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THREE GROUP NEUTRON DIFFUSION
CALCULATION (PROGRAM F₃ - IBM 704)

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REACTOR NUCLEAR ENGINEERING UNIT

May 27, 1958

GENERAL ELECTRIC-AIRCRAFT NUCLEAR PROPULSION DEPARTMENT-CINCINNATI 15, OHIO

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ABSTRACT OF REPORT NO. XDC 58-7-18TITLE: Three Group Neutron Diffusion Calculation (Program F₃ - IBM 704)AUTHOR AND ORIGINATING UNIT: J. G. Keppler, W. L. Orr, Reactor Nuclear
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Program F₃ provides an analysis of a three group, one-dimensional reactor in multi-region slab or cylindrical geometry. Input consists of a description of the geometry of the assembly, energy group constants defining the nuclear characteristics of each region, and control information specifying the type of calculation desired. The fission density and neutron flux, computed at each lattice point, are used to calculate the reactivity of the system.

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1. INTRODUCTION

Program F₃ solves the one-dimensional, three-group diffusion equations as difference equations

$$-\frac{1}{r^4} \frac{d}{dr} \left(r^4 D_1 \frac{d\phi_1}{dr} \right) + (\Sigma_{a1} + \Sigma_{s1} + D_1 K^2) \phi_1 = \frac{1}{k} (\Sigma_{f1} \phi_1 + \Sigma_{f2} \phi_2 + \Sigma_{f3} \phi_3)$$

$$-\frac{1}{r^4} \frac{d}{dr} \left(r^4 D_2 \frac{d\phi_2}{dr} \right) + (\Sigma_{a2} + \Sigma_{s2} + D_2 K^2) \phi_2 = \Sigma_{s1} \phi_1$$

and

$$-\frac{1}{r^4} \frac{d}{dr} \left(r^4 D_3 \frac{d\phi_3}{dr} \right) + (\Sigma_{a3} + D_3 K^2) \phi_3 = \Sigma_{s2} \phi_2$$

in multi-region slab or cylindrical geometry subject to albedo conditions at the outer boundaries. The coefficients of the equations are position dependent and the source terms are linear combinations of the flux. Fission density is improved with each iteration until a selected convergence criterion is met. The principal output consists of reactivity after each iteration and converged values of the fission density and flux at each lattice point. The program was written in the semi-automatic FORTRAN coding system, and the time required for coding and check out was less than 15 man-days. A complete listing of the equations used in the program as well as the source program itself are included.

2. GLOSSARY OF TERMS AND SYMBOLS

<u>Symbol</u>	<u>Program Notation</u>	<u>Definition</u>
A	AL	albedo
a	RECUR 1	recursion coefficient
B	BL	boundary coefficient
b	RECUR 2	recursion coefficient
C	CEE	source term
D	DIFM	diffusion coefficient
E	ZIP 1	solution of recursion equations
F	DENSM, DENSP	fission density
G	ZIP 2	solution of recursion equation
I	VALS	number of intervals in region
K^2	TRANS	perpendicular buckling
k	SUM	reactivity
Q	ABC	absorption parameter
r	RADR	radius of region
r	RADP	radius of point
V	CORE	core volume
W	WIDTH	interval width in region
β	BET	} geometrical constants
δ	DEL	
γ	GAM	
ϕ	FEE	flux
Σ_a	SIGA	absorption cross section
Σ_s	SIG	scattering out cross section
$\nu \Sigma_f$	SIGNU	multiplication cross section

Subscripts

i	group index, equal to 1, 2, or 3
p	lattice point
P	iteration index
r	region index

Superscripts

$\pm$	index indicating the side on which a discontinuous function is evaluated
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3. GENERAL DESCRIPTION OF F_3

The program proper was divided into eight logical sections for ease in programming and were written as follows:

- 1) Reception of input data and calculation of lattice points at each region.
- 2) Computation of geometrical constants for flux solution.
- 3) Calculation of recursion coefficients (these are flux independent).
- 4) Generation of source terms and fission density for three group flux calculation.
- 5) Calculation of flux and reactivity.
- 6) Convergence test and normalization of fission density for next iteration.
- 7) Normalization of flux and fission density after convergence.
- 8) Writing of input and calculated results.

The method used to solve the second order differential equations, subject to specification of the albedo at each boundary, may be broken down into the following two steps:

- A) Continuity of the flux and current are set up at an internal lattice point, noting that the coefficients of the generalized diffusion equation will be different on the right-hand side of the lattice point than on the left-hand side.
- B) A recursion relation of the flux ratios at each lethargy is established. In order to retain an arbitrary constant with which to satisfy the outer boundary condition, flux ratios are computed starting at the inner boundary. Upon reaching the outer boundary and applying the boundary condition, the flux is computed from outer boundary to inner boundary.

4. OPERATING INSTRUCTIONS AND INPUT

Program F₃ has been written for the IBM 704, and provisions have been made to use the production operator program (POP). Conventional use of sense switches and tapes has been employed. Sense switch 2 is down when decimal input is entered on cards; it is up when the input has been written on tape 2. Output is controlled by sense switch 3. If it is down, the output is written on the on-line printer; if it is up, the results are written on tape 3. Share board 2 must be used when the printer is selected.

There are five programmed stops incorporated into F₃. The stop numbers and the associated errors are listed below

<u>Stop Number</u>	<u>Diagnostic</u>
3460, 3470	the direction of calculation is incorrectly specified
3464, 3466, 3474	the number of groups specified is incorrect

334 007

For any other program stops, it is advised that the input be checked for missing format characters.

