

ElectroData

DIVISION OF BURROUGHS CORPORATION

DMM

AMERICAN - Standard

ATOMIC ENERGY DIVISION

Copyright © 1957

Burroughs Corporation

Printed in U.S.A.

LaFarr Stuart

DIFFUSION MULTIGROUP MULTIREGION

JOEL FRANKLIN
ElectroData Division
Burroughs Corporation

EDWARD J. LESHAN
Atomic Energy Division
American-Standard Corporation

R-218

January 4, 1957

CONTENTS

	PAGE
1. Introduction	1
2. Analysis	1
3. Preparation of Input.....	4
4. Operation of the Program.....	6
5. Datatron Code	7
6. Flow Chart	17

DIFFUSION MULTIGROUP MULTIREGION

JOEL FRANKLIN AND EDWARD J. LESHAN

1. INTRODUCTION. The purpose of our program, DMM, is to perform multigroup calculations for nuclear reactors. We have referred extensively to the PROD program of the General Electric Company, which is a masterful piece of work.

By fully utilizing the 4080-word internal capacity of the DATATRON, we have been able to write a program which is different from PROD in several respects. We have been able to permit elastic and inelastic scattering by *every* element of neutrons at any energy level into *all* lower energy levels. DMM, like PROD, is applicable to planar, cylindrical, and spherical reactors. Whereas PROD considers only closed cylinders and spheres, DMM may be applied to hollow cylinders and spheres, or to those whose centers are pure absorbers.

DMM requires only one input, regardless of how many iterations a problem involves. PROD requires two distinct manual inputs for each iteration. For a problem involving ten iterations PROD requires twenty separate manual inputs, whereas DMM requires just one.

DMM is designed to be as flexible as possible. If the number of energy-groups is small, one may use a large number of mesh-points. If the number of mesh-points is small, one may use many energy-groups. Using the notation of PROD, we define

$$(1.1) \quad \left\{ \begin{array}{l} I = \text{number of energy-groups,} \\ K = \text{number of regions in which the reactor} \\ \quad \text{is homogeneous,} \\ N = \text{number of zones used in the numerical} \\ \quad \text{analysis.} \end{array} \right.$$

In every case we shall have $I \geq 1$, $K \geq 1$, $N \geq K$. The sole restriction placed by DMM on the quantities I , K , and N is the inequality

$$(1.2) \quad 3N + 2K + [4 + N + \frac{1}{2}(I + 5)K]I \leq 3450.$$

At this writing, January 4, 1957, five examples have been run on the DATATRON. The values of I , K , N and the lengths of time per iteration are listed below.

I	K	N	Time per iteration
3	2	5	14 sec.
4	3	45	2 min. 38 sec.
1	1	500	6 min. 12 sec.
10	3	40	6 min. 49 sec.
30	3	45	34 min. 52 sec.

2. ANALYSIS. We consider an integro-differential equation of the form

$$-\operatorname{div}[D(\mathbf{r}, E) \operatorname{grad} \phi(\mathbf{r}, E)] + T(\mathbf{r}, E) \phi(\mathbf{r}, E) \quad (2.1)$$

$$= \int_E^{E_{\max}} T(\mathbf{r}, E, E') \phi(\mathbf{r}, E') dE' + \chi(E) P(\mathbf{r}),$$

where

$$(2.2) \quad P(\mathbf{r}) = \frac{1}{k} \int_{E_{\min}}^{E_{\max}} f(\mathbf{r}, E') \phi(\mathbf{r}, E') dE'.$$

On the boundary of the reactor we require a condition of the form

(2.3)

$$[1 - B(\mathbf{r}, E)] \frac{\partial \phi}{\partial n} + B(\mathbf{r}, E) \phi = 0 \quad (\mathbf{r} \text{ on boundary}).$$

By $\frac{\partial \phi}{\partial n}$ we mean the exterior normal derivative of ϕ .

Equations (2.1)–(2.3) pose an eigenvalue problem to be solved for an eigenvalue k and an eigenfunction $\phi(\mathbf{r}, E)$. If $k = 1$, the eigenfunction $\phi(\mathbf{r}, E)$ represents the neutron flux per unit energy. The eigenfunction is normalized by the assumption

$$(2.4) \quad \frac{1}{V} \int_{\text{reactor}} P(\mathbf{r}) dV = 1,$$

where V is the volume of the reactor. The value of k is significant to the physicist because

$$(2.5) \quad k \quad \left\{ \begin{array}{l} > 1 \text{ for supercritical reactor,} \\ = 1 \text{ for critical reactor,} \\ < 1 \text{ for subcritical reactor.} \end{array} \right.$$

The given function $D(\mathbf{r}, E)$ is generally taken to be one-third the transport mean free path. $T(\mathbf{r}, E)$ gives the total removal cross-section. $T(\mathbf{r}, E, E')$ gives the total cross-section for elastic and inelastic scattering. The term $\chi(E)$ is the fission spectrum. The product $\chi(E)P(\mathbf{r})$ represents the production of neutrons by fission. The reader may obtain detailed information concerning all these functions in the authors' pre-

liminary report, *A Multigroup, Multiregion, One-Space Dimensional Program Using Neutron Diffusion Theory*. This report is available from the Atomic Energy Division of the American-Standard Corporation.

DMM applies only to reactors which have planar, cylindrical, or spherical symmetry; a parameter ρ is defined respectively as $\rho = 0, 1$, or 2 . If $\rho = 1$ or 2 , we define a variable x equal to the distance of a point r from the center of the cylinder or sphere. If $\rho = 0$, x equals the distance of a point r from some fixed plane of symmetry. The spatial domain of the reactor may now be described by an inequality of the form

$$(2.6) \quad x_0 \leq x \leq x_N.$$

We require $x_0 \geq 0$.

Equations (2.1)–(2.3) may now be written in the forms

$$(2.7) \quad -x^{-\rho} \frac{\partial}{\partial x} \left[x^\rho D(x, E) \frac{\partial \phi}{\partial x}(x, E) \right] + T(x, E) \phi(x, E)$$

$$= \int_E^{E_{\max}} T(x, E, E') \phi(x, E') dE' + \chi(E) P(x),$$

$$(2.8) \quad P(x) = \frac{1}{k} \int_{E_{\min}}^{E_{\max}} f(x, E') \phi(x, E') dE',$$

$$(2.9) \quad \begin{cases} -[1 - B_0(E)] \frac{\partial \phi}{\partial x} + B_0(E) \phi = 0 & \text{for } x = x_0, \\ [1 - B_N(E)] \frac{\partial \phi}{\partial x} + B_N(E) \phi = 0 & \text{for } x = x_N. \end{cases}$$

In the case of a solid cylinder or sphere, where $x_0 = 0$ and $\rho = 1$ or 2 , symmetry requires that $B_0(E) \equiv 0$.

