EXPERIMENTAL AND THEORETICAL INVESTIGATION OF THE DIFFUSION LENGTH OF THERMAL NEUTRONS IN GRAPHITE

by

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LIST OF SYMBOLS

a	extrapolated x dimension of pile.
b	extrapolated y dimension of pile.
B_m^2	material buckling of loaded pile.
B_G^2	geometric buckling of pile.
c	extrapolated z dimension of pile, measured from source.
d	extrapolated z dimension of multiplying lattice.
D	diffusion coefficient.
f_i	fraction of source neutrons in ith energy group.
f	thermal utilization.
J	neutron current, neutrons per cm^2 - second.
k_∞	multiplication factor in an infinite reactor.
k_{eff}	effective multiplication factor in a finite reactor.
L	diffusion length of thermal neutrons.
L_t	lattice diffusion length.
L_r	reflector diffusion length.
q	slowing down density, neutrons per cm^3 per second.
r_i	Gaussian range of neutrons in the ith energy group.

Greek Letters

γ_{mn}	reciprocal relaxation length of the mnth mode of the flux.
δ	reflector savings.
ϵ	fast fission factor.
η	fast neutrons produced per thermal fission.

LIST OF SYMBOLS (concl.)

κ	ratio of absorption cross section to diffusion coefficient.
λ_{tr}	transport mean free path.
Σ_a	macroscopic absorption cross section.
τ	Fermi age.
ϕ	thermal neutron flux, neutrons per cm^2 - second.
ϕ_{corr}	thermal neutron flux corrected for harmonics and end effects.

INTRODUCTION

The diffusion length of thermal neutrons in a moderating medium is a necessary parameter in most reactor calculations. The determination of this constant is, however, subject to the assumption of a particular mathematical model. The types of solutions most widely used can be classified in two broad categories: 1) One-group diffusion, in which all source neutrons are considered born at thermal energy. In this case the source is treated as a boundary condition on the thermal diffusion equation. 2) Age-diffusion, in which Fermi age theory is used to describe the source term in the thermal diffusion equation as the slowing down density from a source of high energy neutrons.

Discussions of one-group diffusion theory using specific thermal source boundary conditions can be found in several references (1, 10, 13, 25). Descriptions of age-diffusion can be found in references (5, 17, 18). A paper written by Wallace and LeCaine (31) presents mathematical solutions to the neutron diffusion problem in several geometries and subject to several different source considerations. Lee (15), of Hanford, discusses techniques designed to correct for the effect of various inhomogenieties in the moderating medium.

The most elementary technique used in the determination of diffusion length is to use the negative reciprocal of the slope of a plot of $\ln \phi$ vs. z for data taken in an exponential, or sigma pile. This simple analysis is described by Hoag (13) and assumes an infinite moderating medium and thereby avoids consideration of the higher harmonics of the flux function. Glasstone and Edlund (11) describe a harmonic analysis procedure whereby the higher harmonics may be taken into account.

Methods used in this work include two different assumed thermal source boundary conditions; a method whereby consideration of the source condition is avoided completely, and a method which calculates a series of constants which would result from a fictitious thermal source equivalent to the existing fast source. Two approaches based on age-diffusion were used; 1) the assumption of a monoenergetic fast point source, and 2) the use of an empirically determined Gaussian range source which gives a closer approximation to the Pu-Be spectrum than a monoenergetic source. Results of each method are compared, and the extent of validity of the approximations discussed.

Previous work at Kansas State University leading to this work has been the determination of the Fermi age of Pu-Be neutrons both from theory and experiment by Steichen (26) and the empirical fit of a sum of exponential terms to the slowing down density in the KSU pile by Foulke (9).

THEORY

One-Group Diffusion Model

The theory of thermal neutron diffusion has been studied by many investigators (1, 10, 11, 16). The following paragraphs will serve to outline the basic theory with particular attention to the assumptions involved.

The change in neutron density in a volume element of a moderating medium is the result of (a) the net flow of neutrons through the boundary of the element, (b) the number of neutrons absorbed by the medium per unit time, and (c) the production of neutrons by sources within the element. Assuming Fick's law to be valid, the neutron current, defined as the number of neutrons per second flowing through a unit area normal to the direction of flow, can be expressed as

$$J = -D \text{ grad } \phi. \tag{1}$$

The net flow of neutrons into a volume element can be written in terms of the current as

$$-\text{div } J = \text{div } (D \text{ grad } \phi).$$

Assuming D, the diffusion coefficient, to be independent of position, it can be factored out of the above expression. Thus the leakage term can be written $D\nabla^2\phi$ and the equation of continuity becomes

$$D\nabla^2\phi - \Sigma_a \phi + S = \frac{\partial n}{\partial t} \tag{2}$$

For the purpose of this work, only steady state diffusion will be considered. The neutron source will be treated as a boundary condition in thermal source theory so that Eq. (2) becomes

$$D\nabla^2\phi - \Sigma_a \phi = 0. \tag{3}$$

Dividing both terms of (3) by D and defining $\frac{\Sigma_a}{D}$ as κ^2 results in the equation

$$\nabla^2 \phi - \kappa^2 \phi = 0 \tag{4}$$

where $\kappa^2 = \frac{\Sigma_a}{D} = \frac{1}{L^2}$.

Conditions not previously mentioned which are necessary to the validity of elementary diffusion theory include the following:

1. There are no collisions between neutrons, which means that each neutron diffuses independently of all others. Weinberg and Wigner (32), and Hughes (14) point out the importance of this property due to the resulting simplification of the mathematics involved.

2. The neutrons diffuse with a constant (average) energy and no energy is gained or lost (on the average) in a collision with a nucleus. This assumption is supported by Hughes (14) who states that experimental evidence indicates that the Maxwellian distribution is maintained reasonably well throughout the diffusion process.

3. The flux is a slowly varying function throughout the pile, with no sharp dips or spikes. This assumption is essential to the validity of Fick's law, and means that diffusion theory is not applicable in close proximity to concentrated sources, absorbers, or the boundaries of the diffusing medium. It is also necessary that the medium be only slightly absorbing, since a high absorption cross

section would cause the neutron density to vary substantially within one mean-free path.

4. The neutron scattering is spherically symmetric or isotropic, allowing the velocity vector to be treated as a scalar in the equation of continuity. Since scattering is not isotropic near sources, boundaries, and absorbers, this assumption necessitates restrictions similar to those stated in condition (3).

The solution of Eq. (4) in rectangular geometry, with the origin at the source location, is derived in Appendix A, and given here as

$$\phi(x,y,z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} A_{mn} \cos \frac{m\pi x}{a} \cos \frac{n\pi y}{b} \sinh \gamma_{mn}(c-z) \qquad (5)$$

where m and n are odd, and where a, b, and c are the extrapolated x, y, and z dimensions of the pile. The auxiliary separation constants equation is

$$-\alpha_m^2 - \beta_n^2 + \gamma_{mn}^2 = \kappa^2 \qquad (6)$$

where

$$\alpha_m = \frac{m\pi}{a}$$

$$\beta_n = \frac{n\pi}{b} .$$

Equation (5) is derived with the origin at the center of the source plane. The constants A_{mn} may be determined analytically, through the use of a particular source boundary condition, or experimentally.

Point Thermal Source. Numerous investigators (5, 6, 22, 23) have used the assumption of a point source of thermal neutrons at the location of the physical source in diffusion length experiments. Other investigators (3, 7) have used several point sources superimposed upon one another to describe the thermal flux in a diffusing medium.

The application of the point thermal source condition involves the use of the Dirac delta function (11). By expanding the source in a series of orthogonal functions which satisfy the boundary conditions, $S\,\delta(x, y)$ at $z = 0$ can be written

$$S\,\delta(x,y) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} S_{mn} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b} \tag{7}$$

where m and n are odd. The S_{mn}'s may be regarded as sources for each mode of the flux. To obtain the values of the S_{mn}'s, each side of Eq. (7) should be multiplied by $\cos\frac{p\pi x}{a}\ \cos\frac{q\pi y}{b}$ and integrated over the interval of orthogonality, from $-\frac{a}{2}$ to $\frac{a}{2}$ and $-\frac{b}{2}$ to $\frac{b}{2}$. By virtue of the Dirac delta function, the left-hand side of Eq. (7) will reduce to S. Due to the principles of orthogonal functions the right side will become S_{mn} times one-half the orthogonality interval in each of the x and y directions, giving

$$S_{mn} = \frac{4S}{ab}. \tag{8}$$

Since only positive values of z will be used in this work, the current density in any one mode will be equal to one-half the total number of neutrons produced in that mode. The current density in the mn mode can be found by using Fick's law, Eq. (1), and the expression for the thermal flux, Eq. (5), to give

$$J_{mn} = -D\left(\frac{\partial \phi_{mn}}{\partial z}\right)_{z=0} = D\gamma_{mn} A_{mn} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b} \cosh\gamma_{mn}(c-z) \qquad (9)$$

$$m,\ n \ \text{odd}$$

Setting this expression equal to half the number of neutrons emitted by the source in the mn mode,

$$\frac{2S}{ab} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b} ,$$

results in an expression for A_{mn},

$$A_{mn} = \frac{2S}{ab\, D\, \gamma_{mn} \cosh\gamma_{mn} c} . \qquad (10)$$

Substituting Eq. (10) into Eq. (5) will give an expression for the flux due to a point source of thermal neutrons located at the origin of the co-ordinate system

$$\phi(x,y,z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{2S}{ab\, D\, \gamma_{mn}} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b} \frac{\sinh\gamma_{mn}(c-z)}{\cosh\gamma_{mn} c} \qquad (11)$$

where m and n are odd.

If a single point source is located at some arbitrary position $(x_i, y_i, 0)$ in the xy plane, then the integration of

$$S \int_{-a/2}^{a/2} \int_{-b/2}^{b/2} \delta(x_i, y_i) \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b}\, dx\, dy$$

would result in $S \cos\frac{m\pi x_i}{a} \cos\frac{n\pi y_i}{b}$. Since x_i and y_i are constants, these cosine terms would carry through the analysis so that

$$A_{mn} = \frac{2\,S \cos \frac{m\pi x_i}{a} \cos \frac{n\pi y_i}{b}}{ab\,D\,\gamma_{mn} \cosh \gamma_{mn} c} .$$

For N sources located at various positions throughout the xy plane, superposition of fluxes yields

$$A_{mn} = \sum_{i=1}^{N} \frac{2\,S \cos \frac{m\pi x_i}{a} \cos \frac{n\pi y_i}{b}}{ab\,D\,\gamma_{mn} \cosh \gamma_{mn} c} . \tag{12}$$

An equation describing the flux due to N point thermal sources located in the xy plane is then

$$\phi(x,y,z) = \sum_{i=1}^{N} \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{2\,S}{ab\,D\,\gamma_{mn}} \cos \frac{m\pi x_i}{a} \cos \frac{n\pi y_i}{b}$$

$$\cos \frac{m\pi x}{a} \cos \frac{n\pi y}{b} \frac{\sinh \gamma_{mn}(c - z)}{\cosh \gamma_{mn} c} \tag{13}$$

where m and n are odd.

To determine κ from Eq. (5) it is necessary to determine γ_{11} (or any other of the γ_{mn}'s). In order to accomplish this purpose the hyperbolic functions in Eq. (11) can be rewritten as

$$\phi(x,y,z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{2\,S}{ab\,D\,\gamma_{mn}} \cos \frac{m\pi x}{a} \cos \frac{n\pi y}{b}\, e^{-\gamma_{mn} z} \left[\frac{1 - e^{-2\gamma_{mn}(c-z)}}{1 + e^{-2\gamma_{mn} c}} \right] , \tag{14}$$

where m and n are odd.

It is desired to express the flux simply in the form

$$\phi(x, y, z) = C_H \, C_E \; e^{-\gamma_{11} z} \tag{15}$$

so that a linear least squares fit of $\ln\phi$ vs. z will have a slope equal to minus γ_{11}. In order to write Eq. (14) in the form of Eq. (15) it is necessary to factor the fundamental mode, $m = n = 1$, out of the summation. Defining

$$C_E = \left[\frac{1 - e^{-2\gamma_{11}(c - z)}}{1 - e^{-2\gamma_{11} c}} \right], \tag{16}$$

Eq. (14) can be written

$$\phi(x, y, z) = \frac{2S}{ab\,D\,\gamma_{11}} \cos\frac{\pi x}{a} \cos\frac{\pi y}{b} \, e^{-\gamma_{11} z} \, C_E \left\{ 1 + \frac{\displaystyle\sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{\gamma_{11}}{\gamma_{mn}} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b} \, e^{-\gamma_{mn} z} \left[\frac{1 - e^{-2\gamma_{mn}(c-z)}}{1 + e^{-2\gamma_{mn} c}} \right]}{C_E \cos\frac{\pi x}{a} \cos\frac{\pi y}{b}} \right\} \tag{17}$$

where m and n are odd, but not simultaneously equal to one. Thus, C_H for a point thermal source is defined by

$$C_H = 1 + \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{\gamma_{11} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b} \, e^{-\gamma_{mn} z} \left[\dfrac{1 - e^{-2\gamma_{mn}(c-z)}}{1 + e^{-2\gamma_{mn} c}} \right]}{\gamma_{mn} \, C_E \cos\frac{\pi x}{a} \cos\frac{\pi y}{b}} \tag{18}$$

where m and n are odd, but not simultaneously equal to one. The fundamental mode end correction factor, C_E, and the composite end and harmonic correction factor, C_H, for the point thermal source boundary condition are listed in Table 1, along with the corresponding correction factors for all other boundary conditions discussed in this paper.

The correction factors derived above are used in an iteration procedure for determination of an accurate value of γ_{11} starting from an initial estimate of γ_{11}. The initial value can be determined from a semi-log plot of neutron count rates vs. z . The steps in the iteration procedure are:

1. Using the initial estimate, $(\gamma_{11})_1$, C_E and C_H are calculated for each data point in a series of measurements along any vertical axis in the pile.

2. A series of corrected count rates is calculated according to $\phi_{corr} = \frac{\phi}{C_E \, C_H}$.

3. The corrected count rates are used to obtain a new value, $(\gamma_{11})_2$, as the least squares slope of $\ell n \, \phi_{corr}$ vs. z.

4. The new value, $(\gamma_{11})_2$, is compared with $(\gamma_{11})_1$, the value used to calculate the correction factors C_E and C_H. If the difference is not within a previously determined precision, $(\gamma_{11})_2$ replaces $(\gamma_{11})_1$ in step one and new correction factors are calculated leading to a third value, $(\gamma_{11})_3$. The precision is again checked until two successive values of γ_{11} are within the desired precision.

5. When a final value of γ_{11} has been obtained, it is used in Eq. (6) to calculate the diffusion length.

SOURCE BOUNDARY CONDITION	C_H *	C_E
POINT THERMAL	$1+\dfrac{\sum_m\sum_n \frac{\gamma_{11}}{\gamma_{mn}} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b}\, e^{-\gamma_{mn} z}\left[\frac{1-e^{-2\gamma_{mn}(c-z)}}{1+e^{-2\gamma_{mn} c}}\right]}{C_E \cos\frac{\pi x}{a} \cos\frac{\pi y}{b}\, e^{-\gamma_{11} z}}$	$\left\{\dfrac{1-e^{-2\gamma_{11}(c-z)}}{1+e^{-2\gamma_{11} c}}\right\}$
CONSTANT THERMAL	$1+\dfrac{\sum_m\sum_n \left(\frac{1}{mn}\right)(-1)^{\frac{m+n+2}{2}} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b}\, e^{-\gamma_{mn} z}\overset{C_E^{mn}}{\left[\frac{1-e^{-2\gamma_{mn}(c-z)}}{1-e^{-2\gamma_{mn} c}}\right]}}{C_E \cos\frac{\pi x}{a} \cos\frac{\pi y}{b}\, e^{\gamma_{11} z}}$	$\left\{\dfrac{1-e^{-2\gamma_{11}(c-z)}}{1-e^{-2\gamma_{11} c}}\right\}$
DOUBLE ITERATION	$1+\dfrac{\sum_m\sum_n A_{mn} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b}\, e^{\gamma_{mn}(c-z)}\left[1-e^{-2\gamma_{mn}(c-z)}\right]}{C_E \cos\frac{\pi x}{a} \cos\frac{\pi y}{b}\, e^{\gamma_{11}(c-z)}}$ A_n	$\left\{1-e^{-2\gamma_{11}(c-z)}\right\}$
MONOENERGETIC FAST SOURCE	$1+\dfrac{\sum_m\sum_n \frac{\gamma_{11}}{\gamma_{mn}} e^{\kappa^2\tau} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b}\left\{e^{-\gamma_{mn} z}\left[1+\operatorname{erf}\left(\frac{z}{2\sqrt{\tau}}-\gamma_{mn}\sqrt{\tau}\right)\right]+e^{\gamma_{mn} z}\left[1-\operatorname{erf}\left(\frac{z}{2\sqrt{\tau}}+\gamma_{mn}\sqrt{\tau}\right)\right]\right\}\left(1-e^{-2\gamma_{mn}(c-z)}\right)}{C_E\, e^{\kappa^2\tau} \cos\frac{\pi x}{a} \cos\frac{\pi y}{b}\left\{e^{-\gamma_{11} z}\left[1+\operatorname{erf}\left(\frac{z}{2\sqrt{\tau}}-\gamma_{11}\sqrt{\tau}\right)\right]+e^{\gamma_{11} z}\left[1-\operatorname{erf}\left(\frac{z}{2\sqrt{\tau}}+\gamma_{11}\sqrt{\tau}\right)\right]\right\}}$	$\left\{1-e^{-2\gamma_{11}(c-z)}\right\}$
GAUSSIAN RANGE EMPIRICAL SOURCE	$1+\dfrac{\sum_i\sum_m\sum_n \frac{\gamma_{11}}{\gamma_{mn}} f_i e^{\frac{\kappa^2 r_i^2}{4}} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b}\left\{e^{-\gamma_{mn} z}\left[1+\operatorname{erf}\left(\frac{z}{r_i}-\frac{\gamma_{mn} r_i}{2}\right)\right]+e^{\gamma_{mn} z}\left[1-\operatorname{erf}\left(\frac{z}{r_i}+\frac{\gamma_{mn} r_i}{2}\right)\right]\right\}\left(1-e^{-2\gamma_{mn}(c-z)}\right)}{C_E \sum_i f_i e^{\frac{\kappa^2 r_i^2}{4}} \cos\frac{\pi x}{a} \cos\frac{\pi y}{b}\left\{e^{-\gamma_{11} z}\left[1+\operatorname{erf}\left(\frac{z}{r_i}-\frac{\gamma_{11} r_i}{2}\right)\right]+e^{\gamma_{11} z}\left[1-\operatorname{erf}\left(\frac{z}{r_i}+\frac{\gamma_{11} r_i}{2}\right)\right]\right\}}$	$\left\{1-e^{-2\gamma_{11}(c-z)}\right\}$
	* $\underline{m}$ AND $\underline{n}$ ARE ODD, AND NOT SIMULTANEOUSLY EQUAL TO ONE.	

Table 1. Harmonic and end correction factors for methods studied.

An IBM 650 program for the determination of the diffusion length by the above method is described in Appendix C.

Constant Thermal Source. The assumption of a constant source of thermal neutrons in the xy plane at $z = 0$ is not often used since it is an obviously poor geometric assumption in most cases. It is included here primarily for purposes of comparison.

To determine an expression for A_{mn} based on a constant source of thermal neutrons let $z = 0$ in Eq. (5), and let $\phi(x,y,0) = \phi_0$. Thus,

$$\phi_0 = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} A_{mn} \cos \frac{m\pi x}{a} \cos \frac{n\pi y}{b} \sinh \gamma_{mn} c \tag{19}$$

where m and n are odd. As for the point thermal source, multiplying both sides of the equation by $\cos \frac{p\pi x}{a} \cos \frac{q\pi y}{b}$ and integrating over the interval of orthogonality yields

$$\frac{4\phi_0 a b}{mn\pi^2} (-1)^{\frac{m+n+2}{2}} = A_{mn} \sinh \gamma_{mn} c \left(\frac{ab}{4}\right).$$

The resulting expression for A_{mn} is

$$A_{mn} = \frac{16\phi_0 (-1)^{\frac{m+n+2}{2}}}{mn\pi^2 \sinh \gamma_{mn} c}. \tag{20}$$

Substituting Eq. (20) into Eq. (5) gives an expression for the flux due to a constant thermal source as

$$\phi(x,y,z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{16\phi_0 (-1)^{\frac{m+n+2}{2}}}{mn\pi^2 \sinh \gamma_{mn} c} \cos \frac{m\pi x}{a} \cos \frac{n\pi y}{b} \sinh \gamma_{mn}(c-z) \tag{21}$$

where m and n are odd.

Using the same procedure outlined in the section dealing with the point thermal source boundary condition, correction factors C_E and C_H can be derived from Eq. (21), and the flux expressed in the form of Eq. (15). These correction factors may then be used in an iteration procedure identical to that described previously to determine the diffusion length based upon the assumption of a constant thermal source. The correction factors C_E and C_H for this case are listed in Table 1.

An IBM 650 program for the determination of diffusion length by the above method is described in Appendix D.

Ratio Method. In the use of the ratio method, no source boundary condition need be assumed. This method was originally presented by Uhrig (29) in 1959.

The procedure involves the application of orthogonality conditions to Eq. (5). Multiplying both sides of Eq. (5) by $\cos\frac{\pi x}{a} \cos\frac{\pi y}{b}$ and integrating over the interval of orthogonality yields

$$\int_{-a/2}^{a/2} \int_{-b/2}^{b/2} \phi(x,y,z_1) \cos\frac{\pi x}{a} \cos\frac{\pi y}{b}\, dx\, dy = A_{11} \frac{ab}{4} \sinh \gamma_{11}(c - z_1) \tag{22}$$

where z_1 is held constant. If the left side of Eq. (22) is defined as $F_{11}(z_1)$, then

$$F_{11}(z_1) \equiv \int_{-a/2}^{a/2} \int_{-b/2}^{b/2} \phi(x,y,z_1) \cos\frac{\pi x}{a} \cos\frac{\pi y}{b}\, dx\, dy. \tag{23}$$

$F(z_1)$ can be evaluated by using numerical integration techniques such as Simpson's rule. If this integration is performed at two different levels z_1 and z_2 the ratio of $F_{11}(z_1)$ to $F_{11}(z_2)$ can be written

$$\frac{F_{11}(z_1)}{F_{11}(z_2)} = \frac{\sinh \gamma_{11}(c - z_1)}{\sinh \gamma_{11}(c - z_2)} .$$

By expanding the hyperbolic functions in terms of exponentials the above equation becomes

$$\frac{F_{11}(z_1)}{F_{11}(z_2)} = e^{-\gamma_{11}(z_1 - z_2)} \left[\frac{1 - e^{-2\gamma_{11}(c-z_1)}}{1 - e^{-2\gamma_{11}(c-z_2)}} \right] . \qquad (24)$$

Assuming the bracketed term in Eq. (24) to be equal to one, a first approximation of γ_{11} is

$$\gamma_{11} = \frac{1}{z_2 - z_1} \ln \left[\frac{F_{11}(z_1)}{F_{11}(z_2)} \right] \qquad (25)$$

Using an initial estimate provided by Eq. (25) an iterative procedure based upon Eq. (24) can be set up to solve for γ_{11}. IBM 650 programs for the evaluation of $F_{11}(z)$ and for the iterative solution for γ_{11} are described in Appendix E.

