BENCHMARK PROBLEM

Identification	16-A1	Source Situation:	ID.16
Date Submitted:	July 1980	By:	H. L. Dodds, Jr. (Univ. of Tennessee)
Date Accepted:	October 1985	By:	R. M. Westfall (ORNL) C. E. Lee (Consult.)

Descriptive Title: *Delayed Supercritical Transient; One-Dimensional, Two-Group Neutron Transport Problem in a Fast Reactor*

Reduction of Source Situation:

1. One-dimensional (slab with azimuthal symmetry), two-group neutron transport theory
2. Isotropic scattering
3. Zero return current boundary conditions on external surfaces
4. Steady-state critical initial conditions
5. Six delayed neutron precursor groups

The equations for this mathematical model are[1]

$$(1)\quad \frac{1}{v_g}\frac{\partial}{\partial t}\phi_g(x,\mu,t) + \mu\frac{\partial}{\partial x}\phi_g(x,\mu,t) + \Sigma_t^g(x,t)\,\phi_g(x,\mu,t) =$$

$$\frac{1}{2}\sum_{g'=1}^{2}\left[\chi_g^p(1-\beta)\,\nu\Sigma_f^{g'}(x,t) + \Sigma_s^{g'\to g}(x,t)\right]\phi_{g'}(x,t)$$

$$+\frac{1}{2}\sum_{i=1}^{6}\lambda_i C_i(x,t)\,\chi_g^i + Q_g(x,\mu,t):\ g = 1,2$$

$$(2)\quad \frac{\partial}{\partial t}C_i(x,t) + \lambda_i C_i(x,t) = \beta_i\sum_{g=1}^{2}\nu\Sigma_f^g\,\phi_g(x,t);\ i = 1, \ldots, 6$$

where $\phi_g(x,t)$ = scalar group flux (neutrons/cm^2-sec)

$$\phi_g(x,t) = \int_{-1}^{+1}\phi_g(x,\mu,t)\,d\mu$$

$\phi_g(x,\mu,t)$ = angular group flux (neutrons/cm^2-sec-unit cosine)

$$\phi_g(x,\mu,t) = \int_0^{2\pi} \phi_g(x,\mu,\varphi,t)\, d\varphi, \quad \varphi = \text{azimuthal angle}$$

$C_i(x,t)$ = concentration of type i precursor (nuclei/cm^3)

and the remaining terms are defined in detail in References 1, 2, or 3.

For the problem, $\chi_g^p = \chi_g^i = \chi_g$ and $Q_1 = Q_2 = 0$.

Date: Initial two-group constants shown in Table I. Delayed neutron parameters, fission spectra, and 1/v values shown in Table II.

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.

Initial Perturbation:

At time t = 0.0 sec, the density of the material in Zone 2 is increased by 5% and the density of the material in Zone 6 is decreased by 5% (resulting in a step insertion of reactivity at time t = 0.0 sec).

Expected Primary Results:

1. Initial k-eff and initial scalar flux distribution for each group
2. Convergence requirements on flux (and eigenvalue) if an iterative solution is used
3. Total reactor power versus time (normalized such that the total neutron production rate at t = 0.0 is 1.0 neutron/sec)
4. Time-dependent group flux (i.e., scalar flux) distributions
5. Sensitivity of results to time step size
6. CPU time and core storage requirements

Table I. Initial Two-Group Constants[a] (cm^{-1})

Zone	Group g	$\nu\Sigma_f^g$	Σ_t^g	$\Sigma_s^{g\to g}$	$\Sigma_s^{g\to g'}$
1,7[b]	1	8.3441-4	2.411-1	2.33644-1	3.598-3
	2	3.2776-4	4.172-1	4.07004-1	0.0
2,4,6[c]	1	7.4518-3	1.849-1	1.77711-1	2.085-3
	2	1.10612-2	3.668-1	3.53721-1	0.0
3,5[d]	1	0.0	9.432-2	8.571-2	1.7168-3
	2	0.0	1.8762-1	1.7131-1	0.0

[a] $\Sigma_a^g = \Sigma_t^g - \Sigma_s^g$ and $\Sigma_s^g = \Sigma_s^g + \Sigma_s^{g\to g'}$.

[b] Blanket material in Zones 1 and 7.

[c] Core material in Zones 2, 4, and 6.

[d] Mixture of sodium and control rod material in Zones 3 and 5.

Table II. Delayed Neutron Parameters[a]

Type	β_i	λ (sec^{-1})
1	0.81-4	0.0129
2	6.87-4	0.0311
3	6.12-4	0.134
4	11.38-4	0.331
5	5.12-4	1.26
6	1.70-4	3.21

[a] Prompt and delayed neutron spectra are identical with $\chi_1 = 1.0$ and $\chi_2 = 0.0$, Also, $1/v_1 = 1.851\text{-}9 \frac{sec}{cm}$ and $1/v_2 = 1.088\text{-}8 \frac{sec}{cm}$.

Possible Additional Results:

7. Zone-averaged power fractions versus time
8. Sensitivity of results to spatial mesh size
9. Sensitivity of results to angular quadrature (if solution is obtained by the discrete ordinates method)

Based on preliminary static k-eff calculations of the initial critical configuration using ANISN,[4] an S_4 quadrature with 114 spatial intervals (as defined in Tables III and IV) is a sufficiently accurate representation for the angular and spatial discretization. Specifically, by using a finer spatial mesh (i.e., 228 intervals), k-eff changed by 0.0001 and using an S_8 and S_{16} quadrature, k-eff changed by 0.0003 and 0.0003 respectively. Therefore, it is suggested that the "Expected Primary Results" requested above be obtained initially using the discretization indicated in Tables III and IV if the conventional discrete ordinates method is used to obtain solutions. Also, if a discrete ordinates method is used, it may be worthwhile to note that the units for angular flux in most discrete ordinates codes are per "unit weight" rather than per "unit cosine," as indicated earlier in the definitions following Eq. (2).

Table III. S_4 Angular Quadrature

Cosine (μ)	Weight
-1.0	0.0
-0.788675	0.25
-0.211325	0.25
+0.211325	0.25
+0.788675	0.25

Table IV. Spatial Mesh

Zone	Number of Equal Intervals
1	20
2	24
3	5
4	16
5	5
6	24
7	20

REFERENCES

1. G. I. Bell and S. Glasstone, Nuclear Reactor Theory, Van Nostrand Reinhold Co., p. 466 (1970).

2. H. L. Dodds, Jr. et al., Nucl. Sci. Eng., 47, p. 264 (1972).

3. T. R. Hill and W. H. Reed, "TIMEX: A Time-Dependent Explicit Discrete Ordinates Program for the Solution of Multigroup Transport Equations with Delayed Neutrons," LA-6201-MS, Los Alamos Scientific Laboratory (1976).

4. W. W. Engle, Jr., "A User's Manual for ANISN, A One-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering," ORGDP-K-1693, Oak Ridge Gaseous Diffusion Plant (1967).

BENCHMARK PROBLEM

Identification:	16-A1	**Source Situation:**	ID.16
Date Submitted:	July 1980	**By:**	H. L. Dodds, Jr. (Univ. of Tennessee)
Date Accepted:	October 1985	**By:**	R. M. Westfall Oak Ridge National Laboratory C. E. Lee (Consult.)

Acceptance is based upon agreement between independent solutions obtained with the TIMEX and TDA computer programs (solutions 16-A1.1 and 16-A1.2). In comparing the solutions it should be borne in mind that the power is normalized to one neutron per second at time equals zero. Also it should be noted that the tabulated values of the scaler flux are mesh-interval-average values for TDA and mesh-interval-boundary values for TIMEX. With regard to the power, solutions by TIMEX and TDA disagree by 2% or less for $0 \leq t \leq 10^{-1}$ seconds and for $t > 10^{-1}$ seconds, the disagreement varies from 2 to 4%. Therefore, the reviewers find the two solutions acceptable as computational benchmark solutions for the time interval $0 \leq t \leq 10^{-1}$ seconds.

BENCHMARK PROBLEM SOLUTION

Identification: 16-A1-1

Benchmark Problem ID.16-A1

Date Submitted: November 1981

By: T. R. Hill (Los Alamos National Laboratory)

By: R. M. Westfall (ORNL)
C. E. Lee (Consult.)

Date Accepted: October 1985

Descriptive Title: Multigroup Discrete Ordinates Solution with TIMEX[1]

Mathematical Model: Multigroup energy approximation, discrete ordinates angular approximation, linear discontinuous spatial approximation,[2] first- order semi-implicit time difference scheme[1] with fine- mesh rebalance and exponential extraplotation.

Pertinent Features of Techniques Used: S_4 angular quadrature, suggested 114 spatial intervals, 6 delayed neutron groups, exponential extrapolation of the time variable, with the following times steps used in each time zone:

Time Zone (sec)	Δt (sec)
0 to 10^{-3}	2×10^{-8}
10^{-3} to 10^{-1}	2×10^{-6}
10^{-1} to 1.0	2×10^{-5}
1.0 to 10.0	2×10^{-4}

Computer: CDC 7600

Codes: ONETRAN, TIMEX (single precision, 14 decimal digits accuracy)

Date Solved: June 1981 at Los Alamos National Laboratory

References

1. T. R. Hill and Wm. H. Reed, "TIMEX: A Time- Dependent Explicit Discrete Ordinates Program for the Solution of the Multigroup Transport Equations with Delayed Neutrons," Los Alamos Scientific Laboratory report LA-6201-MS (February 1976)

2. T. R. Hill, "ONETRAN: A Discrete Ordinates Finite Element Code for the Solution of the One- Dimensional Multigroup Transport Equation," Los Alamos Scientific Laboratory report LA-5990-MS (June 1975)

Primary Results:

Calculated k_{eff} by ONETRAN for initial two group constants of Table I : 1.000198

Table I $\nu\Sigma_f^g$ were divided by this k_{eff} for all TIMEX calculations.

TIMEX uses a fixed time step in each time zone and requires no inner or outer iterations. CPU time is approximately 0.040 seconds per time step.

Exhibit A : Total power vs. time (relative to an initial total neutron production rate of 1.0) for the reference time step (dt) and for two and ten times the reference time step. Estimated accuracy of the time discretization : less than 0.01% at t= 10.0 seconds.