It has been customary to consider only a finite number, I , of distinct energy levels

$$(2.10) \quad E_1 > E_2 > \dots > E_I.$$

Equations (2.7)–(2.9) are approximated by equations of the forms

$$(2.11) \quad -x^{-\rho} \frac{\partial}{\partial x} \left[x^\rho D^i(x) \frac{\partial \phi^i}{\partial x}(x) \right] + T^i(x) \phi^i(x)$$

$$= \sum_{j=1}^{I-1} T^{ij}(x) \phi^j(x) + \chi^i P(x),$$

$$(2.12) \quad P(x) = \frac{1}{k} \sum_{j=1}^I f^j(x) \phi^j(x),$$

$$(2.13) \quad \begin{cases} -(1 - B^{i_0}) \frac{\partial \phi^i}{\partial x} + B^{i_0} \phi^i = 0 & \text{for } x = 0, \\ (1 - B^{i_N}) \frac{\partial \phi^i}{\partial x} + B^{i_N} \phi^i = 0 & \text{for } x = x_N. \end{cases}$$

All of the physical coefficients are ≥ 0 . The sum of the χ 's is 1. The B 's lie in the interval $0 \leq B \leq 1$.

It is assumed that the reactor consists of K homogeneous regions:

$$(2.14)$$

$$x_{(0)} \leq x < x_{(1)}, x_{(1)} \leq x < x_{(2)}, \dots,$$

$$x_{(K-2)} \leq x < x_{(K-1)}, x_{(K-1)} \leq x \leq x_{(K)}.$$

For the purpose of numerical analysis an increment $\Delta x_{(v)}$ is chosen for each of these regions ($v = 0, 1, \dots, K-1$). The length of the v^{th} region must be an integral multiple of $\Delta x_{(v)}$; let us say that the length of the v^{th} region is $M_v \Delta x_{(v)}$. By means of the increments $\Delta x_{(v)}$ a set of points $x_0 < x_1 < \dots < x_N$ may be marked on the interval $x_0 \leq x \leq x_N$ of formula (2.6). We now define

$$(2.15) \quad N_0 = 0, N_v = M_0 + M_1 + \dots + M_{v-1}$$

$$(v = 1, \dots, K).$$

We now have

$$(2.16) \quad x_{(v)} = x_{N_v} \quad (v = 0, \dots, K),$$

and

$$(2.17) \quad \Delta x_n \equiv x_{n+1} - x_n = \Delta x_{(v)}$$

$$(N_v \leq n < N_{v+1}; v = 0, \dots, K-1).$$

For the numerical analysis of our equations (2.7)–(2.9) it is convenient to make two additional definitions:

$$(2.18)$$

$$x_{n+\frac{1}{2}} = \frac{1}{2} (x_{n+1} + x_n) \quad (n = 0, \dots, N-1),$$

$$(2.19)$$

$$\Delta x_{n-\frac{1}{2}} = \frac{1}{2} (\Delta x_n + \Delta x_{n-1}) = \frac{1}{2} (x_{n+1} - x_{n-1})$$

$$(n = 1, \dots, N-1).$$

For any function of x , say $F(x)$, we denote

$$(2.20) \quad F(x_s) = F_s, F(x_{(v)}) = F_{(v)}.$$

We are now ready to write down the equations which are solved by DMM. These equations are found by replacing the differential equations (2.11), (2.13) by appropriate difference equations. Equations (2.11), (2.13) take the form

$$(2.21) \quad -a^i_n \phi^{i+1} + b^i_n \phi^i - c^i_n \phi^{i-1} = d^i_n \\ (i = 1, \dots, I; n = 0, \dots, N),$$

where for $n = 1, \dots, N-1$

$$(2.22) \quad \left\{ \begin{array}{l} a^i_n = \left[1 + \frac{\Delta x_n}{2x_n} \right]^\rho D^{i+\frac{1}{2}} \frac{\Delta x_{n-\frac{1}{2}}}{\Delta x_n}, \\ b^i_n = a^i_n + c^i_n + \left[\Delta x_{n-\frac{1}{2}} \right]^2 T^i_n, \\ c^i_n = \left[1 - \frac{\Delta x_{n-1}}{2x_n} \right]^\rho D^{i-\frac{1}{2}} \frac{\Delta x_{n-\frac{1}{2}}}{\Delta x_{n-1}}, \\ d^i_n = \left[\Delta x_{n-\frac{1}{2}} \right]^2 \cdot \left[\sum_{j=1}^{i-1} T^{ij} \phi^j_n + \chi^i \bar{P}_n \right]. \end{array} \right.$$

The term \bar{P}_n will be explained later. For $n = 0$ and $n = N$ equation (2.21) corresponds to the boundary conditions (2.13). We set $\phi^{-1} = \phi^{N+1} = 0$ and define, for $i = 1, \dots, I$,

$$(2.23) \quad \left\{ \begin{array}{l} a^i_0 = (1 - B^i_0) D^i_0, b^i_0 = a^i_0 + B^i_0 \Delta x_0, \\ c^i_0 = 0, d^i_0 = 0, \\ a^i_N = 0, b^i_N = c^i_N + B^i_N \Delta x_{N-1}, \\ c^i_N = (1 - B^i_N) D^i_N, d^i_N = 0. \end{array} \right.$$

The term \bar{P}_n , which appears in the definition (2.22) of d^i_n , must correspond to the function $P(x)$ defined in (2.12). In place of the normalization (2.4) we shall require

$$(2.24) \quad \frac{1}{V} \sum_{n=1}^{N-1} \bar{P}_n \Delta V_n = 1,$$

where

$$(2.25) \quad \Delta V_n = x^{\rho_n} \Delta x_{n-\frac{1}{2}}, V = \sum_{n=1}^{N-1} \Delta V_n.$$

For an initial definition we set the quantities \bar{P}_n equal to any set of numbers ≥ 0 which are normalized according to (2.24).

Once the \bar{P}_n are defined, we may compute the numbers d^i_n by the definition (2.22), (2.23) in which

the empty sum $\sum_{j=1}^0$ is given the value zero. The numbers a^i_n, b^i_n, c^i_n are also defined by (2.22), (2.23). The coefficients in (2.21) are now defined for $i = 1$, and we may solve (2.21) for ϕ^i_n ($n = 0, \dots, N$). In fact, as it is easy to prove, the system of linear equations (2.21) always has a unique solution such that

$$(2.26) \quad \phi_{-1} = 0, \phi_{N+1} = 0,$$

provided that

$$(2.27) \quad \left\{ \begin{array}{l} a_n > 0, c_n > 0, b_n \geq a_n + c_n \\ (n = 1, \dots, N-1) \\ b_0 \geq a_0 \geq 0, b_0 > 0; b_N \geq c_N \geq 0, b_N > 0. \end{array} \right.$$

One sees from the definitions (2.22), (2.23) that in our case (2.27) is satisfied.

After we have solved for the numbers ϕ^i_n , we may define the coefficients a^2_n, \dots, d^2_n by (2.22), (2.23). We now solve equations (2.21) for the numbers ϕ^2_n . Continuing in this manner, we find all of the numbers ϕ^i_n ($n = 0, \dots, N$; $i = 1, \dots, I$). We have found all of these numbers on the basis of our first guess for \bar{P}_n .

Now we use the numbers ϕ^i_n just computed, to obtain a better guess for \bar{P}_n . Let us refer to our first guess for \bar{P}_n as "old \bar{P}_n ". We would like to compute "new \bar{P}_n ". From formula (2.12) we write

$$(2.28) \quad \text{new } \bar{P}_n = \frac{1}{k} \sum_{j=1}^I f^j_n \phi^j_n \quad (n = 1, \dots, N-1).$$

The reader will observe that there is no bar over the P_n in (2.28).