The input data for Program F₃ are limited to regional dimensions, energy group constants defining the nuclear characteristics of each region, and control words specifying the type of calculation desired. A maximum of 10 regions may be given, and the total number of intervals requested cannot exceed 150. The transverse buckling is to be entered as input. Albedo conditions are used at the boundaries, and at a boundary crossing no extra intervals can be requested. A reactivity convergence criterion is employed and the flux is normalized to the average fast flux in the core.

On the input forms appear a complete description of the meaning of each input symbol.

5. BIBLIOGRAPHY

- 5.1 IBM Corporation, Automatic Coding System for the IBM 704 EDPM, October 15, 1956.
- 5.2 Unpublished work by D. S. Selengut, who formulated the initial two-group equations.
- 5.3 Unpublished work by W. B. Henderson

6. APPENDIX

6.1 Equations Solved by F31) Radii of Regions and Lattice Points

$$r_n = r_{n-1} + I_n \cdot W_n, \quad 1 \leq n \leq 10$$

$$r_p = r_{p-1} + W_n, \quad 1 \leq p \leq 150$$

2) Geometric Coefficients

If N27 = 1,

$$B_p = \frac{r_{p+1} - r_p}{r_p - r_{p-1}}$$

$$\delta_p = \frac{(r_{p+1} - r_p)(r_p - r_{p-1})}{2}$$

$$\gamma_p = B_p \cdot \delta_p$$

If N27 = 2,

$$Y = \frac{r_p + r_{p+1}}{3r_p - r_{p+1}}$$

$$Z = \frac{r_p + r_{p-1}}{3r_p - r_{p-1}}$$

$$p = 1, \dots, N28-1$$

$$B_p = \frac{r_{p+1} - r_p}{r_p - r_{p-1}} \frac{1 + |Y|}{1 + |Z|}$$

$$\delta_p = .25 \left[\frac{r_{p+1} - r_p}{1 + |Z|} \right] [3r_p - r_{p-1}] - (r_p - r_{p-1}) |Y|$$

$$\gamma_p = .25 \left[\frac{r_{p+1} - r_p}{1 + \left| \frac{1}{Z} \right|} \right] (r_p + r_{p+1}) - (3r_p - r_{p+1}) \left| \frac{1}{Y} \right|$$

5) Fission Density

$$F_p^+ = V \sum_{i,p+1} \Phi_{i,p}$$

$$F_p^- = V \sum_{i,p} \Phi_{i,p}$$

$$i = 1, \dots, N26$$

$$p = 1, \dots, N28$$

6) Reactivity

If N27 = 1,

$$k = \sum (F_p^+ + F_{p+1}^-)(\rho_{p+1} - \rho_p) / 2$$

If N27 = 2,

$$k = \sum (\rho_p F_p^+ + \rho_{p+1} F_{p+1}^-)(\rho_{p+1} - \rho_p) / 2$$

$$p = 1, \dots, N28-1$$

7) Volume of Core

If N27 = 1,

$$V = \sum (F_p^+ / F_p^+ + F_{p+1}^- / F_{p+1}^-) \left(\frac{\rho_{p+1} - \rho_p}{2} \right)$$

If N27 = 2,

$$V = \sum \left(\frac{F_p^+ \rho_p}{F_p^+} + \frac{F_{p+1}^- \rho_{p+1}}{F_{p+1}^-} \right) \left(\frac{\rho_{p+1} - \rho_p}{2} \right)$$

$$p = 1, \dots, N28-1$$

3) Recursion Coefficients and Absorption Parameters

$$Q_{i,p} = \sum s_{i,p} + \sum a_{i,p} + D_{i,p} K^2$$

$$A_{i,p} = D_{i,p+1} + B_p D_{i,p} + \gamma_p Q_{i,p+1} + \delta_p Q_{i,p}$$

$$b_{i,p} = B_p D_{i,p}$$

$$i = 1, \dots, N26$$

$$p = 1, \dots, N28-1$$

4) Boundary Coefficients and Flux

$$E_{i,p} = 1 + \frac{(r_p - r_{p-1})(1 - A_i^-)}{2 D_{i,p}(1 + A_i^-)} \quad i = 1, \dots, N26$$

$$G_{i,p} = 0.00$$

$$p = 1$$

$$C_{1,p} = \gamma_p F_p^+ + \delta_p F_p^-$$

$$C_{2,p} = (\gamma_p \sum s_{1,p+1} + \delta_p \sum s_{1,p}) \Phi_{1,p} \quad p = 1, \dots, N28-1$$

$$C_{3,p} = (\gamma_p \sum s_{2,p+1} + \delta_p \sum s_{2,p}) \Phi_{2,p}$$

$$E_{i,p} = \frac{1}{D_{i,p}} \left(\frac{Q_{i,p-1} - b_{i,p-1}}{E_{i,p-1}} \right) \quad i = 1, \dots, N26$$

$$G_{i,p} = \frac{1}{D_{i,p}} \left(\frac{C_{i,p-1} + b_{i,p-1} G_{i,p-1}}{E_{i,p-1}} \right) \quad p = 2, \dots, N28$$

$$B_i = 1 + \frac{(r_{N28} - r_{N28-1})(1 - A_i^+)}{(2 D_{i,N28})(1 + A_i^+)}$$

$$\Phi_{i,N28} = \frac{G_{i,N28}}{B_i (E_{i,N28} - 1)}$$

$$i = 1, \dots, N26$$

$$\Phi_{i,p} = \frac{G_{i,p+1} + \Phi_{i,p+1}}{E_{i,p+1}}$$

$$i = 1, \dots, N26$$

$$p = N28-1, \dots, 0$$

8) Average Flux

If N27 = 1,

$$\bar{\Phi} = \sum \left(\frac{F_p^+ \Phi_{i,p}}{F_p^+} + \frac{F_{p+1}^- \Phi_{i,p+1}}{F_{p+1}^-} \right) \left(\frac{r_{p+1} - r_p}{2} \right)$$