Exhibit B : Plot of total power vs. time for the reference time step size.

Exhibit C : Scalar flux vs. spatial position at t= 0.0, 0.01, and 1.0 seconds. TIMEX uses a linear discontinuous representation for the spatial distribution of the flux in each mesh interval. For each of the 114 spatial intervals, the scalar flux on the left and right boundaries, respectfully, of each mesh cell is given.

Exhibit D : Plot of data in Exhibit C.

EXHIBIT A

POWER VS. TIME PROBLEM 16-A1

T(SEC)	TIME STEP DT(SEC)	POWER(DT)	POWER(2*DT)	POWER(10*DT)
.0		1.000000E+00		
.00001		1.020201E+00	1.020081E+00	1.013996E+00
.00002		1.040314E+00		
.00003		1.071326E+00		
.00004		1.095005E+00		
.00005		1.117408E+00		
.00006		1.138603E+00		
.00007		1.158656E+00		
.00008		1.177628E+00		
.00009		1.195578E+00		
.0001	2.E-8	1.212560E+00	1.212584E+00	1.213551E+00
.0002		1.339370E+00		
.0003		1.412250E+00		
.0004		1.454142E+00		
.0005		1.478231E+00		
.0006		1.492090E+00		
.0007		1.500071E+00		
.0008		1.504674E+00		
.0009		1.507337E+00		
.001		1.508886E+00	1.508890E+00	1.509053E+00
.002		1.511313E+00		
.003		1.511832E+00		
.004		1.512171E+00		
.005		1.512608E+00		
.006		1.513028E+00		
.007		1.513448E+00		
.008		1.513869E+00		
.009		1.514289E+00		
.01	2.E-6	1.514708E+00	1.514715E+00	1.501635E+00
.02		1.518887E+00		
.03		1.523033E+00		
.04		1.527147E+00		
.05		1.531229E+00		
.06		1.535282E+00		
.07		1.539305E+00		
.08		1.543299E+00		
.09		1.547265E+00		
.1		1.551203E+00	1.551204E+00	1.548958E+00
.2		1.589212E+00		
.3		1.625115E+00		
.4		1.659353E+00		
.5		1.692272E+00		
.6	2.E-5	1.724138E+00		
.7		1.755160E+00		
.8		1.785505E+00		
.9		1.815304E+00		
1.0		1.844662E+00	1.844656E+00	1.861842E+00
2.0		2.127482E+00		
3.0		2.411400E+00		
4.0		2.709651E+00		
5.0		3.028485E+00		
6.0	2.E-4	3.372046E+00		
7.0		3.743840E+00		
8.0		4.147277E+00		
9.0		4.585890E+00		
10.0		5.063440E+00	5.063146E+00	5.063005E+00
CPU TIME (MIN)		126.4	63.1	12.7

CDC 7600
CORE STORAGE : 4,900 WORDS SMALL CORE 5,600 WORDS LARGE CORE

EXHIBIT B

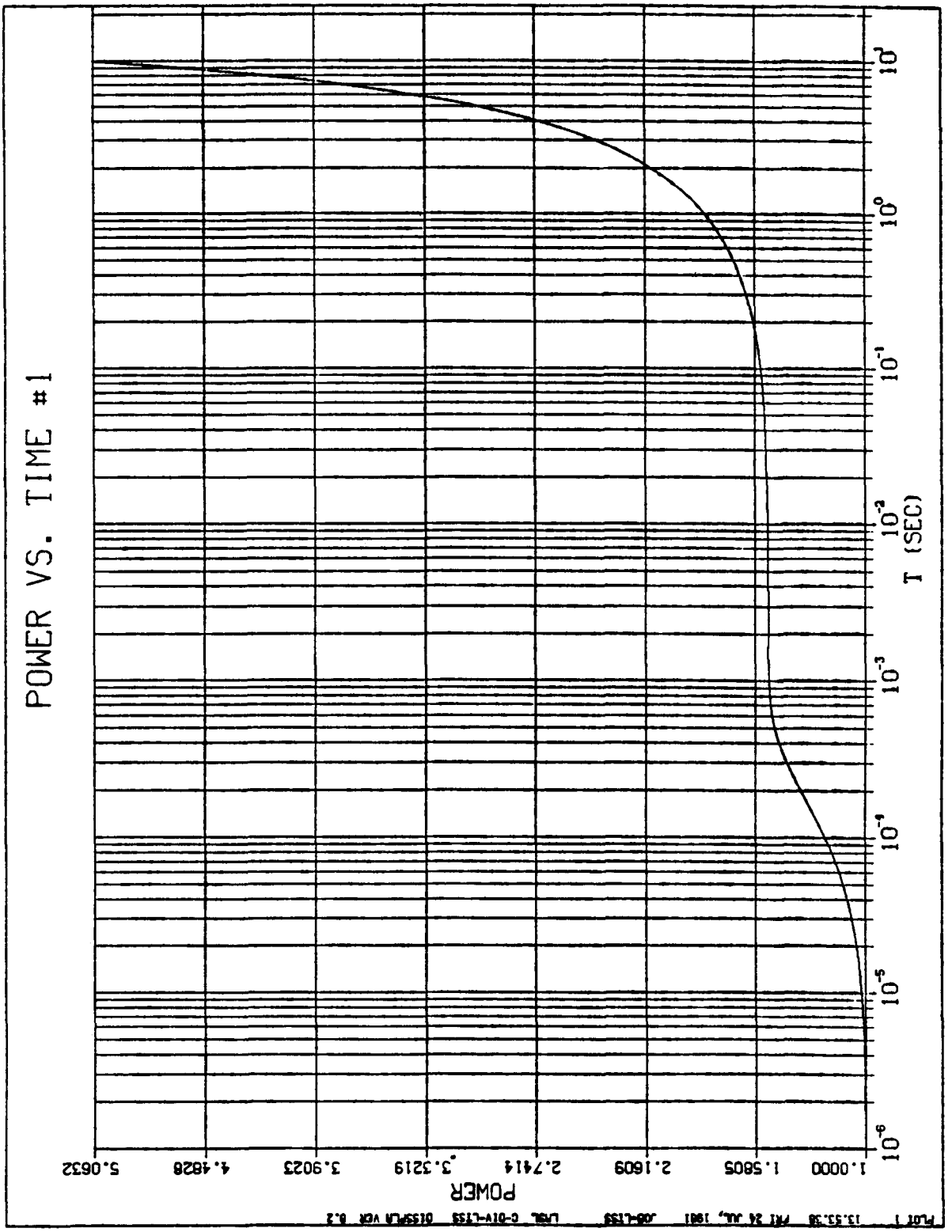

POWER VS. TIME #1
POWER
1.0000
1.5805
2.1609
2.7414
3.3219
3.9023
4.4828
5.0632
T (SEC)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6

EXHIBIT C

PROBLEM 16 SCALAR FLUX (GROUP 1 AT T= 0.0 SEC)

1	9.3314E-03	1.8360E-02	30	8.6221E-01	8.8408E-01	59	9.2875E-01	9.1910E-01	87	8.3675E-01	8.0767E-01
2	1.8367E-02	2.6515E-02	31	8.8408E-01	9.0221E-01	60	9.1911E-01	9.0804E-01	88	8.0769E-01	7.7513E-01
3	2.6531E-02	3.4962E-02	32	9.0220E-01	9.1655E-01	61	9.0805E-01	8.9260E-01	89	7.7515E-01	7.3922E-01
4	3.4981E-02	4.4020E-02	33	9.1654E-01	9.2705E-01	62	8.9261E-01	8.7269E-01	90	7.3923E-01	7.0001E-01
5	4.4040E-02	5.3882E-02	34	9.2704E-01	9.3368E-01	63	8.7271E-01	8.4781E-01	91	7.0003E-01	6.5757E-01
6	5.3904E-02	6.4734E-02	35	9.3368E-01	9.3643E-01	64	8.4781E-01	8.1553E-01	92	6.5759E-01	6.1181E-01
7	6.4758E-02	7.6777E-02	36	9.3643E-01	9.3529E-01	65	8.1549E-01	7.6577E-01	93	6.1182E-01	5.6213E-01
8	7.6804E-02	9.0232E-02	37	9.3529E-01	9.3026E-01	66	7.6126E-01	7.3924E-01	94	5.6210E-01	5.0602E-01
9	9.0263E-02	1.0535E-01	38	9.3027E-01	9.2138E-01	67	7.3893E-01	7.2898E-01	95	5.0325E-01	4.3395E-01
10	1.0538E-01	1.2240E-01	39	9.2139E-01	9.0867E-01	68	7.2889E-01	7.2910E-01	96	4.3386E-01	3.7755E-01
11	1.2244E-01	1.4171E-01	40	9.0868E-01	8.9213E-01	69	7.2919E-01	7.3955E-01	97	3.7744E-01	3.2894E-01
12	1.4176E-01	1.6364E-01	41	8.9214E-01	8.7166E-01	70	7.3986E-01	7.6230E-01	98	3.2884E-01	2.8656E-01
13	1.6369E-01	1.8858E-01	42	8.7166E-01	8.4664E-01	71	7.6653E-01	8.1454E-01	99	2.8647E-01	2.4951E-01
14	1.8864E-01	2.1700E-01	43	8.4662E-01	8.1464E-01	72	8.1464E-01	8.4662E-01	100	2.4943E-01	2.1707E-01
15	2.1707E-01	2.4943E-01	44	8.1454E-01	7.6653E-01	73	8.4664E-01	8.7166E-01	101	2.1700E-01	1.8864E-01
16	2.4951E-01	2.8647E-01	45	7.6230E-01	7.3986E-01	74	8.7166E-01	8.9214E-01	102	1.8858E-01	1.6369E-01
17	2.8656E-01	3.2884E-01	46	7.3955E-01	7.2919E-01	75	8.9213E-01	9.0868E-01	103	1.6364E-01	1.4176E-01
18	3.2894E-01	3.7744E-01	47	7.2910E-01	7.2889E-01	76	9.0867E-01	9.2139E-01	104	1.4171E-01	1.2244E-01
19	3.7755E-01	4.3386E-01	48	7.2898E-01	7.3893E-01	77	9.2138E-01	9.3027E-01	105	1.2240E-01	1.0538E-01
20	4.3395E-01	5.0325E-01	49	7.3924E-01	7.6126E-01	78	9.3026E-01	9.3529E-01	106	1.0535E-01	9.0263E-02
21	5.0602E-01	5.8210E-01	50	7.6577E-01	8.1549E-01	79	9.3529E-01	9.3643E-01	107	9.0232E-02	7.6804E-02
22	5.8213E-01	6.1182E-01	51	8.1553E-01	8.4781E-01	80	9.3643E-01	9.3368E-01	108	7.6777E-02	6.4758E-02
23	6.1181E-01	6.5759E-01	52	8.4781E-01	8.7271E-01	81	9.3368E-01	9.2704E-01	109	6.4734E-02	5.3904E-02
24	6.5757E-01	7.0003E-01	53	8.7269E-01	8.9261E-01	82	9.2705E-01	9.1654E-01	110	5.3882E-02	4.4040E-02
25	7.0001E-01	7.3923E-01	54	8.9260E-01	9.0805E-01	83	9.1655E-01	9.0220E-01	111	4.4020E-02	3.4981E-02
26	7.3922E-01	7.7515E-01	55	9.0804E-01	9.1911E-01	84	9.0221E-01	8.8408E-01	112	3.4962E-02	2.6531E-02
27	7.7513E-01	8.0769E-01	56	9.1910E-01	9.2875E-01	85	8.8406E-01	8.6223E-01	113	2.6515E-02	1.8367E-02
28	8.0767E-01	8.3675E-01	57	9.2575E-01	9.2797E-01	86	8.6221E-01	8.3674E-01	114	1.8360E-02	9.3314E-03
29	8.3674E-01	8.6225E-01	58	9.2797E-01	9.2575E-01						

