25.772
16	276.656	285.370	285.948	52	301.921	287.776	278.455
17	135.036	133.476	136.342	53	70.007	59.962	59.862
18	222.532	216.637	215.208	54	206.714	194.896	186.586
19	241.878	232.950	231.538	55	408.238	397.553	386.614
20	265.277	251.972	248.760	56	456.088	445.962	433.321
21	272.666	257.431	253.829	57	343.830	329.797	319.469
22	257.846	247.545	243.490	58	108.708	109.193	98.483
23	232.773	227.179	224.004	59	333.136	313.819	305.444
24	308.055	326.184	328.317	60	77.967	66.993	66.392
25	266.554	295.838	291.569	61	213.631	199.365	192.726
26	252.151	265.056	267.214	62	421.493	404.074	397.456
27	243.293	256.222	259.610	63	453.203	438.263	428.412
28	265.706	284.432	292.721	64	377.911	362.707	351.570
29	281.331	287.474	286.229	65	133.212	133.476	119.982
30	260.344	276.244	292.242	66	303.337	292.360	280.455
31	248.752	258.785	263.667	67	68.425	72.169	59.260
32	243.669	247.211	247.127	68	172.001	159.800	156.519
33	260.999	266.212	266.312	69	395.630	361.572	374.543
34	247.894	259.470	261.403	70	429.750	417.012	411.641
35	254.714	272.348	276.822	71	369.921	348.008	345.519
36	281.449	283.340	286.199	72	127.679	130.684	115.343

NEUTRON BALANCE IN EACH COMPOSITION, THE CORE AND THE CORE & REFLECTOR

COMP. LETTER	ENERGY GROUP	POINTS/COLUMN	AVERAGE NEUTRON FLUX	AVERAGE GROUP SOURCE	REACTION RATE TYPE/SOURCE			
					FISSION	CAPTURE	SLOWING DOWN	NORMAL LEAKAGE
A	1	1	123.334	.6996	.00397	.03491	1.92169	-.96057
		3	119.128	.6875	.00390	.03431	1.88859	-.92680
		6	118.794	.6948	.00385	.03385	1.86369	-.90139
	2	1	290.807	1.3678	.03059	.93408	.67336	-.63803
		3	274.106	1.3216	.03090	.94369	.68029	-.65488
		6	275.360	1.3182	.03112	.95046	.68517	-.66675
	3	1	37.900	.9210	.01679	.37528	.63944	-.23151
		3	36.368	.8991	.01650	.36891	.82519	-.21060
		6	36.474	.9032	.01648	.36830	.82383	-.20960
	4	1	138.492	.7732	.35287	1.59957	.00000	-.95245
		3	137.082	.7419	.36400	1.65001	.00000	-1.01401
		6	138.915	.7441	.36779	1.66721	.00000	-1.03500
B	1	1	152.621	1.5262	.00225	.00361	1.09003	-.09589
		3	154.331	1.5202	.00228	.00366	1.10658	-.11253
		6	155.315	1.5111	.00231	.00371	1.12735	-.12638
	2	1	389.021	1.7148	.03380	.17445	.74409	.04766
		3	390.330	1.7333	.03355	.17318	.73865	.05462
		6	391.612	1.7437	.03346	.17271	.73665	.05718
	3	1	58.640	1.2760	.01881	.01974	.94071	.02074
		3	59.223	1.2803	.01867	.01980	.94366	.01767
		6	59.453	1.2845	.01888	.01981	.94422	.01708
	4	1	327.015	1.2003	.53670	.23702	.00000	.22628
		3	326.757	1.2082	.53281	.23530	.00000	.23189
		6	324.618	1.2128	.52760	.23300	.00000	.23940
C	1	1	185.735	2.3827	.00308	.00454	.95878	.03360
		3	182.239	2.3456	.00307	.00452	.95562	.03679
		6	180.892	2.3322	.00306	.00451	.95403	.03939
	2	1	434.140	2.3646	.04810	.24970	.67382	.02038
		3	426.600	2.3203	.04817	.25004	.67474	.02705
		6	423.865	2.3033	.04821	.25027	.67537	.02614
	3	1	64.812	1.5933	.02921	.03421	.92746	.00912
		3	63.815	1.5656	.02927	.03428	.92933	.00712
		6	63.438	1.5556	.02928	.03430	.92960	.00662
	4	1	278.242	1.4777	.65149	.35567	.00000	-.00736
		3	275.168	1.4550	.65436	.35744	.00000	-.01180
		6	273.985	1.4464	.65542	.35902	.00000	-.01344

NEUTRON BALANCE IN EACH COMPOSITION, THE CORE AND THE CORE & REFLECTOR

COMP. LETTER	ENERGY GROUP	POINTS/ COLUMN	AVERAGE NEUTRON FLUX	AVERAGE GROUP SOURCE	REACTION RATE TYPE/SOURCE			
					FISSION	CAPTURE	SLOWING DOWN	NORMAL LEAKAGE
D	1	1	134.821	1.8533	.00274	.00442	.89480	.09804
		3	137.622	1.9316	.00268	.00433	.87636	.11663
		6	138.571	1.9634	.00265	.00429	.86810	.12496
	2	1	303.964	1.7206	.04169	.25263	.64837	.05731
		3	311.730	1.7576	.04186	.25362	.65090	.05362
		6	315.553	1.7704	.04206	.25488	.65414	.04891
	3	1	45.196	1.1155	.02621	.03148	.92374	.01056
		3	46.678	1.1441	.02640	.03170	.93025	.01166
		6	47.384	1.1581	.02647	.03179	.93288	.00686
	4	1	247.974	1.0305	.75080	.45000	.00000	-.20079
		3	260.056	1.0642	.76239	.45695	.00000	-.21934
		6	264.614	1.0803	.76477	.45837	.00000	-.22315
E	1	1	121.270	1.7751	.00248	.00426	.84030	.15297
		3	124.482	1.8751	.00241	.00414	.81656	.17689
		6	124.827	1.9074	.00237	.00407	.80410	.18945
	2	1	267.547	1.5512	.03794	.25101	.63297	.07727
		3	275.716	1.5941	.03805	.25252	.63476	.07467
		6	279.390	1.5995	.03843	.25502	.64104	.06551
	3	1	39.642	.9819	.02434	.02960	.92050	.02536
		3	41.239	1.0119	.02458	.03008	.92921	.01614
		6	41.978	1.0254	.02469	.03021	.93343	.01167
	4	1	259.690	.9038	.83610	.53441	.00000	-.37051
		3	276.157	.9403	.85469	.54629	.00000	-.40098
		6	281.704	.9571	.85650	.54745	.00000	-.40395
F	1	1	103.977	1.6307	.00224	.00408	.78429	.20939
		3	106.353	1.7196	.00217	.00396	.76073	.23314
		6	106.387	1.7644	.00212	.00366	.74163	.25239
	2	1	224.566	1.3337	.03435	.25257	.61795	.09513
		3	232.089	1.3659	.03466	.25467	.62359	.08627
		6	234.470	1.3678	.03497	.25713	.62910	.07880
	3	1	33.224	.8242	.02253	.02818	.91913	.03015
		3	34.762	.8518	.02281	.02853	.93050	.01816
		6	35.305	.8605	.02293	.02868	.93544	.01295
	4	1	261.606	.7575	.83245	.63890	.00000	-.57134
		3	277.456	.7926	.84520	.64764	.00000	-.59284
		6	285.437	.8050	.85743	.65601	.00000	-.61744

ADDITIONAL RESULTS: FOUR-GROUP, TWO-DIMENSIONAL HEXAGONAL GEOMETRY HIGR PROBLEM
WITH ALL CONTROL RODS INSERTED (STANDARD DIFFERENTIAL EQN.)

NUMBER OF MESH POINTS PER COLUMN	1	3	6
DISTANCE BETWEEN MESH POINTS	36.2 CM	18.1 CM	12.067 CM
NUMBER OF SPATIAL MESH POINTS IN THE ONE SIXTH CORE CALCULATION PLANE	72	214	427
NEUTRON MULTIPLICATION CONSTANT K _{EFF} (THE FUNDAMENTAL EIGENVALUE)	.98548	.95170	.94064
NUMBER OF POWER ITERATIONS FOR 1.0-05 POINTWISE FLUX CONVERGENCE	21	18	25
IBM 360/195 COMPUTER TIME FOR THE DIFFUSION CALCULATION	6 SEC	7 SEC	10 SEC
CORE/PERIPHERAL STORAGE (1000 BYTES)	360/80	365/100	375/100

ADDITIONAL RESULTS: FOUR-GROUP, TWO-DIMENSIONAL HEXAGONAL GEOMETRY HIGR PROBLEM
WITH ALL CONTROL RODS INSERTED (COARSE MESH EQUATION)

NUMBER OF MESH POINTS PER COLUMN	1	3	6
DISTANCE BETWEEN MESH POINTS	36.2 CM	18.1 CM	12.067 CM
NUMBER OF SPATIAL MESH POINTS IN THE ONE SIXTH CORE CALCULATION PLANE	72	214	427
NEUTRON MULTIPLICATION CONSTANT K _{EFF} (THE FUNDAMENTAL EIGENVALUE)	.94102	.93784	.93407
NUMBER OF POWER ITERATIONS FOR 1.0-05 POINTWISE FLUX CONVERGENCE	28	20	24
IBM 360/195 COMPUTER TIME FOR THE DIFFUSION CALCULATION	9 SEC	7 SEC	10 SEC
CORE/PERIPHERAL STORAGE (1000 BYTES)	360/80	365/100	375/100

BENCHMARK PROBLEM SOLUTION

Identification: 9-A1-3

Benchmark Problem: 9-A1

Date Submitted: June 1976

By: D. R. Vondy, G. W. Cunningham,
D. B. Selby (ORNL)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
M. R. Wagner (KWU)

Descriptive Title: Two-Dimensional HTGR Problem

Mathematical Model: Diffusion theory, mesh-centered formulation;
geometries: hexagonal (6 near neighbors)
triangular (3 near neighbors)

Computer: IBM-360/91, 1976, ORNL
IBM-360/195, 1976, UC-CTC

Program: VENTURE, ORNL-5062 Report

Primary Results: Basic results for the problems are shown below. Extrapolation of results is done on the basis of error dependence on the square of the mesh spacing. Convergence level satisfied was a maximum relative flux change on outer iterations $<10^{-5}$, relatively tight. Typically, 4 inner iterations were used, Chebyshev acceleration was done on outer iterations, and the 6 point per hex problems required 21-26 outer iterations.

Note that desired traverses along material interfaces do not pass through mesh-centered points; flux and fission source maps are available.

Results for Two-Dimensional Problems

(1/6 Core Traverse Mocked Up)

Mesh Intervals	Points Per Hex Assembly	Control Rods Inserted	Multiplication Factor	Peak to Average Fission Source*	Computer cp time, Total (min)
29x29 **	1	7	1.127250	1.4232	0.62 (/91)
38x19	6	7	1.120276	1.4016	0.31 (/91)
76x38	24	7	1.118912	1.3976	0.98 (/195)
114x57	54	7	1.118601	1.4092	2.89 (/195)
Extrapolated			1.11835	1.418	
38x19	6	6	1.133425	2.0929	0.38 (/91)
38x19	6	0	1.175391	1.7026	0.34 (/91)
38x19	6	31	0.940643	1.8985	0.33 (/91)

*At a mesh centered meshpoint.

**Whole core treated.

BENCHMARK SOURCE SITUATION

Identification: 10

Date Submitted: June 1976 By: C. D. Morgan (B&W)
V. J. Esposito (W-NES)

Date Accepted: June 1977 By: H. L. Dodds, Jr. (U. of Tenn.)
D. A. Menzley (Ontario Hydro)

Descriptive Title: PWR Thermal Hydraulics--Flow Between Two
Channels with Different Heat Fluxes

1. Two adjacent channels are identical in all respects except for heat flux, the first channel receiving a heat flux of 150,000 Btu/hr-ft² and the second 200,000 Btu/hr-ft².

2. Thermal-hydraulic Information for the two channels is listed in Table 1.

3. Fluid is assumed incompressible, frictionless with negligible cross flow.

4. Turbulent mixing factors 0.0 and 0.02.

TABLE 1

THERMAL-HYDRAULIC INFORMATION

Axial heat flux distribution is uniform.

System Pressure - 1000 psi

Inlet Enthalpy (h_{in}) - 360 Btu/lbm

Mass Flux (G) - 0.65×10^6 lbm/ft²-hr

Flow Area (A_F) - .0885 in²

Heated Perimeter (P_h) - .6754 in

Wetted Perimeter (P_w) - 1.243

Heated Length - 6 Ft

Cross Flow Area Between Subchannels
(A_{CF}) - .0115 ft²/ft

BENCHMARK PROBLEM

Identification: 10-A1

Source Situation ID.10

Date Submitted: June 1976

By: C. D. Morgan (B&W)
V. J. Esposito (W-NES)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
D. A. Meneley (Ontario Hydro)Descriptive Title: Turbulent Mixing of Flow Between Two Channels
with Different Heat Flux

Reduction of Source Situation

Equations to be solved

$$G_1 A_{F1} \frac{dh_1}{dx} = \phi_1 P_{h1} + \alpha A_{cf} \left(\frac{G_1 + G_2}{2} \right) (h_2 - h_1)$$

$$G_2 A_{F2} \frac{dh_2}{dx} = \phi_2 P_{h2} + \alpha A_{cf} \left(\frac{G_1 + G_2}{2} \right) (h_1 - h_2)$$

where G_i = mass flux in the i^{th} channel, lbm/ft²/hr
 A_{fi} = flow area of the i^{th} channel, ft²
 h_i = enthalpy of the i^{th} channel, Btu/lbm
 ϕ_i = heat flux to the i^{th} channel, Btu/hr ft²
 P_{hi} = heated perimeter of the i^{th} channel, ft
 α = turbulent mixing coefficient
 A_{cf} = cross flow area between subchannels per foot of length, ft²/ft

Expected Primary Results

1. Axial enthalpy distribution in the two subchannels for each value of mixing factor.

Possible Additional Results

1. Sensitivity to axial increment size.

2. Problem could be expanded to include axial cosine heat flux distribution.

Best Solution Available: analytical solution of the differential equation

Solutions

1. Analytical solution of the governing differential equations: 10-A1-1

2. COBRA IIIC finite-difference solution: 10-A1-2

BENCHMARK PROBLEM SOLUTION

Identification:	10-A1-1	Benchmark Problem ID.10-A1
Date Submitted:	June 1976	By: C. D. Morgan (B&W)
Date Accepted:	June 1977	By: H. L. Dodds, Jr. (U. of Tenn.) D. A. Meneley (Ontario Hydro)

Descriptive Title: Analytical Solution of Differential Equations Governing Two Channel Mixing Problem

From the statement of the problem:

$$G_1 = G_2, A_{F1} = A_{F2}, P_{h1} = P_{h2}$$

if we define $q_i = \frac{\phi_i P_h}{A_F G}$ and $B = \frac{\alpha A_{cf}}{A_F}$

then the governing differential equations are

$$\frac{dh_1}{dx} = q_1 + B (h_2 - h_1)$$

$$\frac{dh_2}{dx} = q_2 + B (h_1 - h_2)$$

The solution, subject to the boundary condition that at $x = 0$, $h_i = h_{in}$ the inlet enthalpy, is

$$h_1 - h_{in} = \left(\frac{q_1 - q_2}{4B} \right) (1 - e^{-2BX}) + \frac{q_1 + q_2}{2} \times$$

$$h_2 - h_{in} = - \frac{q_1 - q_2}{4B} \ln \frac{1 - e^{-2BX}}{1 + e^{-2BX}} + \frac{q_1 + q_2}{2} X$$

for the conditions stated

no mixing $\alpha = 0.0$

$$(h_{\text{exit}} - h_{\text{in}})_1 = 169.07$$

$$(h_{\text{exit}} - h_{\text{in}})_2 = 126.80$$

$\alpha = .02$

$$(h_{\text{exit}} - h_{\text{in}})_1 = 152.59$$

$$(h_{\text{exit}} - h_{\text{in}})_2 = 143.28$$

Identification:	10-A1-2	Benchmark Problem ID.10-A1
Date Submitted:	June 1976	By: C. D. Morgan (B&W)
Date Accepted:	June 1977	By: H. L. Dodds, Jr. (U. of Tenn.) D. A. Meneley (Ontario Hydro)

Theory

continuity

$$\left\{ A_j \frac{\rho_j - \bar{\rho}_j}{\Delta t} \right\} + \left\{ \frac{m_j - m_{j-1}}{\Delta x} \right\} = - [s] \{w_j\}$$

energy

$$\left\{ \frac{1}{u_j''} \frac{h_j - \bar{h}_j}{\Delta t} \right\} + \left\{ \frac{h_j - h_{j-1}}{\Delta x} \right\} = [m_{j-1}]^{-1} \left\{ q_j^{-\frac{1}{2}} \right. \\ \left. - [s]^\top [\Delta h_{j-1}] w'_{j-1} - [s]^\top [t_{j-1}] c_{j-1} + \right. \\ \left. [h_{j-1} [s]^\top - [s]^\top [h_{j-1}]^*] w_{j-1} \right\}$$

axial momentum

$$\frac{1}{A_j} \left\{ \frac{m_j - \bar{m}_j}{\Delta t} \right\} - \left\{ 2u_j \frac{\rho_j - \bar{\rho}_j}{\Delta t} \right\} + \left\{ \frac{P'_j - P_{j-1}}{\Delta x} \right\} =$$

$$\{a'_j\} + [A_j]^{-1} \left[[2u_j] [s]^T - [s]^T [u_j^*] \right] \{w_j\}$$

transverse momentum

$$\left\{ \frac{w_j - \bar{w}_j}{\Delta t} \right\} + \left\{ \frac{u_j^* w_j - u_{j-1}^* w_{j-1}}{\Delta x} \right\} + \left(\frac{S}{\ell} \right) \{ c_j w_j \}$$

$$= \left(\frac{S}{\ell} \right) [s] \{ p_{j-1} \}$$

where the elements of the matrix $[s]$ are defined as: $S_{ki}=0$; except, $S_{ki} = 1$, if $i=i(k)$; and $S_{ki}=-1$, if $i=j(k)$ where k implies the connected subchannel pair $i(k)$, $j(k)$. The problem under consideration is a steady state problem with the geometry and flow conditions chosen such that the pressures in both channels will be equal at equal elevations. Thus the diversion cross flow, w_{j-1} will be zero. The energy transfer between channel due to heat conduction $[s]^T [t_{j-1}] C_{j-1}$ is negligible so that the energy equation becomes

$$\frac{h_j - h_{j-1}}{\Delta x} = [m_{j-1}]^{-1} \left\{ q_{j-\frac{1}{2}} - [s]^T [\Delta h_{j-1}] w'_{j-1} \right\}$$

In the nomenclature of the Benchmark Problem

$$m_{j-1} = G_{j-1} A_{j-1}$$

$$w_{j-1} = \alpha A_{cf} \left(\frac{G_{j-1} + G_j}{2} \right)$$

Computer: CDC 7600

Date Solved: February 1976

at: Babcock & Wilcox

Program: COBRA IIIC

Reference

D. S. Rowe, COBRA IIIC: A Digital Computer Program for Steady State and Transient Thermal-Hydraulic Analysis of Rod Bundle Nuclear Fuel Elements, BNWL-1695 (March 1973).

Results for an axial increment size of 3 inches

No mixing $\alpha=0.0$

$$(h_{\text{exit}} - h_{\text{in}})_1 = 169.07$$

$$(h_{\text{exit}} - h_{\text{in}})_2 = 126.82$$

$\alpha=0.02$

$$(h_{\text{exit}} - h_{\text{in}})_1 = 152.61$$

$$(h_{\text{exit}} - h_{\text{in}})_2 = 143.28$$

BENCHMARK SOURCE SITUATION

Identification: 11

Date Submitted: June 1976

By: R. R. Lee (CE)
D. A. Meneley (Ontario Hydro)
B. Micheelsen (Risø-Denmark)
D. R. Vondy (ORNL)
M. R. Wagner (KWU)
W. Werner (GRS-Munich)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
M. V. Gregory (SRL)

Descriptive Title: Multi-dimensional (x-y-z) LWR Model

Suggested Functions: Designed to provide a severe test for the capabilities of coarse mesh methods and flux synthesis approximations

Configuration: Three-dimensional configuration
including space dimensions and region
numbers: 2 Figures

Fig. 1:
Horizontal Cross
Section.
Upper Octant:
Region Assignments
Lower Octant:
Fuel Assembly
Identification

Fig. 2: Vertical Cross Section, $y = 0$

Boundary Conditions:

External Boundaries: Vacuum, no incoming current

Symmetry Boundaries: Reflection, no net current

BENCHMARK PROBLEM

Identification: 11-A1 Source Situation ID.11

Date Submitted: June 1976 By: R. R. Lee (CE)
D. A. Meneley (Ontario Hydro)
B. Micheelsen (Risø-Denmark)
D. R. Vondy (ORNL)
M. R. Wagner (KWU)
W. Werner (GRS-Munich)

Date Accepted: June 1977 By: H. L. Dodds, Jr. (U. of Tenn.)
M. V. Gregory (SRL)

Descriptive Title: Three-dimensional LWR Problem
(also 3D IAEA Benchmark Problem*)

Reduction of Source Situation:

Two-group diffusion theory

Two-Group Diffusion Equations:

$$\begin{aligned} -\nabla D_1 \nabla \phi_1 + (\Sigma_{a1} + \Sigma_{1 \rightarrow 2}) \phi_1 &= \frac{1}{\lambda} \nu \Sigma_{f2} \phi_2 \\ -\nabla D_2 \nabla \phi_2 + \Sigma_{a2} \phi_2 &= \Sigma_{1 \rightarrow 2} \phi_1 \end{aligned}$$

*) Benchmark Problem, originally defined by B. Micheelsen (RISØ) by letter of Dec. 14, 1971 to participants of the Panel on Reactor Burn-up Physics which was organized by the IAEA and held in Vienna, 12 - 16 July 1971

Data

Two-group Constants

Region	D_1	D_2	$\Sigma_{1 \rightarrow 2}$	Σ_{a1}	Σ_{a2}	$\nu \Sigma_{f2}$	Material
1	1.5	0.4	0.02	0.01	0.08	0.135	Fuel 1
2	1.5	0.4	0.02	0.01	0.085	0.135	Fuel 2
3	1.5	0.4	0.02	0.01	0.13	0.135	Fuel 2 + Rod
4	2.0	0.3	0.04	0	0.01	0	Reflector
5	2.0	0.3	0.04	0	0.055	0	Refl. + Rod

Boundary Conditions:

$$J_g^{\text{in}} = 0 \quad \text{No incoming current at external boundaries.}$$

For finite difference diffusion theory codes the following form is considered equivalent

$$\frac{\partial \phi_g}{\partial n} = - \frac{0.4692}{D_g} \phi_g$$

where n the outward directed normal to the surface.
At symmetry boundaries:

$$\frac{\partial \phi_g}{\partial n} = 0$$

Expected Primary Results:

1. Maximum eigenvalue
2. Fundamental flux distributions
 - 2.1 Radial flux traverses in midplane $z = 190$ cm

$$\phi_g(x, o, 190)$$

$$\phi_g(x, x, 190)$$
 - 2.2 Radial flux traverses in planes $z = 275$ cm and $z = 285$ cm

$$\phi_g(x, o, 275), \phi_g(x, o, 285)$$

$$\phi_g(x, x, 275), \phi_g(x, x, 285)$$
 - 2.3 Axial flux traverses for partially rodded assembly

$$\phi_g(40, 40, z)$$

Note: The fluxes ϕ_g shall be normalized such that

$$\frac{1}{V_{\text{Core}}} \int_{V_{\text{Core}}} \sum_g v \Sigma_{t,g} \phi_g dV = 1$$

- 2.4 Value and location of maximum power density. This corresponds to maximum of ϕ_2 in the core. It is recommended that the maximum values of ϕ_2 both in the inner core and at the core/reflector interface be given.

3. Average subassembly powers P_k

$$P_k = \frac{1}{V_k} \int \sum_g v \Sigma_{fg} \phi_g dV ,$$

where V_k volume of the k-th subassembly and k designates the fuel subassemblies as shown in lower octant of Fig. 1

4. Number of unknowns in the problem.
Number of iterations, total and outer
5. Computing time, iteration time, IO-time, computer used
6. Type and numerical values of convergence criteria
7. Table of average group fluxes for a cubical mesh grid of 20 x 20 x 20 cm
8. Dependence of results on mesh spacing.

Best Solution Available: Extrapolated finite difference solution described in 11-A1-1

Solutions

1. Finite Difference Method: 11-A1-1
2. Finite Element Method: 11-A1-2
3. Nodal Expansion Method: 11-A1-3
4. Finite Difference Method: 11-A1-4

BENCHMARK PROBLEM SOLUTION

Identification: 11-A1-1

Benchmark Problem ID.11-A1

Date Submitted: June 1, 1976

By: D. R. Vondy, T. B. Fowler (ORNL)

Date Accepted: June 1, 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
M. V. Gregory (SRL)

Descriptive Title: Three-Dimensional PWR Problem (IAEA)

Mathematical Model: Diffusion Theory, Various Difference Formulations

Computer: IBM-360/91 1974-76, ORNL
IBM-360/195, 1975-76, UC-CTCProgram: (1) VENTURE, ORNL-5062 Report
(2) VANCER, to be documented (ORNL)

Note: To produce acceptable solutions for benchmarking, a tighter convergence of the iterative process was used than is common practice in application, maximum relative flux change on outer iterations = 10^{-5} .

Primary Results:*

- a. Primary results obtained in 1974-75 with the VENTURE code are shown in Table 1. The larger problems were initialized with the results from smaller ones and rather obsolete procedures were in use, so compute times are not representative. A number of reported results for the multiplication factor are shown in Figure 1.
- b. Results have also been obtained with the VANCER code as summarized in Table 2.
- c. Subassembly power density values, relative to the core average, are shown in Table 3 for the mesh-centered VENTURE cases (see the benchmark source situation for number references).
- d. Subassembly power density values are shown in Table 4 for the linear finite-element case with 34x34x38 mesh intervals.
- e. Table 5 is the continuing 57 pages of results. These tables of fluxes and power are for the mesh-centered VENTURE calculations, averaged over 20 centimeter cubes, one page to a plane normal to the reactor centerline, normalized to a ratio

* Extrapolation of results is done on the basis of error dependence on the square of the mesh spacing.

of productions to core volume of unity (one neutron generated per cc in the core on the average). Orientation is such that the reactor centerline is at the upper left hand corner so the first group of data is for the cube about the centerline of the core. For Power tables, the thermal flux was multiplied by $v\Sigma_f = 0.135$ producing results in the non-fueled zones which should be ignored. The numbers in each group are ordered as follows:

Order	Problem Meshpoints (XYZ)
1	17x17x19
2	34x34x38
3	68x68x76
4	102x102x114
5	Extrapolated for infinite points

Block 1 extends from 0-20 cm, Block 2 from 20-40 cm, etc.

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Table 1

THREE-DIMENSIONAL, TWO-GROUP IAEA BENCHMARK PROBLEM RESULTS
(Non-Return External Boundary Conditions)

Meshpoints (Total Unknowns)	Multiplication Factor	Peak-to-Average Power Density*	IBM-360/91 (or 195) Processor Time (min)
9x9x10(1,620)	1.03176	2.3765	0.3 to 1.
17x17x19(10,982)	1.02913	2.5672	1.6 to 5.
34x34x38(87,856)	1.02864	2.5035	49
68x68x76(702,848)	1.02897	2.4081	192
102x102x114(2,372,112)	1.02896	2.3780	360 (195)
Extrapolated	1.02903	2.354	

*Based on neutrons produced by thermal fission, peak at a point (not interpreted between points); with mesh-center points, values at material interfaces are not estimated.

Figure 1. Three-Dimensional Finite-Difference Results

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Three-Dimensional Finite-Difference Results.

Table 2. Results for Mesh-edge Point Location

Formulation (Near Neighbors)	k_{eff}	Peak Power Density	
		Internal	Reflector Edge
VENTURE, Mesh Centered (6)	1.02864	2.50	2.42
VANCER:			
Usual Finite-Difference (6)	1.03064	2.02	2.50
Linear Finite-Element (10)	1.02949	2.21	2.53
Linear Finite-Difference (10)	1.02968	2.18	2.54

Relative computation requirements are estimated at:

Formulation	Memory (Words)	Relative Computation Cost
Mesh Centered (VENTURE)	166,000	1.00
Mesh Edge (VANCER)		
Six Neighbors, Consistent Source	191,000	1.37
Ten Neighbors, Consistent Source	217,000	1.73

Table 3. Subassembly Power Densities (Axial Average)
(Non-Fuel Zone Values Given Also, Mesh Centered, VENTURE Code)

Location/Mesh Intervals	17x17x19	34x34x39	68x68x76	102x102x114	Extrapolated
1	0.7356	0.7500	0.7367	0.7325	0.729
2	1.4485	1.3780	1.3138	1.2957	1.281
3	1.5651	1.5080	1.4508	1.4347	1.422
4	1.3178	1.2657	1.2181	1.2044	1.193
5	0.5802	0.6058	0.6092	0.6098	0.610
6	0.9707	0.9631	0.9569	0.9548	0.953
7	0.9101	0.9317	0.9500	0.9551	0.959
8	0.6574	0.7056	0.7522	0.7659	0.777
(9)	0.9134	1.0125	1.0773	1.0954	1.110
10	1.5604	1.4903	1.4278	1.4109	1.397
11	1.5742	1.5158	1.4595	1.4441	1.432
12	1.4045	1.3557	1.3121	1.3002	1.291
13	1.1406	1.1119	1.0852	1.0779	1.072
14	1.0619	1.0575	1.0555	1.0553	1.055
15	0.9537	0.9438	0.9643	0.9707	0.976
16	0.6366	0.6850	0.7318	0.7460	0.757
(17)	0.8650	0.9595	1.0230	1.0413	1.056
18	1.4797	1.4369	1.3914	1.3786	1.368
19	1.4030	1.3657	1.3292	1.3192	1.311
20	1.2226	1.2067	1.1894	1.1847	1.181
21	1.0755	1.0810	1.0859	1.0877	1.089
22	0.9420	0.9602	0.9855	0.9935	1.000
23	0.5459	0.6138	0.6761	0.6953	0.711
(24)	0.6494	0.7255	0.7825	0.7993	0.813
25	1.2480	1.2180	1.1913	1.1841	1.178
26	1.0083	1.0252	0.9790	0.9753	0.972
27	0.8970	0.9062	0.9168	0.9204	0.923
28	0.7383	0.7898	0.8390	0.8541	0.866
(29)	1.4827	1.6009	1.6807	1.7039	1.722
(30)	0.2759	0.3289	0.3683	0.3802	0.390
31	0.4244	0.4542	0.4685	0.4727	0.476
32	0.6720	0.6783	0.6924	0.6969	0.700
33	0.4725	0.5284	0.5812	0.5976	0.611
(34)	0.6681	0.7462	0.8046	0.8220	0.836
35	0.4717	0.5210	0.5699	0.5852	0.597
(36)	0.9891	1.0610	1.1196	1.1373	1.151
(37)	0.2180	0.2599	0.2917	0.3015	0.309
(38)	0.2560	0.2996	0.3344	0.3451	0.354
18* Rodded Part	0.3042	0.3106	0.3095	0.3094	0.309
18** Unrodded Part	1.8414	1.7834	1.7242	1.7076	1.694

Table 4. Subassembly Power Densities (Axial Average),
(Non-Fuel Zone Values Given Also, Linear Finite Element, VANCER Code)

Location/Mesh Intervals	34x34x38
1	0.7220
2	1.2652
3	1.3317
4	1.1351
5	0.6057
6	0.9450
7	0.9700
8	0.8089
(9)	1.1348
10	1.3404
11	1.3732
12	1.2408
13	1.0410
14	1.0500
15	0.9920
16	0.8000
(17)	1.1116
18	1.3174
19	1.2705
20	1.1615
21	1.0931
22	1.0260
23	0.7770
(24)	0.8752
25	1.1495
26	0.9583
27	0.9358
28	0.9203
(29)	1.8108
(30)	0.4325
31	0.4906
32	0.7186
33	0.6717
(34)	0.9038
35	0.6536
(36)	1.2214
(37)	0.3459
(38)	0.3918
18* Rodded Part	0.3162
18** Unrodded Part	1.6254

Start Table 5 (57 pages)
GROUP 1 BLOCK 1 FLUXES

0.491809
0.581252
0.649134
0.680524
0.705636

0.583971 0.594469
0.682275 0.593158
0.779211 0.794509
0.825847 0.843363
0.863155 0.882446

0.613919 0.568600 0.462309
0.728490 0.669316 0.555361
0.844799 0.770182 0.630505
0.899896 0.818119 0.664297
0.943976 0.856468 0.691330

0.555433 0.562112 0.530850 0.517624
0.660657 0.668454 0.638067 0.626610
0.766918 0.750260 0.748714 0.743564
0.816776 0.832811 0.800087 0.797623
0.856662 0.874851 0.841184 0.840869

0.446127 0.532850 0.556763 0.477717 0.343918
0.550602 0.650789 0.689803 0.591222 0.436880
0.639062 0.773117 0.831690 0.711253 0.521427
0.677828 0.829231 0.896455 0.765772 0.557738
0.708841 0.874121 0.948275 0.809386 0.586786

0.507254 0.540605 0.540891 0.453779 0.327464 0.209493
0.635891 0.660063 0.686835 0.578032 0.417952 0.273049
0.771990 0.831707 0.846920 0.715725 0.520178 0.348337
0.833451 0.900345 0.919081 0.777596 0.565760 0.381501
0.882636 0.955255 0.976809 0.827093 0.602225 0.408032

0.486448 0.488443 0.460142 0.344262 0.212694 0.072370 0.015321
0.630169 0.633037 0.595724 0.451220 0.281629 0.102866 0.021879
0.788923 0.794060 0.751906 0.575129 0.363149 0.133076 0.027831
0.859901 0.866034 0.821690 0.629979 0.398960 0.144975 0.030053
0.916683 0.923612 0.877516 0.673858 0.427608 0.154494 0.031830

0.320521 0.309686 0.250241 0.109184 0.047193 0.013225 0.0 0.0
0.422504 0.409444 0.334185 0.157344 0.068015 0.019355 0.0 0.0
0.541035 0.525546 0.432559 0.203544 0.087984 0.024846 0.0 0.0
0.593440 0.576833 0.475690 0.221676 0.095711 0.026887 0.0 0.0
0.635363 0.617861 0.510195 0.236181 0.101893 0.028519 0.0 0.0

0.067782 0.064206 0.047990 0.016969 0.0 0.0 0.0 0.0
0.098201 0.093125 0.069499 0.024861 0.0 0.0 0.0 0.0
0.126555 0.120286 0.090293 0.031864 0.0 0.0 0.0 0.0
0.137531 0.130821 0.098363 0.034464 0.0 0.0 0.0 0.0
0.146313 0.139248 0.104819 0.036545 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 2 FLUXES

5.229720
4.876290
4.714016
4.699341
4.687597

7.068169 7.264626
6.314484 6.470860
6.069390 6.226661
6.048328 6.207546
6.031474 6.192250

7.533952 6.883982 4.914222
6.829825 6.191372 4.650915
6.627941 5.992641 4.566707
6.622412 5.984154 4.573670
6.617984 5.977359 4.579236

6.718606 6.859634 6.412583 6.311865
6.097737 6.219120 5.879041 5.816854
5.950730 6.088327 5.798501 5.784741
5.957143 6.101273 5.823526 5.824737
5.962269 6.111625 5.843542 5.856730

4.729738 6.431657 6.817832 5.778264 3.669720
4.585157 5.979685 6.424558 5.438983 3.657712
4.596798 5.964885 6.467326 5.490326 3.770639
4.633219 6.011244 6.534152 5.552841 3.832976
4.662353 6.048327 6.587609 5.602849 3.882842

6.110683 6.603089 6.648477 5.579135 4.066138 2.629845
5.819603 6.303431 6.406042 5.397050 3.933128 2.606824
5.927913 6.439398 6.586513 5.584503 4.109794 2.795335
6.011868 6.535919 6.697352 5.689708 4.201124 2.878718
6.079028 6.613131 6.786018 5.773868 4.274185 2.945422

5.971705 6.018558 5.816412 4.344919 2.679133 0.536357 0.084783
5.864732 5.913037 5.685014 4.311991 2.695662 0.647983 0.104392
6.120921 6.182147 5.970173 4.586359 2.910228 0.768197 0.124815
6.251222 6.317180 6.110500 4.710808 3.001954 0.811967 0.132157
6.355458 6.425202 6.222757 4.810364 3.075332 0.846982 0.138031

4.030659 3.898269 3.154867 0.807767 0.324551 0.073240 0.0 0.0
4.017229 3.897941 3.194575 0.988571 0.396238 0.092739 0.0 0.0
4.287787 4.170917 3.456249 1.169500 0.472038 0.111804 0.0 0.0
4.408357 4.291200 3.566901 1.234679 0.499421 0.118576 0.0 0.0
4.504810 4.387424 3.655421 1.286821 0.521327 0.123993 0.0 0.0

0.474359 0.450387 0.335861 0.093673 0.0 0.0 0.0 0.0
0.579692 0.550748 0.409621 0.118323 0.0 0.0 0.0 0.0
0.684175 0.651361 0.488269 0.142332 0.0 0.0 0.0 0.0
0.721501 0.687437 0.516715 0.150861 0.0 0.0 0.0 0.0
0.751362 0.716297 0.539472 0.157683 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 3 FLUXES

10.640157
10.342917
9.949892
9.846301
9.763422

14.320156 14.721536
13.261953 13.583195
12.631366 12.944482
12.484147 12.797089
12.366362 12.679166

15.231454 13.943526 9.992692
14.281724 12.992740 9.847260
13.708546 12.455223 9.611246
13.577841 12.333158 9.551445
13.473267 12.235497 9.503597

13.524257 13.800050 12.890597 12.629105
12.711818 12.945987 12.230785 12.033804
12.281475 12.537839 11.934143 11.830535
12.189589 12.454546 11.879818 11.804875
12.116072 12.387902 11.836349 11.784338

9.463999 12.810762 13.559529 11.481140 7.294127
9.543642 12.317812 13.186732 11.174188 7.564192
9.501802 12.149380 13.103403 11.151026 7.745007
9.499599 12.133391 13.113650 11.175657 7.809531
9.497829 12.120592 13.121839 11.195354 7.861145

12.048614 13.017533 13.106455 10.994577 8.003810 5.153759
11.857074 12.822527 13.023960 10.981101 8.014895 5.285331
11.933986 12.929055 13.211058 11.220655 8.290342 5.615988
11.990616 12.927600 13.303586 11.324881 8.401200 5.737143
12.035911 13.052426 13.377598 11.408254 8.489880 5.834062

11.700757 11.795717 11.400548 8.510855 5.241037 1.043431 0.163607
11.848229 11.950092 11.494193 8.716574 5.445371 1.306125 0.208420
12.198562 12.325664 11.914407 9.161203 5.817193 1.537980 0.247738
12.337196 12.472697 12.078737 9.325022 5.950086 1.613693 0.260601
12.448095 12.590314 12.210193 9.456071 6.056397 1.674263 0.270891

7.864830 7.607886 6.153328 1.569190 0.629551 0.141216 0.0 0.0
8.082984 7.845747 6.428634 1.987680 0.795126 0.184904 0.0 0.0
8.519551 8.291454 6.876891 2.332601 0.940221 0.221502 0.0 0.0
8.678107 8.452088 7.035229 2.443312 0.987371 0.233340 0.0 0.0
8.804945 8.580590 7.161894 2.531879 1.025089 0.242810 0.0 0.0

0.918452 0.872165 0.650000 0.180239 0.0 0.0 0.0 0.0
1.160316 1.102655 0.819655 0.235242 0.0 0.0 0.0 0.0
1.357270 1.292635 0.969222 0.281010 0.0 0.0 0.0 0.0
1.419676 1.353194 1.017788 0.295782 0.0 0.0 0.0 0.0
1.469601 1.401639 1.056639 0.307600 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 4 FLUXES

16.793342
16.559952
15.897389
15.694469
15.532121

22.632385 23.341119
21.264527 21.857876
20.208272 20.784736
19.924055 20.497747
19.696667 20.268141

24.062081 22.143213 15.962351
22.880912 20.936286 15.949408
21.903503 20.018613 15.519597
21.638054 19.770672 15.379701
21.425679 19.572306 15.267773

21.177126 21.650793 20.247122 19.658149
20.166883 20.581989 19.460387 18.960850
19.416893 19.861238 18.910907 18.555542
19.216212 19.670914 18.765547 18.454162
9.055654 19.518641 18.649245 18.373045

14.552325 19.706391 20.856544 17.600751 11.093175
14.835445 19.153563 20.498377 17.309573 11.618643
14.700769 18.798496 20.262738 17.182928 11.833368
14.648810 18.710327 20.208098 17.160798 11.890151
14.607232 18.639778 20.164373 17.142919 11.935569

18.204268 19.692255 19.840064 16.624451 12.062430 7.742822
18.080384 19.574017 19.893820 16.755385 12.191525 8.013793
18.095324 19.623567 20.062060 17.022675 12.541560 8.470140
18.115398 19.655705 20.128432 17.118317 12.664226 8.622908
18.131443 19.681401 20.181515 17.194819 12.762350 8.745116

17.533464 17.685352 17.106201 12.775360 7.862754 1.564450 0.245025
17.907982 18.070867 17.395021 13.197833 8.242122 1.976657 0.315040
18.328993 18.528667 17.924664 13.790986 8.756419 2.314647 0.372626
18.468415 18.679989 18.104677 13.986509 8.924806 2.420274 0.390677
18.579940 18.801034 18.248674 14.142916 9.059509 2.504774 0.405118

11.736941 11.357537 9.193102 2.347457 0.942527 0.211325 0.0 0.0
12.165875 11.812864 9.686709 2.999027 1.200822 0.279201 0.0 0.0
12.748471 12.411585 10.302988 3.499692 1.412282 0.332762 0.0 0.0
12.937822 12.605501 10.501955 3.652703 1.477948 0.349369 0.0 0.0
13.089293 12.760624 10.661121 3.775110 1.530480 0.362654 0.0 0.0

1.368547 1.299941 0.969360 0.268919 0.0 0.0 0.0 0.0
1.743726 1.657506 1.232782 0.354017 0.0 0.0 0.0 0.0
2.028211 1.932173 1.449699 0.420648 0.0 0.0 0.0 0.0
2.113800 2.015410 1.516945 0.441231 0.0 0.0 0.0 0.0
2.182270 2.081998 1.570741 0.457698 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 5 FLUXES

23.980612
23.831962
22.875082
22.567827
22.322007

32.474549 33.856542
30.774210 32.071622
29.244054 30.521623
28.813326 30.084245
28.468723 29.734320

34.640052 32.547240 24.524913
33.221671 31.216968 25.016190
31.789069 29.895484 24.466059
31.378221 29.511274 24.250770
31.049520 29.203885 24.078522

30.081201 31.055876 29.439842 27.970158
28.856385 29.823547 28.664522 27.228027
27.745851 28.757036 27.848418 26.594844
27.428248 28.450721 27.603724 26.410179
27.174147 28.205649 27.407949 26.262428

20.113973 27.307025 28.965182 24.301178 15.112810
20.598408 26.670481 28.605546 24.006049 15.883591
20.353801 26.100551 28.188090 23.750882 16.118412
20.249188 25.935387 28.063291 23.677344 16.164980
20.165482 25.803238 27.963431 23.618497 16.202223

24.558953 26.621120 26.857890 22.466665 16.221827 10.370684
24.471710 26.544781 27.013480 22.711628 16.445412 10.765381
24.407851 26.518878 27.143729 22.988982 16.855509 11.337119
24.389603 26.512727 27.181908 23.073693 16.987505 11.519403
24.374987 26.507787 27.212431 23.141445 17.093090 11.665222

23.405121 23.626309 22.878780 17.096174 10.514462 2.090781 0.327155
23.979163 24.213971 23.333003 17.712195 11.054423 2.648437 0.421855
24.457880 24.740350 23.957383 18.440922 11.701866 3.091063 0.497204
24.597115 24.894843 24.151484 18.666221 11.903975 3.225937 0.520303
24.708487 25.018419 24.306748 18.846447 12.065654 3.333834 0.538783

15.591182 15.094390 12.231341 3.128908 1.257640 0.281917 0.0 0.0
16.211784 15.748059 12.926507 4.008321 1.606683 0.373514 0.0 0.0
16.929990 16.489257 13.700910 4.660677 1.882813 0.443590 0.0 0.0
17.148711 16.714935 13.938793 4.855075 1.966577 0.464845 0.0 0.0
17.323675 16.895466 14.129089 5.010591 2.033588 0.481848 0.0 0.0

1.815252 1.724897 1.287353 0.357485 0.0 0.0 0.0 0.0
2.319786 2.205793 1.641795 0.471863 0.0 0.0 0.0 0.0
2.688999 2.562458 1.923974 0.558706 0.0 0.0 0.0 0.0
2.797128 2.667749 2.009382 0.584927 0.0 0.0 0.0 0.0
2.883630 2.751979 2.077707 0.605904 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 6 FLUXES

31.956508
31.809071
30.540113
30.127386
29.797182

43.649274 46.666822
41.388584 44.195654
39.334298 42.058047
38.751045 41.453154
38.284415 40.969210

46.980801 47.048406 45.277808
44.954204 44.809402 43.052014
42.986849 42.822543 41.169672
42.419970 42.255025 40.631224
41.966436 41.800981 40.200436

40.094836 42.464124 42.380626 38.054806
38.441225 40.707921 40.865191 36.929094
36.922945 39.191024 39.532322 35.968168
36.482689 38.752431 39.143296 35.684379
36.130458 38.401529 38.832047 35.457322

35.961447 35.423637 37.795478 31.434641 19.217081
26.590854 34.577887 37.235683 31.016822 20.193472
26.223190 33.764399 36.591893 30.604300 20.435583
26.065277 33.519393 36.391467 30.475999 20.470392
25.938928 33.323364 36.231101 30.373336 20.498224

30.870422 33.545223 33.906102 28.305864 20.325337 12.937788
30.782912 33.460879 34.102046 28.617386 20.616248 13.438641
30.629352 33.345565 34.176891 28.888606 21.073181 14.114279
30.572643 33.300552 34.185507 28.960550 21.212374 14.323658
30.527255 33.264519 34.192376 29.018084 21.323714 14.491150

29.099955 29.399655 28.504175 21.311336 13.096187 2.602432 0.406837
29.842338 30.155861 29.089679 22.092552 13.778615 3.298589 0.524943
30.365697 30.736657 29.792924 22.941524 14.547349 3.839640 0.617080
30.503615 30.892910 29.999004 23.193936 14.780707 4.002296 0.644968
30.613927 31.017890 30.163846 23.395849 14.967382 4.132418 0.667277

19.290241 18.684717 15.157771 3.884538 1.562989 0.350288 0.0 0.0
20.080151 19.514031 16.033553 4.979320 1.997916 0.464386 0.0 0.0
20.920626 20.384075 16.952713 5.774875 2.335162 0.550079 0.0 0.0
21.166425 20.639088 17.226828 6.008543 2.436106 0.575742 0.0 0.0
21.363050 20.843083 17.446109 6.195473 2.516859 0.596271 0.0 0.0

2.242653 2.131832 1.592457 0.442648 0.0 0.0 0.0 0.0
2.868703 2.728608 2.032431 0.584609 0.0 0.0 0.0 0.0
3.317422 3.162248 2.375954 0.690477 0.0 0.0 0.0 0.0
3.446807 3.288343 2.478513 0.722027 0.0 0.0 0.0 0.0
3.550313 3.389216 2.560558 0.747267 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 7 FLUXES

39.412486
39.416005
37.883454
37.378826
36.975098

53.989732 58.100077
51.467362 55.444231
48.970645 52.867245
48.255315 52.128118
47.683016 51.536779

58.224405 59.031052 58.015407
56.017341 56.788376 56.062747
53.621097 54.428184 53.957884
52.922982 53.739705 53.336542
52.364451 53.188684 52.839431

49.287977 52.526915 52.870105 46.847016
47.468072 50.698902 51.457377 45.746375
45.610775 48.862440 49.876283 44.572463
45.065195 48.320681 49.399550 44.214594
44.628700 47.887240 49.018128 43.928267

31.354830 42.859093 45.801316 37.938833 22.976331
32.185693 41.941442 45.238755 37.516215 24.171457
31.714547 40.921652 44.415174 36.974188 24.422493
31.510138 40.607314 44.151085 36.798927 24.447249
31.346589 40.355814 43.939781 36.658691 24.467037

36.649273 39.885639 40.355603 33.647528 24.073264 15.277292
36.577292 39.818219 40.620834 34.040862 24.431656 15.874830
36.341032 39.621264 40.645766 34.305523 24.928575 16.642285
36.249723 39.541468 40.628144 34.366048 25.073984 16.875823
36.176650 39.477603 40.614018 34.414443 25.190294 17.062642

34.273175 34.647106 33.621608 25.148540 15.445897 3.067962 0.479286
35.167375 35.556317 34.327668 26.080612 16.257316 3.889704 0.618578
35.727483 36.182672 35.098571 27.035288 17.133576 4.519381 0.725820
35.863965 36.340253 35.315150 27.311855 17.394864 4.707102 0.758023
35.973125 36.466292 35.488388 27.533089 17.603881 4.857275 0.783785

22.633933 21.931813 17.807690 4.570101 1.840396 0.412401 0.0 0.0
23.572824 22.916138 18.844033 5.859352 2.352974 0.546844 0.0 0.0
21.520359 23.899249 19.891173 6.783549 2.745176 0.646581 0.0 0.0
24.790173 24.180310 20.197617 7.052586 2.861601 0.676215 0.0 0.0
25.006007 24.405142 20.442758 7.267810 2.954739 0.699922 0.0 0.0

2.628351 2.499228 1.868205 0.519706 0.0 0.0 0.0 0.0
3.363231 3.199833 2.384883 0.686448 0.0 0.0 0.0 0.0
3.882983 3.702272 2.783296 0.809359 0.0 0.0 0.0 0.0
4.031414 3.847012 2.901241 0.845695 0.0 0.0 0.0 0.0
4.150156 3.962802 2.995595 0.874762 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 8 FLUXES

45.539123
45.725571
43.995319
43.418612
42.957216

62.416862 67.247985
59.747004 64.457107
56.911855 61.535550
56.092842 60.690010
55.437591 60.013535

67.292767 68.358742 67.301522
65.004517 66.053091 65.323387
62.286031 63.380533 62.940878
61.486262 62.592603 62.229096
60.846403 61.962214 61.659626

56.751288 60.533813 60.967625 53.803335
54.846528 58.645095 59.560293 52.706887
52.732056 56.557459 57.763598 51.365012
52.104214 55.933936 57.213558 50.948463
51.601903 55.435078 56.773484 50.615188

35.794926 48.945370 52.307181 43.248818 26.076676
36.820739 48.002001 51.775796 42.848290 27.467157
36.274160 46.825282 50.819591 42.210679 27.730751
36.033342 46.456458 50.506326 41.999027 27.748250
35.840661 46.161366 50.255677 41.829675 27.762229

41.449276 45.143970 45.694986 38.073119 27.185955 17.223066
41.406880 45.111027 46.040474 38.551530 27.609343 17.905020
41.106951 44.852651 46.031281 38.816101 28.141998 18.749835
40.987970 44.745316 45.993407 38.868256 28.293086 19.003667
40.892756 44.659416 45.963075 38.909953 28.413936 19.206719

38.573745 39.008595 37.874289 28.338140 17.400132 3.455272 0.539574
39.600761 40.052559 38.689088 29.402262 18.322403 4.382244 0.696594
40.193353 40.718961 39.518593 30.446599 19.288985 5.085892 0.816433
40.329105 40.878150 39.744423 30.743630 19.573688 5.294523 0.852233
40.437677 41.005472 39.925059 30.981233 19.801436 5.461424 0.880872

25.411128 24.629044 20.009480 5.139991 2.071133 0.464078 0.0 0.0
26.475144 25.743765 21.181095 6.591707 2.648659 0.615523 0.0 0.0
27.511940 26.821187 22.335011 7.623103 3.086682 0.726965 0.0 0.0
27.801800 27.123990 22.668422 7.921609 3.216010 0.759909 0.0 0.0
28.033667 27.366213 22.935135 8.160408 3.319471 0.786263 0.0 0.0

2.948550 2.804273 2.097230 0.583731 0.0 0.0 0.0 0.0
3.773795 3.591131 2.677694 0.771098 0.0 0.0 0.0 0.0
4.352499 4.150683 3.121701 0.908174 0.0 0.0 0.0 0.0
4.516741 4.310906 3.252429 0.948487 0.0 0.0 0.0 0.0
4.648131 4.439081 3.357009 0.980737 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 9 FLUXES

49.962814
50.290832
48.426326
47.798620
47.296420

68.478260 73.784138
65.708455 70.891873
62.638496 67.728934
61.745718 66.807179
61.031451 66.069727

73.784716 74.965601 73.779980
71.439436 72.600408 71.759841
68.497395 69.707091 69.178206
67.625270 68.847453 68.400435
66.927522 68.159693 67.778168

62.108843 66.241073 66.685775 58.750369
60.144445 64.299375 65.263248 57.644133
57.851758 62.035326 63.312997 56.183928
57.165443 61.353145 62.709826 55.725169
56.616350 60.807356 62.227244 55.358122

39.009572 53.339985 56.989354 47.077696 28.326044
40.180994 52.380957 56.481111 46.693991 29.860695
39.585284 51.096987 55.435154 45.992372 30.137103
39.318922 50.689637 55.087204 45.755171 30.149965
39.105804 50.363720 54.808805 45.565378 30.160233

44.950929 48.975507 49.580803 41.295492 29.457089 18.645004
44.935193 48.973292 49.990336 41.840349 29.930776 19.390311
44.594315 48.676265 49.962623 42.110050 30.492974 20.293770
44.456072 48.549889 49.911083 42.157013 30.648820 20.562819
44.345446 48.448753 49.869815 42.194554 30.773476 20.778044

41.717214 42.195788 40.981001 30.668399 18.828590 3.738482 0.583671
42.843970 43.341196 41.878520 31.831650 19.833442 4.742764 0.753712
43.464441 44.041166 42.755177 32.944895 20.868133 5.501067 0.882851
43.600361 44.202267 42.988521 33.257487 21.170334 5.725110 0.921301
43.709067 44.331116 43.175165 33.507536 21.412080 5.904341 0.952060

27.441268 26.600712 21.619015 5.556610 2.239863 0.501876 0.0 0.0
28.597328 27.811466 22.890382 7.127498 2.865072 0.665800 0.0 0.0
29.701606 28.960058 24.124319 8.238021 3.336922 0.785879 0.0 0.0
30.006495 29.279133 24.477793 8.558233 3.475757 0.821260 0.0 0.0
30.250384 29.534373 24.760554 8.814396 3.586822 0.849564 0.0 0.0

3.182584 3.027240 2.264648 0.630539 0.0 0.0 0.0 0.0
4.073880 3.877162 2.891784 0.833006 0.0 0.0 0.0 0.0
4.695978 4.478760 3.369361 0.980513 0.0 0.0 0.0 0.0
4.871836 4.650360 3.509484 1.023750 0.0 0.0 0.0 0.0
5.012519 4.787636 3.621579 1.058339 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 10 FLUXES