Double Iteration Method. Previous methods described have used assumed source boundary conditions to evaluate the constants A_{mn} in Eq. (5). In the ratio method described here, the evaluation of these constants was avoided completely. The double iteration method evaluates the constants A_{mn} experimentally.

To express each of the constants A_{mn} in a form in which they may be readily calculated both sides of Eq. (5) should be multiplied by $\cos\frac{p\pi x}{a}\cos\frac{q\pi y}{b}$, and integrated over the interval of orthogonality. Thus,

$$\int_{-a/2}^{a/2}\int_{-b/2}^{b/2}\phi(x,y,z)\cos\frac{p\pi x}{a}\cos\frac{q\pi y}{b}\,dx\,dy = A_{pq}\frac{ab}{4}\sinh\gamma_{pq}(c-z). \tag{26}$$

Defining F_{pq} as

$$F_{pq} = \int_{-a/2}^{a/2}\int_{-b/2}^{b/2}\phi(x,y,z)\cos\frac{p\pi x}{a}\cos\frac{q\pi y}{b}\,dx\,dy,$$

the constant A_{pq} can be written

$$A_{pq} = \frac{4F_{pq}}{ab\sinh\gamma_{pq}(c-z)}. \tag{27}$$

F_{pq} can be evaluated, using numerical integration techniques, from data taken at several points at a given elevation in the pile. Hence, it is possible to evaluate any constant A_{pq} subject to an initial assumption of γ_{11}.

The double iteration process may be described as follows:

1. The values of the constants A_{pq} are calculated using an initial estimate of γ_{11}.

2. Using these values of A_{pq}, correction factors C_E and C_H, derived in the same manner as those for the point thermal source and listed in Table 1, can be calculated. Thus

a correction factor iteration identical to that described previously can be used to determine a more accurate value of γ_{11}.

3. The value of γ_{11} obtained from the correction factor iteration process is then compared with the value used to calculate the constants A_{pq}. If the two values are not within a specified precision, the new value of γ_{11} resulting from the correction factor iteration process is used to calculate another set of A_{pq}'s.

4. The new set of A_{pq}'s is used in another correction factor iteration process to obtain a third value of γ_{11}.

5. The comparison described in step (3) is again made, and the process is repeated until the precision check is satisfied.

An IBM 650 program written to perform the double iteration analysis is described in Appendix F.

Experimental Pile Size. An experimental method of determining the effective x and y dimensions of a sub-critical assembly is outlined by Babb, et. al. (3). This method involves a trial and error solution for the effective pile size.

The variation of the thermal flux along the x axis where y = 0 and z = constant, is described by

$$\phi(x) = \sum_{n=1}^{\infty} A_n \cos \frac{n \pi x}{a}, \tag{28}$$

where n is odd, and where a represents the effective x dimension of the pile. Assuming a value of a, least squares values of the constants A_n can be calculated, along with the error squared of the least squares fit. The best value of a is found by changing the initial estimate by an increment Δa until a minimum is found in the curve of error squared versus a. An IBM 650 program written to perform this analysis using a variable number of harmonics is described in Appendix G.

Age-Diffusion Model

In all of the previously described methods, the source neutrons were assumed to be of thermal energy. In actual practice, however, sources are used which produce neutrons of much higher energies. To account for this discrepancy, a combination of Fermi age theory and thermal diffusion theory is used. Fermi (18) used age - diffusion theory to describe the thermal flux due to a plane source of fast neutrons in a semi-infinite medium. Discussions of the application of age-diffusion theory to the determination of diffusion length can be found in several references (5, 7, 17).

The continuity equation for steady state thermal neutron diffusion is

$$\nabla^2 \phi - \kappa^2 \phi + \frac{S}{D} = 0. \tag{29}$$

Assuming a point source of fast neutrons, the source term in Eq. (29) can be described in terms of the thermal slowing down density, $q_{th}(r, \tau)$. The slowing down density is defined as the number of neutrons being slowed to thermal energy per unit volume per second, and is a function of the distance from the source and the age to thermal of the source neutrons.

Substituting this quantity into Eq. (29) gives

$$\nabla^2 \phi - \kappa^2 \phi + \frac{q_{th}(r, \tau)}{D} = 0 \tag{30}$$

The slowing down density, q_{th}, is described by the Fermi age equation

$$\nabla^2 q(r, \tau) = \frac{\partial q(r, \tau)}{\partial \tau} \tag{31}$$

The solution of Eqs. (30) and (31) for an infinitely tall rectangular parallelepiped is derived in Appendix B and stated here as

$$\phi(x,y,z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{Q_0}{\gamma_{mn} ab\, D}\, e^{\kappa^2 \tau} \cos \frac{m \pi x}{a} \cos \frac{n \pi y}{b} \left[e^{-\gamma_{mn} z} \left\{ 1 + \operatorname{erf}\left(\frac{z}{2\sqrt{\tau}} - \gamma_{mn} \sqrt{\tau} \right) \right\} + e^{\gamma_{mn} z} \left\{ 1 - \operatorname{erf}\left(\frac{z}{2\sqrt{\tau}} + \gamma_{mn} \sqrt{\tau} \right) \right\} \right] \tag{32}$$

where m and n are odd. Q_0 is the source strength in neutrons per second and τ is the age to thermal of the source neutrons.

Monoenergetic Fast Source. Equation (32) describes the thermal flux due to a point source of monoenergetic neutrons. This relationship can be used in two different ways to determine the diffusion length (7, 17). First, corrections to the original C_E and C_H for the point thermal source may be derived.

Second, Eq. (32) may itself be written in the form of Eq. (15)

$$\phi = C_E C_H e^{-\gamma_{11} z} \tag{15}$$

The second and more direct method will be used in this work.

On the basis of Eq. (32) the harmonic correction factor, C_H, can be derived by a procedure analogous to that outlined for the point thermal source. Since Eq. (32) is based upon an infinitely tall pile, C_E cannot be derived in the usual manner. Davenport, et. al. (7) state that an appropriate end correction would be the same as that used in thermal source theory. It was therefore decided to include the terms

$$(1 - e^{-2\gamma_{mn}(c-z)})$$

in Eq. (32). This provides an end correction for each mode of the flux such as would result from replacing an exponential function (which approaches zero as z approaches infinity) by an hyperbolic function (which can be made equal to zero at a finite value of z). Thus the boundary condition that the flux go to zero at a finite value of z can be met intuitively. The correction factors C_E and C_H for the monoenergetic fast source condition are listed in Table I. An IBM 650 program, written to determine the diffusion length using these correction factors, is included in Appendix H.

Gaussian Range Empirical Source. The energy spectrum of Pu-Be sources, shown in Fig. 1, indicates that these sources are definitely not monoenergetic. This fact introduces a difference in the slowing down density from that expected from a monoenergetic fast source.

The one dimensional solution to the Fermi age equation for a monoenergetic point source of fast neutrons at the origin of an infinite column of rectangular sides a and b is derived in Appendix B and given here as

$$q(z,\tau) = \frac{4Q_0}{ab\sqrt{4\pi\tau}} \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} e^{-\pi^2\tau\left(\frac{m^2}{a^2}+\frac{n^2}{b^2}\right)} e^{-\frac{z^2}{4\tau}}$$

where m and n are odd. Defining

$$c = \frac{4}{ab\sqrt{4\pi\tau}} \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} e^{-\pi^2\tau\left(\frac{m^2}{a^2}+\frac{n^2}{b^2}\right)} ,$$

the expression for slowing down density becomes

$$q(z,\tau) = Q_0 c\, e^{-\frac{z^2}{4\tau}} \tag{33}$$

for a monoenergetic fast source.

The $\sqrt{\tau}$ is often refered to as the slowing down length. The quantity $2\sqrt{\tau}$ will be referred to as the Gaussian range denoted by

$$r = 2\sqrt{\tau} \tag{34}$$

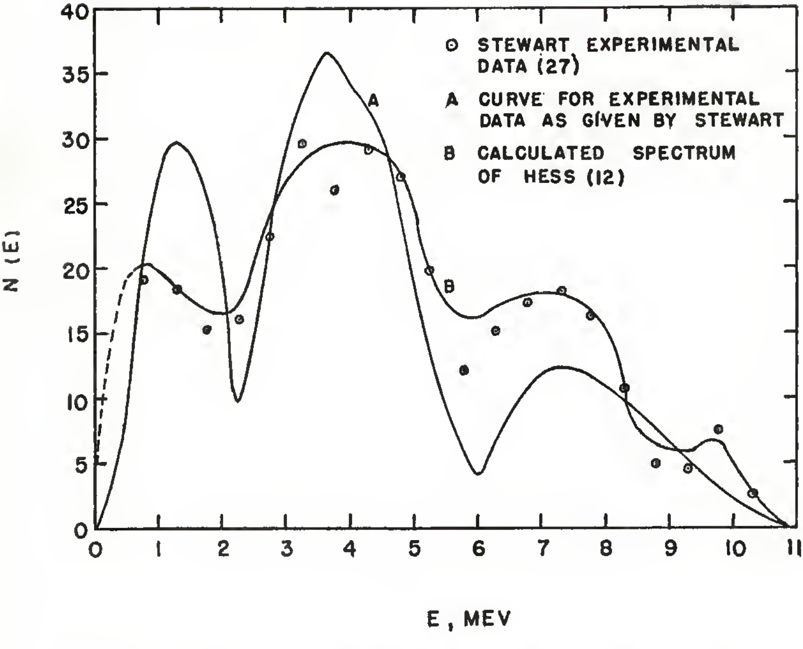

Fig. 1. Calculated and measured neutron energy spectrum for a Pu-Be neutron source.

Thus Eq. (33) can be written in terms of the Gaussian range as

$$q(z, \tau) = Q_0 \, c \, e^{-z^2/r^2} . \tag{35}$$

A plot of the natural logarithm of the slowing down density vs. z^2 for a monoenergetic source would be expected to give a straight line of slope $-1/r^2$. However, in an experiment performed by Foulke (9) a plot of the natural logarithm of the activity of cadmium covered indium foils (proportional to the slowing down density to indium resonance) vs. z^2 was shown to be curved, due to the broad energy spectrum of the Pu-Be sources. This curve could be considered to be due to the superposition of an infinite number of monoenergetic sources. Hence the slowing down density should be expressed as

$$q(z, \tau) = Q_0 \sum_{i=1}^{\infty} f_i \, c_i \, e^{-z^2/r_i^2} \tag{36}$$

where f_i represents the fraction of the source neutrons in the ith energy group, and r_i represents the Gaussian range of the ith energy group. Foulke made a series of empirical fits of Eq. (36) to a plot of the natural logarithm of the activity of the cadmium covered indium foils vs. z^2 for the KSU Pu-Be sources.

If the Gaussian ranges used are defined from source energy to thermal energy, then Eq. (36) may be used as the source term in the thermal diffusion equation. The resulting expression for the thermal flux would be

$$\phi(x,y,z) = \sum_{i=1}^{n} \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{Q_0}{\gamma_{mn}\, ab\, D}\, e^{\kappa^2 r_i^2/4} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b} \left[e^{-\gamma_{mn} z} \left\{ 1 + \operatorname{erf}\left(\frac{z}{r_i} - \frac{\gamma_{mn} r_i}{2} \right) \right\} + e^{\gamma_{mn} z} \left\{ 1 - \operatorname{erf}\left(\frac{z}{r_i} + \frac{\gamma_{mn} r_i}{2} \right) \right\} \right] \qquad (37)$$

where m and n are odd. In order to express the flux in the form of Eq. (15), the above equation must be treated similarly to Eq. (32) to derive the correction factors C_E and C_H. These correction factors for the Gaussian range empirical source are given in Table 1. An IBM 650 program for the determination of diffusion length by this method is described in Appendix I.

Determination of Material Buckling and Effective Multiplication Factor

The continuity equation for neutron diffusion in a multiplying medium differs from the non-multiplying case by the addition of a neutron production term. Thus Eq. (3) for steady state diffusion in a multiplying medium with an external source becomes

$$D\nabla^2\phi - \Sigma_a\phi + k_\infty \Sigma_a \phi = 0 \qquad (38)$$

where k_∞ is the multiplication factor for an infinite reactor (no leakage). Equation (38) can be written in the form

$$\nabla^2\phi + B_m^2\phi = 0 \qquad (39)$$

where the material buckling, B_m^2, is defined by

$$B_m^2 = (k_\infty - 1)\frac{\Sigma_a}{D} \tag{40}$$

The solution of Eq. (39) in rectangular geometry and subject to the same boundary conditions as the non-multiplying case is

$$\phi(x,y,z) = \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} A_{mn} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b} \sinh \gamma_{mn}(c - z) \tag{41}$$

where m and n are odd. The auxiliary separation constants equation is now

$$-\alpha_m^2 - \beta_n^2 + \gamma_{mn}^2 = -B_m^2 . \tag{42}$$

If a point source of thermal neutrons is assumed at the origin of the pile co-ordinates, Fig. 3 as the physical source location, the constants A_{mn} are again given by Eq. (10) The material buckling can thus be calculated by the same procedure as was κ^2 in a non-multiplying medium.

If the reactor were critical, with no external source, the boundary conditions impressed on the solution for $\phi(x,y,z)$ would be that the flux be zero at all extrapolated boundaries. Thus, for a critical reactor at steady state (11),

$$\phi(x,y,z) = A \cos\frac{\pi x}{a} \cos\frac{\pi y}{b} \cos\frac{\pi z}{d} \tag{43}$$

where a, b, and d are the extrapolated x, y, and z dimensions of the critical assembly. The reasons that only one mode is considered here are (a) that criticality can only be achieved in the first mode, and (b) that once criticality is achieved in this mode, the higher modes die out exponentially. The auxiliary separations constants equation for the critical solution is

$$\left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{b}\right)^2 + \left(\frac{\pi}{d}\right)^2 = B_G^2 . \qquad (43)$$

Equation (43) also defines the geometric buckling. Hence it can be seen that a condition for criticality is

$$B_m^2 = B_G^2 . \qquad (44)$$

Glasstone and Edlund (11) define the effective multiplication factor k_{eff} as

$$k_{eff} = \frac{k_\infty e^{-B_G^2 \tau}}{1 + L^2 B_G^2} \qquad (45)$$

where the condition for criticality is $k_{eff} = 1$. Assuming criticality, and simplifying the exponential term gives

$$1 = \frac{k_\infty}{(1 + L^2 B^2)(1 + \tau B^2)} .$$

Since B^2 is generally very small, further simplification yields

$$1 = \frac{k_\infty}{1 + B^2 (L_t^2 + \tau)} , \qquad (47)$$

where L_t represents the diffusion length in the multiplying medium. L_t may be calculated from the diffusion length in the pure moderator by

$$L_t^2 = L^2 (1 - f) \qquad (48)$$

where f is the thermal utilization of the lattice.

The infinite multiplication factor, k_∞, can be determined from Eq. (47) once B_m^2, τ, and L_t are known. B_m^2 can be used in this case due to Eq. (44) and the assumption of criticality in deriving Eq. (47). Once k_∞ has been determined it can be used in Eq. (45) to determine k_{eff} for any size reactor with a constant material buckling by varying B_G^2. An IBM 650 program for the determination of the material buckling, k_∞, and k_{eff} by the methods described above is included as Appendix J.

EXPERIMENTAL FACILITIES

General Pile Description

The Kansas State University graphite pile, shown in Fig. 2, consisted of a rectangular parallelepiped, 68 in. square, and 100 in. high, resting on a concrete foundation. The pile was constructed of machined reactor grade graphite blocks approximately four inches in cross section and of various lengths. In stacking, the long dimension of the blocks was alternated 90° from layer to layer. As can be seen in Fig. 2, certain of the graphite blocks were drilled through their entire length to a diameter of 1.75 in.. The purpose of the holes was to accommodate fuel elements and they were located to provide an 8-in. lattice. For this study, in the effort to make a solid, homogeneous moderator, each of the fuel ports contained three graphite cylinders measuring 1.625 in. in diameter, and 22.68 in. in length. The cylinders were of the same material as the graphite blocks.

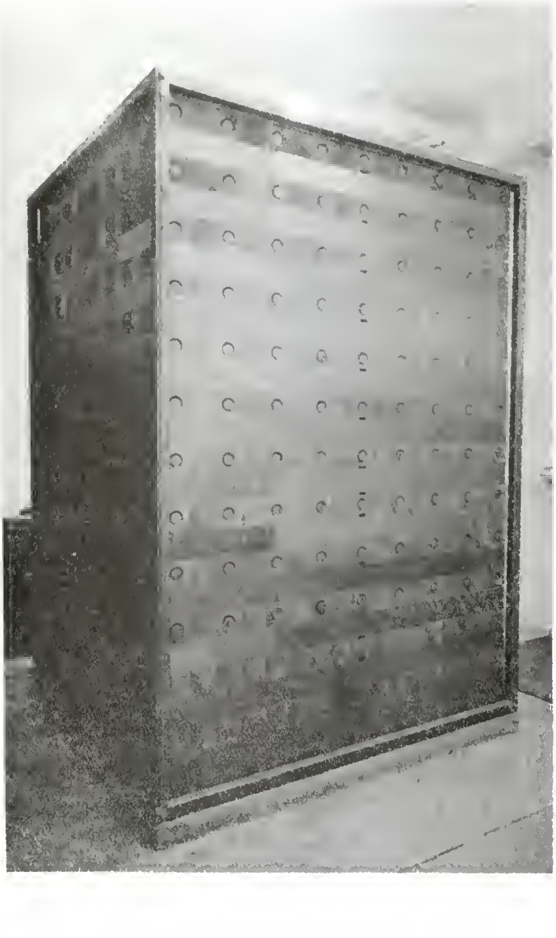

Fig. 2. KSU graphite pile.

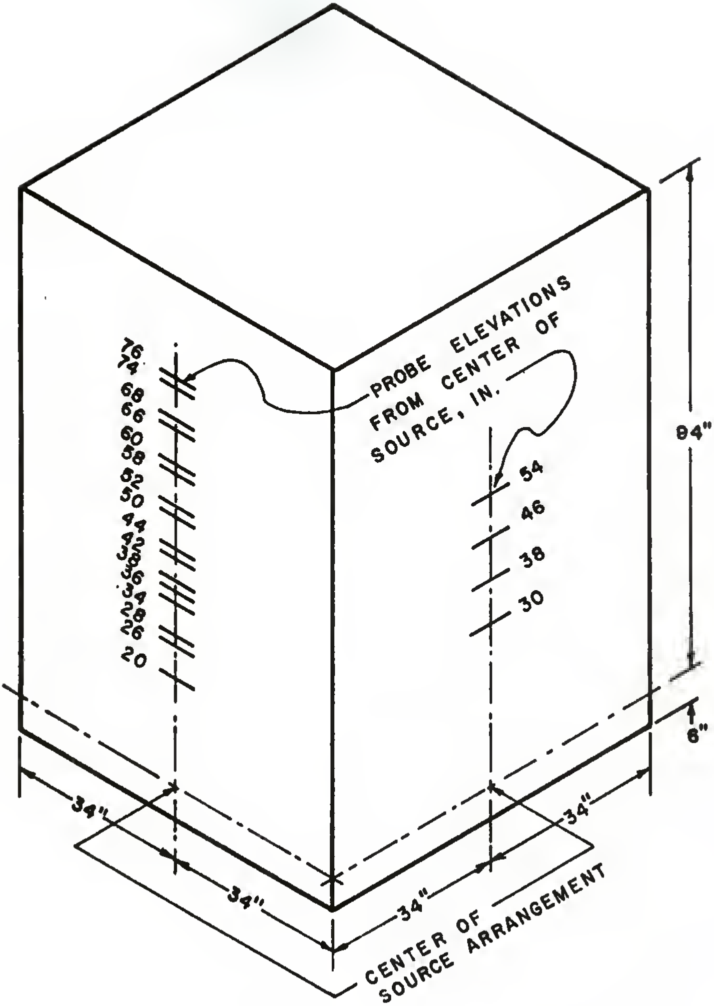

Fig. 3. Schematic diagram of KSU pile.

The graphite used in the construction of this pile was purchased from the Great Lakes Carbon Corporation. The blocks were machined from R-IHLM Nuclear Grade Graphite with a thermal neutron absorption cross section between 3.7 and 4.5 millibarns.

The graphite cylinders, being of smaller diameter than the fuel ports, left crescent-shaped air gaps of 0.125 in. between the tops of the cylinders and the tops of the fuel ports. The blocks along the central vertical axis of the pile contained horizontal foil slots, shown in Fig. 2, with a cross section of 1.281 in. by 0.343 in.. These slots could accommodate foil stringers as well as BF_3 or scintillation probes. The density of the solid graphite blocks was 1.683 g/cc. Steichen (26) calculated the percentage of air voids to be approximately 0.3 per cent. The resulting effective density of the pile was 1.678 g/cc.

A summary of the physical specifications of the one curie Pu-Be neutron sources is given in Table 2.

Non-Multiplying Configuration

For the determination of diffusion length, a solid, homogeneous moderator was needed. To accomplish this, the fuel ports were filled with graphite rods as mentioned above. The source configuration used was a five-source cluster at the center of the source plane (positions 5, 6, 7, 8, and 9 in Fig. 4). In this configuration, one source was located at the exact center of the source plane and the other four were ± four inches from the center in either x or y direction.

Table 2. Summary of physical specifications of Plutonium-Beryllium neutron sources (4).

Source number	Grams Pu	Grams Be	Neutron emission* rate (n/sec)
365	7.87	15.99	1.54×10^6
366	7.87	16.01	1.73×10^6
367	7.86	15.89	1.82×10^6
368	7.86	15.88	1.69×10^6
369	7.86	16.09	1.71×10^6

* Recalibrated September 1961 at Mound Laboratories during integrity tests and recanning.

The inner container of each source is 0.85 in. in diameter, 0.90 in. in height, and is made of tantalum. The outside container of each source is 1.02 in. in diameter, 1.30 in. in height, and is made of stainless steel. All sources are sealed by welding. The melting point of tantalum is 5,425° F. The melting point of 18-8 stainless steel is 2,600° F.