PROBLEM 16 SCALAR FLUX (GROUP 2 AT T= 0.0 SEC)

1	2.8774E-03	7.2825E-03	30	1.3154E-01	1.3408E-01	59	1.3673E-01	1.3567E-01	87	1.2876E-01	1.2570E-01
2	7.2577E-03	1.1202E-02	31	1.3400E-01	1.3605E-01	60	1.3567E-01	1.3391E-01	88	1.2571E-01	1.2247E-01
3	1.1204E-02	1.5240E-02	32	1.3605E-01	1.3767E-01	61	1.3391E-01	1.3144E-01	89	1.2247E-01	1.1916E-01
4	1.5243E-02	1.9428E-02	33	1.3767E-01	1.3881E-01	62	1.3144E-01	1.2827E-01	90	1.1917E-01	1.1591E-01
5	1.9430E-02	2.3815E-02	34	1.3881E-01	1.3945E-01	63	1.2827E-01	1.2438E-01	91	1.1592E-01	1.1288E-01
6	2.3817E-02	2.8448E-02	35	1.3944E-01	1.3955E-01	64	1.2439E-01	1.1977E-01	92	1.1290E-01	1.1029E-01
7	2.8450E-02	3.3369E-02	36	1.3955E-01	1.3911E-01	65	1.1980E-01	1.1361E-01	93	1.1031E-01	1.0841E-01
8	3.3370E-02	3.8612E-02	37	1.3911E-01	1.3811E-01	66	1.1361E-01	1.1049E-01	94	1.0840E-01	1.0825E-01
9	3.8613E-02	4.4204E-02	38	1.3811E-01	1.3653E-01	67	1.1049E-01	1.0935E-01	95	1.0906E-01	1.0789E-01
10	4.4204E-02	5.0159E-02	39	1.3653E-01	1.3438E-01	68	1.0935E-01	1.0939E-01	96	1.0785E-01	1.0360E-01
11	5.0158E-02	5.6474E-02	40	1.3438E-01	1.3164E-01	69	1.0939E-01	1.1061E-01	97	1.0363E-01	9.7932E-02
12	5.6472E-02	6.3128E-02	41	1.3164E-01	1.2831E-01	70	1.1062E-01	1.1335E-01	98	9.7956E-02	9.1382E-02
13	6.3124E-02	7.0066E-02	42	1.2831E-01	1.2437E-01	71	1.1360E-01	1.1984E-01	99	9.1399E-02	8.4367E-02
14	7.0061E-02	7.7198E-02	43	1.2438E-01	1.1980E-01	72	1.1980E-01	1.2438E-01	100	8.4380E-02	7.7189E-02
15	7.7189E-02	8.4380E-02	44	1.1984E-01	1.1380E-01	73	1.2437E-01	1.2831E-01	101	7.7198E-02	7.0061E-02
16	8.4367E-02	9.1399E-02	45	1.1335E-01	1.1062E-01	74	1.2831E-01	1.3164E-01	102	7.0066E-02	6.3124E-02
17	9.1382E-02	9.7956E-02	46	1.1061E-01	1.0939E-01	75	1.3164E-01	1.3438E-01	103	6.3128E-02	5.6472E-02
18	9.7932E-02	1.0363E-01	47	1.0939E-01	1.0935E-01	76	1.3438E-01	1.3653E-01	104	5.6474E-02	5.0158E-02
19	1.0360E-01	1.0785E-01	48	1.0935E-01	1.1048E-01	77	1.3653E-01	1.3811E-01	105	5.0159E-02	4.4204E-02
20	1.0785E-01	1.0906E-01	49	1.1049E-01	1.1314E-01	78	1.3811E-01	1.3911E-01	106	4.4204E-02	3.8613E-02
21	1.0825E-01	1.0840E-01	50	1.1361E-01	1.1982E-01	79	1.3911E-01	1.3955E-01	107	3.8612E-02	3.3370E-02
22	1.0841E-01	1.1031E-01	51	1.1977E-01	1.2439E-01	80	1.3955E-01	1.3944E-01	108	3.3369E-02	2.8450E-02
23	1.1029E-01	1.1290E-01	52	1.2438E-01	1.2827E-01	81	1.3945E-01	1.3881E-01	109	2.8448E-02	2.3817E-02
24	1.1288E-01	1.1592E-01	53	1.2827E-01	1.3144E-01	82	1.3881E-01	1.3767E-01	110	2.3815E-02	1.9430E-02
25	1.1591E-01	1.1917E-01	54	1.3144E-01	1.3391E-01	83	1.3767E-01	1.3605E-01	111	1.9428E-02	1.5243E-02
26	1.1916E-01	1.2247E-01	55	1.3391E-01	1.3567E-01	84	1.3605E-01	1.3400E-01	112	1.5240E-02	1.1204E-02
27	1.2247E-01	1.2571E-01	56	1.3567E-01	1.3673E-01	85	1.3400E-01	1.3154E-01	113	1.1202E-02	7.2577E-03
28	1.2570E-01	1.2876E-01	57	1.3673E-01	1.3708E-01	86	1.3155E-01	1.2876E-01	114	7.2825E-03	2.8774E-03
29	1.2876E-01	1.3155E-01	58	1.3708E-01	1.3673E-01						

EXHIBIT C (Continued)

PROBLEM 16-A1 SCALAR FLUX (GROUP 1 AT T= 1.00E-01 SEC)

1	1.5699E-02	3.0889E-02	30	1.4698E+00	1.5057E+00	59	1.3901E+00	1.3728E+00	87	1.1141E+00	1.0751E+00
2	3.0901E-02	4.4610E-02	31	1.5057E+00	1.5346E+00	60	1.3728E+00	1.3489E+00	88	1.0751E+00	1.0319E+00
3	4.4636E-02	5.8822E-02	32	1.5346E+00	1.5565E+00	61	1.3489E+00	1.3185E+00	89	1.0319E+00	9.8458E-01
4	5.8853E-02	7.4062E-02	33	1.5565E+00	1.5713E+00	62	1.3185E+00	1.2816E+00	90	9.8460E-01	9.3333E-01
5	7.4096E-02	9.0655E-02	34	1.5713E+00	1.5789E+00	63	1.2816E+00	1.2374E+00	91	9.3335E-01	8.7816E-01
6	9.0692E-02	1.0891E-01	35	1.5789E+00	1.5793E+00	64	1.2374E+00	1.1825E+00	92	8.7819E-01	8.1892E-01
7	1.0896E-01	1.2918E-01	36	1.5793E+00	1.5729E+00	65	1.1825E+00	1.1026E+00	93	8.1891E-01	7.5476E-01
8	1.2922E-01	1.5182E-01	37	1.5729E+00	1.5585E+00	66	1.0961E+00	1.0609E+00	94	7.5470E-01	6.8255E-01
9	1.5187E-01	1.7725E-01	38	1.5585E+00	1.5375E+00	67	1.0604E+00	1.0426E+00	95	6.7891E-01	5.8542E-01
10	1.7731E-01	2.0595E-01	39	1.5375E+00	1.5095E+00	68	1.0425E+00	1.0392E+00	96	5.8530E-01	5.0933E-01
11	2.0602E-01	2.3845E-01	40	1.5095E+00	1.4748E+00	69	1.0393E+00	1.0505E+00	97	5.0919E-01	4.4437E-01
12	2.3852E-01	2.7534E-01	41	1.4746E+00	1.4326E+00	70	1.0509E+00	1.0791E+00	98	4.4362E-01	3.8658E-01
13	2.7543E-01	3.1731E-01	42	1.4326E+00	1.3828E+00	71	1.0849E+00	1.1429E+00	99	3.8648E-01	3.3659E-01
14	3.1741E-01	3.6514E-01	43	1.3828E+00	1.3213E+00	72	1.1431E+00	1.1798E+00	100	3.3640E-01	2.9282E-01
15	3.6525E-01	4.1971E-01	44	1.3212E+00	1.2325E+00	73	1.1798E+00	1.2071E+00	101	2.9273E-01	2.5447E-01
16	4.1984E-01	4.8206E-01	45	1.2254E+00	1.1857E+00	74	1.2071E+00	1.2284E+00	102	2.5439E-01	2.2081E-01
17	4.8220E-01	5.5336E-01	46	1.1851E+00	1.1648E+00	75	1.2284E+00	1.2447E+00	103	2.2074E-01	1.9123E-01
18	5.5352E-01	6.3514E-01	47	1.1646E+00	1.1604E+00	76	1.2447E+00	1.2562E+00	104	1.9117E-01	1.6517E-01
19	6.3532E-01	7.3008E-01	48	1.1606E+00	1.1726E+00	77	1.2562E+00	1.2631E+00	105	1.6512E-01	1.4215E-01
20	7.3024E-01	8.4685E-01	49	1.1730E+00	1.2041E+00	78	1.2631E+00	1.2652E+00	106	1.4211E-01	1.2176E-01
21	8.5162E-01	9.5035E-01	50	1.2113E+00	1.2811E+00	79	1.2652E+00	1.2626E+00	107	1.2172E-01	1.0360E-01
22	9.5037E-01	1.0376E+00	51	1.2812E+00	1.3234E+00	80	1.2626E+00	1.2552E+00	108	1.0356E-01	8.7353E-02
23	1.0376E+00	1.1178E+00	52	1.3234E+00	1.3540E+00	81	1.2552E+00	1.2432E+00	109	8.7320E-02	7.2711E-02
24	1.1178E+00	1.1919E+00	53	1.3540E+00	1.3769E+00	82	1.2432E+00	1.2269E+00	110	7.2681E-02	5.9405E-02
25	1.1919E+00	1.2601E+00	54	1.3769E+00	1.3929E+00	83	1.2269E+00	1.2051E+00	111	5.9378E-02	4.7184E-02
26	1.2600E+00	1.3221E+00	55	1.3929E+00	1.4022E+00	84	1.2051E+00	1.1792E+00	112	4.7160E-02	3.5787E-02
27	1.3221E+00	1.3779E+00	56	1.4022E+00	1.4049E+00	85	1.1793E+00	1.1489E+00	113	3.5769E-02	2.4775E-02
28	1.3779E+00	1.4272E+00	57	1.4049E+00	1.4008E+00	86	1.1489E+00	1.1141E+00	114	2.4769E-02	1.2587E-02
29	1.4272E+00	1.4698E+00	58	1.4008E+00	1.3901E+00						