If N27 = 2,

$$\bar{\Phi} = \sum \left(\frac{F_p^+ r_p \Phi_{i,p}}{F_p^+} + \frac{F_{p+1}^- r_{p+1} \Phi_{i,p+1}}{F_{p+1}^-} \right) \left(\frac{r_{p+1} - r_p}{2} \right)$$

9) Convergence

Reactivity,

$$|k_p - k_{p-1}| < .00001$$

If not converged,

$$F_p^+ = F_p^+ / k_p$$

$$F_p^- = F_p^- / k_p$$

If converged,

$$\bar{\Phi} = \bar{\Phi} / V$$

$$F_p^+ = V F_p^+ / k_p$$

$$F_p^- = V F_p^- / k_p$$

6.2 Sample Problem (Input & Output)

PROGRAM F-3

Programmed By: W. L. Orr and J. G. Keppler

	12	50
	Engineer	Identification
	J G KEPPLER	THREE GROUP

N20 XX	N26 X	N27 X	Buckling +X.XXXX±X
01	3	1	+1.0000-3

A ₁ +X.XXXX±X	A ₂ +X.XXXX±X	A ₃ +X.XXXX±X	A ₁ +X.XXXX±X	A ₂ +X.XXXX±X	A ₃ +X.XXXX±X

r ₀ +X.XXXX±X	I +X.XXXX±X	W +X.XXXX±X	I +X.XXXX±X	W +X.XXXX±X	I +X.XXXX±X	W +X.XXXX±X
+0.0000+0	+4.0000+1	+2.0000+0				

I +X.XXXX±X	W +X.XXXX±X	I +X.XXXX±X	W +X.XXXX±X	I +X.XXXX±X	W +X.XXXX±X	I +X.XXXX±X

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INPUT OF GROUP CONSTANTS

1	D1 +X.XXXXX±X	D2 +X.XXXXX±X	D3 +X.XXXXX±X	Σ a1 +X.XXXXX±X	Σ a2 +X.XXXXX±X	Σ a3 +X.XXXXX±X
	+2.4832+0	+5.0627-1	+8.3894 -1	+5.5754-3	+9.6893-2	+6.8784-2

2	Σ s1 +X.XXXXX±X	Σ s2 +X.XXXXX±X	√ Σ f1 +X.XXXXX±X	√ Σ f2 +X.XXXXX±X	√ Σ f3 +X.XXXXX±X
	+3.8635-3	+7.9645-2	+7.8728-3	+1.6954-1	+1.0947-1

1	D1 +X.XXXXX±X	D2 +X.XXXXX±X	D3 +X.XXXXX±X	Σ a1 +X.XXXXX±X	Σ a2 +X.XXXXX±X	Σ a3 +X.XXXXX±X

2	Σ s1 +X.XXXXX±X	Σ s2 +X.XXXXX±X	√ Σ f1 +X.XXXXX±X	Σ f2 +X.XXXXX±X	√ Σ f3 +X.XXXXX±X

1	D1 +X.XXXXX±X	D2 +X.XXXXX±X	D3 +X.XXXXX±X	Σ a1 +X.XXXXX±X	Σ a2 +X.XXXXX±X	Σ a3 +X.XXXXX±X

2	Σ s1 +X.XXXXX±X	Σ s2 +X.XXXXX±X	√ Σ f1 +X.XXXXX±X	√ Σ f2 +X.XXXXX±X	√ Σ f3 +X.XXXXX±X

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DESCRIPTION OF CONTROL CHARACTERS

- N20 = number of regions
- N26 = 2 for use of two group constants as input
 = 3 for use of three group constants as input
- N27 = 1 for slab geometry
 = 2 for cylindrical geometry
- A⁻ = left albedo
- A⁺ = right albedo
- ro = radius for flux normalization
- I = number of intervals
- W = width between adjacent points
- D = diffusion coefficient
- Σ_a = absorption cross section
- Σ_s = scattering out cross section
- $\nu \Sigma_f$ = fission cross section

Note: When two energy groups are being used, subscript 1 will designate the fast group while subscript 2 will be used for the thermal group.

When three energy groups are used, subscripts 1, 2, and 3 will be used to designate the fast, epithermal, and thermal groups respectively.

ENGINEER
J G KEPPLER

PROGRAM F-3

IDENTIFICATION
THREE GROUP

REGIONAL DATA

RADIUS	INTERVALS	REGION	BUCKLING
8.00000E 01	8.00000E 01	1	10.00000E-04

GROUP CONSTANTS

	DIFFUSION	ABSORPTION	FISSION	SCATTER
GROUP 1	2.48320E 00	5.57540E-03	7.89280E-03	3.86350E-03
GROUP 2	5.06240E-01	9.68830E-02	1.69540E-01	7.96450E-02
GROUP 3	8.38940E-01	6.87840E-02	1.09470E-01	0.