In formula (2.28) every term on the right-hand side is known except k . We compute k by using the normalization

$$(2.29) \quad \frac{1}{V} \sum_{n=1}^{N-1} (\text{new } \bar{P}_n) \Delta V_n = 1.$$

From (2.28) and (2.29) we find

$$(2.30) \quad \frac{1}{V} \sum_{n=1}^{N-1} \sum_{j=1}^I f^j_n \phi^j_n \Delta V_n = k.$$

Now that k is defined, we have a well-defined expression (2.28) for new \bar{P}_n .

If we like, we may at once define

$$(2.31) \quad \text{new } \bar{P}_n = \text{new } P_n.$$

In fact, this is a good definition. In order to speed the convergence of our iterative process, it is sometimes desirable to generalize the definition (2.31). We introduce an acceleration-factor $a \geq 0$ and write

$$(2.32) \quad \text{new } \bar{P}_n = \text{new } P_n + a (\text{new } P_n - \text{old } \bar{P}_n).$$

If we set $a = 0$, the definition (2.32) is the same as (2.31). Since the old \bar{P}_n are normalized by (2.24), and since the new P_n are normalized by (2.29), the new \bar{P}_n defined by (2.32) will be normalized by (2.24).

Now we have a second guess for \bar{P}_n . Proceeding as we did with our first guess for \bar{P}_n , we may compute a new guess for ϕ^i_n ($n = 0, \dots, N$; $i = 1, \dots, I$). Now we may compute a second guess for k according to (2.30) and a third guess for the \bar{P}_n according to (2.28), (2.32). This iterative process may be continued until the k 's appear to be converging satisfactorily.

We must now return to an earlier stage of our discussion. We stated that, for any fixed i , the equations (2.21) could be solved for ϕ^i_n ($n = 0, \dots, N$), since (2.27) holds. We should indicate how the equations are solved in practice. Let us suppress the superscript i and rewrite (2.21), (2.26) in the form

$$(2.33) \quad \begin{cases} -a_n \phi_{n+1} + b_n \phi_n - c_n \phi_{n-1} = d_n \\ (n = 0, \dots, N) \\ \phi_{-1} = 0, \phi_{N+1} = 0. \end{cases}$$

For $n = -1, 0, \dots, N$ we introduce auxiliary quantities p_n, q_n such that

$$(2.34) \quad \begin{aligned} \phi_n &= p_n \phi_{n+1} + q_n \\ (n = N, N-1, \dots, 0, -1), \end{aligned}$$

where $\phi_{N+1} = 0$. One sees easily that (2.34) implies (2.33) provided that the quantities p_n, q_n are defined by the recursion formulas

$$(2.35) \quad \begin{cases} p_n = a_n (b_n - c_n p_{n-1})^{-1} \\ (n = 0, 1, \dots, N) \\ q_n = (d_n + c_n q_{n-1}) (b_n - c_n p_{n-1})^{-1}, \end{cases}$$

where

$$(2.36) \quad p_{-1} = 0, q_{-1} = 0.$$

In practice the quantities p_n, q_n are computed first by the forward pass (2.35). The quantities ϕ_n are then computed by the backward pass (2.34).

In evaluating the coefficients a^i_n, \dots, d^i_n according to (2.22), we make use of the assumption that the reactor is homogeneous in each of the K regions (2.14). Using the notation (2.20), we write

$$(2.37) \quad \left\{ \begin{array}{l} \Delta x_n = \Delta x_{(v)} \\ D^{i_{n+\frac{1}{2}}} = D^i_{(v)} \\ T^{i_n} = T^i_{(v)} \\ T^{ij_n} = T^{ij}_{(v)} \\ f^{j_n} = f^i_{(v)} \end{array} \right. ,$$

where

$$(2.38) \quad \begin{aligned} N_v \leq n < N_{v+1}; \quad n = 0, \dots, N-1; \\ v = 0, \dots, K-1. \end{aligned}$$

This completes our analysis in this report. The reader will observe that we do not present a theoretical discussion of the eigenvalue problem. Our aim in this report is just to explain clearly what the program DMM does.

3. PREPARATION OF INPUT. The program DMM is written for the DATATRON equipped with automatic floating point, paper-tape input and output, and Flexowriter output.

The input data are

$$(3.1) \quad \begin{aligned} I, K, N, \rho, a, x_0, B^i_0, B^i_N, N_v, \Delta x_{(v)}, \\ D^i_{(v)}, T^i_{(v)}, f^i_{(v)}, \chi^i, T^{ij}_{(v)}. \end{aligned}$$

One may or may not store an initial guess for the numbers

$$(3.2) \quad \bar{P}_n.$$

If the intial \bar{P}_n are *not* stored as data, the program will compute a first guess for the \bar{P}_n on the basis of the assumption $\phi^i_n = 1$, ($i = 1, \dots, I$; $n = 1, \dots, N-1$); in this case the first k computed is physically meaningless, and the first guess for \bar{P}_n is

$$(3.3) \quad \bar{P}_n = \frac{1}{k} \sum_{j=1}^I f^j_n \quad (n = 1, \dots, N-1),$$

where

$$(3.4) \quad k = \frac{1}{V} \sum_{m=1}^{N-1} \sum_{j=1}^I f^j_m \Delta V_m.$$

The numbers I, K, N, ρ, N_v are integers. They should be stored in absolute form. For example, if $N = 175$, the word representing N has the form + 0000 00 0175.

All the other quantities in (3.1) and (3.2) must appear in floating-point form. In floating-point form the word $\pm d_1 d_2 d_3 \dots d_{10}$ represents the number whose value is

$$\pm (10^{d_1 d_2 - 50}) \times (0.d_3 d_4 \dots d_{10}).$$

For example, if $D^i_3 = 0.006703$, the floating-point representation is $+4867030000$. If $T^i_{(2)} = 275.96384$, the floating-point representation is $+5327596384$. The number 0 is represented in floating-point by $+0000000000$. If a number is not zero, the floating-point representation $\pm d_1 d_2 d_3 \dots d_{10}$ should be written so that the digit d_3 is not zero.

The first six quantities (3.1) are stored as follows:

$$(3.5) \quad I \rightarrow 6000, K \rightarrow 6001, N \rightarrow 6002, \rho \rightarrow 6003;$$

$$(3.6) \quad a \rightarrow 3998, x_0 \rightarrow 3997.$$

The location 3999 is not used; if the physicist wishes, he may store a problem-identification number or some other number in this location.

The other quantities (3.1), (3.2) are stored as compactly as possible commencing at the end of main memory and moving toward the beginning. The program steps of DMM occupy the locations from 0000 to 0545. Therefore, the storage must occupy locations whose addresses are ≥ 546 . After this paragraph the reader will find a table which will enable him to prepare input for DMM. An example follows.