PROBLEM 16-A1 SCALAR FLUX (GROUP 2 AT T= 1.00E-01 SEC)

1	4.8411E-03	1.2253E-02	30	2.2365E-01	2.2774E-01	59	2.0339E-01	2.0272E-01	87	1.7216E-01	1.6812E-01
2	1.2211E-02	1.8847E-02	31	2.2773E-01	2.3105E-01	60	2.0272E-01	1.9901E-01	88	1.6813E-01	1.6392E-01
3	1.8851E-02	2.5642E-02	32	2.3105E-01	2.3352E-01	61	1.9901E-01	1.9425E-01	89	1.6393E-01	1.5967E-01
4	2.5646E-02	3.2687E-02	33	2.3352E-01	2.3508E-01	62	1.9425E-01	1.8846E-01	90	1.5968E-01	1.5554E-01
5	3.2691E-02	4.0069E-02	34	2.3508E-01	2.3569E-01	63	1.8846E-01	1.8163E-01	91	1.5556E-01	1.5173E-01
6	4.0073E-02	4.7866E-02	35	2.3568E-01	2.3530E-01	64	1.8164E-01	1.7375E-01	92	1.5175E-01	1.4850E-01
7	4.7869E-02	5.6146E-02	36	2.3530E-01	2.3389E-01	65	1.7382E-01	1.6364E-01	93	1.4852E-01	1.4618E-01
8	5.6149E-02	6.4970E-02	37	2.3389E-01	2.3144E-01	66	1.6429E-01	1.5862E-01	94	1.4617E-01	1.4607E-01
9	6.4972E-02	7.4380E-02	38	2.3144E-01	2.2793E-01	67	1.5861E-01	1.5644E-01	95	1.4714E-01	1.4550E-01
10	7.4381E-02	8.4402E-02	39	2.2793E-01	2.2337E-01	68	1.5644E-01	1.5596E-01	96	1.4550E-01	1.3976E-01
11	8.4401E-02	9.5031E-02	40	2.2337E-01	2.1774E-01	69	1.5596E-01	1.5716E-01	97	1.3981E-01	1.3212E-01
12	9.5028E-02	1.0623E-01	41	2.1774E-01	2.1103E-01	70	1.5717E-01	1.6052E-01	98	1.3215E-01	1.2328E-01
13	1.0622E-01	1.1791E-01	42	2.1103E-01	2.0324E-01	71	1.6113E-01	1.6826E-01	99	1.2330E-01	1.1382E-01
14	1.1790E-01	1.2991E-01	43	2.0325E-01	1.9433E-01	72	1.6821E-01	1.7337E-01	100	1.1383E-01	1.0413E-01
15	1.2990E-01	1.4200E-01	44	1.9441E-01	1.8301E-01	73	1.7337E-01	1.7770E-01	101	1.0414E-01	9.4514E-02
16	1.4198E-01	1.5382E-01	45	1.8226E-01	1.7731E-01	74	1.7770E-01	1.8127E-01	102	9.4521E-02	8.5156E-02
17	1.5379E-01	1.6485E-01	46	1.7729E-01	1.7477E-01	75	1.8127E-01	1.8411E-01	103	8.5160E-02	7.6181E-02
18	1.6481E-01	1.7441E-01	47	1.7477E-01	1.7412E-01	76	1.8411E-01	1.8622E-01	104	7.6184E-02	6.7662E-02
19	1.7435E-01	1.8152E-01	48	1.7413E-01	1.7535E-01	77	1.8622E-01	1.8762E-01	105	6.7663E-02	5.9690E-02
20	1.8152E-01	1.8356E-01	49	1.7537E-01	1.7899E-01	78	1.8762E-01	1.8832E-01	106	5.9629E-02	5.2087E-02
21	1.8216E-01	1.8255E-01	50	1.7974E-01	1.8825E-01	79	1.8832E-01	1.8835E-01	107	5.2085E-02	4.5014E-02
22	1.8256E-01	1.8606E-01	51	1.8817E-01	1.9417E-01	80	1.8835E-01	1.8772E-01	108	4.5012E-02	3.8376E-02
23	1.8603E-01	1.9078E-01	52	1.9417E-01	1.9902E-01	81	1.8772E-01	1.8646E-01	109	3.8374E-02	3.2126E-02
24	1.9076E-01	1.9625E-01	53	1.9902E-01	2.0278E-01	82	1.8646E-01	1.8460E-01	110	3.2123E-02	2.6209E-02
25	1.9623E-01	2.0206E-01	54	2.0278E-01	2.0544E-01	83	1.8460E-01	1.8218E-01	111	2.6205E-02	2.0560E-02
26	2.0205E-01	2.0794E-01	55	2.0544E-01	2.0703E-01	84	1.8219E-01	1.7926E-01	112	2.0557E-02	1.5113E-02
27	2.0792E-01	2.1362E-01	56	2.0703E-01	2.0755E-01	85	1.7927E-01	1.7589E-01	113	1.5110E-02	9.7895E-03
28	2.1360E-01	2.1891E-01	57	2.0755E-01	2.0700E-01	86	1.7590E-01	1.7215E-01	114	9.8229E-03	3.8811E-03
29	2.1890E-01	2.2366E-01	58	2.0700E-01	2.0539E-01						

EXHIBIT C (Continued)