RADIUS	FISSION DENSITY	FAST FLUX	EPITHERMAL FLUX	THERMAL FLUX
1.00000E 00	2.51794E-01	2.88327E-01	4.67391E-03	4.65540E-03
2.00000E 00	3.12476E-01	3.36523E-01	6.43038E-03	6.33648E-03
3.00000E 00	3.68547E-01	3.84458E-01	7.86728E-03	7.93293E-03
4.00000E 00	4.21548E-01	4.32023E-01	0.12126E-03	9.44082E-03
5.00000E 00	4.72377E-01	4.79130E-01	1.02678E-02	1.08662E-02
6.00000E 00	5.21558E-01	5.25699E-01	1.13485E-02	1.22186E-02
7.00000E 00	5.69394E-01	5.71658E-01	1.23856E-02	1.35076E-02
8.00000E 00	6.16054E-01	6.16940E-01	1.33912E-02	1.47418E-02
9.00000E 00	6.61631E-01	6.61482E-01	1.43715E-02	1.59280E-02
1.00000E 01	7.06167E-01	7.05225E-01	1.53291E-02	1.70717E-02
1.10000E 01	7.49672E-01	7.48110E-01	1.62652E-02	1.81768E-02
1.20000E 01	7.92140E-01	7.90082E-01	1.71799E-02	1.92463E-02
1.30000E 01	8.33550E-01	8.31088E-01	1.80726E-02	2.02820E-02
1.40000E 01	8.73872E-01	8.71075E-01	1.89428E-02	2.12851E-02
1.50000E 01	9.13075E-01	0.09994E-01	1.97894E-02	2.22563E-02
1.60000E 01	9.51121E-01	9.47795E-01	2.06116E-02	2.31958E-02
1.70000E 01	9.87972E-01	9.84431E-01	2.14084E-02	2.41035E-02
1.80000E 01	1.02359E 00	1.01986E 00	2.21788E-02	2.49791E-02
1.90000E 01	1.05793E 00	1.05403E 00	2.29220E-02	2.58222E-02
2.00000E 01	1.09097E 00	1.08691E 00	2.36369E-02	2.66321E-02
2.10000E 01	1.12265E 00	1.11845E 00	2.43227E-02	2.74082E-02
2.20000E 01	1.15294E 00	1.14861E 00	2.49787E-02	2.81498E-02
2.30000E 01	1.18182E 00	1.17736E 00	2.56039E-02	2.88562E-02
2.40000E 01	1.20923E 00	1.20466E 00	2.61976E-02	2.95267E-02
2.50000E 01	1.23516E 00	1.23048E 00	2.67590E-02	3.01605E-02

RADIUS	FISSION DENSITY	FAST FLUX	EPITHERMAL FLUX	THERMAL FLUX
2.60000E 01	1.25956E 00	1.25479E 00	2.72876E-02	3.07569E-02
2.70000E 01	1.28241E 00	1.27755E 00	2.77825E-02	3.13154E-02
2.80000E 01	1.30368E 00	1.29874E 00	2.82433E-02	3.18351E-02
2.90000E 01	1.32335E 00	1.31833E 00	2.86694E-02	3.23156E-02
3.00000E 01	1.34139E 00	1.33630E 00	2.90601E-02	3.27563E-02
3.10000E 01	1.35778E 00	1.35263E 00	2.94152E-02	3.31566E-02
3.20000E 01	1.37250E 00	1.36729E 00	2.97340E-02	3.35161E-02
3.30000E 01	1.38553E 00	1.38027E 00	3.00162E-02	3.38343E-02
3.40000E 01	1.39685E 00	1.39155E 00	3.02616E-02	3.41109E-02
3.50000E 01	1.40646E 00	1.40112E 00	3.04697E-02	3.43454E-02
3.60000E 01	1.41433E 00	1.40897E 00	3.06403E-02	3.45378E-02
3.70000E 01	1.42047E 00	1.41508E 00	3.07732E-02	3.46876E-02
3.80000E 01	1.42486E 00	1.41945E 00	3.08682E-02	3.47948E-02
3.90000E 01	1.42749E 00	1.42208E 00	3.09253E-02	3.48591E-02
4.00000E 01	1.42837E 00	1.42295E 00	3.09443E-02	3.48806E-02
4.10000E 01	1.42749E 00	1.42208E 00	3.09253E-02	3.48591E-02
4.20000E 01	1.42486E 00	1.41945E 00	3.08682E-02	3.47948E-02
4.30000E 01	1.42047E 00	1.41508E 00	3.07732E-02	3.46876E-02
4.40000E 01	1.41433E 00	1.40897E 00	3.06403E-02	3.45378E-02
4.50000E 01	1.40646E 00	1.40112E 00	3.04696E-02	3.43454E-02
4.60000E 01	1.39685E 00	1.30155E 00	3.02616E-02	3.41109E-02
4.70000E 01	1.38553E 00	1.38027E 00	3.00162E-02	3.38343E-02
4.80000E 01	1.37250E 00	1.36729E 00	2.97340E-02	3.35161E-02
4.90000E 01	1.35778E 00	1.35263E 00	2.94152E-02	3.31566E-02