The sources were calibrated by comparison to within ±2 per cent of standards calibrated at Los Alamos Scientific Laboratory. The absolute accuracy of the Los Alamos standard is reported as ±5 per cent, thus giving an absolute accuracy of ±7 per cent to the sources listed above.

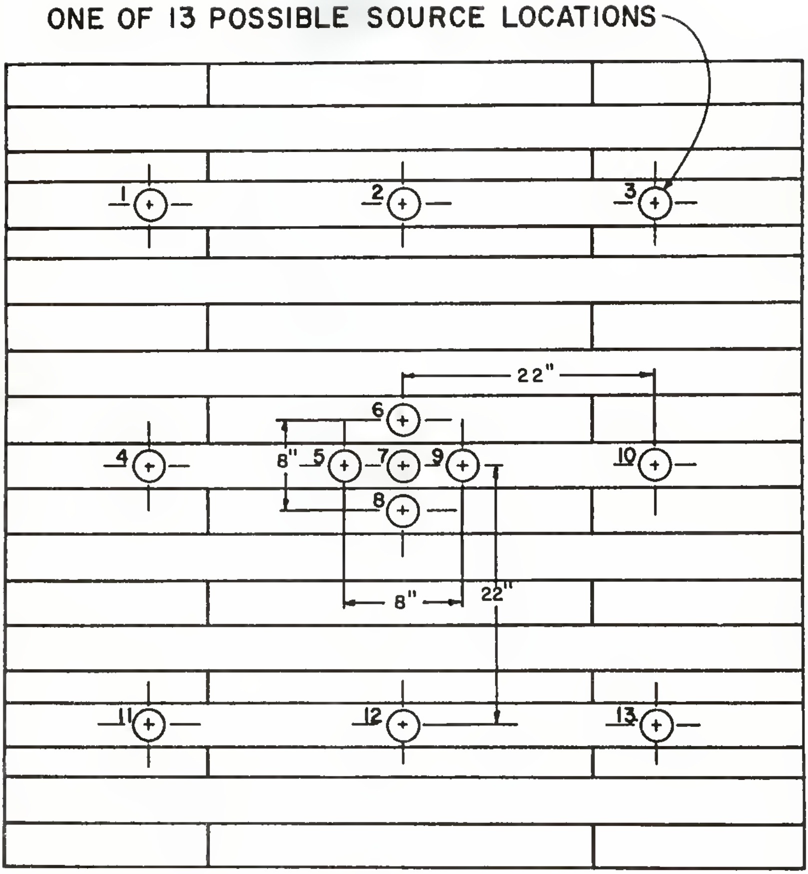

Fig. 4. Source locations in KSU pile.

A schematic diagram of the pile is presented as Fig. 3. The source plane is located six inches above the concrete foundation.

Multiplying Configuration

In this configuration, the fuel holes contain aluminum tubes 68 in. long, and 1.312 in. in outside diameter. Each tube is supported in the fuel port by three aluminum rings, one fixed at the center, and two removable rings at the ends. Eight depleted uranium, Savannah River type MK VII fuel elements, as pictured in Fig. 5, are placed in each tube. Figure 6 illustrates a portion of the loaded pile. The source configuration used with the loaded pile was the five-source cluster described above.

Neutron Detection System

The neutron detection system used throughout this work consisted of a Nuclear Chicago Model NC-202 BF_3 probe, Nuclear Engineering Inventory No. 97; a Nuclear Chicago Model 1062 preamplifier, NEI No. 210; a B. J. Electronics Model DMI-D count rate meter, NEI No. 363; a John Fluke Model 400 BDA high voltage power supply, NEI No. 188; a Baird Atomic Model 132 scaler, NEI No. 144; a Baird Atomic Model 960 timer, NEI No. 147; an Esterline Angus Model A. W. strip chart recorder, NEI No. 360; and a traversing mechanism, NEI No. 568.

The BF_3 probe active volume, with a length of 1/2 inch and diameter of 3/16 inch, contained $B^{10}F_3$ gas at a pressure of

Fig. 5. Fuel elements for KSU pile.

Fig. 6. KSU exponential pile.

70 cm Hg and at an enrichment of 96 per cent. The Model 1062 transistorized preamplifier had a length of 6.25 in. and a diameter of 1.5 in.. The BF_3 probe with the associated counting system is shown in Fig. 7.

The traversing mechanism, illustrated in Fig. 8, was capable of supporting the BF_3 probe in a variety of positions in the pile. This mechanism was designed and built at Kansas State University, and a detailed description of it is provided by L. R. Foulke (9).

In order to accommodate the BF_3 probe in the maximum number of positions and with the minimum amount of created void space, three 1.625 in. diameter graphite cylinders, shown in Fig. 9, were drilled along their central axis to a diameter of 3/8 in.. Their use to accommodate the probe may be seen in Fig. 4.

EXPERIMENTAL PROCEDURE

Cadmium Shutter Technique

The cadmium shutter technique involves the use of a cadmium shutter imposed between source and detector for the purpose of eliminating counts caused by epithermal neutrons. Data is taken without the shutter, and also with the shutter in place. The difference between the two sets of measurements is taken (28) as proportional to the thermal flux.

The cadmium shutter technique is generally used when the detector used is indium foil. The same purpose can be accomplished in this case as when cadmium covers are placed on the individual foils (28).

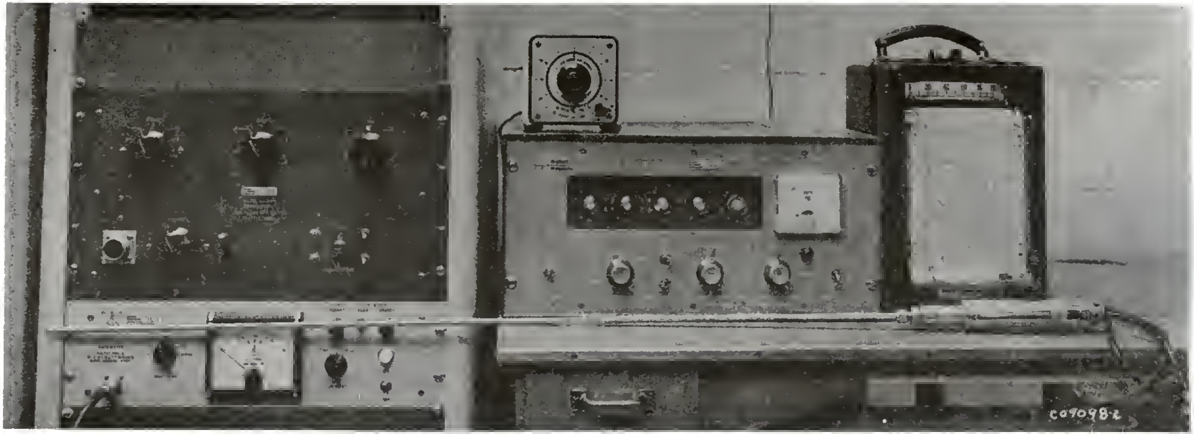

Fig. 7. Neutron probe counting system

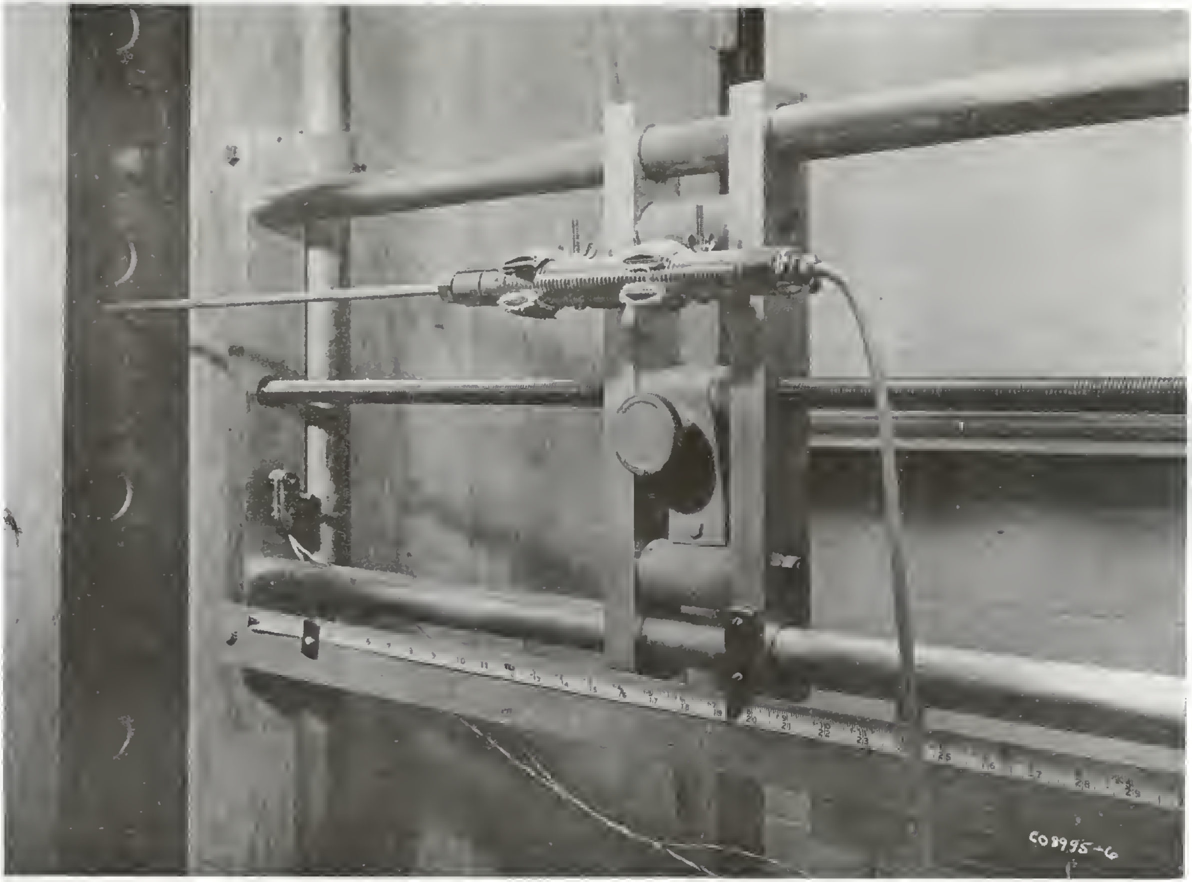

Fig. 8. Sliding assembly of traversing mechanism with scintillation probe

Fig. 9. Special graphite cylinders for accomodation of neutron probes

The cadmium shutter technique is often preferred, however, since it avoids error induced by overlapping of the indium and cadmium resonances.

When individually covered foils are used, the cadmium takes out a certain portion of the indium resonance nuetrons before they reach the foil. Thus the covered foil count rates are not as high as they should be. This results in insufficient correction for epithermal neutrons in calculating the cadmium difference.

With the cadmium shutter technique, any neutron which would be at resonance energy at the foil elevation would be at a considerably higher energy at the lower elevation of the shutter. Thus it would be passed by the shutter and absorbed by the foil. In this way the absorption of resonance neutrons by the cadmium does not affect the cadmium difference count rates.

There is another effect, however, which leads one to believe that the use of the cadmium shutter does not produce accurate results. This is due to the fact that some neutrons are thermalized above the shutter but below the elevation of the foils. These neutrons, since they are epithermal at the shutter location, would not be absorbed by the cadmium. They would be highly absorbed by the indium, however. Since the activity of the foil with the cadmium shutter in place is supposed to be proportional to the indium resonance activity induced in the foils without the shutter, one can see that any activity induced by neutrons thermalized above the shutter is in excess of that desired. Thus the cadmium difference flux calculated in this manner will be too low, and not exactly proportional to the actual thermal flux.

Since the BF_3 probe used in this work had been shown (9) to give count rates consistently proportional to the thermal flux, even in close proximity to the source, it was considered adequate for determination of thermal flux. Further discussion of the cadmium shutter technique can be found in references (5) and (6).

Vertical Traverse Measurements

All data were obtained using the previously described BF_3 probe and associated counting system. Measurements were made in the foil stringer slots and in convenient fuel ports using the specially adapted cylinders shown in Fig. 9. All measurements were made with the active volume of the BF_3 probe centered on the vertical, or z axis of the pile by means of the traversing mechanism.

The counter was operated at 1400 volts with a pulse height sensitivity of 0.8. Some tendency toward day to day variation in counter sensitivity was encountered so that normalization counts were taken each day at a position 10 in. above the source plane at the center of the pile. Several short counts were taken in this position and their average used in the normalization.

Two separate vertical traverses were made, one with the non-multiplying configuration, and one with the multiplying configuration. In each case, data were taken such that approximately 10,000 counts were obtained in each position. This was done with 10 series of measurements getting 1,000 counts in each position. Figure 3 is a schematic diagram of the pile showing data locations.

Double Integral Mesh Data

The data used to evaluate the double integral

$$\int_{-a/2}^{a/2} \int_{-b/2}^{b/2} \phi\,(x, y, z) \cos \frac{m\pi x}{a} \cos \frac{n\pi y}{b}\, dx\, dy$$

for the ratio method and double iteration analyses were obtained by running horizontal traverses in several fuel ports at a given elevation in the pile. Equally spaced measurements were made along the center fuel port from the center of the pile outward. The same procedure was then repeated for each of the remaining four fuel ports on one side of the pile. The space between successive data points was determined by dividing half the extrapolated pile dimension by the number of measurements to be made. The value of zero at the extrapolated boundary was included as an additional data point in evaluating the integral. The data were taken in three sets of 1,000 counts per position, giving a total of 3,000 counts per position.

Due to the symmetry of the pile, it was considered sufficient to evaluate the integral over one-quarter of the pile and multiply the result by four. Figure 10 illustrates the manner in which these data were taken. These data were normalized in the same manner as the vertical traverses.

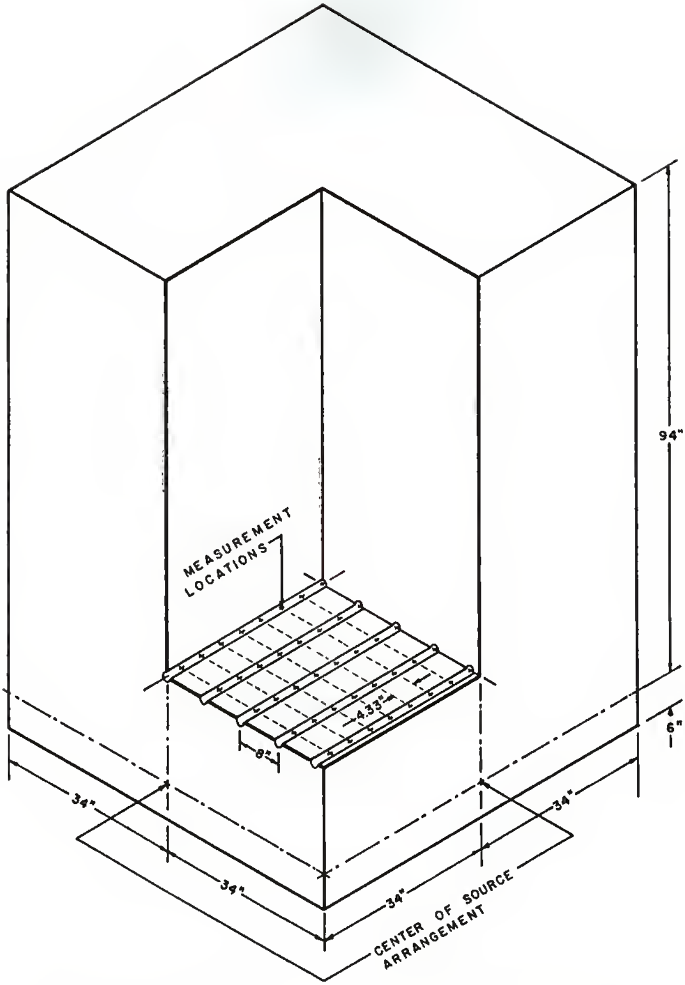

Fig. 10. Schematic diagram of KSU pile illustrating method of obtaining double integral mesh data.

Horizontal Traverses

Horizontal traverses for the experimental determination of the effective pile size were taken such that approximately 5,000 counts were obtained in each of nine positions from the center of the pile outward. This was done with five series of measurements getting 1,000 counts in each position. Certain of the graphite blocks were removed and inverted so that it was possible to make both north-south and east-west traverses at elevations of 38 in., 46 in., and 54 in. above the source. These data were normalized in the same manner as the vertical traverses.

The strip chart recorder was used in conjunction with the count rate meter to monitor the counting during periods of operator absence, thus insuring that no erratic data were recorded.

DATA PRESENTATION AND ANALYSIS

Treatment of Raw Data

The data obtained for each of the vertical traverses were corrected for background and are listed in Table 3 in the form of counts per minute. The deviation reported is the standard deviation of the mean in each case.

The double integral mesh data presented some difficulty due to low count rates and poor statistics near the outside of the pile. An attempt was made to correct this difficulty through a statistical analysis of the data based upon the equation

Table 3. Vertical traverse data sets.

Distance from source plane (Fig. 3)	BF$_3$ Count Rates	
	Non-Multiplying configuration	Multiplying configuration
inches	counts per minute	counts per minute
20.000	3009.8 ± 20.8	
26.156	1906.2 ± 15.8	
28.000	1621.4 ± 14.2	
30.156	1400.0 ± 12.7	
34.156	998.5 ± 9.0	946.0 ± 7.7
36.000	841.1 ± 8.1	
38.843	737.3 ± 7.7	756.0 ± 4.1
42.156	513.7 ± 2.6	597.0 ± 6.3
44.000	434.5 ± 2.9	
46.156	367.1 ± 3.3	
50.156	262.4 ± 3.0	351.3 ± 5.0
52.000	226.5 ± 2.3	
54.156	196.1 ± 2.1	
58.156	138.8 ± 1.7	218.3 ± 2.1
60.000	121.1 ± 1.0	
66.156	71.4 ± 0.8	136.8 ± 1.4
68.000	62.1 ± 0.9	
74.156	36.3 ± 0.4	79.4 ± 1.1
76.000	31.2 ± 0.4	
82.156	16.0 ± 0.2	44.4 ± 2.9
84.000	12.6 ± 0.1	

$$\phi(x) = \sum_{m=1}^{5} A_m \cos \frac{m\pi x}{a} \qquad (49)$$

where m is odd. The constants A_m were determined by a least squares analysis of the data in any one of the five horizontal traverses. Each experimental value was then compared with its least squares value, and if the difference was greater than the calculated 90 per cent confidence limits for that point, the point was rejected. All rejected points were replaced with values calculated from a least squares analysis of the accepted points. An IBM 650 program written to perform this analysis is described in Appendix K. The processed data, corrected for background, appears in Table 4. The deviation reported is the standard deviation of the mean in each case.

Horizontal traverse data, used in the determination of effective pile size, was corrected for background and listed in Table 5. The deviations reported are the standard deviations of the mean.

Analysis of Model Behavior

For reasons stated previously, it is known that elementary diffusion theory is not applicable near sources or boundaries. The amount of error induced in close proximity to the boundary of the diffusing medium is discussed quantitatively by Davison (8), in terms of transport theory. Very little information is available

Table 4a. Thermal neutron count rates at mesh points (Fig. 10) for evaluation of double integral at z = 20 inches.

y co-ord inches	BF$_3$ Count Rates					
	0	8	16	24	32	b=34.6875
x co-ord inches	counts per min.	counts per min.	counts per min.	counts per min.	counts per min.	counts per min.
0	3663.4 ± 20.2	3178.7 ± 28.8	2252.7 ± 45.9	1182.0 ± 19.4	275.1 ± 4.5	0
4.33	3578.6 ± 13.7	3160.7 ± 39.1	2160.0 ± 12.1	1135.0 ± 8.3	268.4 ± 1.2	0
8.66	3205.5 ± 15.2	2833.3 ± 15.4	1962.0 ± 26.1	1048.0 ± 16.8	249.0 ± 7.1	0
13.00	2753.9 ± 4.8	2380.0 ± 16.3	1644.0 ± 25.9	882.7 ± 10.5	215.3 ± 3.9	0
17.34	2150.4 ± 12.0	1860.0 ± 25.0	1316.0 ± 19.1	711.0 ± 2.9	172.5 ± 4.8	0
21.67	1561.1	1345.3 ± 12.8	960.7 ± 1.7	520.7 ± 9.8	129.0 ± 1.0	0
26.00	999.4 ± 5.7	842.0 ± 13.5	638.0 ± 12.4	357.8 ± 4.1	93.7 ± 2.9	0
30.35	477.9 ± 6.0	399.9	313.2 ± 6.1	172.0 ± 6.0	47.4 ± 1.2	0
a=34.687	0	0	0	0	0	0

Table 4b. Thermal neutron count rates at mesh points (Fig. 10) for evaluation of double integral at z = 28 inches.

y co-ord inches	BF$_3$ Count Rates					
	0	8	16	24	32	b=34.6875
x co-ord inches	counts per min.	counts per min.	counts per min.	counts per min.	counts per min.	counts per min.
0	1957.3 ± 29.4	1785.3 ±33.8	1285.3 ± 23.5	730.7 ± 1.7	188.3 ± 7.2	0
4.33	1960.7 ± 20.5	1735.8	1248.0 ± 11.7	710.0 ± 6.0	180.0 ± 7.2	0
8.66	1794.7 ± 34.8	1594.0 ±24.4	1143.0 ± 14.3	646.0 ± 1.0	164.9 ± 9.2	0
13.00	1572.8 ± 7.8	1385.3 ±33.8	1015.0	580.7 ± 4.3	145.3 ± 7.3	0
17.34	1275.3 ± 15.1	1123.7	795.0 ± 7.0	478.7 ± 1.8	119.0 ±11.2	0
21.67	929.3 ± 8.4	839.7 ± 5.4	602.7 ± 9.0	347.7 ± 1.2	95.3 ± 5.5	0
26.00	613.3 ± 7.2	562.0 ± 7.1	399.1 ± 1.3	239.2 ± 1.3	66.1 ± 2.0	0
30.35	302.5 ± 4.5	273.3 ± 3.1	198.2 ± 2.0	119.0 ±0.5	35.7	0
a=34.687	0	0	0	0	0	0

Table 4c. Thermal neutron count rates at mesh points (Fig. 10) for evaluation of double integral at z = 36 inches.

y co-ord: inches	BF$_3$ Count Rates					
	0	8	16	24	32	b=34.6875
x co-ord: inches	counts per min.	counts per min.	counts per min.	counts per min.	counts per min.	counts per min.
0	1050.0 ± 17.7	942.7 ± 1.5	719.0 ± 22.7	416.4 ± 2.6	109.7 ± 1.1	0
4.33	993.3 ± 3.8	919.3 ± 5.4	698.6	399.1 ±13.2	107.3 ± 1.5	0
8.66	951.3 ± 11.0	862.3 ±14.4	641.0 ± 7.6	375.6 ± 7.3	98.4 ± 1.4	0
13.00	815.0 ± 7.0	746.7 ±18.8	574.0 ± 3.6	329.6 ± 4.6	86.0 ± 2.8	0
17.34	675.7 ± 3.8	623.7 ±12.9	476.9 ± 5.2	279.2 ± 5.1	23.3 ± 1.2	0
21.67	515.1 ± 5.7	476.4 ± 5.1	352.3 ± 1.7	211.9 ± 5.0	57.9 ± 1.6	0
26.00	337.2 ± 5.4	323.2 ± 6.7	244.1 ± 1.7	141.5 ± 1.9	41.0 ± 0.4	0
30.35	169.0	166.3 ± 1.6	120.2 ± 1.5	71.7	22.2 ± 1.0	0
a=34.687	0	0	0	0	0	0

Table 4d. Thermal neutron count rates at mesh points (Fig. 10) for evaluation of double integral at z = 44 inches.

y co-ord inches	BF$_3$ Count Rates					
	0	8	16	24	32	b=34.6875
x co-ord inches	counts per min.	counts per min.	counts per min.	counts per min.	counts per min.	counts per min.
0	551.3 ± 11.5	492.0 ± 5.2	379.5 ± 7.3	225.9 ± 4.5	63.3 ± 1.8	0
4.33	529.3 ± 8.4	476.7 ± 1.0	376.2 ± 2.0	225.3 ± 2.5	58.9 ± 1.3	0
8.66	496.0 ± 4.2	442.4 ± 11.2	347.5 ± 3.1	210.1 ± 5.2	58.0 ± 1.5	0
13.00	433.8 ± 3.1	390.0 ± 8.8	310.7 ± 3.7	186.2 ± 3.2	52.6 ± 1.5	0
17.34	375.8 ± 5.6	328.2 ± 4.6	257.7 ± 5.2	153.6 ± 3.5	43.2 ± 1.9	0
21.67	280.0 ± 8.9	252.8 ± 3.2	204.3 ± 3.1	118.9 ± 1.8	35.8 ± 0.6	0
26.00	193.3 ± 2.5	178.8 ± 1.5	136.0 ± 1.6	83.2 ± 2.0	25.8 ± 0.2	0
30.35	99.9 ± 1.2	90.9	69.5 ± 2.4	41.0	13.2	0
a=34.687	0	0	0	0	0	0

Table 5a. Horizontal traverse data in east-west direction at three elevations.