PROBLEM 16-A1 SCALAR FLUX (GROUP 1) WITHIN SET

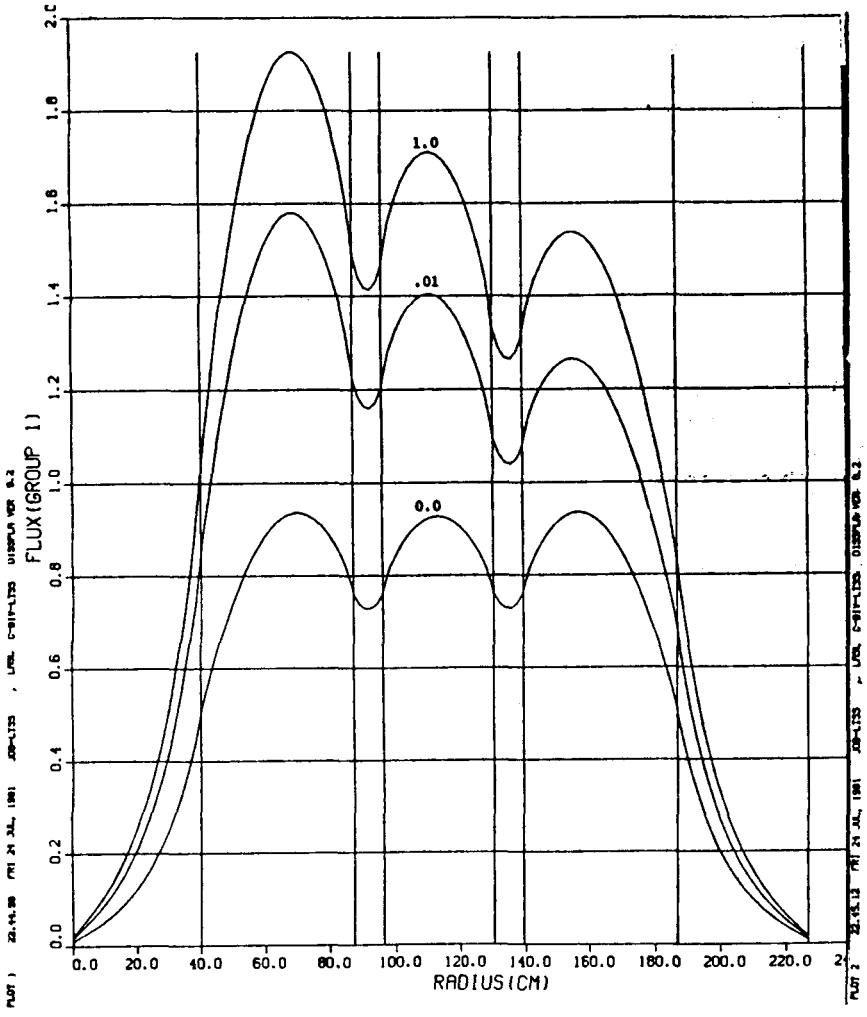
1	1.9142E-02	3.7663E-02	30	1.7920E+00	1.8357E+00	59	1.8928E+00	1.8671E+00	87	1.8950E+00	1.9074E+00	
2	3.7678E-02	5.4392E-02	31	1.8357E+00	1.8709E+00	60	1.8671E+00	1.8423E+00	88	1.9075E+00	1.9249E+00	
3	5.4425E-02	7.1721E-02	32	1.8709E+00	1.8976E+00	61	1.8424E+00	1.8053E+00	89	1.9249E+00	1.9174E+00	
4	7.1759E-02	9.0303E-02	33	1.8976E+00	1.9155E+00	62	1.8053E+00	1.7602E+00	90	1.9174E+00	1.9350E+00	
5	9.0345E-02	1.1054E-01	34	1.9155E+00	1.9247E+00	63	1.7602E+00	1.7063E+00	91	1.9350E+00	1.8679E+00	
6	1.1058E-01	1.3280E-01	35	1.9247E+00	1.9252E+00	64	1.7063E+00	1.6394E+00	92	1.8679E+00	9.9586E-01	
7	1.3285E-01	1.5751E-01	36	1.9252E+00	1.9168E+00	65	1.6393E+00	1.5620E+00	93	9.9586E-01	9.1783E-01	
8	1.5756E-01	1.8511E-01	37	1.9169E+00	1.8998E+00	66	1.5341E+00	1.4912E+00	94	9.1777E-01	8.3003E-01	
9	1.8517E-01	2.1612E-01	38	1.8998E+00	1.8741E+00	67	1.4907E+00	1.4268E+00	95	8.2560E-01	7.1192E-01	
10	2.1620E-01	2.5112E-01	39	1.8741E+00	1.8399E+00	68	1.4268E+00	1.3647E+00	96	7.1177E-01	6.1938E-01	
11	2.5120E-01	2.9074E-01	40	1.8399E+00	1.7972E+00	69	1.3648E+00	1.2784E+00	97	6.1921E-01	5.3964E-01	
12	2.9083E-01	3.3572E-01	41	1.7973E+00	1.7460E+00	70	1.2789E+00	1.3132E+00	98	5.3948E-01	4.7011E-01	
13	3.3582E-01	3.8689E-01	42	1.7460E+00	1.6852E+00	71	1.3202E+00	1.3907E+00	99	4.6996E-01	4.0931E-01	
14	3.8701E-01	4.4521E-01	43	1.6852E+00	1.6102E+00	72	1.3910E+00	1.4355E+00	100	4.0919E-01	3.5609E-01	
15	4.4535E-01	5.1175E-01	44	1.6101E+00	1.5019E+00	73	1.4356E+00	1.4686E+00	101	3.5598E-01	3.0943E-01	
16	5.1191E-01	5.8776E-01	45	1.4933E+00	1.4447E+00	74	1.4687E+00	1.4945E+00	102	3.0935E-01	2.6852E-01	
17	5.8794E-01	6.7470E-01	46	1.4441E+00	1.4192E+00	75	1.4945E+00	1.5143E+00	103	2.6844E-01	2.3234E-01	
18	6.7490E-01	7.7442E-01	47	1.4190E+00	1.4139E+00	76	1.5143E+00	1.5282E+00	104	2.3247E-01	2.0086E-01	
19	7.7464E-01	8.9018E-01	48	1.4141E+00	1.4287E+00	77	1.5282E+00	1.5365E+00	105	2.0079E-01	1.7287E-01	
20	8.9037E-01	1.0326E+00	49	1.4292E+00	1.4671E+00	78	1.5365E+00	1.5390E+00	106	1.7281E-01	1.4806E-01	
21	1.0384E+00	1.1987E+00	50	1.4758E+00	1.5607E+00	79	1.5390E+00	1.5358E+00	107	1.4801E-01	1.2599E-01	
22	1.1988E+00	1.2652E+00	51	1.5608E+00	1.6121E+00	80	1.5358E+00	1.5268E+00	108	1.2594E-01	1.0623E-01	
23	1.2651E+00	1.3629E+00	52	1.6121E+00	1.6493E+00	81	1.5268E+00	1.5121E+00	109	1.0619E-01	8.8420E-02	
24	1.3629E+00	1.4533E+00	53	1.6493E+00	1.6771E+00	82	1.5121E+00	1.4917E+00	110	8.8384E-02	7.2240E-02	
25	1.4532E+00	1.5364E+00	54	1.6771E+00	1.6965E+00	83	1.4917E+00	1.4657E+00	111	7.2206E-02	5.7379E-02	
26	1.5363E+00	1.6120E+00	55	1.6965E+00	1.7078E+00	84	1.4657E+00	1.4342E+00	112	5.7348E-02	4.3518E-02	
27	1.6120E+00	1.6800E+00	56	1.7078E+00	1.7109E+00	85	1.4342E+00	1.3972E+00	113	4.3492E-02	3.0127E-02	
28	1.6799E+00	1.7401E+00	57	1.7109E+00	1.7059E+00	86	1.3973E+00	1.3549E+00	114	3.0116E-02	1.9306E-02	
29	1.7400E+00	1.7920E+00	58	1.7059E+00	1.6927E+00	87						

PROBLEM 16-A1 SCALAR FLUX (GROUP 2) WITHIN SET

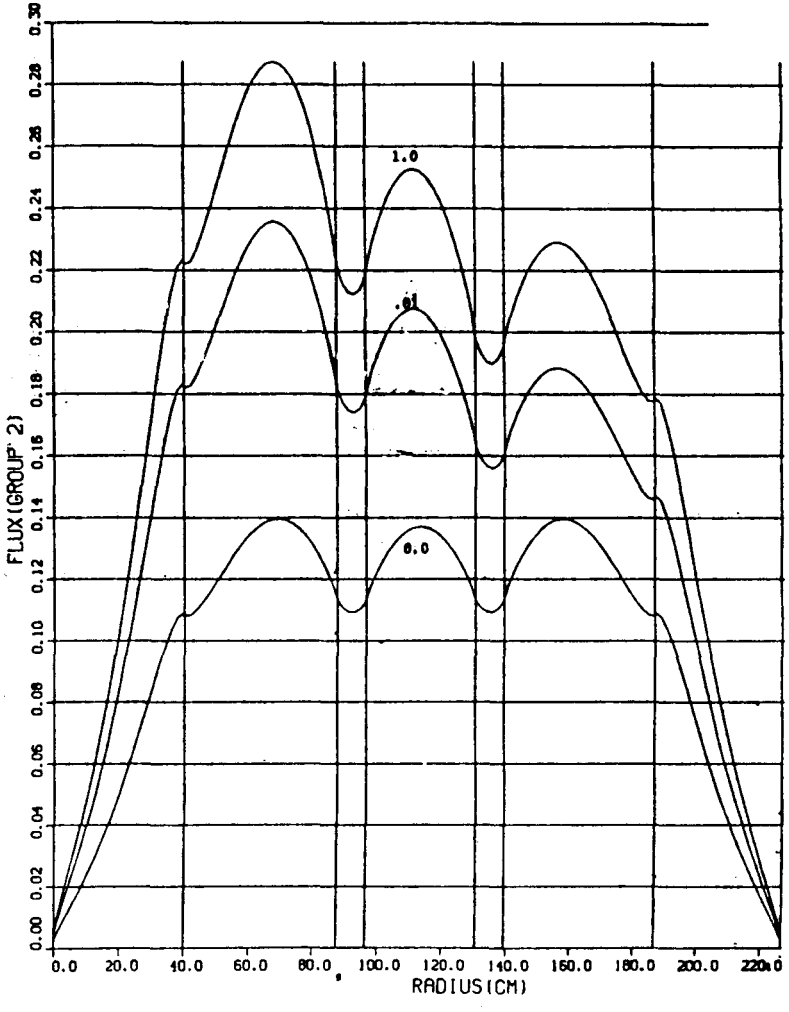
1	5.9027E-03	1.4939E-02	30	2.7266E-01	2.7764E-01	59	2.6010E-01	2.6694E-01	87	2.6938E-01	2.0447E-01	
2	1.4889E-02	2.2980E-02	31	2.7764E-01	2.8168E-01	60	2.6684E-01	2.6230E-01	88	2.0448E-01	1.9935E-01	
3	2.2985E-02	3.1265E-02	32	2.8167E-01	2.8468E-01	61	2.6230E-01	2.5650E-01	89	1.9936E-01	1.9418E-01	
4	3.1270E-02	3.9856E-02	33	2.8468E-01	2.8658E-01	62	2.5650E-01	2.4944E-01	90	1.9420E-01	1.8916E-01	
5	3.9860E-02	4.8856E-02	34	2.8658E-01	2.8731E-01	63	2.4944E-01	2.4112E-01	91	1.8918E-01	1.8453E-01	
6	4.8860E-02	5.8362E-02	35	2.8731E-01	2.8683E-01	64	2.4112E-01	2.3150E-01	92	1.8459E-01	1.8059E-01	
7	5.8366E-02	6.8459E-02	36	2.8683E-01	2.8510E-01	65	2.3150E-01	2.2058E-01	93	1.8062E-01	1.7777E-01	
8	6.8462E-02	7.9217E-02	37	2.8510E-01	2.8211E-01	66	2.1838E-01	2.0306E-01	94	1.7776E-01	1.7784E-01	
9	7.9219E-02	9.0691E-02	38	2.8211E-01	2.7783E-01	67	2.0304E-01	1.9041E-01	95	1.7803E-01	1.7809E-01	
10	9.0692E-02	1.0291E-01	39	2.7783E-01	2.7225E-01	68	1.9040E-01	1.8981E-01	96	1.7695E-01	1.6996E-01	
11	1.0291E-01	1.1587E-01	40	2.7225E-01	2.6538E-01	69	1.8981E-01	1.9126E-01	97	1.7002E-01	1.6087E-01	
12	1.1587E-01	1.2952E-01	41	2.6538E-01	2.5719E-01	70	1.9128E-01	1.9534E-01	98	1.6071E-01	1.4992E-01	
13	1.2952E-01	1.4376E-01	42	2.5719E-01	2.4769E-01	71	1.9609E-01	2.0475E-01	99	1.4995E-01	1.3841E-01	
14	1.4375E-01	1.5840E-01	43	2.4769E-01	2.3682E-01	72	2.0469E-01	2.1096E-01	100	1.3843E-01	1.2663E-01	
15	1.5838E-01	1.7314E-01	44	2.3691E-01	2.2301E-01	73	2.1095E-01	2.1621E-01	101	1.2665E-01	1.1494E-01	
16	1.7311E-01	1.8755E-01	45	2.2210E-01	2.1605E-01	74	2.1621E-01	2.2055E-01	102	1.1495E-01	1.0356E-01	
17	1.8751E-01	2.0100E-01	46	2.1603E-01	2.1295E-01	75	2.2055E-01	2.2399E-01	103	1.0356E-01	9.2642E-02	
18	2.0095E-01	2.1265E-01	47	2.1295E-01	2.1216E-01	76	2.2399E-01	2.2655E-01	104	9.2649E-02	8.2282E-02	
19	2.1259E-01	2.2132E-01	48	2.1216E-01	2.1365E-01	77	2.2655E-01	2.2824E-01	105	8.2283E-02	7.2514E-02	
20	2.2132E-01	2.2381E-01	49	2.1367E-01	2.1807E-01	78	2.2825E-01	2.2909E-01	106	7.2513E-02	6.3341E-02	
21	2.2211E-01	2.2257E-01	50	2.1898E-01	2.2934E-01	79	2.2909E-01	2.2911E-01	107	6.3339E-02	5.4740E-02	
22	2.2259E-01	2.2686E-01	51	2.2925E-01	2.3654E-01	80	2.2912E-01	2.2834E-01	108	5.4738E-02	4.6688E-02	
23	2.2682E-01	2.3261E-01	52	2.3653E-01	2.4243E-01	81	2.2834E-01	2.2680E-01	109	4.6665E-02	3.9068E-02	
24	2.3258E-01	2.3927E-01	53	2.4243E-01	2.4699E-01	82	2.2680E-01	2.2453E-01	110	3.9064E-02	3.1871E-02	
25	2.3924E-01	2.4636E-01	54	2.4699E-01	2.5023E-01	83	2.2454E-01	2.2159E-01	111	3.1868E-02	2.5003E-02	
26	2.4634E-01	2.5352E-01	55	2.5023E-01	2.5215E-01	84	2.2160E-01	2.1803E-01	112	2.4999E-02	1.8378E-02	
27	2.5350E-01	2.6044E-01	56	2.5215E-01	2.5276E-01	85	2.1804E-01	2.1393E-01	113	1.8374E-02	1.1909E-02	
28	2.6043E-01	2.6689E-01	57	2.5276E-01	2.5208E-01	86	2.1394E-01	2.0937E-01	114	1.1945E-02	4.7197E-03	
29	2.6688E-01	2.7267E-01	58	2.5208E-01	2.5010E-01							