RADIUS	FISSION DENSITY	FAST FLUX	EPITHERMAL FLUX	THERMAL FLUX
5.00000E 01	1.34139E 00	1.33630E 00	2.90601E-02	3.27563E-02
5.10000E 01	1.32335E 00	1.31833E 00	2.86694E-02	3.23156E-02
5.20000E 01	1.30368E 00	1.29874E 00	2.82433E-02	3.18351E-02
5.30000E 01	1.28241E 00	1.27755E 00	2.77825E-02	3.13153E-02
5.40000E 01	1.25956E 00	1.25479E 00	2.72876E-02	3.07569E-02
5.50000E 01	1.23515E 00	1.23048E 00	2.67590E-02	3.01604E-02
5.60000E 01	1.20923E 00	1.20466E 00	2.61975E-02	2.95266E-02
5.70000E 01	1.18182E 00	1.17736E 00	2.56039E-02	2.88562E-02
5.80000E 01	1.15294E 00	1.14861E 00	2.49787E-02	2.81498E-02
5.90000E 01	1.12265E 00	1.11845E 00	2.43227E-02	2.74082E-02
6.00000E 01	1.09097E 00	1.08691E 00	2.36369E-02	2.66320E-02
6.10000E 01	1.05793E 00	1.05403E 00	2.29219E-02	2.58221E-02
6.20000E 01	1.02359E 00	1.01986E 00	2.21788E-02	2.49791E-02
6.30000E 01	9.87972E-01	9.84431E-01	2.14084E-02	2.41035E-02
6.40000E 01	9.51120E-01	9.47794E-01	2.06116E-02	2.31958E-02
6.50000E 01	9.13074E-01	0.09993E-01	1.97894E-02	2.22563E-02
6.60000E 01	8.73872E-01	8.71074E-01	1.89428E-02	2.12851E-02
6.70000E 01	8.33549E-01	8.31087E-01	1.80726E-02	2.02820E-02
6.80000E 01	7.92139E-01	7.90081E-01	1.71799E-02	1.92463E-02
6.90000E 01	7.49672E-01	7.48109E-01	1.62652E-02	1.81768E-02
7.00000E 01	7.06166E-01	7.05224E-01	1.53291E-02	1.70717E-02
7.10000E 01	6.61630E-01	6.61482E-01	1.43714E-02	1.50280E-02
7.20000E 01	6.16054E-01	6.16939E-01	1.33912E-02	1.47418E-02
7.30000E 01	5.69393E-01	5.71657E-01	1.23856E-02	1.35076E-02
7.40000E 01	5.21558E-01	5.25699E-01	1.13484E-02	1.22186E-02

RADIUS	FISSION DENSITY	FAST FLUX	EPITHERMAL FLUX	THERMAL FLUX
7.50000E 01	4.72377E-01	4.79130E-01	1.02678E-02	1.08662E-02
7.60000E 01	4.21548E-01	4.32023E-01	9.12126E-03	9.44081E-03
7.70000E 01	3.68546E-01	3.84457E-01	7.86728E-03	7.93292E-03
7.80000E 01	3.12475E-01	3.36523E-01	6.43038E-03	6.33647E-03
7.90000E 01	2.51794E-01	2.88326E-01	4.67391E-03	4.65539E-03
8.00000E 01	1.83846E-01	2.40001E-01	2.35145E-03	2.91693E-03
8.00000E 01	0.	2.40001E-01	2.35145E-03	2.91693E-03

REACTIVITY
2.30988E 02
1.85791E 02
6.69132E 01
3.92864E 01
9.37527E-01
9.43860E-01
9.47215E-01
9.49403E-01
9.50655E-01
9.51372E-01
9.51792E-01
9.52022E-01
9.52153E-01
9.52227E-01
9.52268E-01
9.52291E-01
9.52304E-01
9.52312E-01
0.

6.3 Program F₃ FORTRAN Listing

UNCLASSIFIED

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C   PROGRAM F-3.
C   THIS CHECKOUT FOR J KEPPLER AND L ORR
    DIMENSION AL2(3),VALS(10),WIDTH(10),DIFL(3,10),SIGA(3,10),SIGS(3,1
10),TRIC(3,10),RADP(150),DIFM(3,150),SIG(3,150),ABC(3,150),SIGNU(3,
2150),BET(150),DEL(150),GAM(150),ZIP1(3,150),ZIP2(3,150),CEE(3,150)
3,FEE(3,150),RECUR1(3,150),RECUR2(3,150),B1(3),DENSEP(150),DENSEM(150
4),REACT(50),AL1(3),RADR(10),FEE0(3),N41(10)
4   FORMAT(72H
1       )
5   FORMAT(64H1          ENGINEER          PROGRAM F-3          IDENTI
1FICATION)
1000  FORMAT(I2,2I1,1PE9.4)
1001  FORMAT(1P6E9.4)
1002  FORMAT(1P7E9.4)
1006  FORMAT(1P6E12.5)
1005  FORMAT(1P5E9.4)
2000  FORMAT(1P3E24.5)
1500  FORMAT(1PE14.5,1PE16.5,I14,1PE22.5)
1501  FORMAT(42H0          REGIONAL DATA)
1502  FORMAT(67H0          RADIUS          INTERVALS          REGION
1       BUCKLING/)
1503  FORMAT(44H0          GROUP CONSTANTS)
1504  FORMAT(67H0          DIFFUSION          ABSORPTION          FISSION
1       SCATTER)
1505  FORMAT(9H          GROUPI3,1PE16.5,1P3E14.5)
1506  FORMAT(5H          )
1600  FORMAT(72H1 RADIUS FISSION DENSITY FAST FLUX EPITHERMAL FL
1UX THERMAL FLUX)
1598  FORMAT(1P3E14.5,1PE28.5)
1599  FORMAT(1P5E14.5)
1900  FORMAT(1PE42.5)
1901  FORMAT(42H1          REACTIVITY)
2500  CONTINUE
      IF(SENSESWITCH2)6000,6001
6000  READ4
      READ1000,N20,N26,N27,TRANS
      READ1001,(AL1(IE),IE=1,N26),(AL2(IE),IE=1,N26)
      READ1002,RAD,(VALS(IR),WIDTH(IR),IR=1,N20)
      DO1007IR=1,N20
      READ1001,(DIFL(IE,IR),IE=1,3),(SIGA(IE,IR),IE=1,3)
      READ1005,(SIGS(IE,IR),IE=1,2),(TRIC(IE,IR),IE=1,3)
1007  CONTINUE
      GOTO6002
6001  READINPUTTAPE2,4
      READINPUTTAPE2,1000,N20,N26,N27,TRANS
      READINPUTTAPE2,1001,(AL1(IE),IE=1,N26),(AL2(IE),IE=1,N26)
      READINPUTTAPE2,1002,RAD,(VALS(IR),WIDTH(IR),IR=1,N20)
      DO6010IR=1,N20
      READINPUTTAPE2,1001,(DIFL(IE,IR),IE=1,3),(SIGA(IE,IR),IE=1,3)
      READINPUTTAPE2,1005,(SIGS(IE,IR),IE=1,2),(TRIC(IE,IR),IE=1,3)
6010  CONTINUE
6002  CONTINUE
      RADR(1)=RAD+VALS(1)*WIDTH(1)
      VALL=VALS(1)
      N41(1)=VALL+.001
      IF(N20-2)5000,5001,5002