Distance from center of pile	BF_3 Count Rates		
	z = 38 inches	z = 46 inches	z = 54 inches
inches	counts per min.	counts per min.	counts per min.
0	859.9 ± 22.4	394.3 ± 4.0	201.2 ± 1.6
4	808.7 ± 22.2	387.5 ± 6.9	203.0 ± 7.4
8	779.7 ± 21.5	363.5 ± 8.6	187.7 ± 2.4
12	690.6 ± 14.8	333.7 ± 3.2	167.9 ± 3.0
16	594.8 ± 5.2	288.6 ± 6.8	150.7 ± 1.3
20	481.6 ± 7.9	234.9 ± 5.9	119.1 ± 2.0
24	351.1 ± 3.5	174.7 ± 4.2	92.1 ± 1.4
28	223.4 ± 4.0	113.2 ± 3.9	58.5 ± 0.5
32	104.7 ± 4.6	51.8 ± 4.0	26.3 ± 0.3

Table 5b. Horizontal traverse data in north-south direction at three elevations.

Distance from center of pile	BF$_3$ Count Rates		
	z = 38 inches	z = 46 inches	z = 54 inches
inches	counts per min.	counts per min.	counts per min.
0	723.6 ± 4.2	373.5 ± 5.2	202.1 ± 1.6
4	710.3 ± 9.4	365.9 ± 6.4	191.3 ± 3.5
8	666.6 ± 10.2	339.0 ± 8.2	185.3 ± 2.9
12	605.4 ± 11.5	308.9 ± 8.0	168.5 ± 2.0
16	526.4 ± 5.7	269.2 ± 5.9	144.6 ± 2.4
20	408.0 ± 4.9	218.0 ± 5.3	118.7 ± 1.0
24	308.6 ± 3.5	166.7 ± 2.6	90.7 ± 0.8
28	195.1 ± 2.9	103.6 ± 2.2	58.1 ± 1.0
32	79.9 ± 0.4	47.6 ± 1.0	26.4 ± 0.2

regarding the amount of error induced by using data points in close proximity to the source in a diffusion length analysis.

In attempting to determine the effect of using measurements made near the source to determine diffusion length two sources of error must be examined: (1) The possibility that a given assumed source boundary condition might lead to errors near the source, and (2) the possibility that the thermal diffusion model itself may be invalid.

A preliminary problem which was expected was inconsistency in results obtained using points too far from the source. The primary reason for such inconsistency being poor counting statistics near the top of the pile. For this reason, a series of determinations of L was made in which the point at the highest elevation was dropped from the data set for each determination. Consistency in the values obtained was used as a criterion for judging the highest level in the pile at which useable data could be obtained. The lowest data point used in this analysis was at least two diffusion lengths above the source. At this elevation the harmonic content is negligible (11), so that the one-group model and a given boundary condition could be assumed to be valid. When an effective upper limit had been established, the behavior of the model close to the source could be studied.

To examine a given assumed boundary condition based on either the one-group diffusion model or the age-diffusion model, a procedure was used whereby the effect of adding additional points near the source could be observed. Successive determinations of diffusion length were made, each using one additional data point closer to the source. It is logical to assume that as long as all points used were far enough from the source, neither the assumed boundary condition nor the model would cause any deviation in the values obtained. Hence the apparent deviations of these values of L should be random about the average of the series of determinations.

The appearance of a decisive trend in several determinations of L, either increasing or decreasing, was taken as evidence of error induced by one of the two causes listed above.

RESULTS AND CONCLUSIONS

Experimental Effective Pile Size

The experimental determination of effective pile size described previously was attempted in the KSU pile. For this purpose, several horizontal traverses were made and these data were processed using the IBM 650 code described in Appendix G.

The effective size in each of the horizontal directions was determined at three elevations; 38, 46, and 54 in. above the source. Since it was expected that the harmonic content would not be the same at all elevations, provision was made in the IBM 650 code so that successive analyses could be performed with different assumed harmonic content.

Table 6a lists the results obtained in the east-west direction (parallel to pile void channels) with various assumed harmonic contents. Table 6b lists the corresponding results in the north-south

Table 6a. Results of determination of experimental pile size in the x direction, actual size 68 in. (theoretical value a = 69.375 in.).

Elevation	Effective Pile Size "a" in inches			
	Assumed Harmonic Content			
inches	1, 3	1,3,5	1,3,5,7	1,3,5,7,9
38	68.9 ± 3.71	69.5 ± 3.71	68.9 ± 3.71	68.8 ± 3.71
46	69.1 ± 0.73	69.5 ± 0.73	69.9 ± 0.73	69.7 ± 0.73
54	71.0 ± 2.96	70.1 ± 2.96	71.3 ± 2.96	70.1 ± 2.96

Table 6b. Results of determination of experimental pile size in the y direction, actual size 68 in. (theoretical value b = 69.375).

Elevation	Effective Pile Size "b" in inches			
	Assumed Harmonic Content			
inches	1, 3	1, 3, 5	1,3,5,7	1,3,5,7,9
38	69.8 ± 0.72	69.5 ± 0.72	68.7 ± 0.72	68.3 ± 0.72
46	69.9 ± 1.34	70.0 ± 1.34	70.5 ± 1.34	68.9 ± 1.34
54	70.5 ± 3.64	70.7 ± 3.64	72.0 ± 3.64	70.3 ± 3.64

direction. Deviations reported in these tables were calculated from the experimental data. Eight values of pile size were calculated from the equation

$$a = \frac{\pi x}{\cos^{-1} \frac{\phi}{A_1}}$$

which was derived from Eq. (28) by assuming that all higher modes were insignificant. The value of ϕ at the center of the pile was used as A_1. The standard deviation of the mean of the eight values of a is reported as the expected deviation of the calculated value of pile size. Since these deviations were determined directly from the raw data using only the fundamental mode, no difference in confidence limits appears with variation of assumed harmonic content.

The data in Tables 6a and 6b are much too random in nature to accurately define the effective pile size. The only noticeable trend is the increase of experimental pile size with increase in the elevation at which it was determined. This would indicate that the pile was shaped similar to an inverted pyramid, expanding toward the top. However, the confidence limits placed on these values indicate that a more extensive analysis should be performed before any valid conclusions may be drawn.

Since definite values of a and b could not be determined experimentally due to the difficulties mentioned above, the theoretical extrapolation distance was used in the remainder of this work. This quantity is described from transport theory as $0.71\ \lambda_{tr}$, where λ_{tr} represents the transport mean free path in the medium. The value of λ_{tr} used was 2.58 ± 0.09 centimeters, the same value used by Foulke (9) in the standardization of the KSU pile. The value of the effective pile size obtained in this manner was 69.375 in. in both horizontal directions.

Diffusion Length Results

Point Thermal Source. The results obtained by assuming a point thermal source are listed in Table 7. The first four determinations do not show any definite tendency to increase or decrease, but as points were considered closer to the source than 38 in., a definite increasing trend became apparent.

Table 7. Results obtained for the diffusion length based on assuming a point thermal source.

Elevation of Lowest Data Point	Number of Data Points Used	Diffusion Length $\rho = 1.678$ g/cc
inches		cm
50	8	53.32 ± 0.87
44	9	53.84 ± 0.72
42	10	53.71 ± 0.59
38	11	53.69 ± 0.48
36	12	54.14 ± 0.51
34	13	54.23 ± 0.45
28	14	55.01 ± 0.61
26	15	55.98 ± 0.84

The above values were calculated using the 1, 3, 5, and 7 harmonics with the highest data point 76 inches above the source.

The type of behavior displayed by these calculations was taken as evidence that the point thermal source boundary condition was valid only beyond a distance of approximately 38 in. from the source. Probable causes of this phenomenon are the fact that the assumption disregards the high source energy and that the point source boundary condition exaggerated the harmonic content and would therefore be in error for all elevations low enough for the harmonics to be significant.

Constant Thermal Source. Diffusion length determinations based on an assumed constant thermal source boundary condition are listed in Table 8. Contrary to the case of the assumed point thermal source, no consistent results were obtained using this boundary condition. Instead, a consistent decrease in L was noticed as additional points were included close to the source, and the average value was considerably lower than that obtained using any other method.

Table 8. Results obtained for the diffusions length based on an assumed constant thermal source.

Elevation of Lowest Data Point	Number of Data Points Used	Diffusion Length $\rho = 1.678$ g/cc
inches		cm
50	8	50.38 ± 0.58
44	9	50.17 ± 0.45
42	10	49.62 ± 0.47
38	11	48.92 ± 0.52
36	12	48.78 ± 0.45
34	13	48.37 ± 0.46
28	14	47.86 ± 0.47
26	15	47.58 ± 0.44

The above values were calculated using the 1, 3, 5, and 7 harmonics with the highest data point 76 in. above the source. The conclusion was drawn from these results that since the constant thermal source boundary condition was not at all compatible with actual conditions, and since the results obtained by its use showed none of the desired consistency, that this boundary condition should be considered completely invalid. This was not unexpected in that this particular approximation disregards the high source energy and also uses an incorrect geometric approximation of the source. This boundary condition was used for comparative purposes, and to determine the effect of an erroneous boundary condition on diffusion length calculations.

Ratio Method. Evaluation of the diffusion length by the ratio method was accomplished using integrals evaluated at four different elevations. These integrals were used in six separate pairs, providing six independent determinations of diffusion length. The results of these determinations, at a pile density of 1.678 g/cc, are given in Table 9.

Table 9. Results of the ratio method for determination of diffusion length.

z_1 inches	z_2 inches	Ratio F_1/F_2	Diffusion Length [1] cm
28	20	0.584	126.52
36	28	0.544	61.69
44	36	0.532	55.36
36	20	0.318	79.19
44	28	0.289	58.29
44	20	0.169	68.48

[1] Confidence limits not calculated due to erratic nature of the results.

It is immediately obvious that the range of these results is exceptionally wide. In fact, the difference between the lowest and highest values is 71.12 cm.

The basic difference between this method and all others is the absence of a vertical traverse. Since the diffusion length is known fundamentally to be strongly related to the attenuation in the z direction, it is logical to assume that a larger number of measurements at different elevations would serve to establish the value of L more firmly. The ratio method uses only two z's, and the measurements made at these elevations, the integrals, cannot be calculated to the high degree of accuracy necessary because of the poor counting statistics near the edge of the pile.

Whereas the ratio method appeared desirable, since it avoided the necessity of imposing an erroneous boundary condition, the consideration described above and the actual results obtained indicate that it is not a practical method for the determination of the diffusion length.

Double Iteration. Diffusion length results from the double iteration process, at a pile density of 1.678 g/cc, are listed in Table 10. All of these results were obtained using the 1, 3, and 5 harmonics. Horizontal traverses for the evaluation of the constants A_{mn} were taken at four different levels in the pile. Hence there are four sets of values, each based on constants determined at a different elevation.

It can be seen from Table 10 that the results obtained using constants evaluated at the higher elevations do not display the same consistency as those obtained using constants evaluated at the lower elevations. This can be explained as follows: The value of γ_{11}, and hence the value of L, obtained from this process is the direct result of a least squares analysis of a plot of $\ell n \phi_{corr}$ vs. z. ϕ_{corr} is determined as explained previously by essentially removing the higher harmonics from consideration by means of the correction factor, C_H, derived previously. In order to do this accurately, it is generally advisable to include as many harmonics in the analysis as is feasible. This is particularly true when deriving C_H for a point close to the source where the harmonics are known to be of significance.

However, in determining A_{mn} for the higher harmonics at z = 44 in., for example, one is attempting to evaluate a quantity which is numerically insignificant. This is known to be the case because at

Table 10. Diffusion length results from the double iteration technique using the 1, 3, 5 harmonics.

Elevation of Lowest Point inches	Diffusion Length, cm Elevation at which Constants were Determined, inches			
	20	28	36	44
50	53.34 ± 1.64	53.35 ± 1.65	53.58 ± 1.68	54.47 ± 1.80
46	53.54 ± 1.26	53.55 ± 1.28	53.83 ± 1.29	54.88 ± 1.40
44	53.96 ± 1.06	53.98 ± 1.05	54.31 ± 1.09	55.52 ± 1.21
42	53.67 ± 0.88	53.68 ± 0.88	54.05 ± 0.90	55.37 ± 0.99
38	53.37 ± 0.72	53.38 ± 0.72	53.81 ± 0.74	55.34 ± 0.82
36	53.75 ± 0.67	53.76 ± 0.67	54.27 ± 0.70	56.05 ± 0.83
34	53.65 ± 0.58	53.65 ± 0.58	54.23 ± 0.60	56.20 ± 0.73
30	53.63 ± 0.49	53.63 ± 0.50	54.33 ± 0.52	56.62 ± 0.68
28	54.23 ± 0.59	54.28 ± 0.59	55.14 ± 0.67	-----
26	54.71 ± 0.60	54.70 ± 0.58	55.73 ± 0.71	-----

such distances from the source the harmonic content is negligible (11). The numerical integration process used in this analysis was found to be overestimating the magnitude of these harmonics at higher elevations. This was believed to have been caused by the efforts of the numerical integration process to give credence to the statistical noise inherent in the data. At lower elevations, however, where the harmonic content was appreciable, the estimate was considerably better. This statement is supported by Fig. 11, which illustrates the predicted relative contribution of the 13 and 31 harmonics as a function of distance from the source. Analytical curves based on the point thermal source and constant thermal source boundary conditions are included.

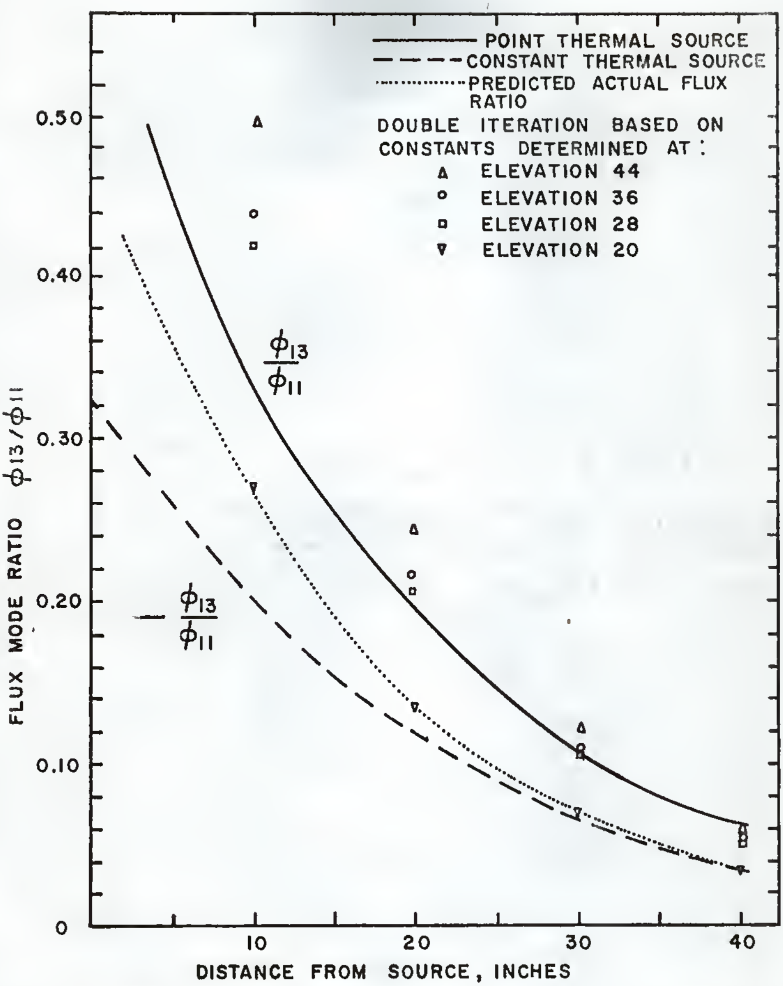

FIG. 11. RELATIVE CONTRIBUTIONS OF ϕ_{13} HARMONICS AS A FUNCTION OF DISTANCE FROM SOURCE.

The fast source used can presumably be represented by an equivalent thermal source which will be neither a point nor constant, but some intermediate configuration. It is therefore logical to assume that the actual harmonic content of the flux function would be something in between these two specific thermal boundary conditions. It can be seen from Fig. 11 that as lower elevations are used to determine the constants A_{mn}, the predicted harmonic content is bounded by the point thermal and constant thermal source predictions.

Further evidence of the effect of harmonic content on the behavior of the double iteration technique is presented in Figs. 12, 13 and 14. Figure 12 is a plot of the data given in Table 10, and shows the behavior of this technique for all four elevations when the 1, 3, and 5 harmonics are used. Figure 13 shows the effect of neglecting the 5th harmonic with constants determined at elevation $z = 44$. Figure 14 shows this same effect plus the effect of taking the 7th harmonic into consideration. The data used in these plots are presented in Table 11. It is interesting to note that the effect of using additional harmonics in the analysis is much more pronounced at the higher elevation.

The conclusions to be reached from the observations mentioned above are that the double iteration technique gives valid results only when the constants A_{mn} are determined from data taken at a level in the pile where the harmonics contribute significantly to the total thermal flux.

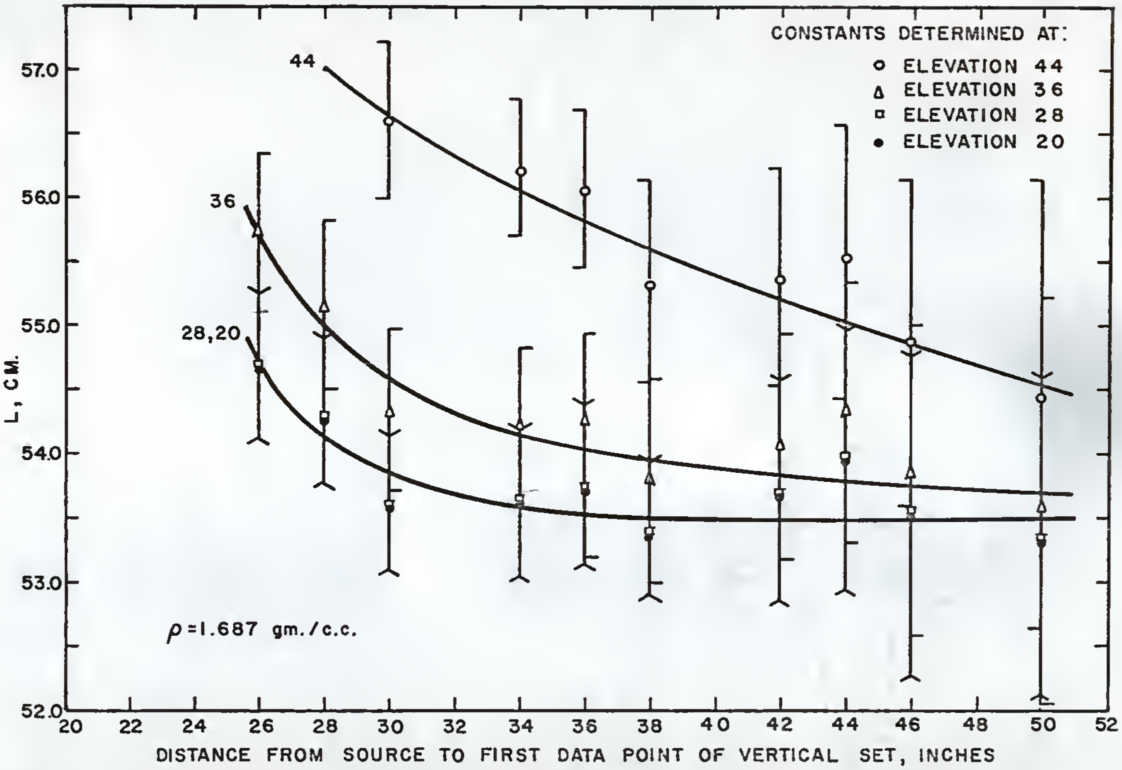

FIG. 12. BEHAVIOR OF DOUBLE ITERATION ANALYSIS AS POINTS ARE INCLUDED CLOSER TO THE SOURCE.