EXHIBIT D

PROB 1 FLUX (T=0,.01,1.0 S)



PROB 1 FLUX (T=0,.01,1.0 ST



BENCHMARK PROBLEM SOLUTION

Identification: 16-A1-2 Benchmark Problem ID.16-A1

Date Submitted: November 1981 By: W. W. Engle, Jr. (ORNL)

By: R. M. Westfall (ORNL)
C. E. Lee (Consult.)

Date Accepted: October 1985

Descriptive Title: Multigroup Discrete Ordinates Solution with TDA

Mathematical Model: Multigroup energy approximation, discrete ordinates angular approximation, weighted difference spatial and time approximation with automatic coarse mesh rebalance.

Pertinent Features of Technique Used: S4 angular quadrature, suggested 114 interval spatial mesh, 6 delayed neutron groups, and the following time mesh:

Time (sec)	delta-t (sec)
0 to 10-4	1 x 10-6
10-4 to 10-1	5 x 10-6
10-1 to 1	5 x 10-5

Computer: IBM 370/3033

Codes: ANISN , TDA (single precision, 6 decimal digits accuracy)

Date solved: August 1981 at Oak Ridge National Laboratory

References:

1. W. W. Engle, Jr. et.al., "One Dimensional Time Dependent Discrete Ordinates," Trans. Am. Nucl. Soc., 12, p 400 (1969)

2. E. T. Tomlinson, W. A. Rhoades and W. W. Engle, Jr., "Flux Extrapolation Models Used in the DOT IV Discrete Ordinates Neutron Transport Code," ORNL/TM-7033 (May 1980). (see p.15, The Theta-Weighted Model)

3. W. W. Engle, Jr., "A Users Manual for ANISN," K-1693 (March 1967).

Primary Results:
k-eff calculated by ANISN for the initial condition constants of Table I: 1.00000

Exhibit A: Total power vs. time (relative to an initial total neutron production rate of 1.0) for the reference time step (delta-t) and for two and ten times the reference time step.

Exhibit B: Plot of total power vs. time for the reference time step size.

Exhibit C: Average interval scalar flux vs. position at t=0, 0.01, and 1.0 sec.

Exhibit D: Plot of data in Exhibit C.

Exhibit A

Power vs. Time

t (sec)	power(delta-t)	power(2*delta-t)	power(10*delta-t)
0	1.0		
1 x 10-5	1.0221	1.0209	
2	1.0476		
4	1.0938		
8	1.1787		
1 x 10-4	1.2130	1.2055	1.2023
2	1.3282		
4	1.4362		
8	1.4929		
1 x 10-3	1.5003	1.5022	1.4948
2	1.5041		
4	1.5055		
8	1.5087		
1 x 10-2	1.5089	1.5080	1.5089
2	1.5120		
4	1.5149		
8	1.5192		
1 x 10-1	1.5215	1.5320	1.5432
2	1.5535		
4	1.6129		
8	1.7195		
1.0	1.7710	1.8170	1.8300
CPU time (min)	117.2	58.6	12.0

Exhibit B

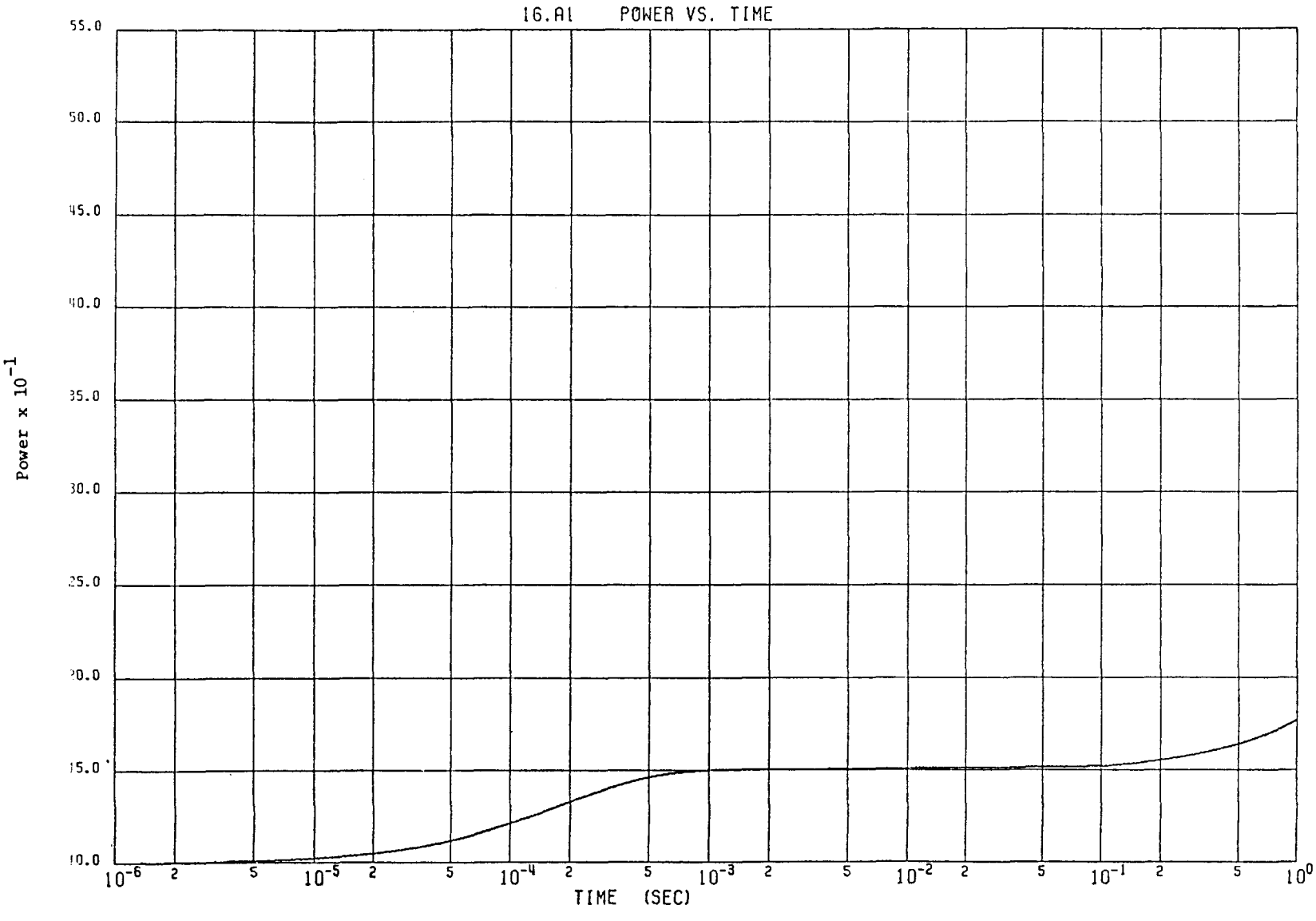

16.A1 POWER VS. TIME
Power x 10^{-1}
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
10^{-6} 2 5 10^{-5} 2 5 10^{-4} 2 5 10^{-3} 2 5 10^{-2} 2 5 10^{-1} 2 5 10^{0}
TIME (SEC)

Exhibit C

Problem 16-A1 Scalar Flux

T=0 SEC.