52.513571
52.925710
50.995986
50.341084
49.817127

71.966517 77.535535
69.140968 74.585505
65.950964 71.299610
65.018423 70.336874
64.272343 69.566634

77.508679 78.741479 77.461837
75.130755 76.340891 75.415163
72.075837 73.336220 72.733823
71.164975 72.438232 71.920912
70.436234 71.719789 71.270531

65.177251 69.499916 69.936715 61.562711
63.177561 67.525357 68.501380 60.446407
60.794798 65.172693 66.475166 58.928352
60.077219 64.459254 65.843880 58.447397
59.503114 63.888456 65.338804 58.062591

40.848189 55.849928 59.657886 49.258498 29.607474
42.101704 54.879744 59.159646 48.881319 31.222324
41.485063 53.543494 58.071784 48.150530 31.510412
41.205509 53.115890 57.705888 47.900237 31.521547
40.981836 52.773769 57.413130 47.699968 31.530433

46.947963 51.160282 51.795190 43.131071 30.750404 19.454427
46.945023 51.172904 52.238360 43.711157 31.250676 20.234340
46.587362 50.861044 52.207388 43.989667 31.833634 21.173579
46.439459 50.725269 52.149552 44.034890 31.993015 21.451810
46.321103 50.616613 52.103245 44.071036 32.120497 21.674380

43.504051 44.007739 42.747647 31.993953 19.641286 3.899622 0.608758
44.684026 45.207355 43.688968 33.211163 20.691588 4.947512 0.786145
45.325655 45.931815 44.597694 34.367579 21.767451 5.737490 0.920664
45.462766 46.095124 44.836408 34.689868 22.080135 5.970450 0.960645
45.572423 46.225738 45.027347 34.947673 22.330267 6.156813 0.992630

28.592256 27.718840 22.532366 5.793271 2.335796 0.523371 0.0 0.0
29.797583 28.981263 23.858132 7.431200 2.987867 0.694334 0.0 0.0
30.943234 30.173267 25.140035 8.587495 3.479286 0.819400 0.0 0.0
31.257301 30.502221 25.505450 8.920243 3.623612 0.856188 0.0 0.0
31.508532 30.765362 25.797763 9.186435 3.739069 0.885617 0.0 0.0

3.315137 3.153558 2.359554 0.657092 0.0 0.0 0.0 0.0
4.243364 4.038759 3.012821 0.868033 0.0 0.0 0.0 0.0
4.890440 4.664561 3.509721 1.021542 0.0 0.0 0.0 0.0
5.072977 4.842702 3.655243 1.066461 0.0 0.0 0.0 0.0
5.219003 4.985211 3.771659 1.102395 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 11 FLUXES

53.121790
53.561368
51.640925
50.985732
50.461542

72.793697 78.420037
69.963500 75.464653
66.776418 72.183075
65.842259 71.219037
65.094884 70.447756

78.376922 79.615783 78.297979
75.998330 77.212984 76.246544
72.949695 74.214947 73.574749
72.038069 73.316367 72.761714
71.308717 72.597452 72.111234

65.869874 70.228377 70.649687 62.161960
63.864760 68.248054 69.210799 61.040435
61.486596 65.901430 67.192580 59.529930
60.768414 65.187759 66.561693 59.049637
60.193825 64.616776 66.056935 58.665361

41.234147 56.374253 60.208986 49.700274 29.856784
42.502183 55.397726 59.707412 49.318649 31.481986
41.894611 54.067644 58.628582 48.595526 31.779769
41.615938 53.640418 58.263826 48.346356 31.792717
41.392969 53.298599 57.971980 48.146985 31.803052

47.325188 51.575875 52.216716 43.477097 30.988503 19.600142
47.316083 51.581999 52.656758 44.055155 31.486715 20.381238
46.966233 51.279389 52.637309 44.344841 32.079549 21.330396
46.819576 51.145223 52.581727 44.392482 32.241366 21.611355
46.702218 51.037853 52.537223 44.430564 32.370797 21.836108

43.816385 44.326184 43.060691 32.230205 19.785784 3.928199 0.613181
44.994465 45.524007 43.998947 33.448734 20.838921 4.982505 0.791649
45.648267 46.261336 44.921530 34.618818 21.925634 5.778844 0.927229
45.788067 46.427553 45.163620 34.944646 22.241284 6.013660 0.967525
45.899873 46.560494 45.357260 35.205284 22.493788 6.201508 0.999761

28.783576 27.905678 22.686881 5.834089 2.352567 0.527130 0.0 0.0
29.988531 29.168429 24.015061 7.481450 3.008492 0.699128 0.0 0.0
31.145923 30.372410 25.308924 8.646719 3.503762 0.825164 0.0 0.0
31.463007 30.704474 25.677576 8.982032 3.649211 0.862236 0.0 0.0
31.716651 30.970102 25.972478 9.250276 3.765567 0.891894 0.0 0.0

3.336777 3.174278 2.375294 0.661549 0.0 0.0 0.0 0.0
4.269681 4.063979 3.031935 0.873634 0.0 0.0 0.0 0.0
4.921385 4.694274 3.532423 1.028258 0.0 0.0 0.0 0.0
5.105222 4.873689 3.678993 1.073504 0.0 0.0 0.0 0.0
5.252288 5.017216 3.796246 1.109700 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 12 FLUXES

51.787866
52.202704
50.367939
49.741797
49.240848

70.961705 76.442018
68.183794 73.539788
65.124902 70.392155
64.230369 69.469796
63.514697 68.731859

76.390857 77.593161 76.294288
74.049523 75.226970 74.270495
71.128644 72.355689 71.713196
70.257506 71.497533 70.938113
69.560546 70.810958 70.317997

64.179743 68.420186 68.818584 60.535188
62.203305 66.465415 67.388921 59.415873
59.926048 64.221025 65.463843 57.979055
59.240505 63.540834 64.864451 57.524406
58.692027 62.996636 64.384890 57.160645

0.149966 54.889787 58.618059 48.379628 29.054775
41.365104 53.913057 58.100825 47.983054 30.618874
40.796835 52.648059 57.082170 47.304332 30.923513
40.534552 52.243702 56.739545 47.071956 30.942526
40.324697 51.920179 56.465404 46.886022 30.957714

46.044867 50.182867 50.806562 42.300160 30.145030 19.064029
46.009128 50.159571 51.204843 42.836978 30.610742 19.811050
45.690981 49.889461 51.210562 43.138845 31.201056 20.742608
45.557678 49.769201 51.167018 43.193959 31.364662 21.019925
45.451002 49.672958 51.132147 43.238018 31.495525 21.241765

42.610584 43.107680 41.878947 31.346748 19.243170 3.820413 0.596336
43.728124 44.244136 42.764062 32.511003 20.254356 4.842616 0.769393
44.383228 44.980702 43.680070 33.663005 21.319775 5.618980 0.901541
44.527967 45.151263 43.924155 33.986517 21.630928 5.848440 0.940904
44.643727 45.287680 44.119392 34.245303 21.879834 6.032004 0.972395

27.963721 27.130967 22.058507 5.673100 2.287824 0.512624 0.0 0.0
29.135570 28.339596 23.334242 7.270116 2.923747 0.679436 0.0 0.0
30.272893 29.521899 24.601867 8.406020 3.406501 0.802259 0.0 0.0
30.587039 29.850477 24.965085 8.733704 3.548605 0.838467 0.0 0.0
30.838334 30.113317 25.255642 8.995844 3.662286 0.867432 0.0 0.0

3.243748 3.085855 2.309259 0.643198 0.0 0.0 0.0 0.0
4.147747 3.948017 2.945589 0.848807 0.0 0.0 0.0 0.0
4.782819 4.562215 3.433245 0.999450 0.0 0.0 0.0 0.0
4.962443 4.737502 3.576396 1.043633 0.0 0.0 0.0 0.0
5.106138 4.877729 3.690914 1.078979 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 13 FLUXES

48.575577
48.919352
47.244825
46.678079
46.224648

66.557704 71.695284
63.892390 68.908231
61.083578 66.020627
60.271060 65.184173
59.621002 64.514963

71.642203 72.766721 71.540347
69.380078 70.479743 69.574047
66.705083 67.851932 67.238904
65.916962 67.076487 66.541063
65.286417 66.456083 65.982743

60.178627 64.151146 64.517839 56.743570
58.267716 62.256080 63.113111 55.636187
56.184828 60.207167 61.363478 54.336747
55.566138 59.595209 60.827724 53.933596
55.071148 59.105600 60.399077 53.611037

37.632830 51.447264 54.938565 45.338765 27.223977
38.730909 50.478262 54.395545 44.918306 28.657547
38.230864 49.334999 53.485971 44.318862 28.965388
38.001138 48.976761 53.187315 44.119615 28.995180
37.817330 48.690136 52.948352 43.960185 29.018993

43.138888 47.016917 47.601261 39.629983 28.239708 17.857709
43.056986 46.942336 47.920542 40.087498 28.643147 18.535950
42.792690 46.726123 47.963330 40.401166 29.217648 19.422037
42.685446 46.632741 47.942327 40.469409 29.382842 19.689693
42.599619 46.558002 47.925491 40.523974 29.514977 19.903803

39.910369 40.376683 39.226831 29.362184 18.024753 3.578488 0.558563
40.909592 41.393069 40.009480 30.417415 18.949874 4.530665 0.719815
41.553783 42.113909 40.897269 31.518858 19.961548 5.260914 0.844070
41.706314 42.290863 41.142589 31.834728 20.261110 5.477976 0.881283
41.828309 42.432397 41.338816 32.087402 20.500745 5.651622 0.911053

26.206236 25.408050 20.658494 5.313362 2.142846 0.480141 0.0 0.0
27.252731 26.508627 21.827516 6.801089 2.735254 0.635635 0.0 0.0
28.337493 27.634966 23.030313 7.869527 3.189241 0.751093 0.0 0.0
28.643191 27.953903 23.379833 8.179623 3.323633 0.785311 0.0 0.0
28.887729 28.209032 23.659433 8.427694 3.431144 0.812685 0.0 0.0

3.037544 2.889729 2.162562 0.602361 0.0 0.0 0.0 0.0
3.879437 3.692680 2.755175 0.793967 0.0 0.0 0.0 0.0
4.476703 4.270279 3.213660 0.935562 0.0 0.0 0.0 0.0
4.646717 4.436152 3.349017 0.977318 0.0 0.0 0.0 0.0
4.782724 4.568847 3.457300 1.010723 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 14 FLUXES

43.610201
43.843701
42.398750
41.920714
41.538255

59.752880 64.363745
57.261583 61.755169
54.816193 59.244780
54.126502 58.536832
53.574710 57.970433

64.313347 65.321144 64.215748
62.174876 63.158366 62.341479
59.855478 60.882352 60.326368
59.191366 60.230372 59.743631
58.660035 59.708745 59.277398

54.016324 57.580119 57.905547 50.923541
52.209425 55.780851 56.544349 49.840348
50.407530 54.013721 55.046103 48.736786
49.888624 53.503456 54.604948 48.410018
49.473463 53.095206 54.251985 48.148568

33.771827 46.168231 49.299588 40.683012 24.426063
34.694800 45.217112 48.724073 40.232427 25.665006
34.289242 44.247549 47.968112 39.743761 25.971663
34.107679 43.957786 47.734459 39.593355 26.016828
33.962404 43.725945 47.547502 39.473002 26.052941

38.702946 42.182808 42.707064 35.554603 25.334461 16.019872
38.558194 42.038211 42.914179 35.898464 25.648537 16.597166
38.367218 41.894530 43.003657 36.222158 26.193588 17.410731
38.298251 41.840515 43.015346 36.309030 26.360243 17.663059
38.243050 41.797273 43.024667 36.378501 26.493549 17.864908

35.800757 36.219404 35.188505 26.339737 16.169316 3.210115 0.501059
36.628349 37.061608 35.823386 27.235232 16.967326 4.056638 0.644496
37.248588 37.751062 36.661011 28.254278 17.893862 4.715920 0.756620
37.411723 37.936459 36.906945 28.557531 18.175155 4.913940 0.790531
37.542204 38.084749 37.103656 28.800113 18.400176 5.072353 0.817660

23.505592 22.789879 18.530162 4.766127 1.922204 0.430703 0.0 0.0
24.398082 23.732151 19.541791 6.089122 2.448990 0.569112 0.0 0.0
25.398500 24.769070 20.642424 7.053841 2.858755 0.673262 0.0 0.0
25.690567 25.072570 20.970450 7.336950 2.981313 0.704428 0.0 0.0
25.924203 25.315352 21.232856 7.563433 3.079357 0.729360 0.0 0.0

2.724429 2.591874 1.939697 0.540296 0.0 0.0 0.0 0.0
3.472934 3.305774 2.466546 0.710808 0.0 0.0 0.0 0.0
4.012215 3.827241 2.880302 0.838533 0.0 0.0 0.0 0.0
4.167517 3.978700 3.003728 0.876575 0.0 0.0 0.0 0.0
4.291756 4.099865 3.102467 0.907008 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 15 FLUXES

37.075704
37.168147
36.013788
35.650542
35.359919

50.798890 54.718047
48.542142 52.350516
46.560198 50.320682
46.029636 49.779118
45.605154 49.345831

54.673793 55.529646 54.587618
52.704621 53.537208 52.841891
50.837442 51.708317 51.232734
50.333756 51.215985 50.798656
49.930771 50.822082 50.451357

45.917026 48.945457 49.220191 43.283212
44.253316 47.279254 47.923990 42.239254
42.808540 45.869613 46.743452 41.382367
42.418604 45.490663 46.424233 41.153860
42.106625 45.187471 46.168825 40.971025

28.704355 39.240310 41.900938 34.576524 20.758714
29.402919 38.319799 41.290680 34.093210 21.747189
29.114232 37.568991 40.726541 33.742041 22.047574
28.994515 37.367337 40.576268 33.654116 22.111854
28.898720 37.205986 40.456021 33.583752 22.163261

32.890661 35.848234 36.293819 30.215205 21.529491 13.613662
32.670741 35.619692 36.361862 30.416872 21.731432 14.062030
32.568975 35.563524 36.504811 30.747317 22.233426 14.777778
32.548753 35.559537 36.557703 30.857185 22.400940 15.009307
32.532553 35.556321 36.599991 30.945057 22.534935 15.194519

30.421641 30.777596 29.901957 22.382886 13.740421 2.727919 0.425794
31.031907 31.399151 30.350424 23.074578 14.375335 3.436938 0.546039
31.614705 32.041319 31.116318 23.981114 15.187507 4.002635 0.642175
31.790349 32.236358 31.361645 24.266725 15.444137 4.175522 0.671730
31.930841 32.392366 31.557885 24.495196 15.649430 4.313829 0.695374

19.972925 19.364908 15.745626 4.050017 1.633434 0.366003 0.0 0.0
20.668922 20.104894 16.555247 5.158662 2.074821 0.482164 0.0 0.0
21.555056 21.020965 17.518980 5.986654 2.426299 0.571416 0.0 0.0
21.828328 21.303313 17.618059 6.234157 2.533243 0.598557 0.0 0.0
22.046930 21.529175 18.057309 6.432154 2.618797 0.620269 0.0 0.0

2.314942 2.202324 1.648193 0.459106 0.0 0.0 0.0 0.0
2.942036 2.800444 2.089531 0.602169 0.0 0.0 0.0 0.0
3.404945 3.247980 2.444386 0.711636 0.0 0.0 0.0 0.0
3.540850 3.380435 2.552087 0.744782 0.0 0.0 0.0 0.0
3.649572 3.486397 2.638246 0.771298 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 16 FLUXES

29.209624
29.139970
28.326066
28.098573
27.916559

40.020937 43.108125
38.056581 41.041615
36.620417 39.577284
36.278291 39.232633
36.004564 38.956884

43.072572 43.746315 43.002997
41.318308 41.970249 41.423426
39.982600 40.666575 40.290351
39.668620 40.362947 40.031774
39.417408 40.120016 39.824883

36.172506 38.557716 38.773187 34.095431
34.690985 37.062236 37.566134 33.108628
33.665625 36.071655 36.757049 32.539239
33.428047 35.847882 36.581457 32.426198
33.237962 35.668678 36.440957 32.335742

32.611087 30.910351 33.005780 27.236019 16.351572
33.047059 30.035999 32.363792 26.721752 17.044520
22.892669 29.540116 32.021606 26.528748 17.332816
22.845432 29.441974 31.968935 26.513684 17.418496
22.807626 29.363438 31.926774 26.501614 17.487028

25.906721 28.236412 28.587526 23.799902 16.958807 10.723906
25.604939 27.916102 28.497536 23.838276 17.031415 11.020820
25.603928 27.957995 28.697338 24.170478 17.476930 11.615803
25.640155 28.011783 28.797269 24.305772 17.643717 11.821048
25.669118 28.054794 28.877193 24.413990 17.777133 11.985236

23.961076 24.241589 23.552370 17.630556 10.823565 2.148913 0.335434
24.318261 24.606052 23.784358 18.082978 11.265980 2.693614 0.427953
24.849930 25.185080 24.457686 18.849266 11.937430 3.146080 0.504745
25.038399 25.389424 24.699955 19.111759 12.163106 3.288398 0.529002
25.189156 25.552880 24.893752 19.321739 12.343638 3.402249 0.548407

15.731450 15.252684 12.402321 3.190168 1.286714 0.288328 0.0 0.0
16.196598 15.754657 12.973249 4.042612 1.626024 0.377882 0.0 0.0
16.941137 16.521276 13.768826 4.705198 1.906990 0.449116 0.0 0.0
17.190167 16.776549 14.031659 4.909401 1.994949 0.471364 0.0 0.0
17.389378 16.980756 14.241914 5.072760 2.065314 0.489162 0.0 0.0

1.823383 1.734694 1.298263 0.361648 0.0 0.0 0.0 0.0
2.305429 2.194484 1.637422 0.471888 0.0 0.0 0.0 0.0
2.675998 2.552624 1.921057 0.559278 0.0 0.0 0.0 0.0
2.788325 2.661978 2.009647 0.586475 0.0 0.0 0.0 0.0
2.878185 2.749459 2.080519 0.608232 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 17 FLUXES

20.295270
20.053891
19.616741
19.539402
19.477517

27.807620 29.952089
26.189503 28.242337
25.360099 27.406229
25.226942 27.279858
25.120399 27.178741

29.926909 30.394464 29.877159
28.431845 28.879232 28.501195
27.685869 28.157961 27.895134
27.582009 28.063230 27.830545
27.498901 27.987425 27.778853

25.132500 26.789190 26.938061 23.688082
23.871414 25.501792 25.846545 22.779307
23.311206 24.975769 25.447609 22.526544
23.242147 24.923054 25.430383 22.540467
23.186883 24.880865 25.416583 22.551590

15.709194 21.475583 22.930848 18.922630 11.360855
15.858059 20.666315 22.266042 18.384348 11.726367
15.849689 20.451234 22.166661 18.363370 11.996197
15.881723 20.466838 22.220816 18.427635 12.103770
15.907338 20.479306 22.264124 18.479033 12.189820

17.998767 19.617103 19.861005 16.535959 11.784856 7.454301
17.615537 19.204561 19.603120 16.398579 11.717543 7.583522
17.722269 19.350381 19.859553 16.725881 12.093463 8.037076
17.819388 19.466297 20.009244 16.886764 12.256667 8.210200
17.697071 19.559017 20.128983 17.015459 12.387221 8.348693

16.646928 16.841894 16.364186 12.251707 7.523281 1.494125 0.233337
16.727110 16.924498 16.359248 12.439053 7.751327 1.853593 0.294559
17.194273 17.424998 16.920005 13.039681 8.258494 2.176402 0.349143
17.394097 17.636559 17.155189 13.272730 8.446674 2.283300 0.367235
17.553944 17.805795 17.343325 13.450160 8.597212 2.368818 0.381709

10.931497 10.599039 8.619552 2.217586 0.894674 0.200567 0.0 0.0
11.140928 10.836827 8.924112 2.781032 1.118851 0.260082 0.0 0.0
11.719477 11.428454 9.523659 3.254225 1.319026 0.310646 0.0 0.0
11.938276 11.650251 9.742693 3.408267 1.384968 0.327206 0.0 0.0
12.113307 11.827679 9.917914 3.531498 1.437720 0.340455 0.0 0.0

1.267454 1.205838 0.902604 0.251527 0.0 0.0 0.0 0.0
1.585991 1.509671 1.126539 0.324706 0.0 0.0 0.0 0.0
1.850930 1.765526 1.328620 0.386766 0.0 0.0 0.0 0.0
1.935966 1.848137 1.395068 0.407045 0.0 0.0 0.0 0.0
2.003994 1.914225 1.448226 0.423269 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 18 FLUXES

10.639729
10.211849
10.147739
10.215478
10.269662

14.584353 15.705715
13.336321 14.372508
13.115340 14.162073
13.184710 14.246072
13.240196 14.313262

15.690918 15.934602 15.662036
14.464173 14.688619 14.493321
14.300500 14.540531 14.401036
14.397704 14.644953 14.519599
14.475457 14.728481 14.614440

13.180178 14.046326 14.121871 12.419408
12.153329 12.975927 13.144572 11.588117
12.052575 12.903639 13.138684 11.634674
12.144139 13.012669 13.268523 11.764770
12.217381 13.099883 13.372385 11.868839

8.234985 11.262620 12.021896 9.922623 5.955418
8.073864 10.521729 11.324383 9.355596 5.965583
8.196764 10.573303 11.444697 9.487546 6.195106
8.300595 10.693051 11.593475 9.620671 6.315673
8.383653 10.788841 11.712490 9.727164 6.412121

9.439586 10.285547 10.411057 8.670343 6.184858 3.920502
8.968007 9.768652 9.962660 8.335809 5.962113 3.864096
9.160464 9.991075 10.241481 8.625363 6.238602 4.143529
9.307223 10.156116 10.425947 8.797834 6.385558 4.271084
9.424623 10.288142 10.573512 8.935804 6.503119 4.373125

8.727225 8.828638 8.580864 6.431795 3.955753 0.790045 0.124323
8.500401 8.597271 8.308408 6.323281 3.946516 0.946100 0.151684
8.864377 8.978032 8.710368 6.712644 4.253622 1.119715 0.181033
9.059834 9.180256 8.919849 6.898007 4.389953 1.184108 0.191772
9.216194 9.342028 9.087427 7.046292 4.499016 1.235622 0.200362

5.738583 5.564221 4.530313 1.171391 0.473736 0.106861 0.0 0.0
5.665181 5.509506 4.540314 1.417510 0.572115 0.133905 0.0 0.0
6.036745 5.884734 4.901775 1.672545 0.679803 0.161047 0.0 0.0
6.208984 6.056682 5.060229 1.766146 0.719422 0.170852 0.0 0.0
6.346769 6.194236 5.186989 1.841026 0.751116 0.178696 0.0 0.0

0.669969 0.637423 0.477635 0.133955 0.0 0.0 0.0 0.0
0.809814 0.770773 0.575713 0.167110 0.0 0.0 0.0 0.0
0.953723 0.909521 0.684530 0.200457 0.0 0.0 0.0 0.0
1.006007 0.960113 0.724543 0.212498 0.0 0.0 0.0 0.0
1.047833 1.000586 0.756552 0.222130 0.0 0.0 0.0 0.0

GROUP 1 BLOCK 19 FLUXES

1.009072
1.255014
1.479058
1.583564
1.667168

1.216794 1.294537
1.480917 1.575436
1.752656 1.868810
1.881975 2.008421
1.985429 2.120108

1.290484 1.309604 1.286779
1.580335 1.603843 1.581828
1.880543 1.910802 1.891479
2.022698 2.056046 2.037356
2.136422 2.172241 2.154057

1.097710 1.157336 1.160541 1.022779
1.347284 1.421705 1.435070 1.268835
1.608169 1.701940 1.726277 1.533464
1.730889 1.833679 1.862468 1.656616
1.829064 1.939068 1.971420 1.755137

0.780977 0.939620 0.988510 0.825394 0.560764
0.992144 1.168216 1.236862 1.035571 0.727616
1.194446 1.412596 1.504232 1.263656 0.895721
1.286432 1.525922 1.627872 1.368678 0.971008
1.360019 1.616582 1.726782 1.452695 1.031236

0.789170 0.847377 0.852285 0.709606 0.501288 0.314103
0.997454 1.069879 1.082811 0.906141 0.644920 0.411200
1.225411 1.316727 1.338929 1.127699 0.812269 0.528500
1.329638 1.429803 1.455949 1.228513 0.887877 0.580706
1.413019 1.520262 1.549564 1.309163 0.948362 0.622472

0.714550 0.720146 0.682350 0.512322 0.315702 0.107143 0.022600
0.923588 0.930465 0.880098 0.669278 0.417381 0.152056 0.032193
1.158140 1.168309 1.111142 0.853437 0.539014 0.197069 0.040995
1.264171 1.275857 1.215613 0.935918 0.593018 0.215018 0.044325
1.348994 1.361895 1.299190 1.001903 0.636220 0.229377 0.046988

0.458385 0.444022 0.360967 0.159082 0.069209 0.019411 0.0 0.0
0.601374 0.584121 0.479441 0.227838 0.099223 0.028273 0.0 0.0
0.770034 0.749579 0.620219 0.294470 0.128287 0.036281 0.0 0.0
0.845356 0.823415 0.682581 0.320937 0.139675 0.039296 0.0 0.0
0.905613 0.882483 0.732470 0.342111 0.148786 0.041709 0.0 0.0

0.096149 0.091263 0.068543 0.024405 0.0 0.0 0.0 0.0
0.138382 0.131468 0.098543 0.035466 0.0 0.0 0.0 0.0
0.178200 0.169664 0.127883 0.045384 0.0 0.0 0.0 0.0
0.193785 0.184641 0.139395 0.049113 0.0 0.0 0.0 0.0
0.206252 0.196623 0.148605 0.052095 0.0 0.0 0.0 0.0

GROUP 2 BLOCK 1 FLUXES

0.489074
0.598900
0.650410
0.665694
0.677921

1.899366 2.001086
1.953516 2.069368
1.929215 2.055268
1.927212 2.056881
1.925609 2.058171

2.086484 1.851758 0.459863
2.214946 1.918753 0.572516
2.230968 1.908616 0.632135
2.241266 1.910755 0.650258
2.249503 1.912464 0.664755

1.810772 1.893578 1.726303 1.744965
1.894888 1.997131 1.827634 1.873741
1.900585 2.020005 1.855436 1.926791
1.907444 2.032826 1.869203 1.948796
1.912930 2.043081 1.880215 1.966399

0.444362 1.736642 1.896037 1.563634 0.341218
0.568363 1.867571 2.101378 1.704125 0.449357
0.641590 1.918749 2.200670 1.772060 0.521814
0.664428 1.939951 2.237249 1.798077 0.545024
0.682698 1.956911 2.266511 1.818889 0.563591

1.651644 1.833651 1.841376 1.534003 1.046338 0.720626
1.824393 2.054758 2.091061 1.741215 1.178839 0.845058
1.917051 2.180774 2.239898 1.871419 1.272099 0.942834
1.951481 2.226453 2.292717 1.917564 1.305288 0.976458
1.979024 2.262995 2.334971 1.954478 1.331838 1.003356

1.656331 1.660752 1.554313 1.179079 0.738602 0.346653 0.086849
1.918960 1.925007 1.805690 1.392240 0.885891 0.440264 0.113646
2.086959 2.097965 1.983126 1.548503 0.999746 0.519539 0.136657
2.145543 2.158280 2.045233 1.602298 1.038438 0.549282 0.145255
2.192410 2.206530 2.094917 1.645333 1.069392 0.573076 0.152132

1.098742 1.060686 0.870573 0.522691 0.233587 0.074478 0.0 0.0
1.305848 1.263991 1.052614 0.670813 0.303734 0.099410 0.0 0.0
1.459176 1.415635 1.192411 0.790957 0.362221 0.120464 0.0 0.0
1.511881 1.467687 1.239885 0.835956 0.384025 0.128290 0.0 0.0
1.554043 1.509328 1.277863 0.871955 0.401468 0.134551 0.0 0.0

0.326456 0.308663 0.232882 0.095693 0.0 0.0 0.0 0.0
0.424665 0.401973 0.304610 0.128054 0.0 0.0 0.0 0.0
0.503388 0.477485 0.364522 0.155002 0.0 0.0 0.0 0.0
0.532874 0.505789 0.386858 0.165002 0.0 0.0 0.0 0.0
0.556462 0.528431 0.404726 0.173002 0.0 0.0 0.0 0.0

GROUP 2 BLOCK 2 FLUXES

0.853762							
0.819833							
0.820458							
0.830348							
0.838259							
1.671712	1.725899						
1.521356	1.571812						
1.499969	1.556677						
1.512243	1.571925						
1.522061	1.584123						
1.790595	1.628354	0.802261					
1.661583	1.491975	0.781985					
1.661825	1.481335	0.794025					
1.682620	1.496583	0.808276					
1.699255	1.508781	0.818957					
1.589359	1.629719	1.516513	1.499612				
1.469578	1.510867	1.416520	1.413310				
1.471151	1.522539	1.433474	1.446985				
1.489984	1.545582	1.456706	1.475991				
1.505050	1.564015	1.475290	1.499194				
0.772234	1.521292	1.620482	1.367421	0.600585			
0.771107	1.441222	1.563454	1.311908	0.617283			
0.800486	1.475257	1.622610	1.359199	0.659524			
0.819208	1.504400	1.661584	1.391102	0.680936			
0.834185	1.527714	1.692761	1.416624	0.698065			
1.445127	1.569223	1.581790	1.328183	1.014119	0.726963		
1.402591	1.533165	1.561503	1.316222	0.999500	0.784135		
1.466449	1.614082	1.656271	1.404631	1.071279	0.896452		
1.505050	1.660259	1.707344	1.450649	1.107668	0.943229		
1.535930	1.697200	1.748202	1.487463	1.136779	0.980650		
1.420692	1.433209	1.458777	1.142421	0.734029	1.544161	0.403304	
1.429550	1.443411	1.460571	1.198866	0.803506	1.597060	0.454675	
1.539316	1.557597	1.581352	1.338718	0.925534	1.728198	0.517964	
1.593754	1.613813	1.640049	1.399674	0.975633	1.782324	0.541629	
1.637302	1.658784	1.687005	1.448439	1.015712	1.825624	0.560560	
1.051000	1.015702	0.867460	2.341896	1.052805	0.344856	0.0	0.0
1.107189	1.072636	0.955696	2.441916	1.135242	0.396407	0.0	0.0
1.241034	1.204863	1.102926	2.632244	1.254689	0.454525	0.0	0.0
1.298808	1.261772	1.163124	2.710859	1.300982	0.476003	0.0	0.0
1.345027	1.307299	1.211283	2.773749	1.338015	0.493185	0.0	0.0
1.475666	1.395194	1.044677	0.443416	0.0	0.0	0.0	0.0
1.579768	1.494761	1.127648	0.510321	0.0	0.0	0.0	0.0
1.724981	1.635491	1.247263	0.584128	0.0	0.0	0.0	0.0
1.782339	1.691002	1.293560	0.611331	0.0	0.0	0.0	0.0
1.828223	1.735410	1.330597	0.633094	0.0	0.0	0.0	0.0

GROUP 2 BLOCK 3 FLUXES

1.726815							
1.708811							
1.671354							
1.663657							
1.657499							
3.346049	3.454374						
3.087574	3.184965						
2.931379	3.033112						
2.893929	2.997887						
2.863967	2.969706						
3.575168	3.258404	1.621637					
3.352032	3.025277	1.626843					
3.217520	2.890824	1.614398					
3.186858	2.859220	1.613754					
3.162326	2.833935	1.613238					
3.160722	3.238148	3.011584	2.963405				
2.960114	3.035549	2.847067	2.821697				
2.850617	2.937820	2.769218	2.772141				
2.826015	2.917636	2.753516	2.765504				
2.806331	2.901486	2.740953	2.760193				
1.536087	2.993455	3.182757	2.684055	1.186722			
1.576957	2.867921	3.095038	2.603392	1.254342			
1.596327	2.819743	3.075492	2.590070	1.307154			
1.605340	2.812860	3.077915	2.592959	1.326259			
1.612548	2.807351	3.079852	2.595268	1.341543			
2.814771	3.055184	3.079554	2.585134	1.972850	1.407116		
2.760075	3.008428	3.061991	2.584166	1.970434	1.539503		
2.769342	3.032627	3.107790	2.642556	2.033338	1.702947		
2.779431	3.048449	3.130177	2.667787	2.058435	1.759106		
2.787501	3.061104	3.148085	2.687971	2.078510	1.804031		
2.749072	2.774181	2.824760	2.210340	1.418204	2.980495	0.773785	
2.785339	2.813830	2.851498	2.343127	1.570961	3.167836	0.897126	
2.869391	2.905450	2.958462	2.517356	1.747448	3.381455	1.012432	
2.902579	2.941193	2.999700	2.578045	1.807296	3.455592	1.051193	
2.929128	2.969784	3.032689	2.626562	1.855173	3.514899	1.082200	
2.025558	1.957917	1.671157	4.514534	2.026464	0.661110	0.0	0.0
2.153034	2.086633	1.861678	4.833469	2.243855	0.781081	0.0	0.0
2.319469	2.252994	2.073078	5.133616	2.447588	0.886707	0.0	0.0
2.376715	2.310143	2.144287	5.236332	2.515709	0.921843	0.0	0.0
2.422511	2.355860	2.201253	5.318500	2.570204	0.949952	0.0	0.0
2.835750	2.681467	2.006445	0.848428	0.0	0.0	0.0	0.0
3.115153	2.948135	2.222491	1.002954	0.0	0.0	0.0	0.0
3.351439	3.178499	2.424093	1.135997	0.0	0.0	0.0	0.0
3.429988	3.255278	2.491185	1.179990	0.0	0.0	0.0	0.0
3.492825	3.316698	2.544856	1.215184	0.0	0.0	0.0	0.0

GROUP 2 BLOCK 4 FLUXES

2.725430
2.736019
2.670475
2.651860
2.636965

5.287992 5.476582
4.950623 5.125051
4.689792 4.870154
4.618505 4.801817
4.561652 4.747144

5.647551 5.174050 2.589888
5.370183 4.874468 2.634319
5.140904 4.645857 2.606096
5.078640 4.583052 2.597702
5.028825 4.532805 2.590985

4.949224 5.079973 4.729597 4.612453
4.696447 4.825885 4.529250 4.445816
4.507342 4.653753 4.387279 4.347879
4.455663 4.608115 4.348600 4.323157
4.414317 4.571601 4.317654 4.303377

2.361940 4.604454 4.895222 4.114524 1.804752
2.451364 4.459367 4.811009 4.032864 1.926623
2.469786 4.362902 4.755809 3.991251 1.997099
2.475525 4.337556 4.743029 3.981766 2.019185
2.480114 4.317276 4.732801 3.974175 2.036853

4.252324 4.621407 4.661368 3.908577 2.972907 2.113400
4.208248 4.592313 4.676936 3.942845 2.996900 2.333384
4.198590 4.602800 4.719308 4.008853 3.075640 2.567405
4.198608 4.609961 4.735871 4.032419 3.102554 2.642887
4.198619 4.615687 4.749117 4.051269 3.124083 2.703271

4.119164 4.159047 4.238133 3.317092 2.127164 4.465670 1.158186
4.209752 4.254916 4.315159 3.546702 2.377170 4.789794 1.355357
4.311339 4.367572 4.450691 3.788418 2.629675 5.086522 1.522149
4.345012 4.404878 4.496050 3.865560 2.710149 5.180453 1.575257
4.371948 4.434719 4.532334 3.927270 2.774527 5.255595 1.617742

3.022360 2.922467 2.496406 6.749430 3.031606 0.988798 0.0 0.0
3.240053 3.141196 2.804841 7.289183 3.386594 1.178895 0.0 0.0
3.470259 3.371995 3.105598 7.699317 3.674549 1.331644 0.0 0.0
3.542805 3.444824 3.200665 7.825679 3.763841 1.379819 0.0 0.0
3.600840 3.503086 3.276716 7.926763 3.835272 1.418358 0.0 0.0

4.223038 3.994324 2.990391 1.265328 0.0 0.0 0.0 0.0
4.679451 4.429657 3.341100 1.508874 0.0 0.0 0.0 0.0
5.006598 4.749521 3.624530 1.700128 0.0 0.0 0.0 0.0
5.105629 4.846935 3.711806 1.759936 0.0 0.0 0.0 0.0
5.184851 4.924863 3.781623 1.807780 0.0 0.0 0.0 0.0

GROUP 2 BLOCK 5 FLUXES

3.892212
3.937934
3.843098
3.813751
3.790270

7.587765 7.943831
7.164920 7.519954
6.787184 7.151887
6.679687 7.047882
6.593685 6.964672

8.130277 7.604370 3.997069
7.797175 7.267641 4.161209
7.461118 6.938852 4.153797
7.364739 6.842602 4.151691
7.287631 6.765597 4.150003

7.030763 7.286702 6.875951 6.562710
6.721023 6.992834 6.670502 6.384296
6.442060 6.738395 6.460780 6.231821
6.361166 6.665193 6.397391 6.187242
6.296447 6.606627 6.346676 6.151575

3.264816 6.380444 6.790390 5.681102 2.458750
3.403849 6.209621 6.713778 5.593399 2.633877
3.419774 6.057814 6.615947 5.517325 2.720299
3.422207 6.012722 6.586713 5.494315 2.745153
3.424151 5.976644 6.563320 5.475902 2.765033

5.736260 6.247463 6.310116 5.282065 3.997748 2.830038
5.695204 6.227700 6.350628 5.344340 4.042139 3.133459
5.662458 6.220062 6.385033 5.413766 4.132995 3.434999
5.651913 6.218101 6.395284 5.435105 4.161071 3.529135
5.643473 6.216528 6.403479 5.452172 4.183529 3.604441

5.498574 5.556153 5.668227 4.438152 2.844125 5.964903 1.545841
5.636909 5.701320 5.788027 4.758413 3.187463 6.416283 1.814327
5.752923 5.831743 5.948396 5.063906 3.513144 6.789335 2.030451
5.786840 5.870335 5.997457 5.156942 3.613651 6.901493 2.097327
5.813969 5.901205 6.036702 5.231368 3.694054 6.991215 2.150827

4.014565 3.883720 3.321358 8.992239 4.042810 1.318689 0.0 0.0
4.316991 4.187034 3.742643 9.738290 4.528863 1.576728 0.0 0.0
4.607736 4.479045 4.129382 10.249391 4.896371 1.774761 0.0 0.0
4.695058 4.567015 4.247625 10.397548 5.005750 1.835486 0.0 0.0
4.764912 4.637389 4.342216 10.516066 5.093249 1.884065 0.0 0.0

5.599502 5.298093 3.969720 1.681745 0.0 0.0 0.0 0.0
6.223464 5.893033 4.448080 2.010947 0.0 0.0 0.0 0.0
6.635804 6.296894 4.808755 2.257932 0.0 0.0 0.0 0.0
6.754169 6.413799 4.915172 2.332913 0.0 0.0 0.0 0.0
6.848855 6.507318 5.000301 2.392897 0.0 0.0 0.0 0.0

GROUP 2 BLOCK 6 FLUXES

5.187528							
5.256816							
5.131679							
5.092102							
5.060437							
10.199213	10.951459						
9.636794	10.367773						
9.129760	9.863006						
8.984311	9.719996						
8.867946	9.605582						
11.026878	11.042186	10.610146					
10.550854	10.514643	10.069660					
10.089332	10.046019	9.603498					
9.956339	9.911549	9.462125					
9.849938	9.803966	9.349020					
9.372180	9.965320	9.946616	8.930713				
8.954622	9.549827	9.588996	8.663660				
8.574659	9.190950	9.273915	8.435578				
8.462961	9.087041	9.181383	8.368093				
8.373678	9.003906	9.107350	8.314099				
4.214361	8.277150	8.871003	7.349141	3.126616			
4.394492	8.050975	8.739305	7.227446	3.348650			
4.406364	7.836917	8.588386	7.110061	3.448982			
4.405604	7.771337	8.541414	7.072680	3.476374			
4.404997	7.718868	8.503830	7.042771	3.498285			
7.209822	7.872392	7.965964	6.654799	5.008638	3.529762		
7.163168	7.850241	8.016953	6.733890	5.066722	3.910194		
7.104787	7.821193	8.039274	6.802890	5.166432	4.274683		
7.083642	7.809973	8.042883	6.821558	5.195149	4.386380		
7.066721	7.800991	8.045764	6.836488	5.218119	4.475734		
6.836434	6.913834	7.061811	5.531354	3.541938	7.420699	1.921675	
7.015151	7.100333	7.215840	5.933417	3.971947	7.987387	2.257007	
7.142485	7.245123	7.397035	6.297487	4.366060	8.429346	2.519279	
7.176366	7.284649	7.449259	6.405376	4.485471	8.558141	2.599116	
7.203465	7.316264	7.491032	6.491682	4.580997	8.661171	2.662983	
4.966683	4.807138	4.115916	11.158905	5.021533	1.638012	0.0	0.0
5.346392	5.187613	4.641873	12.092477	5.628834	1.959862	0.0	0.0
5.692909	5.536068	5.108909	12.694579	6.069804	2.200319	0.0	0.0
5.794041	5.638196	5.248997	12.862636	6.197908	2.272871	0.0	0.0
5.874942	5.719894	5.361064	12.997073	6.300388	2.330911	0.0	0.0
6.915599	6.545669	4.908591	2.082040	0.0	0.0	0.0	0.0
7.693822	7.287514	5.504589	2.491202	0.0	0.0	0.0	0.0
8.184255	7.768437	5.936541	2.790237	0.0	0.0	0.0	0.0
8.320549	7.903429	6.060793	2.879487	0.0	0.0	0.0	0.0
8.429577	8.011416	6.160191	2.950886	0.0	0.0	0.0	0.0

GROUP 2 BLOCK 7 FLUXES

6.398207							
6.514411							
6.366114							
6.318285							
6.280017							
12.615576	13.634611						
11.963856	13.006883						
11.366879	12.398588						
11.168336	12.223975						
11.045491	12.084276						
13.665875	13.855335	13.616804					
13.147402	13.328398	13.158057					
12.585273	12.774716	12.664323					
12.421485	12.613194	12.518570					
12.290447	12.483967	12.401959					
11.521690	12.326902	12.409283	10.994153				
11.058623	11.894003	12.077197	10.732561				
10.593457	11.459821	11.706345	10.454279				
10.455311	11.351634	11.594531	10.369372				
10.344787	11.229076	11.505073	10.301439				
5.090078	10.014622	10.750062	8.870004	3.738298			
5.319377	9.765650	10.617647	8.742316	4.008359			
5.329393	9.498384	10.424569	8.590460	4.121902			
5.326218	9.414884	10.362665	8.540642	4.151774			
5.323674	9.348078	10.313134	8.500783	4.175668			
8.558984	9.360341	9.481149	7.910561	5.931904	4.167346		
8.510794	9.341687	9.549320	8.009944	6.003906	4.617798		
8.428752	9.293081	9.560764	8.078324	6.110978	5.038692		
8.398024	9.273567	9.558485	8.094608	6.140180	5.166191		
8.373436	9.257949	9.556654	8.107629	6.163537	5.268187		
8.051748	8.147840	8.329543	6.526386	4.176969	8.744734	2.263302	
8.266886	8.371857	8.514968	7.002844	4.685543	9.415055	2.658964	
8.403603	8.528782	8.714075	7.419090	5.140987	9.917675	2.962545	
8.437393	8.569090	8.769072	7.540313	5.277413	10.061204	3.054020	
8.464419	8.601330	8.813062	7.637286	5.386549	10.176020	3.127198	
5.827262	5.642211	4.835385	13.123931	5.910236	1.928036	0.0	0.0
6.275654	6.091355	5.455194	14.225113	6.626510	2.307423	0.0	0.0
6.671557	6.489834	5.993921	14.907076	7.132778	2.585861	0.0	0.0
6.785016	6.604605	6.153608	15.092727	7.277614	2.669035	0.0	0.0
6.875779	6.696417	6.281354	15.241238	7.393479	2.735573	0.0	0.0
8.102814	7.671561	5.756752	2.444187	0.0	0.0	0.0	0.0
9.017951	8.543851	6.457404	2.924948	0.0	0.0	0.0	0.0
9.577232	9.092766	6.952487	3.270420	0.0	0.0	0.0	0.0
9.729442	9.243824	7.092631	3.372452	0.0	0.0	0.0	0.0
9.851203	9.364663	7.204741	3.454075	0.0	0.0	0.0	0.0

GROUP 2 BLOCK 8 FLUXES

7.392887
7.557334
7.393321
7.339359
7.296185

14.584752 15.781399
13.911798 15.121267
13.210265 14.431531
13.005627 14.231752
12.841908 14.071919

15.794316 16.044674 15.796543
15.256715 15.502861 15.331605
14.618997 14.875904 14.772715
14.431358 14.691046 14.605738
14.281237 14.543150 14.472147

13.266660 14.205960 14.309885 12.626693
12.778125 13.758230 13.978983 12.365614
12.248160 13.264622 13.557559 12.047519
12.089187 13.117087 13.428549 11.948709
11.962000 12.999050 13.325331 11.869654

5.810943 11.436788 12.277060 10.111590 4.242741
6.085510 11.176834 12.151908 9.985046 4.554884
6.095708 10.868739 11.927732 9.807370 4.680240
6.090893 10.771076 11.854295 9.747838 4.712352
6.087038 10.692939 11.795536 9.700206 4.738038

9.679648 10.594352 10.735538 8.950971 6.698711 4.697648
9.634052 10.583392 10.823315 9.071236 6.784466 5.207470
9.533499 10.520038 10.827449 9.140362 6.898261 5.675601
9.495051 10.493952 10.820642 9.154928 6.927987 5.816314
9.464286 10.473075 10.815188 9.166575 6.951764 5.928881

9.062054 9.173500 9.383055 7.353494 4.705130 9.846380 2.547584
9.309021 9.430484 9.596686 7.893525 5.280047 10.604571 2.993851
9.453992 9.598010 9.811265 8.353635 5.786785 11.157948 3.331885
9.487816 9.639087 9.868695 8.486052 5.937426 11.313783 3.433062
9.514869 9.671943 9.914632 8.591979 6.057934 11.438443 3.514000

6.542023 6.335857 5.433185 14.757429 6.649407 2.169330 0.0 0.0
7.047790 6.842438 6.131496 15.999698 7.457230 2.596891 0.0 0.0
7.484783 7.282556 6.729923 16.748355 8.017977 2.906988 0.0 0.0
7.608503 7.407853 6.905931 16.948697 8.176764 2.999012 0.0 0.0
7.707473 7.508085 7.046732 17.108959 8.303788 3.072629 0.0 0.0

9.088287 8.606261 6.461119 2.745076 0.0 0.0 0.0 0.0
10.117053 9.586893 7.248835 3.285468 0.0 0.0 0.0 0.0
10.733408 10.192194 7.796323 3.669532 0.0 0.0 0.0 0.0
10.898823 10.356582 7.949663 3.782187 0.0 0.0 0.0 0.0
11.031147 10.488085 8.072328 3.872309 0.0 0.0 0.0 0.0

GROUP 2 BLOCK 9 FLUXES

8.111038							
8.311864							
8.137942							
8.079742							
8.033177							
16.001099	17.315269						
15.299887	16.630827						
14.539506	15.884022						
14.316280	15.666220						
14.137689	15.491967						
17.318045	17.595390	17.317123					
16.767007	17.039538	16.842263					
16.076849	16.360795	16.236663					
15.872235	16.159114	16.054206					
15.708533	15.997759	15.908230					
14.519259	15.545335	15.652009	13.787682				
14.012716	15.084752	15.317485	13.523967				
13.437702	14.549393	14.860045	13.177815				
13.263906	14.387979	14.718572	13.069006				
13.124859	14.258837	14.605384	12.981950				
6.332829	12.463652	13.376017	11.006845	4.608719			
6.640897	12.196434	13.256258	10.881325	4.951796			
6.652153	11.860251	13.011037	10.686163	5.086351			
6.646298	11.752546	12.929467	10.619782	5.120202			
6.641610	11.666374	12.864202	10.566670	5.147279			
10.497205	11.493526	11.648442	9.708521	7.258218	5.085209		
10.454687	11.489490	11.751814	9.845051	7.354721	5.638911		
10.341904	11.416821	11.752114	9.915946	7.474274	6.142221		
10.298037	11.386187	11.742266	9.929476	7.504534	6.292723		
10.262937	11.361672	11.734380	9.940294	7.528737	6.413120		
9.800531	9.923010	10.152680	7.957784	5.091207	10.652049	2.755540	
10.071388	10.204784	10.387732	8.544974	5.715071	11.475338	3.239043	
10.223363	10.381070	10.614691	9.038072	6.259944	12.066957	3.602612	
10.257379	10.422886	10.674087	9.178844	6.421104	12.231999	3.710954	
10.284583	10.456330	10.721597	9.291455	6.550027	12.364024	3.797625	
7.064512	6.842908	5.870187	15.951699	7.189978	2.345835	0.0	0.0
7.612361	7.391652	6.626129	17.298019	8.065244	2.808807	0.0	0.0
8.079986	7.862803	7.268796	18.096969	8.666599	3.142342	0.0	0.0
8.211311	7.995900	7.456848	18.308328	8.835735	3.240899	0.0	0.0
8.316364	8.102372	7.607285	18.477402	8.971038	3.319743	0.0	0.0
9.808539	9.289435	6.976005	2.965056	0.0	0.0	0.0	0.0
10.920320	10.349269	7.827451	3.549133	0.0	0.0	0.0	0.0
11.579119	10.996491	8.413819	3.961703	0.0	0.0	0.0	0.0
11.754312	11.170749	8.576909	4.082186	0.0	0.0	0.0	0.0
11.894459	11.310147	8.707375	4.178569	0.0	0.0	0.0	0.0

GROUP 2 BLOCK 10 FLUXES

8.525119							
8.747328							
8.569744							
8.509489							
8.461279							
16.816180	18.195626						
16.099112	17.497331						
15.308358	16.721424						
15.075055	16.493928						
14.888402	16.311920						
18.192098	18.481637	18.181303					
17.633370	17.917442	17.700180					
16.916734	17.212578	17.071192					
16.703037	17.001905	16.880497					
16.532067	16.833354	16.727928					
15.236656	16.310118	16.415046	14.447692				
14.719537	15.841583	16.077486	14.181424				
14.121510	15.285225	15.602229	13.821529				
13.939741	15.116412	15.454165	13.707460				
13.794316	14.981351	15.335703	13.616195				
6.631317	13.050133	14.002350	11.516753	4.817209			
6.958348	12.778247	13.884918	11.391103	5.177587			
6.971409	12.428102	13.629872	11.187676	5.318117			
6.965205	12.315067	13.544097	11.117735	5.353116			
6.960237	12.224630	13.475468	11.061773	5.381112			
10.963461	12.006243	12.168672	10.140048	7.576832	5.305814		
10.922134	12.005525	12.280259	10.285226	7.678949	5.884062		
10.803896	11.929233	12.280088	10.358513	7.802742	6.408093		
10.757245	11.896350	12.268860	10.371742	7.833509	6.564328		
10.719916	11.870034	12.259869	10.382317	7.858116	6.689312		
10.220301	10.349112	10.590328	8.301511	5.310852	11.110409	2.873837	
10.503920	10.644165	10.836757	8.914853	5.962110	11.969798	3.378254	
10.661125	10.826704	11.072056	9.427770	6.529376	12.584507	3.756724	
10.695507	10.869204	11.132844	9.573528	6.696682	12.755090	3.869237	
10.723006	10.903196	11.181467	9.690126	6.830522	12.891548	3.959245	
7.360723	7.130443	6.118167	16.630009	7.497261	2.446198	0.0	0.0
7.931632	7.702334	6.906165	18.033813	8.410152	2.929062	0.0	0.0
8.417438	8.191881	7.574668	18.863255	9.035505	3.276245	0.0	0.0
8.553251	8.329576	7.769725	19.081305	9.210740	3.378599	0.0	0.0
8.661896	8.439727	7.925765	19.255731	9.350922	3.460479	0.0	0.0
10.216374	9.676376	7.267808	3.089835	0.0	0.0	0.0	0.0
11.373866	10.779856	8.154484	3.698304	0.0	0.0	0.0	0.0
12.057774	11.451847	8.763674	4.127409	0.0	0.0	0.0	0.0
12.238751	11.631931	8.932477	4.252424	0.0	0.0	0.0	0.0
12.383523	11.775989	9.067513	4.352433	0.0	0.0	0.0	0.0

GROUP 2 BLOCK 11 FLUXES

8.623846							
8.852372							
8.678104							
8.618440							
8.570702							
17.009457	18.403195						
16.290621	17.703574						
15.499937	16.928612						
15.266049	16.700797						
15.078928	16.518533						
18.395884	18.686547	18.377556					
17.836993	18.122127	17.895778					
17.121834	17.418820	17.268563					
16.907966	17.208017	17.077846					
16.736859	17.039362	16.925260					
15.398622	16.481074	16.582390	14.588327				
14.879729	16.011134	16.243990	14.320796				
14.282314	15.456145	15.770610	13.962637				
14.100247	15.287267	15.622647	13.848716				
13.954583	15.152154	15.504265	13.757569				
6.693975	13.172645	14.131699	11.620058	4.857771			
7.024539	12.898848	14.013481	11.493046	5.220643			
7.040233	12.549753	13.760556	11.291109	5.363570			
7.034584	12.436672	13.675054	11.221326	5.399160			
7.030060	12.346199	13.606642	11.165491	5.427629			
11.051496	12.103771	12.267696	10.221390	7.635468	5.345471		
11.008375	12.101497	12.378603	10.366155	7.736893	5.926616		
10.891637	12.027343	12.381194	10.442127	7.862939	6.455325		
10.845167	11.994831	12.370518	10.455947	7.894233	6.612906		
10.807983	11.968812	12.361968	10.466995	7.919262	6.738966		
10.293672	10.423996	10.667870	8.362686	5.349865	11.191407	2.894641	
10.576888	10.718715	10.913619	8.978378	6.004433	12.053949	3.401814	
10.736996	10.904366	11.152413	9.496353	6.576636	12.674627	3.783407	
10.772028	10.947583	11.214051	9.643480	6.745354	12.846810	3.896839	
10.800047	10.982148	11.263353	9.761175	6.880324	12.984547	3.987582	
7.409917	7.178447	6.160110	16.746573	7.550719	2.463710	0.0	0.0
7.982327	7.751948	6.951533	18.155047	8.467782	2.949223	0.0	0.0
8.472386	8.245762	7.625456	18.992543	9.098591	3.299216	0.0	0.0
8.609340	8.384610	7.822055	19.212666	9.275329	3.402391	0.0	0.0
8.718896	8.495683	7.979329	19.388750	9.416712	3.484929	0.0	0.0
10.282660	9.739557	7.315974	3.110747	0.0	0.0	0.0	0.0
11.443954	10.846728	8.205874	3.722132	0.0	0.0	0.0	0.0
12.133573	11.524304	8.819983	4.154506	0.0	0.0	0.0	0.0
12.316041	11.705864	8.990133	4.280471	0.0	0.0	0.0	0.0
12.462007	11.851104	9.126247	4.381241	0.0	0.0	0.0	0.0