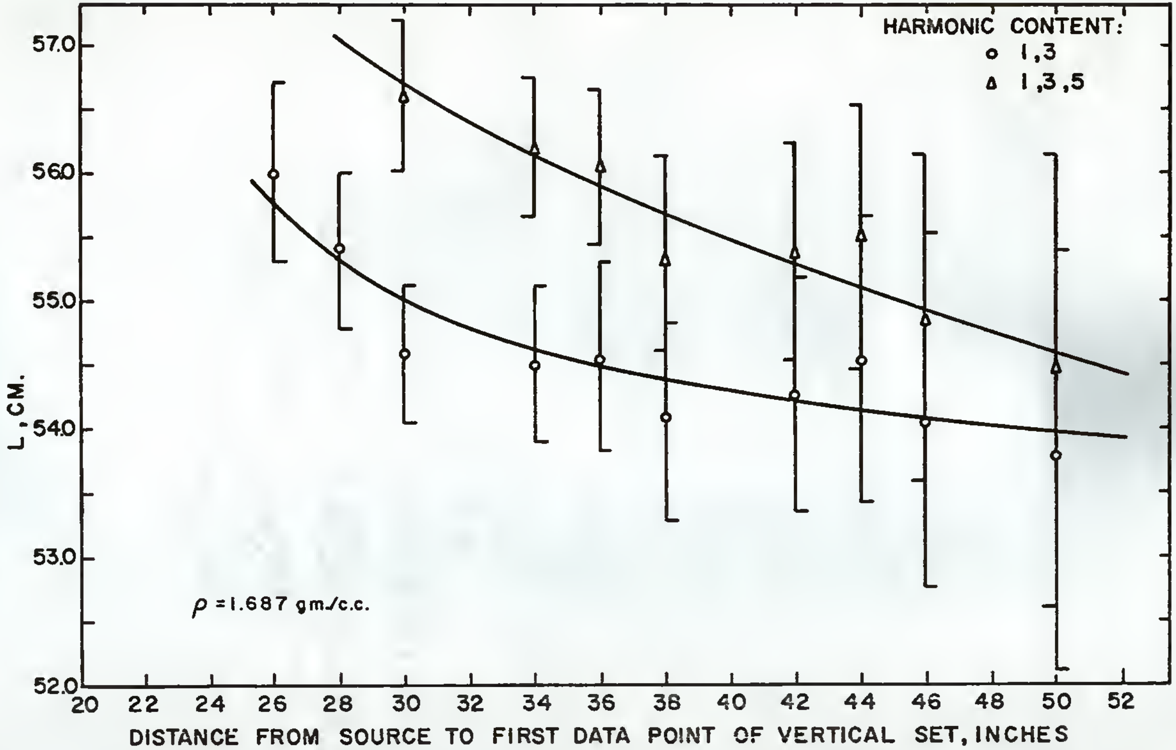

FIG. 13. EFFECT OF ASSUMPTION OF DIFFERENT HARMONIC CONTENT ON BEHAVIOR OF DOUBLE ITERATION METHOD USING CONSTANTS DETERMINED AT Z = 44

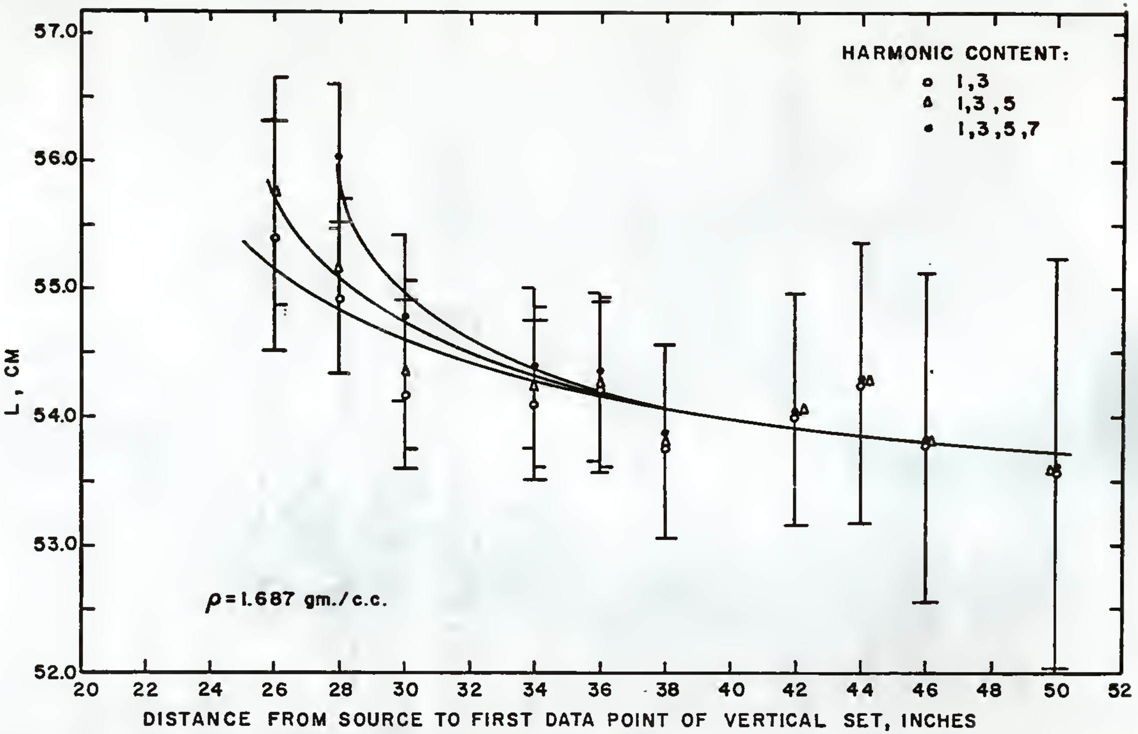

FIG.14. EFFECT OF ASSUMPTION OF DIFFERENT HARMONIC CONTENT ON BEHAVIOR OF DOUBLE ITERATION METHOD USING CONSTANTS DETERMINED AT Z = 36

Table 11. Diffusion length results obtained from the double iteration method with different harmonic contents.

Constants evaluation elevation, inches	44		36		
Harmonics used	1,3	1,3,5	1,3	1,3,5	1,3,5,7
Elevation of lowest data point	Diffusion length	Diffusion length	Diffusion length	Diffusion length	Diffusion length
inches	cm	cm	cm	cm	cm
50	53.76 ± 1.70	54.47 ± 1.80	53.58 ± 1.52	53.58 ± 1.68	53.57 ± 1.68
46	54.03 ± 1.31	54.88 ± 1.40	53.82 ± 1.29	53.83 ± 1.29	53.82 ± 1.29
44	54.53 ± 1.11	55.52 ± 1.21	54.29 ± 1.09	54.31 ± 1.09	54.29 ± 1.09
42	54.27 ± 0.92	55.37 ± 0.99	54.01 ± 0.91	54.05 ± 0.90	54.04 ± 0.91
38	54.04 ± 0.76	55.34 ± 0.82	53.75 ± 0.74	53.81 ± 0.74	53.84 ± 0.74
36	54.53 ± 0.71	56.05 ± 0.83	54.19 ± 0.69	54.27 ± 0.70	54.35 ± 0.71
34	54.49 ± 0.62	56.20 ± 0.73	54.13 ± 0.60	54.23 ± 0.60	54.38 ± 0.62
30	54.59 ± 0.53	56.62 ± 0.68	54.17 ± 0.52	54.33 ± 0.52	54.76 ± 0.58
28	55.40 ± 0.68	----	54.91 ± 0.65	55.14 ± 0.67	56.03 ± 0.94
26	55.98 ± 0.72	----	55.41 ± 0.87	55.73 ± 0.71	----

Using the values of A_{mn} determined at elevation $z = 20$ in., the magnitude of the fundamental and the higher harmonics at the source plane could be calculated. Thus an equivalent thermal source condition can be described based upon the actual flux distribution in the pile. The constants A_{mn} used to calculate this equivalent source are listed in Table 12. The equivalent source, with calculated flux plots at distances of 10, 20, 30, and 40 in. above the source, is plotted in Fig. 15. A similar plot is made for the point thermal source boundary condition in Fig. 16. The double iteration equivalent boundary condition was plotted using the 11, 13, 31, and 33 harmonics. As indicated on the plot, these curves fit the normalized data accurately. It is believed that this equivalent thermal source condition could be duplicated within limits of experimental error using constants determined at elevation $z = 28$ in. and possibly also using constants evaluated at $z = 36$ in.

Table 12. Values of the constants A_{mn} evaluated by the double iteration technique at elevation $z = 20$ inches.

m	n	A_{mn}	
1	1	15.70	0.040
1	3	7.59	0.002×10^{-2}
3	1	7.59	0.002×10^{-2}
3	3	3.28	0.004×10^{-6}

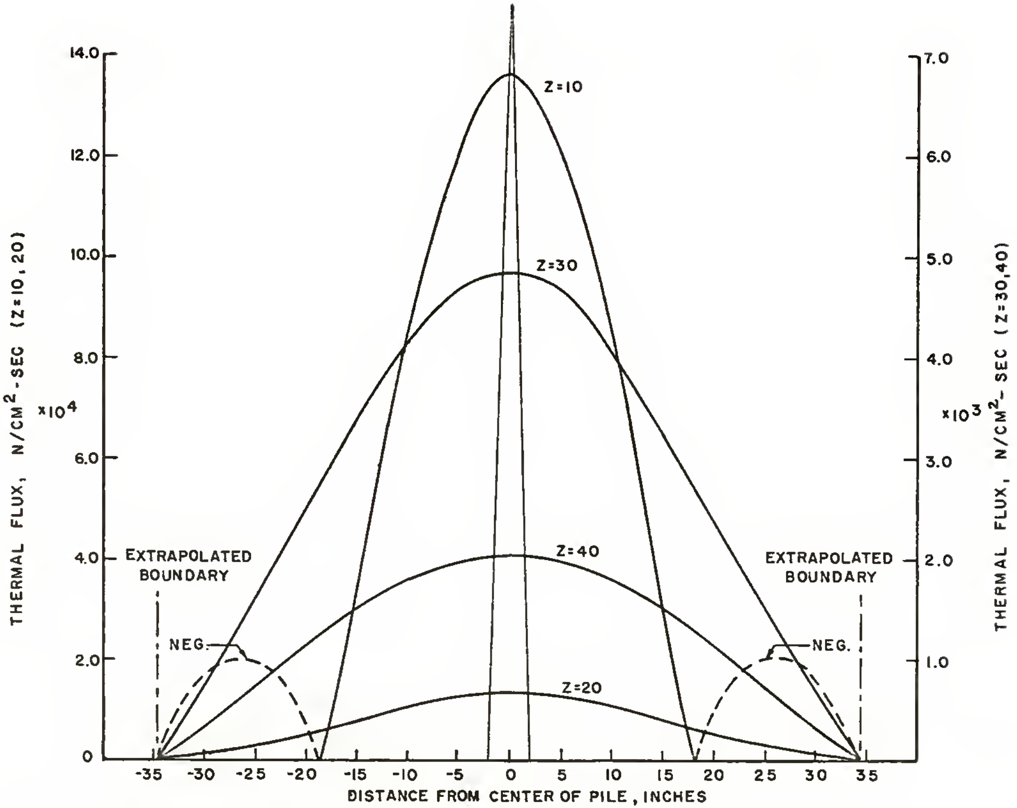

FIG. 15. HORIZONTAL BEHAVIOR OF FLUX FROM POINT THERMAL SOURCE AT Z=0, ELEVATIONS Z=10,20,30 AND 40 INCHES

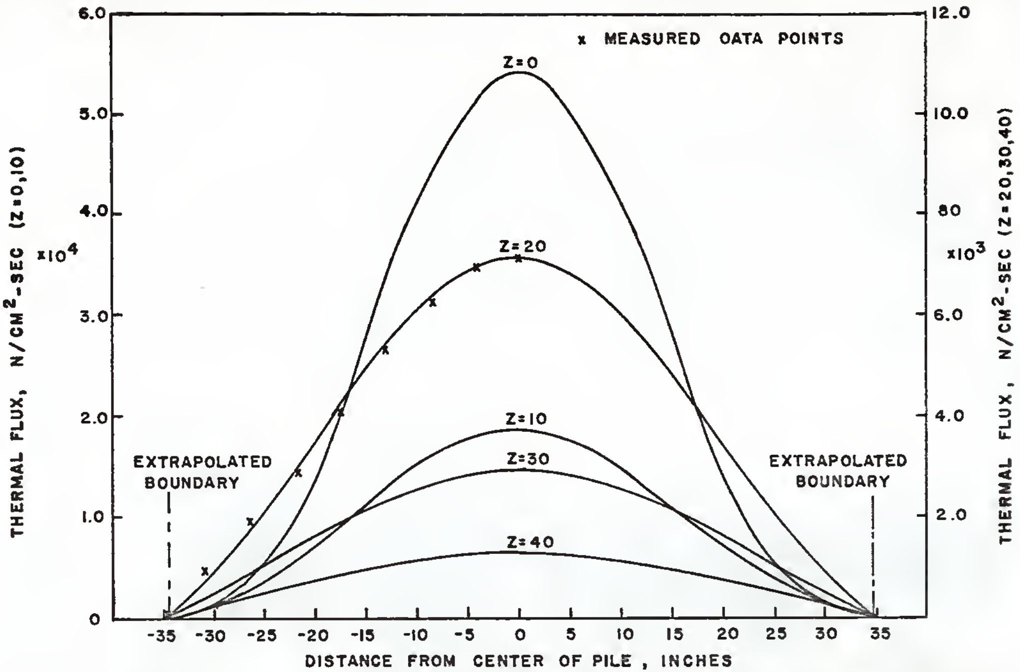

FIG. 15. HORIZONTAL BEHAVIOR OF FLUX FROM EQUIVALENT THERMAL SOURCE AT Z=0, ELEVATIONS Z=10, 20, 30, AND 40 INCHES.

Monoenergetic Fast Source. Diffusion length results based on age-diffusion theory assuming a monoenergetic fast source at a pile density of 1.678 g/cc are listed in Table 13. These results show a fair degree of consistency, but have a slight increasing trend not noticed in the double iteration results based on constants evaluated at elevation $z = 20$ inches.

Table 13. Diffusion length results based on a monoenergetic point source of fast neutrons.

Elevation of Lowest Data Point inches	Number of Data Points Used	Diffusion Length cm
46	10	53.09 ± 0.81
44	11	53.52 ± 0.74
42	12	53.50 ± 0.64
38	13	53.45 ± 0.55
36	14	53.79 ± 0.53
34	15	53.76 ± 0.47
30	16	53.64 ± 0.42
28	17	53.90 ± 0.40
26	18	53.92 ± 0.37

Examination of the results listed in Table 13 indicate that the assumption of a monoenergetic fast source for the determination of diffusion length is reasonably good over the region studied. In order to more firmly establish the validity of this assumption, the effect of variation of the age of Pu-Be neutrons should be studied. The value used in this work was 426 cm^2 as reported by Steichen (26). Table 14 lists diffusion length results for several values of age.

Table 14. Effect of variation of age on determinations of L assuming a monoenergetic fast source.

Number of Data Points	Fermi Age of Pu-Be Neutrons	Diffusion Length
	cm^2	cm
10	446	53.08 ± 0.81
10	436	53.09 ± 0.81
10	426	53.09 ± 0.81
10	416	53.09 ± 0.81
10	406	53.10 ± 0.81
10	396	53.10 ± 0.81
10	386	53.11 ± 0.81
10	376	53.11 ± 0.81

The obvious conclusion to be drawn from Table 14 is that the results obtained by assuming a monoenergetic fast point source are almost completely insensitive to normal uncertainty in the value of the Fermi age.

Gaussian Range Empirical Source. The results of the determination of diffusion length based on an empirically determined fast source described by Gaussian ranges and range fractions, at a pile density of 1.678 g/cc, are given in Table 15. The uniformity of the results is quite good, however, the average is slightly lower than that of the point thermal source, double iteration, and monoenergetic fast source methods.

Table 15. Diffusion length results from Gaussian range empirical source.

Elevation of lowest data point	Number of data points used	Diffusion length	
inches		cm	
50	7	52.82	± 1.56
46	8	52.96	± 1.19
44	9	53.33	± 0.92
42	10	53.01	± 0.83
38	11	52.66	± 0.70
36	12	52.99	± 0.63
34	13	52.85	± 0.55
30	14	52.76	± 0.47

Table 16. Effect on diffusion length of using varying Gaussian range sets.

Set number	No. of terms	Error squared of fit to slowing down density	Equivalent Age $\Sigma f_i r_i^2/4$, cm^2	Diffusion length, cm	
1	3	7.94×10^3	378.1	53.53	± 1.58
2	3	8.17×10^3	379.6	53.56	± 1.58
3	3	9.08×10^3	397.2	53.56	± 1.58
4	3	9.17×10^3	396.5	53.12	± 1.57
5	3	1.51×10^4	411.9	52.82	± 1.56

Foulke (9) determined several sets of ranges from one set of indium foil data. Each set was determined by an exponential stripping method. The differences between the several sets of ranges was in the treatment of the raw indium foil count rates. Table 16 lists diffusion length results obtained using several of these sets with nine data points. The elevation of the lowest point was 50 in.

Set number five was used in the calculations for this work because it appeared to be the best fit of the experimental slowing down data (9). The empirical curve based on this set passed within the experimental deviations of the slowing down data for a greater portion of the points than did any of the other curves. Details on the data treatment and analysis may be found in reference (9). This evidence is presented here to point out the fact that the determination of diffusion length in this manner requires a very precise knowledge of the Gaussian ranges and range fractions. The small variations in the age and the equivalent age for the two methods indicate that neither can be said to be highly sensitive to determinations of these quantities.

General Comparison. The behavior of each of the methods studied is illustrated in Fig. 17. For clarity, confidence limits have been eliminated from this plot. However, the confidence limits for each value are listed in the respective tables of results for each method. It is apparent from this figure that all of the methods, with the exception of the constant thermal source, give results of essentially the same magnitude when considered only in the region where consistent results were obtained. Table 17 lists the value of diffusion length obtained

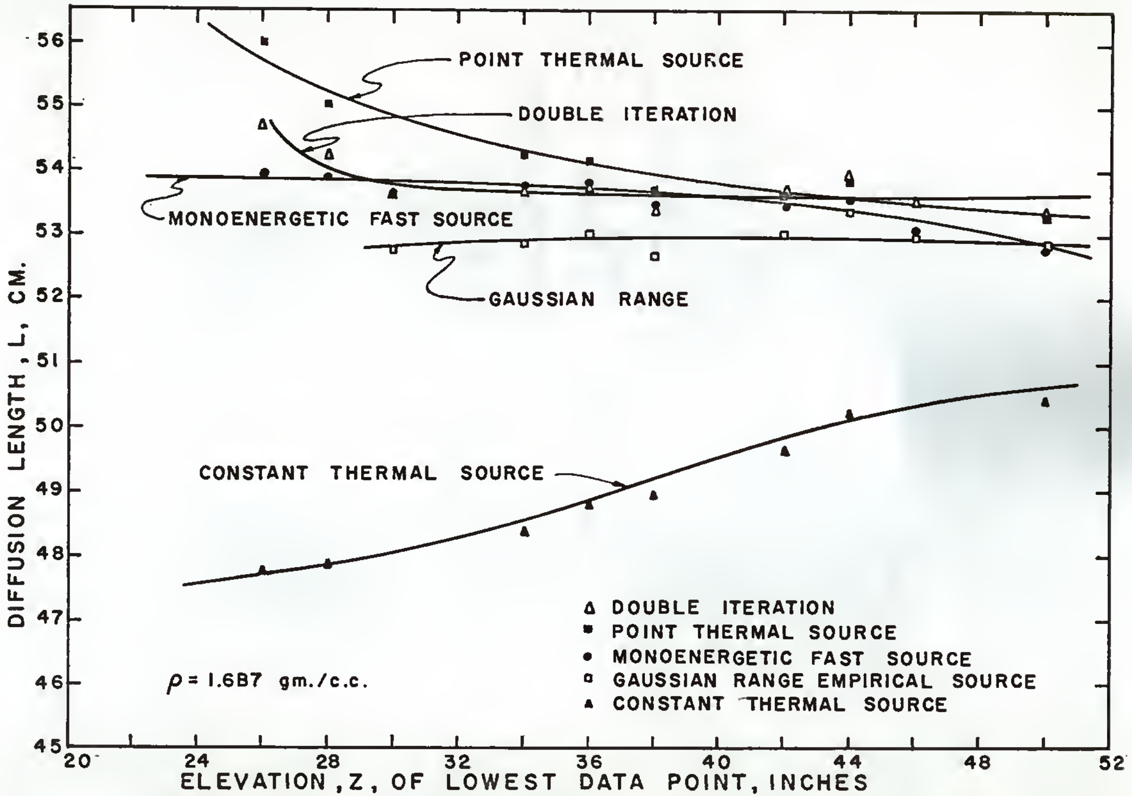

FIG. 17. VARIATION OF DIFFUSION LENGTH CAUSED BY INCLUDING DATA CLOSER TO THE SOURCE.

Table 17. Results of the determination of diffusion length for all methods considered.

Graphite Density g/cc	Diffusion length, centimeters					
	One-group model				Age-diffusion model	
	Point thermal source*	Constant thermal source	Ratio method	Double iteration**	Monoenergetic fast source	Gaussian Range empirical source
1.678	53.64 ± 0.48	48.96 ± 0.58	74.92 ± 10.80	53.61 ± 0.60	53.53 ± 0.37	52.92 ± 0.47
1.600	56.25 ± 0.48	51.35 ± 0.58	78.57 ± 11.33	56.22 ± 0.60	56.14 ± 0.37	55.50 ± 0.47

* Average of first four determinations listed in Table 7.

** Average of first eight determinations listed in Table 10, constants determined at elevation $z = 20$ inches.

from each method. These values were obtained by taking the average of all determinations which exhibited only an apparent random distribution about the average. The confidence limits quoted with these values are the confidence limits obtained using all points in the region of consistent results. Values are reported at the KSU pile density and at a density of 1.6 g/cc as is commonly quoted in the literature.

Using as criteria for judgment; (1) the degree of consistency of results as data are included closer to the source, (2) the number of determinations for which this consistency is observed, and (3) the extent to which the average value, reported in Table 17, of a given method conformed to the averages of the other methods, after rejecting the ratio and constant thermal source methods, the best method appeared to be the double iteration procedure, based on one-group diffusion.

It can be seen from Fig. 17 that age-diffusion results did not exhibit the erratic behavior, as points were included near the source, that was displayed in the results obtained using the thermal diffusion model. This leads to the conclusion that age-diffusion may be the more reliable method for determination of diffusion length. However, the slight increasing trend noticed in the monoenergetic fast source results as data were included closer to the source cast some doubt on the reliability of this method. The Gaussian range method has been shown to be sensitive to determination of ranges and range fractions, and gives an average value somewhat lower than would be expected after examining the results of the other methods.

The point thermal source gave consistent results only at a considerably greater distance from the source than the other methods and was ruled out for this reason. The constant thermal source method and the ratio method failed to produce satisfactory results. The double iteration method gave highly consistent results to within 30 in. of the source, and its average value was within 0.08 cm of the average values of the point thermal and monoenergetic fast source methods.