STORAGE TABLE

Quantities	Storage Length	Relative Location
$B^i_0 (1 \leq i \leq I)$	I	$i - 1$
$B^i_N (1 \leq i \leq I)$	I	$i - 1$
$N_v (1 \leq v \leq K)$	K	$v - 1$
$\Delta x_{(v)} (0 \leq v \leq K - 1)$	K	v
$D^i_{(v)} (1 \leq i \leq I, 0 \leq v \leq K - 1)$	IK	$(i - 1)K + v$
$T^i_{(v)} (1 \leq i \leq I, 0 \leq v \leq K - 1)$	IK	$(i - 1)K + v$
$f^j_{(v)} (1 \leq j \leq I, 0 \leq v \leq K - 1)$	IK	$(j - 1)K + v$
$\chi^i (1 \leq i \leq I)$	I	$i - 1$
$T^{ij}_{(v)} (1 \leq j < i \leq I, 0 \leq v \leq K - 1)$	$\frac{1}{2}I(I - 1)K$ $[\frac{1}{2}(i - 1)(i - 2) + j]K + v$	
$\bar{P}_n (1 \leq n \leq N - 1)$	$N - 1$	$n - 1$
$\phi^i_n (1 \leq i \leq I, 0 \leq n \leq N)$	$(N + 1)I$	$(i - 1)(N + 1) + n$
$p_n (0 \leq n \leq N)$	$N + 1$	n
$q_n (0 \leq n \leq N)$	$N + 1$	n
$kP_n (1 \leq n \leq N - 1)$	$N - 1$	$n - 1$

The first double line in the table appears below those quantities which must, along with the quantities (3.5), (3.6), be stored as input for every problem. The quantities \bar{P}_n may or may not be stored initially. The auxiliary quantities q_n and kP_n are bracketed because they have the same initial location. That is to say, the kP_n are written over the q_n .

The total storage length, L, can be found by adding together all the storage lengths in the table except the length $N - 1$ which belongs to kP_n . We find

$$(3.7) \quad L = 3I + 2K + 3IK +$$

$$\frac{1}{2}I(I - 1)K + (N + 1)I + 3N + 1.$$

Since the last step in the program lies in 0545, and since x_0 lies in 3997, we require

$$(3.8) \quad 545 + L \leq 3996.$$

From (3.7) and (3.8) we find formula (1.2), namely

$$(3.9) \quad 3N + 2K + [4 + N + \frac{1}{2}(I + 5)K]I \leq 3450.$$

Let us apply the storage table to an illustrative example. Suppose that we wish to run a problem for which

$$I = 10, \quad K = 3, \quad N = 40.$$

We then prepare the following chart.

EXAMPLE

Quantities	Initial Address	Storage Length	Relative Location
B^i_0	3987	10	$i - 1$
B^i_N	3977	10	$i - 1$
N_v	3974	3	$v - 1$
$\Delta x_{(v)}$	3971	3	v
$D^i_{(v)}$	3941	30	$(i - 1) \cdot 3 + v$
$T^i_{(v)}$	3911	30	$(i - 1) \cdot 3 + v$
$f^j_{(v)}$	3881	30	$(j - 1) \cdot 3 + v$
χ^i	3871	10	$i - 1$
$T^{ij}_{(v)}$	3736	135	$[\frac{1}{2}(i - 1)(i - 2) + j] \cdot 3 + v$
\bar{P}_n	3697	39	$n - 1$
ϕ^i_n	3287	410	$(i - 1) \cdot 41 + n$
p_n	3246	41	n
q_n	3205	41	n
kP_n	3205	39	$n - 1$

To prepare the chart one first marks down the quantities which are mentioned in the general storage table. One then computes the storage lengths and the relative locations from the known values of I, K, N. One obtains the initial address for the quantities B^i_0 by subtracting the length, which is 10 in this case, from 3997, which is the location in which x_0 should be stored. One computes each of the other initial addresses by subtracting the storage length from the initial address of the preceding set of quantities. For instance, the initial address for the ϕ^i_n is, in this example, 3287, which is found by subtracting length 410 from the previous initial address, 3697.

The relative location is the number of locations beyond the initial address, at which a particular quantity is stored. Suppose one would like to know where $T^{73}_{(2)}$ is stored in our example. The relative location is

$$(3.10) \quad \left[\frac{1}{2}(i-1)(i-2) + j \right] 3 + v \\ = \left[\frac{1}{2}(6)(5) + 3 \right] \cdot 3 + 2 = 56.$$

The initial location in this case is found from the chart to be 3736. Therefore, in this example,

$$(3.11) \quad T^{73}_{(2)} \rightarrow 3736 + 56 = 3792.$$

The reader will notice that the initial addresses depend on I, K, N, and therefore change from problem to problem. We need this dependence in order to use the memory efficiently. The program knows where to look for storage by computing addresses exactly as we have done in the preceding example. The addresses are automatically stored in the 6000-loop, and they are kept there for permanent reference during the entire run of a problem.

4. OPERATION OF THE PROGRAM. First the data (3.1) and possibly (3.2) are read into memory. Then the program, which appears in the last section of this report, is read in. The output switch should be set to PAGE.

In order to begin operation, we must give a command by keyboard. If initial values for \bar{P}_n are not stored, the proper command is

6 0000 30 0051.

If initial values for \bar{P}_n are stored, the proper command is

6 0000 30 0000.

In other words, one enters DMM by a command CUB 0051 or CUB 0000 according as initial \bar{P}_n are

not or are stored.

Now the computation begins. Suppose that the breakpoint switch is off. The first approximation to k is printed out, and the computation immediately proceeds to the next iteration. The next approximation to k is printed out, and so on.

The breakpoint is used by DMM in order to obtain output. At any stage of the computation one may press the STOP button, turn the breakpoint switch on to any of the three positions 1, 2, or 4, and resume computation by pressing the CONTINUOUS button. If one wishes to have the breakpoint switch on during the whole computation, he may turn it on before the computation begins.

When the breakpoint switch is on, the computer stops after a value for k is typed out. If one wishes to proceed directly to another iteration, he merely presses the CONTINUOUS button. If, instead, one wishes to obtain output, he must first decide whether he wants the output to be typed out by the Flexowriter or to be punched on paper tape; accordingly, he leaves the output switch on PAGE or sets it to TAPE. He then manually places the initial and final locations of the desired output in the A and R registers. Suppose in our example in the preceding section that one wishes to print out the ϕ^i_n . He places

+ 0000 00 3287

in the A register and places

+ 0000 00 3696

in the R register. After the initial and final addresses have been placed in the A and R registers, one presses the continuous button. The output is given, the A and R registers are cleared, and the computer stops on breakpoint. No new computation takes place. If one now desires further output, he simply repeats the process of appropriately setting the output switch, filling the A and R registers with initial and final addresses, and pressing the CONTINUOUS button.

When one desires no further output and would like to resume computation, he leaves the A and R registers clear, sees that the output switch is set to PAGE, and presses the CONTINUOUS button.

As a rule, one will prefer to take output on paper tape. When one later desires a type-out, he feeds the tape into the Flexowriter off-line, while the central computer is being used for another purpose.

When output is punched on paper tape by DMM, the tape can be used directly as input at a later date. Suppose that we are running the problem used as an example in the preceding section. Suppose that the computer has stopped on breakpoint after two iterations, and suppose that we have to leave the computer. We decide to punch out the \bar{P}_n in order to use them for input at a later date. We set the output switch

to TAPE, place + 0000 00 3697 in the A register and + 0000 00 3735 in the R register, and press the CONTINUOUS button. Tape output now begins. First, about 18 inches of blank tape are fed out. The first word put on tape is

4 0000 00 3697,

which represents the command to read into 3697. The next 39 words consist of the \bar{P}_n . The final word put on tape is

6 0000 08 0000,

which represents the command to stop and lock out further read-in. We now have a tape which can be used without modification for input of the \bar{P}_n at a later date.

If the output switch had been set to PAGE in the last paragraph, the first word typed out would have been

+ 0000 00 3697.