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5001  RADR(2)=RADR(1)+VALS(2)*WIDTH(2)
      VALL=VALL+VALS(2)
      N41(2)=VALL+.001
      GOTO5000
5002  DO1008IR=2,N20
      VALL=VALL+VALS(IR)
      N41(IR)=VALL+.001
      RADR(IR)=RADR(IR-1)+VALS(IR)*WIDTH(IR)
1008  CONTINUE
5000  CONTINUE
      VALL=VALL+.001
      N28=VALL
      DO1009IE=1,N26
      DIFM(IE,1)=DIFL(IE,1)
      SIG(IE,1)=SIGS(IE,1)
      ABC(IE,1)=SIG(IE,1)+SIGA(IE,1)+DIFM(IE,1)*TRANS
      SIGNU(IE,1)=TRIC(IE,1)
1009  CONTINUE
      RADP(1)=RAD+WIDTH(1)
      IR=1
      DO1013IP=2,N28
      RADP(IP)=RADP(IP-1)+WIDTH(IR)
      IF(N41(IR)-IP)1015,1015,1016
1015  CONTINUE
      DO1020IE=1,N26
      DIFM(IE,IP)=DIFL(IE,IR)
      SIG(IE,IP)=SIGS(IE,IR)
      ABC(IE,IP)=SIG(IE,IP)+SIGA(IE,IR)+DIFM(IE,IP)*TRANS
      SIGNU(IE,IP)=TRIC(IE,IR)
1020  CONTINUE
      IR=IR+1
      GOTO1013
1016  CONTINUE
      DO1050IE=1,N26
      DIFM(IE,IP)=DIFL(IE,IR)
      SIG(IE,IP)=SIGS(IE,IR)
      ABC(IE,IP)=SIG(IE,IP)+SIGA(IE,IR)+DIFM(IE,IP)*TRANS
      SIGNU(IE,IP)=TRIC(IE,IR)
1050  CONTINUE
1013  CONTINUE
      N29=N28-1
      IF(N27-1)8011,1051,1053
1051  BET(1)=(RADP(2)-RADP(1))/(RADP(1)-RAD)
      DEL(1)=(RADP(2)-RADP(1))*(RADP(1)-RAD)/2.
      GAM(1)=BET(1)*DEL(1)
      DO1052IP=2,N29
      BET(IP)=(RADP(IP+1)-RADP(IP))/(RADP(IP)-RADP(IP-1))
      DEL(IP)=(RADP(IP+1)-RADP(IP))*(RADP(IP)-RADP(IP-1))/2.
      GAM(IP)=BET(IP)*DEL(IP)
1052  CONTINUE
      GOTO1055
1053  CONTINUE
      ABLE=(RADP(1)+RADP(2))/(3.*RADP(1)-RADP(2))
      BAKER=(RADP(1)+RAD)/(3.*RADP(1)-RAD)
      BET(1)=((RADP(2)-RADP(1))/(RADP(1)-RAD))*(1.+ABSF(BAKER))/(1.+ABSF
1(ABLE))