GROUP 2 BLOCK 12 FLUXES

8.407288								
8.627808								
8.464170								
8.408159								
8.363344								
16.581376	17.939003							
15.876217	17.252011							
15.116578	16.508597							
14.892311	16.290606							
14.712887	16.116202							
17.929733	18.212111	17.907263						
17.379605	17.656005	17.431525						
16.694420	16.982438	16.831642						
16.490059	16.781127	16.649837						
16.326559	16.620066	16.504381						
15.003541	16.056731	16.152606	14.206553					
14.492676	15.592927	15.816391	13.939658					
13.919887	15.062036	15.364863	13.598887					
13.745796	14.901055	15.224294	13.491019					
13.606513	14.772260	15.111829	13.404715					
6.517969	12.825776	13.758291	11.311296	4.727282				
6.836609	12.553153	13.636412	11.181820	5.077512				
6.855756	12.220244	13.397602	10.991124	5.219054				
6.851793	12.112837	13.317296	10.925562	5.254775				
6.848618	12.026903	13.253041	10.873104	5.263348				
10.752481	11.776860	11.936393	9.944689	7.427622	5.199213			
10.704256	11.767783	12.037279	10.079512	7.521620	5.760724			
10.595836	11.701337	12.045588	10.158134	7.647571	6.277316			
10.552796	11.672117	12.037682	10.173645	7.679529	6.431803			
10.518356	11.648733	12.031349	10.186046	7.705091	6.555388			
10.010393	10.137443	10.375097	8.133389	5.203116	10.884099	2.815078		
10.279205	10.417364	10.607301	8.726537	5.835929	11.715251	3.306127		
10.439439	10.602500	10.844182	9.233977	6.394805	12.323686	3.678534		
10.475577	10.646632	10.906274	9.378875	6.560136	12.493543	3.789566		
10.504479	10.681930	10.955940	9.494787	6.692397	12.629419	3.878390		
7.203973	6.979129	5.989483	16.284128	7.342720	2.395883	0.0	0.0	
7.755213	7.531601	6.754428	17.641821	8.229023	2.866119	0.0	0.0	
8.234797	8.014754	7.412370	18.463405	8.845762	3.207596	0.0	0.0	
8.369534	8.151296	7.604956	18.681050	9.019355	3.308557	0.0	0.0	
8.477318	8.260524	7.759020	18.855153	9.158223	3.389324	0.0	0.0	
9.995754	9.468027	7.112407	3.024433	0.0	0.0	0.0	0.0	
11.116884	10.536976	7.971989	3.616336	0.0	0.0	0.0	0.0	
11.791660	11.199825	8.572137	4.038091	0.0	0.0	0.0	0.0	
11.971317	11.378491	8.739213	4.161344	0.0	0.0	0.0	0.0	
12.115034	11.521415	8.872867	4.259944	0.0	0.0	0.0	0.0	

GROUP 2 BLOCK 13 FLUXES

7.885798							
8.085146							
7.939334							
7.890275							
7.851022							
15.552305	16.825064						
14.876983	16.165475						
14.178511	15.483372						
13.974312	15.285636						
13.810942	15.127437						
16.815173	17.079282	16.791451					
16.283676	16.541817	16.329255					
15.656178	15.925372	15.781492					
15.471302	15.743473	15.617814					
15.323390	15.597943	15.486861					
14.068199	15.054880	15.143165	13.316726				
13.575754	14.605410	14.812845	13.052902				
13.050895	14.120651	14.402477	12.744593				
12.893261	13.975768	14.276842	12.648885				
12.767146	13.859852	14.176324	12.572309				
6.109336	12.021380	12.894673	10.600338	4.429406			
6.401244	11.753391	12.766775	10.467630	4.752265			
6.424555	11.451240	12.553549	10.297465	4.888574			
6.423557	11.355388	12.483559	10.20330	4.924068			
6.422754	11.276699	12.427558	10.194614	4.952460			
10.073854	11.033877	11.183343	9.316932	6.958149	4.870197		
10.017399	11.012996	11.265200	9.432557	7.038131	5.389900		
9.923681	10.959389	11.281780	9.513472	7.161403	5.877607		
9.887447	10.936539	11.279031	9.531917	7.194265	6.024702		
9.858453	10.918252	11.276824	9.546666	7.220549	6.142373		
9.376042	9.495205	9.718057	7.618427	4.873655	10.194751	2.636743	
9.616649	9.746074	9.924041	8.164538	5.460029	10.960437	3.093061	
9.773919	9.926760	10.153302	8.645724	5.987353	11.538199	3.444009	
9.811759	9.972152	10.215608	8.784965	6.144646	11.701986	3.549409	
9.842024	10.008459	10.265445	8.896352	6.270476	11.833007	3.633726	
6.746369	6.535910	5.609337	15.251354	6.877308	2.244045	0.0	0.0
7.254005	7.044959	6.318268	16.503464	7.698377	2.681330	0.0	0.0
7.708273	7.502423	6.938843	17.284785	8.281455	3.003004	0.0	0.0
7.837578	7.633338	7.122022	17.495659	8.447413	3.098789	0.0	0.0
7.941016	7.738064	7.268560	17.664347	8.580174	3.175414	0.0	0.0
9.360204	8.866152	6.660492	2.832394	0.0	0.0	0.0	0.0
10.397615	9.855364	7.456547	3.382676	0.0	0.0	0.0	0.0
11.036800	10.482997	8.023759	3.779949	0.0	0.0	0.0	0.0
11.209513	10.654562	8.183479	3.896913	0.0	0.0	0.0	0.0
11.347676	10.791806	8.311249	3.990481	0.0	0.0	0.0	0.0

GROUP 2 BLOCK 14 FLUXES

7.079712							
7.246265							
7.124963							
7.086106							
7.055016							
13.962243	15.104537						
13.333035	14.487408						
12.723744	13.894279						
12.549648	13.726844						
12.410361	13.592887						
15.095013	15.331709	15.072271					
14.592598	14.823467	14.631749					
14.048526	14.289560	14.159068					
13.892749	14.136631	14.022397					
13.768117	14.014278	13.913050					
12.627620	13.512802	13.591175	11.950866				
12.164251	13.086309	13.271137	11.693132				
11.708935	12.668078	12.919742	11.431135				
11.575906	12.547187	12.816302	11.353462				
11.459475	12.450465	12.733540	11.291315				
5.482539	10.787858	11.571144	9.511811	3.974179			
5.734177	10.528381	11.435666	9.375651	4.256013			
5.762180	10.270381	11.258469	9.234451	4.383313			
5.765424	10.191726	11.203726	9.189778	4.418273			
5.768014	10.128795	11.159924	9.154033	4.446237			
9.037958	9.899413	10.033508	8.358817	6.242303	4.368966		
8.970722	9.862454	10.088298	8.446879	6.302294	4.626115		
8.897389	9.826161	10.115180	8.529417	6.420178	5.268898		
8.871199	9.812643	10.119897	8.552005	6.454181	5.404549		
8.850241	9.801822	10.123663	8.570069	6.481380	5.513065		
8.410576	8.517555	8.717600	6.834192	4.371961	9.145236	2.365281	
8.610253	8.726223	8.885709	7.310323	4.888778	9.813612	2.769400	
8.761288	8.898384	9.101589	7.750184	5.367133	10.342831	3.087174	
8.801421	8.945388	9.163902	7.880546	5.512000	10.497006	3.183884	
8.833521	8.982984	9.213747	7.984830	5.627890	10.620338	3.261250	
6.051123	5.862409	5.031436	13.680495	6.169118	2.012981	0.0	0.0
6.494147	6.307060	5.656625	14.775702	6.892620	2.400707	0.0	0.0
6.908786	6.724350	6.219376	15.493064	7.423211	2.691809	0.0	0.0
7.029623	6.846502	6.388053	15.693107	7.577288	2.779617	0.0	0.0
7.126288	6.944219	6.522990	15.853130	7.700544	2.849861	0.0	0.0
8.395278	7.952222	5.974040	2.540548	0.0	0.0	0.0	0.0
9.308037	8.822681	6.675354	3.028374	0.0	0.0	0.0	0.0
9.891573	9.395311	7.191380	3.387920	0.0	0.0	0.0	0.0
10.053431	9.555790	7.339687	3.495209	0.0	0.0	0.0	0.0
10.182910	9.684167	7.458328	3.581038	0.0	0.0	0.0	0.0

GROUP 2 BLOCK 15 FLUXES

6.018895							
6.142962							
6.051990							
6.026220							
6.005600							
11.869995	12.840936						
11.302761	12.281131						
10.807389	11.801371						
10.672326	11.673168						
10.564268	11.570598						
12.832509	13.033518	12.812423					
12.369906	12.565352	12.402165					
11.931927	12.136344	12.024723					
11.813790	12.020872	11.922929					
11.719271	11.928487	11.841485					
10.734216	11.486434	11.552609	10.157814				
10.310568	11.091817	11.247912	9.909827				
9.943812	10.758006	10.971048	9.706170				
9.842614	10.668096	10.896212	9.651698				
9.761648	10.596160	10.836335	9.608115				
4.659882	9.169051	9.834601	8.084096	3.377492			
4.859562	8.922406	9.691030	7.944988	3.606324			
4.892539	8.720208	9.558820	7.839957	3.721033			
4.901115	8.663713	9.523633	7.811262	3.755115			
4.907973	8.618511	9.495477	7.788300	3.782379			
7.680662	8.412822	8.526793	7.103534	5.304773	3.712736		
7.600975	8.356625	8.547974	7.157064	5.339789	4.088939		
7.552761	8.341254	8.586542	7.240227	5.449515	4.472083		
7.539405	8.339597	8.600655	7.267910	5.484756	4.592526		
7.528715	8.338266	8.611939	7.290051	5.512945	4.688878		
7.146874	7.237829	7.407909	5.807527	3.715219	7.771507	2.009990	
7.294693	7.392987	7.528182	6.193525	4.141943	8.314438	2.346328	
7.436135	7.552528	7.725041	6.578016	4.555363	8.778419	2.620203	
7.478945	7.601308	7.787014	6.696444	4.683739	8.919556	2.705397	
7.513188	7.640327	7.836588	6.791183	4.786436	9.032458	2.773550	
5.141693	4.981375	4.275360	11.624982	5.242322	1.710590	0.0	0.0
5.501529	5.343069	4.792128	12.517825	5.839498	2.033928	0.0	0.0
5.863290	5.706789	5.278299	13.149009	6.300222	2.284604	0.0	0.0
5.972789	5.817218	5.427751	13.334226	6.438424	2.361848	0.0	0.0
6.060384	5.905558	5.547309	13.482391	6.548981	2.423642	0.0	0.0
7.133432	6.757012	5.076227	2.158783	0.0	0.0	0.0	0.0
7.885108	7.473988	5.654991	2.565521	0.0	0.0	0.0	0.0
8.394379	7.973259	6.102969	2.875213	0.0	0.0	0.0	0.0
8.541644	8.118857	6.236046	2.969698	0.0	0.0	0.0	0.0
8.659449	8.235330	6.342503	3.045283	0.0	0.0	0.0	0.0

GROUP 2 BLOCK 16 FLUXES

4.741911							
4.816104							
4.760094							
4.749665							
4.741319							
9.351553	10.116386						
8.861257	9.628128						
8.500201	9.281795						
8.411400	9.200026						
8.340354	9.134604						
10.109586	10.267824	10.093366					
9.697511	9.850551	9.722215					
9.384215	9.544762	9.456460					
9.310586	9.473564	9.395840					
9.251677	9.416598	9.347336					
8.456205	9.048661	9.100568	8.001606				
8.082647	8.694883	8.816891	7.767675				
7.820050	8.460095	8.627163	7.632029				
7.756495	8.406751	8.586019	7.604826				
7.705645	8.364070	8.553097	7.583058				
3.670699	7.222642	7.746815	6.367867	2.660441			
3.809098	6.993600	7.595867	6.227165	2.826483			
3.847028	6.856610	7.515708	6.163953	2.925309			
3.861698	6.826196	7.503411	6.153941	2.958071			
3.873432	6.801860	7.493568	6.145928	2.984279			
6.049766	6.626491	6.716296	5.595312	4.178579	2.924650		
5.957084	6.549310	6.699222	5.609126	4.184913	3.204621		
5.937555	6.557413	6.750093	5.691544	4.283670	3.515178		
5.939127	6.569461	6.774914	5.724829	4.319965	3.616954		
5.940381	6.579094	6.794767	5.751452	4.348999	3.698373		
5.629113	5.700788	5.834866	4.574482	2.926554	6.122118	1.583474	
5.716512	5.793540	5.899522	4.853706	3.246054	6.516269	1.838924	
5.844983	5.936428	6.071943	5.170318	3.580513	6.899800	2.059451	
5.890492	5.986805	6.132928	5.273878	3.688672	7.024424	2.130540	
5.926894	6.027102	6.181712	5.356722	3.775197	7.124118	2.187410	
4.049804	3.923565	3.367577	9.157077	4.129634	1.347593	0.0	0.0
4.311112	4.186951	3.755279	9.809688	4.576381	1.594043	0.0	0.0
4.608218	4.485192	4.148399	10.334337	4.951711	1.795626	0.0	0.0
4.703642	4.581086	4.274308	10.500553	5.070234	1.859944	0.0	0.0
4.779978	4.657798	4.375033	10.633518	5.165049	1.911397	0.0	0.0
5.618799	5.322355	3.998563	1.700556	0.0	0.0	0.0	0.0
6.178918	5.856781	4.431445	2.010477	0.0	0.0	0.0	0.0
6.597220	6.266226	4.796321	2.259639	0.0	0.0	0.0	0.0
6.726240	6.393251	4.910533	2.338460	0.0	0.0	0.0	0.0
6.829451	6.494866	5.001899	2.401515	0.0	0.0	0.0	0.0

GROUP 2 BLOCK 17 FLUXES

3.294952
3.314477
3.296544
3.302872
3.307932

6.498171 7.029491
6.098258 6.625690
5.886554 6.427465
5.849095 6.397149
5.819125 6.372892

7.024652 7.134471 7.013050
6.673226 6.778250 6.689524
6.498148 6.608961 6.547274
6.473791 6.586747 6.532137
6.454301 6.568971 6.520023

5.875751 6.287284 6.323153 5.559572
5.561965 5.982957 6.066448 5.344455
5.414922 5.857740 5.972812 5.283621
5.393042 5.844788 5.968793 5.286388
5.375534 5.834422 5.965574 5.288597

2.550398 5.018431 5.382495 4.424483 1.848554
2.620995 4.812101 5.226055 4.284368 1.944621
2.663498 4.747019 5.202733 4.266774 2.024646
2.684592 4.745316 5.215469 4.277166 2.055513
2.701465 4.743950 5.225655 4.285476 2.080206

4.203390 4.604044 4.666429 3.887844 2.903954 2.033185
4.098440 4.505657 4.608453 3.858687 2.879297 2.205252
4.109830 4.538585 4.671344 3.938566 2.964183 2.432160
4.127588 4.565359 4.707450 3.977425 3.000981 2.512034
4.141792 4.586776 4.736332 4.008509 3.030417 2.575931

3.911092 3.960910 4.054355 3.179163 2.034430 4.257956 1.101855
3.932171 3.985022 4.057910 3.338946 2.233522 4.484905 1.266039
4.044327 4.107324 4.200653 3.576738 2.477054 4.773300 1.424770
4.092130 4.158710 4.259600 3.662513 2.561535 4.877282 1.479179
4.130370 4.199816 4.306755 3.731131 2.629117 4.960464 1.522705

2.814392 2.726721 2.340709 6.367245 2.872305 0.937709 0.0 0.0
2.965566 2.880130 2.583362 6.749479 3.149536 1.097394 0.0 0.0
3.187872 3.102613 2.869384 7.147654 3.425167 1.242188 0.0 0.0
3.266563 3.181243 2.967745 7.289623 3.519945 1.291253 0.0 0.0
3.329514 3.244145 3.046432 7.403193 3.595765 1.330504 0.0 0.0

3.906357 3.700834 2.780816 1.183110 0.0 0.0 0.0 0.0
4.251440 4.029808 3.049393 1.383750 0.0 0.0 0.0 0.0
4.563378 4.334269 3.317397 1.562875 0.0 0.0 0.0 0.0
4.670118 4.438680 3.408881 1.623196 0.0 0.0 0.0 0.0
4.755507 4.522206 3.482066 1.671452 0.0 0.0 0.0 0.0

GROUP 2 BLOCK 18 FLUXES

1.753069							
1.762882							
1.846284							
1.899188							
1.941509							
3.452451	3.733197						
3.225063	3.499512						
3.263979	3.557355						
3.323613	3.627983						
3.371317	3.684482						
3.730089	3.787999	3.723178					
3.522848	3.577397	3.529750					
3.593961	3.654092	3.618886					
3.668681	3.731545	3.699408					
3.728454	3.793505	3.763822					
3.121393	3.338792	3.357068	2.952098				
2.940569	3.159404	3.201326	2.821596				
3.001316	3.241285	3.301756	2.922542				
3.063252	3.313922	3.380782	2.996131				
3.112800	3.372030	3.444001	3.054999				
1.356846	2.666090	2.857868	2.350154	0.983291			
1.393789	2.544355	2.758083	2.263924	1.032817			
1.491292	2.631245	2.876135	2.362902	1.131120			
1.543157	2.695453	2.954071	2.427121	1.178596			
1.584649	2.746819	3.016418	2.478494	1.216576			
2.233253	2.444860	2.477131	2.064377	1.543280	1.082732		
2.167094	2.378557	2.429712	2.034879	1.519405	1.161206		
2.277798	2.509626	2.578203	2.173732	1.635103	1.328120		
2.344074	2.586370	2.661474	2.248390	1.694414	1.399056		
2.397093	2.647762	2.728089	2.308114	1.741862	1.455804		
2.076410	2.102530	2.152132	1.689670	1.083113	2.268605	0.590364	
2.072982	2.099578	2.135212	1.756027	1.175328	2.325578	0.659597	
2.231383	2.264050	2.308752	1.957218	1.351751	2.512143	0.750095	
2.312506	2.347793	2.396144	2.047476	1.425816	2.592064	0.784729	
2.377402	2.414786	2.466056	2.119680	1.485067	2.655999	0.812435	
1.495869	1.449289	1.245594	3.388788	1.532265	0.502440	0.0	0.0
1.560780	1.515493	1.358190	3.494489	1.634744	0.571726	0.0	0.0
1.746797	1.699469	1.564296	3.757165	1.802225	0.654057	0.0	0.0
1.829017	1.780562	1.650319	3.870223	1.869195	0.685178	0.0	0.0
1.894791	1.845434	1.719136	3.960666	1.922770	0.710075	0.0	0.0
2.080448	1.970823	1.482549	0.633603	0.0	0.0	0.0	0.0
2.203465	2.088481	1.582153	0.720433	0.0	0.0	0.0	0.0
2.401030	2.280134	1.745789	0.822474	0.0	0.0	0.0	0.0
2.481501	2.358079	1.810942	0.860905	0.0	0.0	0.0	0.0
2.545877	2.420433	1.863063	0.891649	0.0	0.0	0.0	0.0

GROUP 2 BLOCK 19 FLUXES

3.621994							
3.977359							
4.041360							
4.067709							
4.088784							
4.210581	4.448545						
4.575986	4.838931						
4.697730	4.983622						
4.756288	5.051651						
4.803132	5.106071						
4.426973	4.489504	4.409653					
4.844286	4.914110	4.845202					
5.005800	5.084412	5.031638					
5.078614	5.160401	5.112116					
5.136862	5.221188	5.176495					
3.794157	3.975772	3.978182	3.511908				
4.159347	4.365503	4.396701	3.894506				
4.307427	4.537542	4.593103	4.086901				
4.371609	4.611101	4.674244	4.164396				
4.422951	4.669944	4.739152	4.226389				
2.803161	3.251260	3.390260	2.849988	2.004195			
3.144140	3.609522	3.790672	3.194114	2.297378			
3.263493	3.785939	4.003273	3.381786	2.439185			
3.304265	3.856102	4.086401	3.453850	2.485879			
3.336879	3.912229	4.152900	3.511500	2.523234			
2.734099	2.910647	2.914022	2.427630	1.719770	1.100976		
3.084716	3.284568	3.309741	2.771531	1.981289	1.303061		
3.286314	3.509496	3.554855	2.995543	2.167299	1.464449		
3.361933	3.594301	3.646279	3.078074	2.234602	1.521361		
3.422427	3.662142	3.719416	3.144097	2.288443	1.566890		
2.443768	2.456901	2.311972	1.760193	1.101726	0.514145	0.128161	
2.822860	2.838158	2.674956	2.070547	1.317822	0.651562	0.167229	
3.074233	3.095852	2.938253	2.303464	1.488862	0.769865	0.201248	
3.165219	3.189121	3.033758	2.386322	1.548724	0.815073	0.214171	
3.238006	3.263734	3.110160	2.452606	1.596613	0.851239	0.224509	
1.575232	1.524510	1.258852	0.761922	0.342616	0.109344	0.0	0.0
1.862487	1.806882	1.513185	0.971634	0.443067	0.145233	0.0	0.0
2.080661	2.022818	1.712866	1.144387	0.527981	0.175907	0.0	0.0
2.157725	2.098975	1.782446	1.210321	0.560211	0.187497	0.0	0.0
2.219374	2.159900	1.838109	1.263067	0.585994	0.196769	0.0	0.0
0.463285	0.438905	0.332752	0.137672	0.0	0.0	0.0	0.0
0.598613	0.567640	0.432050	0.182745	0.0	0.0	0.0	0.0
0.708914	0.673566	0.516357	0.220832	0.0	0.0	0.0	0.0
0.750904	0.713920	0.548296	0.235190	0.0	0.0	0.0	0.0
0.784495	0.746203	0.573847	0.246677	0.0	0.0	0.0	0.0

BLOCK 1 POWER

0.066025							
0.080852							
0.087805							
0.089869							
0.091519							
0.256414	0.270147						
0.263725	0.279365						
0.260444	0.277461						
0.260174	0.277679						
0.259957	0.277853						
0.281675	0.249987	0.062082					
0.299018	0.259032	0.077290					
0.301181	0.257663	0.085338					
0.302571	0.257952	0.087785					
0.303683	0.258183	0.089742					
0.244454	0.255633	0.233051	0.235570				
0.255810	0.269613	0.246731	0.252955				
0.256579	0.272701	0.250484	0.260117				
0.257505	0.274431	0.252342	0.263087				
0.258245	0.275816	0.253829	0.265464				
0.059989	0.234447	0.255965	0.211091	0.046064			
0.076729	0.252122	0.283686	0.230057	0.060663			
0.086615	0.259031	0.297090	0.239228	0.070445			
0.089698	0.261893	0.302029	0.242740	0.073578			
0.092164	0.264183	0.305979	0.245550	0.076085			
0.222972	0.247543	0.248586	0.207090	0.141256	0.097284		
0.246293	0.277392	0.282293	0.235064	0.159143	0.114083		
0.258602	0.294405	0.302386	0.252642	0.171733	0.127283		
0.263450	0.300571	0.309517	0.258871	0.176214	0.131822		
0.267168	0.305504	0.315221	0.263855	0.179798	0.135453		
0.223605	0.224202	0.209832	0.159176	0.099711	0.046798	0.011725	
0.259060	0.259876	0.243768	0.187952	0.119595	0.059436	0.015342	
0.281739	0.283225	0.267722	0.209048	0.134966	0.070138	0.018449	
0.289648	0.291368	0.276106	0.216310	0.140189	0.074153	0.019609	
0.295975	0.297882	0.282814	0.222120	0.144368	0.077365	0.020538	
0.148330	0.143193	0.117527	0.070563	0.031534	0.010055	0.0	0.0
0.176289	0.170639	0.142103	0.090560	0.041004	0.013420	0.0	0.0
0.196989	0.191111	0.160975	0.106779	0.048900	0.016263	0.0	0.0
0.204104	0.198138	0.167384	0.112854	0.051843	0.017319	0.0	0.0
0.209796	0.203759	0.172512	0.117714	0.054198	0.018164	0.0	0.0
0.044072	0.041670	0.031439	0.012919	0.0	0.0	0.0	0.0
0.057330	0.054266	0.041122	0.017287	0.0	0.0	0.0	0.0
0.067957	0.064460	0.049210	0.020925	0.0	0.0	0.0	0.0
0.071938	0.068281	0.052226	0.022275	0.0	0.0	0.0	0.0
0.075122	0.071338	0.054638	0.023355	0.0	0.0	0.0	0.0

BLOCK 2 POWER

0.115258
0.110677
0.110762
0.112097
0.113165

0.225681 0.232996
0.205383 0.212195
0.202496 0.210151
0.204153 0.212210
0.205478 0.213857

0.241730 0.219828 0.108305
0.224314 0.201417 0.105568
0.224346 0.199980 0.107315
0.227154 0.202039 0.109117
0.229399 0.203685 0.110559

0.214563 0.220012 0.204729 0.202448
0.198393 0.203967 0.191230 0.190797
0.198605 0.205543 0.193519 0.195343
0.201148 0.208654 0.196655 0.199259
0.203182 0.211142 0.199164 0.202391

0.104252 0.205374 0.218765 0.184602 0.081079
0.104099 0.194565 0.211066 0.177108 0.083333
0.108066 0.199160 0.219052 0.183492 0.089036
0.110593 0.203094 0.224314 0.187799 0.091926
0.112615 0.206241 0.228523 0.191244 0.094239

0.195092 0.211845 0.213542 0.179305 0.136906 0.098140
0.189350 0.206977 0.210803 0.177690 0.134932 0.105858
0.197971 0.217901 0.223597 0.189625 0.144623 0.121021
0.203182 0.224135 0.230491 0.195838 0.149535 0.127336
0.207351 0.229122 0.236007 0.200808 0.153465 0.132388

0.191793 0.193483 0.196935 0.154227 0.099094 0.208462 0.054446
0.192989 0.194860 0.197177 0.161847 0.108473 0.215603 0.061381
0.207808 0.210276 0.213483 0.180727 0.124947 0.233307 0.069925
0.215157 0.217865 0.221407 0.188956 0.131710 0.240614 0.073120
0.221036 0.223936 0.227746 0.195539 0.137121 0.246459 0.075676

0.141885 0.137120 0.117107 0.316156 0.142129 0.046556 0.0 0.0
0.149471 0.144806 0.129019 0.329659 0.153258 0.053515 0.0 0.0
0.167540 0.162656 0.148895 0.355353 0.169383 0.061361 0.0 0.0
0.175339 0.170339 0.157022 0.365966 0.175633 0.064260 0.0 0.0
0.181579 0.176485 0.163523 0.374456 0.180632 0.066580 0.0 0.0

0.199215 0.188351 0.141031 0.059861 0.0 0.0 0.0 0.0
0.213269 0.201793 0.152232 0.068893 0.0 0.0 0.0 0.0
0.232872 0.220791 0.168360 0.078857 0.0 0.0 0.0 0.0
0.240616 0.228285 0.174631 0.082530 0.0 0.0 0.0 0.0
0.246810 0.234280 0.179631 0.085468 0.0 0.0 0.0 0.0

BLOCK 3 POWER

0.233120
0.230690
0.225633
0.224594
0.223762

0.451717 0.466340
0.416822 0.429970
0.395736 0.409470
0.390680 0.404715
0.386636 0.400910

0.482648 0.439884 0.218921
0.452524 0.408412 0.219624
0.434365 0.390261 0.217944
0.430226 0.385995 0.217857
0.426914 0.382581 0.217787

0.426697 0.437150 0.406564 0.400060
0.399615 0.409799 0.384354 0.380929
0.384833 0.396606 0.373844 0.374239
0.381512 0.393881 0.371725 0.373343
0.378855 0.391701 0.370029 0.372626

0.207372 0.404116 0.429672 0.362347 0.160207
0.212889 0.387169 0.417830 0.351458 0.169336
0.215504 0.380665 0.415191 0.349659 0.176466
0.216721 0.379736 0.415519 0.350049 0.179045
0.217694 0.378992 0.415780 0.350361 0.181108

0.379994 0.412450 0.415740 0.348993 0.266335 0.189961
0.372610 0.406138 0.413369 0.348862 0.266009 0.207833
0.373861 0.409405 0.419552 0.356745 0.274501 0.229898
0.375223 0.411541 0.422574 0.360151 0.277889 0.237479
0.376313 0.413249 0.424991 0.362876 0.280599 0.243544

0.371125 0.374514 0.381343 0.298396 0.191458 0.402367 0.104461
0.375021 0.379867 0.384952 0.316322 0.212080 0.427658 0.121112
0.387368 0.392236 0.399392 0.339848 0.235905 0.456496 0.136678
0.391848 0.397061 0.404960 0.348036 0.243985 0.466505 0.141911
0.395432 0.400921 0.409413 0.354586 0.250448 0.474511 0.146097

0.273450 0.264319 0.225606 0.609462 0.273573 0.089250 0.0 0.0
0.290660 0.281695 0.251326 0.652518 0.302920 0.105446 0.0 0.0
0.313128 0.304154 0.279866 0.693038 0.330424 0.119705 0.0 0.0
0.320857 0.311869 0.289479 0.706905 0.339621 0.124449 0.0 0.0
0.327039 0.318041 0.297169 0.717998 0.346978 0.128243 0.0 0.0

0.382826 0.361998 0.270870 0.114538 0.0 0.0 0.0 0.0
0.420546 0.397998 0.300036 0.135399 0.0 0.0 0.0 0.0
0.452444 0.429097 0.327253 0.153360 0.0 0.0 0.0 0.0
0.463048 0.439462 0.336310 0.159299 0.0 0.0 0.0 0.0
0.471531 0.447754 0.343556 0.164050 0.0 0.0 0.0 0.0

BLOCK 4 POWER

0.367933
0.369362
0.360514
0.358001
0.355990

0.713879 0.739338
0.668334 0.691882
0.633122 0.657471
0.623512 0.648245
0.615823 0.640864

0.762419 0.698497 0.349635
0.724975 0.658053 0.355633
0.694022 0.627191 0.351823
0.685616 0.618712 0.350690
0.678891 0.611929 0.349783

0.668145 0.685796 0.638496 0.622681
0.634020 0.651494 0.611449 0.600185
0.608491 0.628257 0.592283 0.586964
0.601514 0.622096 0.587061 0.583626
0.595933 0.617166 0.582883 0.580956

0.318862 0.621601 0.660855 0.555461 0.243642
0.330934 0.602015 0.649486 0.544437 0.260094
0.333421 0.588992 0.642034 0.538819 0.269608
0.334196 0.585570 0.640309 0.537538 0.272590
0.334815 0.582832 0.638928 0.536514 0.274975

0.574064 0.623890 0.629285 0.527658 0.401342 0.285309
0.568113 0.619962 0.631386 0.532284 0.404582 0.315007
0.566810 0.621378 0.637107 0.541195 0.415211 0.346600
0.566812 0.622345 0.639342 0.544376 0.418845 0.356790
0.566813 0.623118 0.641131 0.546921 0.421751 0.364942

0.556087 0.561471 0.572148 0.447807 0.287167 0.602865 0.156355
0.568316 0.574414 0.582546 0.478805 0.320918 0.646622 0.182973
0.582031 0.589622 0.600843 0.511436 0.355006 0.686680 0.205490
0.586577 0.594658 0.606967 0.521851 0.365870 0.699361 0.212660
0.590213 0.598687 0.611865 0.530181 0.374561 0.709505 0.218395

0.408019 0.394533 0.337015 0.911173 0.409267 0.133488 0.0 0.0
0.437407 0.424061 0.378653 0.984040 0.457190 0.159151 0.0 0.0
0.468485 0.455219 0.419256 1.039408 0.496064 0.179772 0.0 0.0
0.478279 0.465051 0.432090 1.056467 0.508119 0.186276 0.0 0.0
0.486113 0.472917 0.442357 1.070113 0.517762 0.191478 0.0 0.0

0.570110 0.539234 0.403703 0.170819 0.0 0.0 0.0 0.0
0.631726 0.598004 0.451049 0.203698 0.0 0.0 0.0 0.0
0.675891 0.641185 0.489312 0.229517 0.0 0.0 0.0 0.0
0.689260 0.654336 0.501094 0.237591 0.0 0.0 0.0 0.0
0.699955 0.664856 0.510519 0.244050 0.0 0.0 0.0 0.0

BLOCK 5 POWER

0.525449							
0.531621							
0.518818							
0.514856							
0.511686							
1.024348	1.072417						
0.967264	1.015194						
0.916270	0.965505						
0.901758	0.951464						
0.890147	0.940231						
1.097587	1.026590	0.539604					
1.052619	0.981132	0.561763					
1.007251	0.936745	0.560763					
0.994240	0.923751	0.560478					
0.983830	0.913356	0.560250					
0.949153	0.983705	0.928253	0.885966				
0.907338	0.944032	0.900518	0.861830				
0.869678	0.909683	0.872205	0.841296				
0.858757	0.899801	0.863648	0.835278				
0.850020	0.891895	0.856801	0.830463				
0.440750	0.861360	0.917783	0.766949	0.331931			
0.459520	0.838299	0.906360	0.755109	0.355573			
0.461669	0.817805	0.893153	0.744839	0.367240			
0.461998	0.811717	0.889206	0.741732	0.370596			
0.462260	0.806847	0.886048	0.739247	0.373279			
0.774395	0.843407	0.851866	0.713079	0.539696	0.382055		
0.768852	0.840740	0.857335	0.721486	0.545689	0.423017		
0.764432	0.839708	0.861979	0.730858	0.557954	0.463725		
0.763008	0.839444	0.863363	0.733739	0.561745	0.476433		
0.761869	0.839231	0.864470	0.736043	0.564776	0.486600		
0.742307	0.750081	0.765211	0.599151	0.383957	0.805262	0.208689	
0.760983	0.769678	0.781384	0.642386	0.430307	0.866198	0.244934	
0.776645	0.787285	0.803033	0.683527	0.474274	0.916560	0.274111	
0.781223	0.792495	0.809657	0.696187	0.487843	0.931702	0.283139	
0.784886	0.796663	0.814955	0.706235	0.498697	0.943814	0.290362	
0.541966	0.524302	0.448383	1.213952	0.545779	0.178023	0.0	0.0
0.582794	0.565249	0.505257	1.314669	0.611397	0.212858	0.0	0.0
0.622044	0.604671	0.557467	1.383668	0.661010	0.239593	0.0	0.0
0.633833	0.616547	0.573429	1.403669	0.675776	0.247791	0.0	0.0
0.643263	0.626047	0.586199	1.419669	0.687589	0.254349	0.0	0.0
0.755933	0.715243	0.535912	0.227036	0.0	0.0	0.0	0.0
0.840168	0.795559	0.600491	0.271478	0.0	0.0	0.0	0.0
0.895834	0.850081	0.649182	0.304821	0.0	0.0	0.0	0.0
0.911813	0.865863	0.663548	0.314943	0.0	0.0	0.0	0.0
0.924595	0.878488	0.675041	0.323041	0.0	0.0	0.0	0.0

BLOCK 6 POWER

0.700316
0.709670
0.692777
0.687434
0.683159

1.376894 1.478447
1.300967 1.399549
1.232518 1.331506
1.212882 1.312199
1.197173 1.296753

1.488628 1.490695 1.432370
1.424365 1.419477 1.359404
1.362060 1.356212 1.296472
1.344106 1.338059 1.277387
1.329742 1.323535 1.262118

1.265244 1.345318 1.342793 1.205646
1.208901 1.289226 1.294514 1.169594
1.157565 1.240778 1.251978 1.138803
1.142500 1.226750 1.239487 1.129693
1.130446 1.215527 1.229492 1.122403

0.566939 1.117415 1.197585 0.992134 0.422093
0.593256 1.086882 1.179806 0.975705 0.452068
0.594859 1.057984 1.159432 0.959858 0.465613
0.594757 1.049130 1.153091 0.954812 0.469310
0.594674 1.042047 1.148017 0.950774 0.472268

0.973326 1.062773 1.075405 0.898398 0.676166 0.476518
0.967028 1.059782 1.082289 0.909075 0.684007 0.527876
0.959146 1.055861 1.085302 0.918390 0.697468 0.577082
0.956292 1.054346 1.085789 0.920910 0.701345 0.592161
0.954007 1.053134 1.086178 0.922926 0.704446 0.604224

0.922918 0.933368 0.953344 0.746733 0.478162 1.001794 0.259426
0.947045 0.958545 0.974138 0.801011 0.536213 1.002297 0.304696
0.964235 0.978092 0.998600 0.850161 0.589418 1.107962 0.340103
0.968809 0.983427 1.005650 0.864726 0.605539 1.155349 0.350881
0.972468 0.987696 1.011289 0.876377 0.618435 1.169258 0.359503

0.670502 0.648964 0.555649 1.506452 0.677907 0.221132 0.0 0.0
0.721763 0.700328 0.626653 1.632484 0.759893 0.264581 0.0 0.0
0.768543 0.747369 0.689703 1.713768 0.819423 0.297043 0.0 0.0
0.782195 0.761156 0.708615 1.736456 0.836718 0.306838 0.0 0.0
0.793117 0.772186 0.723744 1.754605 0.850552 0.314673 0.0 0.0

0.933606 0.883665 0.662660 0.231075 0.0 0.0 0.0 0.0
1.038666 0.983814 0.743119 0.336312 0.0 0.0 0.0 0.0
1.104874 1.048739 0.801433 0.376682 0.0 0.0 0.0 0.0
1.123274 1.066963 0.818207 0.388731 0.0 0.0 0.0 0.0
1.137993 1.081541 0.831626 0.398370 0.0 0.0 0.0 0.0

BLOCK 7 POWER

0.863758
0.879445
0.859425
0.852968
0.847802

1.703103 1.840672
1.617820 1.755929
1.534529 1.673809
1.510425 1.650237
1.491141 1.631377

1.844893 1.870470 1.838268
1.774899 1.799334 1.776338
1.699012 1.724587 1.709684
1.676900 1.702781 1.690007
1.659210 1.685335 1.674264

1.555428 1.664132 1.675253 1.484211
1.492914 1.605690 1.630422 1.448896
1.430117 1.547076 1.580356 1.411328
1.411467 1.529770 1.565262 1.399865
1.396546 1.515925 1.553185 1.390694

0.687161 1.351974 1.451258 1.197451 0.504670
0.718116 1.318363 1.433382 1.180213 0.541128
0.719468 1.282282 1.407317 1.159712 0.556457
0.719039 1.271009 1.398960 1.152987 0.560489
0.718696 1.261990 1.392273 1.147606 0.563715

1.155463 1.263646 1.279955 1.067926 0.800807 0.562592
1.148957 1.261128 1.289158 1.081342 0.810527 0.623403
1.137881 1.254566 1.290703 1.090574 0.824982 0.680223
1.133733 1.251931 1.290395 1.092772 0.828924 0.697436
1.130414 1.249823 1.290148 1.094530 0.832077 0.711205

1.086986 1.099958 1.124488 0.881062 0.563891 1.180539 0.305546
1.116029 1.130201 1.149521 0.945384 0.632548 1.271032 0.358960
1.134486 1.151386 1.176400 1.001577 0.694033 1.338886 0.399944
1.139048 1.156827 1.183825 1.017942 0.712451 1.358262 0.412293
1.142697 1.161180 1.189763 1.031034 0.727184 1.373763 0.422172

0.786680 0.761698 0.652777 1.771730 0.797882 0.260285 0.0 0.0
0.847213 0.822333 0.736451 1.920390 0.894579 0.311502 0.0 0.0
0.900660 0.876128 0.809179 2.012455 0.962925 0.349091 0.0 0.0
0.915977 0.891622 0.830737 2.037518 0.982478 0.360320 0.0 0.0
0.928230 0.904016 0.847983 2.057567 0.998120 0.369302 0.0 0.0

1.093880 1.035661 0.777161 0.329965 0.0 0.0 0.0 0.0
1.217423 1.153420 0.871749 0.394868 0.0 0.0 0.0 0.0
1.292926 1.227523 0.938586 0.441507 0.0 0.0 0.0 0.0
1.313475 1.247916 0.957505 0.455281 0.0 0.0 0.0 0.0
1.329912 1.264229 0.972640 0.466300 0.0 0.0 0.0 0.0

BLOCK 8 POWER

0.998040
1.020240
0.998098
0.990813
0.984985

1.968941 2.130489
1.878093 2.041371
1.783386 1.948256
1.755760 1.921286
1.733657 1.899709

2.132232 2.166031 2.132533
2.059656 2.092886 2.069767
1.973564 2.008247 1.994316
1.948233 1.983291 1.971775
1.927967 1.963325 1.953740

1.790999 1.917804 1.931834 1.704603
1.725047 1.857361 1.887163 1.669358
1.653502 1.790724 1.830270 1.626415
1.632040 1.770807 1.812854 1.613076
1.614870 1.754872 1.798920 1.602403

0.784477 1.543966 1.657403 1.365064 0.572770
0.821544 1.508872 1.640507 1.347981 0.614909
0.822920 1.467280 1.610244 1.323995 0.631832
0.822271 1.454095 1.600330 1.315958 0.636167
0.821750 1.443547 1.592397 1.309528 0.639635

1.306752 1.430237 1.449298 1.208381 0.904326 0.634182
1.300597 1.428758 1.461147 1.224617 0.915903 0.703008
1.287022 1.420205 1.461705 1.233949 0.931265 0.766206
1.281832 1.416683 1.460787 1.235915 0.935278 0.785202
1.277679 1.413865 1.460050 1.237488 0.938488 0.800399

1.223377 1.238422 1.266712 0.992722 0.635192 1.329261 0.343924
1.256718 1.273115 1.295553 1.065626 0.712806 1.431617 0.404170
1.276289 1.295731 1.324521 1.127741 0.781216 1.506323 0.449805
1.280855 1.301277 1.332274 1.145617 0.801552 1.527361 0.463463
1.284507 1.305712 1.338475 1.159917 0.817821 1.544190 0.474390

0.883173 0.855341 0.733480 1.992253 0.897670 0.292859 0.0 0.0
0.951452 0.923729 0.827752 2.159959 1.006726 0.350580 0.0 0.0
1.010446 0.983145 0.908540 2.261028 1.082427 0.392443 0.0 0.0
1.027148 1.000060 0.932301 2.288074 1.103863 0.404867 0.0 0.0
1.040509 1.013591 0.951309 2.309709 1.121011 0.414805 0.0 0.0

1.226919 1.161845 0.872251 0.370585 0.0 0.0 0.0 0.0
1.365802 1.294230 0.978593 0.443538 0.0 0.0 0.0 0.0
1.449010 1.375946 1.052504 0.495387 0.0 0.0 0.0 0.0
1.471341 1.398138 1.073204 0.510595 0.0 0.0 0.0 0.0
1.489205 1.415891 1.089764 0.522762 0.0 0.0 0.0 0.0

BLOCK 9 POWER

1.094990
1.122102
1.098622
1.090765
1.084479

2.160148 2.337561
2.065485 2.245161
1.962833 2.144343
1.932698 2.114940
1.908588 2.091415

2.337936 2.375377 2.337811
2.263546 2.300337 2.273705
2.170374 2.208707 2.191949
2.142752 2.181480 2.167318
2.120652 2.159697 2.147611

1.960100 2.098620 2.113021 1.861337
1.891717 2.036441 2.067860 1.825735
1.814090 1.964168 2.006106 1.779005
1.790627 1.942377 1.987007 1.764316
1.771856 1.924943 1.971727 1.752563

0.854932 1.682593 1.805762 1.485924 0.622177
0.896521 1.646518 1.789595 1.468979 0.668492
0.898041 1.601134 1.756490 1.442632 0.686657
0.897250 1.586594 1.745478 1.433671 0.691227
0.896617 1.574960 1.736667 1.426500 0.694883

1.417123 1.551626 1.572540 1.310650 0.979859 0.686503
1.411383 1.551081 1.586495 1.329082 0.992887 0.761253
1.396157 1.541271 1.586535 1.338653 1.009027 0.829200
1.390235 1.537135 1.585206 1.340479 1.013112 0.849518
1.385496 1.533826 1.584141 1.341940 1.016379 0.865771

1.323072 1.339606 1.370612 1.074301 0.687313 1.438026 0.371998
1.359637 1.377646 1.402344 1.153571 0.771534 1.549171 0.437271
1.380154 1.401444 1.432983 1.220140 0.845092 1.629039 0.486353
1.384746 1.407089 1.441002 1.239144 0.866849 1.651320 0.500979
1.388419 1.411604 1.447415 1.254346 0.884254 1.669143 0.512679

0.953709 0.923793 0.792475 2.153479 0.970647 0.316688 0.0 0.0
1.027669 0.997873 0.894527 2.335232 1.088808 0.379189 0.0 0.0
1.090798 1.061478 0.981287 2.443091 1.169991 0.424216 0.0 0.0
1.108527 1.079446 1.006674 2.471624 1.192824 0.437521 0.0 0.0
1.122709 1.093820 1.026983 2.494449 1.211090 0.448165 0.0 0.0

1.324153 1.254074 0.941761 0.400283 0.0 0.0 0.0 0.0
1.474243 1.397151 1.056706 0.479133 0.0 0.0 0.0 0.0
1.563181 1.484526 1.135865 0.534830 0.0 0.0 0.0 0.0
1.586832 1.508051 1.157883 0.551095 0.0 0.0 0.0 0.0
1.605752 1.526870 1.175496 0.564107 0.0 0.0 0.0 0.0

BLOCK 10 POWER

1.150891							
1.180889							
1.156915							
1.148781							
1.142273							
2.270184	2.456409						
2.173380	2.362140						
2.066628	2.257392						
2.035132	2.226680						
2.009934	2.202109						
2.455933	2.495021	2.454476					
2.380505	2.418855	2.389524					
2.283759	2.323698	2.304611					
2.254910	2.295257	2.278867					
2.231829	2.272503	2.258270					
2.056948	2.201866	2.216031	1.950438				
1.987137	2.138614	2.170460	1.914492				
1.906404	2.063505	2.106301	1.865906				
1.881865	2.040715	2.086312	1.850507				
1.862233	2.022482	2.070320	1.838186				
0.895228	1.761768	1.890317	1.554762	0.650323			
0.939377	1.725063	1.874464	1.537799	0.698974			
0.941140	1.677794	1.840033	1.510336	0.717946			
0.940303	1.662534	1.828453	1.500894	0.722671			
0.939632	1.650325	1.819188	1.493339	0.726450			
1.480067	1.620843	1.642771	1.368906	1.022872	0.716285		
1.474488	1.620746	1.657835	1.388505	1.036658	0.794348		
1.458526	1.610446	1.657812	1.398399	1.053370	0.865092		
1.452228	1.606007	1.656296	1.400185	1.057524	0.886184		
1.447189	1.602455	1.655082	1.401613	1.060846	0.903057		
1.379740	1.397130	1.429694	1.120704	0.716965	1.499905	0.387968	
1.418029	1.436962	1.462962	1.203505	0.804885	1.615923	0.456064	
1.439252	1.461605	1.494727	1.272749	0.881466	1.698908	0.507158	
1.443893	1.467342	1.502934	1.292426	0.904052	1.721937	0.522347	
1.447606	1.471931	1.509498	1.308167	0.922120	1.740359	0.534498	
0.993698	0.962610	0.825953	2.245051	1.012130	0.330237	0.0	0.0
1.070770	1.039815	0.932332	2.434565	1.135370	0.395423	0.0	0.0
1.136354	1.105904	1.022580	2.546539	1.219793	0.442293	0.0	0.0
1.154689	1.124493	1.048913	2.575976	1.243450	0.456111	0.0	0.0
1.169356	1.139363	1.069978	2.599524	1.262374	0.467165	0.0	0.0
1.379210	1.306311	0.981154	0.417128	0.0	0.0	0.0	0.0
1.535472	1.455280	1.100855	0.499271	0.0	0.0	0.0	0.0
1.627799	1.545999	1.183096	0.557200	0.0	0.0	0.0	0.0
1.652231	1.570311	1.205884	0.574077	0.0	0.0	0.0	0.0
1.671776	1.589758	1.224114	0.587578	0.0	0.0	0.0	0.0

BLOCK 11 POWER

1.164219
1.195070
1.171544
1.163489
1.157045

2.296277 2.484431
2.199234 2.389982
2.092491 2.285362
2.060916 2.254607
2.035655 2.230002

2.483444 2.522724 2.480970
2.407994 2.446487 2.415930
2.311447 2.351541 2.331256
2.282575 2.323082 2.305509
2.259476 2.300314 2.284910

2.078814 2.224945 2.238622 1.969424
2.008763 2.161503 2.192938 1.933307
1.928112 2.086579 2.129032 1.884956
1.903533 2.063781 2.109057 1.869576
1.883869 2.045541 2.093076 1.857272

0.903687 1.778307 1.907779 1.568708 0.655799
0.948313 1.741344 1.891820 1.551561 0.704787
0.950431 1.694217 1.857675 1.524300 0.724082
0.949669 1.678951 1.846132 1.514879 0.728887
0.949058 1.666737 1.836897 1.507341 0.732730

1.491952 1.634009 1.656139 1.379888 1.030788 0.721639
1.486131 1.633702 1.671111 1.399431 1.044480 0.800093
1.470371 1.623691 1.671461 1.409687 1.061497 0.871469
1.464097 1.619302 1.670020 1.411553 1.065721 0.892742
1.459078 1.615789 1.668866 1.413044 1.069100 0.909760

1.389646 1.407239 1.440162 1.128963 0.722232 1.510840 0.390777
1.427880 1.447026 1.473339 1.212081 0.810598 1.627283 0.459245
1.449494 1.472089 1.505576 1.282008 0.887846 1.711075 0.510760
1.454224 1.477924 1.513897 1.301870 0.910623 1.734319 0.526073
1.458006 1.482590 1.520553 1.317759 0.928844 1.752914 0.538323

1.000339 0.969090 0.831615 2.260787 1.019347 0.332601 0.0 0.0
1.077614 1.046513 0.938457 2.450931 1.143151 0.398145 0.0 0.0
1.143772 1.113178 1.029437 2.563993 1.228310 0.445394 0.0 0.0
1.162261 1.131922 1.055977 2.593710 1.252169 0.459323 0.0 0.0
1.177051 1.146917 1.077209 2.617481 1.271256 0.470465 0.0 0.0

1.388159 1.314840 0.987656 0.419951 0.0 0.0 0.0 0.0
1.544934 1.464308 1.107793 0.502488 0.0 0.0 0.0 0.0
1.638032 1.555781 1.190698 0.560858 0.0 0.0 0.0 0.0
1.662665 1.580292 1.213668 0.577864 0.0 0.0 0.0 0.0
1.682371 1.599899 1.232043 0.591467 0.0 0.0 0.0 0.0

BLOCK 12 POWER

1.134984
1.164754
1.142663
1.135101
1.129051

2.238486 2.421765
2.143289 2.329021
2.040738 2.228660
2.010462 2.199232
1.986240 2.175687

2.420514 2.458635 2.417480
2.346246 2.383560 2.353256
2.253746 2.292629 2.272271
2.226158 2.265452 2.247728
2.204085 2.243709 2.228091

2.025478 2.167659 2.180602 1.917884
1.956511 2.105045 2.135213 1.881854
1.879185 2.033375 2.074256 1.835850
1.855682 2.011642 2.055280 1.821287
1.836879 1.994255 2.040097 1.809636

0.879926 1.731480 1.857369 1.527025 0.638183
0.922942 1.694676 1.840916 1.509546 0.685464
0.925527 1.649733 1.808676 1.483802 0.704572
0.924992 1.635233 1.797835 1.474951 0.709395
0.924563 1.623632 1.789160 1.467869 0.713252

1.451585 1.589876 1.611413 1.342533 1.002729 0.701894
1.445074 1.588651 1.625033 1.360734 1.015419 0.777698
1.430438 1.579680 1.626154 1.371348 1.032422 0.847438
1.424627 1.575736 1.625087 1.373442 1.036736 0.868293
1.419978 1.572579 1.624232 1.375116 1.040187 0.884977

1.351403 1.368555 1.400638 1.098007 0.702421 1.469353 0.380036
1.387693 1.406344 1.431986 1.178082 0.787850 1.581559 0.446327
1.409324 1.431337 1.463964 1.246587 0.863299 1.663698 0.496602
1.414203 1.437295 1.472347 1.266148 0.885618 1.686628 0.511591
1.418105 1.442060 1.479052 1.281796 0.903473 1.704971 0.523583

0.972536 0.942182 0.808580 2.198357 0.991267 0.323444 0.0 0.0
1.046954 1.016766 0.911848 2.381646 1.110918 0.386926 0.0 0.0
1.111697 1.081992 1.000670 2.492559 1.194178 0.433025 0.0 0.0
1.129887 1.100425 1.026669 2.521942 1.217613 0.446655 0.0 0.0
1.144438 1.115171 1.047468 2.545445 1.236360 0.457559 0.0 0.0

1.349427 1.278184 0.960175 0.408298 0.0 0.0 0.0 0.0
1.500779 1.422492 1.076218 0.488205 0.0 0.0 0.0 0.0
1.591874 1.511976 1.157238 0.545142 0.0 0.0 0.0 0.0
1.616128 1.536096 1.179794 0.561781 0.0 0.0 0.0 0.0
1.635529 1.555391 1.197837 0.575092 0.0 0.0 0.0 0.0

BLOCK 13 POWER

1.064583							
1.091495							
1.071810							
1.065187							
1.059668							
2.099561	2.271383						
2.008393	2.182339						
1.914099	2.090255						
1.886532	2.063561						
1.864477	2.042204						
2.270048	2.305703	2.266846					
2.198296	2.233145	2.204449					
2.113584	2.149925	2.130501					
2.088626	2.125369	2.108405					
2.068657	2.105722	2.090726					
1.899207	2.032409	2.044327	1.797758				
1.832727	1.971730	1.999734	1.762142				
1.761871	1.906288	1.944334	1.720520				
1.740590	1.886729	1.927374	1.707599				
1.723565	1.871080	1.913804	1.697262				
0.824760	1.622886	1.740781	1.431045	0.597970			
0.864168	1.586708	1.723514	1.413130	0.641556			
0.867315	1.545917	1.694729	1.390158	0.659957			
0.867180	1.532977	1.685280	1.382444	0.664749			
0.867072	1.522624	1.677720	1.376273	0.668582			
1.359970	1.489573	1.509751	1.257786	0.939350	0.657477		
1.352349	1.486754	1.520802	1.273395	0.950148	0.727636		
1.339697	1.479517	1.523040	1.284319	0.966789	0.793477		
1.334805	1.476433	1.522669	1.286809	0.971226	0.813335		
1.330891	1.473964	1.522371	1.288800	0.974774	0.829220		
1.265766	1.281853	1.311938	1.028488	0.657943	1.376291	0.355960	
1.298243	1.315720	1.339745	1.102209	0.737104	1.479659	0.417563	
1.319479	1.340113	1.370696	1.167173	0.808293	1.557657	0.464941	
1.324587	1.346240	1.379107	1.185970	0.829527	1.579768	0.479170	
1.328673	1.351142	1.385835	1.201007	0.846514	1.597456	0.490553	
0.910760	0.882348	0.757260	2.058933	0.928437	0.302946	0.0	0.0
0.979291	0.951069	0.852966	2.227968	1.039281	0.361979	0.0	0.0
1.040617	1.012827	0.936744	2.333446	1.117996	0.405406	0.0	0.0
1.058073	1.030500	0.961473	2.361914	1.140401	0.418336	0.0	0.0
1.072037	1.044639	0.981256	2.384687	1.158323	0.428681	0.0	0.0
1.263628	1.196930	0.899166	0.382373	0.0	0.0	0.0	0.0
1.403678	1.330474	1.006634	0.456661	0.0	0.0	0.0	0.0
1.489968	1.415204	1.083207	0.510293	0.0	0.0	0.0	0.0
1.513284	1.438366	1.104770	0.526083	0.0	0.0	0.0	0.0
1.531936	1.456894	1.122019	0.538715	0.0	0.0	0.0	0.0