Then the \bar{P}_n would have been typed out, and the last

word typed out would have been

+ 0000 08 0000.

5. DATATRON CODE. The following pages contain the Datatron code for DMM. The code occupies the locations from 0000 to 0545.

The last fourteen words of the paper tape for DMM consist of a little program which reads into the 7000 loop. This program is a sum-check, which checks whether the main program is correctly read into memory. If the command

08 5555

appears in the C register after a read-in, the read-in is incorrect or the paper tape is incorrect. After a correct read-in of a properly punched paper tape, the command

08 0000

appears in the C register.

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
	4	0000 00 0000	4	PTR	0000	Enter by		
0000	0	0000 64 6000	CAD	6000	CUB 0000			
0001	0	0000 60 6001	M	6001	if \bar{P}_n are			
0002	0	0000 14 0010	SL	0010	pre-stored.			
0003	0	0000 12 4000	ST	4000	Begin			
0004	0	0000 60 6000	M	6000	computing			
0005	0	0000 14 0010	SL	0010	addresses.			
0006	0	0000 75 4000	SU	4000				
0007	0	0000 60 7016	M	7016				
0008	0	0000 02 4001	STC	4001				
0009	0	0000 64 6002	CAD	6002				
0010	0	0000 74 7017	AD	7017				
0011	0	0000 12 4002	ST	4002				
0012	0	0000 60 6000	M	6000				
0013	0	0000 14 0010	SL	0010				
0014	0	0000 02 4003	STC	4003				
0015	0	0000 30 0018	CUB	0018				
0016	0	5000 00 0000						
0017	0	0000 00 0001						
0018	0	0000 64 7036	CAD	7036				
0019	0	0000 75 6000	SU	6000				
0020	0	0000 12 6004	ST	6004				
0021	0	0000 75 6000	SU	6000				
0022	0	0000 12 6005	ST	6005				
0023	0	0000 75 6001	SU	6001				
0024	0	0000 12 6006	ST	6006				
0025	0	0000 75 6001	SU	6001				
0026	0	0000 12 6007	ST	6007				
0027	0	0000 75 4000	SU	4000				
0028	0	0000 12 6008	ST	6008				
0029	0	0000 75 4000	SU	4000				
0030	0	0000 12 6009	ST	6009				
0031	0	0000 75 4000	SU	4000				
0032	0	0000 12 6010	ST	6010				
0033	0	0000 75 6000	SU	6000				
0034	0	0000 12 6011	ST	6011				
0035	0	0000 30 0037	CUB	0037				
0036	0	0000 00 3997						

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
0037	0	0000 75 4001	SU	4001				
0038	0	0000 12 6012	ST	6012				
0039	0	0000 75 6002	SU	6002				
0040	0	0000 74 0017	AD	0017				
0041	0	0000 12 6013	ST	6013				
0042	0	0000 75 4003	SU	4003				
0043	0	0000 12 6014	ST	6014				
0044	0	0000 75 4002	SU	4002				
0045	0	0000 12 6015	ST	6015				
0046	0	0000 75 4002	SU	4002				
0047	0	0000 02 6016	STC	6016				
0048	0	0000 64 3998	CAD	3998				
0049	0	0000 02 5019	STC	5019				
0050	0	0000 30 0075	CUB	0075	All addresses have now been formed.			
0051	0	0000 64 7054	CAD	7054				
0052	0	0000 02 0048	STC	0048				
0053	0	0000 30 0000	CUB	0000	Enter by			
0054	0	0000 30 0055	CUB	0055	CUB 0051			
0055	0	0000 64 7072	CAD	7072	if \bar{P}_n are			
0056	0	0000 02 0048	STC	0048	not			
0057	0	0000 64 6013	CAD	6013	pre-stored.			
0058	0	0000 75 6014	SU	6014				
0059	0	0000 02 4000	STC	4000				
0060	0	0000 72 4000	SB	4000				
0061	0	0000 22 7062	DB	7062				
0062	0	0000 65 6014	CSU	6014				
0063	0	0000 75 7066	SU	7066				
0064	0	0000 02 7066	STC	7066				
0065	0	0000 64 7073	CAD	7073				
0066	0	0000 12 0000	ST	0000				
0067	0	0000 22 7066	DB	7066				
0068	0	0000 64 7074	CAD	7074				
0069	0	0000 02 4019	STC	4019				
0070	0	0000 02 5019	STC	5019				
0071	0	0000 30 0365	CUB	0365				
0072	0	0000 64 3998	CAD	3998				
0073	0	5110 00 0000						
0074	0	0000 00 0001						

Location	Numerical Code				Instruction			Continuity	Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.			Sign	Spare	Order	Addr.	S	Order	Addr.	
0075	0	0000	02	6017	STC	6017	Set		0107	0	0000	64	6017	CAD	6017		
0076	0	0000	02	6018	STC	6018	tallies.		0108	0	0000	74	6004	AD	6004		
0077	0	0000	02	6019	STC	6019			0109	0	0000	74	7011	AD	7011		
0078	0	0000	64	6006	CAD	6006			0110	0	0000	02	7011	STC	7011		
0079	0	0000	74	7081	AD	7081			0111	0	0000	64	0000	CAD	0000		
0080	0	0000	02	7081	STC	7081			0112	0	0000	12	4001	ST	4001		
0081	0	0000	64	0000	CAD	0000			0113	0	0000	82	5003	FM	5003		
0082	0	0000	02	5000	STC	5000			0114	0	0000	02	4002	STC	4002		
0083	0	0000	64	3997	CAD	3997			0115	0	0000	65	4001	CSU	4001		
0084	0	0000	02	5002	STC	5002			0116	0	0000	82	5005	FM	5005		
0085	0	0000	64	6007	CAD	6007			0117	0	0000	80	5005	FAD	5005		
0086	0	0000	74	7088	AD	7088			0118	0	0000	12	5010	ST	5010		
0087	0	0000	02	7088	STC	7088			0119	0	0000	80	4002	FAD	4002		
0088	0	0000	64	0000	CAD	0000			0120	0	0000	02	5011	STC	5011		
0089	0	0000	02	5003	STC	5003			0121	0	0000	20	0122	CU	0122		
0090	0	0000	30	0091	CUB	0091			0122	0	0000	31	0124	CUBR	0124		
0091	0	0000	64	6018	CAD	6018	Begin		0123	0	0000	30	0153	CUB	0153		
0092	0	0000	04	7106	CNZ	7106	computing		0124	0	0000	14	0004	SL	0004	Subroutine to compute p_n, q_n .	
0093	0	0000	02	5012	STC	5012	a_0, b_0, \dots		0125	0	0000	02	4000	STC	4000		
0094	0	0000	02	5013	STC	5013			0126	0	0000	65	5012	CSU	5012		
0095	0	0000	02	5014	STC	5014			0127	0	0000	82	5014	FM	5014		
0096	0	0000	02	5015	STC	5015			0128	0	0000	80	5011	FAD	5011		
0097	0	0000	64	6017	CAD	6017			0129	0	0000	02	4001	STC	4001		
0098	0	0000	60	6001	M	6001			0130	0	0000	64	5015	CAD	5015		
0099	0	0000	14	0010	SL	0010			0131	0	0000	82	5012	FM	5012		
0100	0	0000	74	6008	AD	6008			0132	0	0000	80	5013	FAD	5013		
0101	0	0000	74	7103	AD	7103			0133	0	0000	83	4001	FDIV	4001		
0102	0	0000	02	7103	STC	7103			0134	0	0000	02	5015	STC	5015		
0103	0	0000	64	0000	CAD	0000			0135	0	0000	64	6015	CAD	6015		
0104	0	0000	02	5005	STC	5005			0136	0	0000	74	6018	AD	6018		
0105	0	0000	30	0107	CUB	0107			0137	0	0000	30	0138	CUB	0138		
0106	0	0000	30	0191	CUB	0191											