INT.	GRP. 1	GRP. 2	INT.	GRP. 1	GRP. 2
1	1.37294E-02	5.04370E-03	58	9.26557E-01	1.36850E-01
2	2.24807E-02	9.27842E-03	59	9.22127E-01	1.36145E-01
3	3.07236E-02	1.32175E-02	60	9.13237E-01	1.34735E-01
4	3.94552E-02	1.73451E-02	61	9.00066E-01	1.32620E-01
5	4.89082E-02	2.16354E-02	62	8.82482E-01	1.29802E-01
6	5.92630E-02	2.61520E-02	63	8.60312E-01	1.26261E-01
7	7.07110E-02	3.09363E-02	64	8.32039E-01	1.22106E-01
8	8.34630E-02	3.60272E-02	65	7.89319E-01	1.16604E-01
9	9.77575E-02	4.14549E-02	66	7.51030E-01	1.11915E-01
10	1.13856E-01	4.72395E-02	67	7.34302E-01	1.09959E-01
11	1.32059E-01	5.33868E-02	68	7.29226E-01	1.09412E-01
12	1.52702E-01	5.98834E-02	69	7.34727E-01	1.10046E-01
13	1.76169E-01	6.66903E-02	70	7.51900E-01	1.12090E-01
14	2.02896E-01	7.37136E-02	71	7.89374E-01	1.16728E-01
15	2.33361E-01	8.08932E-02	72	8.31019E-01	1.22133E-01
16	2.68192E-01	8.79868E-02	73	8.59347E-01	1.26308E-01
17	3.07960E-01	9.47570E-02	74	8.81912E-01	1.29951E-01
18	3.53514E-01	1.00811E-01	75	9.00340E-01	1.32987E-01
19	4.05937E-01	1.05781E-01	76	9.14931E-01	1.35433E-01
20	4.69663E-01	1.08265E-01	77	9.25720E-01	1.37294E-01
21	5.33752E-01	1.08441E-01	78	9.32671E-01	1.38579E-01
22	5.87045E-01	1.09316E-01	79	9.35745E-01	1.39297E-01
23	6.34699E-01	1.11592E-01	80	9.34940E-01	1.39461E-01
24	6.78734E-01	1.14371E-01	81	9.30244E-01	1.39087E-01
25	7.19525E-01	1.17494E-01	82	9.21667E-01	1.38195E-01
26	7.57069E-01	1.20763E-01	83	9.09246E-01	1.36813E-01
27	7.91286E-01	1.24030E-01	84	8.93017E-01	1.34972E-01
28	8.22063E-01	1.27173E-01	85	8.73030E-01	1.32716E-01
29	8.49356E-01	1.30095E-01	86	8.49362E-01	1.30095E-01
30	8.73024E-01	1.32716E-01	87	8.22086E-01	1.27174E-01
31	8.93011E-01	1.34972E-01	88	7.91291E-01	1.24030E-01
32	9.09240E-01	1.36812E-01	89	7.57074E-01	1.20763E-01
33	9.21660E-01	1.38195E-01	90	7.19530E-01	1.17494E-01
34	9.30238E-01	1.39086E-01	91	6.78739E-01	1.14372E-01
35	9.34932E-01	1.39460E-01	92	6.34703E-01	1.11593E-01
36	9.35737E-01	1.39296E-01	93	5.87049E-01	1.09317E-01
37	9.32663E-01	1.38579E-01	94	5.33755E-01	1.08442E-01
38	9.25713E-01	1.37293E-01	95	4.69666E-01	1.08266E-01
39	9.14924E-01	1.35432E-01	96	4.05940E-01	1.05782E-01
40	9.00334E-01	1.32985E-01	97	3.53516E-01	1.00812E-01
41	8.81906E-01	1.29950E-01	98	3.07982E-01	9.47580E-02
42	8.59342E-01	1.26307E-01	99	2.68194E-01	8.79878E-02
43	8.31015E-01	1.22132E-01	100	2.33383E-01	8.08942E-02
44	7.89371E-01	1.16727E-01	101	2.02898E-01	7.37348E-02
45	7.51898E-01	1.12090E-01	102	1.76170E-01	6.66913E-02
46	7.34727E-01	1.10045E-01	103	1.52703E-01	5.98845E-02
47	7.29254E-01	1.09411E-01	104	1.32060E-01	5.33877E-02
48	7.34303E-01	1.09959E-01	105	1.13357E-01	4.72404E-02
49	7.51630E-01	1.11914E-01	106	9.77535E-02	4.14557E-02
50	7.89319E-01	1.16603E-01	107	8.34649E-02	3.60280E-02
51	8.32039E-01	1.22105E-01	108	7.07119E-02	3.09371E-02
52	8.60310E-01	1.26260E-01	109	5.92637E-02	2.61526E-02
53	8.82481E-01	1.29801E-01	110	4.89099E-02	2.16360E-02
54	9.00066E-01	1.32619E-01	111	3.94553E-02	1.73456E-02
55	9.13286E-01	1.34735E-01	112	3.07240E-02	1.32179E-02
56	9.22127E-01	1.36144E-01	113	2.24811E-02	9.27871E-03
57	9.26557E-01	1.36850E-01	114	1.37296E-02	5.04387E-03

Exhibit C (Con't)

PROBLEM 16-A1 SCALAR FLUX

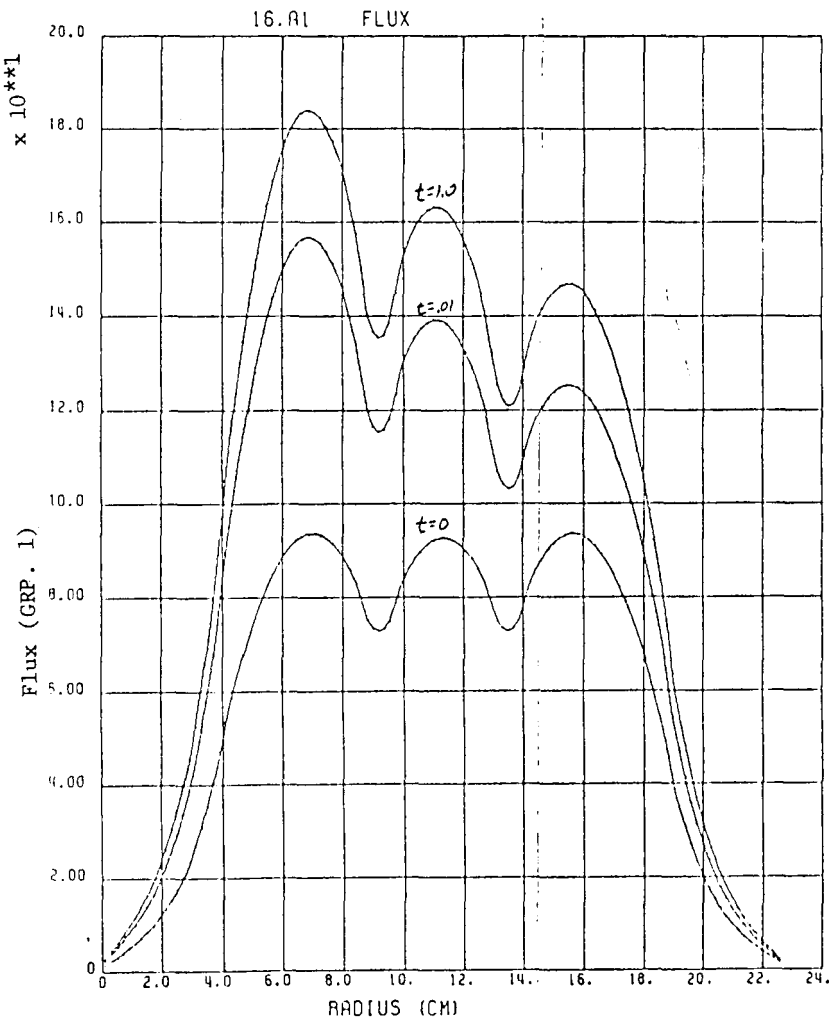
T=0.01 SEC.