BLOCK 14 POWER

0.955761
0.978246
0.961870
0.956624
0.952427

1.884903 2.039112
1.799960 1.955800
1.717705 1.875728
1.694202 1.853124
1.675399 1.835040

2.037827 2.069781 2.034756
1.970001 2.001168 1.975286
1.896551 1.929090 1.911474
1.875521 1.908445 1.893023
1.858696 1.891927 1.878262

1.704729 1.824228 1.834808 1.613367
1.642174 1.756652 1.791603 1.578573
1.580706 1.710190 1.744165 1.543203
1.562747 1.693870 1.730201 1.532717
1.548379 1.680813 1.719028 1.524327

0.740143 1.456361 1.562104 1.284094 0.536514
0.774114 1.421331 1.543815 1.265713 0.574562
0.777894 1.386501 1.519893 1.246651 0.591747
0.778332 1.375883 1.512503 1.240620 0.596467
0.778682 1.367387 1.506590 1.235794 0.600242

1.220124 1.336421 1.354524 1.128440 0.842711 0.589810
1.211047 1.331431 1.361920 1.140329 0.850810 0.651525
1.201147 1.326532 1.365549 1.151471 0.866724 0.711301
1.197612 1.324707 1.366186 1.154521 0.871314 0.729614
1.194782 1.323246 1.366694 1.156959 0.874986 0.744264

1.135428 1.149870 1.176876 0.922616 0.590215 1.234607 0.319313
1.162384 1.178040 1.199571 0.986694 0.659985 1.324838 0.373869
1.182774 1.201282 1.228714 1.046275 0.724563 1.396282 0.416768
1.188192 1.207627 1.237127 1.063874 0.744120 1.417096 0.429824
1.192525 1.212703 1.243856 1.077952 0.759765 1.433746 0.440269

0.816902 0.791425 0.679244 1.846867 0.832831 0.271752 0.0 0.0
0.876710 0.851453 0.763644 1.994720 0.930504 0.324095 0.0 0.0
0.932686 0.907787 0.839616 2.091564 1.002133 0.363394 0.0 0.0
0.948999 0.924278 0.862387 2.118569 1.022934 0.375248 0.0 0.0
0.962049 0.937470 0.880604 2.140172 1.039573 0.384731 0.0 0.0

1.133362 1.073550 0.806495 0.342974 0.0 0.0 0.0 0.0
1.256585 1.191062 0.901173 0.408830 0.0 0.0 0.0 0.0
1.335362 1.268367 0.970836 0.457369 0.0 0.0 0.0 0.0
1.357213 1.290032 0.990858 0.471853 0.0 0.0 0.0 0.0
1.374693 1.307362 1.006874 0.483440 0.0 0.0 0.0 0.0

BLOCK 15 POWER

0.812551
0.829300
0.817019
0.813540
0.810756

1.602449 1.733526
1.525873 1.657953
1.458997 1.593185
1.440764 1.575878
1.426176 1.562031

1.732389 1.759525 1.729677
1.669937 1.696322 1.674292
1.610810 1.638406 1.623337
1.594862 1.622818 1.609595
1.582102 1.610346 1.598600

1.449119 1.550668 1.559602 1.371305
1.391927 1.497395 1.518468 1.337827
1.342415 1.452331 1.481091 1.310333
1.328753 1.440193 1.470988 1.302979
1.317822 1.430481 1.462905 1.297095

0.629084 1.237822 1.327671 1.091353 0.455961
0.656041 1.204525 1.308289 1.072573 0.486854
0.660493 1.177228 1.290441 1.058394 0.502339
0.661651 1.169601 1.285690 1.054520 0.506941
0.662576 1.163499 1.281889 1.051420 0.510621

1.036889 1.135731 1.151117 0.958977 0.716144 0.501219
1.026131 1.128144 1.153976 0.966204 0.720871 0.552007
1.019623 1.126069 1.159183 0.977431 0.735685 0.603731
1.017820 1.125846 1.161088 0.981163 0.740442 0.619991
1.016376 1.125666 1.162612 0.984157 0.744248 0.632998

0.964828 0.977107 1.000068 0.784016 0.501555 1.049153 0.271349
0.984784 0.998053 1.016305 0.836126 0.559162 1.122449 0.316754
1.003878 1.019591 1.042880 0.888032 0.614974 1.185087 0.353727
1.009658 1.026177 1.051247 0.904020 0.632305 1.204140 0.365229
1.014280 1.031444 1.057939 0.916810 0.646169 1.219382 0.374429

0.694128 0.672486 0.577174 1.569372 0.707713 0.230930 0.0 0.0
0.742706 0.721314 0.646937 1.689906 0.788332 0.274580 0.0 0.0
0.791544 0.770416 0.712570 1.775116 0.850530 0.308422 0.0 0.0
0.806326 0.785324 0.732746 1.800120 0.869187 0.318850 0.0 0.0
0.818152 0.797250 0.748887 1.820123 0.884112 0.327192 0.0 0.0

0.963013 0.912197 0.685291 0.291436 0.0 0.0 0.0 0.0
1.064490 1.008988 0.763424 0.346345 0.0 0.0 0.0 0.0
1.133241 1.076390 0.823901 0.388154 0.0 0.0 0.0 0.0
1.153122 1.096046 0.841866 0.400909 0.0 0.0 0.0 0.0
1.169026 1.111769 0.856238 0.411113 0.0 0.0 0.0 0.0

BLOCK 16 POWER

0.640158							
0.650174							
0.642613							
0.641205							
0.640078							
1.262460	1.365712						
1.196270	1.299797						
1.147527	1.253042						
1.135539	1.242003						
1.125948	1.233171						
1.364794	1.386156	1.362604					
1.309164	1.329824	1.312499					
1.266869	1.288543	1.276622					
1.256929	1.278931	1.268438					
1.248976	1.271241	1.261890					
1.141588	1.221569	1.228577	1.080217				
1.091157	1.173809	1.190280	1.048636				
1.055707	1.142113	1.164667	1.030324				
1.047127	1.134911	1.159112	1.026651				
1.040262	1.129149	1.154668	1.023713				
0.495544	0.975057	1.045820	0.859662	0.359159			
0.514228	0.944136	1.025442	0.840667	0.381575			
0.519349	0.925642	1.014620	0.832134	0.394917			
0.521329	0.921536	1.012960	0.830782	0.399340			
0.522913	0.918251	1.011632	0.829700	0.402878			
0.816718	0.894576	0.906700	0.755367	0.564108	0.394828		
0.804206	0.884157	0.904395	0.757232	0.564963	0.432624		
0.801570	0.885251	0.911262	0.768358	0.578295	0.474549		
0.801782	0.886877	0.914613	0.772852	0.583195	0.488289		
0.801951	0.888178	0.917293	0.776446	0.587115	0.499280		
0.759930	0.769606	0.787707	0.617555	0.395085	0.826486	0.213769	
0.771729	0.782128	0.796435	0.655250	0.438217	0.879696	0.248255	
0.789073	0.801418	0.819712	0.697993	0.483369	0.931473	0.278026	
0.795216	0.808219	0.827945	0.711973	0.497971	0.948297	0.287623	
0.800131	0.813659	0.834531	0.723157	0.509652	0.961756	0.295300	
0.546724	0.529681	0.454623	1.236205	0.557501	0.181925	0.0	0.0
0.582000	0.565238	0.506963	1.324308	0.617811	0.215196	0.0	0.0
0.622109	0.605501	0.560034	1.395135	0.668481	0.242409	0.0	0.0
0.634992	0.618447	0.577032	1.417575	0.684482	0.251092	0.0	0.0
0.645297	0.628303	0.590629	1.435525	0.697282	0.258039	0.0	0.0
0.758538	0.718518	0.539806	0.229575	0.0	0.0	0.0	0.0
0.834154	0.790665	0.598245	0.271414	0.0	0.0	0.0	0.0
0.890625	0.845940	0.647503	0.305051	0.0	0.0	0.0	0.0
0.908042	0.863089	0.662922	0.315692	0.0	0.0	0.0	0.0
0.921976	0.876807	0.675256	0.324204	0.0	0.0	0.0	0.0

BLOCK 17 POWER

0.444818
0.447454
0.445033
0.445888
0.446571

0.877253 0.948981
0.823265 0.894468
0.794685 0.867708
0.789628 0.863615
0.785582 0.860340

0.948328 0.963154 0.946762
0.900885 0.915064 0.903086
0.877250 0.892210 0.883882
0.873962 0.889211 0.881838
0.871331 0.886811 0.880203

0.793226 0.848783 0.853626 0.750542
0.750865 0.807699 0.818970 0.721501
0.731014 0.790795 0.806330 0.713289
0.728061 0.789046 0.805787 0.713662
0.725697 0.787647 0.805352 0.713961

0.344304 0.677488 0.726637 0.597305 0.249555
0.353834 0.649634 0.705517 0.578390 0.262524
0.359572 0.640848 0.702369 0.576014 0.273327
0.362420 0.640618 0.704088 0.577417 0.277494
0.364698 0.640433 0.705463 0.578539 0.280828

0.567458 0.621546 0.629968 0.524859 0.392034 0.274480
0.553289 0.608264 0.622141 0.520923 0.388705 0.297709
0.554827 0.612709 0.630631 0.531706 0.400165 0.328342
0.557224 0.616323 0.635506 0.536952 0.405132 0.339125
0.559142 0.619215 0.639405 0.541149 0.409106 0.347751

0.527997 0.534723 0.547338 0.429187 0.274648 0.574824 0.148750
0.530843 0.537978 0.547818 0.450758 0.301526 0.605462 0.170915
0.545984 0.554489 0.567088 0.482860 0.334402 0.644395 0.192344
0.552438 0.561426 0.575046 0.494439 0.345807 0.658433 0.199689
0.557600 0.566975 0.581412 0.503703 0.354931 0.669663 0.205565

0.379943 0.368107 0.315996 0.859578 0.387761 0.126591 0.0 0.0
0.400351 0.388818 0.348754 0.911180 0.425187 0.148148 0.0 0.0
0.430363 0.418853 0.387367 0.964933 0.462398 0.167695 0.0 0.0
0.440986 0.429468 0.400646 0.984099 0.475193 0.174319 0.0 0.0
0.449484 0.437960 0.411268 0.999431 0.485428 0.179618 0.0 0.0

0.527426 0.499613 0.375410 0.159720 0.0 0.0 0.0 0.0
0.573944 0.544024 0.411668 0.186806 0.0 0.0 0.0 0.0
0.616056 0.585126 0.447849 0.210988 0.0 0.0 0.0 0.0
0.630466 0.599222 0.460199 0.219131 0.0 0.0 0.0 0.0
0.641993 0.610498 0.470079 0.225646 0.0 0.0 0.0 0.0

BLOCK 18 POWER

0.236664
0.237989
0.249248
0.256390
0.262104

0.466081 0.503982
0.435384 0.472434
0.440637 0.480243
0.448688 0.489778
0.455128 0.497405

0.503562 0.511380 0.502629
0.475584 0.482949 0.476516
0.485185 0.493302 0.488550
0.495272 0.503759 0.499420
0.503341 0.512123 0.508116

0.421388 0.450737 0.453204 0.398533
0.396977 0.426532 0.432179 0.380915
0.405178 0.437573 0.445737 0.394543
0.413539 0.447379 0.456406 0.404478
0.420228 0.455224 0.464940 0.412425

0.183174 0.359922 0.385812 0.317271 0.132744
0.188161 0.343489 0.372341 0.305630 0.139430
0.201324 0.355218 0.388278 0.318992 0.152701
0.208326 0.363886 0.398800 0.327661 0.159110
0.213928 0.370820 0.407216 0.334597 0.164238

0.301489 0.330056 0.334413 0.278691 0.208343 0.146169
0.292558 0.321105 0.328011 0.274709 0.205120 0.156763
0.307503 0.338800 0.348057 0.293454 0.220739 0.179296
0.316450 0.349160 0.359299 0.303533 0.228746 0.188873
0.323608 0.357448 0.368292 0.311595 0.235151 0.196533

0.280315 0.283842 0.290538 0.228105 0.146220 0.306262 0.079699
0.279853 0.283443 0.288254 0.237064 0.158669 0.313953 0.089046
0.301237 0.305647 0.311681 0.264224 0.182486 0.339139 0.101263
0.312188 0.316952 0.323479 0.276409 0.192485 0.349929 0.105938
0.320949 0.325996 0.332918 0.286157 0.200484 0.358560 0.109679

0.201942 0.195654 0.168155 0.457486 0.206856 0.067829 0.0 0.0
0.210705 0.204592 0.183356 0.471756 0.220690 0.077183 0.0 0.0
0.235818 0.229428 0.211180 0.507217 0.243300 0.088298 0.0 0.0
0.246917 0.240376 0.222793 0.522480 0.252341 0.092499 0.0 0.0
0.255797 0.249134 0.232083 0.534690 0.259574 0.095860 0.0 0.0

0.280860 0.266061 0.200144 0.085536 0.0 0.0 0.0 0.0
0.297468 0.281945 0.213591 0.097265 0.0 0.0 0.0 0.0
0.324139 0.307818 0.235682 0.111034 0.0 0.0 0.0 0.0
0.335003 0.318341 0.244477 0.116222 0.0 0.0 0.0 0.0
0.343693 0.326758 0.251514 0.120373 0.0 0.0 0.0 0.0

BLOCK 19 POWER

0.488969							
0.536943							
0.545584							
0.549141							
0.551986							
0.568428	0.600554						
0.617758	0.653256						
0.634193	0.672789						
0.642099	0.681973						
0.648423	0.689319						
0.597641	0.606083	0.595303					
0.653979	0.663405	0.654102					
0.675783	0.686396	0.679271					
0.685613	0.696654	0.690136					
0.693476	0.704860	0.698827					
0.512211	0.536729	0.537054	0.474108				
0.561512	0.589343	0.593555	0.525758				
0.581503	0.612568	0.620069	0.551732				
0.590167	0.622499	0.631023	0.562193				
0.597098	0.630442	0.639786	0.570562				
0.378427	0.438920	0.457685	0.384748	0.270566			
0.424459	0.487285	0.511741	0.431205	0.310146			
0.440572	0.511102	0.540442	0.456541	0.329290			
0.446076	0.520574	0.551664	0.466270	0.335594			
0.450479	0.528151	0.560642	0.474052	0.340637			
0.369103	0.392937	0.393393	0.327730	0.232169	0.148632		
0.416437	0.443417	0.446815	0.374157	0.267474	0.175913		
0.443652	0.473782	0.479905	0.404398	0.292585	0.197701		
0.453861	0.485231	0.492248	0.415540	0.301671	0.205384		
0.462028	0.494339	0.502121	0.424453	0.308940	0.211530		
0.329909	0.331682	0.312116	0.237626	0.148733	0.069410	0.017302	
0.381086	0.383151	0.361119	0.279524	0.177906	0.087961	0.022576	
0.415021	0.417940	0.396664	0.310968	0.200996	0.103932	0.027168	
0.427305	0.430531	0.409557	0.322153	0.209078	0.110035	0.028913	
0.437131	0.440604	0.419872	0.331102	0.215543	0.114917	0.030309	
0.212656	0.205809	0.169945	0.102859	0.046253	0.014761	0.0	0.0
0.251436	0.243929	0.204280	0.131171	0.059814	0.019606	0.0	0.0
0.280889	0.273080	0.231237	0.154492	0.071277	0.023747	0.0	0.0
0.291293	0.283362	0.240630	0.163393	0.075628	0.025312	0.0	0.0
0.299616	0.291587	0.248145	0.170514	0.079109	0.026564	0.0	0.0
0.062543	0.059252	0.044921	0.018586	0.0	0.0	0.0	0.0
0.080813	0.076631	0.058327	0.024671	0.0	0.0	0.0	0.0
0.095703	0.090931	0.069708	0.029812	0.0	0.0	0.0	0.0
0.101372	0.096379	0.074020	0.031751	0.0	0.0	0.0	0.0
0.105907	0.100737	0.077469	0.033301	0.0	0.0	0.0	0.0

BENCHMARK PROBLEM SOLUTION

Identification: 11-A1-2

Benchmark Problem ID, 11-A1

Date Submitted: June 1976

By: Ib Misfeldt (Risø-Denmark)

Date Accepted: June 1977

By: H. L. Doids, Jr. (U. of Tenn.)
M. V. Gregory (SRL)

Descriptive Title: Three-dimensional PWR Problem

Mathematical Model: FEM (2nd order Lagrange interpolation, box-shaped elements)

Pertinent features of solution method

The calculations were performed with a rather coarse grid (16 x 16 x 13 meshes; 33 x 33 x 27 flux-points). To obtain the required additional results interpolation was used.

Computer: B 6700

Date solved: Spring 1975

at: Risø, Denmark

Program: FEM3D

Reference: Ib Misfeldt, "Solution of the multigroup neutron diffusion equations by the finite element method," Risø-M-1809 (1975).

Results

1. Maximum eigenvalue $k_{\text{eff}} = 1.0292$
2. Fundamental flux distributions
 - 2.1, 2.2, 2.3 See Tables 3A-G of flux traverses
 - 2.4 Maximum power density
Uninterpolated values are given
$$(\phi_2)_{\text{max},1} = 17.60 \text{ at } (x,y,z) = (130,55,190)$$
$$(\phi_2)_{\text{max},2} = 16.80 \text{ at } (x,y,z) = (30,35,190)$$
3. Average subassembly powers
See Table 3H
4. Number of unknowns and iteration-number
33 x 33 x 27 x 2 unknowns; 71 iterations
5. Computing times
23 hours cp-time, io-time 6 hours, on B 6700

6. Convergence criteria

Maximal flux-error-estimate less than 0.1% of $\phi_{\max}$ in each group

7. Average group fluxes for 20 x 20 x 20 cm grid

See Table 3J

8. Dependence of results on mesh spacing

No data available

Table 3A
z = 190 cm
FLUX ALONG X-AXIS

X	PHI1	PHI2
0.000	43.616	7.293
5.000	45.454	7.443
10.000	50.801	10.175
20.000	62.837	14.868
30.000	68.498	15.878
35.000	69.391	16.270
40.000	69.316	16.261
45.000	68.233	16.014
50.000	66.143	15.522
55.000	62.978	14.775
60.000	58.612	13.683
65.000	52.690	12.233
70.000	45.393	8.903
75.000	39.323	6.431
80.000	36.430	6.073
85.000	36.604	5.985
90.000	39.638	7.748
95.000	43.655	10.127
100.000	46.378	10.820
105.000	47.713	11.193
110.000	48.029	11.273
115.000	47.493	11.151
120.000	46.228	10.867
125.000	44.342	10.429
130.000	41.822	10.100
135.000	38.279	9.498
140.000	33.227	8.613
145.000	26.979	7.287
150.000	16.812	12.443
155.000	8.252	20.102
160.000	4.090	14.566
165.000	2.041	7.785
170.000	1.082	0.324

Table 3B
z = 190 cm
FLUX ALONG THE DIAGONAL X=Y

X	Y	PHI1	PHI2
0.000	0.000	43.616	7.293
5.000	5.000	47.151	7.463
10.000	10.000	55.944	12.195
20.000	20.000	68.322	16.028
30.000	30.000	71.653	16.800
35.000	35.000	71.455	16.759
40.000	40.000	70.383	16.510
45.000	45.000	68.542	16.076
50.000	50.000	65.926	15.470
55.000	55.000	62.409	14.648
60.000	60.000	57.761	13.552
65.000	65.000	51.559	12.079
70.000	70.000	43.017	9.168
75.000	75.000	33.780	5.344
80.000	80.000	28.426	4.741
85.000	85.000	27.423	4.341
90.000	90.000	28.739	6.350
95.000	95.000	27.729	6.896
100.000	100.000	23.086	6.346
105.000	105.000	16.539	4.911
110.000	110.000	6.969	9.840
115.000	115.000	2.264	8.707
120.000	120.000	0.788	3.862
125.000	125.000	0.275	1.069
130.000	130.000	0.091	0.012
135.000	135.000	0.000	0.000
140.000	140.000	0.000	0.000
145.000	145.000	0.000	0.000
150.000	150.000	0.000	0.000
155.000	155.000	0.000	0.000
160.000	160.000	0.000	0.000
165.000	165.000	0.000	0.000
170.000	170.000	0.000	0.000

Table 3C

 $z = 275 \text{ cm}$

FLUX ALONG X-AXIS

X	PHI1	PHI2
0.000	24.388	4.077
5.000	25.402	4.159
10.000	28.350	5.677
20.000	34.940	8.268
30.000	37.995	8.806
35.000	38.499	9.025
40.000	38.526	9.037
45.000	38.057	8.930
50.000	37.086	8.702
55.000	35.553	8.341
60.000	33.361	7.787
65.000	30.277	7.028
70.000	26.382	5.170
75.000	23.178	3.790
80.000	21.816	3.636
85.000	22.268	3.641
90.000	24.443	4.781
95.000	27.203	6.312
100.000	29.141	6.799
105.000	30.188	7.082
110.000	30.567	7.175
115.000	30.377	7.133
120.000	29.693	6.980
125.000	28.582	6.723
130.000	27.036	6.530
135.000	24.803	6.154
140.000	21.568	5.592
145.000	17.537	4.738
150.000	10.940	8.101
155.000	5.373	13.096
160.000	2.665	9.495
165.000	1.331	5.076
170.000	0.705	0.211

Table 3D

 $z = 275 \text{ cm}$

FLUX ALONG THE DIAGONAL X=Y

X	Y	PHI1	PHI2
0.000	0.000	24.388	4.077
5.000	5.000	26.335	4.168
10.000	10.000	31.140	6.786
20.000	20.000	37.364	8.765
30.000	30.000	37.260	8.641
35.000	35.000	35.874	8.018
40.000	40.000	34.891	7.824
45.000	45.000	34.736	7.762
50.000	50.000	34.993	8.096
55.000	55.000	34.584	8.114
60.000	60.000	33.036	7.750
65.000	65.000	30.203	7.075
70.000	70.000	25.692	5.473
75.000	75.000	20.540	3.249
80.000	80.000	17.586	2.933
85.000	85.000	17.210	2.724
90.000	90.000	18.207	4.024
95.000	95.000	17.666	4.394
100.000	100.000	14.763	4.060
105.000	105.000	10.604	3.150
110.000	110.000	4.475	6.322
115.000	115.000	1.455	5.600
120.000	120.000	0.507	2.486
125.000	125.000	0.177	0.689
130.000	130.000	0.059	0.008
135.000	135.000	0.000	0.000
140.000	140.000	0.000	0.000
145.000	145.000	0.000	0.000
150.000	150.000	0.000	0.000
155.000	155.000	0.000	0.000
160.000	160.000	0.000	0.000
165.000	165.000	0.000	0.000
170.000	170.000	0.000	0.000

Table 3E
 $z = 285 \text{ cm}$
 FLUX ALONG X-AXIS

X	PHI1	PHI2
0.000	21.093	3.525
5.000	21.962	3.595
10.000	24.488	4.902
20.000	30.098	7.122
30.000	32.643	7.560
35.000	33.055	7.738
40.000	33.084	7.752
45.000	32.719	7.667
50.000	31.950	7.491
55.000	30.715	7.205
60.000	28.915	6.747
65.000	26.337	6.112
70.000	23.042	4.514
75.000	20.341	3.326
80.000	19.244	3.207
85.000	19.736	3.227
90.000	21.750	4.254
95.000	24.277	5.632
100.000	26.064	6.081
105.000	27.049	6.344
110.000	27.429	6.437
115.000	27.291	6.407
120.000	26.703	6.276
125.000	25.725	6.049
130.000	24.349	5.880
135.000	22.350	5.544
140.000	19.443	5.040
145.000	15.814	4.271
150.000	9.867	7.307
155.000	4.847	11.814
160.000	2.404	8.566
165.000	1.200	4.580
170.000	0.636	0.191

Table 3F
 $z = 285 \text{ cm}$
 FLUX ALONG THE DIAGONAL X=Y

X	Y	PHI1	PHI2
0.000	0.000	21.093	3.525
5.000	5.000	22.759	3.602
10.000	10.000	26.848	5.843
20.000	20.000	31.748	7.443
30.000	30.000	29.525	6.504
35.000	35.000	26.448	4.497
40.000	40.000	24.924	4.410
45.000	45.000	25.628	4.355
50.000	50.000	27.851	6.010
55.000	55.000	29.012	6.796
60.000	60.000	28.397	6.658
65.000	65.000	26.314	6.163
70.000	70.000	22.579	4.808
75.000	75.000	18.173	2.875
80.000	80.000	15.649	2.609
85.000	85.000	15.381	2.434
90.000	90.000	16.314	3.606
95.000	95.000	15.854	3.942
100.000	100.000	13.262	3.646
105.000	105.000	9.531	2.831
110.000	110.000	4.024	5.685
115.000	115.000	1.309	5.037
120.000	120.000	0.456	2.236
125.000	125.000	0.159	0.620
130.000	130.000	0.053	0.007
135.000	135.000	0.000	0.000
140.000	140.000	0.000	0.000
145.000	145.000	0.000	0.000
150.000	150.000	0.000	0.000
155.000	155.000	0.000	0.000
160.000	160.000	0.000	0.000
165.000	165.000	0.000	0.000
170.000	170.000	0.000	0.000

Table 3G

AXIAL FLUX-DISTRIBUTION FOR (X,Y) = (40.000 40.000)

Z	PHI1	PHI2
380.000	0.151	0.014
375.000	0.279	0.263
370.000	0.530	0.481
365.000	0.995	0.845
360.000	1.833	0.673
355.000	3.067	0.522
350.000	4.169	0.722
325.000	9.577	1.584
300.000	16.735	2.857
290.000	21.264	3.460
280.000	29.515	5.793
270.000	39.539	9.351
260.000	46.650	10.888
225.000	62.711	14.727
190.000	70.383	16.510
155.000	70.217	16.482
120.000	62.311	14.625
85.000	47.642	11.181
50.000	27.822	6.537
40.000	21.502	5.037
30.000	14.924	3.641
25.000	11.577	2.936
20.000	7.053	5.023
15.000	3.451	8.316
10.000	1.706	6.035
5.000	0.849	3.227
0.000	0.450	0.134

Table 3J
Flux averages

GROUP 1

340.00 < Z < 360.00

170.00

0.8293	0.7907	0.5981	0.1812	0.0140	0.0029	0.0001	0.0000	0.0000
--------	--------	--------	--------	--------	--------	--------	--------	--------

150.00

4.7282	4.6081	3.8544	1.3932	0.5746	0.1416	0.0065	0.0001	0.0000
--------	--------	--------	--------	--------	--------	--------	--------	--------

130.00

6.5806	6.6569	6.4660	5.0205	3.2295	0.9174	0.1567	0.0065	0.0001
--------	--------	--------	--------	--------	--------	--------	--------	--------

110.00

6.2107	6.7652	6.9601	5.9401	4.4247	3.0833	0.9166	0.1414	0.0029
--------	--------	--------	--------	--------	--------	--------	--------	--------

90.00

4.6794	6.0951	6.6669	5.6863	3.9627	4.4197	3.2235	0.5732	0.0139
--------	--------	--------	--------	--------	--------	--------	--------	--------

70.00

5.9155	6.0807	5.8430	5.8898	5.6801	5.9277	5.0062	1.3881	0.1804
--------	--------	--------	--------	--------	--------	--------	--------	--------

50.00

6.5214	5.8895	4.5251	5.8385	6.6554	6.9408	6.4419	3.8367	0.5949
--------	--------	--------	--------	--------	--------	--------	--------	--------

30.00

5.9089	6.0754	5.8874	6.0748	6.0830	6.7434	6.6283	4.5841	0.7860
--------	--------	--------	--------	--------	--------	--------	--------	--------

10.00

4.5685	5.9083	6.5188	5.9098	4.6695	6.1887	6.5501	4.7017	0.8239
--------	--------	--------	--------	--------	--------	--------	--------	--------

0.00	10.00	30.00	50.00	70.00	90.00	110.00	130.00	150.00	170.00
------	-------	-------	-------	-------	-------	--------	--------	--------	--------

Table 3J, group 1 (cont'd)

Table 3J, group 1 (cont'd)

Table 3J, group 1 (cont'd)

[illegible]

Table 3J, group 1 (cont'd)

Table 3J, group 1 (cont'd)

Table 3J, group 2

Group 2

[illegible]

Table 3J, group 2 (cont'd)

Table 3J, group 2 (cont'd)

Table 3J, group 2 (cont'd)

Table 3J, group 2 - cont'd)

BENCHMARK PROBLEM SOLUTION

Identification: 11-A1-3

Benchmark Problem ID.11-A1

Date Submitted: June 1976

By: H. Finnemann (KWU)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
M. V. Gregory (SRL)

Descriptive Title: Fifth Order Nodal Solution with IQSBOX

Mathematical Model

The IQSBOX program solves the time-dependent two-group neutron diffusion equation in one, two or three dimensions by the nodal expansion method (NEM).

NEM is a consistent nodal technique that converges towards the exact solution of the diffusion equation for small mesh sizes. Subsidiary 1-D diffusion equations are solved in each box by polynomial expansion to obtain spatial coupling coefficients. Polynomials up to fifth order can be used.

Computer: CDC 6600

References

H. Finnemann

A Consistent Nodal Method for the Analysis of Space-Time Effects in Large LWR's.

Proc. of the Joint NEACRP/CSNI Specialists' Meeting on New Developments in Three-Dimensional Neutron Kinetics and Review of Kinetics Benchmark Calculations

Munich, January 22-24 (1975), MRR 145

F. Bennewitz, H. Finnemann, H. Moldaschl

Solution of the Multidimensional Neutron Diffusion Equation by Nodal Expansion

CONF-750413, Proc. Conf. on Comput.

Methods in Nucl. Eng., April 15 - 17, 1975

Charleston, South Carolina

F. Bennewitz, H. Finnemann, M. R. Wagner

Higher Order Corrections in Nodal Reactor Calculations.

Trans. Am. Nucl. Soc. 22, 250 (1975).

Results

1 Maximum Eigenvalue

1.1 Solution 1 $k_{\text{eff}} = 1.02911$
Mesh size 20 cm
Number of Unknowns 5054 per group
44 iterations were required
for a pointwise flux
convergence of $\epsilon < 10^{-5}$
Computing time 50 s

1.2 Solution 2 $k_{\text{eff}} = 1.02904$
Mesh size in the x-y plane
and in the axial reflector 10 cm
Axial mesh size in the core 20 cm
Number of Unknowns 18669 per group
74 iterations were required
for a pointwise flux
convergence of $\epsilon < 10^{-5}$
Computing time 4.6 min

2 Power and Flux Distributions

2.1 Average Subassembly Powers

Table I : Axial Average

Table II: Average Subassembly Powers for layers 2 to 18
where 2 is lowest and 18 the highest layer
in the core consisting of cubical boxes with
a sidelength of 20 cm.

2.2 Average Subassembly Thermal Core Fluxes

Table III: Axial Average

Table IV : Thermal Core Fluxes

for layers 2 to 18 defined above.

2.3 Average Subassembly Fast Core Fluxes

Table V : Axial Average

Table VI: Fast Core Fluxes

for layers 2 to 18 defined above.

Table II

Average Subassembly Powers

Layer 2

				20 x 20 x 20	mesh
				10 x 10 x 20 (10)	mesh
				.199	
				.197	
		.166		.237	.202
		.165		.253	.201
			.416	.315	.288
			.413	.312	.287
	.511	.410		.370	.233
	.509	.408		.369	.232
	.501	.373		.360	.250
	.499	.372		.358	.249
.264	.458	.216		.326	.256
.263	.456	.215		.324	.255

Table II cont.

Average Subassembly Powers
Layer 6

.745 20 x 20 x 20 mesh
.743 10 x 10 x 20 (10) mesh

.598 .878 .761
.599 .874 .757

1.526 1.236 1.160 1.078
1.526 1.237 1.157 1.076

1.876 1.720 1.507 1.365 1.239 .877
1.880 1.721 1.508 1.367 1.242 .877

1.837 1.892 1.682 1.368 1.322 1.211 .932
1.837 1.894 1.683 1.369 1.324 1.211 .933

.948 1.676 1.859 1.549 .775 1.195 1.191 .953
.952 1.677 1.860 1.550 .778 1.195 1.191 .957

Table II cont.

Average Subassembly Powers

Layer 7

.830	20 x 20 x 20	mesh
.828	10 x 10 x 20 (10)	mesh

.666	.978	.847
.667	.974	.844

1.698	1.376	1.292	1.200
1.699	1.377	1.289	1.198

2.088	1.914	1.677	1.520	1.380	.977
2.092	1.915	1.678	1.522	1.383	.977

2.043	2.105	1.872	1.522	1.472	1.349	1.038
2.044	2.107	1.873	1.524	1.474	1.350	1.039

1.055	1.865	2.069	1.723	.862	1.330	1.326	1.061
1.059	1.866	2.070	1.725	.866	1.331	1.327	1.066

Table II cont.

Average Subassembly Powers				.903	20 x 20 x 20	mesh		
Layer 10				.901	10 x 10 x 20 (10)	mesh		
				.722	1.063	.922		
				.725	1.059	.918		
			1,837	1.491	1,404	1.306		
			1.839	1.493	1,401	1.304		
		2,252	2.068	1.817	1.651	1.501	1,064	
		2.258	2,070	1.819	1.654	1.505	1,065	
		2,200	2.269	2,021	1.648	1.599	1,468	1.131
		2,203	2.273	2,023	1.650	1.602	1,469	1,133
	1.153	2.008	2,229	1.859	.934	1.445	1,443	1,157
	1.140	2,010	2,232	1.863	.938	1.446	1,445	1.162

Average Subassembly Powers

.800	20 x 20 x 20	mesh
.799	10 x 10 x 20 (10)	mesh

[illegible]

Table II cont,
Average Subassembly Powers
Layer 13

[illegible]

Table II cont.

[illegible]

Table II cont.
Average Subassembly Powers
Layer 15

				20 x 20 x 20	10 x 10 x 20 (10)	mesh
			.487			mesh
			.486			
				.371	.499	
				.372	.497	
		.831	.739	.705		
		.831	.739	.704		
		.558	.885	.811	.583	
		.560	.886	.813	.583	
	.941	.912	.807	.795	.622	
	.941	.913	.807	.795	.622	
.509	.891	.983	.460	.783	.636	
.511	.891	.984	.461	.783	.639	

Table II cont.
Average Subassembly Powers
Layer 17

				20 x 20 x 20	20 x 20 x 20 (10)	mesh
			.244			mesh
			.243			mesh
		.181	.282	.251		
		.180	.279	.249		
		.374	.365	.355		
		.372	.362	.353		
	.217	.372	.425	.408	.296	
	.217	.369	.423	.407	.295	
.403	.384	.393	.414	.401	.317	
.400	.382	.391	.412	.399	.315	
.223	.388	.380	.377	.396	.324	
.223	.386	.378	.375	.393	.324	

Table III

Average Subassembly Thermal Fluxes

Axial Average

4.430

20 x 20 x 20

mesh

4.419

10 x 10 x 20 (10)

mesh

3.511

5.205

4.526

3.519

5.179

4.507

8.734

7.199

6.856

6.413

8.732

7.201

6.834

6.398

10.12

9.711

8.747

8.054

7.372

5.239

10.14

9.714

8.747

8.061

7.387

5.240

10.36

10.60

9.566

7.939

7.805

7.215

5.573

10.36

10.61

9.566

7.941

7.812

7.214

5.579

5.379

9.498

10.54

8.844

4.501

7.060

7.098

5.702

5.398

9.500

10.54

8.849

4.517

7.060

7.097

5.726

Table IV cont.

Average Subassembly Therm. Fluxes

Layer 3

			2.588	20 x 20 x 20	mesh
			2.570	10 x 10 x 20 (10)	mesh
		2.080	3.051	2.640	
		2.070	3.019	2.617	
	5.312	4.299	4.034	3.744	
	5.279	4.275	3.998	3.716	
	6.536	5.988	4.747	4.304	3.045
	6.506	5.953	4.723	4.288	3.030
6.399	6.592	5.859	4.599	4.210	3.236
6.362	6.556	5.824	4.575	4.184	3.222
3.306	5.840	6.477	4.155	4.139	3.310
3.293	5.807	6.441	4.130	4.114	3.306

Table IV cont.

Average Subassembly Therm. Fluxes

Layer 4

3.708 20 x 20 x 20 mesh

3.696 10 x 10 x 20 (10) mesh

2.976 4.371 5.784

2.981 4.346 3.765

7.602 6.154 5.776 5.364

7.593 6.151 5.754 5.347

9.351 8.568 7.506 6.796 6.165 4.363

9.357 8.562 7.500 6.797 6.172 4.360

9.154 9.430 8.383 6.812 6.583 6.028 4.637

9.148 9.427 8.376 6.809 6.583 6.023 4.637

4.726 8.356 9.267 7.716 3.860 5.947 5.927 4.742

4.739 8.351 9.262 7.715 3.871 5.943 5.922 4.757

Table IV cont.
Average Subassembly Therm. Fluxes
Layer 5

				4.698	20 x 20 x 20	mesh
				4.685	10 x 10 x 20 (10)	mesh
			3.769	5.537	4.794	
			3.777	5.508	4.772	
		9.625	7.793	7.316	6.795	
		9.620	7.794	7.293	6.778	
	11.84	10.85	9.504	8.607	7.810	5.528
	11.85	10.85	9.502	8.613	7.823	5.527
11.59	11.94	10.61	8.626	8.337	7.636	5.874
11.59	11.94	10.61	8.627	8.342	7.634	5.878
5.982	10.58	11.73	9.768	7.532	7.508	6.007
6.001	10.58	11.73	9.773	7.531	7.506	6.031

Average Subassembly Therm. Fluxes

6.688	20 x 20 x 20	mesh
6.676	10 x 10 x 20 (10)	mesh

[illegible]

Table IV cont.

Average Subassembly Therm. Fluxes
Layer 12

				5.926	20 x 20 x 20	mesh
				5.916	10 x 10 x 20 (10)	mesh
				4.710	6.053	
				4.725	6.032	
		11.86		9.178	8.576	
		11.87		9.159	8.564	
		13.31		10.78	9.857	7.005
		13.32		10.80	9.885	7.011
		12.99		10.68	9.643	7.449
		13.00		10.69	9.652	7.464
		11.94		6.047	9.485	7.621
		11.96		6.074	9.493	7.660
7.250	12.83	14.26		9.445		
7.283	12.84	14.28		9.456		

Average Subassembly Therm. Fluxes
Layer 13

[illegible]

Table IV cont.

Average Subassembly Therm. Fluxes

Layer 14

				20 x 20 x 20	mesh
				10 x 10 x 20 (10)	mesh
	4.476				
	4.466				
		3.479		4.579	
		3.489		4.561	
			8.314		
		7.035		6.482	
		7.014		6.470	
			8.319		
	9.289	8.500	9.105	7.450	5.330
	9.344	8.502	9.116	7.469	5.334
	9.606	7.712	9.004	7.296	5.677
	9.614	7.719	9.011	7.301	5.686
5.030	8.865	4.378	8.367	7.183	5.810
5.052	8.872	4.396	8.377	7.187	5.838

Table IV cont.

Average Subassembly Therm. Fluxes

Layer 16

				20 x 20 x 20	mesh
				10 x 10 x 20 (10)	mesh
			2.707		
			2.698		
		2.028	3.135	2.777	
		2.032	3.118	2.763	
		4.310	4.064	3.925	
		4.304	4.048	3.915	
	2.585	4.320	4.742	4.512	3.261
	2.585	4.315	4.744	4.519	3.261
	4.757	4.534	4.612	4.427	3.480
	4.750	4.531	4.613	4.425	3.482
2.626	4.570	5.032	4.196	4.365	3.565
2.634	4.564	5.029	4.195	4.362	3.578

Table IV cont.
Average Subassembly Therm. Fluxes
Layer 17

				1.810	20 x 20 x 20	mesh
				1.798	10 x 10 x 20 (10)	mesh
			1.338	2.090	1.861	
			1.336	2.069	1.844	
		2.772	2.602	2.703	2.631	
		2.754	2.587	2.678	2.612	
	1.609	2.752	3.089	3.151	3.025	2.195
	1.610	2.735	3.069	3.135	3.015	2.186
2.984	2.845	2.914	2.815	3.066	2.971	2.345
2.964	2.828	2.895	2.799	3.050	2.955	2.336
1.653	2.875	3.174	1.607	2.791	2.931	2.403
1.653	2.857	3.153	1.607	2.777	2.914	2.402

Table VI
Average Subassembly Fast Fluxes
Layer 2

		4.375	20 x 20 x 20	mesh
		4.366	10 x 10 x 20 (10)	mesh
		6.485	4.515	
		6.429	4.490	
		11.94	9.769	7.066
		11.87	9.724	7.032
		14.68	11.78	9.109
		14.61	11.71	9.073
		14.39	10.84	9.376
		14.31	10.79	9.328
		14.80	10.33	6.192
		14.73	10.28	6.174
		14.56	9.464	6.339
		14.47	9.418	6.323
10.37		12.27	8.467	
10.30		12.22	8.408	

	20 x 20 x 20	mesh
8.351		
8.342	10 x 10 x 20 (10)	mesh

12.25	12.44	8.630
12.20	12.39	8.586
22.62	18.51	17.08
22.57	18.49	17.02
27.82	25.49	22.33
27.81	25.44	22.28
27.25	24.95	20.51
27.21	24.91	20.50
19.55	25.16	27.59
19.51	25.15	27.53
12.25	12.44	8.630
12.20	12.39	8.586
22.62	18.51	17.08
22.57	18.49	17.02
27.82	25.49	22.33
27.81	25.44	22.28
27.25	24.95	20.51
27.21	24.91	20.50
19.55	25.16	27.59
19.51	25.15	27.53
12.25	12.44	8.630
12.20	12.39	8.586
22.62	18.51	17.08
22.57	18.49	17.02
27.82	25.49	22.33
27.81	25.44	22.28
27.25	24.95	20.51
27.21	24.91	20.50
19.55	25.16	27.59
19.51	25.15	27.53

Table VI cont.

Average Subassembly Fast Fluxes
Layer 4

					11.98	20 x 20 x 20	mesh
					11.97	10 x 10 x 20 (10)	mesh
				17.55	17.84	12.38	
				17.50	17.78	12.32	
			32.40	26.51	24.47	19.33	
			32.37	26.52	24.42	19.30	
		39.84	36.50	31.99	28.89	24.87	14.20
		39.86	36.48	31.95	28.88	24.88	14.20
	39.02	40.17	35.73	29.38	28.06	25.54	16.93
	39.00	40.16	35.71	29.39	28.06	25.53	16.94
27.99	36.03	39.50	33.25	22.86	25.67	25.17	17.32
27.95	36.04	39.46	33.27	22.83	25.67	25.17	17.34

Table VI cont.

Average Subassembly Fast Fluxes

Layer 6

	17.83	20 x 20 x 20	mesh
	17.84	10 x 10 x 20 (10)	mesh
	26.11	18.43	
	26.07	18.36	
	48.19	36.42	28.77
	48.19	36.38	28.76
	59.22	47.59	37.01
	59.33	47.58	37.08
	57.99	53.12	38.01
	58.03	53.15	38.05
	41.59	58.71	37.46
	41.59	58.71	37.50
	59.71	41.75	25.21
	59.76	41.80	25.24
	53.55	33.99	25.78
	53.63	34.00	25.84

Table VI **cont.**

Average Subassembly Fast Fluxes Layer 9

Subassembly Fast Fluxes		20 x 20 x 20 mesh		10 x 10 x 20 (10) mesh	
		21.77	22.50	21.79	22.43
31.83	32.39	31.83	32.39	31.83	32.39
31.80	32.35	31.80	32.35	31.80	32.35
48.04	44.42	48.04	44.42	48.04	44.42
48.14	44.40	48.14	44.40	48.14	44.40
57.94	52.42	57.94	52.42	57.94	52.42
57.97	52.51	57.97	52.51	57.97	52.51
53.19	50.91	53.19	50.91	53.19	50.91
53.30	51.01	53.30	51.01	53.30	51.01
41.38	46.58	41.38	46.58	41.38	46.58
41.41	46.67	41.41	46.67	41.41	46.67
60.07	64.58	60.07	64.58	60.07	64.58
60.21	64.67	60.21	64.67	60.21	64.67
71.28	71.28	71.28	71.28	71.28	71.28
71.32	71.32	71.32	71.32	71.32	71.32
70.38	72.51	70.38	72.51	70.38	72.51
70.47	72.62	70.47	72.62	70.47	72.62
64.98	71.28	64.98	71.28	64.98	71.28
65.11	71.32	65.11	71.32	65.11	71.32

Table VI cont.

Average Subassembly Fast Fluxes

Layer 10

				20 x 20 x 20	mesh
				21.60	
				21.62	10 x 10 x 20 (10)
					mesh
				31.55	22.33
				31.52	22.26
				47.58	34.86
				47.68	34.86
				58.02	
				58.06	
				71.09	51.97
					44.85
					25.65
				71.27	52.06
					44.96
					25.70
				69.48	52.65
					46.06
					30.59
				69.58	52.77
					46.15
					30.65
				49.80	40.95
					46.19
					31.29
				49.84	40.99
					46.28
					45.49
					31.38

Table VI cont.

Average Subassembly Fast Fluxes

Layer 11

				20 x 20 x 20	mesh
				20.70	
				20.72	mesh
				30.17	21.41
				30.15	21.34
				45.45	33.42
				45.54	33.42
				67.59	42.17
				62.14	42.99
				54.76	24.61
				67.77	49.74
				62.22	43.10
				54.79	24.66
				65.98	48.31
				60.73	44.17
				68.04	29.36
				66.07	44.25
				60.81	29.42
				50.35	
				47.27	44.21
				66.87	43.54
				39.07	30.03
				47.31	44.30
				66.92	43.62
				56.61	30.12

Table VI cont.

Average Subassembly Fast Fluxes

Layer 12

			19.14	20 x 20 x 20	mesh
			19.16	10 x 10 x 20 (10)	mesh
		27.77	28.42	19.79	
		27.75	28.38	19.74	
		50.57	38.88	30.90	
		50.61	38.87	30.90	
	61.48	56.69	45.84	39.75	22.80
	61.64	56.77	45.92	39.86	22.84
59.93	61.86	55.37	46.05	40.85	27.20
60.02	61.96	55.44	46.15	40.92	27.26
42.93	60.80	51.47	40.76	40.28	27.83
42.97	60.84	51.60	40.85	40.35	27.91

Table VI cont.

Average Subassembly Fast Fluxes

Layer 16

				8.728	20 x 20 x 20	mesh
				8.723	10 x 10 x 20 (10)	mesh
				11.96	9.072	
				11.93	9.031	
				17.13	14.12	
				17.13	14.10	
				20.18	18.19	10.61
				20.15	18.21	10.62
				18.63	18.75	12.70
				18.63	18.76	12.71
				14.62	18.53	13.01
				14.61	18.54	13.03
				15.30		
				15.29		
				19.56		
				19.56		
				20.29		
				20.27		
				19.71		
				19.70		
15.56				18.10		
15.54				18.11		

BENCHMARK PROBLEM SOLUTION

Identification: 11-A1-4 Benchmark Problem ID.11-A1
Date Submitted: June 1976 By: D. A. Meneley (Ontario Hydro)
Date Accepted: June 1977 By: H. L. Dodds, Jr. (U. of Tenn.)
 M. V. Gregory (SRL)

Descriptive Title: Three-dimensional PWR Problem

Mathematical Model: Seven-point central-difference formula with fluxes calculated at the center of the mesh cell. Two term Taylor series expansion to cell boundary in each direction to satisfy flux and current continuity at cell boundaries.

Special Acceleration Techniques: The code is based on I/O transfer of all data for one mesh plane in a single group. Line inversion with successive overrelaxation is used in each plane, with optimum overrelaxation factor calculated from data for all planes and groups. Inner iteration is continued for all points in a plane until the error norm is 10 percent of that found in the first iteration (arbitrary choice). The planar fluxes are overrelaxed using a second optimum overrelaxation factor calculated from the rate of relaxation of plane fluxes. A one-dimensional rebalance calculation is carried out in the direction perpendicular to the mesh planes. Asymptotic acceleration of all fluxes is carried out periodically when the convergence rate becomes asymptotic.

Initialization: Group one fluxes set to 1.0 and group two fluxes set to 0.25. Eigenvalue set to 1.0. Over relaxation factor for iterations in plane set to 1.2 and factor for overrelaxation of plane fluxes set to 1.4.

Convergence: Maximum value of flux change over two iterations relative to root mean square flux in the reactor less than 5×10^{-5} .

Primary Results:

1. Maximum Eigenvalue

<u>Uniform Mesh</u>	<u>Eigenvalue</u>
17 x 17 x 19	1.02913
34 x 34 x 38	1.02864

2. Fundamental flux distributions (Values for 34 x 34 x 38 mesh).

2.1 Radial Flux Traverses in Midplane

x(cm)	$\phi_1(x, 2.5, 185)$	$\phi_2(x, 2.5, 185)$	$\phi_1(x, x, 195)$	$\phi_2(x, x, 85)$
2.5	49.61	7.872	49.61	7.872
7.5	53.46	8.40	56.77	9.707
12.5	61.56	13.97	67.70	15.80
17.5	67.76	15.85	73.78	17.31
22.5	72.10	16.92	77.09	18.09
27.5	74.86	17.56	78.48	18.42
32.5	76.25	17.90	78.48	18.42
37.5	76.49	17.96	77.39	18.16
42.5	75.71	17.77	75.41	17.70
47.5	73.78	17.32	72.58	17.04
52.5	70.83	16.62	68.85	16.16
57.5	66.68	15.64	64.15	15.06
62.5	61.14	14.30	58.12	13.64
67.5	53.98	12.27	50.24	11.73
72.5	45.27	7.510	39.24	6.728
77.5	40.34	6.403	31.08	4.935
82.5	38.54	6.108	27.38	4.345
87.5	39.70	6.554	27.20	4.682
92.5	43.92	9.954	27.67	6.812
97.5	46.74	10.92	24.01	6.011
102.5	48.12	11.29	17.86	4.831
107.5	48.36	11.35	10.30	4.825
112.5	47.69	11.19	2.911	9.539
117.5	46.25	10.86	0.9978	4.870
122.5	44.17	10.38	0.3278	1.757
127.5	41.52	9.803	0.08347	0.2827
132.5	38.29	9.430		
137.5	33.71	8.383		
142.5	27.79	7.155		
147.5	20.27	6.993		
152.5	9.298	18.09		
157.5	4.598	14.99		
162.5	2.229	9.171		
167.5	.9918	3.633		

2.2 Radial Flux Traverses at $z = 275$

$x(\text{cm})$	$\phi_1(x, 2.5, 275)$	$\phi_2(x, 2.5, 275)$	$\phi_1(x, x, 275)$	$\phi_2(x, x, 275)$
2.5	27.74	4.466	27.74	4.400
7.5	29.87	4.938	38.68	5.414
12.5	34.32	7.787	37.61	8.774
17.5	37.73	8.822	40.67	9.545
22.5	40.06	9.394	41.93	9.839
27.5	41.51	9.743	41.81	9.809
32.5	42.26	9.918	40.62	9.472
37.5	42.43	9.960	39.26	9.135
42.5	42.06	9.870	38.37	8.931
47.5	41.16	9.659	37.94	8.846
52.5	39.71	9.322	37.39	8.774
57.5	37.63	8.828	35.93	8.431
62.5	34.78	8.136	33.36	7.829
67.5	30.99	7.041	29.40	6.860
72.5	26.32	4.356	23.34	4.001
77.5	23.74	3.766	18.79	2.983
82.5	23.00	3.648	16.80	2.667
87.5	24.02	3.966	16.87	2.907
92.5	26.86	6.090	17.29	4.256
97.5	28.84	6.740	15.07	3.773
102.5	29.91	7.026	11.24	3.042
107.5	30.24	7.095	6.499	3.045
112.5	29.98	7.035	1.838	6.024
117.5	29.20	6.855	.6307	3.080
122.5	27.99	6.572	.2074	1.112
127.5	26.40	6.235	.05286	0.1790
132.5	24.40	6.011		
137.5	21.53	5.353		
142.5	17.78	4.576		
147.5	12.99	4.481		
152.5	5.966	11.60		
157.5	2.955	9.617		
162.5	1.430	5.886		
167.5	0.6367	2.333		

2.3 Radial Flux Traverses at $z = 285$

$x(\text{cm})$	$\phi_1(x, 2.5, 285)$	$\phi_2(x, 2.5, 285)$	$\phi_1(x, x, 285)$	$\phi_2(x, x, 285)$
2.5	24.01	3.808	24.01	3.808
7.5	25.83	4.270	27.38	4.678
12.5	29.65	6.728	32.39	7.559
17.5	32.55	7.613	34.80	8.166
22.5	34.50	8.094	35.38	8.305
27.5	35.71	8.377	34.15	7.968
32.5	36.31	8.521	30.16	5.205
37.5	36.44	8.552	27.20	4.390
42.5	36.14	8.475	26.54	4.283
47.5	35.42	8.311	28.11	4.844
52.5	34.25	8.040	30.58	7.137
57.5	32.55	7.637	30.50	7.155
62.5	30.18	7.059	28.83	6.764
67.5	26.99	6.126	25.67	5.993
72.5	23.01	3.808	20.53	3.518
77.5	20.85	3.307	16.62	2.639
82.5	20.29	3.218	14.94	2.371
87.5	21.28	3.514	15.06	2.593
92.5	23.88	5.414	15.45	3.805
97.5	25.70	6.007	13.49	3.338
102.5	26.70	6.265	10.07	2.724
107.5	27.04	6.343	5.822	2.729
112.5	26.83	6.301	1.647	5.402
117.5	26.17	6.144	0.5655	2.762
122.5	25.11	5.898	0.1860	0.9978
127.5	23.70	5.595	0.04741	0.1606
132.5	21.92	5.399		
137.5	19.34	4.811		
142.5	15.98	4.114		
147.5	11.68	4.030		
152.5	5.358	10.44		
157.5	2.652	8.654		
162.5	1.287	5.295		
167.5	0.5727	2.098		

2.4 Axial Flux Traverses for Partially Rodded Assembly

$z(\text{cm})$	$\phi_1(37.5, 37.5, z)$	$\phi_2(37.5, 37.5, z)$
5	0.6295	2.556
15	2.596	7.324
25	11.08	2.852
35	18.48	4.346
45	25.61	6.011
55	32.50	7.631
65	39.10	9.177
75	45.35	10.65
85	51.18	12.01
95	56.55	13.27
105	61.38	14.41
115	65.72	15.42
125	69.39	16.28
135	72.46	17.00
145	74.80	17.56
155	76.55	17.96
165	77.51	18.20
175	77.81	18.26
185	77.39	18.16
195	76.25	17.89
205	74.38	17.45
215	71.79	16.84
225	68.48	16.07
235	64.45	15.13
245	59.74	14.02
255	54.21	12.72
265	47.63	11.18
275	39.26	9.135
285	27.20	4.390
295	20.93	3.321
305	16.75	2.656
315	13.44	2.132
325	10.57	1.678
335	7.986	1.267
345	5.554	0.8816
355	3.172	0.5210
365	0.8491	0.6746
375	0.2221	0.2007

2.5 Value and Location of Maximum Power Density
(Values for 34 x 34 x 38 mesh)

<u>Max/Avg in Core</u>	<u>Location</u>
2.503	27.5,32.5,165
2.243*	57.5,130,165

* Interpolated between adjacent points using finite-difference equation.