Based on the double iteration method, the value of L reported here will be 53.61 ± 0.60 cm, at a graphite density of 1.678 g/cc. At a density of 1.60 g/cc, this value becomes 56.22 ± 0.60 cm. Table 18 lists this value of L along with several other values obtained from the literature.

Table 18. Comparison of measurements of the diffusion length of thermal neutrons in graphite.

Diffusion Length L, cm	Graphite Density ρ, gr/cc	References
50.0	1.62	(10)
50.2	1.62	(11), (32)
52.39	1.60	(3)
53.39 - 55.21	1.60	(23)
54.40 ± 0.5	1.60	(7)
56.22 ± 0.6	1.60	this work

The range of diffusion lengths quoted from reference (23) include several values obtained in several different piles. The fact that the diffusion length measured in the KSU pile is higher than the literature values is attributed to the purity of the graphite (described in "EXPERIMENTAL FACILITIES").

Confidence Limits. Unless otherwise specified, all confidence limits placed on determinations of diffusion length in this work were calculated in the following manner: First, the standard deviation of γ_{11} was calculated from a linear regression analysis based on the corrected count rates from which that value of γ_{11} had been determined. The standard deviation of L was then calculated by means of propagation of errors. An IBM 650 program written to perform this analysis is described in Appendix L.

Material Buckling and Effective Multiplication Factor

The material buckling of the fully loaded KSU pile was determined experimentally using Eqs. (41) and (42) of the Theory. Equations (45) and (47) were used to evaluate the effective multiplication factor and the infinite multiplication factor respectively. The calculation of the material buckling was based on a point thermal source, so the data used was restricted to that which was within the previously determined region of validity of this boundary condition. The value of B_m^2 used in the remainder of the calculations was $7.755 \pm 0.41 \times 10^{-4}$ in.$^{-2}$. This value is the average of five separate determinations and the confidence limits are the standard deviation of the mean. The infinite multiplication factor, k_∞, was calculated to be 1.104 ± 0.05. This result was then used to extrapolate the KSU pile to critical size by varying B_G^2. This was done by writing B_G^2 as a function of the extrapolated dimension a only. Thus by increasing a, the pile was expanded proportionally. Table 19 lists the extrapolated values of geometric buckling and k_{eff}. These values of k_{eff} are plotted vs. pile size in Fig. 18.

Comparison of the values of material buckling calculated in the KSU pile compare favorably with values calculated by Richey (21) of Hanford in an eight-inch lattice with natural uranium as fuel.

Effective Size. Certain problems were encountered in determining the effective size of the multiplying lattice in the KSU pile. Whereas the top and side boundaries could be defined by adding the extrapolation distance of $0.71\ \lambda_{tr}$, the bottom boundary required more detailed considerations.

It was decided to treat the unfueled pedestal of the pile as a reflector, so that the reflector savings δ could be approximately calculated from

$$\delta \approx L_t \tanh \frac{T}{L_r}$$

where T is the reflector thickness, and L_r the reflector diffusion length. The above equation is based on a slab reactor, and will thus overestimate the reflector savings. The error thus induced will not seriously affect the results of this analysis, however. The reflector was considered to be present throughout the entire analysis, although in a critical experiment it may be desirable not to have the reflector entering into the analysis.

The result of the reflector savings calculations was used to define an equivalent bare reactor, so that the extrapolation distance $0.71\ \lambda_{tr}$ was also included in defining the lower boundary of the equivalent multiplying medium.

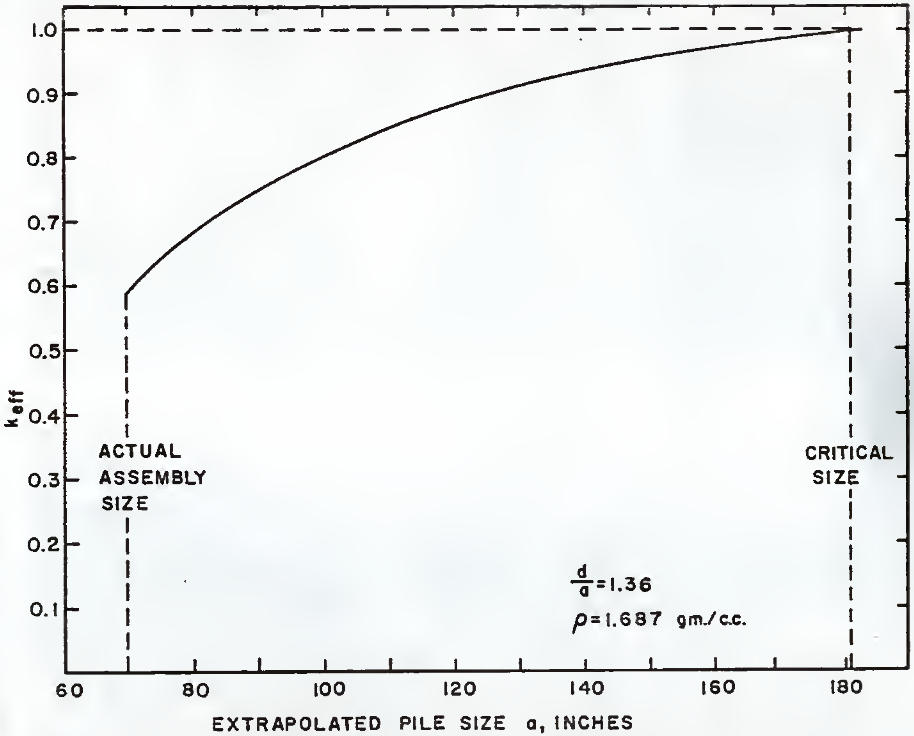

FIG. 18. MULTIPLICATION FACTOR, k_{eff}, vs. PILE SIZE, a.

Table 19. Extrapolation values of k_{eff} for the KSU pile (8-in. lattice, $\rho_{graph} = 1.689$ g/cc.

Extrapolated Pile Dimension a inches	Geometric Buckling in^{-2}	k_{eff}
69.375	5216×10^{-6}	0.58
86.375	3365×10^{-6}	0.72
101.375	2443×10^{-6}	0.81
116.375	1853×10^{-6}	0.87
131.375	1454×10^{-6}	0.91
146.375	1172×10^{-6}	0.95
161.375	964×10^{-6}	0.97
171.375	855×10^{-6}	0.98
180.895	767×10^{-6}	0.99

Lattice Diffusion Length. In the calculation of k_∞ from Eq. (47) the value of L used should be that for the multiplying lattice. This value may be found from the diffusion length in the pure moderator by the equation

$$L_t^2 = L^2 (1 - f),$$

where L_t is the lattice diffusion length and f is the thermal utilization.

Thermal utilization was calculated as shown in Appendix M, from equations presented in ANL 5800 (20) which were based on integral transport theory in cylindrical geometry. These equations considered the case of a rod of fissionable material surrounded by an annular cooling gap and an annular moderator region. The value of f obtained in this manner was 0.820. Glasstone (10) uses a value of 1.308 for η, the number of neutrons produced per fission, in natural uranium. If the product of the fast fission factor ϵ, and the resonance escape probability p is assumed to be one which will be high (10), the four factor formula for k_∞ yields $k_\infty = 1.073$. This value is slightly lower than the value obtained in this paper. The reason for this discrepancy is believed to be in the calculation of thermal utilization. Other methods of calculation of f were tried, but proved less satisfactory than that referred to above.

Since the thermal neutron flux in the uranium core of a heterogeneous cell is greatly depressed, the absorption of neutrons in the fuel is less for a heterogeneous cell than for a homogeneous cell. Hence the value of f for a homogeneous cell, calculated as 0.910, could be regarded as an upper limit of the actual value of the thermal utilization.

Fermi Age. The value of the Fermi age to thermal used in the calculations of material buckling and effective multiplication factor was 350 cm^2. This value is reported by Weinberg and Wigner (32) and Glasstone and Edlund (11).

Suggestions for Further Work

The basic problem encountered in determination of diffusion length is in obtaining an accurate mathematical descroption of the thermal flux. Because of the nature of a sigma pile, the flux attenuation in the z direction will always be very nearly exponential. Determination of the fundamental mode attenuation coefficient, γ_{11}, should always lead to knowledge of the diffusion length, L.

One possible model for further research in diffusion analysis is the use of a first collision density function as a boundary condition for age-diffusion theory. Instead of describing all neutrons as starting the slowing down process at the location of the physical point source, they should be considered as starting from the location of their first collisions. This would constitute a further refinement of the age-diffusion model.

Another such possibility is the use of two group methods to determine L. In a moderating medium (no multiplication) the fast flux would be independent of the thermal flux and could be solved for separately. The boundary condition of a point source, applied to the fast group, would be necessary to completely define the fast flux. The fast flux would then be used as a source term for the thermal flux equation, depending upon the knowledge of an appropriate slowing down cross section. This method would be subject to the same complications arising in most two-group calculations, that of determining constants for the fast group.

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APPENDICES

APPENDIX A

Solution to the Thermal Diffusion Equation

The geometry for the solution to the thermal diffusion equation is shown in Fig. 19.

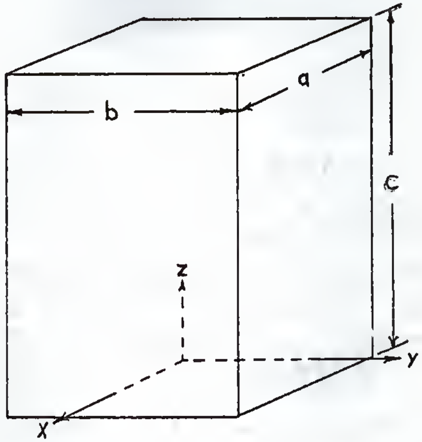


Fig. 19. Pile geometry for solution to thermal diffusion equation.

The equation to be solved is

$$\nabla^2\phi - \kappa^2\phi = 0 \qquad (A-1)$$

The solution is subject to the boundary conditions that the flux, ϕ, be zero at all extrapolated boundaries. This may be stated mathematically as

$$\phi\left(\pm\frac{a}{2}, y, z\right) = 0$$

$$\phi\left(x, \pm\frac{b}{2}, z\right) = 0$$

$$\phi(x, y, c) = 0$$

where a, b, and c are the extrapolated x, y, and z dimensions of the pile.

Equation (4) may be written in the form

$$\frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + \frac{\partial^2\phi}{\partial z^2} - \kappa^2\phi = 0 \quad . \tag{A-2}$$

Assuming a solution of the form

$$\phi(x, y, z) = X(x)\,Y(y)\,Z(z) \tag{A-3}$$

equation (A-2) becomes

$$X''YZ + XY''Z + XYZ'' - \kappa^2 XYZ = 0 \quad .$$

Dividing both sides of this equation by XYZ gives

$$\frac{X''}{X} + \frac{Y''}{Y} + \frac{Z''}{Z} - \kappa^2 = 0 \quad . \tag{A-4}$$

In order to meet the boundary conditions let each term of equation (A-4) be equal to a constant as follows:

$$\frac{X''}{X} = -\alpha_m^2 \tag{A-5a}$$

$$\frac{Y''}{Y} = -\beta_n^2 \tag{A-5b}$$

$$\frac{Z''}{Z} = +\gamma_{mn}^2 \tag{A-5c}$$

Rewriting equation (A-5a) gives

$$X'' + \alpha_m^2 X = 0 \quad .$$

A solution of this equation is

$$X(x) = A_m \cos \alpha_m x \quad .$$

To meet the boundary conditions that $X(a/2) = 0$,

$$\alpha_m = \frac{m\pi}{a}, m = 1, 3, 5, \cdots$$

so that the solution for $X(x)$ is

$$X(x) = A_m \cos \frac{m\pi x}{a}, m = 1, 3, 5, \cdots. \qquad \text{(A-6)}$$

Similarly for $Y(y)$,

$$Y(y) = A_n \cos \frac{n\pi x}{b}, n = 1, 3, 5, \cdots , \qquad \text{(A-7)}$$

Rewriting equation (A-5c) gives

$$Z'' - \gamma_{mn}^2 Z = 0,$$

which has as a solution

$$Z(z) = C_{mn} \sinh \gamma_{mn} z \quad .$$

This function may be made to fit the boundary condition by altering the argument to give

$$Z(z) = C_{mn} \sinh \gamma_{mn}(c - z). \qquad \text{(A-8)}$$

Combining the solutions for $X(x)$, $Y(y)$ and $Z(z)$ in the manner indicated previously and combining coefficients yields

$$\phi(x, y, z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} A_{mn} \cos \frac{m\pi x}{a} \cos \frac{n\pi y}{b} \sinh \gamma_{mn} (c - z) \qquad \text{(A-9)}$$

where m and n are summed over odd integers. Substituting (A-5a), (A-5b) and (A-5c) into equation (A-4) yields

$$-\alpha_m^2 - \beta_n^2 + \gamma_{mn}^2 = \kappa^2 \qquad \text{(A-10)}$$

which shall be referred to as the auxiliary separation constants equation in this work. Substituting in the expressions for α_m and β_n the above equation becomes

$$-\left(\frac{m\pi}{a}\right)^2 - \left(\frac{n\pi}{b}\right)^2 + \gamma_{mn}^2 = \kappa^2$$

where a and b are the effective lateral dimensions of the pile and κ is the reciprocal of the diffusion length.

Discussion of this solution can be found in Glasstone and Edlund (11) and many other Nuclear Engineering texts.

When considering a Multiplying medium, equation (A-1) becomes

$$\nabla^2 \phi + B_m^2 \phi = 0 \quad . \qquad \text{(A-11)}$$

By a completely analogous procedure, the solution to this equation is

$$\phi(x, y, z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} A_{mn} \cos \frac{m\pi x}{a} \cos \frac{n\pi y}{b} \sinh \gamma_{mn} (c - z) \qquad \text{(A-12)}$$

where m and n are odd and the auxiliary separation constants equation becomes

$$+\alpha_m^2 + \beta_n^2 - \gamma_{mn}^2 = B_m^2 \quad . \qquad \text{(A-13)}$$

APPENDIX B

Solution to the Fermi Age Equation and the Thermal Diffusion Equation

The geometry for this solution is shown in Fig. 20 .

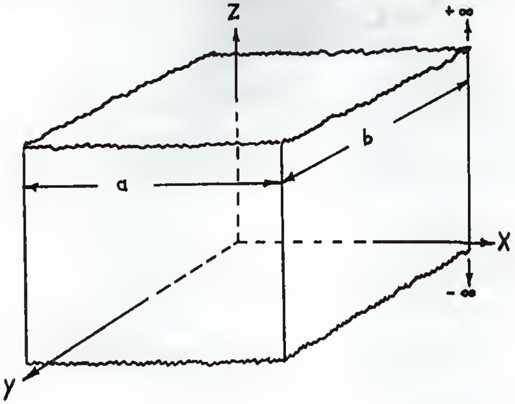


Fig. 20. Pile geometry for solution to the age-diffusion problem.

The equations involved were the Fermi age equation

$$\nabla^2 q = \frac{\partial q}{\partial \tau} \qquad \text{(B-1)}$$

and the thermal diffusion equation

$$D \nabla^2 \phi - \Sigma_a \phi + S = 0 \quad . \qquad \text{(B-2)}$$

The Fermi age equation was subjected to the boundary conditions that $q = 0$ at $x = \pm a/2$, $y = \pm b/2$, and $q \to 0$ as $|z| \to \infty$. The source condition was that all source neutrons entered the system at $x = y = z = 0$, at an age $\tau = 0$.

This condition was written into the Fermi age equation in the form

$$\nabla^2 q = \frac{\partial q}{\partial \tau} - Q_o \; \delta(\tau) \; \delta(x) \; \delta(y) \; \delta(z). \qquad \text{(B-3)}$$

The boundary conditions to the thermal diffusion equation were that $\phi = 0$ at $x = \pm a/2$, $y = \pm b/2$, and $\phi \to 0$ as $|z| \to \infty$. The source condition was that $S = q(x, y, z, \tau_{th})$.

Q_o, q and ϕ were expressed as double Fourier series satisfying the boundary conditions

$$\phi = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \phi_{mn}(z) \cos \frac{m\pi x}{a} \cos \frac{n\pi y}{b} \qquad \text{(B-4)}$$

$$q = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} q_{mn}(z) \cos \frac{m\pi x}{a} \cos \frac{n\pi y}{b} \qquad \text{(B-5)}$$

and

$$Q_o \, \delta(\tau)\, \delta(x)\, \delta(y)\, \delta(z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} Q_{mn}(z) \cos \frac{m\pi x}{a} \cos \frac{n\pi x}{b} \qquad \text{(B-6)}$$

where m and n are summed over odd integers. Each side of Eq. B-6 was multiplied by orthogonal functions and then was integrated over the range of orthogonality which resulted in

$$Q_o \, \delta(\tau)\, \delta(x)\, \delta(y)\, \delta(z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{4\, Q_o}{ab} \, \delta(\tau)\, \delta(z) \cos \frac{m\pi x}{a} \cos \frac{n\pi y}{b} \qquad \text{(B-7)}$$

Substitution of Eqs. B-5 and B-7 into the age equation, Eq. B-3 gave

$$\sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \left[- \frac{\partial q_{mn}}{\partial \tau} + \frac{\partial^2 q_{mn}}{\partial z^2} - \left(\frac{m^2 \pi^2}{a^2} - \frac{n^2 \pi^2}{b^2} \right) q_{mn} + \frac{4 Q_o}{ab} \delta(\tau) \delta(z) \right] = 0 \tag{B-8}$$

Taking the Fourier trnasform of the equation for a particular m and n and letting

$$\alpha_m = \frac{m \pi}{a} \tag{B-9}$$

and

$$\beta_n = \frac{n \pi}{b} \tag{B-10}$$

led to

$$\frac{\partial \bar{q}\, \omega}{\partial (\tau)} + (\alpha_m^2 + \beta_n^2 + \omega^2)\, \bar{q}\,(\omega) = \frac{4 Q_o}{ab}\, \delta(\tau)\,, \tag{B-11}$$

where $\bar{q}\,(\omega)$ represents the Fourier transform of $q_{mn}(z)$.

The solution to this differential equation was

$$\bar{q}\,(\omega) = \frac{4 Q_o}{ab}\, e^{-(\alpha_m^2 + \beta_n^2 + \omega^2)\, \tau} \tag{B-12}$$

Taking the inverse transform of Eq. B-12 and substituting it into Eq. B-5 gave the slowing down density along the z axis as

$$q(z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{4 Q_o e^{-(\alpha_m^2 + \beta_n^2)\tau}}{ab \sqrt{4 \pi \tau}}\, e^{-z^2/4\tau} . \tag{B-13}$$

Substitution of Eqs. B-4 and B-5 into the thermal diffusion equation. Equation A-2, and designating Σ_a/D as κ^2 gave

$$\sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \left[\frac{\partial^2 \phi_{mn}}{\partial z^2} - (\alpha_m^2 + \beta_n^2 + \kappa^2)\phi_{mn} + \frac{q_{mn}}{D} \right] = 0 \ . \qquad \text{(B-14)}$$

Taking the Fourier transform of Eq. B-14 for a particular m and n and designating the Fourier transforms of ϕ_{mn} and q_{mn} by $\bar{\phi}(\omega)$ and $\bar{q}(\omega)$, respectively, gave

$$\bar{\phi}(\omega) = \frac{\bar{q}(\omega)}{D(\alpha_m^2 + \beta_n^2 + \omega^2} \ . \qquad \text{(B-15)}$$

Taking the inverse transform of Eq. B-15 by means of the convolution theorem (30), after Eq. B-12 had been used to express $\bar{q}(\omega)$ gave

$$\phi_{mn} = \frac{2Q_o e^{-(\alpha_m^2 + \beta_n^2)\tau}}{D_{ab}\ \gamma_{mn} \sqrt{4\pi\tau}} \int_{-\infty}^{\infty} e^{-z'^2/4\tau}\ e^{-|z-z'|\gamma_{mn}}\ dz' \qquad \text{(B-16)}$$

where

$$\gamma_{mn} = \sqrt{\alpha_m^2 + \beta_n^2 + \kappa^2} \qquad \text{(B-17)}$$

Glasstone and Edlund (11), on pages 185 to 187, give the development showing how the integral in Eq. B-16 may be expressed in terms of the error function

$$\mathrm{erf}(t) = \frac{2}{\sqrt{\pi}} \int_0^t e^{-u^2}\ du \ . \qquad \text{(B-18)}$$

Writing Eq. B-16 in terms of the error function and substituting it into Eq. B-4 gave the thermal flux along the z axis as

$$\phi(z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{Q_o}{D_{ab}\,\gamma_{mn}}\, e^{\kappa^2 \tau} \Bigg[e^{-\gamma_{mn} z} \left[1 + \operatorname{erf}\left(\frac{z}{2\sqrt{\tau}} - \gamma_{mn}\sqrt{\tau} \right) \right] + e^{\gamma_{mn} z} \left[1 - \operatorname{erf}\left(\frac{z}{2\sqrt{\tau}} + \gamma_{mn}\sqrt{\tau} \right) \right] \Bigg] \, . \qquad \text{(B-19)}$$

To describe the thermal flux due to an empirical source which is defined by a set of Gaussian ranges, the quantity $\frac{r_i^2}{4}$ should be substituted into Eq. B-19 for the age τ. The flux must then be multiplied by the appropriate f_i and summed over the number of terms in the empirical source, which gave

$$\phi(z) = \sum_{i=1}^{N} \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{Q_o}{D_{ab}\,\gamma_{mn}}\, e^{\frac{\kappa^2 r_i^2}{4}} \Bigg[e^{-\gamma_{mn} z} \left[1 + \operatorname{erf}\left(\frac{z}{r_i} - \frac{\gamma_{mn} r_i}{2} \right) \right] + e^{\gamma_{mn} z} \left[1 - \operatorname{erf}\left(\frac{z}{r_i} + \frac{\gamma_{mn} r_i}{2} \right) \right] \Bigg] \, . \qquad \text{(B-20)}$$

The above derivation is identical to that presented by L. R. Foulke (9).

APPENDIX C

IBM 650 Program for Diffusion Length, Point Thermal Source

This code was written to determine an experimental value of diffusion length based on the assumption of a point source of thermal neutrons. The program was written in SOAP II and floating point form. The object program and a logic diagram are given in this section.