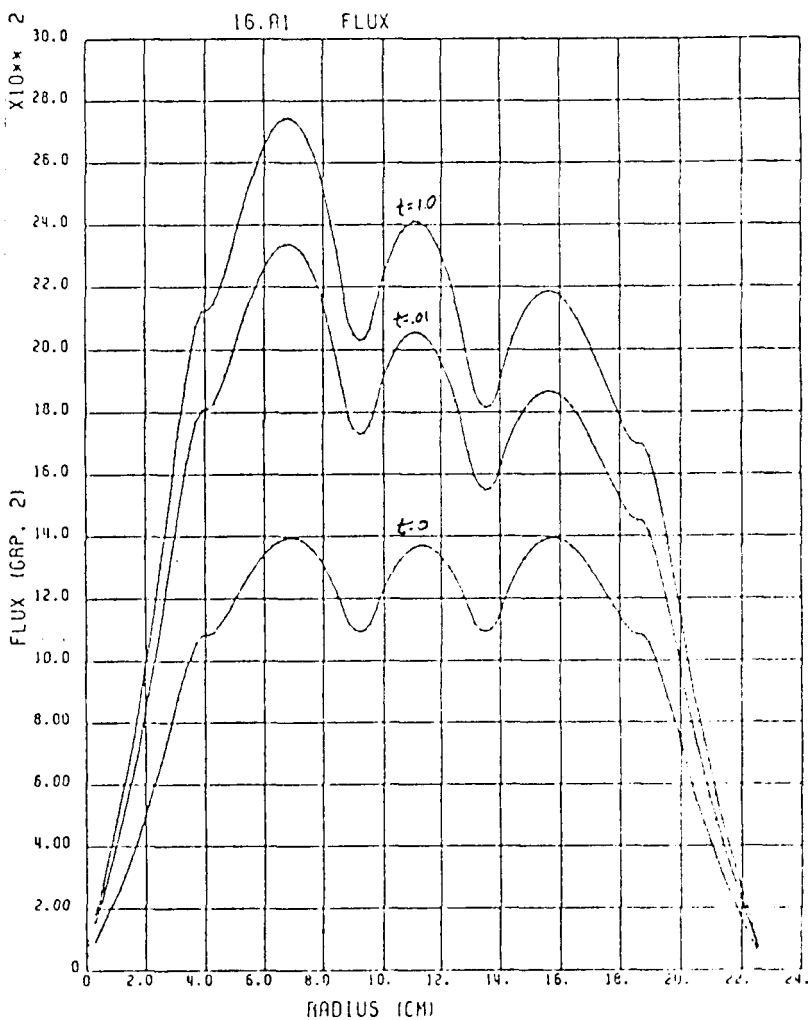
INT.	GRP. 1	GRP. 2	INT.	GRP. 1	GRP. 2
1	2.29398E-02	8.42790E-03	58	1.38374E 00	2.04445E-01
2	3.75620E-02	1.55042E-02	59	1.36978E 00	2.02316E-01
3	5.13347E-02	2.20965E-02	60	1.34930E 00	1.99145E-01
4	6.59242E-02	2.89838E-02	61	1.32238E 00	1.94938E-01
5	8.17195E-02	3.61530E-02	62	1.28997E 00	1.89703E-01
6	9.90216E-02	4.37005E-02	63	1.24911E 00	1.83420E-01
7	1.18151E-01	5.16955E-02	64	1.20030E 00	1.76248E-01
8	1.39461E-01	6.02328E-02	65	1.13106E 00	1.67151E-01
9	1.63346E-01	6.93731E-02	66	1.07050E 00	1.59570E-01
10	1.90246E-01	7.89402E-02	67	1.04310E 00	1.56246E-01
11	2.20665E-01	8.92139E-02	68	1.03229E 00	1.54928E-01
12	2.55162E-01	1.00072E-01	69	1.03645E 00	1.55283E-01
13	2.94379E-01	1.11450E-01	70	1.05702E 00	1.57626E-01
14	3.39044E-01	1.23223E-01	71	1.10273E 00	1.63146E-01
15	3.89989E-01	1.35191E-01	72	1.15185E 00	1.69363E-01
16	4.48165E-01	1.47050E-01	73	1.18336E 00	1.73958E-01
17	5.14659E-01	1.58360E-01	74	1.20716E 00	1.77879E-01
18	5.90757E-01	1.68492E-01	75	1.22565E 00	1.81054E-01
19	6.78369E-01	1.76905E-01	76	1.23939E 00	1.83503E-01
20	7.84863E-01	1.83966E-01	77	1.24846E 00	1.85240E-01
21	8.94181E-01	1.81308E-01	78	1.25288E 00	1.86279E-01
22	9.87227E-01	1.82976E-01	79	1.25262E 00	1.86637E-01
23	1.07019E 00	1.87111E-01	80	1.24768E 00	1.86333E-01
24	1.14667E 00	1.92110E-01	81	1.23807E 00	1.85393E-01
25	1.21722E 00	1.97696E-01	82	1.22381E 00	1.83845E-01
26	1.28181E 00	2.03472E-01	83	1.20495E 00	1.81726E-01
27	1.34025E 00	2.09194E-01	84	1.18155E 00	1.79080E-01
28	1.39237E 00	2.14633E-01	85	1.15367E 00	1.75962E-01
29	1.43797E 00	2.19612E-01	86	1.12140E 00	1.72438E-01
30	1.47690E 00	2.23992E-01	87	1.08484E 00	1.68588E-01
31	1.50902E 00	2.27660E-01	88	1.04409E 00	1.64513E-01
32	1.53419E 00	2.30527E-01	89	9.99258E-01	1.60332E-01
33	1.55234E 00	2.32524E-01	90	9.50455E-01	1.56195E-01
34	1.56334E 00	2.33595E-01	91	8.97760E-01	1.52282E-01
35	1.56731E 00	2.33690E-01	92	8.41133E-01	1.48824E-01
36	1.56409E 00	2.32801E-01	93	7.80940E-01	1.46023E-01
37	1.55375E 00	2.30682E-01	94	7.11967E-01	1.44999E-01
38	1.53635E 00	2.27922E-01	95	6.28052E-01	1.44738E-01
39	1.51197E 00	2.23911E-01	96	5.42835E-01	1.41462E-01
40	1.48072E 00	2.13842E-01	97	4.72729E-01	1.34814E-01
41	1.44263E 00	2.12711E-01	98	4.11036E-01	1.26716E-01
42	1.39755E 00	2.05491E-01	99	3.58628E-01	1.17661E-01
43	1.34247E 00	1.97338E-01	100	3.12077E-01	1.08173E-01
44	1.26519E 00	1.87104E-01	101	2.71311E-01	9.85901E-02
45	1.19763E 00	1.78569E-01	102	2.35569E-01	8.91786E-02
46	1.16650E 00	1.74743E-01	103	2.04183E-01	8.00756E-02
47	1.15394E 00	1.73162E-01	104	1.76584E-01	7.13879E-02
48	1.15810E 00	1.73451E-01	105	1.52243E-01	6.31673E-02
49	1.18061E 00	1.75957E-01	106	1.30716E-01	5.54323E-02
50	1.23444E 00	1.82386E-01	107	1.11603E-01	4.81744E-02
51	1.29263E 00	1.89720E-01	108	9.45497E-02	4.13670E-02
52	1.32826E 00	1.94949E-01	109	7.92419E-02	3.49694E-02
53	1.35440E 00	1.99233E-01	110	6.53960E-02	2.89299E-02
54	1.37352E 00	2.02409E-01	111	5.27562E-02	2.31931E-02
55	1.38600E 00	2.04513E-01	112	4.10809E-02	1.76739E-02
56	1.39187E 00	2.05549E-01	113	3.00593E-02	1.24067E-02
57	1.39111E 00	2.05524E-01	114	1.83577E-02	6.74419E-03

T=1.0 SEC.

INT.	GRP. 1	GRP. 2	INT.	GRP. 1	GRP. 2
1	2.69223E-02	9.89110E-03	58	1.62237E 00	2.39705E-01
2	4.40832E-02	1.81457E-02	59	1.60593E 00	2.37200E-01
3	6.02469E-02	2.59207E-02	60	1.58185E 00	2.33472E-01
4	7.73693E-02	3.40154E-02	61	1.55021E 00	2.28529E-01
5	9.59067E-02	4.24290E-02	62	1.51109E 00	2.22342E-01
6	1.16213E-01	5.12966E-02	63	1.46417E 00	2.15036E-01
7	1.38663E-01	6.06694E-02	64	1.40699E 00	2.06588E-01
8	1.63673E-01	7.06531E-02	65	1.32566E 00	1.95915E-01
9	1.91795E-01	8.12979E-02	66	1.25463E 00	1.87021E-01
10	2.23277E-01	9.26431E-02	67	1.22248E 00	1.83120E-01
11	2.58974E-01	1.04701E-01	68	1.20978E 00	1.81570E-01
12	2.99459E-01	1.17444E-01	69	1.21461E 00	1.81992E-01
13	3.45484E-01	1.30797E-01	70	1.23869E 00	1.84722E-01
14	3.97902E-01	1.44613E-01	71	1.29220E 00	1.91194E-01
15	4.57691E-01	1.58659E-01	72	1.34969E 00	1.98460E-01
16	5.25966E-01	1.72576E-01	73	1.38655E 00	2.03936E-01
17	6.04002E-01	1.85861E-01	74	1.41438E 00	2.08422E-01
18	6.93305E-01	1.97741E-01	75	1.43599E 00	2.12134E-01
19	7.96129E-01	2.07496E-01	76	1.45204E 00	2.14996E-01
20	9.21110E-01	2.12380E-01	77	1.46262E 00	2.17024E-01
21	1.04941E 00	2.12782E-01	78	1.46775E 00	2.18235E-01
22	1.15860E 00	2.14739E-01	79	1.46740E 00	2.18648E-01
23	1.25596E 00	2.19591E-01	80	1.46157E 00	2.18287E-01
24	1.34571E 00	2.25456E-01	81	1.45028E 00	2.17181E-01
25	1.42851E 00	2.31998E-01	82	1.43354E 00	2.15363E-01
26	1.50430E 00	2.38787E-01	83	1.41142E 00	2.12876E-01
27	1.57288E 00	2.45500E-01	84	1.38398E 00	2.09773E-01
28	1.63403E 00	2.51980E-01	85	1.35130E 00	2.06116E-01
29	1.68753E 00	2.57721E-01	86	1.31349E 00	2.01985E-01
30	1.73320E 00	2.62857E-01	87	1.27064E 00	1.97473E-01
31	1.77086E 00	2.67158E-01	88	1.22294E 00	1.92696E-01
32	1.80038E 00	2.70519E-01	89	1.17037E 00	1.87797E-01
33	1.82164E 00	2.72958E-01	90	1.11319E 00	1.82949E-01
34	1.83456E 00	2.74110E-01	91	1.05147E 00	1.78364E-01
35	1.83914E 00	2.74225E-01	92	9.85141E-01	1.74312E-01
36	1.83532E 00	2.73167E-01	93	9.13594E-01	1.71030E-01
37	1.82314E 00	2.70908E-01	94	8.33853E-01	1.69830E-01
38	1.80268E 00	2.67428E-01	95	7.35574E-01	1.69582E-01
39	1.77403E 00	2.62715E-01	96	6.35768E-01	1.65586E-01
40	1.73730E 00	2.56760E-01	97	5.53660E-01	1.57899E-01
41	1.69255E 00	2.49559E-01	98	4.92342E-01	1.48414E-01
42	1.63937E 00	2.41080E-01	99	4.20024E-01	1.37907E-01
43	1.57491E 00	2.31505E-01	100	3.65503E-01	1.26695E-01
44	1.48419E 00	2.19491E-01	101	3.17759E-01	1.15490E-01
45	1.40408E 00	2.09471E-01	102	2.75898E-01	1.04448E-01
46	1.36834E 00	2.04978E-01	103	2.39144E-01	9.37856E-02
47	1.35357E 00	2.03118E-01	104	2.06814E-01	8.36101E-02
48	1.35842E 00	2.03452E-01	105	1.78306E-01	7.39822E-02
49	1.38478E 00	2.06397E-01	106	1.53094E-01	6.49226E-02
50	1.44786E 00	2.13919E-01	107	1.30708E-01	5.64222E-02
51	1.51609E 00	2.22510E-01	108	1.10736E-01	4.84493E-02
52	1.55775E 00	2.28633E-01	109	9.28074E-02	4.09565E-02
53	1.58833E 00	2.33646E-01	110	7.65913E-02	3.38830E-02
54	1.61067E 00	2.37359E-01	111	6.17876E-02	2.71640E-02
55	1.62524E 00	2.39817E-01	112	4.81136E-02	2.06998E-02
56	1.63205E 00	2.41021E-01	113	3.52052E-02	1.45308E-02
57	1.63109E 00	2.40982E-01	114	2.15004E-02	7.89087E-03

Exhibit D


16.A1 FLUX
x 10**1
Flux (GRP. 1)
t=1.0
t=.01
t=0
RADIUS (CM)


16.A1 FLUX
X10** 2
FLUX (GRP. 2)
t=1.0
t=.01
t=0
RADIUS (CM)