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
0138	0	0000	74	7046	AD	7046		
0139	0	0000	12	7046	ST	7046		
0140	0	0000	75	6002	SU	6002		
0141	0	0000	75	7048	SU	7048		
0142	0	0000	02	7048	STC	7048		
0143	0	0000	64	5010	CAD	5010		
0144	0	0000	83	4001	FDIV	4001		
0145	0	0000	12	5014	ST	5014		
0146	0	0000	02	0000	STC	0000		
0147	0	0000	64	5015	CAD	5015		
0148	0	0000	00	0001				
0149	0	0000	64	4000	CAD	4000		
0150	0	0000	74	7052	AD	7052		
0151	0	0000	02	7052	STC	7052		
0152	0	0000	30	0000	CUB	0000		
0153	0	0000	64	5003	CAD	5003	n + 1	
0154	0	0000	12	5004	ST	5004	replaces n.	
0155	0	0000	80	5002	FAD	5002		
0156	0	0000	02	5002	STC	5002		
0157	0	0000	64	5005	CAD	5005		
0158	0	0000	02	5006	STC	5006		
0159	0	0000	64	6018	CAD	6018		
0160	0	0000	74	7069	AD	7069		
0161	0	0000	12	6018	ST	6018		
0162	0	0000	75	5000	SU	5000		
0163	0	0000	04	7070	CNZ	7070		
0164	0	0000	64	7069	CAD	7069		
0165	0	0000	74	6019	AD	6019		
0166	0	0000	12	6019	ST	6019		
0167	0	0000	74	6006	AD	6006		
0168	0	0000	30	0171	CUB	0171		
0169	0	0000	00	0001				
0170	0	0000	30	0191	CUB	0191		

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
0171	0	0000	74	7073	AD	7073		
0172	0	0000	02	7073	STC	7073		
0173	0	0000	64	0000	CAD	0000		
0174	0	0000	02	5000	STC	5000		
0175	0	0000	64	6007	CAD	6007		
0176	0	0000	74	6019	AD	6019		
0177	0	0000	74	7079	AD	7079		
0178	0	0000	02	7079	STC	7079		
0179	0	0000	64	0000	CAD	0000		
0180	0	0000	02	5003	STC	5003		
0181	0	0000	64	6017	CAD	6017		
0182	0	0000	60	6001	M	6001		
0183	0	0000	14	0010	SL	0010		
0184	0	0000	74	6019	AD	6019		
0185	0	0000	74	6008	AD	6008		
0186	0	0000	74	7088	AD	7088		
0187	0	0000	02	7088	STC	7088		
0188	0	0000	64	0000	CAD	0000		
0189	0	0000	02	5005	STC	5005		
0190	0	0000	30	0191	CUB	0191		
0191	0	0000	64	6002	CAD	6002		
0192	0	0000	75	6018	SU	6018		
0193	0	0000	04	7108	CNZ	7108		
0194	0	0000	02	5010	STC	5010		
0195	0	0000	02	5013	STC	5013		
0196	0	0000	64	6017	CAD	6017		
0197	0	0000	74	6005	AD	6005		
0198	0	0000	74	7100	AD	7100		
0199	0	0000	02	7100	STC	7100		
0200	0	0000	64	0000	CAD	0000		
0201	0	0000	12	4001	ST	4001		
0202	0	0000	82	5004	FM	5004		
0203	0	0000	02	4002	STC	4002		
0204	0	0000	64	6017	CAD	6017		
0205	0	0000	60	6001	M	6001		
0206	0	0000	14	0010	SL	0010		
0207	0	0000	30	0209	CUB	0209		
0208	0	0000	30	0226	CUB	0226		

Compute
a_N, b_N, ...

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
0209	0	0000	74	6001	AD	6001		
0210	0	0000	75	7025	SU	7025		
0211	0	0000	74	6008	AD	6008		
0212	0	0000	74	7014	AD	7014		
0213	0	0000	02	7014	STC	7014		
0214	0	0000	64	0000	CAD	0000		
0215	0	0000	02	4003	STC	4003		
0216	0	0000	65	4001	CSU	4001		
0217	0	0000	82	4003	FM	4003		
0218	0	0000	80	4003	FAD	4003		
0219	0	0000	12	5012	ST	5012		
0220	0	0000	80	4002	FAD	4002		
0221	0	0000	02	5011	STC	5011		
0222	0	0000	20	0223	CU	0223		
0223	0	0000	31	0124	CUBR	0124		
0224	0	0000	30	0340	CUB	0340		
0225	0	0000	00	0001				
0226	0	0000	64	5003	CAD	5003	Compute a_n, b_n, \dots $(1 \leq n \leq N-1)$.	
0227	0	0000	80	5004	FAD	5004		
0228	0	0000	82	7042	FM	7042		
0229	0	0000	02	5007	STC	5007		
0230	0	0000	64	5005	CAD	5005		
0231	0	0000	82	5007	FM	5007		
0232	0	0000	83	5003	FDIV	5003		
0233	0	0000	02	5010	STC	5010		
0234	0	0000	64	5006	CAD	5006		
0235	0	0000	82	5007	FM	5007		
0236	0	0000	83	5004	FDIV	5004		
0237	0	0000	02	5012	STC	5012		
0238	0	0000	72	6003	SB	6003		
0239	0	0000	22	7041	DB	7041		
0240	0	0000	30	0266	CUB	0266		
0241	0	0000	30	0243	CUB	0243		
0242	0	5050	00	0000				

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
0243	0	0000	64	5003	CAD	5003		
0244	0	0000	83	5002	FDIV	5002		
0245	0	0000	82	7058	FM	7058		
0246	0	0000	80	7059	FAD	7059		
0247	0	0000	02	4000	STC	4000		
0248	0	0000	65	5004	CSU	5004		
0249	0	0000	83	5002	FDIV	5002		
0250	0	0000	82	7058	FM	7058		
0251	0	0000	80	7059	FAD	7059		
0252	0	0000	02	4001	STC	4001		
0253	0	0000	64	5010	CAD	5010		
0254	0	0000	82	4000	FM	4000		
0255	0	0000	22	7054	DB	7054		
0256	0	0000	02	5010	STC	5010		
0257	0	0000	30	0260	CUB	0260		
0258	0	5050	00	0000				
0259	0	5110	00	0000				
0260	0	0000	72	6003	SB	6003		
0261	0	0000	22	7062	DB	7062		
0262	0	0000	64	5012	CAD	5012		
0263	0	0000	82	4001	FM	4001		
0264	0	0000	22	7063	DB	7063		
0265	0	0000	02	5012	STC	5012		
0266	0	0000	64	6017	CAD	6017		
0267	0	0000	60	6001	M	6001		
0268	0	0000	14	0010	SL	0010		
0269	0	0000	74	6019	AD	6019		
0270	0	0000	74	6009	AD	6009		
0271	0	0000	74	7073	AD	7073		
0272	0	0000	02	7073	STC	7073		
0273	0	0000	64	0000	CAD	0000		
0274	0	0000	82	5007	FM	5007		
0275	0	0000	82	5007	FM	5007		
0276	0	0000	30	0277	CUB	0277		