The method of calculation was an iteration procedure based upon the equation

$$\phi(x, y, z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{2S}{abD} \cos \frac{m\pi x}{a} \cos \frac{n\pi y}{b} \frac{\sinh \gamma_{mn}(c - z)}{\cosh \gamma_{mn} C} .$$

Values of the correction factors C_E and C_H, were calculated using an initial estimate of γ_{11}, the data was corrected according to these factors, and a new value of γ_{11} was obtained by a least squares analysis of the corrected data. The new value of γ_{11} was then used to calculate a second set of correction factors. This procedure was repeated until the least squares value of γ_{11} obtained at the end of one trial was within a specified precision of the value obtained from the previous trial. At this point the last value of γ_{11} obtained was used to calculate the diffusion length according to

$$\frac{1}{L^2} = -\alpha_1^2 - \beta_1^2 + \gamma_{11}^2$$

where

$$\alpha_1 = \frac{\pi}{a}, \quad \beta_1 = \frac{\pi}{b}$$

a and b being the extrapolated pile dimensions.

Input for this code consisted of the data and accompanying position co-ordinates as well as certain parameters listed in Table 20. Table 21 gives the form of the two types of output of this program.

Table 20. Input data for IBM 650 program for diffusion length based on a point thermal source.

Symbol	Explanation	Drum Storage Location
FIRST	Initial value of γ_{11}	0100
POINT	No. of data points, in form 00 0000 00xx	0101
DATPT	No. of data points, in floating point form	0102
A	Extrapolated x-dimension	0103
B	Extrapolated y-dimension	0104
C	Extrapolated z-dimension	0105
X	x co-ordinate of data	0106
Y	y co-ordinate of data	0107
Z	z co-ordinate of data, to be stored consecutively starting at	0301
N	neutron count rates, to be stored consecutively starting at	0501

The input parameters and data listed in Table 19 should be punched on one-word load cards and fed into the machine with the object program. Point Stripping may be accomplished by listing the data, N and z, with the points to be dropped last and varying the parameters POINT and DATPT.

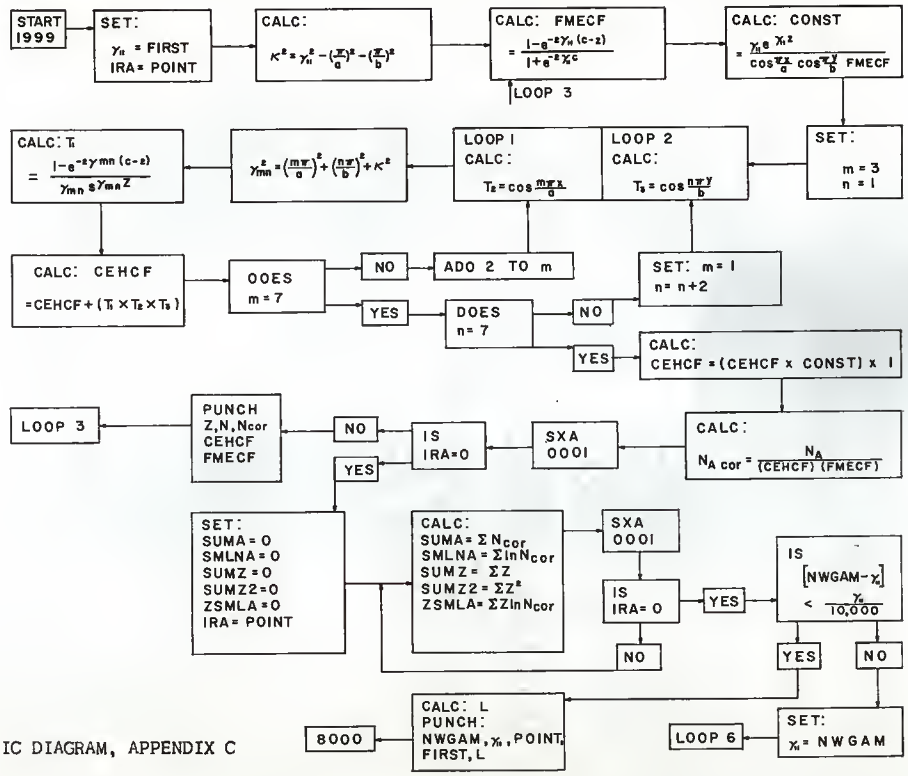
The form one output is punched after the calculation of each corrected data point. One card of this form will be obtained for each data point during a given trial. When the desired precision is reached, the final calculations are made and one card of form two is punched.

Table 21. Output forms for IBM 650 program for diffusion length based on a point thermal source.

Word No. 1	2	3	4	5
Form One:				
z co-ordinate	data	corrected data	Harmonic Correction	End Correction
Form Two:				
γ_{11}, Last value	γ_{11} Next to Last value	POINT	γ_{11}, Initial value	Diffusion Length

The operating time necessary to calculate the correction factor for one data point using four harmonics is approximately 45 seconds. The capacity of the program is 200 data points.

LOGIC DIAGRAM FOR IBM 650 PROGRAM FOR POINT THERMAL SOURCE METHOD



LOGIC DIAGRAM, APPENDIX C

```
         BLR  1951    1958                        1   0000    00 0000 0000
         BLR  1977    1984                        2   0000    00 0000 0000
         BLR  0300    0900                        3   0000    00 0000 0000
         SYN  FIRST   0100                        4   0000    00 0000 0000
         SYN  POINT   0101    INDEX FORM          5   0000    00 0000 0000
         SYN  DATPT   0102    DATA FORM           6   0000    00 0000 0000
         SYN  A       0103    X DIMEN             7   0000    00 0000 0000
         SYN  B       0104    Y DIMEN             8   0000    00 0000 0000
         SYN  C       0105    Z DIMEN             9   0000    00 0000 0000
         SYN  X       0106       DATA            10   0000    00 0000 0000
         SYN  Y       0107    COORDINATE         11   0000    00 0000 0000
         SYN  Z       0300                       12   0000    00 0000 0000
         SYN  N       0500                       13   0000    00 0000 0000
         SYN  NCOR    0700                       14   0000    00 0000 0000
         SYN  START   1999                       15   0000    00 0000 0000
ZERO      00  0000    0000                       16   0000    00 0000 0000
ONE       10  0000    0051                       17   0050    10 0000 0051
TWO       20  0000    0051                       18   0150    20 0000 0051
MTWO   -  20  0000    0051                       19   0200    20 0000 0051
THREE     30  0000    0051                       20   0250    30 0000 0051
PI        31  4160    0051                       21   0950    31 4160 0051
SEVEN     70  0000    0051                       22   1000    70 0000 0051
CONVT     25  3600    0051                       23   1050    25 3600 0051
10000     10  0000    0055                       24   1100    10 0000 0055
LNX01    STD  LNX08                              25   1150    24 0003 0006
         NZE          LNX14                      26   0006    45 0010 0011
         BMI  LNX14                              27   0010    46 0011 0014
         STU  LNX09                              28   0014    21 0018 0021
         RSL  FPONE                              29   0021    66 0024 0029
         STD  LNX10                              30   0029    24 0032 0035
         STL  LNX02                              31   0035    20 0039 0042
         RAU  LNX09                              32   0042    60 0018 0023
         STL  LNX05                              33   0023    20 0027 0030
         STL  LNX11                              34   0030    20 0085 0038
         SLT  0008                               35   0038    35 0008 0007
         SUP  FIFTY                              36   0007    11 0060 0015
         NZE          LNX04                      37   0015    45 0068 0019
         BMI          LNX03                      38   0068    46 0071 0022
         RSU  0003                               39   0071    61 8003 0079
         LDD  FPONE                              40   0079    69 0024 0077
         STD  LNX02   LNX03                      41   0077    24 0039 0022
LNX03    SRT  0008                               42   0022    30 0008 0041
         SCT  0000                               43   0041    36 0000 0013
         AUP  SIXTY                              44   0013    10 0016 0121
         SUP  8002                               45   0121    11 8002 0129
         RAU  8003                               46   0129    60 8003 0037
         FMP  LNX02                              47   0037    39 0039 0089
         FMP  LNTEN                              48   0089    39 0092 0142
         STU  LNX05   LNX04                      49   0142    21 0027 0019
LNX04    RAL  LNX09                              50   0019    65 0018 0073
         SRT  0002                               51   0073    30 0002 0179
         RAU  8002                               52   0179    60 8002 0087
         ALO  FIFTY                              53   0087    15 0060 0065
         SLT  0002                               54   0065    35 0002 0171
         FAD  FPONE                              55   0171    32 0024 0001
         STU  LNX09                              56   0001    21 0018 0221
         FSB  FPTWO                              57   0221    33 0074 0051
         FDV  LNX09                              58   0051    34 0018 0118
         STU  LNX13                              59   0118    21 0072 0025
         STD  LNX12                              60   0025    24 0028 0031
         STD  LNX11                              61   0031    24 0085 0088
         FMP  8001                               62   0088    39 8001 0091
         STU  FACTR   LNX06                      63   0091    21 0046 0049
LNX06    RAU  LNX10                              64   0049    60 0032 0137
         FAD  FPTWO                              65   0137    32 0074 0151
         STU  LNX10                              66   0151    21 0032 0135
         RAU  LNX13                              67   0135    60 0072 0127
         FMP  FACTR                              68   0127    39 0046 0096
         FDV  LNX10                              69   0096    34 0032 0082
         STU  LNX13                              70   0082    21 0072 0075
         FAD  LNX12                              71   0075    32 0028 0005
         STU  LNX12                              72   0005    21 0028 0081
         FSB  LNX11                              73   0081    33 0085 0061
         FDV  LNX11                              74   0061    34 0085 0185
         RAM  8003                               75   0185    67 8003 0043
         RAU  8002                               76   0043    60 8002 0201
         FSB  SIZE7                              77   0201    33 0004 0131
         BMI  LNX07                              78   0131    46 0034 0235
         LDD  LNX12                              79   0235    69 0028 0181
         STD  LNX11                              80   0181    24 0085 0138
         RAU  LNX13                              81   0138    60 0072 0177
         FMP  LNX10                              82   0177    39 0032 0132
         STU  LNX13   LNX06                      83   0132    21 0072 0049
LNX07    RAU  LNX12                              84   0034    60 0028 0033
         FMP  FPTWO                              85   0033    39 0074 0124
         FSB  LNX05   LNX08                      86   0124    33 0027 0003
FPONE     10  0000    0051                       87   0024    10 0000 0051
FPTWO     20  0000    0051                       88   0074    20 0000 0051
SIZE7     10  0000    0043                       89   0004    10 0000 0043
LNTEN     23  0258    5151                       90   0092    23 0258 5151
FIFTY     50  0000    0000                       91   0060    50 0000 0000
SIXTY     00  0000    0060                       92   0016    00 0000 0060
LNX14     01  2345    6789                       93   0011    01 2345 6789
EODAO    STD  SEXT                            1  94   1200    24 0053 0056
         BMI  SERR                            2  95   0056    46 0009 0110
         NZE          SEXT                    3  96   0110    45 0064 0053
         STU  SA                              4  97   0064    21 0168 0271
         FAD  S10                             5  98   0271    32 0174 0251
         FMP  SHAF    SB                      6  99   0851    39 0054 0154
SB       STU  SSAV    SAB                     7 100   0154    21 0008 0111
SAB      RAU  SA              S CAPT A        8 101   0111    60 0168 0123
         FDV  SSAV                            9 102   0123    34 0008 0058
         FAD  SSAV                           10 103   0058    32 0008 0285
         FMP  SHAF                           11 104   0285    39 0054 0204
```

```
          FSH  SSAV                          12  1U5   0204   33 0008 U935
          NZU             BR                 13  1U6   0935   44 0139 0040
          BMI             BR                 14  1U7   0139   46 0192 0040
          FAU  SSAV                          15  108   0192   32 0U08 0985
          STU  SSAV       SAH                16  109   0985   21 0008 0111
BR        RAU  SSAV       SEXT               17  110   0040   60 0008 M053
SERR      HLT   0000      SEXT               18  111   0009   01 0000 M053
BHAF       50   0U00       0050              19  112   0U54   50 0U0U 0050
S10        10   000U       0051              20  113   0174   10 0U00 0051
EUOEA     STU  AAA1              EXIT INSTR      114   1250   24 0153 U156
          STL  AAA2               STORE X        115   0156   20 0161 0114
          RAM  AAA2                              116   0114   67 0161 U115
          STL  AAA3              X FOR CALC      117   0115   20 0069 U122
          RAU  AAA3                              118   0122   60 0069 M173
          FMP  AAA16                             119   0173   39 0026 M076
          FAU  AAA15                             120   0076   32 0229 0055
          FMP  AAA3                              121   0055   39 0069 0119
          FAU  AAA14                             122   0119   32 0172 0099
          FMP  AAA3                              123   0099   39 0069 U169
          FAU  AAA13                             124   0169   32 0228 0149
          FMP  AAA3                              125   0149   39 0069 0219
          FAD  AAA12                             126   0219   32 0272 0199
          FMP  AAA3                              127   0199   39 0069 0269
          FAU  AAA11                             128   0269   32 0928 0249
          FMP  AAA3                              129   0249   39 0069 0919
          FAU  AAA1U                             130   0919   32 0972 0299
          STU  AAA4                              131   0299   21 0254 0057
          FMP  AAA4                              132   0057   39 0254 M904
          STU  AAA4                              133   0904   21 0254 M157
          FMP  AAA4                              134   0157   39 0254 0954
          STU  AAA4                              135   0954   21 0254 M207
          RAU  AAA2                              136   0207   60 0161 0165
          BMI  AAA5       AAA6                   137   0165   46 0218 U969
AAA5      RAU  AAA10                             138   0218   60 0972 0227
          FDV  AAA4                              139   0227   34 0254 1004
          STU  AAA4       AAA6                   140   1004   21 0254 0969
AAA6      RAL  AAA4       AAA1                   141   0969   65 0254 0153
AAA10      1U   000U       0051                  142   0972   10 000U 0051
AAA11      24   9998       6850                  143   0922   24 9998 6850
AAA12      31   2575       8349                  144   0272   31 2575 8349
AAA13      25   9137       1248                  145   0222   25 9137 1248
AAA14      17   1562       0047                  146   0172   17 1562 0047
AAA15      54   3U2U       0045                  147   0229   54 3U2U 0045
AAA16      69   0600       0044                  148   0026   69 0600 M044
EOOCH     STU  FXIT                              149   1300   24 0203 M806
          RAU   8002                             150   0206   60 8002 0215
          BMI  NEGAT      REDUC                  151   0215   46 0268 1019
NEGAT     FAD  TWOPI                             152   0268   32 0921 M047
          BMI  NEGAT                             153   0047   46 0268 M901
          FSB  UNEPI      COBIU                  154   0901   33 1054 0231
RFDUC     FSB  TWOPI                             155   1019   33 0921 M097
          BMI             REDUC                  156   0097   46 1350 1019
          FAD  UNEPI      CUSIU                  157   1350   32 1054 0231
COBIO     STU  TRETA                             158   0231   21 0036 0189
          RBU  FPONE                             159   0189   61 0084 0279
          STU  TERMM                             160   0279   21 0084 0187
          STU  FUNKT                             161   0187   21 0242 0045
          STL  ENN        NEGST                  162   0045   20 0949 U002
EUOSH     STU  FXIT                              163   1400   24 0203 0256
          RAU   8002                             164   0256   60 8002 M265
          BMI  NEGAV      REOUU                  165   0265   46 0918 1069
NEGAV     FAU  TWOPI                             166   0918   32 0921 0147
          BMI  NEGAV                             167   0147   46 0918 M951
          FSH  ONEPI      SINET                  168   0951   33 1054 0281
REOUU     FSH  TWOPI                             169   1069   33 0921 0197
          BMI             REUUU                  170   0197   46 1450 1069
          FAU  UNEPI      SINET                  171   1450   32 1054 0281
SINET     STU  TRETA                             172   0281   21 0036 U239
          RSU   8003                             173   0239   61 8003 M247
          STU  TERMM                             174   0247   21 0084 0237
          STU  FUNKT                             175   0237   21 0242 0095
          LOU  FPONE                             176   0095   69 0024 0277
          STO  ENN        NEGST                  177   0277   24 0949 M008
NEGST     RAU  ENN                               178   0002   60 0949 0253
          FAU  FPONE                             179   0853   32 0024 1001
          STU  NPONE                             180   1001   21 0906 0059
          FAD  FPONE                             181   0059   32 0024 1051
          STU  ENN                               182   1051   21 0949 0052
          RSU  TERMM                             183   0052   61 0084 0289
          FMP  THETA                             184   0289   39 0036 0086
          FMP  TNETA                             185   0026   39 0036 0136
          FOV  NPONE                             186   0136   34 0906 0956
          FDV  ENN                               187   0956   34 0949 0999
          STU  TERMM                             188   0999   21 0084 0287
          RAM  FUNKT                             189   0287   67 0248 0297
          STL  FMAG                              190   0297   20 1101 1104
          RAM  TERMM                             191   1104   67 0084 0939
          RAU   8002                             192   0939   60 8008 0947
          FOV  FMAO                              193   0947   34 1101 1151
          FSB  SIZE8                             194   1151   33 1154 0931
          BMI  ENUFF                             195   0931   46 0134 1035
          RAU  FUNKT                             196   1035   60 0242 0997
          FAO  TERMM                             197   0997   32 0084 0211
          STU  FUNKT      NEGST                  198   0211   21 0242 0002
ENUFF     RAL  FUNKT      EXIT                   199   0134   65 0242 0203
SIZE8      10   0000       0043                  200   1154   10 0000 0043
TWUPI      62   8318       5351                  201   0921   62 8318 5351
ONEPI      31   4159       8751                  202   1054   31 4159 2751
FPUNE      10   0000       0051                  203   0024   10 0000 0051
START     LOO  FIRST             INITIAL         204   1999   69 0100 0903
          STO  GAM11      LOOP6   GAMMA          805   0903   24 1006 0109
LOOP6     LOO  POINT             OATA POINT      206   0109   69 0101 1204
          RAA   8001                             207   1204   80 8001 0160
```

```
          LDD  ZERO                                  208    0160    69  0000  0953
          STD  ALPHA                                 209    0953    24  1056  0159
          STD  BETA                                  210    0159    24  0012  0915
          RAU  GAM11                                 211    0915    60  1006  0261
          FMP  GAM11                                 212    0261    39  1006  1106
          STU  GAMSQ                    GAMMA SQR    213    1106    21  0210  0063
          STU  TEMP1                                 214    0063    21  0968  0971
          RAU  PI                                    215    0971    60  0950  0155
          FDV  A                                     216    0155    34  0103  1003
          STU  TEMP2                                 217    1003    21  0108  0911
          FMP  TEMP2                      ALPHA      218    0911    39  0108  0158
          STU  TEMP2                       SQR       219    0158    21  0108  0961
          RAU  PI                                    220    0961    60  0950  0205
          FDV  B                                     221    0205    34  0104  1254
          STU  TEMP3                                 222    1254    21  0208  1011
          FMP  TEMP3                       BETA      223    1011    39  0208  0258
          STU  TEMP3                        SQR      224    0258    21  0208  1061
          RAU  TEMP1                                 225    1061    60  0968  0223
          FSB  TEMP2                                 226    0223    33  0108  1085
          FSB  TEMP3                      KAPPA      227    1085    33  0208  1135
          STU  KAPSQ       LOOP3           SQR       228    1135    21  0090  0093
LOOP3     LDD  ZERO                                  229    0093    69  0000  1053
          STD  CEHCF                                 230    1053    24  1156  0209
          RAU  C                        CORRECTION   231    0209    60  0105  0259
          FSB  Z       A                   FOR       232    0259    33  2300  0927
          FMP  GAM11                      END        233    0927    39  1006  1206
          FMP  MTWO                          EFFECT  234    1206    39  0200  1500
          RAL   8003                                 235    1500    65  8003  0257
          LDD              E00EA                     236    0257    69  0260  1250
          STL  TEMP1                                 237    0260    20  0968  1021
          RAU  ONE                                   238    1021    60  0050  0255
          FSB  TEMP1                                 239    0255    33  0968  0145
          STU  TEMP1                                 240    0145    21  0968  1071
          RAU  C                                     241    1071    60  0105  0909
          FMP  GAM11                                 242    0909    39  1006  1256
          FMP  MTWO                                  243    1256    39  0200  1550
          RAL   8003                                 244    1550    65  8003  0907
          LDD              E00EA                     245    0907    69  0910  1250
          STL  TEMP2                                 246    0910    20  0108  1111
          RAU  ONE                                   247    1111    60  0050  0905
          FSB  TEMP2                                 248    0905    33  0108  1185
          STU  TEMP2                                 249    1185    21  0108  1161
          RAU  TEMP1                    FUND MODE    250    1161    60  0968  0273
          FDV  TEMP2                    CORRECTION   251    0273    34  0108  0908
          STU  FMECF                      FACTOR     252    0908    21  0062  0965
          RAU  PI                        CALCULATE   253    0965    60  0950  0955
          FMP  X                          CONSTANT   254    0955    39  0106  1306
          FDV  A                            FACTOR   255    1306    34  0103  1103
          RAL   8003                    FOR CEHCF    256    1103    65  8003  1211
          LDD              E00CH                     257    1211    69  0164  1300
          STL  TEMP1                                 258    0164    20  0968  1121
          RAU  PI                                    259    1121    60  0950  1005
          FDV  B                                     260    1005    34  0104  1304
          FMP  Y                                     261    1304    39  0107  0957
          RAL   8003                                 262    0957    65  8003  1015
          LDD              E00CH                     263    1015    69  1018  1300
          STL  TEMP2                                 264    1018    20  0108  1261
          RAU  GAM11                                 265    1261    60  1006  1311
          FMP  Z       A                             266    1311    39  2300  1600
          RAL   8003                                 267    1600    65  8003  1007
          LDD              E00EA                     268    1007    69  0960  1250
          RAU   8002                                 269    0960    60  8002  1119
          FMP  GAM11                                 270    1119    39  1006  1356
          FDV  TEMP1                                 271    1356    34  0968  1068
          FDV  TEMP2                                 272    1068    34  0108  0958
          FDV  FMECF                                 273    0958    34  0062  0112
          STU  CONST                     CONSTANT    274    0112    21  0066  1169
          LDD  THREE                                 275    1169    69  0250  1153
          STD  M                                     276    1153    24  1406  0959
          LDD  ONE                                   277    0959    69  0050  1203
          STD  N           LOOP2                     278    1203    24  0500  1253
LOOP2     RAU  N                                     279    1253    60  0500  1055
          FMP  PI                                    280    1055    39  0950  1650
          FMP  Y                                     281    1650    39  0107  1057
          FDV  B                                     282    1057    34  0104  1354
          RAL   8003                                 283    1354    65  8003  1361
          LDD              E00CH                     284    1361    69  0214  1300
          STL  TEMP3       LOOP1                     285    0214    20  0208  1411
LOOP1     RAU  M                                     286    1411    60  1406  1461
          FMP  PI                                    287    1461    39  0950  1700
          FMP  X                                     288    1700    39  0106  1456
          FDV  A                                     289    1456    34  0103  1303
          RAL   8003                                 290    1303    65  8003  1511
          LDD              E00CH                     291    1511    69  0264  1300
          STL  TEMP2                                 292    0264    20  0108  1561
          RAU  M                                     293    1561    60  1406  1611
          FMP  PI                                    294    1611    39  0950  1750
          FDV  A                                     295    1750    34  0103  1353
          STU  TEMP4                                 296    1353    21  1008  1661
          FMP  TEMP4                                 297    1661    39  1008  1058
          STU  ALPH2                                 298    1058    21  0162  1065
          RAU  N                                     299    1065    60  0500  1105
          FMP  PI                                    300    1105    39  0950  1800
          FDV  B                                     301    1800    34  0104  1404
          STU  TEMP4                                 302    1404    21  1008  1711
          FMP  TEMP4                                 303    1711    39  1008  1108
          STU  BETA2                                 304    1108    21  0212  1115
          FAD  ALPH2                                 305    1115    32  0162  0989
          FAD  KAPSQ                                 306    0989    32  0090  0017
          LDD              E00AU                     307    0017    69  0020  1200
          STU  GAMMA                                 308    0020    21  0224  0977
          RAU  C                                     309    0977    60  0105  1009
          FSB  Z       A                             310    1009    33  2300  1027
```