4. Convergence Data (34 x 34 x 38 mesh)

Number of unknowns in problem : 73,264
Number of outer iterations : 73
Average number of iterations on
each plane per outer iteration : 3

5. Computer Data (34 x 34 x 38 mesh)

Machine : CDC6600
Field Length : 34,368 words
Iteration Time : 1037 CP seconds
Total Time : 1200 CP seconds
4470 PP seconds

BENCHMARK PROBLEM

Identification: 11-A2

Source Situation ID.11

Date Submitted: June 1976

By: R. R. Lee (CE)
 D. A. Meneley (Ontario Hydro)
 B. Micheelsen (Risø-Denmark)
 D. R. Vondy (ORNL)
 M. R. Wagner (KWU)
 W. Werner (GRS-Munich)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
 M. V. Gregory (SRL)

Descriptive Title: Two-dimensional LWR Problem,
 also 2D IAEA Benchmark Problem

Reduction of Source Situation

1. Two-group diffusion theory
2. Two-dimensional (x,y)-geometry

Two-Group Diffusion Equations:

$$\begin{aligned}
 -\nabla D_1 \nabla \phi_1 + (\Sigma_{a1} + \Sigma_{1 \rightarrow 2} + D_1 B_{z1}^2) \phi_1 &= \frac{1}{\lambda} \nu \Sigma_{f2} \phi_2 \\
 -\nabla D_2 \nabla \phi_2 + (\Sigma_{a2} + D_2 B_{z2}^2) \phi_2 &= \Sigma_{1 \rightarrow 2} \phi_1
 \end{aligned}$$

Data

Two-group Constants

Region	D_1	D_2	$\Sigma_{1 \rightarrow 2}$	Σ_{a1}	Σ_{a2}	$\nu \Sigma_{f2}$	Material
1	1.5	0.4	0.02	0.01	0.08	0.135	Fuel 1
2	1.5	0.4	0.02	0.01	0.085	0.135	Fuel 2
3	1.5	0.4	0.02	0.01	0.13	0.135	Fuel 2 + Rod
4	2.0	0.3	0.04	0	0.01	0	Reflector

Axial buckling $B_{z,g}^2 = 0.8 \cdot 10^{-4}$ for all regions and energy groups.

Note: This 2D IAEA Benchmark Problem represents the midplane $z = 190$ cm of the 3D IAEA Benchmark Problem.

Boundary Conditions:

$$J_g^{\text{in}} = 0 \quad \text{No incoming current at external boundaries.}$$

For finite difference diffusion theory codes the following form is considered equivalent

$$\frac{\partial \phi_g}{\partial n} = -\frac{0.4692}{D_g} \phi_g,$$

where n the outward directed normal to the surface.
At symmetry boundaries:

$$\frac{\partial \phi_g}{\partial n} = 0$$

Expected Primary Results:

1. Maximum eigenvalue
2. Fundamental flux distributions
 - 2.1 Radial flux traverses $\phi_g(x,0)$ and $\phi_g(x,x)$

Note: The fluxes shall be normalized such that

$$\frac{1}{V_{\text{Core}}} \int_{V_{\text{Core}}} \sum_g v \Sigma_{tg} \phi_g dV = 1$$

- 2.2 Value and location of maximum power density. This corresponds to maximum of ϕ_2 in the core. It is recommended that the maximum values of ϕ_2 both in the inner core and at the core/reflector interface be given.

3. Average subassembly powers P_k

$$P_k = \frac{1}{V_k} \int \sum_g v \Sigma_{fg} \phi_g dV$$

where V_k volume of the k-th subassembly and k designates the fuel subassemblies as shown in lower octant of Fig. 1

4. Number of unknowns in the problem, number of iterations, total and outer
5. Total computing time, iteration time, IO-time, computer used
6. Type and numerical values of convergence criteria
7. Table of average group fluxes for a square mesh grid of 20 x 20 cm
8. Dependence of results on mesh spacing

Best Solution Available: Extrapolated finite difference solution described in 11-A2-1

Solutions

1. Finite Difference Method: 11-A2-1
2. Finite Element Method: 11-A2-2
3. Nodal Expansion Method: 11-A2-3
4. Finite Difference Method: 11-A2-4

Benchmark Problem 11.A2

By: D. R. Vondy, T. B. Fowler (ORNL)

By: H. L. Dodds, Jr. (U. of Tenn.)
M. V. Gregory (SRL)

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ORNL-DWG 74-10811

Table 1

IAEA BENCHMARK PROBLEM

(Two-Group, Two-Dimensional, $B_1^2=8 \times 10^{-5}$)

Meshpoints (Total Unknowns)	k_{eff}	Peak-to-Average Power Density	IBM-360/91 Processor Time (min)
<u>Old Code External-2</u> (mesh-edge points, zero flux external boundary)			
16x16(512)	1.03651	2.2404	0.20
33x33(2,178)	1.03065	1.6538	1.0
67x67(8,978)	1.03033	1.5314	(10.)
Extrapolated	1.03022	1.491	
<u>VENTURE</u> (mesh-centered points, non-return external boundary)			
9x9(162)	1.03208	1.5493	0.05
17x17(578)	1.02965	1.6486	0.06
34x34(2,312)	1.02924	1.5985	0.32
68x68(9,248)	1.02944	1.5442	3.4
136x136(36,992)	1.02954	1.5217	13.5
272x272(147,968)	1.02958	1.5149	80
Extrapolated	1.02959	1.5126	

Figure 1. Two-Dimensional Finite-Difference Results

Two-Dimensional Finite-Difference Results.

Table 2. Zone Average Fast Group Flux - Mesh Centered VENTURE

(Results below should be multiplied by 1.78 for proper normalization)

Location/ Intervals	9x9	17x17	34x34	68x68	272x272	Extrapolated
1	17.35	19.28	19.37	18.77	18.37	18.34
2	25.20	26.42	25.30	24.27	23.71	23.67
3	27.12	28.43	27.46	26.49	25.96	25.92
4	23.48	23.87	23.06	22.30	21.89	21.86
5	13.14	14.92	15.32	15.16	15.02	15.01
6	17.53	17.09	17.01	16.95	16.92	16.92
7	16.19	15.80	16.15	16.45	16.61	16.62
8	11.55	10.37	10.76	11.21	11.47	11.49
9	0.954	1.202	1.531	1.772	1.898	1.906
10	27.14	28.46	27.28	26.23	25.65	25.61
11	27.61	28.87	27.90	26.94	26.42	26.39
12	24.73	25.45	24.63	23.90	23.49	23.46
13	19.56	20.39	19.96	19.56	19.35	19.34
14	18.77	18.62	18.54	18.51	18.49	18.49
15	16.45	15.98	16.34	16.67	16.85	16.86
16	11.23	10.06	10.46	10.93	11.20	11.22
17	0.921	1.144	1.458	1.690	1.813	1.821
18	27.28	28.38	27.53	26.99	26.23	26.18
19	24.82	25.59	24.96	24.35	24.01	23.99
20	21.14	21.77	21.50	21.20	21.04	21.03
21	19.02	18.85	18.93	19.00	19.03	19.03
22	16.96	15.53	15.80	16.19	16.42	16.43
23	9.222	8.176	8.616	9.114	9.394	9.413
24	0.733	0.856	1.088	1.272	1.372	1.380
25	22.21	22.50	22.00	21.55	21.30	21.28
26	17.86	17.97	17.75	17.57	17.46	17.45
27	16.14	15.70	15.83	16.00	16.09	16.10
28	12.77	11.62	12.01	12.48	12.74	12.76
29	1.682	2.104	2.686	3.115	3.346	3.361
30	0.188	0.239	0.3136	0.3704	0.4012	0.4033
31	9.374	10.79	11.32	11.48	11.52	11.52
32	12.26	11.18	11.31	11.57	11.72	11.73
33	8.075	7.136	7.482	7.903	8.141	8.157
34	0.712	0.849	1.080	1.263	1.362	1.369
35	8.206	7.071	7.320	7.690	7.904	7.918
36	1.217	1.417	1.789	2.083	2.244	2.255
37	0.150	0.190	0.2511	0.2975	0.3226	0.3243
38	0.190	0.221	0.2844	0.3343	0.3616	0.3634

Table 3. Zone Average Thermal Group Flux - Mesh Centered VENTURE

(Results below should be multiplied by 1.78 for proper normalization)

Location/ Intervals	9x9	17x17	34x34	68x68	272x272	Extrapolated
1	2.796	3.131	3.202	3.155	3.122	3.120
2	5.898	6.173	5.891	5.633	5.491	5.482
3	6.367	6.673	6.446	6.218	6.093	6.085
4	5.501	5.581	5.372	5.181	5.075	5.068
5	2.113	2.422	2.531	2.548	2.552	2.552
6	4.105	3.990	3.957	3.921	3.915	3.914
7	3.803	3.712	3.797	3.869	3.908	3.911
8	2.900	2.670	2.863	3.050	3.153	3.160
9	3.286	3.706	4.105	4.368	4.505	4.514
10	6.372	6.678	6.401	6.151	6.015	6.006
11	6.483	6.777	6.548	6.342	6.202	6.193
12	5.806	5.972	5.779	5.604	5.510	5.503
13	4.580	4.766	4.647	4.541	4.481	4.477
14	4.407	4.371	4.351	4.342	4.336	4.336
15	3.865	3.759	3.848	3.930	3.974	3.977
16	2.818	2.587	2.781	2.969	3.072	3.079
17	3.163	3.510	3.891	4.149	4.284	4.293
18	6.406	6.662	6.462	6.265	6.157	6.149
19	5.826	6.005	5.860	5.714	5.635	5.630
20	4.964	5.111	5.047	4.977	4.938	4.935
21	4.468	4.430	4.450	4.469	4.479	4.480
22	4.201	3.847	3.918	4.019	4.076	4.080
23	2.369	2.220	2.494	2.746	2.887	2.896
24	2.498	2.637	2.944	3.176	3.299	3.307
25	5.214	5.280	5.162	5.055	4.996	4.992
26	4.185	4.201	4.138	4.082	4.049	4.047
27	3.794	3.690	3.726	3.768	3.792	3.794
28	3.223	3.016	3.224	3.423	3.533	3.540
29	5.641	6.040	6.518	6.844	7.013	7.024
30	0.9503	1.122	1.336	1.497	1.584	1.590
31	1.506	1.755	1.878	1.937	1.967	1.969
32	3.031	2.756	2.780	2.836	2.867	2.869
33	2.071	1.930	2.156	2.371	2.490	2.498
34	2.543	2.724	3.041	3.280	3.406	3.414
35	2.115	1.929	2.129	2.327	2.440	2.448
36	4.045	4.038	4.330	4.570	4.698	4.707
37	0.7636	0.889	1.059	1.190	1.261	1.266
38	0.9518	1.045	1.222	1.364	1.443	1.448

Table 4. TWO-DIMENSIONAL, TWO-GROUP IAEA BENCHMARK PROBLEM RESULTS

Formulation (Near Neighbors)	Mesh Intervals	k_{eff}	Peak Relative Power Density	
			Internal	Near Reflector
Meshpoint Centered, VENTURE (4)	9 ²	1.03208	1.549	
	17 ²	1.02965	1.649	
	34 ²	1.02924	1.599	
	68 ²	1.02944	1.544	
	136 ²	1.02954	1.522	
Extrapolated	272 ²	1.02958	1.515	
	(∞)	1.02959	1.513	
Mesh Edge, VANCER				
Usual Finite-Difference (4)	9 ²	1.07647	none	4.28
	17 ²	1.03733	0.962	2.231
	34 ²	1.03077	1.364	1.660
	68 ²	1.02983	1.475	1.546
	(∞)	1.02952	1.512	1.508
Taylor Series (8)	34 ²	1.03080	1.364	1.652
Higher Order Taylor Series (8)	17 ²	1.03442	1.095	2.043
	34 ²	1.03036	1.405	1.629
	68 ²	1.02975	1.485	1.544
	(∞)	1.02955	1.512	1.516
	17 ²	1.03109	1.309	1.779
Linear Finite-Element (8)*	34 ²	1.02985	1.462	1.605
	68 ²	1.02965	1.499	1.545
	(∞)	1.02958	1.511	1.525
	17 ²	1.03236	1.214	1.887
	34 ²	1.03006	1.437	1.614
Linear Finite-Difference (8)*	68 ²	1.02969	1.493	1.544
	(∞)	1.02957	1.512	1.521
	17 ²	1.03390	1.123	2.009
	34 ²	1.03028	1.412	1.625
	68 ²	1.02973	1.487	1.544
Compromise (8)	(∞)	1.02955	1.512	1.517
	34 ²	1.03051	1.389	1.645
	68 ²	1.02978	1.481	1.544
	(∞)	1.02954	1.512	1.510
	17 ²	1.03206	1.228	1.900
Simple Compromise (4)	34 ²	1.03002	1.438	1.628
	68 ²	1.02968	1.493	1.547
	(∞)	1.02957	1.511	1.520
	17 ²	1.03206	1.228	1.900
	34 ²	1.03002	1.438	1.628
Compensated Difference (4)*	68 ²	1.02968	1.493	1.547
	(∞)	1.02957	1.511	1.520
	17 ²	1.03206	1.228	1.900
	34 ²	1.03002	1.438	1.628
	68 ²	1.02968	1.493	1.547
Local Source				
H-O Taylor Series (8)	34 ²	1.03162	1.393	1.724
Linear Finite-Element (8)	34 ²	1.03229	1.402	1.792
Linear Finite-Difference (8)	34 ²	1.03280	1.422	1.860
Compromise (8)	34 ²	1.03178	1.387	1.737
Simple Compromise (4)	34 ²	1.03126	1.375	1.700
Compensated Difference (4)	34 ²	1.03224	1.403	1.799
Apparent Solution		1.02958	1.51	1.52

*Results for 9² mesh inadequate, resulting flux skewed; the only clue of inadequate solution is a neutron balance k .

BENCHMARK PROBLEM SOLUTION

Identification: 11-A2-2

Benchmark Problem ID.11-A2

Date Submitted: June 1976

By: Ib Misfeldt (Risø-Denmark)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
M. V. Gregory (SRL)

Descriptive Title: Two-dimensional PWR Problem

Mathematical Model: FEM (2nd order Lagrange interpolation,
rectangular elements)Pertinent Features of Solution Method: The grid had 36 x 36 meshes and
73 x 73 flux points.

Computer: B 6700

Date Solved: August 25, 1975
at: Risø, Denmark

Program: FEMB

References

1. Ib Misfeldt, "Solution of the multigroup neutron diffusion equations by the finite element method," Risø-M-1809 (1975).
2. G. K. Kristiansen, "Investigation of the accuracy of centerpoint-, cornerpoint-, and finite-element-methods for solution of the neutron diffusion equation," NEACRP-L-149 (1976).

Results

1. Maximum eigenvalue: $k_{\text{eff}} = 1.0296$

2. Fundamental flux distributions

2.1. See Tables 2A and 2B of flux traverses.

2.2. Maximum power density

Uninterpolated values are given

 $(\phi_2)_{\text{max},1} = 12.31$ at $(x,y) = (130,55)$ $(\phi_2)_{\text{max},2} = 11.18$ at $(x,y) = (30,30)$

3. Average subassembly powers

See Table 2C.

4. Number of unknowns and iteration number

73 x 73 x 2 unknowns; 120 iterations.

5. Computing times

2½ hours cp=time; ½ hour io-time, on B 6700.

6. Convergence criteria

Maximal flux-error-estimate less than 0.01% of $\phi_{\max}$ in each group.

7. Average group-fluxes for 20 x 20 cm grid

See Table 2D.

8. Dependence of results on mesh spacing

See Refs. 1 and 2.

Table 2A

Flux along x-axis

X	PHI1	PHI2
0.000	29.350	4.620
1.250	29.422	4.633
2.500	29.641	4.675
3.750	30.009	4.750
5.000	30.531	4.868
6.250	31.211	5.049
7.500	32.052	5.336
8.750	33.046	5.809
10.000	34.166	6.646
12.500	36.512	8.164
15.000	38.666	8.945
17.500	40.501	9.468
20.000	42.030	9.853
22.500	43.280	10.155
25.000	44.282	10.393
27.500	45.061	10.577
30.000	45.635	10.712
32.500	46.019	10.802
35.000	46.223	10.850
37.500	46.255	10.857
40.000	46.120	10.826
42.500	45.819	10.755
45.000	45.355	10.646
47.500	44.725	10.498
50.000	43.926	10.310
52.500	42.950	10.081
55.000	41.788	9.808
57.500	40.426	9.486
60.000	38.845	9.107
62.500	37.021	8.656
65.000	34.934	8.085
67.500	32.576	7.289
70.000	30.063	5.846
72.500	27.763	4.618
75.000	25.984	4.157
77.500	24.760	3.909
80.000	24.042	3.787
82.500	23.801	3.756
85.000	24.035	3.840
87.500	24.765	4.107
90.000	25.939	5.020
92.500	27.277	6.087
95.000	28.463	6.579
97.500	29.398	6.871
100.000	30.097	7.055
102.500	30.582	7.176
105.000	30.879	7.247
107.500	31.010	7.279
110.000	30.991	7.274
112.500	30.836	7.238
115.000	30.557	7.173

Table 2A (cont'd)

117.500	30.164	7.081
120.000	29.664	6.964
122.500	29.064	6.827
125.000	28.371	6.676
127.500	27.585	6.525
130.000	26.689	6.434
132.500	25.629	6.300
135.000	24.355	6.025
137.500	22.854	5.677
140.000	21.128	5.292
142.500	19.178	4.920
145.000	16.945	4.746
147.500	14.273	5.182
150.000	10.430	7.976
152.500	7.301	12.063
155.000	5.107	12.443
157.500	3.565	11.132
160.000	2.480	9.136
162.500	1.711	6.976
165.000	1.162	4.838
167.500	0.762	2.743
170.000	0.459	0.580

Table 2BFlux along the diagonal $x = y$

x	y	PHI1	PHI2
0.000	0.000	29.350	4.620
1.250	1.250	29.494	4.647
2.500	2.500	29.927	4.730
3.750	3.750	30.642	4.876
5.000	5.000	31.628	5.101
6.250	6.250	32.865	5.440
7.500	7.500	34.317	5.961
8.750	8.750	35.921	6.778
10.000	10.000	37.562	8.030
12.500	12.500	40.453	9.391
15.000	15.000	42.671	10.000
17.500	17.500	44.343	10.406
20.000	20.000	45.590	10.701
22.500	22.500	46.493	10.913
25.000	25.000	47.108	11.058
27.500	27.500	47.480	11.145
30.000	30.000	47.642	11.183
32.500	32.500	47.621	11.178
35.000	35.000	47.436	11.135
37.500	37.500	47.106	11.057
40.000	40.000	46.640	10.948
42.500	42.500	46.046	10.808
45.000	45.000	45.325	10.639
47.500	47.500	44.476	10.440
50.000	50.000	43.493	10.209
52.500	52.500	42.363	9.944
55.000	55.000	41.073	9.641
57.500	57.500	39.601	9.295
60.000	60.000	37.922	8.901
62.500	62.500	35.998	8.448
65.000	65.000	33.776	7.916
67.500	67.500	31.177	7.241
70.000	70.000	28.120	6.013
72.500	72.500	24.843	4.306
75.000	75.000	21.997	3.572
77.500	77.500	19.869	3.146
80.000	80.000	18.479	2.914
82.500	82.500	17.783	2.815
85.000	85.000	17.681	2.873
87.500	87.500	18.019	3.145
90.000	90.000	18.447	4.081
92.500	92.500	18.398	4.495
95.000	95.000	17.696	4.385
97.500	97.500	16.444	4.103
100.000	100.000	14.747	3.746
102.500	102.500	12.688	3.400
105.000	105.000	10.293	3.301
107.500	107.500	7.555	3.832
110.000	110.000	4.283	6.272
112.500	112.500	2.399	6.920

Table 2B (cont'd)

115.000	115.000	1.382	5.429
117.500	117.500	0.803	3.767
120.000	120.000	0.463	2.387
122.500	122.500	0.260	1.360
125.000	125.000	0.138	0.652
127.500	127.500	0.066	0.211
130.000	130.000	0.025	0.010
132.500	132.500	0.000	0.000

Table 2C

Average subassembly powers

170.00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
150.00	0.7571	0.7379	0.6952	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
130.00	0.9350	0.9512	0.9761	0.8485	0.5997	0.0000	0.0000	0.0000	0.0000	0.0000
110.00	0.9345	1.0359	1.0706	0.9068	0.6859	0.5874	0.0000	0.0000	0.0000	0.0000
90.00	0.6099	1.0684	1.1783	0.9661	0.4712	0.6860	0.5998	0.0000	0.0000	0.0000
70.00	1.2083	1.3128	1.3433	1.1916	0.9662	0.9070	0.8487	0.0000	0.0000	0.0000
50.00	1.4509	1.4772	1.4671	1.3434	1.1785	1.0708	0.9764	0.6954	0.0000	0.0000
30.00	1.3068	1.4323	1.4773	1.3130	1.0686	1.0362	0.9516	0.7382	0.0000	0.0000
10.00	0.7443	1.3068	1.4510	1.2084	0.6100	0.9348	0.9354	0.7574	0.0000	0.0000
0.00	10.00	30.00	50.00	70.00	90.00	110.00	130.00	150.00	170.00	170.00

Table 2D, group 1

Flux averages

Group 1

170.00									
3.3944	3.2431	2.4578	0.7188	0.0215	0.0040	0.0000	0.0000	0.0000	
150.00									
20.3675	19.8959	16.7075	5.9875	2.4387	0.5778	0.0100	0.0000	0.0000	
130.00									
29.4320	29.8661	29.1220	22.6278	14.4753	4.0186	0.6479	0.0100	0.0000	
110.00									
29.9296	32.7203	33.6976	28.5075	20.7859	14.0517	4.0194	0.5781	0.0040	
90.00									
20.5281	34.1781	37.1833	30.8752	20.3850	20.7890	14.4796	2.4397	0.0215	
70.00									
38.6266	41.4685	42.3909	37.6359	30.8782	28.5131	22.6343	5.9895	0.7190	
50.00									
45.7876	46.6162	46.2972	42.3941	37.1893	33.7055	29.1304	16.7128	2.4586	
30.00									
41.8016	45.2435	46.6185	41.4731	34.1849	32.7299	29.8766	19.9035	3.2444	
10.00									
32.3916	41.8032	45.7911	38.6309	26.5336	29.9397	29.4437	20.3760	3.3959	
0.00	10.00	30.00	50.00	70.00	90.00	110.00	130.00	150.00	170.00

BENCHMARK PROBLEM SOLUTION

Identification:	11-A2-3	Benchmark Problem ID.11-A2
Date Submitted:	June 1976	By: K. Koebke (KWU) M. R. Wagner (KWU)
Date Accepted:	June 1977	By: H. L. Dodds, Jr. (U. of Tenn.) M. V. Gregory (SRL)

Descriptive Title: Nodal Solutions for Two-dimensional LWR Problem (2D IAEA Benchmark Problem)

Mathematical Model

The nodal expansion method, a higher order nodal method as described in References 1 to 4, is used. Nodal balance equations are obtained by integrating the P1-form of the group diffusion equations over parallelepipeds (nodes). The spatial coupling between nodes is expressed in terms of interface current relations.

Pertinent Features of Solution Methods

A consistent scheme is used for the iterative self-generation of spatial coupling coefficients as an integral part of the overall calculational procedure. The nodal coefficients are computed from auxiliary one-dimensional diffusion equations for the transverse average of the group fluxes, for each space direction of every node.

The channel fluxes are represented by high order polynomial expansion and a Galerkin scheme is used to determine the free expansion coefficients. The spatial distribution of the transverse leakage is approximated by a second order polynomial based on information from adjacent nodes, see Refs. 3 and 4 for details.

After convergence local flux and power distributions may be computed a posteriori by a high order local interpolation method, Ref. 5. The point fluxes in Exhibits A1 and A2 and in Tables 1 and 2, as well as the maximum local power densities per assembly, shown in Table 3, were obtained in that way.

Solution Technique

A conventional outer fission source iteration is used with one inner per outer iteration. For convergence acceleration a combination of coarse mesh rebalancing and asymptotic source extrapolation is applied.

Program Name: MEDIUM-2 (KWU)

Type of Program: Multidimensional LWR depletion code

Results of two solutions for an octant with a square mesh of $h = 3^{1/3}$ and $h = 10$ cm are given below. The order of approximation is G_3B^2 (5th-order polynomial expansion for the channel fluxes and second order approximation for the transverse neutron leakage).

1. k-effective:	1.029585	$h = 3^{1/3}$ cm
	1.029611	$h = 10$ cm

2. Fundamental Flux Distributions

2.1 Radial flux traverses, see Exhibits A1 and A2.
The pointwise flux values are given in Tables 1 and 2.

2.2 Value and Location of Maximum Thermal Flux ϕ_2

h (cm)	Inner Core		at Core Boundary	
	Value	Location	Value	Location
$3^{1/3}$	11.206	(31, 31)	11.317	(130, 55.35)
10	11.195	(30, 30)	11.335	(130, 56)

3. Average Subassembly Powers P_k , see Table 3

	$h = 3 \frac{1}{3} \text{ cm}$	10 cm
4. Number of Unknowns/Group	5481	609
Number of Iterations	42	26

Note: Number of unknowns per node and energy group:
average node flux plus 4 partial out-currents

	$h = 3 \frac{1}{3} \text{ cm}$	10 cm
5. Iteration Time (CP)	15.12 sec	1.34 sec
Computer Used	CYBER 175	

6. Pointwise Convergence Criterium:

$$\text{Max}_m \left| \frac{Q_{fm}^n - Q_{fm}^{n-1}}{Q_{fm}^{n-1}} \right| < \epsilon_{\text{point}}$$

where

$$Q_{fm}^n = \sum_g v \Sigma_{fg}^m \phi_g^{m,n}$$

$\phi_g^{m,n}$ average group flux for node m , outer iteration n .

Numerical value of $\epsilon_{\text{point}} = 1 \cdot 10^{-6}$ for $h = 3 \frac{1}{3} \text{ cm}$
 $= 7 \cdot 10^{-6}$ $h = 10 \text{ cm}$

7. Table of average group fluxes, see Tables 4 and 5.

References

1. H. Finnemann, A Consistent Nodal Method for the Analysis of Space-Time Effects in Large LWR's Proc. of the Joint NEACRP/CSNI Specialists' Meeting on New Developments in Three-Dimensional Neutron Kinetics and Review of Kinetics Benchmark Calculations MRR 145. p. 131 (1975)
2. F. Bennewitz, H. Finnemann, H. Moldaschl, CONF-750413, Proc. Conf. on Comput. Methods in Nucl. Eng., April 15 - 17, 1975 Charleston, South Carolina
3. H. Finnemann, M.R. Wagner, The Nodal Expansion Method: A New Computational Technique for the Solution of Multidimensional Neutron Diffusion Problems, IAEA Specialists' Meeting on Methods of Neutron Transport Theory in Reactor Calculations, Bologna, Italy 3 - 5 Nov. 1975.
4. F. Bennewitz, H. Finnemann, M.R. Wagner, Higher Order Corrections in Nodal Reactor Calculations, Trans. Am. Nucl. Soc. 22, 250 (1975).
5. K. Koebeke, Berechnung lokaler Fluß- und Leistungsverteilungen durch nachträgliche Interpolation nodaler Grobmaschenverfahren, Reactor-Congress Düsseldorf 1976, Paper No. 120, Proceedings p. 79 - 82.

$x(\text{cm})$	$\phi_1(x,0)$	$\phi_2(x,0)$	$x(\text{cm})$	$\phi_1(x,0)$	$\phi_2(x,0)$
0	29.419	4.631	60	38.909	9.123
2	29.603	4.665	62	37.469	8.770
4	30.171	4.780	64	35.859	8.351
6	31.135	5.017	66	34.075	7.824
8	32.506	5.506	68	32.132	7.083
10	34.246	6.654	70	30.111	5.863
12	36.133	7.953	72	28.225	4.789
14	37.921	8.701	74	26.668	4.301
16	39.521	9.200	76	25.468	4.037
18	40.917	9.576	78	24.607	3.878
20	42.116	9.875	80	24.071	3.789
22	43.140	10.122	82	23.835	3.756
24	43.999	10.326	84	23.908	3.786
26	44.709	10.494	86	24.289	3.910
28	45.282	10.628	88	24.983	4.224
30	45.725	10.733	90	25.954	5.030
32	46.047	10.808	92	27.030	5.940
34	46.252	10.856	94	28.025	6.425
36	46.345	10.878	96	28.871	6.718
38	46.329	10.874	98	29.559	6.916
40	46.206	10.846	100	30.095	7.056
42	45.978	10.792	102	30.497	7.155
44	45.644	10.714	104	30.774	7.222
46	45.205	10.611	106	30.939	7.262
48	44.659	10.482	108	31.003	7.277
50	44.003	10.328	110	30.973	7.270
52	43.236	10.148	112	30.857	7.243
54	42.349	9.940	114	30.659	7.196
56	41.339	9.702	116	30.386	7.133
58	40.197	9.432	118	30.042	7.052

Table 1: Radial Flux Traverse $\phi_g(x,0)$ Along Main Axis

$x(\text{cm})$	$\phi_1(x,0)$	$\phi_2(x,0)$
120	29.631	6.956
122	29.156	6.847
124	28.621	6.727
126	28.027	6.603
128	27.372	6.489
130	26.643	6.423
132	25.810	6.329
134	24.843	6.134
136	23.731	5.880
138	22.475	5.587
140	21.078	5.273
142	19.537	4.968
144	17.833	4.742
146	15.904	4.764
148	13.573	5.473
150	10.371	7.978
152	7.797	11.582
154	5.858	12.527
156	4.397	11.993
158	3.294	10.702
160	2.461	9.077
162	1.828	7.350
164	1.344	5.630
166	.971	3.946
168	.676	2.271
170	.437	.538

Table 1: (continued)

x(cm)	$\phi_1(x,x)$	$\phi_2(x,x)$	x(cm)	$\phi_1(x,x)$	$\phi_2(x,x)$
0	29.419	4.631	70	28.145	6.024
2	29.789	4.700	72	25.498	4.568
4	30.889	4.925	74	23.077	3.801
6	32.673	5.372	76	21.073	3.363
8	35.025	6.257	78	19.543	3.085
10	37.649	8.040	80	18.486	2.910
12	40.019	9.242	82	17.874	2.821
14	41.945	9.814	84	17.659	2.818
16	43.487	10.201	86	17.772	2.933
18	44.715	10.494	88	18.100	3.276
20	45.682	10.722	90	18.430	4.081
22	46.428	10.898	92	18.440	4.476
24	46.984	11.028	94	18.021	4.451
26	47.374	11.120	96	17.222	4.276
28	47.617	11.177	98	16.101	4.022
30	47.729	11.203	100	14.709	3.726
32	47.724	11.202	102	13.087	3.439
34	47.612	11.175	104	11.258	3.255
36	47.402	11.126	106	9.216	3.363
38	47.102	11.056	108	6.889	4.150
40	46.716	10.965	110	4.254	6.257
42	46.247	10.855	112	2.669	7.066
44	45.698	10.726	114	1.711	6.074
46	45.068	10.578	116	1.106	4.723
48	44.354	10.411	118	.715	3.444
50	43.552	10.223	120	.459	2.372
52	42.657	10.013	122	.289	1.525
54	41.662	9.779	124	.176	.889
56	40.556	9.519	126	.102	.437
58	39.328	9.231	128	.055	.149
60	37.964	8.911	130	.033	.030
62	36.443	8.553			
64	34.740	8.149			
66	32.818	7.680			
68	30.632	7.080			

Table 2: Radial Flux Traverse $\phi_g(x,x)$
Along Diagonal

J/I	1	2	3	4	5	6	7	8
1	.744 1.085 11 11	1.308 1.462 11 11	1.452 1.478 4 11	1.210 1.406 1 11	.609 .951 1 11	.935 .998 9 11	.934 .993 1 11	.755 1.079 11 6
2		1.434 1.511 11 11	1.479 1.511 1 11	1.314 1.446 1 11	1.069 1.265 1 11	1.036 1.122 1 11	.951 1.059 1 11	.736 1.070 11 1
3			1.468 1.511 1 1	1.344 1.446 1 1	1.179 1.274 1 4	1.071 1.132 1 4	.976 1.125 11 11	.693 1.439 3 11
4				1.192 1.379 1 1	.967 1.206 1 1	.907 1.062 1 1	.847 1.530 11 4	
		h = 10 cm						
5					.471 .814 1 1	.686 .810 6 1	.599 1.079 11 1	
6						.587 1.043 11 3		

Table 3 Average and Maximum Power Density per Subassembly

Table of average thermal group fluxes ϕ_2
for a square mesh grid of 20 x 20 cm

[illegible]

Mesh description-non-uniform mesh problem.

<u>No. of Intervals In Each Direction</u>	<u>Mesh Spacing</u>
16	2.5
4	2.0
4	1.0
4	2.0
8	2.5
4	2.0
4	1.0
8	2.0
4	1.0
3	2.0
4	1.0
8	2.0
4	1.0
4	2.0
4	2.5

Note: This mesh places two intervals of 1.0 cm width on each side of core-reflector boundary.

2. Fundamental flux distributions- values for 88 x 88 mesh

2.1 Radial Flux Traverses $\phi_g(x,0)$ and $\phi_g(x,x)$

x(cm)	$\phi_1(x,1.25)$	$\phi_2(x,1.25)$	$\phi_1(x,x)$	$\phi_2(x,x)$
1.25	29.83	4.704	29.83	4.704
3.75	30.42	4.822	30.99	4.936
6.25	31.62	5.116	33.22	5.493
8.75	33.48	5.817	36.32	6.726
11.25	35.89	7.776	39.62	9.085
13.75	38.18	8.756	42.16	9.862
16.25	40.16	9.362	44.07	10.34
18.75	41.82	9.797	45.50	10.68
21.25	43.19	10.13	46.55	10.93
23.75	44.30	10.40	47.29	11.10
26.25	45.18	10.60	47.76	11.21
28.75	45.84	10.76	48.01	11.27
31.25	46.31	10.87	48.06	11.28
33.75	46.59	10.94	47.93	11.25
36.25	46.70	10.96	47.66	11.19
38.75	46.64	10.95	47.24	11.09
41.00	46.43	10.90	46.74	10.97
43.00	46.15	10.83	46.22	10.85
45.00	45.76	10.74	45.62	10.71

2.1 Radial Flux Traverses $\phi_g(x,o)$ and $\phi_g(x,x)$ (Continued)

x(cm)	$\phi_1(x,1.25)$	$\phi_2(x,1.25)$	$\phi_1(x,x)$	$\phi_2(x,x)$
47.00	45.26	10.62	44.93	10.55
48.50	44.80	10.52	44.36	10.41
49.50	44.47	10.44	43.95	10.32
50.50	44.12	10.36	43.52	10.22
51.50	43.73	10.26	43.06	10.11
53.00	43.11	10.12	42.35	9.939
55.00	42.16	9.894	41.29	9.691
57.00	41.08	9.640	40.11	9.415
59.00	39.87	9.351	38.81	9.109
61.25	38.34	8.981	37.17	8.725
63.75	36.38	8.484	35.10	8.235
66.25	34.16	7.840	32.70	7.650
68.75	31.68	6.875	29.87	6.855
71.25	29.10	5.066	26.52	4.926
73.75	27.02	4.376	23.37	3.872
76.25	25.50	4.044	20.85	3.324
78.75	24.52	3.866	19.06	3.007
81.00	24.07	3.794	18.11	2.855
83.00	23.97	3.788	17.68	2.803
85.00	24.17	3.855	17.62	2.847
87.00	24.69	4.042	17.84	3.037
88.50	25.32	4.381	18.13	3.410
89.50	25.80	4.753	18.29	3.790
90.50	26.33	5.368	18.40	4.259
91.50	26.86	5.795	18.39	4.422
93.00	27.64	6.252	18.19	4.471
95.00	28.54	6.608	17.56	4.351
97.00	29.29	6.838	16.57	4.128
99.00	29.88	6.998	15.30	3.846
101.00	30.32	7.112	13.78	3.547
103.00	30.64	7.190	12.05	3.292
105.00	30.84	7.239	10.13	3.202
107.00	30.94	7.262	7.995	3.517
108.50	30.94	7.262	6.139	4.446
109.50	30.92	7.257	4.836	5.414
110.50	30.87	7.247	3.695	6.774
111.50	30.81	7.231	2.927	7.032
113.00	30.68	7.201	2.072	6.570
115.00	30.43	7.143	1.337	5.303
117.00	30.11	7.067	0.8669	3.977
119.00	29.72	6.976	0.5602	2.818
121.00	29.26	6.871	0.3578	1.882
123.00	28.75	6.754	0.2232	1.163
125.00	28.17	6.628	0.1339	0.6348
127.00	27.54	6.502	0.07498	0.2724
128.50	27.02	6.423	0.04537	0.09840
129.50	26.65	6.385	0.03048	0.02939

2.1 Radial Flux Traverses $\phi_g(x,o)$ and $\phi_g(x,x)$ (Continued)

$x(\text{cm})$	$\phi_1(x,1.25)$	$\phi_2(x,1.25)$	$\phi_1(x,x)$	$\phi_2(x,x)$
130.50	26.26	6.371		
131.50	25.85	6.319		
133.00	25.17	6.200		
135.00	24.13	5.970		
137.00	22.94	5.693		
139.00	21.61	5.387		
141.00	20.14	5.073		
143.00	18.52	4.794		
145.00	16.72	4.649		
147.00	14.65	4.883		
148.50	12.71	5.794		
149.50	11.16	6.926		
150.50	9.479	6.214		
151.50	8.227	10.87		
153.00	6.599	12.27		
155.00	4.963	12.25		
157.00	3.728	11.23		
159.00	2.796	9.740		
161.25	2.002	7.854		
163.75	1.374	5.741		
166.25	0.9195	3.690		
168.75	0.5818	1.648		

2.2 Value and Location of Maximum Power Density

Mesh	Max/Avg Power Density in Core	Location	Refl. Boundary	Location*
34 x 34	1.598	27.5,32.5	1.435	130,52.5
68 x 68	1.545	31.25,31.25	1.508	130,56.25
88 x 88	1.523	31.25,31.25	1.521	130,55

* Interpolated between adjacent points.

3. Average subassembly powers (88 x 88 mesh)

<u>Subassembly Number</u>	<u>Average Power</u>
1	0.7421
2	1.325
3	1.464
4	1.222
5	0.6054
6	0.9357
7	0.9303
8	0.7464
10	1.448
11	1.4905
12	1.323
13	1.077

3. Average subassembly powers (88 x 88 mesh) (Continued)

<u>Subassembly Number</u>	<u>Average Power</u>
14	1.036
15	0.9457
16	0.7272
18	1.478
19	1.351
20	1.182
21	1.069
22	0.9702
23	0.6810
25	1.198
26	0.9714
27	0.9041
28	0.8370
31	0.4656
32	0.6831
33	0.5876
35	0.5762

4. Convergence data

	<u>34x34</u>	<u>68x68</u>	<u>88x88</u>
Number of unknowns	1,928	7,712	11,328
Outer iterations	42	57	73
Avg. No. of inner iteration per outer iteration	5	4	5

5. Computer data (CDC6600 machine)

	<u>34x34</u>	<u>68x68</u>	<u>88x88</u>
Field length (words)	33,664	68,544	100,352
Iteration time (CP)	19	160	340
Total time (CP)	26	182	378
(PP)	70	309	606

6. Type and numerical values of convergence criteria.

Type and value noted above.

7. Average group fluxes on subassembly mesh grid
(20x20 cm, 88 x 88 mesh)

Subassembly Number	$\bar{\phi}_1$	$\bar{\phi}_2$
1	32.71	5.497
2	42.29	9.817
3	46.21	10.85
4	38.98	9.054
5	26.63	4.484
6	29.94	6.931
7	29.29	6.891
8	20.17	5.529
9	3.295	7.898
10	45.72	10.72
11	47.02	11.04
12	41.79	9.802
13	34.37	7.979
14	32.73	7.677
15	29.71	7.005
16	19.69	5.387
17	3.147	7.510
18	46.63	10.95
19	42.64	10.01
20	37.30	8.756
21	33.66	7.919
22	28.94	7.187
23	16.49	5.044
24	2.381	5.777
25	37.82	8.871
26	30.97	7.196
27	28.43	6.697
28	22.42	6.200
29	5.812	12.32
30	0.6944	2.768
31	20.79	3.449
32	20.67	5.060
33	14.30	4.353
34	2.364	5.964
35	13.90	4.293
36	3.899	8.251
37	0.5584	2.197
38	0.6269	2.517

BENCHMARK SOURCE SITUATION

Identification: 12

Date Submitted: June 1976

By: C. T. McDaniel (GE-San Jose)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
D. R. Vondy (ORNL)

Descriptive Title: Neutron Transport in a Cylindrical 'Black' Rod

Suggested Function: Provide severe test of transport programs and approximations

Configuration

Details

Infinite cylinder of radius R

Known angular input current, I

Specified Total Cross Section, Σ_T

Variable ratio, C ($C = \Sigma_S / \Sigma_T$)

Vacuum Boundary

Isotropic scattering

BENCHMARK PROBLEM

Identification: 12-A1

Source Situation ID.12

Date Submitted: June 1976

By: C. T. McDaniel (GE-San Jose)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
D. R. Vondy (ORNL)

Descriptive Title: Cylindrical 'Black' Rod with Known Input Current

Reduction of Source Problem

1. One Group Problem
2. Isotropic Scattering Assumed
3. Input Current: 1 neutron per sec per unit length
4. Input Current Angular Distribution:
Cos θ to surface normal

Data:

Rod Radius $R(\text{cm})$ 0.5
 Total Cross Section, $\Sigma_T (\text{cm}^{-1})$ 1.0; 2.0; 10.0, 100.0
 Ratio C , ($C = \Sigma_S/\Sigma_T$) 0(.2)1.0

The equation to be solved is:

$$\vec{\Omega} \cdot \nabla \psi + \Sigma_T \psi = \int \Sigma_S \psi(\vec{r}, \vec{\Omega}') d\Omega'$$

Expected Primary Results

Indicated Solution Method

Rod Multiple Scattering Albedo

Rod Absorption Rate

Interior spatial flux distribution, $\phi(r)$ Rod Average Flux, $\bar{\phi}$ Rod Surface Flux, $\phi(R)$ The Ratio of Rod Surface Flux to Rod Average
Flux, $G(R) \equiv \phi(R)/\bar{\phi}$

Best Solution Available

Monte Carlo

Analytic Solution Available for $\Sigma_S/\Sigma_T = 0$

References

1. Case, K. M., F. deHoffman and G. Placzek, "Introduction to the Theory of Neutron Diffusion," Vol. 1, U. S. Government Printing Office (1953).
2. Kushneriuk, S. A., "The One Velocity Neutron Flux Distribution in a Cylindrical Cell," AECL-2709 (May 1967).
3. McDaniel, C. T., et al., "Benchmark Calculations for a Cylindrical 'Black' Rod," TANSO 23, 212, Toronto, Canada (June 1976).

Solutions

1. Semi-Analytic Transport Theory	12-A1-1
2. Modified Collision Probability Method	12-A1-2
3. Collision Probability Using Ray Tracing	12-A1-3
4. Weakly Singular Integral Transport	12-A1-4
5. Monte Carlo Solution	12-A1-5

BENCHMARK PROBLEM SOLUTIONS

Identification: 12-A1-1
12-A1-2
12-A1-3
12-A1-4
12-A1-5

Benchmark Problem ID.12-A1

Date Submitted: June 1976

By: 12-A1-1 S. A. Kushneriuk (AECL-CNRL)
12-A1-2 A. Leonard (NASA-Ames)
C. T. McDaniel (GE-San Jose)
12-A1-3 P. T. Choong (GE-San Jose)
12-A1-4 S. K. Loyalka (U. of Mo.)
12-A1-5 D. F. Biron (GAAA-France)
C. T. McDaniel (GE-San Jose)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
D. R. Vondy (ORNL)

Descriptive Title: Cylindrical 'Black' Rod with Known Input Current

Mathematical Models and Solution Methods:

12-A1.1 A Semi-Analytic Transport Solution¹

The asymptotic solution to the transport equation is found and the extrapolation distance, λ , for the asymptotic distribution is obtained explicitly. In the transient region near the rod surface, another quantity, termed $\gamma(r)$, which is the functional behavior of the transient flux, is also obtained. These two quantities, along with diffusion theory, enable one to describe the neutron flux distribution within the cell.

12-A1-2 A Modified Collision Probability Method²

The current-coupling collision probability method is used to solve the integral transport equation. First flight neutrons are treated explicitly on flights to interior radial rings, whereas a cosine current coupling for multiply scattered neutrons is assumed.

12-A1-3 Collision Probability Solutions Using Ray Tracing³

The integral transport equation is solved by means of the slicing technique, in which the rod is subdivided into radial rings and ring-to-ring collision probabilities developed using Bickley function kernels and a variable number of slices normal to the rod diameter.

12-A1-4 The Weakly Singular Integral Transport Method⁴

The weakly singular integral transport equation is solved by means of a method based on removal of the singularity. Bickley function kernels are used with a Gaussian integration procedure for the radial variation of flux.

12-A1-5 The Monte Carlo Method⁵

Here, the three dimensional rod geometry and scattering mechanics are modeled explicitly. The angular distribution of incident neutrons is treated exactly and neutrons are followed until they escape or are absorbed.

Primary Results

The results for each of these five methods are given in Tables I. For Methods 2 and 3, the calculations have been performed for (a) equal radial increment rings, (b) equal volume rings, and (c) the "onion skin" technique² where rings are clustered near the outer surface of the rod. Where possible, the "exact" results of Case, deHoffman and Placzek⁶ are also quoted. Table II contains a comparison of computing time for the various methods. The computed radial flux distributions are given in Table III.

References

1. Kusneriuk, S. A., "The One Velocity Neutron Flux Distribution in a Cylindrical Cell", AECL-2709, May 1967. Results quoted by personal communication.
2. Leonard, A., McDaniel, C. T., and Petrick, W. P., "Integral Transport Calculation of Spatial Gadolinium Depletion", Transactions of the American Nuclear Society 19, p. 406 (1974).
3. Choong, P. T., "Implementation of the Slicing Technique for GE BWR Calculations", Transactions of the American Nuclear Society 20, p. 221 (1975).
4. Loyalka, S. K. and Tsai, R. W., "Integral Transport for 2-D Benchmark Shielding Problems", Transactions of the American Nuclear Society 20, p. 230 (1975).
5. Biron, D. F., "A One-Rod Cell Monte Carlo Program", personal communication.
6. Case, K. M., deHoffman, F. and Placzek, G., "Introduction to the Theory of Neutron Diffusion", Volume 1, U. S. Government Printing Office (1953).

Table I
Benchmark Black Rod Problem
($R = 0.5$ cm)

Σ_T	Quantity	Method	Σ_S/Σ_T					
			0	.2	.4	.6	.8	1.0
1.0 cm ⁻¹	Absorption Rate	1	.5964	.5186	.4264	.3144	.1760	0.0
		2 (a)	.59595	.51801	.42558	.31391	.17582	0.0
		(b)	.59595	.51832	.42618	.31468	.17650	0.0
		(c)	.59595	.51793	.42542	.31368	.17560	0.0
		3 (a)	.59632	.51833	.42579	.31397	.17575	0.0
		(b)	.59619	.51821	.42569	.31389	.17570	0.0
		(c)	.59634	.51833	.42576	.31391	.17569	0.0
		4	.59595	.51814	.42568	.31396	.17581	0.0
		5 (b)	.5964	.51721	.4257	.3127	.17621	0.0
			$\pm .0006$	$\pm .0004$	$\pm .0004$	$\pm .0003$	$\pm .0002$	
		Exact	.59595	----	----	----	----	0.0
	Scattering Albedo	1	0.0	.07775	.1700	.2819	.4203	.5964
		2 (a)	0.0	.07794	.17037	.28204	.42013	.59595
		(b)	0.0	.07763	.16977	.28127	.41945	.59595
		(c)	0.0	.07802	.17053	.28227	.42035	.59595
		3 (a)	0.0	.07799	.17053	.28235	.42057	.59634
		(b)	0.0	.07798	.17050	.28230	.42049	.59619
		(c)	0.0	.07801	.17053	.28243	.42065	.59634
		4	0.0	.07781	.17027	.28099	.42014	.59595
		5 (b)	0.0	.07883	.1726	.2801	.4205	.5950
				$\pm .001$	$\pm .002$	$\pm .004$	$\pm .006$	$\pm .008$
		Exact	0.0	----	----	----	----	.59595
	Rod Average Flux	1	.7593	.8254	.9049	1.009	1.1207	1.2732
		2 (a)	.75879	.82443	.90312	.99921	1.1193	1.2738
		(b)	.75879	.82494	.90439	1.0017	1.1236	1.2812
		(c)	.75879	.82431	.90277	.99848	1.1179	1.2713
		3 (a)	.75926	.82494	.90356	.99939	1.1189	1.2720
		(b)	.75909	.82476	.90335	.99914	1.1186	1.2717
		(c)	.75928	.82494	.90350	.99922	1.1185	1.2713
		4	.75879	.82465	.90331	.99938	1.1192	1.2732
		5 (b)	.75939	.8232	.9033	.9955	1.1214	1.259
			$\pm .0007$	$\pm .0007$	$\pm .0008$	$\pm .0008$	$\pm .001$	$\pm .012$
		Exact	.75879	----	----	----	----	1.2732
	Ratio, Surface to Average Flux	1	1.2295	1.1852	1.1393	1.0939	1.0472	1.0
		2 (a)	1.2306	1.1875	1.1429	1.0968	1.0489	1.0004
		(b)	1.2306	1.1869	1.1415	1.0945	1.0456	.9946
		(c)	1.2306	1.1876	1.1433	1.0974	1.0500	1.0007
		3 (a)	1.2298	1.1868	1.1425	1.0968	1.0496	1.0007
		(b)	1.2301	1.1871	1.1429	1.0972	1.0499	1.0009
		(c)	1.2298	1.1868	1.1425	1.0969	1.0498	.0011
		4*	1.2124	1.1475	1.1316	1.0890	1.0447	1.0
		5 (b)	1.2251	1.2031	1.1517	1.1005	1.0428	.9876
			$\pm .030$	$\pm .025$	$\pm .016$	$\pm .016$	$\pm .013$	$\pm .009$
		Exact	1.2306	----	----	----	----	1.0

*Calculated at relative radius of .99204.

Table I (cont)

Benchmark Black Rod Problem
(R = 0.5 cm)

Σ_T	Quantity	Method	Σ_S/Σ_T					
			0	.2	.4	.6	.8	1.0
2.0 cm ⁻¹	Absorption Rate	1	.8137	.7367	.6370	.5022	.3079	0.0
		2 (a)	.81429	.73630	.63645	.50234	.30933	0.0
		(b)	.81429	.73659	.63717	.50357	.31081	0.0
		(c)	.81429	.73648	.63688	.50303	.31010	0.0
		3 (a)	.81505	.73648	.63575	.50055	.30683	0.0
		(b)	.81475	.73616	.63544	.50029	.30667	0.0
		(c)	.81487	.73625	.63548	.50027	.30659	0.0
		4	.8143	.7359	.6354	.5005	.3070	0.0
		5 (b)	.8142	.7386	.6369	.4991	.3076	0.0
			$\pm .0009$	$\pm .0010$	$\pm .0008$	$\pm .00005$	$\pm .0003$	
		Exact	.81430					0.0
	Scattering Albedo	1	0.0	.07697	.1766	.3115	.5058	.8137
		2 (a)	0.0	.07799	.17784	.31195	.50496	.81429
		(b)	0.0	.07770	.17712	.31072	.50348	.81429
		(c)	0.0	.07781	.17741	.31108	.50419	.81429
		3 (a)	0.0	.07857	.17930	.31450	.50822	.81505
		(b)	0.0	.07859	.17931	.31446	.50808	.81475
		(c)	0.0	.07862	.17939	.31460	.50828	.81487
		4	0.0	.07842	.1789	.3138	.5073	.8143
		5 (b)	0.0	.07846	.1799	.3125	.5081	.8135
				$\pm .002$	$\pm .004$	$\pm .008$	$\pm .013$	$\pm .010$
		Exact	0.0					.81430
	Rod Average	1	.5180	.5862	.6759	.7992	.9800	1.2732
		2 (a)	.51839	.58593	.67529	.79950	.98462	1.2917
		(b)	.51839	.58616	.67606	.80145	.98933	1.3036
		(c)	.51839	.58607	.67575	.80060	.98708	1.2974
		3 (a)	.51888	.58607	.67455	.79665	.97668	1.2701
		(b)	.51869	.58582	.67422	.79624	.97617	1.2695
		(c)	.51876	.58589	.67427	.79620	.97591	1.2686
		4	.5184	.5856	.6741	.7965	.9773	1.2729
		5 (b)	.5184	.5878	.6758	.7944	.9790	1.274
			$\pm .0005$	$\pm .0008$	$\pm .0008$	$\pm .0007$	$\pm .0009$	$\pm .0009$
		Exact	.51840					1.2732
	Ratio, Surface to Average Flux	1	1.5632	1.4576	1.3501	1.2391	1.1232	1.0
		2 (a)	1.5603	1.4605	1.3547	1.2418	1.1203	.9882
		(b)	1.5603	1.4604	1.3538	1.2395	1.1161	.9814
		(c)	1.5603	1.4605	1.3543	1.2407	1.1182	.9851
		3 (a)	1.5589	1.4603	1.3565	1.2464	1.1287	1.0015
		(b)	1.5594	1.4613	1.3576	1.2475	1.1295	1.0018
		(c)	1.5592	1.4610	1.3574	1.2473	1.1296	1.0023
		4*	1.5108	1.4225	1.3282	1.2270	1.1173	.9973
		5 (b)	1.5623	1.4419	1.3470	1.2550	1.127	.9980
			$\pm .022$	$\pm .020$	$\pm .029$	$\pm .024$	$\pm .013$	$\pm .017$
		Exact	1.5603					1.0

*Calculated at relative radius of .99204.