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      DEL(1)=.25*((RADP(2)-RADP(1))/(1.+ABSF(ABLE)))*((3.*RADP(1)-RADP(1)+RADP(1)+RADP(1))*ABSF(BAKER))
      GAM(1)=.25*((RADP(2)-RADP(1))/(1.+ABSF(1./ABLE)))*((RADP(1)+RADP(2)-3.*RADP(1)-RADP(2))*ABSF(1./ABLE))
      DO1054 IP=2,N29
      ABLE=(RADP(IP)+RADP(IP+1))/(3.*RADP(IP)-RADP(IP+1))
      BAKER=(RADP(IP)+RADP(IP-1))/(3.*RADP(IP)-RADP(IP-1))
      BET(IP)=(RADP(IP+1)-RADP(IP))/(RADP(IP)-RADP(IP-1))*(1.+ABSF(BAKER))
      DEL(IP)=.25*((RADP(IP+1)-RADP(IP))/(1.+ABSF(ABLE)))*((3.*RADP(IP)-RADP(IP-1)-RADP(IP)+RADP(IP-1))*ABSF(BAKER))
      GAM(IP)=.25*((RADP(IP+1)-RADP(IP))/(1.+ABSF(1./ABLE)))*((RADP(IP)+RADP(IP+1)-3.*RADP(IP)-RADP(IP+1))*ABSF(1./ABLE))
1054  CONTINUE
1055  CONTINUE
      LL=1
      DO1060 IE=1,N26
      ZIP1(IE,1)=1.+(RADP(1)-RADP(1))*(1.-AL1(IE))/(2.*DIFM(IE,1)*(1.+AL1(IE)))
      ZIP2(IE,1)=0.0
      IFDIVIDECHECK1060,1060
1060  CONTINUE
      DO1066 IP=1,N29
      DO1066 IE=1,N26
      RECUR1(IE,IP)=DIFM(IE,IP+1)+BET(IP)*DIFM(IE,IP)+GAM(IP)*ABC(IE,IP+1)+DEL(IP)*ABC(IE,IP)
      RECUR2(IE,IP)=BET(IP)*DIFM(IE,IP)
1066  CONTINUE
4000  CONTINUE
      DO1065 IP=1,N29
      IF(LL-1)8012,1061,1062
1061  CEE(1,IP)=1.0
      CEE(2,IP)=1.0
      IF(N26-2)8013,1065,1059
1059  CEE(3,IP)=1.0
      GOTO1065
1062  CONTINUE
      CEE(1,IP)=GAM(IP)*DENSP(IP)+DEL(IP)*DENSM(IP)
      CEE(2,IP)=(GAM(IP)*SIG(1,IP+1)+DEL(IP)*SIG(1,IP))*FEE(1,IP)
      IF(N26-2)8014,1065,1064
1064  CONTINUE
      CEE(3,IP)=(GAM(IP)*SIG(2,IP+1)+DEL(IP)*SIG(2,IP))*FEE(2,IP)
1065  CONTINUE
4002  CONTINUE
      DO1067 IP=2,N28
      DO1067 IE=1,N26
      ZIP1(IE,IP)=(1./DIFM(IE,IP))*(RECUR1(IE,IP-1)-RECUR2(IE,IP-1)/ZIP1(IE,IP-1))
      ZIP2(IE,IP)=(1./DIFM(IE,IP))*(CEE(IE,IP-1)+RECUR2(IE,IP-1)*ZIP2(IE,IP-1)/ZIP1(IE,IP-1))
1067  CONTINUE
4001  CONTINUE
      DO1070 IE=1,N26
      B1(IE)=1.+(RADP(N28)-RADP(N29))*(1.-AL2(IE))/(2.*DIFM(IE,N28)*(1.+AL2(IE)))
      FEE(IE,N28)=ZIP2(IE,N28)/(B1(IE)*ZIP1(IE,N28)-1.)

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1070  CONTINUE
      IP=N29
1071  CONTINUE
      DO1074 IE=1,N26
1074  FEE(IE,IP)=(ZIP2(IE,IP+1)+FEE(IE,IP+1))/ZIP1(IE,IP+1)
      IP=IP+1
3006  IF(IP-1)1075,1071,1071
1075  CONTINUE
      DENSPO=0.0
      DO1800 IE=1,N26
      FEE0(IE)=(ZIP2(IE,1)+FEE(IE,1))/ZIP1(IE,1)
1800  DENSPO=DENSPO+SIGNU(IE,1)*FEE0(IE)
      DO1076 IP=1,N29
      SUM=0.0
      SUM1=0.0
      DO1077 IE=1,N26
      SUM=SUM+SIGNU(IE,IP+1)*FEE(IE,IP)
      SUM1=SUM1+SIGNU(IE,IP)*FEE(IE,IP)
1077  CONTINUE
      DENS( IP)=SUM
      DENSM( IP)=SUM1
1076  CONTINUE
      DENSM(N28)=SIGNU(1,N28)*FEE(1,N28)+SIGNU(2,N28)*FEE(2,N28)+SIGNU(3
1,N28)*FEE(3,N28)
      IF(N27-1)8015,1078,1080
1078  SUM=(DENSPO+DENSM(1))*(RADP(1)-RAD)/2.
      CORE=(DENSPO/DENSPO+DENSM(1)/DENSM(1))*(RADP(1)-RAD)/2.
      FEEBAR=(DENSPO*FEE0(1)/DENSPO+DENSM(1)*FEE(1,1)/DENSM(1))*(RADP(1)
1-RAD)/2.
      DO1079 IP=1,N29
      SUM=(DENS( IP)+DENSM( IP+1))*(RADP( IP+1)-RADP( IP))/2.+SUM
      CORE=CORE+(DENS( IP)/DENS( IP)+DENSM( IP+1)/DENSM( IP+1))*(RADP( IP+1)
1-RADP( IP))/2.
      FEEBAR=FEEBAR+(DENS( IP)*FEE(1, IP)/DENS( IP)+DENSM( IP+1)*FEE(1, IP+
11)/DENSM( IP+1))*(RADP( IP+1)-RADP( IP))/2.
      IFDIVIDECHECK1802,1802
1802  CONTINUE
1079  CONTINUE
      GOTO1091
1080  SUM=(RAD*DENSPO+RADP(1)*DENSM(1))*(RADP(1)-RAD)/2.
      CORE=(DENSPO*RAD/DENSPO+DENSM(1)*RADP(1)/DENSM(1))*(RADP(1)-RAD)/2
1.
      FEEBAR=(DENSPO*RAD*FEE0(1)/DENSPO+DENSM(1)*RADP(1)*FEE(1,1)/DENSM(
11))*(RADP(1)-RAD)/2.
      IFDIVIDECHECK1801,1801
1801  CONTINUE
      DO1081 IP=1,N29
      SUM=(RADP( IP)*DENS( IP)+RADP( IP+1)*DENSM( IP+1))*(RADP( IP+1)-RADP( I
1P))/2.+SUM
      CORE=CORE+(DENS( IP)*RADP( IP)/DENS( IP)+DENSM( IP+1)*RADP( IP+1)/DEN
1SM( IP+1))*(RADP( IP+1)-RADP( IP))/2.
      FEEBAR=FEEBAR+(DENS( IP)*RADP( IP)*FEE(1, IP)/DENS( IP)+DENSM( IP+1)*
1RADP( IP+1)*FEE(1, IP+1)/DENSM( IP+1))*(RADP( IP+1)-RADP( IP))/2.
1081  CONTINUE
1091  CONTINUE
      REACT(LL)=SUM