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
0277	0	0000	80	5010	FAD	5010		
0278	0	0000	80	5012	FAD	5012		
0279	0	0000	02	5011	STC	5011		
0280	0	0000	64	6017	CAD	6017		
0281	0	0000	74	6011	AD	6011		
0282	0	0000	74	7089	AD	7089		
0283	0	0000	02	7089	STC	7089		
0284	0	0000	72	6018	SB	6018		
0285	0	0000	22	7086	DB	7086		
0286	0	0000	65	6013	CSU	6013		
0287	0	0000	75	7090	SU	7090		
0288	0	0000	02	7090	STC	7090		
0289	0	0000	64	0000	CAD	0000		
0290	0	0000	82	0000	FM	0000		
0291	0	0000	02	4010	STC	4010		
0292	0	0000	72	6017	SB	6017		
0293	0	0000	22	7095	DB	7095		
0294	0	0000	30	0333	CUB	0333		
0295	0	0000	30	0296	CUB	0296		
0296	0	0000	11	0000	BA	0000		
0297	0	0000	60	6017	M	6017		
0298	0	0000	14	0010	SL	0010		
0299	0	0000	60	7111	M	7111		
0300	0	0000	60	6001	M	6001		
0301	0	0000	14	0010	SL	0010		
0302	0	0000	74	6019	AD	6019		
0303	0	0000	74	6012	AD	6012		
0304	0	0000	74	7112	AD	7112		
0305	0	0000	02	4011	STC	4011		
0306	0	0000	64	6014	CAD	6014		
0307	0	0000	74	6018	AD	6018		
0308	0	0000	74	7113	AD	7113		
0309	0	0000	02	4012	STC	4012		
0310	0	0000	30	0314	CUB	0314		
0311	0	5000	00	0000				
0312	0	0000	64	0000	CAD	0000		
0313	0	0000	82	0000	FM	0000		

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
0314	0	0000	64	6002	CAD	6002		
0315	0	0000	74	7027	AD	7027		
0316	0	0000	02	4013	STC	4013		
0317	0	0000	11	0000	BA	0000		
0318	0	0000	60	6001	M	6001		
0319	0	0000	14	0010	SL	0010		
0320	0	0000	74	4011	AD	4011		
0321	0	0000	02	7027	STC	7027		
0322	0	0000	11	0000	BA	0000		
0323	0	0000	60	4013	M	4013		
0324	0	0000	14	0010	SL	0010		
0325	0	0000	74	4012	AD	4012		
0326	0	0000	02	7028	STC	7028		
0327	0	0000	00	0001				
0328	0	0000	08	0000	STOP	0000		
0329	0	0000	80	4010	FAD	4010		
0330	0	0000	02	4010	STC	4010		
0331	0	0000	22	7017	DB	7017		
0332	0	0000	30	0333	CUB	0333		
0333	0	0000	64	4010	CAD	4010		
0334	0	0000	82	5007	FM	5007		
0335	0	0000	82	5007	FM	5007		
0336	0	0000	02	5013	STC	5013		
0337	0	0000	20	0338	CU	0338		
0338	0	0000	31	0124	CUBR	0124		
0339	0	0000	30	0153	CUB	0153		

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
0340	0	0000	65	6017	CSU	6017		
0341	0	0000	60	6002	M	6002		
0342	0	0000	14	0010	SL	0010		
0343	0	0000	75	6017	SU	6017		
0344	0	0000	75	6014	SU	6014		
0345	0	0000	75	7056	SU	7056		
0346	0	0000	02	7056	STC	7056		
0347	0	0000	65	6015	CSU	6015	Begin computing ϕ^i_n .	
0348	0	0000	75	7054	SU	7054		
0349	0	0000	02	7054	STC	7054		
0350	0	0000	65	6016	CSU	6016		
0351	0	0000	75	7055	SU	7055		
0352	0	0000	02	7055	STC	7055		
0353	0	0000	72	6002	SB	6002		
0354	0	0000	82	0000	FM	0000		
0355	0	0000	80	0000	FAD	0000		
0356	0	0000	12	0000	ST	0000		
0357	0	0000	22	7054	DB	7054		
0358	0	0000	30	0359	CUB	0359		
0359	0	0000	64	7072	CAD	7072		
0360	0	0000	12	4019	ST	4019		
0361	0	0000	74	6017	AD	6017	Reset i tally.	
0362	0	0000	12	6017	ST	6017		
0363	0	0000	75	6000	SU	6000		
0364	0	0000	04	7073	CNZ	7073		
0365	0	0000	02	4000	STC	4000		
0366	0	0000	02	4001	STC	4001		
0367	0	0000	02	6019	STC	6019		
0368	0	0000	02	6018	STC	6018		
0369	0	0000	64	3997	CAD	3997		
0370	0	0000	02	5002	STC	5002		
0371	0	0000	30	0375	CUB	0375		
0372	0	0000	00	0001				
0373	0	0000	02	4000	STC	4000		
0374	0	0000	30	0076	CUB	0076		

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
0375	0	0000	64	6006	CAD	6006		
0376	0	0000	74	7080	AD	7080		
0377	0	0000	12	7080	ST	7080		
0378	0	0000	75	6001	SU	6001		
0379	0	0000	02	7082	STC	7082		
0380	0	0000	64	0000	CAD	0000		
0381	0	0000	02	5000	STC	5000		
0382	0	0000	08	0000	STOP	0000		
0383	0	0000	02	5003	STC	5003		
0384	0	0000	64	5003	CAD	5003		
0385	0	0000	12	5004	ST	5004		
0386	0	0000	80	5002	FAD	5002		
0387	0	0000	02	5002	STC	5002		
0388	0	0000	64	6018	CAD	6018		
0389	0	0000	74	4019	AD	4019		
0390	0	0000	12	6018	ST	6018		
0391	0	0000	75	5000	SU	5000		
0392	0	0000	04	7094	CNZ	7094		
0393	0	0000	30	0395	CUB	0395		
0394	0	0000	30	0408	CUB	0408		
0395	0	0000	64	6019	CAD	6019		
0396	0	0000	74	4019	AD	4019		
0397	0	0000	12	6019	ST	6019		
0398	0	0000	74	6006	AD	6006		
0399	0	0000	74	7103	AD	7103		
0400	0	0000	12	7103	ST	7103		
0401	0	0000	75	6001	SU	6001		
0402	0	0000	02	7105	STC	7105		
0403	0	0000	64	0000	CAD	0000		
0404	0	0000	02	5000	STC	5000		
0405	0	0000	08	0000	STOP	0000		
0406	0	0000	02	5003	STC	5003		
0407	0	0000	30	0408	CUB	0408		