Table I (cont)
Benchmark Black Rod Problem
(R = 0.5 cm)

Σ_T	Quantity	Method	Σ_S/Σ_T					
			0	.2	.4	.6	.8	1.0
10.0 cm ⁻¹	Absorption Rate	1	.9923	---	.8702	.77185	.6032	0.0
		2 (a)	.99226	.94269	.87592	.77828	.60917	0.0
		(b)	.99227	.93996	.87069	.77131	.60287	0.0
		(c)	.99228	.93909	.87039	.77477	.61459	0.0
		3 (a)	.99568	.94639	.87986	.78219	.61181	0.0
		(b)	.99496	.94365	.87527	.77623	.60602	0.0
		(c)	1.0	.94806	.87964	.78192	.61536	0.0
		4	.99203	.93969	.87038	.77068	.60071	0.0
		5	.9924	.9367	.8686	.7712	.6003	0.0
			$\pm .001$	$\pm .0011$	$\pm .001$	$\pm .001$	$\pm .001$	
		Exact	.99227	---	---	---	---	0.0
	Scattering Albedo	1	0.0	---	.1221	.2205	.3891	.9923
		2 (a)	0.0	.04958	.11634	.21398	.38309	.99226
		(b)	0.0	.05232	.12158	.22096	.38940	.99227
		(c)	0.0	.05318	.12188	.21781	.37769	.99228
		3 (a)	0.0	.04930	.11532	.21349	.38387	.99568
		(b)	0.0	.05132	.11965	.21873	.38894	.99496
		(c)	0.0	.05194	.12036	.21808	.38464	1.0
		4	0.0	.05201	.12132	.22102	.39099	.99170
		5 (b)	0.0	.05232	.1229	.2212	.3939	.9925
				$\pm .008$	$\pm .011$	$\pm .023$	$\pm .04$	$\pm .09$
		Exact	0.0	---	---	---	---	.99227
	Rod Average Flux	1	.12634	---	.1847	.2457	.3840	1.2732
		2 (a)	.12634	.15003	.18588	.24773	.38781	1.3026
		(b)	.12634	.14960	.18477	.24551	.38380	1.3259
		(c)	.12634	.14946	.18470	.24652	.39126	1.3417
		3 (a)	.12677	.15062	.18671	.24898	.38949	1.2639
		(b)	.12668	.15019	.18574	.24708	.38580	1.2624
		(c)	.12732	.15089	.18667	.24889	.39175	1.2497
		4	.12631	.14956	.18470	.24532	.38242	1.27327
		5 (b)	.12636	.1491	.1843	.2455	.3821	1.2676
			$\pm .0002$	$\pm .0002$	$\pm .0002$	$\pm .0003$	$\pm .0006$	$\pm .001$
		Exact	.12634	---	---	---	---	1.2732
	Ratio, Surface to Average Flux	1	5.2931	---	4.0825	3.3347	2.4117	1.0
		2 (a)	5.2923	4.6774	4.0119	3.2642	2.3579	.9783
		(b)	5.2927	4.7085	4.0626	3.3203	2.3988	.9620
		(c)	5.2929	4.7207	4.0712	3.3053	2.3398	.9523
		3 (a)	5.2741	4.6590	3.9941	3.2489	2.3500	1.0039
		(b)	5.2784	4.6898	4.0420	3.3021	2.3919	1.0045
		(c)	5.2520	4.6753	4.0306	3.2817	2.3493	1.0099
		4*	4.5592	4.1441	3.6603	3.0720	2.2966	.9982
		5 (b)	5.2719	4.6725	4.0685	3.3327	2.4153	1.0143
			$\pm .11$	$\pm .078$	$\pm .076$	$\pm .031$	$\pm .048$	$\pm .033$
		Exact	5.2929	---	---	---	---	1.0

*Calculated at relative radius of .99204.

Table I (cont)

Benchmark Black Rod Problem
(R = 0.5 cm)

Σ_T	Quantity	Method	Σ_S/Σ_T					
			0	.2	.4	.6	.8	1.0
100 cm ⁻¹	Absorption Rate	1	---	---	---	---	---	---
		2 (a)	.99993	.98713	.96711	.93119	.84674	0.0
		(b)	.99991	.97736	.94374	.88775	.77207	0.0
		(c)	.99992	.95267	.89309	.81425	.70091	0.0
		3 (a)	1.0000	.98718	.96712	.93115	.84658	0.0
		(b)	1.0000	.97740	.93472	.88764	.77184	0.0
		(c)	1.0000	.95139	.88907	.80519	.68257	0.0
		4	---	---	---	---	---	---
		5 (b)	.99991	.95456 ± 0008	.89135 ± 0008	.79807 ± 0006	.65430 ± 0008	0.0
		Exact	.99997					0.0
	Scattering Albedo	1	---	---	---	---	---	---
		2 (a)	0.0	.01280	.03282	.06874	.15319	.99993
		(b)	0.0	.02255	.05617	.11216	.22784	.99991
		(c)	0.0	.04725	.10683	.18567	.29901	.99992
		3 (a)	0.0	.01282	.03288	.06885	.15342	1.0000
		(b)	0.0	.02260	.05628	.11236	.22816	1.0000
		(c)	0.0	.04861	.11093	.19481	.30743	1.0000
		4	---	---	---	---	---	---
		5 (b)	0.0	.04725 ± .019	.10937 ± .035	.19953 ± .075	.34663 ± .09	.99991
		Exact	0.0					.99997
	Rod Average Flux	1	---	---	---	---	---	---
		2 (a)	.012732	.015711	.020523	.029641	.053905	1.2733
		(b)	.012731	.015555	.020027	.028258	.049152	1.2738
		(c)	.012731	.015162	.018952	.025919	.044621	1.3466
		3 (a)	.012732	.015711	.020523	.029639	.053895	1.2508
		(b)	.012732	.015556	.020026	.028254	.049137	1.2396
		(c)	.012732	.015142	.018867	.02563	.043454	1.1162
		4	---	---	---	---	---	---
		5 (b)	.012752	.015192	.018915	.025403	.041654	---
		Exact	± .000007 .012732	± .00001	± .00002	± .00002	± .00005	1.2732
	Ratio, Surface to Average Flux	1	---	---	---	---	---	---
		2 (a)	50.064	41.088	32.075	22.979	13.633	1.0
		(b)	50.122	41.954	33.663	25.129	15.953	.99956
		(c)	50.253	44.458	37.800	29.748	18.991	.94482
		3 (a)	50.060	41.087	32.075	22.980	13.634	1.0102
		(b)	50.117	41.952	33.665	25.132	15.957	1.0245
		(c)	50.249	44.411	37.808	29.916	19.384	1.0707
		4	---	---	---	---	---	---
		5 (b)	50.205	44.018	38.035	31.239	21.518	---
		Exact	± 1.01 50.172	± .37	± .52	± 1.04	± 1.07	1.0

*Calculated at relative radius of .99204.

Table II

Comparison of Computing Time and Cost

Method	Machine	Processor Time [†] 24 Cases	Processor Time [†] per Case	Computing Cost \$ (all cases)
1	----	-----	-----	-----
2 (a)	H-6000	.240	~.010	\$ 1.71
(b)	H-6000	.246	~.010	\$ 1.76
(c)	H-6000	.186	~.008	\$ 1.48
3 (a)	H-6000	.618	~.026	\$ 3.21
(b)	H-6000	.708	~.030	\$ 3.62
(c)	H-6000	.348	~.015	\$ 2.09
4	IBM 370/168	~.960	.04	\$ 30.24
5	H-6000	4.6 (hrs.)	11.5 (min.)	\$700.0

[†]Time in minutes unless noted otherwise.

Table III
Benchmark Black Rod Problem
Computed Radial Flux Distribution
Method 1

(The Radial Flux results from Method 1 are not available.)

Table III (cont)

BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTION

METHOD: 2
EQUAL ΔR

Total Cross Section, $\Sigma_T = 1.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.1	.6470	.7314	.8348	.9640	1.1291	1.3458
.2	.6494	.7323	.8337	.9602	1.1214	1.3327
.3	.6565	.7373	.8359	.9584	1.1141	1.3176
.4	.6676	.7458	.8409	.9587	1.1078	1.3020
.5	.6830	.7583	.8494	.9616	1.1032	1.2869
.6	.7035	.7753	.8618	.9679	1.1010	1.2731
.7	.7301	.7979	.8792	.9784	1.1023	1.2617
.8	.7646	.8278	.9033	.9949	1.1088	1.2544
.9	.8106	.8687	.9376	1.0209	1.1238	1.2547
1.0	.8791	.9314	.9631	1.0672	1.1583	1.2736
Surface Flux	.9338	.9790	1.0322	1.0959	1.1740	1.2727
Average Flux	.7588	.8244	.9031	.9992	1.1193	1.2738

Table III (cont)

BENCHMARK BLACK ROD PROBLEM
COMPLETED RADIAL FLUX DISTRIBUTION

METHOD: 2

EQUAL AR

Total Cross Section, $\Sigma_T = 2.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.1	.3503	.4281	.5372	.6981	.9522	1.3978
.2	.3545	.4319	.5399	.6985	.9478	1.3830
.3	.3644	.4411	.5475	.7026	.9447	1.3643
.4	.3798	.4556	.5599	.7105	.9434	1.3436
.5	.4015	.4762	.5777	.7227	.9446	1.3219
.6	.4309	.5039	.6018	.7401	.9490	1.3000
.7	.4701	.5406	.6341	.7641	.9580	1.2792
.8	.5226	.5897	.6774	.7976	.9741	1.2623
.9	.5957	.6581	.7385	.8469	1.0034	1.2552
1.0	.7114	.7676	.8388	.9331	1.0671	1.2790
Surface Flux	.8089	.8558	.9148	.9928	1.1030	1.2765
Average Flux	.5184	.5859	.6753	.7995	.9846	1.2917

Table III (cont)

BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTION

METHOD: 2
EQUAL ΔR

Total Cross Section, $\Sigma_T = 10.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.1	.00423	.00638	.01142	.02672	.09915	1.3516
.2	.00498	.00756	.01343	.03059	.1075	1.3503
.3	.00671	.01016	.01770	.03840	.1233	1.3479
.4	.00996	.01492	.02521	.05142	.1480	1.3441
.5	.01582	.02324	.03779	.07188	.1834	1.3380
.6	.02644	.03776	.05858	.1033	.2325	1.3283
.7	.04620	.06349	.09313	.1513	.2992	1.3131
.8	.08480	.1107	.1518	.2251	.3891	1.2902
.9	.1669	.2036	.2574	.3442	.5144	1.2607
1.0	.3879	.4341	.4960	.5855	.7384	1.2738
Surface Flux	.6686	.7018	.7457	.8086	.9144	1.2743
Average Flux	.12634	.1500	.1859	.2477	.3878	1.3026

Table III (cont)

BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTION

METHOD: 2
EQUAL AR

Total Cross Section, $\Sigma_T = 100$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						1.2733
.1	---	---	---	---		1.2733
.2	---	---	---	---		1.2733
.3	---	---	---	---		1.2733
.4	---	---	---	---		1.2733
.5	---	---	---	---	.00003	1.2733
.6	---		.0000002	.000004	.00015	1.2733
.7		.0000003	.0000046	.000054	.00095	1.2733
.8	.0000005	.0000182	.000129	.000742	.00598	1.2733
.9	.000124	.001202	.003648	.01037	.03807	1.2732
1.0	.06689	.08160	.1047	.1461	.2442	1.2732
Surface Flux	.63739	.64553	.65827	.6811	.7349	1.2732
Average Flux	.01273	.01571	.02052	.02964	.05391	1.2733

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 2
 EQUAL VOLUME

Total Cross Section, $\Sigma_T = 1.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3162	.6550	.7381	.8399	.9668	1.1288	1.3417
.4472	.6714	.7498	.8453	.9635	1.1134	1.3091
.5477	.6919	.7667	.8572	.9686	1.1093	1.2921
.6325	.7131	.7843	.8701	.9754	1.1076	1.2788
.7071	.7358	.8036	.8849	.9842	1.1085	1.2687
.7746	.7605	.8248	.9016	.9952	1.1118	1.2617
.8367	.7877	.8485	.9209	1.0089	1.1180	1.2579
.8944	.8182	.8755	.9435	1.0258	1.1278	1.2580
.9487	.8540	.9076	.9712	1.0480	1.1428	1.2636
1.0	.9002	.9503	1.0094	1.0805	1.1683	1.2800
Surface Flux	.9338	.9791	1.0324	1.0963	1.1748	1.2742
Average Flux	.7588	.8249	.9044	1.0017	1.1236	1.2812

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 2
 EQUAL VOLUME

Total Cross Section, $\Sigma_T = 2.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3162	.3614	.4392	.5478	.7069	.9570	1.3951
.4472	.3859	.4623	.5673	.7187	.9532	1.3576
.5477	.4143	.4892	.5907	.7352	.9560	1.3321
.6325	.4450	.5180	.6157	.7532	.9608	1.3103
.7071	.4789	.5494	.6431	.7734	.9678	1.2916
.7746	.5163	.5843	.6735	.7962	.9775	1.2763
.8367	.5588	.6237	.7081	.8229	.9909	1.2651
.8944	.6080	.6695	.7485	.8551	1.0095	1.2595
.9487	.6676	.7250	.7982	.8961	1.0369	1.2629
1.0	.7481	.8001	.8679	.9569	1.0837	1.2860
Surface Flux	.8089	.8560	.9153	.9934	1.1041	1.2794
Average Flux	.5184	.5862	.6761	.8015	.9893	1.3036

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 2
 EQUAL VOLUME

Total Cross Section, $\Sigma_T = 10.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3162	.00610	.00926	.01626	.03584	.1184	1.3852
.4472	.01163	.01715	.02838	.05622	.1558	1.3798
.5477	.02008	.02886	.04557	.08326	.2008	1.3716
.6325	.03269	.04572	.06907	.1177	.2524	1.3600
.7071	.05134	.06964	.1007	.1606	.3107	1.3443
.7746	.07890	.1034	.1428	.2139	.3760	1.3239
.8367	.1200	.1514	.1992	.2801	.4492	1.2990
.8944	.1828	.2209	.2762	.3641	.5331	1.2713
.9487	.2838	.3275	.3876	.4774	.6371	1.2491
1.0	.4761	.5221	.5819	.6660	.8045	1.2948
Surface Flux	.6687	.7044	.7506	.8152	.9207	1.2755
Average Flux	.1263	.1496	.1848	.2455	.3838	1.3259

Table III (cont)

BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTION

METHOD: 2
Equal Volume

Total Cross Section, $\Sigma_T = 100$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3162	---	---	---	---	---	1.2739
.4472	---	---	---	---	---	1.2739
.5477	---	---	---	---	.000006	1.2739
.6325	---	---	---	---	.000038	1.2739
.7071	---	---	---	.000006	.000211	1.2739
.7746	---	---	.000006	.000058	.001064	1.2739
.8367	.000006	.000020	.000090	.000528	.005004	1.2739
.8944	.000148	.000408	.001246	.004397	.02213	1.2939
.9487	.003575	.007454	.01519	.03337	.09223	1.2732
1.0	.1236	.1477	.1837	.2442	.3708	1.2732
Surface Flux	.6381	.6526	.6742	.7101	.7841	1.2732
Average Flux	.01273	.01556	.020027	.02826	.04915	1.2738

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION*
 METHOD: 2
 ONION SKIN

Total Cross Section, $\Sigma_T = 1.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3998	.6605	.7401	.8370	.9571	1.1095	1.3081
.5932	.6928	.7658	.8539	.9621	1.1098	1.2737
.7536	.7384	.8051	.8848	.9819	1.1029	1.2551
.8880	.7965	.8563	.9273	1.0131	1.1192	1.2543
1.0	.8745	.9274	.9897	1.0644	1.1563	1.2726
Surface Flux	.9338	.9790	1.0321	1.0958	1.1738	1.2722
Average Flux	.7588	.8243	.9028	.9985	1.1179	1.2713

* Numbers tabulated represent $\int_{r_1}^{r_2} \phi(r) r dr$

Table III (cont)
BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTION*
METHOD: 2

Onion Skin

Total Cross Section, $\sum_T = 2.0$; Rod Radius = 0.5

Normalized Radius (r/R)	$\sum_S / \sum_T$					
	0.0	.2	.4	.6	.8	1.0
0.0	---	---	---	---	---	---
.4298	.3722	.4490	.5552	.7093	.9489	1.3633
.5810	.4172	.4914	.5917	.7342	.9509	1.3177
.6999	.4662	.5376	.6324	.7647	.9624	1.2914
.7966	.5214	.5891	.6777	.7993	.9783	1.2716
.8768	.5835	.6469	.7287	.8395	1.0004	1.2606
.9440	.6548	.7134	.7880	.8881	1.0318	1.2618
1.0	.7441	.7974	.8649	.9545	1.0821	1.2850
Surface Flux	.8089	.8560	.9152	.9933	1.1038	1.2781
Average Flux	.5184	.5861	.6758	.8006	.9871	1.2974

* Numbers tabulated represent $\int_{r_1}^{r_2} \phi(r) r dr$

Table III (cont)

BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTION

METHOD: 2
ONION SKIN

Total Cross Section, $\Sigma_T = 10.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.7862	.0355	.0492	.0737	.1244	.2666	1.3755
.8455	.1283	.1589	.2043	.2799	.4399	1.3326
.8859	.1819	.2189	.2717	.3545	.5155	1.3037
.9162	.2377	.2787	.3353	.4206	.5775	1.2789
.9400	.2966	.3397	.3977	.4827	.6326	1.2595
.9593	.3596	.4034	.4611	.5436	.6848	1.2469
.9754	.4283	.4715	.5276	.6063	.7378	1.2426
.9888	.5056	.5474	.6008	.6748	.7962	1.2502
1.0	.6007	.6402	.6904	.7590	.8703	1.2797
Surface Flux	.6687	.7056	.7520	.8148	.9155	1.2777
Average Flux	.1263	.1495	.1847	.2465	.3913	1.3417

Table III (cont)
BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTION

METHOD: 2
ONION SKIN

Total Cross Section, $\Sigma_T = 100$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.9786	.00263	.00374	.00581	.01045	.02592	1.3499
.9846	.1092	.1326	.1653	.2134	.2929	1.3115
.9886	.1596	.1901	.2318	.2916	.3864	1.2854
.9916	.2131	.2482	.2951	.3608	.4617	1.2632
.9940	.2703	.3082	.3577	.4257	.5276	1.2461
.9959	.3321	.3713	.4216	.4894	.5890	1.2354
.9975	.4000	.4392	.4889	.5549	.6501	1.2330
.9989	.4768	.5151	.5631	.6260	.7156	1.2423
1.0	.5717	.6084	.6538	.7129	.7962	1.2734
Surface Flux	.6398	.6741	.7164	.7710	.8474	1.2723
Average Flux	.01273	.01516	.01895	.02592	.04462	1.3466

Table III (cont)

BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTIONMETHOD: 3
EQUAL ΔR Total Cross Section, $\Sigma_T = 1.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.1	.6450	.7214	.8147	.9308	1.0786	1.2720
.2	.6492	.7253	.8181	.9335	1.0802	1.2720
.3	.6564	.7319	.8239	.9381	1.0830	1.2720
.4	.6675	.7422	.8329	.9451	1.0872	1.2720
.5	.6830	.7564	.8453	.9548	1.0930	1.2720
.6	.7035	.7751	.8615	.9675	1.1004	1.2720
.7	.7307	.7999	.8828	.9839	1.1101	1.2720
.8	.7652	.8310	.9093	1.0042	1.1220	1.2720
.9	.8113	.8721	.9440	1.0305	1.1371	1.2720
1.0	.8802	.9326	.9942	1.0680	1.1583	1.2720
Surface Flux	.9338	.9791	1.0323	1.0962	1.1744	1.2729
Average Flux	.7593	.8249	.9036	.9994	1.1189	1.2720

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 3
 EQUAL ΔR

Total Cross Section, $\Sigma_T = 2.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.1	.3487	.4196	.5181	.6616	.8832	1.2701
.2	.3547	.4256	.5239	.6668	.8888	1.2701
.3	.3644	.4356	.5337	.6756	.8951	1.2701
.4	.3798	.4511	.5488	.6892	.9047	1.2701
.5	.4015	.4730	.5699	.7080	.9179	1.2701
.6	.4308	.5022	.5980	.7327	.9350	1.2701
.7	.4709	.5417	.6354	.7651	.9570	1.2701
.8	.5233	.5925	.6826	.8054	.9839	1.2701
.9	.5963	.6619	.7459	.8582	1.0182	1.2701
1.0	.7123	.7690	.8404	.9343	1.0660	1.2701
Surface Flux	.8089	.8558	.9150	.9929	1.1023	1.2721
Average Flux	.5189	.5861	.6746	.7967	.9767	1.2701

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 3
 EQUAL ΔR

Total Cross Section, $\Sigma_T = 10.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.1	.00419	.00702	.01328		.1073	1.2639
.2	.00748	.01079	.01784	.03704	.1167	1.2639
.3	.00822	.01224	.02067	.04274	.1289	1.2639
.4	.01101	.01633	.02712	.05390	.1500	1.2639
.5	.01656	.02409	.03867	.07246	.1820	1.2639
.6	.02694	.03805	.05841	.1021	.2285	1.2639
.7	.04740	.06422	.09310	.1499	.2955	1.2639
.8	.08535	.1108	.1516	.2246	.3888	1.2639
.9	.1668	.2047	.2602	.3498	.5248	1.2639
1.0	.3871	.4334	.4955	.5855	.7395	1.2639
Surface Flux	.6686	.7018	.7457	.8089	.9153	1.2688
Average Flux	.1268	.1506	.1867	.2490	.3895	1.2639

Table III (cont)

BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTION

METHOD: 3
EQUAL AR

Total Cross Section, $\Sigma_T = 100$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.1	---	---	---		---	1.2314
.2	---	---	---		---	1.2314
.3	---	---	---		---	1.2398
.4	---	---	---		.000004	1.2460
.5	---	---	---		.000025	1.2508
.6	---	---	.0000002	.000004	.000153	1.2547
.7	---	---	.0000046	.000054	.000952	1.2529
.8	---	.000018	.000128	.000743	.005991	1.2619
.9	.000119	.001198	.003647	.01038	.03809	1.2653
1.0	.06691	.08161	.1047	.1461	.2441	1.2684
Surface Flux	.6374	.6455	.6583	.6811	.7348	1.2708
Average Flux	.01273	.01571	.02052	.02964	.05390	1.2580

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 3
 EQUAL VOLUME

Total Cross Section, $\Sigma_T = 1.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3162	.6531	.7288	.8212	.9359	1.0816	1.2717
.4472	.6749	.7488	.8385	.9494	1.0896	1.2717
.5477	.6926	.7651	.8528	.9606	1.0962	1.2717
.6325	.7133	.7840	.8691	.9733	1.1037	1.2717
.7071	.7358	.8044	.8866	.9868	1.1116	1.2717
.7746	.7603	.8265	.9055	1.0012	1.1201	1.2717
.8367	.7880	.8513	.9265	1.0172	1.1293	1.2717
.8944	.8185	.8784	.9492	1.0344	1.1392	1.2717
.9487	.8541	.9099	.9754	1.0540	1.1503	1.2717
1.0	.9005	.9503	1.0087	1.0786	1.1641	1.2717
Surface Flux	.9338	.9791	1.0324	1.0962	1.1744	1.2728
Average Flux	.7791	.8248	.9034	.9991	1.1186	1.2717

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 3
 EQUAL VOLUME

Total Cross Section, $\Sigma_T = 2.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3162	.3597	.4309	.5291	.6716	.8921	1.2695
.4472	.3906	.4617	.5283	.6977	.9103	1.2695
.5477	.4152	.4866	.5829	.7193	.9254	1.2695
.6325	.4451	.5163	.6112	.7441	.9424	1.2695
.7071	.4785	.5490	.6421	.7707	.9605	1.2695
.7746	.5158	.5852	.6758	.7994	.9797	1.2695
.8367	.5590	.6266	.7137	.8314	1.0006	1.2695
.8944	.6080	.6729	.7556	.8660	1.0230	1.2695
.9487	.6673	.7280	.8047	.9059	1.0483	1.2695
1.0	.7478	.8013	.8684	.9564	1.0794	1.2695
Surface Flux	.8089	.8560	.9153	.9933	1.1026	1.2719
Average Flux	.5187	.5858	.6742	.7962	.9762	1.2695

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 3
 EQUAL VOLUME

Total Cross Section, $\Sigma_T = 10.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3162	.00603	.00973	.01765	.03878	.1228	1.2624
.4472	.01781	.02417	.03645	.06542	.1643	1.2624
.5477	.02060	.02957	.04636	.08372	.1986	1.2624
.6325	.03284	.04553	.06819	.1153	.2461	1.2624
.7071	.05128	.06885	.09868	.1567	.3028	1.2624
.7746	.07862	.1022	.1404	.2099	.3695	1.2624
.8367	.1204	.1512	.1985	.2792	.4489	1.2624
.8944	.1825	.2212	.2777	.3679	.5420	1.2624
.9487	.2828	.3289	.3924	.4874	.6557	1.2624
1.0	.4740	.5205	.5811	.6666	.8074	1.2624
Surface Flux	.6687	.7043	.7508	.8159	.9228	1.2681
Average Flux	.1267	.1502	.1857	.2471	.3858	1.2624

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 3
 EQUAL VOLUME

Total Cross Section, $\Sigma_T = 100$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3162	---	---	---	---	---	1.2047
.4472	---	---	---	---	---	1.2047
.5477	---	---	---	---	.000006	1.2253
.6325	---	---	---	---	.000039	1.2349
.7071	---	---	---	.000006	.000212	1.2417
.7746	---	---	.000006	.000058	.001068	1.2471
.8367	.000004	.000017	.000875	.000525	.00500	1.2515
.8944	.000120	.000373	.001198	.004330	.022022	1.2570
.9487	.003558	.007441	.01519	.03338	.09227	1.2621
1.0	.1236	.1477	.1838	.2442	.3708	1.2669
Surface Flux	.6381	.6526	.6742	.7101	.7841	1.2700
Average Flux	.01273	.01556	.02003	.02825	.04914	1.2396

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 3
 ONION SKIN

Total Cross Section, $\Sigma_T = 1.0$, Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3998	.6584	.7339	.8257	.9395	1.0836	1.2713
.5932	.6959	.7681	.8554	.9626	1.0973	1.2713
.7536	.7389	.8073	.8890	.9886	1.1126	1.2713
.8880	.7966	.8590	.9329	1.0220	1.1319	1.2713
1.0	.8748	.9278	.9902	1.0648	1.1562	1.2713
Surface Flux	.9338	.9790	1.0323	1.0960	1.1742	1.2727
Average Flux	.7593	.8249	.9035	.9992	1.1185	1.2713

Table III (cont)

BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTION

METHOD: 5
ONION SKIN

Total Cross Section, $\Sigma_T = 2.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.4298	.3704	.4418	.5400	.6814	.8989	1.2686
.5810	.4234	.4944	.5901	.7253	.9292	1.2686
.6999	.4668	.5375	.6313	.7613	.9539	1.2686
.7966	.5211	.5092	.6804	.8032	.9819	1.2686
.8768	.5827	.6490	.7340	.8481	1.0112	1.2686
.9440	.6536	.7153	.7933	.8965	1.0421	1.2686
1.0	.7436	.7974	.8649	.9534	1.0772	1.2686
Surface Flux	.8089	.8560	.9152	.9931	1.1023	1.2715
Average Flux	.5188	.5859	.6743	.7962	.9759	1.2686

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 3
 ONION SKIN

Total Cross Section, $\Sigma_T = 10.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.7862	.03476	.04812	.07178	.1207	.2568	1.2497
.8454	.1541	.1847	.2299	.3046	.4599	1.2497
.8860	.1844	.2221	.2762	.3614	.5255	1.2497
.9162	.2356	.2781	.3373	.4274	.5918	1.2497
.9400	.2920	.3377	.4000	.4918	.6524	1.2497
.9593	.3531	.4007	.4640	.5550	.7088	1.2497
.9754	.4214	.4692	.5316	.6192	.7634	1.2497
.9838	.4968	.5430	.6023	.6842	.8163	1.2497
1.0	.5998	.6313	.6843	.7567	.8724	1.2497
Surface Flux	.6687	.7055	.7524	.8168	.9204	1.2621
Average Flux	.12732	.1509	.1867	.2489	.3918	1.2497

Table III (cont)

BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTION

METHOD: 3
ONION SKIN

Total Cross Section, $\Sigma_T = 100$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.9786	.00230	.00334	.00528	.00964	.02413	1.1162
.9846	.1578	.1829	.2170	.2659	.3438	1.1162
.9986	.1787	.2108	.2540	.3156	.4115	1.1162
.9916	.2183	.2543	.3025	.3702	.4736	1.1162
.9940	.2640	.3027	.3537	.4241	.5295	1.1162
.9959	.3139	.3541	.4062	.4770	.5811	1.1162
.9975	.3741	.4141	.4653	.5338	.6329	1.1162
.9989	.4354	.4743	.5234	.5882	.6806	1.1162
1.0	.5105	.5460	.5903	.6484	.7306	1.1162
Surface Flux	.6398	.6725	.7133	.7667	.8423	1.1951
Average Flux	.01273	.01514	.01887	.02563	.04345	1.1162

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 4

Total Cross Section, $\Sigma_T = 1.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.00796	.6447	.7215	.8145	.9308	1.0790	1.2732
.0469	.6451	.7223	.8148	.9311	1.0792	1.2732
.1229	.6474	.7256	.8167	.9325	1.0800	1.2732
.2308	.6542	.7335	.8222	.9369	1.0827	1.2732
.3602	.6684	.7483	.8336	.9459	1.0880	1.2932
.5000	.6920	.77-8	.8525	.9606	1.0968	1.2732
.6398	.7263	.8014	.8795	.9816	1.1092	1.2732
.7692	.7714	.8387	.9142	1.0082	1.1247	1.2732
.8771	.8244	.8798	.9540	1.0383	1.1420	1.2732
.9531	.8783	.9187	.9933	1.0675	1.1585	1.2730
.9920	.9199	.9463	1.0222	1.0333	1.1692	1.2720
1.0	---	---	---	---	---	---
*Surface Flux	.9199	.9463	1.0222	1.0883	1.1692	1.2720
Average Flux	.7588	.8247	.0933	.9994	1.1192	1.2732

*"Surface" Flux at r/R = .9920

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 4

Total Cross Section, $\Sigma_T = 2.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.00796	.3484	.4191	.5174	.6610	.8853	1.2731
.0469	.3489	.4196	.5179	.6615	.8856	1.2731
.1229	.3520	.4228	.5211	.6643	.8876	1.2731
.2308	.3613	.4323	.5304	.6727	.8937	1.2731
.3602	.3809	.4522	.5498	.6901	.9060	1.2731
.5000	.4143	.4557	.5822	.7189	.9261	1.2731
.6398	.4644	.5353	.6294	.7602	.9544	1.2731
.7692	.5331	.6019	.6914	.8132	.9898	1.2731
.8771	.6181	.6825	.7646	.8740	1.0293	1.2730
.9531	.7091	.7666	.8389	.9338	1.0668	1.2727
.9920	.7832	.8330	.8954	.9774	1.0920	1.2695
1.0	---	---				
*Surface Flux	.7832	.8330	.8954	.9774	1.0920	1.2695
Average Flux	.5184	.5856	.6741	.7965	.9773	1.2729

*"Surface" Flux at r/R = .9920

Table III (cont)

BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTION

METHOD: 4

Total Cross Section, $\Sigma_T \approx 10$. Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.00796	.00405	.00642	.01177	.02720	.09630	1.27328
.0469	.00412	.00653	.01195	.02751	.09694	1.27328
.1229	.00459	.00721	.01303	.02944	.10090	1.27328
.2308	.00616	.00948	.01660	.03571	.11341	1.27328
.3602	.01020	.01522	.02535	.05042	.14106	1.27329
.5000	.01991	.02841	.04439	.08018	.19153	1.27330
.6398	.04256	.05769	.08389	.13635	.27459	1.27330
.7692	.09338	.11950	.16090	.23458	.39869	1.27330
.8771	.19678	.23679	.29473	.38671	.56201	1.27337
.9531	.37062	.41977	.48540	.58003	.73970	1.27388
.9920	.57587	.61980	.67606	.75362	.87827	1.27096
1.0						
*Surface Flux	.57587	.61980	.67606	.75362	.87827	1.27096
Average Flux	.12631	.14956	.18470	.24532	.38242	1.27327

**"Surface" Flux at r/R = .9920

Table III (cont)
BENCHMARK BLACK ROD PROBLEM
COMPUTED RADIAL FLUX DISTRIBUTION
METHOD: 5

Total Cross Section, $\Sigma_T = 1.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3162	.6515±.0014	.7204±.0009	.8282±.0010	.9298±.0011	1.0955±.0014	1.2838±.0015
.4472	.6715±.0007	.7411±.0010	.8341±.0007	.9380±.0008	1.1011±.0009	1.2804±.0017
.5477	.6910±.0008	.7644±.0008	.8498±.0008	.9498±.0007	1.0947±.0009	1.2740±.0012
.6325	.7099±.0009	.7844±.0007	.8629±.0010	.9648±.0009	1.1039±.0014	1.2802±.0013
.7071	.7369±.0005	.7994±.0006	.8841±.0010	.9785±.0010	1.1152±.0014	1.2739±.0009
.7746	.7629±.0007	.8219±.0007	.9052±.0009	1.0063±.0006	1.1177±.0013	1.2710±.0007
.8367	.7912±.0007	.8512±.0005	.9280±.0008	1.0208±.0008	1.1289±.0009	1.2743±.0008
.8944	.8198±.0005	.8787±.0007	.9522±.0006	1.0319±.0009	1.1393±.0008	1.2692±.0010
.9487	.8572±.0004	.9147±.0005	.9796±.0005	1.0546±.0007	1.1514±.0004	1.2695±.0006
1.0	.9021±.0005	.9555±.0003	1.0085±.0005	1.0802±.0005	1.1662±.0004	1.2719±.0007
Surface Flux	.9304±.0220	.9903±.0202	1.0403±.0142	1.0955±.0162	1.1693±.0146	1.2683±.0089
Average Flux	.7594±.0007	.8232±.0007	.9033±.0008	.9954±.0008	1.1214±.0010	1.2748±.0010

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 5

Total Cross Section, $\Sigma_T = 2.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3162	.3622±.0009	.4347±.0012	.5281±.0018	.6694±.0008	.8858±.0017	1.2744±.0018
.4472	.3848±.0006	.4545±.0012	.5556±.0013	.6911±.0011	.9104±.0012	1.2783±.0009
.5477	.4181±.0003	.4854±.0009	.5840±.0009	.7166±.0006	.9276±.0006	1.2718±.0006
.6325	.4468±.0006	.5230±.0008	.6133±.0006	.7388±.0007	.9498±.0007	1.2764±.0006
.7071	.4779±.0004	.5555±.0007	.6453±.0007	.7694±.0008	.9674±.0011	1.2752±.0008
.7746	.5142±.0005	.5976±.0007	.6768±.0012	.7952±.0006	.9886±.0008	1.2747±.0010
.8367	.5587±.0004	.6338±.0007	.7161±.0008	.8306±.0006	1.0023±.0006	1.2757±.0008
.8944	.6065±.0005	.6712±.0008	.7589±.0004	.8673±.0007	1.0247±.0009	1.2780±.0010
.9487	.6657±.0006	.7234±.0004	.8074±.0004	.9090±.0009	1.0484±.0008	1.2693±.0010
1.0	.7486±.0007	.7987±.0007	.8721±.0007	.9562±.0006	1.0851±.0005	1.2723±.0006
Surface Flux	.8098±.0115	.8476±.0120	.9102±.0199	.9969±.0193	1.1036±.0131	1.2721±.0217
Average Flux	.5184±.0005	.5878±.0008	.6758±.0009	.7944±.0008	.9790±.0009	1.2746±.0009

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 5

Total Cross Section, $\Sigma_T = 10.0$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3162	.00635±.00008	.00907±.0001	.01569±.0001	.03730±.0003	.1143±.0006	1.2667±.002
.4472	.01185±.00007	.01669±.0002	.02770±.0001	.05605±.0003	.1477±.0006	1.2668±.002
.5477	.02035±.0001	.02765±.0002	.04396±.0001	.08137±.0002	.1904±.0007	1.2606±.002
.6325	.03267±.0001	.04482±.0001	.06579±.0002	.1125 ±.0002	.2432±.0007	1.2641±.002
.7071	.05212±.0001	.06858±.0001	.09786±.0002	.1552 ±.0002	.3037±.0008	1.2619±.0009
.7746	.07930±.0002	.1021 ±.0002	.1396 ±.0003	.2091 ±.0003	.3682±.0008	1.2693±.0008
.8367	.1201 ±.0003	.1515 ±.0002	.1972 ±.0004	.2766 ±.0005	.4470±.0006	1.2734±.001
.8944	.1825 ±.0002	.2206 ±.0003	.2773 ±.0002	.3669 ±.0004	.5398±.0007	1.2722±.001
.9487	.2842 ±.0002	.3283 ±.0003	.3933 ±.0002	.4898 ±.0004	.6547±.0005	1.2717±.001
1.0	.4742 ±.0003	.5215 ±.0002	.5949 ±.0003	.6699 ±.0003	.8124±.0004	1.2696±.0008
Surface Flux	.6662 ±.0141	.6966 ±.0117	.7499 ±.0139	.8181 ±.008	.9230±.0181	1.2858±.0422
Average Flux	.1264 ±.0002	.1490 ±.0002	.1843 ±.0002	.2455 ±.0003	.3821±.0006	1.2676±.001

Table III (cont)
 BENCHMARK BLACK ROD PROBLEM
 COMPUTED RADIAL FLUX DISTRIBUTION
 METHOD: 5

Total Cross Section, $\Sigma_T = 100$; Rod Radius = 0.5

Normalized Radius (r/R)	Σ_S/Σ_T					
	0.0	.2	.4	.6	.8	1.0
0.0						
.3162	---	---	---	---	---	---
.4472	---	---	---	---	---	---
.5477	---	---	---	---	---	---
.6325	---	---	---	---	---	---
.7071	---	---	---	.0000017 $\pm .0000005$	.00000011 $\pm .00000002$	---
.7746	---	.00000257 $\pm .00000006$	.0000014 $\pm .00000002$	.0000206 $\pm .0000002$	.000076 $\pm .0000005$	---
.8367	.00001034 $\pm .00000008$	.0000184 $\pm .0000001$	.0000196 $\pm .0000001$	.0000917 $\pm .0000003$	.000917 $\pm .000003$	---
.8944	.0001722 $\pm .0000004$	.000299 $\pm .0000009$	.000484 $\pm .0000009$	.001417 $\pm .000002$	.007437 $\pm .000004$	---
.9487	.003689 $\pm .000001$	.005618 $\pm .000004$	.008976 $\pm .000003$	.01792 $\pm .000005$	.05293 $\pm .0001$	---
1.0	.12365 $\pm .00005$	.1460 $\pm .00009$	.1797 $\pm .0001$	.2346 $\pm .0001$	.3552 $\pm .0003$	---
Surface Flux	.6402 $\pm .0130$	.6687 $\pm .0056$	.7194 $\pm .0098$	.7936 $\pm .0264$	.8963 $\pm .0447$	---
Average Flux	.012752 $\pm .0000007$	.01519 $\pm .00001$	.01892 $\pm .00002$	.02540 $\pm .00002$	.04165 $\pm .00005$	---

BENCHMARK SOURCE SITUATION

Identification: 13

Date Submitted: November 1975

By: B. A. Zolotar (EPRI)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
W. A. Wittkopf (B&W)

Descriptive Title: Neutron Transport in a BWR Rod Bundle
7 x 7 BWR Fuel Assembly as Shown in Figure 1

Suggested Functions: Test Methods for Few-group, Two-dimensional Assembly
Analysis

Figure 1. Bundle Diagram - Materials 1-4 represent fuel, material 5 contains fuel with poison, and the assembly wall is stainless steel.

BENCHMARK PROBLEM

Identification: 13-A1

Source Situation ID.13

Date Submitted: November 1975

By: B. A. Zolotar (EPRI)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
W. A. Wittkopf (B&W)Descriptive Title: Two-group, Two-dimensional (X-Y) Discrete Ordinates
Model of a BWR Fuel Bundle as Shown in Figure 2

Reflective boundary conditions on external surfaces.

Two-Group Constants

<u>Composition</u>	<u>Group 1</u>	$\Sigma_f(\text{cm}^{-1})$	$\Sigma_a(\text{cm}^{-1})$	$\nu\Sigma_f(\text{cm}^{-1})$	$\Sigma_T(\text{cm}^{-1})$	$\Sigma_{1-2}(\text{cm}^{-1})$
1	1	2.281-3	8.983-3	5.925-3	2.531-1	1.069-2
	2	4.038-2	5.892-2	9.817-2	5.732-1	--
2	1	2.003-3	8.726-3	5.242-3	2.536-1	1.095-2
	2	3.385-2	5.174-2	8.228-2	5.767-1	--
3	1	1.830-3	8.587-3	4.820-3	2.535-1	1.112-2
	2	2.962-2	4.717-2	7.200-2	5.797-1	--
4	1	1.632-3	8.480-3	4.337-3	2.533-1	1.113-2
	2	2.428-2	4.140-2	5.900-2	5.837-1	--
5	1	2.155-3	9.593-3	5.605-3	2.506-1	1.016-2
	2	9.968-3	1.626-1	2.424-2	5.853-1	--
19	1	--	1.043-3	--	2.172-1	9.095-3
	2	--	4.394-3	--	4.748-1	--
20	1	--	1.983-4	--	2.476-1	3.682-2
	2	--	7.796-3	--	1.123+0	--

NOTE: Material 19 represents stainless steel; Material 20 represents water; Material 5 represents poison pins.

Expected Primary Results: 1. Group flux distribution
2. K_{eff}

Solutions: Solutions by DOT-III (13-A1-1) and TWOTRAN-II (13-A1-2)

20	20	20	20	20	20	20	20	20	20	20	20	0.47625
20	20	20	20	20	20	20	20	20	20	20	20	0.47625
20	19	19	19	19	19	19	19	19	19	20	20	0.34544
20	19	3	2	2	2	3	3	4	19	20	20	1.87452
20	19	1	1	1	5	1	2	3	19	20	20	1.87452
20	19	1	1	1	1	1	1	3	19	20	20	1.87452
20	19	1	5	1	1	1	5	2	19	20	20	1.87452
20	19	1	1	1	1	1	1	2	19	20	20	1.87452
20	19	1	1	1	5	1	1	2	19	20	20	1.87452
20	19	2	1	1	1	1	1	3	19	20	20	1.87452
20	19	19	19	19	19	19	19	19	19	20	20	0.34544
20	20	20	20	20	20	20	20	20	20	20	20	0.47498
0.47498	0.34544	1.87452	1.87452	1.87452	1.87452	1.87452	1.87452	1.87452	1.87452	0.34544	0.47625	0.47625

NOTE: All dimensions in centimeters.

Figure 2. Bundle Configuration and Material Assignments

BENCHMARK PROBLEM SOLUTION

Identification: 13-A1-1

Benchmark Problem ID.13-A1

Date Submitted: June 1976

By: B. A. Zolotar (EPRI)
F. J. Rahn (EPRI)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
W. A. Wittkopf (B&W)

Descriptive Title: Discrete Ordinate Solution

Computer: IBM-360, Model 195

Code: DOT III(1)

Date Solved: May 1976 at EPRI

References

1. W. A. Rhoades and F. R. Mynatt, "The DOT III Two-Dimensional Discrete Ordinates Transport Code," ORNL-TM-4280, Oak Ridge National Lab. (1973).

Results

Discrete Ordinate Representation: S_8 Mesh Spacing: $4 \times 4 = 16$ meshes per region in configuration map $K_{eff} = 1.08714$ Convergence criteria = 2×10^{-5}

Exhibit A: Benchmark Solution

Exhibit B: S_8 Angular QuadratureExhibit C: Mesh and Angular Quadrature Convergence of K_{eff}

Exhibit D: Mesh Convergence - Group 1 Fluxes

Exhibit E: Mesh Convergence - Group 2 Fluxes

Exhibit F: Angular Quadrature Convergence - Group 1 Fluxes

Exhibit G: Angular Quadrature Convergence - Group 2 Fluxes

.1767 .1115	.1757 .1108	.1764 .1065	.1793 .0998	.1792 .0957	.1781 .0953	.1755 .0991	.1721 .1069	.1660 .1183	.1629 .1260	.1629 .1283	.1625 .1303
.1779 .1081	.1774 .1066	.1788 .1015	.1819 .0944	.1820 .0903	.1808 .0900	.1783 .0939	.1747 .1018	.1680 .1137	.1642 .1222	.1638 .1256	
.1788 .1066	.1797 .1011	.1827 .0950	.1863 .0876	.1862 .0834	.1851 .0831	.1824 .0871	.1788 .0952	.1716 .1076	.1663 .1171		
.1840 .0945	.1864 .0902	.1924 .0827	.1970 .0748	.1964 .0703	.1944 .0690	.1922 .0741	.1891 .0828	.1805 .0960			
.1920 .0813	.1949 .0773	.2023 .0687	.2064 .0607	.2048 .0554	.1999 .0497	.2015 .0587	.1984 .0687				
.1954 .0733	.1980 .0693	.2048 .0606	.2080 .0520	.2082 .0490	.2071 .0483	.2055 .0518					
.1972 .0699	.1995 .0659	.2054 .0565	.2060 .0441	.2096 .0459	.2098 .0471						
.1976 .0706	.2000 .0667	.2066 .0580	.2100 .0495	.2103 .0466	Group 1 Flux Group 2 Flux						
.1969 .0750	.1997 .0710	.2067 .0626	.2111 .0546								
.1928 .0834	.1951 .0790	.2014 .0708									
.1906 .0884	.1916 .0853										
.1910 .0903											

$$K_{eff} = 1.08714$$

BENCHMARK SOLUTION

S₈ - 4x4 Mesh Intervals

EXHIBIT A

ANGL	WEIGHT	ETA	MU
1	0.0	-0.2182178E+00	-0.9758998E+00
2	0.2665018E-01	-0.2182178E+00	-0.9511893E+00
3	0.2529317E-01	-0.2182178E+00	-0.7867955E+00
4	0.2529317E-01	-0.2182178E+00	-0.5773501E+00
5	0.2665018E-01	-0.2182178E+00	-0.2182178E+00
6	0.2665018E-01	-0.2182178E+00	0.2182178E+00
7	0.2529317E-01	-0.2182178E+00	0.5773501E+00
8	0.2529317E-01	-0.2182178E+00	0.7867955E+00
9	0.2665018E-01	-0.2182178E+00	0.9511893E+00
10	0.0	-0.5773501E+00	-0.3164963E+00
11	0.2529317E-01	-0.5773501E+00	-0.7867955E+00
12	0.1829034E-01	-0.5773501E+00	-0.5773501E+00
13	0.2529317E-01	-0.5773501E+00	-0.2182178E+00
14	0.2529317E-01	-0.5773501E+00	0.2182178E+00
15	0.1829034E-01	-0.5773501E+00	0.5773501E+00
16	0.2529317E-01	-0.5773501E+00	0.7867955E+00
17	0.0	-0.7867955E+00	-0.6172131E+00
18	0.2529317E-01	-0.7867955E+00	-0.5773501E+00
19	0.2529317E-01	-0.7867955E+00	-0.2182178E+00
20	0.2529317E-01	-0.7867955E+00	0.2182178E+00
21	0.2529317E-01	-0.7867955E+00	0.5773501E+00
22	0.0	-0.9511893E+00	-0.3086066E+00
23	0.2665018E-01	-0.9511893E+00	-0.2182178E+00
24	0.2665018E-01	-0.9511893E+00	0.2182178E+00
25	0.0	0.2182178E+00	-0.9758998E+00
26	0.2665018E-01	0.2182178E+00	-0.9511893E+00
27	0.2529317E-01	0.2182178E+00	-0.7867955E+00
28	0.2529317E-01	0.2182178E+00	-0.5773501E+00
29	0.2665018E-01	0.2182178E+00	-0.2182178E+00
30	0.2665018E-01	0.2182178E+00	0.2182178E+00
31	0.2529317E-01	0.2182178E+00	0.5773501E+00
32	0.2529317E-01	0.2182178E+00	0.7867955E+00
33	0.2665018E-01	0.2182178E+00	0.9511893E+00
34	0.0	0.5773501E+00	-0.3164963E+00
35	0.2529317E-01	0.5773501E+00	-0.7867955E+00
36	0.1829034E-01	0.5773501E+00	-0.5773501E+00
37	0.2529317E-01	0.5773501E+00	-0.2182178E+00
38	0.2529317E-01	0.5773501E+00	0.2182178E+00
39	0.1829034E-01	0.5773501E+00	0.5773501E+00
40	0.2529317E-01	0.5773501E+00	0.7867955E+00
41	0.0	0.7867955E+00	-0.6172131E+00
42	0.2529317E-01	0.7867955E+00	-0.5773501E+00
43	0.2529317E-01	0.7867955E+00	-0.2182178E+00
44	0.2529317E-01	0.7867955E+00	0.2182178E+00
45	0.2529317E-01	0.7867955E+00	0.5773501E+00
46	0.0	0.9511893E+00	-0.3086066E+00
47	0.2665018E-01	0.9511893E+00	-0.2182178E+00
48	0.2665018E-01	0.9511893E+00	0.2182178E+00

S₈ ANGULAR QUADRATURE

EXHIBIT B

Mesh convergence with S_8 $1 \times 1 \ K_{\text{eff}} = 1.08441$ $2 \times 2 \ K_{\text{eff}} = 1.08709$ $4 \times 4 \ K_{\text{eff}} = 1.08714 \text{ (Benchmark Solution)}$ Angular Quadrature Convergence with 2×2 Mesh Interval $S_2 \ K_{\text{eff}} = 1.09195$ $S_4 \ K_{\text{eff}} = 1.08724$ $S_8 \ K_{\text{eff}} = 1.08709$ MESH AND ANGULAR QUADRATURE CONVERGENCE OF K_{eff}

EXHIBIT C

.1771	.1757	.1764	.1788	.1796	.1782	.1760	.1718	.1658	.1631	.1632	.1630
.1768	.1758	.1764	.1793	.1793	.1781	.1756	.1721	.1659	.1629	.1629	.1627
.1767	.1757	.1764	.1793	.1792	.1781	.1755	.1721	.1660	.1629	.1629	.1625
.1777	.1774	.1787	.1818	.1826	.1809	.1788	.1746	.1680	.1642	.1634	
.1779	.1772	.1788	.1820	.1821	.1809	.1784	.1748	.1680	.1641	.1637	
.1779	.1774	.1788	.1819	.1820	.1808	.1783	.1747	.1680	.1642	.1638	
.1785	.1792	.1824	.1858	.1867	.1852	.1827	.1785	.1716	.1649		
.1785	.1796	.1835	.1863	.1863	.1850	.1825	.1789	.1715	.1664		
.1788	.1797	.1827	.1863	.1862	.1851	.1824	.1788	.1716	.1663		
.1838	.1860	.1916	.1964	.1957	.1937	.1917	.1886	.1796			
.1840	.1863	.1923	.1969	.1962	.1944	.1921	.1890	.1803			
.1840	.1864	.1924	.1970	.1964	.1944	.1922	.1891	.1805			
.1919	.1946	.2018	.2075	.2052	.2014	.2018	.1996				
.1921	.1950	.2023	.2065	.2050	.2001	.2016	.1984				
.1920	.1949	.2023	.2064	.2048	.1999	.2015	.1984				
.1963	.1984	.2042	.2086	.2080	.2073	.2053					
.1965	.1981	.2047	.2082	.2082	.2072	.2055					
.1954	.1980	.2048	.2080	.2082	.2071	.2055					
.1975	.1999	.2046	.2074	.2095	.2114						
.1973	.1996	.2054	.2062	.2096	.2100						
.1972	.1995	.2054	.2060	.2096	.2098						
.1984	.2005	.2060	.2104	.2101							
.1977	.2001	.2065	.2101	.2103							
.1976	.2000	.2066	.2100	.2103							
.1967	.1992	.2061	.2120								
.1970	.1997	.2066	.2112								
.1969	.1997	.2067	.2111								
.1926	.1947	.2006									
.1928	.1950	.2013									
.1928	.1951	.2014									
.1907	.1907										
.1904	.1916										
.1906	.1916										
.1911											
.1911											
.1910											

1x1	} meshes per interval
2x2	
4x4	

MESH CONVERGENCE WITH S_8

GROUP 1 FLUXES

EXHIBIT D

1.1085	1.1040	1.0629	.9944	.9546	.9544	.9901	1.0686	1.1853	1.2602	1.2825	1.3006
1.1136	1.1067	1.0651	.9971	.9563	.9533	.9902	1.0684	1.1836	1.2599	1.2828	1.3022
1.1145	1.1075	1.0651	.9976	.9570	.9532	.9906	1.0685	1.1831	1.2602	1.2833	1.3027
1.0751	1.0618	1.0120	.9393	.9000	.9008	.9370	1.0161	1.1380	1.2212	1.2530	
1.0802	1.0654	1.0153	.9437	.9023	.8996	.9376	1.0176	1.1374	1.2215	1.2548	
1.0814	1.0661	1.0151	.9444	.9034	.8996	.9385	1.0179	1.1368	1.2221	1.2556	
1.0374	1.0078	.9531	.8741	.8358	.8418	.8750	.9532	1.0828	1.1678		
1.0416	1.0112	.9507	.8760	.8345	.8305	.8710	.9528	1.0770	1.1710		
1.0659	1.0113	.9503	.8757	.8343	.8306	.8713	.9522	1.0761	1.1708		
.9435	.9109	.8350	.7502	.7034	.6907	.7426	.8325	.9705			
.9450	.9086	.8285	.7485	.7029	.6910	.7413	.8284	.9610			
.9447	.9016	.8274	.7479	.7030	.6898	.7413	.8275	.9595			
.8072	.7717	.6893	.6080	.5480	.5068	.5822	.6898				
.8119	.7734	.6877	.6076	.5543	.4973	.5871	.6874				
.8128	.7731	.6871	.6073	.5544	.4965	.5871	.6867				
.7278	.6921	.6048	.5123	.4778	.4740	.5050					
.7314	.6928	.6054	.5193	.4878	.4820	.5154					
.7328	.6930	.6057	.5197	.4898	.4827	.5175					
.6975	.6663	.5632	.4479	.4503	.4802						
.6986	.6587	.5657	.4413	.4578	.4704						
.6991	.6592	.5649	.4409	.4587	.4705						
.7003	.6648	.5786	.4870	.4539							
.7048	.6662	.5797	.4944	.4635							
.7064	.6665	.5802	.4947	.4655							
.7424	.7068	.6260	.5448								
.7489	.7102	.6260	.5462								
.7501	.7102	.6258	.5463								
.8240	.7905	.7135									
.8276	.7900	.7089									
.8341	.7897	.7082									
.8793	.8484										
.8832	.8521										
.8844	.8529										
.8918											
.8989											
.9031											

1x1	} meshes per interval
2x2	
4x4	

MESH CONVERGENCE WITH S_8

GROUP 2 FLUXES x 10

EXHIBIT E

.1904	.1901	.1840	.1817	.1871	.1861	.1830	.1735	.1718	.1771	.1772	.1797
.1788	.1778	.1774	.1801	.1827	.1797	.1770	.1726	.1664	.1647	.1648	.1648
.1768	.1758	.1764	.1793	.1793	.1781	.1756	.1721	.1659	.1629	.1629	.1627
.1903	.1879	.1857	.1837	.1879	.1875	.1838	.1754	.1733	.1755	.1794	
.1797	.1787	.1793	.1826	.1831	.1818	.1793	.1751	.1680	.1652	.1656	
.1779	.1772	.1788	.1820	.1821	.1809	.1784	.1748	.1680	.1641	.1637	
.1884	.1897	.1876	.1867	.1889	.1897	.1846	.1786	.1757	.1771		
.1797	.1808	.1825	.1861	.1867	.1852	.1827	.1785	.1710	.1670		
.1785	.1796	.1835	.1863	.1863	.1850	.1825	.1789	.1715	.1664		
.1870	.1882	.1933	.1963	.1933	.1932	.1888	.1880	.1829			
.1840	.1860	.1914	.1959	.1955	.1938	.1913	.1878	.1793			
.1840	.1863	.1923	.1969	.1962	.1944	.1921	.1890	.1803			
.1908	.1925	.1990	.2052	.2023	.1937	.1986	.1979				
.1926	.1949	.2015	.2055	.2047	.1987	.2013	.1973				
.1921	.1950	.2023	.2065	.2050	.2001	.2016	.1984				
.1995	.1998	.2013	.2047	.2044	.2051	.2019					
.1973	.1990	.2042	.2081	.2079	.2072	.2050					
.1965	.1981	.2047	.2082	.2082	.2072	.2055					
.2022	.2033	.2042	.2003	.2069	.2103						
.1990	.2006	.2051	.2064	.2097	.2110						
.1973	.1996	.2054	.2062	.2096	.2100						
.2019	.2020	.2031	.2072	.2070							
.1993	.2011	.2061	.2100	.2102							
.1977	.2001	.2065	.2101	.2103							
.1949	.1972	.2042	.2098								
.1978	.1999	.2061	.2103								
.1970	.1997	.2066	.2112								
.1971	.1973	.2008									
.1936	.1952	.2008									
.1928	.1950	.2013									
.1980	.2025										
.1919	.1934										
.1904	.1916										
.2008											
.1929											
.1911											