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      IF(LL-1)8016,1086,1082
1086  LL=LL+1
      GOTO4000
1082  CON=ABSF(React(LL)-React(LL-1))
      IF(.00001-CON)1083,1083,1085
1083  DO1084IP=1,N28
      DENSP(IP)=DENSP(IP)/React(LL)
1084  DENSM(IP)=DENSM(IP)/React(LL)
      LL=LL+1
      GOTO4000
1085  N31=LL
      FEEBAR=FEEBAR/CORE
      DO1850IP=1,N28
      DENSM(IP)=CORE*DENSM(IP)/React(LL)
      DENSP(IP)=CORE*DENSP(IP)/React(LL)
      DO1850IE=1,N26
      FEE(IE,IP)=FEE(IE,IP)/FEEBAR
1850  CONTINUE
8008  CONTINUE
      IF(SENSESWITCH3)1872,1873
1872  PRINT5
      PRINT4
      GOTO1874
1873  WRITEOUTPUTTAPE3,5
      WRITEOUTPUTTAPE3,4
1874  CONTINUE
      IF(SENSESWITCH3)1317,1318
1317  PRINT1501
      PRINT1502
      GOTO1319
1318  WRITEOUTPUTTAPE3,1501
      WRITEOUTPUTTAPE3,1502
1319  CONTINUE
      N100=1
      DO1320IR=1,N20
      IF(SENSESWITCH3)1321,1322
1321  PRINT1500,RADR(IR),VALS(IR),N100,TRANS
      N100=N100+1
      GOTO1320
1322  WRITEOUTPUTTAPE3,1500,RADR(IR),VALS(IR),N100,TRANS
      N100=N100+1
1320  CONTINUE
      IF(SENSESWITCH3)1314,1315
1314  PRINT1503
      PRINT1504
      GOTO1316
1315  WRITEOUTPUTTAPE3,1503
      WRITEOUTPUTTAPE3,1504
1316  CONTINUE
      DO1509IR=1,N20
      IF(SENSESWITCH3)1307,1308
1307  PRINT1506
      GOTO1309
1308  WRITEOUTPUTTAPE3,1506
1309  CONTINUE
      DO1510IE=1,N26
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W/E DATE	UNIT	TASK IEWA	CHG	TE	EA	MACH HRS
						19.50
				*	*	19.50*
				**	**	19.50 **
				**	**	**
				*	*	*

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      N100=IE
      IF(SENSESWITCH3)1311,1312
1311  PRINT1505,N100,DIFL(IE,IR),SIGA(IE,IR),TRIC(IE,IR),SIGS(IE,IR)
      GOTO1510
1312  WRITEOUTPUTTAPE3,1505,N100,DIFL(IE,IR),SIGA(IE,IR),TRIC(IE,IR),SIG
1S(IE,IR)
1510  CONTINUE
1509  CONTINUE
      IF(SENSESWITCH3)1601,1602
1601  PRINT1600
      GOTO1603
1602  WRITEOUTPUTTAPE3,1600
1603  CONTINUE
      DO1610IP=1,N28
      IF(N26-2)8017,1605,1604
1604  CONTINUE
      IF(SENSESWITCH3)1606,1607
1606  PRINT1599,RADP(IP),DENSM(IP),FEE(1,IP),FEE(2,IP),FEE(3,IP)
      IF(DENSM(IP)-DENSP(IP))1611,1610,1611
1611  PRINT1599,RADP(IP),DENSP(IP),FEE(1,IP),FEE(2,IP),FEE(3,IP)
      GOTO1610
1607  WRITEOUTPUTTAPE3,1599,RADP(IP),DENSM(IP),FEE(1,IP),FEE(2,IP),FEE(3
1,IP)
      IF(DENSM(IP)-DENSP(IP))1612,1610,1612
1612  WRITEOUTPUTTAPE3,1599,RADP(IP),DENSP(IP),FEE(1,IP),FEE(2,IP),FEE(3
1,IP)
      GOTO1610
1605  CONTINUE
      IF(SENSESWITCH3)1608,1609
1608  PRINT1598,RADP(IP),DENSM(IP),FEE(1,IP),FEE(2,IP)
      IF(DENSM(IP)-DENSP(IP))1613,1610,1613
1613  PRINT1598,RADP(IP),DENSP(IP),FEE(1,IP),FEE(2,IP)
      GOTO1610
1609  WRITEOUTPUTTAPE3,1598,RADP(IP),DENSM(IP),FEE(1,IP),FEE(2,IP)
      IF(DENSM(IP)-DENSP(IP))1614,1610,1614
1614  WRITEOUTPUTTAPE3,1598,RADP(IP),DENSP(IP),FEE(1,IP),FEE(2,IP)
1610  CONTINUE
      IF(SENSESWITCH3)1903,1904
1903  PRINT1901
      GOTO1905
1904  WRITEOUTPUTTAPE3,1901
1905  CONTINUE
      DO1910LL=1,N31
      IF(SENSESWITCH3)1906,1907
1906  PRINT1900,REACT(LL)
      GOTO1910
1907  WRITEOUTPUTTAPE3,1900,REACT(LL)
1910  CONTINUE
      WRITEOUTPUTTAPE3,1900,FXTK
      IF(SENSESWITCH4)8000,8001
8000  WRITEOUTPUTTAPE3,1006,BET,DEL,GAM,RECURI,B1,CORE,FEEBAR
8001  CONTINUE
      GOTO2500
8011  STOP2
8012  STOP3
8013  STOP4
```

8014 STOP5
8015 STOP6
8016 STOP7
8017 STOP8