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
0408	0	0000	64	5003	CAD	5003		
0409	0	0000	80	5004	FAD	5004		
0410	0	0000	82	7021	FM	7021		
0411	0	0000	72	6003	SB	6003		
0412	0	0000	22	7018	DB	7018		
0413	0	0000	12	4002	ST	4002		
0414	0	0000	80	4000	FAD	4000		
0415	0	0000	02	4000	STC	4000		
0416	0	0000	02	4005	STC	4005		
0417	0	0000	30	0422	CUB	0422		
0418	0	0000	82	5002	FM	5002		
0419	0	0000	22	7018	DB	7018		
0420	0	0000	20	7013	CU	7013		
0421	0	5050	00	0000				
0422	0	0000	64	6010	CAD	6010		
0423	0	0000	74	6019	AD	6019		
0424	0	0000	74	7036	AD	7036		
0425	0	0000	02	4006	STC	4006		
0426	0	0000	64	6014	CAD	6014		
0427	0	0000	74	6018	AD	6018		
0428	0	0000	74	7037	AD	7037		
0429	0	0000	02	4007	STC	4007		
0430	0	0000	64	4019	CAD	4019		
0431	0	0000	74	6002	AD	6002		
0432	0	0000	02	4008	STC	4008		
0433	0	0000	72	6000	SB	6000		
0434	0	0000	22	7035	DB	7035		
0435	0	0000	30	0438	CUB	0438		
0436	0	0000	64	0000	CAD	0000		
0437	0	0000	82	0000	FM	0000		

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
0438	0	0000	11	0000				BA 0000
0439	0	0000	60	6001				M 6001
0440	0	0000	14	0010				SL 0010
0441	0	0000	74	4006				AD 4006
0442	0	0000	02	7048				STC 7048
0443	0	0000	11	0000				BA 0000
0444	0	0000	60	4008				M 4008
0445	0	0000	14	0010				SL 0010
0446	0	0000	74	4007				AD 4007
0447	0	0000	02	7049				STC 7049
0448	0	0000	08	0000				STOP 0000
0449	0	0000	08	0000				STOP 0000
0450	0	0000	80	4005				FAD 4005
0451	0	0000	02	4005				STC 4005
0452	0	0000	22	7038				DB 7038
0453	0	0000	30	0454				CUB 0454
0454	0	0000	64	6018				CAD 6018
0455	0	0000	75	4019				SU 4019
0456	0	0000	74	6016				AD 6016
0457	0	0000	74	7060				AD 7060
0458	0	0000	02	7060				STC 7060
0459	0	0000	64	4005				CAD 4005
0460	0	0000	12	0000				ST 0000
0461	0	0000	82	4002				FM 4002
0462	0	0000	80	4001				FAD 4001
0463	0	0000	02	4001				STC 4001
0464	0	0000	64	6002				CAD 6002
0465	0	0000	75	4019				SU 4019
0466	0	0000	75	6018				SU 6018
0467	0	0000	04	7069				CNZ 7069
0468	0	0000	30	0470				CUB 0470
0469	0	0000	30	0384				CUB 0384

Location	Numerical Code				Instruction			Continuity	Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.			Sign	Spare	Order	Addr.	S	Order	Addr.	
0470	0	0000	64	4000	CAD	4000			0503	0	0000	07	0500	PTWF	0500		
0471	0	0000	83	4001	FDIV	4001			0504	0	0000	64	7019	CAD	7019		
0472	0	0000	02	5001	STC	5001			0505	0	0000	03	8410	PTW	8410		
0473	0	0000	64	4001	CAD	4001			0506	0	0000	64	5018	CAD	5018		
0474	0	0000	83	4000	FDIV	4000			0507	0	0000	03	8010	PTW	8010		
0475	0	0000	02	5018	STC	5018	k → 5018.		0508	0	0000	07	0500	PTWF	0500	Print out k.	
0476	0	0000	72	6002	SB	6002			0509	0	0000	02	4015	STC	4015		
0477	0	0000	22	7078	DB	7078			0510	0	0007	33	0000	CR	0000		
0478	0	0000	22	7079	DB	7079			0511	0	0000	02	4000	STC	4000		
0479	0	0000	64	7084	CAD	7084			0512	0	0000	14	0010	SL	0010		
0480	0	0000	80	5019	FAD	5019			0513	0	0000	04	7015	CNZ	7015		
0481	0	0000	02	4010	STC	4010			0514	0	0000	30	0048	CUB	0048		
0482	0	0000	65	6016	CSU	6016			0515	0	0000	75	4000	SU	4000		
0483	0	0000	30	0485	CUB	0485			0516	0	0000	02	4001	STC	4001		
0484	0	5110	00	0000					0517	0	0000	72	7020	SB	7020		
0485	0	0000	75	7095	SU	7095			0518	0	0000	30	0521	CUB	0521		
0486	0	0000	02	7095	STC	7095			0519	0	2772	30	2427				
0487	0	0000	65	6013	CSU	6013			0520	0	0000	00	0200				
0488	0	0000	75	7100	SU	7100			0521	0	0000	07	0100	PTWF	0100		
0489	0	0000	02	7100	STC	7100			0522	0	0000	22	7021	DB	7021		
0490	0	0000	65	6013	CSU	6013			0523	0	0000	64	4000	CAD	4000		
0491	0	0000	75	7098	SU	7098			0524	0	0000	13	0004	SR	0004	Output subroutine.	
0492	0	0000	02	7098	STC	7098			0525	0	0000	64	7040	CAD	7040		
0493	0	0000	64	4010	CAD	4010			0526	0	0000	01	0000	CIRA	0000		
0494	0	0000	82	5001	FM	5001			0527	0	0000	14	0004	SL	0004		
0495	0	0000	82	0000	FM	0000			0528	0	0000	03	8510	PTW	8510		
0496	0	0000	02	4011	STC	4011			0529	0	0000	72	7026	SB	7026		
0497	0	0000	65	5019	CSU	5019			0530	0	0000	65	4000	CSU	4000		
0498	0	0000	82	0000	FM	0000			0531	0	0000	75	7033	SU	7033		
0499	0	0000	80	4011	FAD	4011			0532	0	0000	02	7033	STC	7033		
0500	0	0000	02	0000	STC	0000			0533	0	0000	64	0000	CAD	0000		
0501	0	0000	22	7093	DB	7093			0534	0	0000	03	8510	PTW	8510		
0502	0	0000	30	0503	CUB	0503			0535	0	0000	11	0000	BA	0000		
									0536	0	0000	75	4001	SU	4001		
									0537	0	0000	32	0000	IB	0000		
									0538	0	0000	04	7033	CNZ	7033		
									0539	0	0000	30	0541	CUB	0541		
									0540	0	4000	00	0000				

Location	Numerical Code				Instruction			Continuity
	Sign	Spare	Order	Addr.	S	Order	Addr.	
0541	0	0000	64	7045		CAD	7045	
0542	0	0000	01	0000		CIRA	0000	
0543	0	0000	03	8510		PTW	8510	
0544	0	0000	30	0509		CUB	0509	
0545	0	6000	00	8000				
7000	0	0000	72	7010	4	PTR	7000	
7001	0	0000	02	7000		SB	7010	
7002	1	0000	74	0000	1	STC	7000	
7003	0	0000	28	7004		AD	0000	
7004	0	0000	22	7002		CC	7004	
7005	0	0000	75	7011		DB	7002	
7006	0	0000	28	7007		SU	7011	Sum Check.
7007	0	0000	04	7009		CC	7007	
7008	0	0000	08	0000		CNZ	7009	
7009	0	0000	08	5555		STOP	0000	
7010	0	0000	00	0545		STOP	5555	
7011	0	3483	62	4191	6	CU	7000	
	6	0000	20	7000				

6. FLOW CHART.