S₂
S₄
S₈

ANGULAR QUADRATURE CONVERGENCE WITH 2x2 MESH INTERVAL

GROUP 1 FLUXES

EXHIBIT F

1.0650	1.0722	1.0488	.9679	.9365	.9404	.9758	1.0501	1.1835	1.2547	1.2616	1.2615
1.1185	1.1161	1.0734	1.0042	.9619	.9595	.9957	1.0755	1.1923	1.2705	1.2937	1.3129
1.1136	1.1067	1.0651	.9971	.9563	.9533	.9902	1.0684	1.1836	1.2599	1.2828	1.3022
1.0437	1.0397	1.0031	.9170	.8851	.8903	.9261	1.0007	1.1402	1.2162	1.2389	
1.0825	1.0716	1.0213	.9478	.9056	.9027	.9407	1.0220	1.1437	1.2302	1.2628	
1.0802	1.0654	1.0153	.9437	.9023	.8996	.9376	1.0176	1.1374	1.2215	1.2548	
1.0201	1.0004	.9472	.8626	.8247	.8327	.8673	.9477	1.0872	1.1726		
1.0458	1.0175	.9557	.8789	.8378	.8337	.8748	.9560	1.0825	1.1793		
1.0416	1.0112	.9507	.8760	.8345	.8305	.8710	.9528	1.0770	1.1710		
.9351	.9061	.8363	.7587	.7030	.7026	.7455	.8462	.9803			
.9483	.9119	.8326	.7503	.7040	.6930	.7425	.8303	.9668			
.9450	.9086	.8285	.7485	.7029	.6910	.7413	.8284	.9610			
.7793	.7551	.6463	.6199	.5652	.5001	.6003	.6927				
.8145	.7754	.6890	.6065	.5531	.4987	.5859	.6866				
.8119	.7734	.6877	.6076	.5543	.4973	.5871	.6874				
.7066	.6764	.6011	.5268	.4783	.4901	.5075					
.7323	.6948	.6063	.5179	.4852	.4817	.5129					
.7314	.6928	.6054	.5193	.4878	.4820	.5154					
.6751	.6481	.5690	.4382	.4632	.4803						
.6996	.6609	.5676	.4418	.4577	.4716						
.6986	.6587	.5657	.4413	.4578	.4704						
.6760	.6461	.5716	.4997	.4525							
.7059	.6686	.5808	.4931	.4612							
.7048	.6662	.5797	.4944	.4635							
.7194	.6833	.6278	.5519								
.7516	.7127	.6277	.5451								
.7489	.7102	.6260	.5462								
.8069	.7755	.7047									
.8311	.7938	.7133									
.8276	.7900	.7089									
.8407	.8246										
.8860	.8587										
.8832	.8521										
.8355											
.8973											
.8989											

ANGULAR QUADRATURE CONVERGENCE WITH 2x2 MESH INTERVAL

GROUP 2 FLUXES x 10

EXHIBIT G

BENCHMARK PROBLEM SOLUTION

Identification: 13-A1-2

Benchmark Problem ID.13-A1

Date Submitted: July 1976

By: A. N. Mallen (SRL)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
W. A. Wittkopf (B&W)

Descriptive Title: Discrete Ordinate Solution

Computer: IBM-360, Model 195

Code: TWOTRAN-II⁽¹⁾

Date Solved: June, 1976 at SRL

References

1. K. D. Lathrop, F. W. Brinkley, "TWOTRAN-II, An Interfaced, Exportable Version of the TWOTRAN Code for Two Dimensional Transport," LA-4848-MS, Los Alamos Scientific Laboratory (1973)
2. B. A. Zolotar, F. J. Rahn, A. Nero, "BWR Rod Bundle Benchmark Problem," Trans. of Am. Nucl. Soc. 23, 214 (1976)

Results:

Discrete Ordinate Representation: S_8

Mesh Spacing: $4 \times 4 = 16$ meshes per region in configuration map

Normalization = 1 source neutron; K_{eff} convergence criteria = 2×10^{-5}

$K_{eff} = 1.08727$

Exhibit A-1: Benchmark Solution

Exhibit A-2: Comparison with DOT-III Benchmark Solution

Exhibit B: S_8 Angular Quadrature

Exhibit C-1: Mesh and Angular Quadrature Convergence of K_{eff}

Exhibit C-2: Difference in Benchmark Solutions of K_{eff} $\{(\text{DOT-III}) - (\text{TWOTRAN2})\}$

Exhibit D: Mesh Convergence - Group 1 Fluxes

Exhibit E: Mesh Convergence - Group 2 Fluxes

Exhibit F: Angular Quadrature Convergence - Group 1 Fluxes

Exhibit G: Angular Quadrature Convergence - Group 2 Fluxes

Exhibit H: TWOTRAN2 Execution Parameters

.1745	.1738	.1752	.1783	.1781	.1769	.1747	.1715	.1652	.1614	.1611	.1603
.1119	.1110	.1066	.0999	.0960	.0956	.0995	.1073	.1188	.1267	.1292	.1312
.1761	.1758	.1779	.1811	.1812	.1801	.1777	.1742	.1675	.1631	.1623	
.1086	.1068	.1016	.0946	.0907	.0903	.0943	.1023	.1142	.1229	.1264	
.1775	.1787	.1822	.1860	.1860	.1848	.1823	.1789	.1715	.1655		
.1045	.1012	.0950	.0876	.0836	.0832	.0875	.0955	.1079	.1175		
.1834	.1860	.1928	.1976	.1969	.1950	.1929	.1899	.1811			
.0946	.0908	.0825	.0747	.0703	.0690	.0742	.0828	.0961			
.1914	.1948	.2029	.2071	.2055	.2004	.2023	.1994				
.0815	.0774	.0686	.0606	.0554	.0496	.0588	.0687				
.1946	.1976	.2052	.2085	.2088	.2076	.2062					
.0736	.0695	.0605	.0520	.0491	.0483	.0519					
.1961	.1989	.2058	.2062	.2099	.2099						
.0701	.0660	.0564	.0440	.0459	.0469						
.1966	.1996	.2069	.2103	.2107							
.0710	.0668	.0580	.0494	.0466							
.1961	.1992	.2070	.2115								
.0752	.0711	.0624	.0545								
.1919	.1945	.2016									
.0829	.0789	.0706									
.1890	.1904										
.0887	.0854										
.1891											
.0906											

S-8 (4X4) MESH GROUP 1
 S-8 (4X4) MESH GROUP 2

BENCHMARK SOLUTION
 S_8 - 4x4 Mesh Intervals
 EXHIBIT A-1

.988 1.004	.989 1.002	.993 1.001	.994 1.001	.994 1.003	.993 1.003	.995 1.004	.997 1.004	.995 1.004	.991 1.006	.989 1.007	.986 1.007
.990 1.005	.991 1.002	.995 1.001	.996 1.003	.996 1.004	.996 1.003	.997 1.004	.997 1.005	.997 1.004	.993 1.006	.991 1.006	
.993 1.001	.994 1.001	.998 1.000	.998 1.000	.999 1.002	.998 1.001	.999 1.005	1.001 1.004	.999 1.004	.995 1.003		
.997 1.001	.998 1.007	1.002 .998	1.003 .999	1.003 1.000	1.003 1.000	1.004 1.001	1.004 1.000	1.003 1.001			
.997 1.002	.999 1.001	1.003 .999	1.003 .998	1.003 1.000	1.003 .998	1.004 1.002	1.005 1.000				
.996 1.004	.998 1.003	1.002 .998	1.002 1.000	1.003 1.002	1.002 1.000	1.003 1.002					
.994 1.003	.990 1.002	1.002 .998	1.001 .998	1.001 1.000	1.000 .996						
.995 1.006	.998 1.001	1.001 1.000	1.001 .998	1.002 1.000							
.996 1.003	.997 1.001	1.001 .997	1.002 .998								
.995 .994	.997 .999	1.001 .997									
.992 1.003	.994 1.001										
.990 1.003											

TWOTRAN2 $K_{eff} = 1.08727$

DOT-III $K_{eff} = 1.08714$

BENCHMARK FLUX RATIO

(TWOTRAN2/DOT-III)

S_8 - 4x4 Mesh Intervals

EXHIBIT A-2

<u>ANGLE</u>	<u>MU</u>	<u>ETA</u>	<u>WEIGHT</u>
1	0.192327	0.962299	0.291971
2	0.577350	0.793521	0.233138
3	0.192327	0.793521	0.233138
4	0.793521	0.577350	0.233138
5	0.577350	0.577350	0.225257
6	0.192327	0.577350	0.233138
7	0.962299	0.192327	0.291971
8	0.793521	0.192327	0.233138
9	0.577350	0.192327	0.233138
10	0.192327	0.192327	0.291971

S₈ ANGULAR QUADRATURE

EXHIBIT B

MESH CONVERGENCE WITH S_8

$$(1 \times 1) K_{\text{eff}} = 1.08427$$

$$(2 \times 2) K_{\text{eff}} = 1.08712$$

$$(4 \times 4) K_{\text{eff}} = 1.08727$$

ANGULAR QUADRATURE CONVERGENCE WITH 2x2 MESH INTERVAL

$$S_2 K_{\text{eff}} = 1.09214$$

$$S_4 K_{\text{eff}} = 1.08708$$

$$S_8 K_{\text{eff}} = 1.08712$$

MESH AND ANGULAR QUADRATURE
CONVERGENCE OF K_{eff}

EXHIBIT C-1

MESH CONVERGENCE WITH S_8

$$(1 \times 1) \quad \Delta K_{\text{eff}} = +0.00014$$

$$(2 \times 2) \quad \Delta K_{\text{eff}} = -0.00003$$

$$(4 \times 4) \quad \Delta K_{\text{eff}} = -0.00013$$

ANGULAR QUADRATURE CONVERGENCE WITH 2×2 MESH INTERVAL

$$S_2 \quad \Delta K_{\text{eff}} = -0.00019$$

$$S_4 \quad \Delta K_{\text{eff}} = +0.00016$$

$$S_8 \quad \Delta K_{\text{eff}} = -0.00003$$

$$\Delta K_{\text{eff}} = K_{\text{eff}} (\text{DOT-III}) - K_{\text{eff}} (\text{TWOTRAN2})$$

DIFFERENCE IN K_{eff} SOLUTIONS
OF BENCHMARK PROBLEM

EXHIBIT C-2

.1751	.1736	.1751	.1778	.1785	.1768	.1750	.1711	.1648	.1613	.1617	.1607
.1747	.1738	.1751	.1783	.1781	.1770	.1746	.1715	.1651	.1613	.1610	.1605
.1745	.1738	.1752	.1783	.1781	.1769	.1747	.1715	.1652	.1614	.1611	.1603
.1762	.1760	.1775	.1811	.1816	.1801	.1781	.1742	.1672	.1630	.1616	
.1762	.1757	.1779	.1811	.1812	.1801	.1777	.1743	.1674	.1629	.1623	
.1761	.1758	.1779	.1811	.1812	.1801	.1777	.1742	.1675	.1631	.1623	
.1770	.1782	.1818	.1855	.1863	.1849	.1824	.1786	.1711	.1645		
.1773	.1785	.1821	.1860	.1860	.1847	.1823	.1789	.1714	.1655		
.1775	.1787	.1822	.1860	.1860	.1848	.1823	.1789	.1715	.1655		
.1831	.1855	.1918	.1971	.1962	.1940	.1922	.1893	.1801			
.1834	.1859	.1926	.1975	.1968	.1950	.1928	.1899	.1809			
.1834	.1860	.1928	.1976	.1969	.1950	.1929	.1899	.1811			
.1915	.1947	.2024	.2085	.2059	.2021	.2026	.2008				
.1915	.1949	.2028	.2072	.2056	.2005	.2024	.1994				
.1914	.1948	.2029	.2071	.2055	.2004	.2023	.1994				
.1955	.1980	.2045	.2092	.2084	.2077	.2058					
.1946	.1976	.2051	.2086	.2088	.2076	.2062					
.1946	.1976	.2052	.2085	.2088	.2076	.2062					
.1964	.1993	.2048	.2078	.2098	.2118						
.1962	.1989	.2058	.2063	.2099	.2101						
.1961	.1989	.2058	.2062	.2099	.2099						
.1974	.2001	.2062	.2109	.2103							
.1966	.1996	.2068	.2104	.2107							
.1966	.1996	.2069	.2103	.2107							
.1961	.1990	.2066	.2128								
.1962	.1993	.2070	.2117								
.1961	.1992	.2070	.2115								
.1916	.1941	.2006									
.1919	.1944	.2014									
.1919	.1945	.2016									
.1892	.1894										
.1888	.1903										
.1890	.1904										
.1895											
.1893											
.1891											

S-8 (1X1) MESH
S-8 (2X2) MESH
S-8 (4X4) MESH

MESH CONVERGENCE WITH S₈

GROUP 1 FLUXES

EXHIBIT D

.1113	.1106	.1064	.0996	.0957	.0956	.0993	.1072	.1188	.1264	.1289	.1308
.1118	.1108	.1066	.0999	.0959	.0956	.0994	.1073	.1188	.1266	.1291	.1312
.1119	.1110	.1066	.0999	.0960	.0956	.0995	.1073	.1188	.1267	.1292	.1312

.1079	.1064	.1013	.0941	.0903	.0903	.0940	.1019	.1140	.1226	.1258
.1084	.1067	.1016	.0945	.0905	.0902	.0942	.1022	.1142	.1228	.1263
.1086	.1068	.1016	.0946	.0907	.0903	.0943	.1023	.1142	.1229	.1264

.1040	.1009	.0953	.0875	.0838	.0844	.0878	.0956	.1084	.1171
.1044	.1012	.0950	.0877	.0836	.0832	.0874	.0956	.1080	.1176
.1045	.1012	.0950	.0876	.0836	.0832	.0875	.0955	.1079	.1175

.0945	.0910	.0833	.0749	.0703	.0690	.0743	.0832	.0970
.0946	.0908	.0826	.0747	.0703	.0691	.0742	.0829	.0962
.0946	.0908	.0825	.0747	.0703	.0690	.0742	.0828	.0961

.0810	.0773	.0688	.0607	.0548	.0506	.0582	.0689
.0814	.0774	.0686	.0606	.0554	.0496	.0588	.0688
.0815	.0774	.0686	.0606	.0554	.0496	.0588	.0687

.0731	.0695	.0605	.0512	.0479	.0474	.0506
.0735	.0694	.0605	.0519	.0489	.0482	.0517
.0736	.0695	.0605	.0520	.0491	.0483	.0519

.0701	.0668	.0562	.0447	.0451	.0479
.0701	.0660	.0565	.0440	.0458	.0469
.0701	.0660	.0564	.0440	.0459	.0469

.0704	.0667	.0578	.0487	.0455
.0708	.0668	.0579	.0494	.0465
.0710	.0668	.0580	.0494	.0466

.0745	.0708	.0625	.0544
.0751	.0711	.0625	.0545
.0752	.0711	.0624	.0545

.0826	.0791	.0712
.0829	.0790	.0707
.0829	.0789	.0706

.0884	.0850
.0886	.0853
.0887	.0854

.0899
.0905
.0906

S-8 (1X1) MESH
S-8 (2X2) MESH
S-8 (4X4) MESH

MESH CONVERGENCE WITH S_8
 GROUP 2 FLUXES
 EXHIBIT E

.1904	.1901	.1840	.1817	.1872	.1862	.1831	.1737	.1719	.1773	.1774	.1798
.1764	.1756	.1756	.1788	.1792	.1780	.1757	.1717	.1649	.1624	.1623	.1621
.1747	.1738	.1751	.1733	.1781	.1770	.1746	.1715	.1651	.1613	.1610	.1605
.1903	.1879	.1857	.1837	.1879	.1876	.1839	.1755	.1735	.1756	.1796	
.1774	.1765	.1778	.1815	.1820	.1806	.1785	.1744	.1667	.1631	.1633	
.1762	.1757	.1779	.1811	.1812	.1801	.1777	.1743	.1674	.1629	.1623	
.1884	.1897	.1876	.1867	.1890	.1898	.1847	.1787	.1758	.1772		
.1778	.1790	.1813	.1855	.1860	.1846	.1824	.1782	.1700	.1652		
.1773	.1785	.1821	.1860	.1860	.1847	.1823	.1789	.1714	.1655		
.1869	.1882	.1933	.1963	.1934	.1933	.1889	.1881	.1831			
.1832	.1852	.1912	.1962	.1960	.1944	.1919	.1884	.1790			
.1834	.1859	.1926	.1975	.1968	.1950	.1928	.1899	.1809			
.1908	.1925	.1990	.2052	.2024	.1938	.1987	.1981				
.1923	.1949	.2021	.2065	.2056	.2008	.2022	.1983				
.1915	.1949	.2028	.2072	.2056	.2005	.2024	.1994				
.1995	.1998	.2012	.2047	.2044	.2052	.2020					
.1966	.1987	.2049	.2089	.2089	.2081	.2061					
.1946	.1976	.2051	.2086	.2088	.2076	.2062					
.2022	.2032	.2041	.2002	.2068	.2111						
.1980	.2000	.2055	.2070	.2105	.2115						
.1962	.1989	.2058	.2063	.2099	.2101						
.2018	.2019	.2030	.2071	.2070							
.1985	.2007	.2065	.2107	.2109							
.1966	.1996	.2068	.2104	.2107							
.1948	.1971	.2041	.2097								
.1973	.1997	.2065	.2112								
.1962	.1993	.2070	.2117								
.1970	.1972	.2007									
.1926	.1945	.2007									
.1919	.194	.2014									
.1981	.2024										
.1904	.1921										
.1888	.1903										
.2007											
.1911											
.1893											

S-2 (2X2) MESH
S-4 (2X2) MESH
S-8 (2X2) MESH

ANGULAR QUADRATURE CONVERGENCE WITH 2x2 MESH INTERVAL
GROUP 1 FLUXES
EXHIBIT F

.1065	.1072	.1048	.0968	.0937	.0941	.0977	.1052	.1187	.1258	.1266	.1265
.1130	.1125	.1078	.1010	.0968	.0965	.1002	.1081	.1197	.1278	.1303	.1328
.1118	.1108	.1066	.0999	.0959	.0956	.0994	.1073	.1188	.1266	.1291	.1312
.1043	.1039	.1003	.0917	.0885	.0891	.0928	.1003	.1143	.1220	.1243	
.1092	.1078	.1025	.0953	.0911	.0907	.0946	.1027	.1148	.1236	.1272	
.1084	.1067	.1016	.0945	.0905	.0902	.0942	.1022	.1142	.1228	.1263	
.1020	.1000	.0947	.0863	.0825	.0833	.0869	.0950	.1090	.1176		
.1052	.1021	.0957	.0881	.0841	.0835	.0878	.0959	.1084	.1183		
.1044	.1012	.0950	.0877	.0836	.0832	.0874	.0956	.1080	.1176		
.0935	.0906	.0836	.0759	.0703	.0703	.0747	.0848	.0983			
.0952	.0913	.0830	.0748	.0704	.0692	.0742	.0829	.0964			
.0946	.0908	.0826	.0747	.0703	.0691	.0742	.0829	.0962			
.0779	.0755	.0696	.0620	.0565	.0500	.0601	.0707				
.0820	.0779	.0687	.0604	.0552	.0496	.0585	.0684				
.0814	.0774	.0686	.0606	.0554	.0496	.0588	.0688				
.0706	.0676	.0601	.0527	.0478	.0490	.0508					
.0739	.0699	.0607	.0517	.0487	.0482	.0515					
.0735	.0694	.0605	.0519	.0489	.0482	.0517					
.0675	.0648	.0569	.0438	.0463	.0480						
.0706	.0664	.0568	.0441	.0458	.0471						
.0701	.0660	.0565	.0440	.0458	.0469						
.0676	.0646	.0571	.0499	.0452							
.0713	.0673	.0581	.0493	.0463							
.0708	.0668	.0579	.0494	.0465							
.0705	.0683	.0627	.0551								
.0759	.0717	.0627	.0544								
.0751	.0711	.0625	.0545								
.0806	.0775	.0704									
.0837	.0797	.0712									
.0829	.0790	.0707									
.0840	.0824										
.0896	.0865										
.0886	.0853										
.0835											
.0911											
.0905											

S-2 (2X2) MESH
S-4 (2X2) MESH
S-8 (2X2) MESH

ANGULAR QUADRATURE CONVERGENCE WITH 2x2 MESH INTERVAL
GROUP 2 FLUXES
EXHIBIT G

<u>S_n</u>	<u>Mesh</u>	<u>K_{eff} Convergence</u>	<u>CPU Time Min:Sec</u>	<u>Core Size Bytes</u>
2	1x1	2×10^{-5}	:11	310K
4	1x1	2×10^{-5}	:13	310K
8	1x1	2×10^{-5}	:21	312K
2	2x2	2×10^{-5}	:21	319K
4	2x2	2×10^{-5}	:40	320K
8	2x2	2×10^{-5}	1:17	323K
2	4x4	2×10^{-5}	1:07	355K
4	4x4	2×10^{-5}	2:16	357K
8	4x4	2×10^{-5}	4:35	363K

TWOTRAN2 EXECUTION PARAMETERS

EXHIBIT H

BENCHMARK PROBLEM

Identification:	13-A2	Source Situation	ID.13
Date Submitted:	January 1977	By:	B. A. Zolotar (EPRI)
Date Accepted:	June 1977	By:	H. L. Dodds, Jr.(U. of Tenn.) W. A. Wittkopf (B&W)

Descriptive Title: Diffusion Theory Problem for the LWR Bundle

This problem is defined precisely the same as Problem 13-A1 but with $D = \frac{1}{3\Sigma_T}$ (for each group)

resulting in a two-group, two-dimensional diffusion theory problem.

Solutions:

1. Finite difference and linear finite-element: 13-A2-1
2. Finite difference: 13-A2-2

BENCHMARK PROBLEM SOLUTION

Identification: 13-A2-1

Benchmark Problem ID.13-A2

Date Submitted: January 1977

By: T. B. Fowler and D. R. Vondy
(ORNL)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
W. A. Wittkopf (B&W)

Descriptive Title: Diffusion Theory Solution of LWR Bundle Problem

Computer: IBM-360/95

Code: VENTURE (Report ORNL-5062), mesh-centered finite difference

VANCER (Report to be published), mesh-edge finite difference

Results: The problem was solved with several uniform meshpoint arrangements assuming $D = \frac{1}{3\Sigma_T}$, and results normalized to

one neutron source for the problem are displayed in Table 1. The VANCER code is not yet structured to solve small problems the most efficiently. For short execution times, the processor use time allocation is often more than reasonable under the multi-tasking system executing several jobs simultaneously. Fission source values by fueled assembly are shown in Table 2 for the mesh-centered formulation and in Table 3 for the mesh edge formulations; data is for horizontal rows of assemblies to the diagonal from the top down, normalized to one neutron source per unit volume in the fueled zone (unit average fission source). It should be noted that if the error from the difference formulation is assumed to be proportional to the square of the mesh spacing, there is little difference between these formulations for this problem (13^2 is somewhat $> 12^2$). The convergence level satisfied for these problems was 5×10^{-5} maximum relative flux change on outer iteration. Flux values for the 48 x 48 VENTURE mesh centered case are shown in Table 4 normalized to one source neutron (times 100).

Table 1. LWR Bundle Problem
Diffusion Theory Solutions

Meshpoints	Points Per Assembly	k_{eff}	Peak to Average Point Source	Peak Point Fast Flux	Processor Time* (min)
<u>Mesh-centered finite-difference (VENTURE)</u>					
12 x 12	1	1.09238	1.2543	0.1900	0.074
24 x 24	4	1.08759	1.3379	0.1907	0.102
48 x 48	16	1.08606	1.3851	0.1909	0.229
96 x 96	64	1.08565	1.4100	0.1910	0.921
Extrapolated	(∞)	1.0855	1.418	0.1910	
<u>Mesh-edge finite-difference (VANCER) usual finite-difference (4 neighbors)</u>					
13 x 13	(1)	1.08061	1.2607	0.1917	0.224
25 x 25	(4)	1.08389	1.3411	0.1912	0.477
49 x 49	(16)	1.08506	1.3861	0.1911	1.198
<u>Linear finite-element (8 neighbors) (VANCER)</u>					
13 x 13	(1)	1.08185	1.2659	0.1919	0.238
25 x 25	(4)	1.08454	1.3429	0.1913	0.500
49 x 49	(16)	1.08525	1.3869	0.1911	1.465

*Eigenvalue problem set up and solution; for the VENTURE solutions, the flux solution from the next smaller problem was used as a starting guess.

Table 2. LWR Bundle Problem Assembly Fission Source
(Mesh-centered VENTURE code results)

Assembly (Horizontal row to diagonal, starts at top)	Mesh Points				
	12X12	24X24	48X48	96X96	Extrapolated
1	1.09074	1.09238	1.09353	1.09388	1.09396
2	1.14093	1.14285	1.14351	1.14372	1.14379
3	1.08737	1.08492	1.08435	1.08426	1.08423
4	1.06877	1.06881	1.06852	1.06841	1.06837
5	1.00338	1.00068	0.99999	0.99983	0.99978
6	1.09826	1.10063	1.10136	1.10157	1.10164
7	1.03213	1.03492	1.03581	1.03608	1.03617
8	1.25429	1.25888	1.26031	1.26072	1.26086
9	1.13426	1.13782	1.13862	1.13882	1.13889
10	1.05726	1.05700	1.05669	1.05655	1.05650
11	0.36380	0.37364	0.37668	0.37750	0.37777
12	1.10952	1.11015	1.11011	1.11004	1.11002
13	1.06466	1.06756	1.06812	1.06826	1.06830
14	1.13258	1.13063	1.13026	1.13022	1.13021
15	1.00320	1.00120	1.00048	1.00025	1.00017
16	0.96005	0.95104	0.94875	0.94820	0.94802
17	0.94115	0.93831	0.93728	0.93695	0.93684
18	1.00445	0.99613	0.99400	0.99350	0.99333
19	1.06608	1.06594	1.06565	1.06554	1.06550
20	0.34673	0.35498	0.35756	0.35825	0.35848
21	0.90326	0.89939	0.89814	0.89776	0.89763
22	0.91053	0.91070	0.91023	0.91006	0.91000
23	1.09183	1.08898	1.08838	1.08828	1.08825
24	0.96327	0.96071	0.95985	0.95958	0.95949
25	0.92118	0.91180	0.90943	0.90885	0.90866
26	1.15758	1.15953	1.16027	1.16051	1.16059
27	1.03817	1.03928	1.03946	1.03950	1.03951
28	1.08032	1.08162	1.08220	1.08241	1.08248

Table 3. LWR Bundle Problem Assembly Fission Source
(Mesh-edge VANCER code results,
49X49 meshpoints)

Assembly	Usual Finite-Difference	Linear Finite-Element
1	1.09375	1.09424
2	1.14367	1.14399
3	1.08403	1.08412
4	1.06794	1.06824
5	0.99960	0.99954
6	1.10163	1.10157
7	1.03615	1.03609
8	1.26091	1.26123
9	1.13887	1.13908
10	1.05647	1.05633
11	0.37864	0.37822
12	1.11008	1.10975
13	1.06824	1.06821
14	1.13013	1.13024
15	1.00001	1.00001
16	0.94817	0.94750
17	0.93688	0.93650
18	0.99358	0.99272
19	1.06515	1.06558
20	0.35922	0.35893
21	0.89758	0.89734
22	0.90980	0.90992
23	1.08814	1.08834
24	0.95938	0.95939
25	0.90875	0.90824
26	1.16055	1.16100
27	1.03941	1.03975
28	1.08225	1.08291

Table 4. Average Flux Values x 100 for the 48 x 48 Mesh-Centered VENTURE
Case by Zone (Fast and Thermal Values for the Map)

16.82	16.84	16.96	17.11	17.12	17.01	16.80	16.47	16.01	15.74	15.66	15.62
10.01	9.916	9.527	8.921	8.561	8.534	8.915	9.669	10.77	11.52	11.77	11.95
16.90	16.93	17.06	17.23	17.24	17.12	16.91	16.58	16.11	15.81	15.72	
9.718	9.553	9.105	8.476	8.108	8.078	8.972	9.240	10.37	11.17	11.52	
17.01	17.06	17.22	17.41	17.41	17.29	17.08	16.75	16.25	15.92		
9.335	9.090	8.612	7.956	7.580	7.546	7.955	8.739	9.901	10.72		
		Fuel									
17.38	17.46	17.71	17.74	17.93	17.78	17.58	17.26	16.70			
8.435	8.202	7.636	6.929	6.512	6.410	6.889	7.729	8.969			
17.94	18.03	18.33	18.56	18.52	18.30	18.21	17.89				
7.216	6.966	6.350	5.616	5.134	4.793	5.469	6.400				
18.25	18.34	18.61	18.82	18.85	18.74	18.57					
6.456	6.203	5.563	4.783	4.476	4.414	4.760					
18.40	18.48	18.72	18.86	18.99	18.95						
6.119	5.862	5.175	4.205	4.167	4.241						
18.46	18.54	18.81	19.02	19.07							
6.190	5.936	5.304	4.531	4.230							
18.39	18.48	18.78	19.03								
6.589	6.338	5.731	5.001								
18.16	18.24	18.51									
7.274	7.034	6.460									
17.98	18.04										
7.765	7.534										
17.94											
7.929											

BENCHMARK PROBLEM SOLUTION

Identification: 13-A2-2

Benchmark Problem ID.13-A2

Date Submitted: January 1977

By: B. A. Zolotar (EPRI)
F. J. Rahn (EPRI)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
W. A. Wittkopf (B&W)

Descriptive Title: Diffusion Theory Solution with CITATION

Computer: IBM-360, Model 195

Code: CITATION

Date Solved: November 1975 at EPRI

Results:

 $K_{eff} = 1.087575$

Mesh Spacing: 4 meshes per region in configuration map

Convergence criteria: eigenvalue 0.0001
flux 0.00004

Exhibit A: Group 1 Fluxes

Exhibit B: Group 2 Fluxes

.1679	.1681	.1692	.1707	.1709	.1697	.1676	.1642	.1597	.1571	.1563	.1558
.1687	.1689	.1703	.1719	.1720	.1708	.1687	.1654	.1607	.1579	.1569	
.1698	.1703	.1719	.1737	.1738	.1726	.1705	.1672	.1622	.1589		
.1735	.1743	.1769	.1793	.1792	.1777	.1757	.1725	.1668			
.1791	.1800	.1832	.1855	.1850	.1827	.1820	.1787				
.1822	.1831	.1861	.1880	.1883	.1872	.1856					
.1836	.1845	.1871	.1883	.1898	.1893						
.1843	.1851	.1880	.1901	.1906							
.1836	.1843	.1877	.1901								
.1813	.1820	.1850									
.1795	.1801										
.1791											

Exhibit A: Group 1 Fluxes

.1003	.0994	.0955	.0894	.0858	.0855	.0894	.0969	.1079	.1154	.1179	.1197
.0975	.0958	.0913	.0850	.0813	.0809	.0850	.0926	.1039	.1120	.1155	
.0936	.0909	.0863	.0796	.0759	.0755	.0797	.0892	.0992	.1072		
.0846	.0821	.0763	.0693	.0651	.0641	.0690	.0772	.0896			
.0724	.0698	.0635	.0562	.0514	.0474	.0548	.0639				
.0648	.0622	.0557	.0479	.0449	.0443	.0478					
.0615	.0588	.0518	.0415	.0418	.0425						
.0620	.0595	.0530	.0454	.0424							
.0661	.0636	.0573	.0500								
.0730	.0705	.0646									
.0778	.0754										
.0795											

Exhibit B: Group 2 Fluxes

BENCHMARK SOURCE SITUATION

Identification: 14

Date Submitted: June 1976

By: S. Langenbuch (GRS-Munich)
W. Werner (GRS-Munich)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
F. N. McDonnell (AECL-CRNL)

Descriptive Title: Multi-dimensional (x-y-z) BWR Model

Suggested Function: Test 2d, 3d Neutron Kinetics Solution,
Especially for Coarse Mesh Methods

Fig. 1: Quadrant of Reactor Horizontal Cross Section,
Region Assignment

Fig. 2: Quadrant of Reactor Horizontal Cross Section, Fuel Assembly Identification

Fig. 3: Vertical Cross Section, $y=0$, Region Assignment, Vertical Slice Identification

BOUNDARY CONDITIONS:

External Boundaries: zero flux
 Symmetry Boundaries: Reflection, $\frac{\partial \phi_g}{\partial n} = 0$

BENCHMARK PROBLEM

Identification: 14-A1

Source Situation ID.14

Date Submitted: June 1976

By: S. Langenbuch and W. Werner
(GRS-Munich)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
F. N. McDonnell (AECL-CRNL)

Descriptive Title: Super Prompt-critical Transient; Two-dimensional, Two-group Neutron Diffusion Problem, with Adiabatic Heatup and Doppler Feedback in Thermal Reactor

Reduction of Source Situation:

1. Two-dimensional (xy), two-group diffusion theory
2. Two delayed neutron precursor groups.

$$\nabla D_1(\vec{x}, t) \nabla \phi_1(\vec{x}, t) - (\Sigma a_1(\vec{x}, t) + \Sigma_{1 \rightarrow 2}(\vec{x}, t)) \phi_1(\vec{x}, t) + v(1 - \beta) \left[\Sigma f_1(\vec{x}, t) \phi_1(\vec{x}, t) + \Sigma f_2(\vec{x}, t) \phi_2(\vec{x}, t) \right] + \sum_{i=1}^2 \lambda_i C_i(\vec{x}, t) = \frac{1}{v_1} \frac{\partial}{\partial t} \phi_1(\vec{x}, t)$$

$$\nabla D_2(\vec{x}, t) \nabla \phi_2(\vec{x}, t) - \Sigma a_2(\vec{x}, t) \phi_2(\vec{x}, t) + \Sigma_{1 \rightarrow 2}(\vec{x}, t) \phi_1(\vec{x}, t) = \frac{1}{v_2} \frac{\partial}{\partial t} \phi_2(\vec{x}, t)$$

$$v \beta_i (\Sigma f_1(\vec{x}, t) \phi_1(\vec{x}, t) + \Sigma f_2(\vec{x}, t) \phi_2(\vec{x}, t)) - \lambda_i C_i(\vec{x}, t) = \frac{\partial}{\partial t} C_i(\vec{x}, t), \quad i=1, 2.$$

with zero flux boundary conditions on external surfaces, reflection conditions at symmetry boundaries, and steady state initial conditions.

3. Adiabatic Heatup

$$\alpha \left[\Sigma f_1(\vec{x}, t) \phi_1(\vec{x}, t) + \Sigma f_2(\vec{x}, t) \phi_2(\vec{x}, t) \right] = \frac{\partial}{\partial t} T(\vec{x}, t)$$

4. Doppler Feedback

$$\Sigma a_1(\vec{x}, t) = \Sigma a_1(\vec{x}, t=0) [1 + \gamma(\sqrt{T(\vec{x}, t)} - \sqrt{T_0})]$$

5. Power

$$P(\vec{x}, t) = \epsilon [\Sigma f_1(\vec{x}, t) \phi_1(\vec{x}, t) + \Sigma f_2(\vec{x}, t) \phi_2(\vec{x}, t)]$$

Data:

Initial Two-Group Constants

Region	Material	Group i	D_i (cm)	Σa_i (cm ⁻¹)	$v\Sigma f_i$ (cm ⁻¹)	$\Sigma_{i \rightarrow 2}$ (cm ⁻¹)
1	Fuel 1 with rod	1	1.255	0.008252	0.004602	0.02533
		2	0.211	0.1003	0.1091	
2	Fuel 1 out rod	1	1.268	0.007181	0.004609	0.02767
		2	0.1902	0.07047	0.08675	
3	Fuel 2 with rod	1	1.259	0.008002	0.004663	0.02617
		2	0.2091	0.08344	0.1021	
4	Fuel 2 out rod	1	1.259	0.008002	0.004663	0.02617
		2	0.2091	0.073324	0.1021	
5	Reflector	1	1.257	0.0006034	0	0.04754
		2	0.1592	0.01911	0	

Additional Parameters for all Regions:

 $B^2 = 1.0 \cdot 10^{-4}$ axial buckling for both energy groups $\nu = 2.43$ mean number of neutrons per fission $\nu_1 = 3.0 \cdot 10^7$ cm·sec⁻¹ $\nu_2 = 3.0 \cdot 10^5$ cm·sec⁻¹

Delayed Neutron Data:

Group	β_i	λ_i (sec ⁻¹)
1	0.0054	0.00654
2	0.001087	1.35

Data for Feedback Model

$$\begin{aligned}
 \alpha &= 3.83 \cdot 10^{-11} \text{ } ^\circ\text{K cm}^3 && \text{conversion factor} \\
 \gamma &= 2.034 \cdot 10^{-3} \text{ } ^\circ\text{K}^{1/2} && \text{feedback constant} \\
 \epsilon &= 3.204 \cdot 10^{-11} \text{ Wsec/p.fission} && \text{energy conversion factor}
 \end{aligned}$$

The initial configuration is made critical by dividing the production cross sections by k_{eff} . The initial flux distribution shall be normalized such that the average power density

$$\bar{P} = \frac{\epsilon}{V_{\text{core}}} \int_{V_{\text{core}}} (\Sigma f_1 \phi_1 + \Sigma f_2 \phi_2) dV = 1.0 \cdot 10^{-6} \text{ W cm}^{-3}$$

The initial precursor concentrations are in equilibrium with the initial critical flux distribution.

The initial temperature $T_0 = 300 \text{ } ^\circ\text{K}$.

Initiating Perturbation:

$$\frac{\Sigma a_2(t)}{\Sigma a_2(0)} = \begin{cases} 1 - 0.0606184 \cdot t & t \leq 2 \\ 0.8787631 & t > 2 \end{cases}$$

where t = time (sec).

Expected Primary Results:

1. Maximum eigenvalue for initial flux distribution
2. Normalized Power Densities P_k for initial flux distribution:

$$P_k = \frac{\epsilon}{V_k \bar{P}} \int_{V_k} (\Sigma f_1 \phi_1 + \Sigma f_2 \phi_2) dV, \quad V_k = \text{Volume of Fuel Assembly } k$$

$$k = 1, \dots, 78$$

3. Maximum eigenvalue for configuration of withdrawn rod for cold reactor (feedback effects neglected)
4. Average Power density $\bar{P}$ versus time
5. Normalized Power Densities P_k at $t=0,4$ sec, $0,8$ sec, $1,2$ sec, $1,4$ sec, $2,0$ sec, $3,0$ sec.
6. Maximum of $\bar{P}$, time of occurrence
7. Average temperature $\bar{T} = \frac{1}{V_{\text{core}}} \int_{V_{\text{core}}} T(\vec{x}, t) dV$ versus time
8. Number of unknowns in the problem, number of time-steps, computing time, and computer used.

Possible additional results:

9. Table of temperatures in volumes V_k , $k=1, \dots, 78$.
10. Dependence of results on spatial and temporal discretization.

Solutions:Coarse-mesh finite-difference methods

1. Flux expansion:
2. Nodal expansion:

14-A1-1

14-A1-2

BENCHMARK PROBLEM SOLUTION

Identification:	14-A1-1	Benchmark Problem ID.14-A1
Date Submitted:	February 1977	By: S. Langenbuch (GRS-Munich) W. Werner (GRS-Munich)
Date Accepted:	June 1977	By: H. L. Dodds, Jr. (U. of Tenn.) F. N. McDonnell (AECL-CRNL)

Descriptive Title: Direct 2d-Coarse Mesh Solution with
CUBBOX.^{1,2,3}

Mathematical Model: A 5-point difference operator with coupling coefficients derived from expansion of neutron flux into local polynomials is used for the approximation of the spatial differential operator,^{1,2,3}. Time integration is performed by a combined ADE-ADI technique⁴ with spectral matching⁵, and frequency prediction from space-averaged kinetic equations⁶.

Computer: IBM-360, Model 91
Code: CUBBOX⁷ with 6-order nonseparated polynomials
Date Solved: February 1977 at Laboratorium für
Reaktorregelung und Anlagensicherung (LRA)

References:

- 1 A. Birkhofer and W. Werner, Efficiency of Various Methods
for the Analysis of Space-Time Kinetics, Proc. Conf.
Mathematical Models and Computational Techniques for
Analysis of Nuclear Systems, CONF-730414, Vol. 2,
p. IX-31-41 (1973)

- 2 A. Birkhofer, S. Langenbuch and W. Werner, Coarse-Mesh Method for Space-Time Kinetics, Trans. Am. Nuc. Soc., 18, 153 (1974)
- 3 S. Langenbuch, W. Maurer and W. Werner, High Order Schemes for Neutron Kinetics Calculations, Based on Local Polynomial Approximation, to be publ. Nucl. Sci. Eng. Oct. 1977
- 4 S. Langenbuch and W. Werner, Implicit Matrix Decomposition Scheme for Coarse-Mesh Methods, Trans. Am. Nuc. Soc. 21, 224 (1974)
- 5 J. Devought and E. Mund, A - Stable Algorithms for Neutron Kinetics, MRR 145, Proc. of the Joint NEACRP/CSNI Specialists' Meeting on New Developments in Three-Dimensional Neutron Kinetics, 21-71 (1975)
- 6 S. Langenbuch and W. Werner, Eine Methode zur Verbesserung der Zeitintegration in 3d Neutronenkinetik-Rechnungen durch eine Form der Periodenfaktorisierung, Proc. Reaktortagung (1976)
- 7 Program Description of the QUABOX/CUBBOX Code, Internal Report, LRA, D-8046 Garching

Results:

Uniform mesh width $\Delta x = \Delta y = 15$ cm (11 x 11 intervals)

1. Maximum eigenvalue for initial flux distribution:

$$k_{\text{eff}} = 0.99633$$

2. Exhibit A:

Normalized Power Densities P_{ki} for initial flux distribution:

$$P_{ki} = \frac{\epsilon}{P_{Vki}} \int_{V_{ki}} (\Sigma f_1 \phi_1 + \Sigma f_2 \phi_2) dV, \quad V_k = \text{Volume of Fuel}$$

Assembly k

$$k = 1, \dots, 78$$

3. Maximum eigenvalue for configuration of withdrawn rod for cold reactor (feedback effects neglected):

$$k_{\text{eff}} = 1.01546$$

4. Exhibit B:

Average Power density $\bar{P}$ versus time

5. Exhibit C:

Normalized Power Densities P_k at $t = 0.4$ sec, 0.8 sec, 1.2 sec, 1.4 sec, 2.0 sec, 3.0 sec.

6. Maximum of $\bar{P} = 5.734 \cdot 10^3$; time of occurrence = 1.421 sec.

7. Exhibit D:

Average temperature $\bar{T} = \frac{1}{V_{\text{core}}} \int_{V_{\text{core}}} T(\vec{x}, t) dV$ versus time

8. Number of unknowns in the problem $121 \times (2 \text{ prompt neutron groups} + 2 \text{ delayed precursor groups} + \text{temperature}) = 605$

Number of time-steps: 1200

Computing time: 180 sec on IBM-360/91

9. Exhibit E:

Average temperatures in volumes V_k , $k = 1, \dots, 78$, at $t = 0.4$ sec, 0.8 sec, 1.2 sec, 1.4 sec, 2.0 sec, 3.0 sec.

EXHIBIT A

NORMALIZED POWER DENSITY

INITIAL STATE

Y/X	1	2	3	4	5	6	7	8	9
1	0.6214	0.4438	0.4134	0.5107	0.7939	1.3984	1.6725	1.4769	0.9059
2	0.4438	0.4010	0.4092	0.4931	0.6708	0.9416	1.1512	1.2703	0.8538
3	0.4134	0.4092	0.4275	0.4958	0.6209	0.7794	0.9608	1.1655	0.8145
4	0.5107	0.4931	0.4958	0.5565	0.6816	0.8400	1.0173	1.2168	0.8427
5	0.7939	0.6708	0.6209	0.6816	0.8655	1.1570	1.3450	1.4185	0.9260
6	1.3984	0.9416	0.7794	0.8400	1.1570	1.8739	2.0743	1.6882	0.9580
7	1.6725	1.1512	0.9608	1.0173	1.3450	2.0743	2.1888	1.6176	0.8403
8	1.4769	1.2703	1.1655	1.2168	1.4185	1.6882	1.6176	1.3323	0.0
9	0.9059	0.8538	0.8145	0.8427	0.9260	0.9580	0.8403	0.0	0.0

EXHIBIT C-1

NORMALIZED POWER DENSITY

T = 0.4 SEC

Y/X	1	2	3	4	5	6	7	8	9
1	0.3647	0.4056	0.3820	0.4770	0.7466	1.3193	1.5820	1.4007	0.8607
2	0.4046	0.3679	0.3799	0.4635	0.6358	0.8967	1.1012	1.2202	0.8221
3	0.3789	0.3778	0.4002	0.4718	0.5992	0.7603	0.9452	1.1526	0.8079
4	0.4697	0.4574	0.4679	0.5375	0.6733	0.8456	1.0398	1.2663	0.8747
5	0.7308	0.6230	0.5889	0.6659	0.8712	1.1956	1.4263	1.5428	1.0200
6	1.2869	0.8742	0.7405	0.8248	1.1757	1.9589	2.2457	1.9520	1.1403
7	1.5396	1.0692	0.9131	0.9985	1.3663	2.1688	2.3712	1.8785	1.0139
8	1.3604	1.1812	1.1071	1.1914	1.4330	1.7540	1.7310	1.4795	0.0
9	0.8349	0.7943	0.7734	0.8233	0.9313	0.9880	0.8876	0.0	0.0

EXHIBIT C-2

NORMALIZED POWER DENSITY

T = 0.8 SEC

Y/X	1	2	3	4	5	6	7	8	9
1	0.4776	0.3469	0.3342	0.4264	0.6764	1.2029	1.4492	1.2889	0.7945
2	0.3443	0.3172	0.3354	0.4190	0.5840	0.8309	1.0281	1.1474	0.7761
3	0.3255	0.3295	0.3587	0.4360	0.5676	0.7332	0.9238	1.1360	0.7999
4	0.4063	0.4023	0.4256	0.5094	0.6622	0.8559	1.0760	1.3182	0.9244
5	0.6331	0.5493	0.5401	0.6429	0.8815	1.2559	1.5507	1.7298	1.1617
6	1.1145	0.7702	0.6812	0.8026	1.2059	2.0899	2.5030	2.3413	1.4134
7	1.3344	0.9429	0.8402	0.9709	1.4004	2.3137	2.6446	2.2655	1.2739
8	1.1812	1.0443	1.0181	1.1538	1.4568	1.8550	1.9018	1.6987	0.0
9	0.7259	0.7033	0.7110	0.7945	0.9404	1.0345	0.9593	0.0	0.0

EXHIBIT C-3

NORMALIZED POWER DENSITY

T - 1.2 SEC

Y/X	1	2	3	4	5	6	7	8	9
1	0.3671	0.2724	0.2731	0.3610	0.5846	1.0491	1.2731	1.1409	0.7064
2	0.2677	0.2527	0.2783	0.3615	0.5162	0.7442	0.9315	1.0505	0.7144
3	0.2576	0.2677	0.3052	0.3893	0.5258	0.6970	0.8948	1.1127	0.7878
4	0.3248	0.3313	0.3705	0.4720	0.6462	0.8679	1.1225	1.3991	0.9891
5	0.5067	0.4537	0.4759	0.6110	0.8917	1.3312	1.7130	1.9807	1.3535
6	0.8903	0.6346	0.6025	0.7703	1.2395	2.2524	2.8393	2.8764	1.7966
7	1.0668	0.7777	0.7429	0.9302	1.4370	2.4917	2.9998	2.7914	1.6400
8	0.9472	0.8645	0.8985	1.0983	1.4784	1.9767	2.1196	1.9877	0.0
9	0.5832	0.5833	0.6266	0.7516	0.9456	1.0882	1.0475	0.0	0.0

EXHIBIT C-4
NORMALIZED POWER DENSITY

T = 1.4 SEC

Y/X	1	2	3	4	5	6	7	8	9
1	0.3266	0.2449	0.2499	0.3348	0.5458	0.9816	1.1944	1.0743	0.6669
2	0.2395	0.2287	0.2565	0.3384	0.4876	0.7061	0.8879	1.0060	0.6861
3	0.2321	0.2443	0.2845	0.3703	0.5076	0.6801	0.8801	1.0996	0.7807
4	0.2935	0.3037	0.3484	0.4558	0.6374	0.8699	1.1396	1.4318	1.0157
5	0.4569	0.4157	0.4493	0.5956	0.8912	1.3562	1.7790	2.0942	1.4444
6	0.8004	0.5799	0.5690	0.7527	1.2442	2.3051	2.9778	3.1392	1.9948
7	0.9589	0.7103	0.7005	0.9070	1.4394	2.5457	3.1418	3.0478	1.8288
8	0.8527	0.7905	0.8458	1.0669	1.4731	2.0095	2.2000	2.1123	0.0
9	0.5256	0.5337	0.5892	0.7281	0.9383	1.1000	1.0766	0.0	0.0

EXHIBIT C-5

NORMALIZED POWER DENSITY

T = 2.0 SEC

Y/X	1	2	3	4	5	6	7	8	9
1	0.3031	0.2261	0.2287	0.3031	0.4893	0.8760	1.0653	0.9619	0.6025
2	0.2206	0.2101	0.2349	0.3086	0.4427	0.6399	0.8078	0.9237	0.6370
3	0.2105	0.2224	0.2604	0.3412	0.4710	0.6374	0.8363	1.0599	0.7632
4	0.2611	0.2726	0.3175	0.4226	0.6023	0.8412	1.1341	1.4628	1.0617
5	0.3991	0.3675	0.4059	0.5518	0.8483	1.3362	1.8421	2.2956	1.6435
6	0.6919	0.5064	0.5093	0.6933	1.1844	2.2846	3.1584	3.7559	2.5321
7	0.8242	0.6164	0.6226	0.8293	1.3607	2.5086	3.3176	3.6522	2.3560
8	0.7319	0.6862	0.7506	0.9721	1.3823	1.9583	2.2663	2.3526	0.0
9	0.4532	0.4655	0.5248	0.6649	0.8806	1.0662	1.0910	0.0	0.0

EXHIBIT C-6
NORMALIZED POWER DENSITY

T = 3.0 SEC

Y/X	1	2	3	4	5	6	7	8	9
1	0.3333	0.2466	0.2454	0.3203	0.5115	0.9105	1.1035	0.9943	0.6228
2	0.2412	0.2277	0.2506	0.3241	0.4599	0.6604	0.8298	0.9461	0.6523
3	0.2279	0.2385	0.2749	0.3542	0.4827	0.6473	0.8443	1.0673	0.7685
4	0.2800	0.2896	0.3315	0.4330	0.6076	0.8399	1.1251	1.4476	1.0510
5	0.4254	0.3881	0.4206	0.5595	0.8459	1.3179	1.8054	2.2439	1.6073
6	0.7357	0.5335	0.5255	0.6992	1.1735	2.2410	3.0795	3.6504	2.4622
7	0.8748	0.6481	0.6413	0.8352	1.3466	2.4579	3.2311	3.5456	2.2883
8	0.7761	0.7206	0.7732	0.9805	1.3713	1.9225	2.2113	2.2894	0.0
9	0.4809	0.4890	0.5413	0.6723	0.8766	1.0508	1.0694	0.0	0.0

EXHIBIT E-1
AVERAGE FUEL TEMPERATURE

T = 0.4 SEC

VALUES ARE IDENTICAL TO 300.0

EXHIBIT E-2
AVERAGE FUEL TEMPERATURE

T = 0.8 SEC

VALUES ARE IDENTICAL TO 300.0

EXHIBIT E-3
AVERAGE FUEL TEMPERATURE

T = 1.2 SEC

VALUES ARE IDENTICAL TO 300.0

EXHIBIT E-4

AVERAGE FUEL TEMPERATURE

T = 1.4 SEC

Y/X	1	2	3	4	5	6	7	8	9
1	3.08380+02	3.06300+02	3.06420+02	3.08610+02	3.14060+02	3.25240+02	3.30710+02	3.27660+02	3.17160+02
2	3.06160+02	3.05870+02	3.06590+02	3.08700+02	3.12520+02	3.18180+02	3.22870+02	3.25850+02	3.17640+02
3	3.05960+02	3.06280+02	3.07310+02	3.09510+02	3.13050+02	3.17490+02	3.22630+02	3.26270+02	3.20060+02
4	3.07540+02	3.07810+02	3.08950+02	3.11710+02	3.16390+02	3.22360+02	3.29290+02	3.36800+02	3.26110+02
5	3.11760+02	3.10670+02	3.11550+02	3.15310+02	3.22870+02	3.34910+02	3.45790+02	3.53740+02	3.37070+02
6	3.20570+02	3.14930+02	3.14630+02	3.19360+02	3.32050+02	3.59260+02	3.76490+02	3.80570+02	3.51120+02
7	3.24650+02	3.18290+02	3.18010+02	3.23330+02	3.37100+02	3.65450+02	3.80750+02	3.78090+02	3.47080+02
8	3.21950+02	3.20310+02	3.21750+02	3.27450+02	3.37860+02	3.51760+02	3.56510+02	3.54570+02	3.00000+02
9	3.13520+02	3.13720+02	3.15150+02	3.18720+02	3.24140+02	3.28300+02	3.27850+02	3.00000+02	3.00000+02

EXHIBIT E-5
AVERAGE FUEL TEMPERATURE

T = 2.0 SEC

Y/X	1	2	3	4	5	6	7	8	9
1	4.9314D+02	4.4354D+02	4.4380D+02	4.8959D+02	6.0611D+02	8.4705D+02	9.6380D+02	8.9754D+02	6.7194D+02
2	4.4053D+02	4.3273D+02	4.4688D+02	4.9107D+02	5.7227D+02	6.9334D+02	7.9391D+02	8.5924D+02	6.8340D+02
3	4.3424D+02	4.4032D+02	4.6145D+02	5.0778D+02	5.8273D+02	6.7765D+02	7.8927D+02	9.1404D+02	7.3841D+02
4	4.6749D+02	4.7242D+02	4.9581D+02	5.5367D+02	6.5289D+02	7.8182D+02	9.3511D+02	1.1054D+03	8.7761D+02
5	5.5873D+02	5.3360D+02	5.5047D+02	6.2892D+02	7.8936D+02	1.0503D+03	1.2981D+03	1.4967D+03	1.1390D+03
6	7.5075D+02	6.2506D+02	6.1536D+02	7.1328D+02	9.8273D+02	1.5724D+03	1.9777D+03	2.1493D+03	1.5039D+03
7	8.3830D+02	6.9702D+02	6.8702D+02	7.9650D+02	1.0877D+03	1.7014D+03	2.0672D+03	2.0924D+03	1.4154D+03
8	7.7857D+02	7.4630D+02	7.6761D+02	8.8469D+02	1.1037D+03	1.4052D+03	1.5267D+03	1.5210D+03	3.0000D+02
9	5.9538D+02	5.9846D+02	6.2661D+02	7.0032D+02	8.1445D+02	9.0524D+02	9.0380D+02	3.0000D+02	3.0000D+02

EXHIBIT E-6

AVERAGE FUEL TEMPERATURE

T = 3.0 SEC

Y/X	1	2	3	4	5	6	7	8	9
1	5.59050+02	4.92590+02	4.93030+02	5.54400+02	7.10370+02	1.03290+03	1.18950+03	1.10150+03	7.99620+02
2	4.88540+02	4.78100+02	4.97330+02	5.56900+02	6.66120+02	8.28940+02	9.64800+02	1.05410+03	8.17860+02
3	4.79720+02	4.88170+02	5.17130+02	5.80220+02	6.82190+02	8.11720+02	9.64710+02	1.13630+03	8.98350+02
4	5.23640+02	5.30840+02	5.63360+02	6.42880+02	7.79250+02	9.57510+02	1.17130+03	1.40980+03	1.69790+03
5	6.44430+02	6.12000+02	6.36560+02	7.44910+02	9.66070+02	1.32820+03	1.68020+03	1.97150+03	1.47930+03
6	8.98900+02	7.33250+02	7.23160+02	8.58630+02	1.22950+03	2.04560+03	2.63020+03	2.92480+03	2.02670+03
7	1.01460+03	8.28620+02	8.18660+02	9.70200+02	1.37110+03	2.22050+03	2.75240+03	2.84450+03	1.96350+03
8	9.35320+02	8.86770+02	9.26370+02	1.08850+03	1.39100+03	1.81140+03	1.99440+03	2.00990+03	3.00000+02
9	6.92410+02	6.97720+02	7.37650+02	8.39840+02	9.98060+02	1.12650+03	1.13120+03	3.00000+02	3.00000+02

BENCHMARK PROBLEM SOLUTION

Identification: 14-A1-2 Benchmark Problem ID.14-A1

Date Submitted: June 1976 By: H. Finnemann (KWU)

Date Accepted: June 1977 By: H.L. Dodds, Jr.(U. of Tenn.)
F.N. McDonnell (AECL-CRNL)

Descriptive Title: BWR Kinetics Benchmark Problem:
 2-D Nodal Solution: Fifth Order
 Polynomial Expansion

Mathematical Model

The IQSBOX program solves the time-dependent two-group neutron diffusion equation in one, two or three dimensions by the nodal expansion method (NEM).

NEM is a consistent nodal technique that converges towards the exact solution of the diffusion equation for small mesh sizes. Subsidiary 1-D diffusion equations are solved in each box by polynomial expansion to obtain spatial coupling coefficients. Polynomials up to fifth order can be used. Time integration is performed by the backwards-difference algorithm combined with an exponential transformation technique.

Computer: CDC CYBER 175

Code: IQSBOX

Date Solved: January 1976 at Kraftwerk Union Erlangen

References

H. Finnemann

A Consistent Nodal Method for the Analysis of Space-Time Effects in Large LWR's.

Proc. of the Joint NEACRP/CSNI Specialists' Meeting on New Developments in Three-Dimensional Neutron Kinetics and Review of Kinetics Benchmark Calculations Munich, January 22-24 (1975), MRR 145

F. Bennewitz, H. Finnemann, H. Moldaschl

Solution of the Multidimensional Neutron Diffusion Equation by Nodal Expansion

CONF-750413, Proc. Conf. on Comput.

Methods in Nucl. Eng., April 15 - 17, 1975
Charleston, South Carolina

F. Bennewitz, H. Finnemann, M.R. Wagner

Higher Order Corrections in Nodal Reactor Calculations.
Trans. Am. Nucl. Soc. 22, 250 (1975).

Results:

Uniform mesh with $\Delta x = \Delta y = 15$ cm (11 x 11 intervals)

1. Maximum eigenvalue for initial flux distribution:

$$k_{\text{eff}} = .99631$$

2. Exhibit A:

Normalized local power densities P_{ki} for initial flux distribution:

$$P_{ki} = \frac{\epsilon}{V_k} \int_{V_k} (\Sigma f_1 \phi_1 + \Sigma f_2 \phi_2) dV / \bar{P}$$

Assembly k , V_k = Volume of Fuel

$$k = 1, \dots, 78$$

3. Maximum eigenvalue for configuration of withdrawn rod for cold reactor (feedback effects neglected):

$$k_{\text{eff}} = 1.01531$$

4. Exhibit B:

Average Power density $\bar{P}$ versus time

5. Exhibit C:

Normalized Local Power Densities P_k and Average temperatures in volumes V_k , $k = 1, \dots, 78$, at $t = 0.4$ sec, 0.8 sec, 1.2^k sec, 1.4 sec, 2.0 sec, 3.0 sec.

6. Maximum of $\bar{P} = 5.451 \cdot 10^3$; time of occurrence = 1.445 sec.

7. Exhibit D:

Average temperature $\bar{T} = \frac{1}{V_{\text{core}}} \int_{V_{\text{core}}} T(\vec{x}, t) dV$ versus time

8. Number of unknowns in the problem: The unknowns are average node fluxes, average partial currents on the six surfaces of the node and average delayed precursor concentrations. The number of unknowns per mesh is given by $(2N+1) \cdot G + I$, where G is the number of energy groups, N the spatial dimension, and I the number of delayed precursor groups. The number of unknowns is independent on the degree of the approximating polynomial. The total number of unknowns for this problem is thus given by $(5 \cdot 2 + 2) \cdot 121 = 1452$
Number of time steps: 522 (automatic time-step selection such that local power change less than 12 % between time steps).

Computing time: 255 sec

EXHIBIT A

AVERAGE SUBASSEMBLY POWER (ABOVE) AND AVERAGE FUEL TEMPERATURE (BELOW)

9	.919 300.	.862 300.	.821 300.	.846 300.	.924 300.	.965 300.	.834 300.		
8	1.484 300.	1.285 300.	1.173 300.	1.221 300.	1.422 300.	1.675 300.	1.614 300.	1.311 300.	
7	1.672 300.	1.150 300.	.967 300.	1.022 300.	1.334 300.	2.054 300.	2.161 300.	1.614 300.	.834 300.
6	1.396 300.	.942 300.	.785 300.	.845 300.	1.150 300.	1.857 300.	2.054 300.	1.675 300.	.965 300.
5	.792 300.	.674 300.	.620 300.	.680 300.	.866 300.	1.150 300.	1.334 300.	1.422 300.	.924 300.
4	.515 300.	.493 300.	.495 300.	.555 300.	.680 300.	.845 300.	1.022 300.	1.221 300.	.846 300.
3	.416 300.	.409 300.	.427 300.	.495 300.	.620 300.	.785 300.	.967 300.	1.173 300.	.821 300.
2	.443 300.	.403 300.	.409 300.	.493 300.	.674 300.	.941 300.	1.150 300.	1.285 300.	.862 300.
1	.621 300.	.443 300.	.416 300.	.515 300.	.792 300.	1.396 300.	1.672 300.	1.484 300.	.919 300.
	1	2	3	4	5	6	7	8	9

EXHIBIT C-1

t = 0.4 sec

AVERAGE SUBASSEMBLY POWER (ABOVE) AND AVERAGE FUEL TEMPERATURE (BELOW)

9	.842 300.	.798 300.	.777 300.	.826 300.	.930 300.	.998 300.	.883 300.		
8	1.358 300.	1.188 300.	1.111 300.	1.194 300.	1.439 300.	1.744 300.	1.733 300.	1.461 300.	
7	1.529 300.	1.062 300.	.916 300.	1.003 300.	1.357 300.	2.154 300.	2.349 300.	1.881 300.	1.010 300.
6	1.276 300.	.869 300.	.744 300.	.830 300.	1.171 300.	1.948 300.	2.232 300.	1.945 300.	1.153 300.
5	.724 300.	.623 300.	.587 300.	.664 300.	.874 300.	1.192 300.	1.420 300.	1.558 300.	1.023 300.
4	.471 300.	.455 300.	.465 300.	.535 300.	.673 300.	.853 300.	1.048 300.	1.265 300.	.882 300.
3	.379 300.	.376 300.	.398 300.	.470 300.	.599 300.	.767 300.	.953 300.	1.163 300.	.816 300.
2	.401 300.	.368 300.	.378 300.	.462 300.	.638 300.	.896 300.	1.100 300.	1.235 300.	.831 300.
1	.560 300.	.402 300.	.382 300.	.480 300.	.743 300.	1.316 300.	1.581 300.	1.407 300.	.874 300.
	1	2	3	4	5	6	7	8	9

EXHIBIT C-2

t = 0.8 sec

AVERAGE SUBASSEMBLY POWER (ABOVE) AND AVERAGE FUEL TEMPERATURE (BELOW)

9	.734 300.	.708 300.	.715 300.	.796 300.	.938 300.	1.043 300.	.952 300.		
8	1.182 300.	1.053 300.	1.023 300.	1.157 300.	1.461 300.	1.841 300.	1.900 300.	1.673 300.	
7	1.328 300.	.939 300.	.844 300.	.976 300.	1.390 300.	2.294 300.	2.613 300.	2.260 300.	1.264 300.
6	1.107 300.	.768 300.	.686 300.	.809 300.	1.201 300.	2.075 300.	2.482 300.	2.326 300.	1.424 300.
5	.629 300.	.551 300.	.539 300.	.642 300.	.885 300.	1.251 300.	1.541 300.	1.736 300.	1.163 300.
4	.408 300.	.401 300.	.424 300.	.508 300.	.662 300.	.864 300.	1.084 300.	1.327 300.	.932 300.
3	.326 300.	.329 300.	.358 300.	.435 300.	.588 300.	.741 300.	.933 300.	1.148 300.	.810 300.
2	.342 300.	.318 300.	.335 300.	.419 300.	.588 300.	.888 300.	1.030 300.	1.164 300.	.787 300.
1	.475 300.	.345 300.	.386 300.	.430 300.	.675 300.	1.203 300.	1.452 300.	1.299 300.	.809 300.
	1	2	3	4	5	6	7	8	9

EXHIBIT C-3

t = 1.2 sec

AVERAGE SUBASSEMBLY POWER (ABOVE) AND AVERAGE FUEL TEMPERATURE (BELOW)

9	.596 300.	.593 300.	.634 300.	.755 300.	.941 300.	1.094 300.	1.035 300.		
8	.958 300.	.880 300.	.908 300.	1.102 300.	1.480 300.	1.954 300.	2.109 300.	1.946 300.	
7	1.073 300.	.782 300.	.751 300.	.938 300.	1.424 300.	2.461 300.	2.948 300.	2.771 300.	1.617 300.
6	.894 300.	.639 300.	.611 300.	.779 300.	1.233 300.	2.229 300.	2.801 300.	2.841 300.	1.798 300.
5	.509 300.	.459 300.	.479 300.	.612 300.	.895 300.	1.323 300.	1.696 300.	1.978 300.	1.348 300.
4	.330 300.	.334 300.	.372 300.	.473 300.	.647 300.	.875 300.	1.130 300.	1.406 300.	.996 300.
3	.261 300.	.270 300.	.307 300.	.391 300.	.523 300.	.705 300.	.904 300.	1.126 300.	.798 300.
2	.270 300.	.256 300.	.281 300.	.364 300.	.523 300.	.749 300.	.937 300.	1.070 300.	.727 300.
1	.370 300.	.275 300.	.277 300.	.367 300.	.587 300.	1.054 300.	1.281 300.	1.155 300.	.723 300.
	1	2	3	4	5	6	7	8	9

EXHIBIT C-4

t = 1.4 sec

AVERAGE SUBASSEMBLY POWER (ABOVE) AND AVERAGE FUEL TEMPERATURE (BELOW)

	9	8	7	6	5	4	3	2	1	
	.539 302.	.543 302.	.596 302.	.731 303.	.934 304.	1.106 305.	1.064 304.			
	.865 304.	.806 303.	.856 304.	1.071 305.	1.475 306.	1.988 308.	2.191 309.	2.069 309.		
	.968 304.	.716 303.	.709 303.	.915 304.	1.428 306.	2.517 311.	3.091 313.	3.029 313.	1.803 308.	
	.807 303.	.586 302.	.578 302.	.762 303.	1.238 305.	2.283 310.	2.940 312.	3.103 313.	1.996 308.	
	.461 302.	.422 302.	.453 302.	.597 302.	.895 304.	1.349 306.	1.763 307.	2.091 309.	1.438 306.	
	.299 301.	.307 301.	.350 301.	.457 302.	.638 303.	.877 304.	1.147 305.	1.438 306.	1.023 304.	
	.236 301.	.247 301.	.286 301.	.371 302.	.509 302.	.687 303.	.889 304.	1.111 305.	.90 308.	
	.242 301.	.232 301.	.259 301.	.341 301.	.493 302.	.710 303.	.893 303.	1.023 304.	.697 303.	
	.329 301.	.247 301.	.254 301.	.341 301.	.548 302.	.985 304.	1.201 305.	1.086 305.	.682 303.	
	1	2	3	4	5	6	7	8	9	

EXHIBIT C-5

t = 2.0 sec

AVERAGE SUBASSEMBLY POWER (ABOVE) AND AVERAGE FUEL TEMPERATURE (BELOW)

9	.461 595.	.471 596.	.529 622.	.667 692.	.877 800.	1.074 895.	1.080 880.		
8	.737 772.	.696 738.	.757 761.	.975 .872	1.386 1087.	1.942 1368.	2.266 1497.	2.309 1464.	
7	.825 829.	.618 689.	.628 682.	.836 788.	1.352 1062.	2.487 1655.	3.272 2001.	3.640 2048.	2.328 1373.
6	.692 742.	.508 619.	.514 611.	.701 708.	1.180 962.	2.269 1532.	3.125 1921.	3.722 2089.	2.537 1480.
5	.399 553.	.370 531.	.407 546.	.552 621.	.852 780.	1.331 1028.	1.830 1266.	2.296 1470.	1.641 1118
4	.264 466.	.273 469.	.318 492.	.422 548.	.602 645.	.849 775.	1.143 925.	1.475 1092.	1.073 869.
3	.212 433.	.223 438.	.261 458.	.341 503.	.472 577.	.645 673.	.846 783.	1.076 908.	.776 735.
2	.220 438.	.211 431.	.236 444.	.310 488.	.447 569.	.645 687.	.814 785.	.943 858.	.651 682.
1	.303 490.	.226 441.	.231 442.	.307 488.	.491 600.	.881 836.	1.074 954.	.977 892.	.619 673.
	1	2	3	4	5	6	7	8	9

EXHIBIT C-6

t = 3.0 sec

AVERAGE SUBASSEMBLY POWER (ABOVE) AND AVERAGE FUEL TEMPERATURE (BELOW)

9	.502 714.	.503 717.	.553 756.	.677 858.	.871 1016.	1.053 1157.	1.050 1142.		
8	.802 963.	.746 916.	.789 952.	.987 1115.	1.371 1427.	1.894 1841.	2.192 2046.	2.225 2022.	
7	.900 1043.	.664 848.	.654 840.	.844 996.	1.332 1393.	2.419 2260.	3.157 2794.	3.497 2927.	2.236 1935.
6	.756 922.	.547 750.	.537 741.	.708 881.	1.163 1251.	2.208 2084.	3.018 2678.	3.579 2989.	2.439 2093.
5	.437 657.	.400 626.	.427 649.	.561 758.	.848 990.	1.303 1353.	1.776 1710.	2.222 2027.	1.589 1516.
4	.291 535.	.297 540.	.337 573.	.435 654.	.607 794.	.844 983.	1.127 1205.	1.450 1452.	1.055 1131.
3	.237 486.	.245 496.	.280 525.	.358 590.	.487 696.	.656 84.	.855 993.	1.083 1174.	.781 927.
2	.250 496.	.236 487.	.257 505.	.331 567.	.471 683.	.672 849.	.843 990.	.973 1095.	.670 845.
1	.346 570.	.255 501.	.254 502.	.331 567.	.521 725.	.929 1062.	1.128 1227.	1.021 1139.	.646 829.

1 2 3 4 5 6 7 8 9

BENCHMARK SOURCE SITUATION

Identification: 15

Date Submitted: July 1976

By: M. V. Gregory (SRL)

Date Adopted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)

R. R. Lee (CE)

Descriptive Title

Neutronic Depletion Benchmark Problems

Suggested Function

Test solutions of the neutronic depletion equations.

Configuration

An infinite homogeneous medium with the isotopic concentrations given below. At time zero, the neutron flux becomes nonzero.

Details

<u>Isotope</u>	<u>Concentration, atom/ (barn-cm)</u>
^{235}U	$0.74003\text{E}-4^*$
^{238}U	$0.69360\text{E}-2$
All others	0

* $\text{E}-X = 10^{-X}$

BENCHMARK PROBLEM

Identification: 15-A1 Source Situation ID.15
 Date Submitted: July 1976 By: M. V. Gregory (SRL)
 Date Accepted: June 1977 By: H. L. Dodds, Jr. (U. of Tenn.)
 R. R. Lee (CE)

Descriptive Title

Two-Group Constant Parameter Point Depletion Problem

Reduction from Source Situation

1. Solution of isotopic depletion equations at a point with constant flux and cross sections.

$$\frac{d}{dt} \underline{N}(t) = \underline{A} \underline{N}(t)$$

where

$\underline{N}$ = vector of isotopic concentrations

$\underline{A}$ = net production matrix coupling the isotopes

The general ij^{th} entry in $\underline{A}$ (i.e., the production rate of isotope i from isotope j) is

$$A_{ij} = Y_{ij} \sum_g \sigma_{fj}^g \phi^g + \lambda_{ij} + \sum_g \sigma_{c_{ij}}^g \phi^g$$

where

g = energy group index

Y_{ij} = fission yield of isotope i from the fissioning of isotope j (Y_{ii} is defined as -1.0)

σ_{fj}^g = microscopic fission cross section of isotope j in group g

ϕ^g = flux in group g

λ_{ij} = decay constant for production of isotope i from the decay of isotope j (λ_{ii} is the negative of the decay constant)

$\sigma_{c_{ij}}^g$ = microscopic capture cross section in group g for isotope j that produces i ($\sigma_{c_{ii}}^g$ is the negative of the capture cross section)

2. Constant two-group flux:

Group 1 = $6.1374\text{E}+14$ n/(cm²-sec)

Group 2 = $2.5078\text{E}+14$ n/(cm²-sec)

3. Fission product yields are defined in Table B.1.
4. Decay constants are defined in Table B.2.
5. Microscopic cross sections are defined in Table B.3.
6. Depletion chains are defined in Figure B.1 where the dashed line processes (α -, β ⁺-decay) are excluded, resulting in a triangular matrix for A.

Expected Primary Results

1. Variation of isotopic concentrations with time; 50-day concentrations.
2. Calculational statistics.

Solutions Available

1. Fourth-order Runge-Kutta integration of depletion equations, various time-step sizes: 15-A1-1
2. Analytical and finite-difference solutions for various time-step sizes: 15-A1-2, 15-A1-3

TABLE B.1. Fission Product Yield, %

Fission Product	Fissioning Isotope			
	^{235}U	^{238}U	^{239}Pu	^{241}Pu
^{135}I	6.17	5.78	6.93	6.26
^{135}Xe	0.24	0.22	0.27	0.24
^{149}Pm	1.13	2.10	1.30	1.20
^{147}Nd	2.36	2.80	2.05	2.20
Long-Lived Fission Products	90.10	89.10	89.45	90.10

TABLE B.2. Decay Constants

<u>Isotope</u>	<u>Emitted Particle</u>	<u>Decay Constant, sec⁻¹</u>
¹³⁵ I	β ⁻	2.874E-5*
¹³⁵ Xe	β ⁻	2.093E-5
¹⁴⁷ Nd	β ⁻	7.228E-7
¹⁴⁷ Pm	β ⁻	8.289E-9
¹⁴⁸ Pm	β ⁻	1.488E-6
^{148m} Pm	β ⁻	1.976E-7
¹⁴⁹ Pm	β ⁻	3.626E-6
²³⁷ U	β ⁻	1.190E-6
²³⁹ U	β ⁻	4.915E-4
²³⁸ Np	β ⁻	3.820E-6
²³⁹ Np	β ⁻	3.410E-6
²⁴⁰ Np	β ⁻	1.583E-3
²⁴¹ Pu	β ⁻	1.680E-9
²⁴³ Pu	β ⁻	3.886E-5
²⁴² Am	β ⁻	9.930E-6
²⁴⁴ Am	β ⁻	4.440E-4

* E-X = 10^{-X}

TABLE B.3. Microscopic Cross Sections, barns*

Isotope	σ_{c1}	σ_{c2}	σ_{f1}	σ_{f2}	$\sigma_{(n,\gamma)_1}^m$	$\sigma_{(n,\gamma)_2}^m$
^{234}U	33.575	26.368	0.42744	0	0	0
^{235}U	5.9872	26.420	12.370	148.18	0	0
^{236}U	16.859	1.4399	0.16664	0	0	0
^{237}U	16.991	132.12	0.17139	0.55512	0	0
^{238}U	0.53258	0.73141	0.081338	0	0	0
^{239}U	0.40015	6.1613	0.27283	4.2009	0	0
^{237}Np	24.072	71.864	0.41867	0.0094250	0	0
^{238}Np	5.2648	55.512	47.412	555.12	0	0
^{239}Np	26.341	16.654	0	0	0	0
^{240}Np	0	0	0	0	0	0
^{238}Pu	7.3125	119.91	1.587	3.5496	0	0
^{239}Pu	9.8658	196.77	14.46	348.89	0	0
^{240}Pu	366.09	96.479	0.54033	0.016744	0	0
^{241}Pu	8.0305	152.24	29.986	352.73	0	0
^{242}Pu	51.820	5.1903	0.43460	0	0	0
^{243}Pu	11.030	21.649	28.382	49.960	0	0
^{241}Am	50.633	392.68	1.1130	2.3817	6.7486	39.543
^{242}Am	2.3381	0	31.137	693.90	0	0
^{242m}Am	20.016	444.09	108.79	1776.4	0	0
^{243}Am	91.056	24.080	0.30784	0	0	0
^{244}Am	0	0	26.192	403.29	0	0
^{242}Cm	3.1202	1.7185	0	0.83267	0	0
^{243}Cm	9.9059	69.389	92.299	194.29	0	0
^{244}Cm	32.129	3.6915	1.5663	0.33307	0	0
^{245}Cm	4.8993	82.972	37.165	537.15	0	0
^{135}I	0	0	0	0	0	0
^{135}Xe	243.47	1064780.0	0	0	0	0
^{147}Nd	0	0	0	0	0	0
^{147}Pm	248.78	65.814	0	0	117.44	31.087
^{148}Pm	3368.4	420.09	0	0	0	0
^{148m}Pm	2921.0	7561.6	0	0	0	0
^{149}Pm	0	0	0	0	0	0
^{149}Sm	105.85	23387.4	0	0	0	0
Fission Products	10.376	19.429	0	0	0	0

* σ_{c1} = capture in Group 1 [all captures except fission and (n,2n); includes (n, γ) to excited state, if any].

σ_{c2} = capture in Group 2.

σ_{f1} = fission in Group 1.

σ_{f2} = fission in Group 2.

$\sigma_{(n,\gamma)_1}^m$ = (n, γ) to first excited state, Group 1.

$\sigma_{(n,\gamma)_2}^m$ = (n, γ) to first excited state, Group 2.

FIGURE B.1 Depletion Chains

FIGURE B.1 Depletion Chains (Continued)

BENCHMARK PROBLEM SOLUTION

Identification: 15-A1-1 Benchmark Problem ID.15-A1
 Date Submitted: July 1976 By: M. V. Gregory (SRL)
 Date Accepted: June 1977 By: H. L. Dodds, Jr. (U. of Tenn.)
 R. R. Lee (CE)

Descriptive Title

Two-Group Constant Parameter Point Depletion Problem

Technique Used

1. Fourth-order Runge-Kutta-Gill numerical integration technique (Reference 1).
2. Time-step selection may be automatic or user defined. Automatic time-step selection is defined by

$$\Delta t = 0.13 / \left| \left(\sum_i A_{ij} \right)_{\max} \right|$$

where the denominator is the maximum absolute columnar sum in the A matrix. Some isotopes have very large time constants (e.g., decay very rapidly) and are excluded from the time-step determination and defined in equilibrium:

$$N_i(t + \Delta t) = \left(\sum_{j \neq i} A_{ij} N_j / A_{ii} N_i \right)_t \cdot N_i(t)$$

The criterion is that for $\left| \left(\sum_i A_{ij} \right)_{\max} \right| > 1.0E-5$, the isotope j is defined to be in equilibrium. Solutions will be presented both with and without the use of defined equilibrium.

Computer

IBM 360/195

Program

BURGR

References

1. *The JOSHUA System, Volume 10.1 Generalized Reactor Analysis Subsystem: Physics.* (draft) DPSTM-500 (1975).
2. M. M. Anderson et al., "Three-Dimensional Coupled Neutronics and Engineering Calculation of Savannah River Reactors," CONF-750413, Vol. II., p. VI-123.

Primary Results

Isotopic concentrations at 50 days are summarized in Table C.1 for a range of time-step sizes. The " $\Delta t = 1$ min" and " $\Delta t = 10$ min" results make no assumptions about equilibrium. The " $\Delta t = 1$ hr" solution uses the standard equilibrium condition. The " $\Delta t \approx 6.09$ hr" solution uses automatic time-step selection and the standard equilibrium condition to set Δt to 21923 seconds.

Computational statistics are summarized at the end of the table.

TABLE C.1. SRL Solutions to Constant-Parameter Problem,
atoms/(barn-cm) at 50 days

Isotope	Δt Integration Time Step		
	1 min, 10 min ^a	1 hour ^b	~6.09 hours ^c
²³⁵ U	0.583393E-4	0.583393E-4	0.583391E-4
²³⁶ U	0.286054E-5	0.286054E-5	0.286059E-5
²³⁷ U	0.206091E-7	0.206091E-7	0.206095E-7
²³⁸ U	0.691915E-2	0.691915E-2	0.691915E-2
²³⁹ U	0.718357E-8	0.718356E-8	0.718356E-8
²³⁷ Np	0.450818E-7	0.450818E-7	0.450837E-7
²³⁸ Np	0.324870E-9	0.324870E-9	0.324885E-9
²³⁹ Np	0.102943E-5	0.102943E-5	0.102943E-5
²⁴⁰ Np	0.132291E-10	0.132291E-10	0.132291E-10
²³⁸ Pu	0.147272E-8	0.147272E-8	0.147282E-8
²³⁹ Pu	0.105746E-4	0.105774E-4	0.105717E-4
²⁴⁰ Pu	0.995886E-6	0.996402E-6	0.995317E-6
²⁴¹ Pu	0.334194E-6	0.334479E-6	0.333869E-6
²⁴² Pu	0.163642E-7	0.163842E-7	0.163404E-7
²⁴³ Pu	0.136270E-10	0.139428E-10	0.139055E-10
²⁴¹ Am	0.586414E-9	0.587114E-9	0.585583E-9
²⁴² Am	0.617228E-11	0.669732E-11	0.667986E-11
^{242m} Am	0.504837E-11	0.505566E-11	0.503955E-11
²⁴³ Am	0.456826E-9	0.470206E-9	0.467301E-9
²⁴⁴ Am	0.637702E-13	0.658008E-13	0.653939E-13
²⁴² Cm	0.549962E-10	0.610962E-10	0.607208E-10
²⁴³ Cm	0.115382E-12	0.130911E-12	0.129927E-12
²⁴⁴ Cm	0.206820E-10	0.214767E-10	0.212434E-10
²⁴⁵ Cm	0.243404E-12	0.254329E-12	0.251092E-12
¹³⁵ I	0.882735E-8	0.883435E-8	0.883286E-8
¹³⁵ Xe	0.914750E-9	0.915483E-9	0.915350E-9
¹⁴⁷ Nd	0.121154E-6	0.121163E-6	0.121144E-6
¹⁴⁷ Pm	0.201810E-6	0.201826E-6	0.201795E-6
¹⁴⁸ Pm	0.457029E-8	0.457067E-8	0.456997E-8
^{148m} Pm	0.386726E-8	0.386758E-8	0.386699E-8
¹⁴⁹ Pm	0.199678E-7	0.199694E-7	0.199662E-7
¹⁴⁹ Sm	0.119776E-7	0.119786E-7	0.119766E-7
Fission Products	0.145224E-4	0.145238E-4	0.145212E-4
CPU time, sec	429.8	7.0	1.2
IBM 360/195	43.2		
	($\Delta t = 10$ min)		

a. No equilibrium assumption.

b. Equilibrium assumed.

c. Equilibrium assumed and time step automatically selected.

BENCHMARK PROBLEM SOLUTION

Identification: 15-A1-2 Benchmark Problem ID.15-A1
Date Submitted: July 1976 By: B. A. Weate (GA)
Date Accepted: June 1977 By: H. L. Dodds, Jr. (U. of Tenn.)
R. R. Lee (CE)

Descriptive Title

Two-Group Constant Parameter Point Depletion Problem

Technique Used

1. In solving the nuclide depletion equation over a time-step, the flux and reaction rate cross sections are assumed constant.
2. Both analytic and difference solutions are defined. The difference solution is used when the nuclide and all chain nuclides above or below it have a removal rate $[(\lambda + \sigma\phi)\Delta t]$ less than a (where $e^{-a} - \frac{2-a}{2+a} = \epsilon$ {error criterion}). Otherwise, the analytic solution is used. For the present solution, $a = 0.05$ and $\epsilon = 10^{-5}$.

Computer

Univac 1110

Program

BURNUP

Reference

1. M. R. Wagner, *GAUGE, A Two-Dimensional Few Group Neutron Diffusion-Depletion Program for a Uniform Triangular Mesh*.
GA-8307, "Chapter 4 - Nuclear Depletion Calculation" (1968).

Primary Results

Fifty-day isotopic concentrations are described in Table C.5 for time-step sizes ranging from 2 days to 10 minutes.

Computational statistics are defined in the table by SUP time, which is a combination of CPU time and I/O time.

TABLE C.5. GA Solutions to Constant Parameter Problem.
atoms/(barn-cm) at 50 days

Isotope	GA Small Time Step		
	10 min	1 hr	2 days
^{235}U	5.83386-5	5.83387-5	5.83393-5
^{236}U	2.86058-6	2.86058-6	2.86060-6
^{237}U	2.06103-8	2.06103-8	2.05937-8
^{238}U	6.91924-3	6.91938-3	6.91923-3
^{239}U	7.18270-9	7.18385-9	7.18404-9
^{237}Np	4.50845-8	4.50846-8	4.50933-8
^{238}Np	3.24895-10	3.24895-10	3.25098-10
^{239}Np	1.02945-6	1.02947-6	1.02946-6
^{240}Np	1.32294-11	1.32297-11	1.32295-11
^{238}Pu	1.47281-9	1.47284-9	1.47573-9
^{239}Pu	1.05749-5	1.05747-5	1.05744-5
^{240}Pu	9.95921-7	9.95925-7	9.95900-7
^{241}Pu	3.34194-7	3.34204-7	3.34495-7
^{242}Pu	1.63649-8	1.63651-8	1.64266-8
^{243}Pu	1.36278-11	1.36274-11	1.30074-11
^{241}Am	5.86427-10	5.86434-10	5.88396-10
^{242}Am	6.17245-12	6.17252-12	6.07897-12
$^{242\text{m}}\text{Am}$	5.04845-12	5.04856-12	5.07729-12
^{243}Am	4.56845-10	4.56857-10	4.61643-10
^{244}Am	6.37716-14	6.37420-14	5.89385-14
^{242}Cm	5.49980-11	5.49992-11	5.56397-11
^{243}Cm	1.15385-13	1.15390-13	1.17834-13
^{244}Cm	2.06829-11	2.06835-11	2.11112-11
^{245}Cm	2.43419-13	2.43427-13	2.51613-13
^{135}I	8.82753-9	8.82752-9	8.81797-9
^{135}Xe	9.14759-10	9.14758-10	9.13807-10
^{147}Nd	1.21159-7	1.21157-7	1.21155-7
^{147}Pm	2.01810-7	2.01815-7	2.01813-7
^{148}Pm	4.57034-9	4.57045-9	4.55895-9
$^{148\text{m}}\text{Pm}$	3.86715-9	3.86724-9	3.85696-9
^{149}Pm	1.99681-8	1.99682-8	1.99655-8
^{149}Sm	1.19776-8	1.19777-8	1.19778-8
Fission Products	1.45224-5	1.45228-5	1.45235-5
SUP	45.16	9.41	2.14 (seconds)

BENCHMARK PROBLEM SOLUTION

Identification:	15-A1-3	Benchmark Problem ID.15-A1
Date Submitted:	June 1976	By: M. R. Wagner (KWU)
Date Accepted:	June 1977	By: H. L. Dodds, Jr. (U. of Tenn.) R. R. Lee (CE)

Descriptive Title: Two-group Constant Parameter Point
Depletion Problem

Mathematical Model

For each time-step the reaction rates, which are the entries of the nuclide depletion matrix $\underline{A}$ are assumed constant. Furthermore, the matrix $\underline{A}$ is assumed to be a lower triangular matrix which can be decomposed into

1. a number of lower triangular submatrices corresponding to independent heavy nuclide and fission product chains,
2. a rectangular matrix which provides the coupling of the fission product chains to the heavy nuclide chains.

Both analytic and third-order difference solutions are defined.

Pertinent Features of Solution Method

The code automatically investigates the structure of the depletion matrix and separates the independent fuel and fission product chains. The depletion equations for the fuel chains are solved first. A constant fission product source vector S is then computed

$$S_i = \sum_{j=1}^{N_{\text{fuel}}} \gamma_{ij} \bar{N}_j^{\Delta t} \sum_g \sigma_{fj}^g \phi^g$$

where S_i is the component for fission product i , to replace the actual time-dependent rates $S_i(t)$ of fission product formation. Finally the decoupled fission product depletion chains are solved for that source.

In solving the depletion chains the code decides internally for every time-step and each nuclide whether the analytic solution or difference approximation will be applied. An input error criterion ϵ is used and by solving the equation

$$e^{-\alpha} - \frac{2 - \alpha}{2 + \alpha} = \epsilon$$

a critical value α for the magnitude of the removal term $|A_{ii}| \Delta t$ is determined. If

$$|A_{ii}| \Delta t > \epsilon$$

an analytic solution is requested for nuclide i .

Table 1 shows that the analytic solution ($\epsilon \rightarrow 0$) deteriorates with reduced time-step lengths due to buildup of round-off errors for very long depletion chains.

Table 2 illustrates that the error buildup is reduced when using a combination of analytic and difference solutions.

Table 3 shows the dependence of the solution on the parameter ϵ for a time step length of $\Delta t = 2$ days

Column 1 of Table 2 is considered the best solution of this series.

Computer: CYBER 175

Date Solved: May 1976

at: KWU

Program: MEDIUM-2

Type of Program: Multidimensional LWR depletion code

References

1. M.R. Wagner, GAUGE, A Two-Dimensional Few-Group Neutron Diffusion-Depletion Program for a Uniform Triangular Mesh, GA 8307, Gulf General Atomic (1968)

2. M.R. Wagner, MEDIUM, ein mehrdimensionales Abbrandprogramm für Druckwasserreaktoren, Reaktortagung 1972 des Deutschen Atomforums/KTG, Hamburg, April 1972, Proceedings p. 161

Table 1. MEDIUM-2 Solutions to Constant-Parameter Problem
atoms/ (barn-cm) at 50 days
Analytic Solutions, $\epsilon = 10^{-20}$

	Time Steps		
	10 min.	1 hour	2 days
U 235	.583394E-04	.583394E-04	.583394E-04
U 236	.286058E-05	.286058E-05	.286058E-05
U 237	.206103E-07	.206103E-07	.206103E-07
U 238	.691924E-02	.691924E-02	.691924E-02
U 239	.718370E-08	.718370E-08	.718370E-08
Np 237	.450845E-07	.450845E-07	.450845E-07
Np 238	.324894E-09	.324894E-09	.324894E-09
Np 239	.102945E-05	.102945E-05	.102945E-05
Np 240	.132294E-10	.132294E-10	.132294E-10
Pu 238	.147282E-08	.147283E-08	.147283E-08
Pu 239	.105747E-04	.105747E-04	.105747E-04
Pu 240	.995928E-06	.995928E-06	.995928E-06
Pu 241	.334210E-06	.334206E-06	.334205E-06
Pu 242	.163653E-07	.163651E-07	.163651E-07
Pu 243	.136281E-10	.136280E-10	.136280E-10
Am 241	.586454E-09	.586437E-09	.586433E-09
Am 242	.617274E-11	.617255E-11	.617251E-11
Am 242m	.504883E-11	.504860E-11	.504854E-11
Am 243	.456904E-09	.456855E-09	.456858E-09
Am 244	.637807E-13	.637740E-13	.637743E-13
Cm 242	.550017E-10	.549986E-10	.549984E-10
Cm 243	.113558E-12	.115114E-12	.115372E-12
Cm 244	.203962E-10	.206754E-10	.206821E-10
Cm 245	.199554E-12	.241771E-12	.243340E-12
I 135	.882757E-08	.882757E-08	.881793E-08
Xe 135	.914763E-09	.914763E-09	.913803E-09
Nd 147	.121157E-06	.121157E-06	.121154E-06
Pm 147	.201815E-06	.201815E-06	.201816E-06
Pm 148	.457044E-08	.457044E-08	.457048E-08
Pm 148m	.386724E-08	.386724E-08	.386727E-08
Pm 149	.199683E-07	.199683E-07	.199657E-07
Sm 149	.119777E-07	.119777E-07	.119776E-07
Fission Products	.145228E-04	.145228E-04	.145228E-04

CPU time, sec 88.94

15.74

0.39

CYBER 175

Table 2. MEDIUM-2 Solutions to Constant Parameter Problem
atoms/ (barn-cm) at 50 days

Combination of Analytic and Difference Solutions $\epsilon=10^{-5}$

		Time Steps		
		10 min.	1 hour	2 days
U 235		.583394E-04	.583394E-04	.583393E-04
U 236		.286058E-05	.286058E-05	.286059E-05
U 237		.206103E-07	.206103E-07	.205936E-07
U 238		.691924E-02	.691924E-02	.691924E-02
U 239		.718370E-08	.718371E-08	.718404E-08
Np 237		.450845E-07	.450845E-07	.450929E-07
Np 238		.324894E-09	.324894E-09	.325096E-09
Np 239		.102945E-05	.102945E-05	.102946E-05
Np 240		.132294E-10	.132294E-10	.132295E-10
Pu 238		.147283E-08	.147284E-08	.147572E-08
Pu 239		.105747E-04	.105747E-04	.105744E-04
Pu 240		.995928E-06	.995929E-06	.995900E-06
Pu 241		.334205E-06	.334206E-06	.334496E-06
Pu 242		.163651E-07	.163652E-07	.164267E-07
Pu 243		.136280E-10	.136275E-10	.130075E-10
Am 241		.586433E-09	.586435E-09	.588397E-09
Am 242		.617251E-11	.617253E-11	.607898E-11
Am 242m		.504854E-11	.504857E-11	.507732E-11
Am 243		.456858E-09	.456861E-09	.461644E-09
Am 244		.637734E-13	.637426E-13	.589387E-13
Cm 242		.549983E-10	.549993E-10	.556398E-10
Cm 243		.115387E-12	.115390E-12	.117634E-12
Cm 244		.206834E-10	.206836E-10	.211114E-10
Cm 245		.243424E-12	.243428E-12	.251615E-12
I 135		.882757E-08	.882757E-08	.881797E-08
Xe 135		.914763E-09	.914763E-09	.913807E-09
Nd 147		.121157E-06	.121157E-06	.121155E-06
Pm 147		.201815E-06	.201815E-06	.201813E-06
Pm 148		.457044E-08	.457044E-08	.455895E-08
Pm 148m		.386724E-08	.386724E-08	.385697E-08
Pm 149		.199683E-07	.199683E-07	.199655E-07
Sm 149		.119777E-07	.119777E-07	.119778E-07
Fission Products		.145228E-04	.145228E-04	.145234E-04

CPU time, sec 36.40

7.26

0.23

CYBER 175

Table 3. MEDIUM-2 Solutions to Constant Parameter Problem
atoms/ (barn-cm) at 50 days
Combination of Analytic and Difference Solutions, $\Delta T=2$ days

	$\epsilon = 10^{-5}$	$\epsilon = 10^{-6}$	$\epsilon = 10^{-7}$
	$\alpha = 0.050$	$\alpha = 0.023$	$\alpha = 0.0106$
U 235	.583393E-04	.583393E-04	.583393E-04
U 236	.286059E-05	.286059E-05	.286059E-05
U 237	.205936E-07	.205936E-07	.205936E-07
U 238	.691924E-02	.691924E-02	.691924E-02
U 239	.718404E-08	.718404E-08	.718404E-08
Np 237	.450929E-07	.450929E-07	.450929E-07
Np 238	.325096E-09	.325096E-09	.325096E-09
Np 239	.102946E-05	.102946E-05	.102946E-05
Np 240	.132295E-10	.132295E-10	.132295E-10
Pu 238	.147572E-08	.147582E-08	.147582E-08
Pu 239	.105744E-04	.105747E-04	.105747E-04
Pu 240	.995900E-06	.995927E-06	.995927E-06
Pu 241	.334496E-06	.334205E-06	.334205E-06
Pu 242	.164267E-07	.163640E-07	.163651E-07
Pu 243	.130075E-10	.129556E-10	.136280E-10
Am 241	.588397E-09	.586297E-09	.586432E-09
Am 242	.607898E-11	.605585E-11	.617250E-11
Am 242m	.507732E-11	.504976E-11	.504853E-11
Am 243	.461644E-09	.458475E-09	.456857E-09
Am 244	.589387E-13	.585170E-13	.637742E-13
Cm 242	.556398E-10	.552501E-10	.549979E-10
Cm 243	.117834E-12	.116581E-12	.115757E-12
Cm 244	.211114E-10	.208856E-10	.206816E-10
Cm 245	.251615E-12	.247885E-12	.244501E-12
I 135	.881797E-08	.881792E-08	.881792E-08
Xe 135	.913807E-09	.913802E-09	.913802E-09
Nd 147	.121155E-06	.121154E-06	.121154E-06
Pm 147	.201813E-06	.201816E-06	.201816E-06
Pm 148	.455895E-08	.457048E-08	.457048E-08
Pm 148m	.385697E-08	.386727E-08	.386727E-08
Pm 149	.199655E-07	.199657E-07	.199657E-07
Sm 149	.119778E-07	.119776E-07	.119776E-07
Fission Products	.145234E-04	.145228E-04	.145228E-04

CPU time, sec

0.23

0.237

0.279

CYBER 175

BENCHMARK PROBLEM SOLUTION

Identification: 15-A1-4

Benchmark Problem ID.15-A1

Date Submitted: January 1977

By: G. W. Cunningham and D. R.
Vondy (ORNL)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
R. R. Lee (CE)

Descriptive Title: Two-Group Constant Parameter Point Depletion Problem

Computer: IBM-360/91

Code: BURNER module of the system containing the VENTURE neutronics
code (Report ORNL-5180)

Date Solved: Dec. 1976 at ORNL

Results: Primary results are shown in Table 1 for benchmark quality calculations applying the matrix exponential method and the difference solution using average generation rates, to the linear chain equations. Other results have been obtained, as to test the explicit chain solution and criteria on series termination and dependence of the results on steps taken, which could be made available. These calculations were done with minimum computer memory use; only the direct coupling terms were stored, not the matrices, a procedure of calculation which is not directed toward minimizing processor time. No assumptions about equilibrium were used in obtaining the results. Calculations were done in double-precision (IBM long word).

TABLE 1. ORNL SOLUTIONS TO CONSTANT-PARAMETER PROBLEM,
ATOMS/(BARN-CM) AT 50 DAYS

NUCLIDE	MATRIX EXPONENTIAL (570 STEPS)	AVERAGE GENERATION RATE			
		(24 STEPS)	(768 STEPS)	(1536 STEPS)	
U 235	5.83394-05	5.83394-05	5.83394-05	5.83394-05	
U 236	2.86058-06	2.86061-06	2.86058-06	2.86058-06	
U 237	2.06102-08	2.05921-08	2.06102-08	2.06102-08	
U 238	6.91923-03	6.91923-03	6.91923-03	6.91923-03	
U 239	7.18369-09	7.18404-09	7.18369-09	7.18369-09	
NP237	4.50843-08	4.50166-08	4.50842-08	4.50843-08	
NP238	3.24893-10	3.22611-10	3.24891-10	3.24892-10	
NP239	1.02945-06	1.02951-06	1.02945-06	1.02945-06	
NP240	1.32294-11	1.32307-11	1.32294-11	1.32294-11	
PU238	1.47282-09	1.46092-09	1.47281-09	1.47282-09	
PU239	1.05747-05	1.03861-05	1.05725-05	1.05741-05	
PU240	9.95924-07	9.60185-07	9.95490-07	9.95805-07	
PU241	3.34204-07	3.14777-07	3.33954-07	3.34134-07	
PU242	1.63650-08	1.50433-08	1.63467-08	1.63599-08	
PU243	1.36279-11	1.18517-11	1.36113-11	1.36232-11	
AM241	5.86430-10	5.39966-10	5.85792-10	5.86249-10	
AM242	6.17244-12	5.55259-12	6.16540-12	6.17045-12	
AM242M	5.04867-12	4.57492-12	5.04189-12	5.04674-12	
AM243	4.56854-10	3.83676-10	4.56117-10	4.56645-10	
AM244	6.37737-14	4.85960-14	6.35965-14	6.37245-14	
CM242	5.49975-11	4.81328-11	5.49124-11	5.49732-11	
CM243	1.15385-13	9.88914-14	1.15162-13	1.15321-13	
CM244	2.06831-11	1.49807-11	2.06116-11	2.06631-11	
CM245	2.43421-13	1.69228-13	2.42425-13	2.43141-13	
I 135	8.82755-09	8.76837-09	8.82697-09	8.82740-09	
XE135	9.14763-10	9.06947-10	9.14688-10	9.14743-10	
CS135	7.71695-08	7.39781-08	7.71478-08	7.71639-08	
ND147	1.21157-07	1.20533-07	1.21150-07	1.21155-07	
PM147	2.01814-07	2.00596-07	2.01801-07	2.01811-07	
PM148	4.57044-09	4.52948-09	4.57012-09	4.57035-09	
PM148M	3.86722-09	3.83199-09	3.86695-09	3.86715-09	
PM149	1.99682-08	1.98139-08	1.99669-08	1.99679-08	
SM149	1.19777-08	1.18613-08	1.19769-08	1.19775-08	
FDLL	1.45228-05	1.44349-05	1.45217-05	1.45225-05	

IBM 360/91					
CPU TIME					
(SEC)					
	14.19	4.79	9.87	14.04	

BENCHMARK PROBLEM

Identification: 15-A2

Source Situation ID.15

Date Submitted: July 1976

By: M. V. Gregory (SRL)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
R. R. Lee (CE)

Descriptive Title

Two-Group Constant Parameter Point Depletion Problem with Feedback

Reduction from Source Situation

1. Identical to Problem 15-A1 with the exception that α -decay and β^+ -decay are NOT excluded, thus matrix A is not simply triangular.
2. The additional data required for the problem with feedback are given in Table C.2a. Remaining data same as in Problem 15-A1.

Expected Primary Results

1. 50-day concentrations
2. Calculational statistics

Solutions Available

1. Fourth-order Runge-Kutta integration of depletion equations: 15-A2-1
2. Matrix exponential method and finite difference solution: 15-A2-2

The above two solutions are identical to four significant places with the smallest time-step.

BENCHMARK PROBLEM SOLUTION

Identification:	15-A2-1	Benchmark Problem ID 15-A2
Date Submitted:	July 1976	By: M. V. Gregory (SRL)
Date Accepted:	June 1977	By: H. L. Dodds, Jr. (U. of Tenn.) R. R. Lee (CE)

Descriptive Title

Two-Group Constant Parameter Point Depletion Problem with Feedback

Technique Used

Identical to solution of Problem ID 15-A1 without feedback, using atypically small integration time-step of 1 minute.

Computer

IBM-360/195

Program

BURGR

References

1. *The JOSHUA System, Volume 10.1 Generalized Reactor Analysis Subsystem: Physics.* (Draft) DPSTM-500 (1975)
2. M. M. Anderson et al., "Three-Dimensional Coupled Neutronics and Engineering Calculation of Savannah River Reactors," CONF-750413, Vol. II., p. VI-123.

Primary Results

The isotopic inventory at 50 days is given in Table C.2b. A fixed time-step of 1 minute was used for the Runge-Kutta integration. The CPU time required was 430 seconds. BURGR was constrained to such a small time-step size for the specific purpose of obtaining a benchmark-quality solution, thus the long running time should not be considered typical of production runs.

TABLE C.2a. Extra Data Required for Full-Chain Problem

Decay Constants		
Isotope	Emitted Particle	Constant, sec^{-1}
^{238}Pu	α	$2.550\text{E}-10$
^{241}Am	α	$5.090\text{E}-11$
^{242}Am	β^+	$2.030\text{E}-6$
^{242}Cm	α	$4.910\text{E}-8$
^{243}Cm	α	$6.860\text{E}-10$
^{244}Cm	α	$1.250\text{E}-9$

(n,2n) Microscopic Cross Sections
(Group 1 only)

Isotope	σ , barns
^{235}U	0.002603
^{238}U	0.0043972
^{237}Np	0.00020144

TABLE C.2b. SRL Solution to Full-Chain Constant Parameter Point
Depletion Problem, atoms/barn-cm at 50 days,
Integration Time-Step of 1 minute

<u>Isotope</u>	<u>Concentration</u>	<u>Isotope</u>	<u>Concentration</u>
^{234}U	0.428817E-9	^{241}Am	0.586390E-9
^{235}U	0.583395E-4	^{242}Am	0.520984E-11
^{236}U	0.286054E-5	$^{242\text{m}}\text{Am}$	0.504819E-11
^{237}U	0.356768E-7	^{243}Am	0.457037E-9
^{238}U	0.691916E-2	^{244}Am	0.637996E-13
^{239}U	0.718357E-8	^{242}Cm	0.449667E-10
^{237}Np	0.104736E-6	^{243}Cm	0.950949E-13
^{238}Np	0.780485E-9	^{244}Cm	0.206737E-10
^{239}Np	0.102944E-5	^{245}Cm	0.243318E-12
^{240}Np	0.132292E-10	^{135}I	0.882738E-8
^{238}Pu	0.441854E-8	^{135}Xe	0.914753E-9
^{239}Pu	0.105748E-4	^{147}Nd	0.121154E-6
^{240}Pu	0.995892E-6	^{147}Pm	0.201810E-6
^{241}Pu	0.334195E-6	^{148}Pm	0.457029E-8
^{242}Pu	0.163736E-7	$^{148\text{m}}\text{Pm}$	0.386727E-8
^{243}Pu	0.136348E-10	^{149}Pm	0.199679E-7
		^{149}Sm	0.119776E-7
		Fission Products	0.145225E-4

BENCHMARK PROBLEM SOLUTION

Identification: 15-A2-2

Benchmark Problem ID.15-A2

Date Submitted: January 1977

By: G. W. Cunningham and D. R. Vondy (ORNL)

Date Accepted: June 1977

By: H. L. Dodds, Jr. (U. of Tenn.)
R. R. Lee (CE)

Descriptive Title: Solutions for the Constant Parameter Depletion Problem with Feedback

Computer: IBM-360/91

Code: BURNER module of the system containing the VENTURE neutronics code (Report ORNL-5180)

Date Solved: December 1976 at ORNL

Results: Primary results are shown in Table 1 for benchmark quality calculations applying the matrix exponential method and the difference solution using average generation rates, to the linear chain equations with feedback. Other results have been obtained, as to test the explicit chain solution and criteria on series termination and dependence of the results on steps taken, which could be made available. These calculations were done with minimum computer memory use; only the direct coupling terms were stored, not the matrices, a procedure of calculation which is not directed toward minimizing processor time. Calculations were done in double-precision (IBM long word).

Table 1. Nuclide Concentrations for the Constant Parameter
Point Depletion Problem with Feedback

Nuclide	Matrix Exponential (570 steps)	Average Generation Rate		
		(24 steps)	(768 steps)	(1536 steps)
^{234}U	.428821-9	.43280-9	.42895-9	.42888-9
^{235}U	.583390-4	.58339-4	.58339-4	.58339-4
^{236}U	.286057-5	.28606-5	.28606-5	.28606-5
^{237}U	.356780-7	.35661-7	.35678-7	.35678-7
^{238}U	.691915-2	.69191-2	.69191-2	.69191-2
^{239}U	.718360-8	.71840-8	.71836-8	.71836-8
^{237}Np	.104739-6	.10462-6	.10474-6	.10474-6
^{238}Np	.780515-9	.77641-9	.78051-9	.78052-9
^{239}Np	.102944-5	.10295-5	.10294-5	.10294-5
^{240}Np	.132292-10	.13231-10	.13229-10	.13229-10
^{238}Pu	.441870-8	.43857-8	.44187-8	.44187-8
^{239}Pu	.105747-4	.10386-4	.10573-4	.10574-4
^{240}Pu	.995926-6	.96019-6	.99549-6	.99580-6
^{241}Pu	.334204-6	.31478-6	.33395-6	.33413-6
^{242}Pu	.163743-7	.15050-7	.16356-7	.16369-7
^{243}Pu	.136356-10	.11857-10	.13619-10	.13631-10
^{241}Am	.586404-9	.53994-9	.58577-9	.58622-9
^{242}Am	.520999-11	.46704-11	.52040-11	.52083-11
^{242m}Am	.504831-11	.45746-11	.50415-11	.50464-11
^{243}Am	.457064-9	.38380-9	.45632-9	.45685-9
^{244}Am	.638030-13	.48611-13	.63625-13	.63754-13
^{242}Cm	.449681-10	.39205-10	.44899-10	.44948-10
^{243}Cm	.950979-13	.81087-13	.94915-13	.95045-13
^{244}Cm	.206748-10	.14973-10	.20603-10	.20655-10
^{245}Cm	.243334-12	.16915-12	.24234-12	.24305-12
^{135}I	.882752-8	.87683-8	.88269-8	.88274-8
^{135}Xe	.914759-9	.90694-9	.91468-9	.91474-9
^{135}Cs	.771693-7	.73978-7	.77148-7	.77164-7
^{147}Nd	.121156-6	.12053-6	.12115-6	.12115-6
^{147}Pm	.201814-6	.20060-6	.20180-6	.20181-6

Table 1 (continued)

Nuclide	Matrix Exponential (570 steps)	Average Generation Rate		
		(24 steps)	(768 steps)	(1536 steps)
^{148}Pm	.457042-8	.45295-8	.45701-8	.45703-8
$^{148\text{m}}\text{Pm}$	.386722-8	.38320-8	.38669-8	.38671-8
^{149}Pm	.199682-7	.19814-8	.19967-7	.19968-7
^{149}Sm	.119776-7	.11861-7	.11977-7	.11977-7
F.P.	.145227-4	.14435-4	.14522-4	.14522-4
Processor Time (min)	0.18	0.02	0.11	0.19