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          FMP  GAMMA                                   311   1027   39 0224 0274
          FMP  MTWO                                    312   0274   39 0200 1850
          RAL   8003                                   313   1850   65 8003 1107
          LDD             EODEA                        314   1107   69 1010 1250
          STL  TEMP5                                   315   1010   20 1165 1118
          RAU  C                                       316   1118   60 0105 1059
          FMP  GAMMA                                   317   1059   39 0224 0924
          FMP  MTWO                                    318   0924   39 0200 1900
          RAL   8003                                   319   1900   65 8003 1157
          LDD             EODEA                        320   1157   69 1060 1250
          STL  TEMP7                                   321   1060   20 1215 1168
          RAU  ONE                                     322   1168   60 0050 1155
          FSB  TEMP7                                   323   1155   35 1215 0141
          STU  TEMP7                                   324   0141   21 1215 1218
          RAU  GAMMA                                   325   1218   60 0224 0929
          FMP  Z       A                               326   0929   39 2300 1950
          RAL   8003                                   327   1950   65 8003 1207
          LDD             EODEA                        328   1207   69 1110 1250
          STL  TEMP6                                   329   1110   20 1265 1268
          RAU  ONE                                     330   1268   60 0050 1205
          FSB  TEMP5                                   331   1205   33 1165 0191
          FDV  TEMP6                                   332   0191   34 1265 1315
          FDV  TEMP7                                   333   1315   34 1215 1365
          FDV  GAMMA                                   334   1365   34 0224 0974
          FMP  TEMP3                                   335   0974   39 0208 1158
          FMP  TEMP2                                   336   1158   39 0108 1208
          FAD  CEHCF                                   337   1208   32 1156 0083
          STU  CEHCF                                   338   0083   21 1156 1109
          RAU  SEVEN                                   339   1109   60 1000 1255
          FSB  M                                       340   1255   33 1406 0133
          NZE  CONT1      CONT2                        341   0133   45 0186 0937
CONT1     RAU  M                                       342   0186   60 1406 1761
          FAD  TWO                                     343   1761   32 0150 1077
          STU  M          LOOP1                        344   1077   21 1406 1411
CONT2     RAU  N                                       345   0937   60 0500 1305
          FSB  SEVEN                                   346   1305   33 1000 1127
          NZE  CONT3      CONT4                        347   1127   45 0080 0981
CONT3     LDD  ONE                                     348   0080   69 0050 1403
          STD  M                                       349   1403   24 1406 1159
          RAU  N                                       350   1159   60 0500 1355
          FAD  TWO                                     351   1355   32 0150 1177
          STU  N          LOOP2                        352   1177   21 0500 1253
CONT4     RAU  CEHCF              CALC OF              353   0981   60 1156 1811
          FMP  CONST              HARMONIC             354   1811   39 0066 0116
          FAD  ONE                END                  355   0116   32 0050 1227
          STU  CFHCF              CORRECTION           356   1227   21 1156 1209
          RAU  N       A                               357   1209   60 2500 1405
          FDV  CFHCF                                   358   1405   34 1156 1506
          FDV  FMECF                                   359   1506   34 0062 0262
          STU  NCOR    A                               360   0262   21 2700 1453
          LDD  Z       A                               361   1453   69 2300 1503
          STD   1977                                   362   1503   24 1977 0130
          LDD  N       A                               363   0130   69 2500 1553
          STD   1978                                   364   1553   24 1978 1031
          LDD  NCOR    A                               365   1031   69 2700 1603
          STD   1979                                   366   1603   24 1979 0182
          LDD  CFHCF                                   367   0182   69 1156 1259
          STD   1980                                   368   1259   24 1980 0183
          LDD  FMECF                                   369   0183   69 0062 1415
          STD   1981                                   370   1415   24 1981 0184
          PCH   1977                                   371   0184   71 1977 1277
          SXA   0001                                   372   1277   51 0001 0233
          NZA  LOOP3      CONT6                        373   0233   40 0093 0987
CONT6     LDD  POINT                                   374   0987   69 0101 1454
          RAA   8001                                   375   1454   80 8001 1160
          LDD  ZERO                                    376   1160   69 0000 1653
          STD  SUMA                                    377   1653   24 1556 1309
          STD  SMLNA                                   378   1309   24 0912 1465
          STD  SUMZ                                    379   1465   24 1318 1171
          STD  SUMZ2                                   380   1171   24 1024 1327
          STD  ZSMLA                                   381   1327   24 0180 0283
          LDD  DATPT                                   382   0283   69 0102 1455
          STD  P          LOOP5                        383   1455   24 1258 1861
LOOP5     RAU  NCOR    A                               384   1861   60 2700 1505
          FAD  SUMA                                    385   1505   32 1556 0933
          STU  SUMA                                    386   0933   21 1556 1359
          RAU  NCOR    A                               387   1359   60 2700 1555
          LDD             LNX01                        388   1555   69 1308 1150
          FAD  SMLNA                                   389   1308   32 0912 1039
          STU  SMLNA                                   390   1039   21 0912 1515
          RAU  Z       A                               391   1515   60 2300 1605
          FAD  SUMZ                                    392   1605   32 1318 0195
          STU  SUMZ                                    393   0195   21 1318 1221
          RAU  Z       A                               394   1221   60 2300 1655
          FMP  Z       A                               395   1655   39 2300 1201
          FAD  SUMZ2                                   396   1201   32 1024 1251
          STU  SUMZ2                                   397   1251   21 1024 1377
          RAU  NCOR    A                               398   1377   60 2700 1705
          LDD             LNX01                        399   1705   69 1358 1150
          FMP  Z       A                               400   1358   39 2300 1301
          FAD  ZSMLA                                   401   1301   32 0180 1257
          STU  ZSMLA                                   402   1257   21 0180 0983
          SXA   0001                                   403   0983   51 0001 1089
          NZA  LOOP5      CONT7                        404   1089   40 1861 0143
CONT7     RAU  SMLNA                                   405   0143   60 0912 0067
          FMP  SUMZ                                    406   0067   39 1318 1368
          STU  TEMP1                                   407   1368   21 0968 1271
          RAU  P                                       408   1271   60 1258 0113
          FMP  ZSMLA                                   409   0113   39 0180 0230
          STU  TEMP2                                   410   0230   21 0108 1911
          RAU  P                                       411   1911   60 1258 0163
          FMP  SUMZ2                                   412   0163   39 1024 1074
```

```
          STU  TEMP3                     413    1074    21 0208 1961
          RAU  SUMZ                      414    1961    60 1318 0923
          FMP  SUMZ                      415    0923    39 1318 1418
          STU  TEMP4                     416    1418    21 1008 0962
          RAU  TEMP3                     417    0962    60 0208 0213
          FSB  TEMP4                     418    0213    33 1008 1235
          STU  TEMP3                     419    1235    21 0208 1012
          RAU  TEMP1                     420    1018    60 0968 0973
          FSB  TEMP2                     421    0973    33 0108 1285
          FDV  TEMP3                     422    1285    34 0208 1408
          STU  NWGAM                     423    1408    21 1062 1565
          FDV  10000                     424    1565    34 1100 1351
          STU  PREC                      425    1351    21 1606 1409
          RAU  GAM11                     426    1409    60 1006 1112
          FSB  NWGAM                     427    1112    33 1062 1139
          RAM   8003                     428    1139    67 8003 1047
          RAU   8002                     429    1047    60 8002 1755
          FSB  PREC                      430    1755    33 1606 1033
          BMI  CONT8    CONT9            431    1033    46 0236 1037
CONT9     RAU  NWGAM                     432    1037    60 1062 0117
          STU  GAM11    LOOP6----------  433    0117    21 1006 0109
CONT8     RAU  PI                        434    0236    60 0950 1805
          FDV  A                         435    1805    34 0103 1703
          STU  ALPH2                     436    1703    21 0162 1615
          FMP  ALPH2                     437    1615    39 0162 1162
          STU  ALPH2                     438    1162    21 0162 1665
          RAU  PI                        439    1665    60 0950 1855
          FDV  B                         440    1855    34 0104 1504
          STU  BETA2                     441    1504    21 0212 1715
          FMP  BETA2                     442    1715    39 0212 1212
          STU  BETA2                     443    1212    21 0212 1765
          RAU  NWGAM                     444    1765    60 1062 0167
          FMP  NWGAM                     445    0167    39 1062 1262
          FSB  BETA2                     446    1262    33 0212 1189
          FSB  ALPH2                     447    1189    33 0162 1239
          LDD           EOOAU            448    1239    69 0292 1200
          STU  TEMP1                     449    0292    21 0968 1321
          RAU  UNE                       450    1321    60 0050 1905
          FDV  TEMP1                     451    1905    34 0968 1468
          FMP  CONVT                     452    1468    39 1050 1401
          STU  DL                        453    1401    21 1656 1459
          LDD  NWGAM                     454    1459    69 1062 1815
          STD   1977                     455    1815    24 1977 0280
          LDD  GAM11                     456    0280    69 1006 1509
          STD   1978                     457    1509    24 1978 1081
          LDD  POINT                     458    1081    69 0101 1554
          STD   1979                     459    1554    24 1979 0232
          LDD  FIRST                     460    0232    69 0100 1753
          STD   1980                     461    1753    24 1980 1083
          LDD  DL                        462    1083    69 1656 1559
          STD   1981                     463    1559    24 1981 0234
          PCH   1977     8000            464    0234    71 1977 8000
```

APPENDIX D

IBM 650 Program for Diffusion Length
Constant Thermal Source

The purpose of this program was to determine an experimental value of the diffusion length based on the assumption of a constant source of thermal neutrons. The program was written in SOAP II and floating point form. The object program and a logic diagram are given in this section.

The calculations in this program are based on the equation

$$\phi(x, y, z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{16\phi_0(-1)^{\frac{m+n+2}{2}}}{mn\pi^2 \sinh \gamma_{mn} c} \cos\frac{m\pi x}{a} \cos\frac{n\pi y}{b} \sinh \gamma_{mn}(c-z).$$

The same iterative procedure is used in this program as was used in the point thermal source program described in Appendix C.

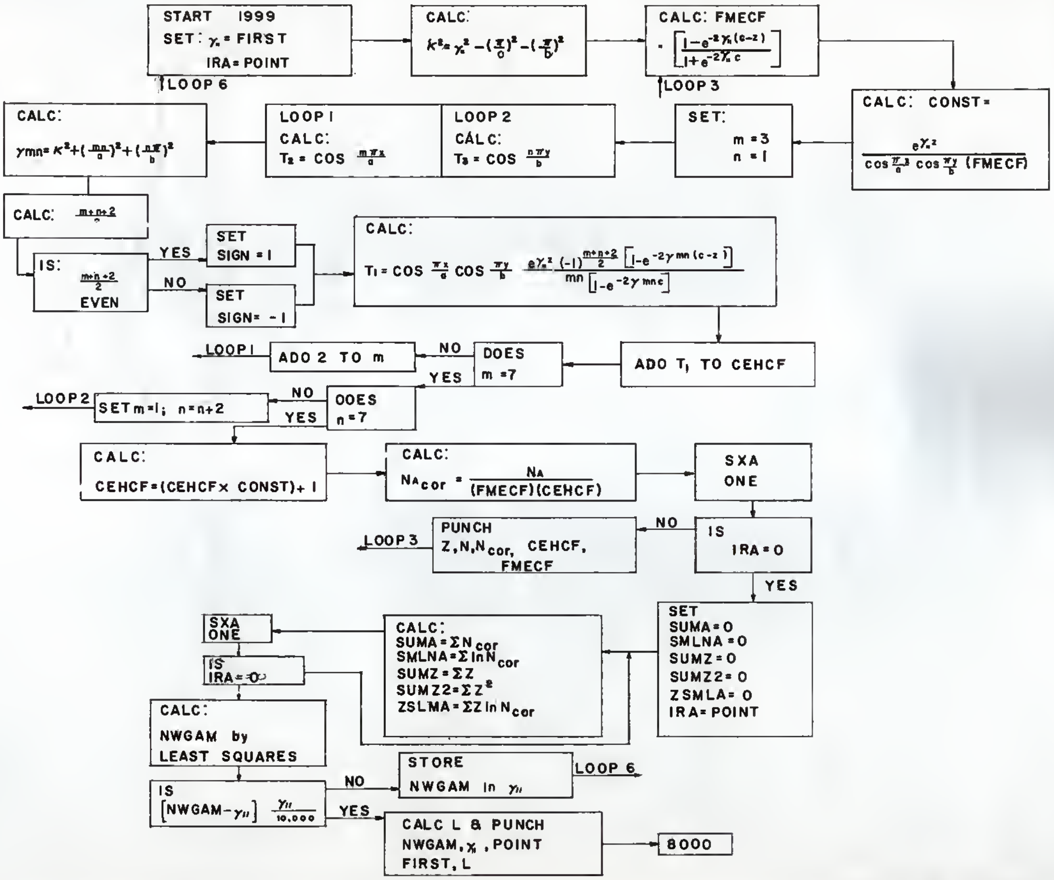
Input parameters and data are identical to those used in the point thermal source program and are listed in Table 20. Output is similar, and is described in Table 22.

Table 22. Output forms for IBM 650 program for diffusion length based on a constant thermal source.

Word No. 1	2	3	4	5
Form One:				
z co-ordinate	data	corrected data	Harmonic Correction	End Correction
Form Two:				
γ_{11}, Last value	γ_{11} Next to Last value	γ_{11} Initial value	POINT	Diffusion Length

The output sequence is identical to that for the point thermal source program. The operating time necessary to calculate the correction factor for one data point using four harmonics is about 45 seconds. The capacity of the program is 200 data points.

LOGIC DIAGRAM FOR IBM650 PROGRAM FOR CONSTANT THERMAL SOURCE METHOD



LOGIC DIAGRAM, APPENDIX D

```
               BLR   0300     0900                       1  0000    00 0000 0000
               BLR   1950     1999                       2  0000    00 0000 0000
               SYN  Z         0300                       3  0000    00 0000 0000
               SYN  N         0500                       4  0000    00 0000 0000
               SYN  FIRST     0100                       5  0000    00 0000 0000
               SYN  POINT     0101     INDEX FORM        6  0000    00 0000 0000
               SYN  DATPT     0102     DATA FORM         7  0000    00 0000 0000
               SYN  A         0103     X DIMEN           8  0000    00 0000 0000
               SYN  B         0104     Y DIMEN           9  0000    00 0000 0000
               SYN  C         0105     Z DIMEN          10  0000    00 0000 0000
               SYN  X         0106       DATA           11  0000    00 0000 0000
               SYN  Y         0107     COORDINATE       12  0000    00 0000 0000
               SYN  NCOR      0700                      13  0000    00 0000 0000
               SYN  START     1999                      14  0000    00 0000 0000
1 SINE         AND   COS      RAD      OR DEGREES       25  0000    00 0000 0000
  ZERO          00  0000      0000                      15  0000    00 0000 0000
  MTWO      -   20  0000      0051                      16  0050    20 0000 0051
  PI            31  4160      0051                      17  0150    31 4160 0051
  ONE           10  0000      0051                      18  0200    10 0000 0051
  TWO           20  0000      0051                      19  0250    20 0000 0051
  THREE         30  0000      0051                      20  0950    30 0000 0051
  SEVEN         70  0000      0051                      21  1000    70 0000 0051
  10000         10  0000      0055                      22  1050    10 0000 0055
  PRECN         10  0000      0047                      23  1100    10 0000 0047
  CONVT         25  3600      0051                      24  1150    25 3600 0051
  E00SD        STD  B13                                 26  1200    24 0003 0006
               RAU   8002                               27  0006    60 8002 0015
               FMP  B7        B14                       28  0015    39 0018 0068
  E00SR        STD  B13                                 29  1250    24 0003 0056
               RAU   8002     B14                       30  0056    60 8002 0060
  E00CD        STD  B13                                 31  1300    24 0003 0156
               RAU   8002                               32  0156    60 8002 0065
               FMP  B7        B15                       33  0065    39 0018 0118
  E00CR        STD  B13                                 34  1350    24 0003 0206
               RAU   8002     B15                       35  0206    60 8002 0118
  B14          LDD  B9                                  36  0068    69 0021 0074
               STD  B17                                 37  0024    24 0027 0030
               STU  B11       B16      STORE X          38  0030    21 0034 0037
  B15          LDD  B10                                 39  0118    69 0071 0074
               STD  B17                                 40  0074    24 0027 0080
               LDD  B1                                  41  0080    69 0033 0036
               STD  B12       B16      STORE ONE        42  0036    24 0039 0037
  B16          STU  B5                                  43  0037    21 0042 0045
  B21          FSB  2PI                                 44  1400    33 0053 0029
               BMI  B20       B21                       45  0029    46 0032 1400
  B20          FAD  2PI                                 46  0032    32 0053 0079
               STU  B5                                  47  0079    21 0042 0095
               LDD  B8                                  48  0095    69 0048 0001
               STD  B3                                  49  0001    24 0004 0007
               FMP  B5                 X SQUARED        50  0007    39 0042 0092
               FDV  B3                 2 FACTOR         51  0092    34 0004 0054
               STU  B4        B18                       52  0054    21 0008 0011
  B18          RSU  B4                                  53  0011    61 0000 0013
               STU  B4                                  54  0013    21 0008 0061
               FAD  B12                                 55  0061    32 0039 0115
               STU  B12                                 56  0115    21 0039 0142
               RAU  B3                                  57  0142    60 0004 0009
               FAD  B1                                  58  0009    32 0033 0059
               STU  B3                                  59  0059    21 0004 0057
               RAU  B5                                  60  0057    60 0042 0047
               FDV  B3                                  61  0047    34 0004 0154
               FMP  B4                                  62  0154    39 0008 005R
               STU  B4                                  63  0058    21 0008 0111
               FAD  B11                                 64  0111    32 0034 0161
               STU  B11                                 65  0161    21 0034 0087
               RAU  B3                                  66  0087    60 0004 0109
               FAD  B1                                  67  0109    32 0033 0159
               STU  B3                                  68  0159    21 0004 0157
               RAU  B5                                  69  0157    60 0042 0097
               FDV  B3                                  70  0097    34 0004 0204
               FMP  B4                                  71  0204    39 0008 0108
               STU  B4                                  72  0108    21 0008 0211
               RAM  B4                                  73  0211    67 0008 0063
               RAU   8002                               74  0063    60 8002 0121
               FAD  B6                                  75  0121    32 0124 0051
               BMI  B17       B18                       76  0051    46 0027 0011
  B2            10  0000      0000      ONE             77  1450    10 0000 0000
  B6        -   10  0000      0040      ERROR           78  0124    10 0000 0040
  B7            17  4532      9349     PI D DEG         79  0018    17 4532 9349
  B8            20  0000      0051                      80  0048    20 0000 0051
  B9           RAL  B11       B13                       81  0021    65 0034 0003
  B10          RAL  B12       B13                       82  0071    65 0039 0003
  B1            10  0000      0051                      83  0033    10 0000 0051
  2PI           62  8318      5551                      84  0053    62 8318 5551
  E00AU        STD  SEXT                             1  85  1500    24 0153 0256
               BMI  SERR                             2  86  0256    46 0209 0010
               NZE            SEXT                   3  87  0010    45 0014 0153
               STU  SA                               4  88  0014    21 0168 0171
               FAD  S10                              5  89  0171    32 0174 0151
               FMP  SHAF      SS                     6  90  0151    39 0254 0904
  SS           STU  SSAV      SAB                    7  91  0904    21 0158 0261
  SAB          RAU  SA                 S CAPT A      8  92  0261    60 0168 0023
               FDV  SSAV                             9  93  0023    34 0158 0208
               FAD  SSAV                            10  94  0208    32 0158 0035
               FMP  SHAF                            11  95  0035    39 0254 0954
               FSB  SSAV                            12  96  0954    33 0158 0085
               NZU            SR                    13  97  0085    44 0089 0040
               BMI            SR                    14  98  0089    46 0192 0040
               FAD  SSAV                            15  99  0192    32 0158 0135
               STU  SSAV      SAB                   16 100  0135    21 0158 0261
  SR           RAU  SSAV      SEXT                  17 101  0040    60 0158 0153
  SERR         HLT   0000     SEXT                  18 102  0209    01 0000 0153
  SHAF          50   0000      0050                 19 103  0254    50 0000 0050
```

```
 10       10   0000    0051            20 104    0174    10  0000  0051
 OOCR     STO  EXIT                       105    1350    24  0203  0906
          RAU   8002                      106    0906    60  8002  0165
          BMI  NEGAT   REDUC              107    0165    46  0218  0019
 EGAT     FAD  TWOPI                      108    0218    32  0221  0147
          BMI  NEGAT                      109    0147    46  0218  0201
          FSB  ONEPI   COSIO              110    0201    33  1004  0031
 EDUC     FSB  TWOPI                      111    0019    33  0221  0197
          BMI          REDUC              112    0197    46  1550  0019
          FAD  ONEPI   COSIO              113    1550    32  1004  0031
 OSIO     STU  THETA                      114    0031    21  0086  0139
          RSU  FPONE                      115    0139    61  0242  0247
          STU  TERMM                      116    0247    21  0002  0005
          STU  FUNKT                      117    0005    21  0060  0113
          STL  ENN     NEGST              118    0113    20  0017  0020
 OOSR     STO  EXIT                       119    1250    24  0203  0956
          RAU   8002                      120    0956    60  8002  0215
          BMI  NEGAV   REDUO              121    0215    46  0268  0069
 EGAV     FAD  TWOPI                      122    0268    32  0221  0297
          BMI  NEGAV                      123    0297    46  0268  0251
          FSB  ONEPI   SINET              124    0251    33  1004  0081
 EDUO     FSB  TWOPI                      125    0069    33  0221  0947
          BMI          REDUO              126    0947    46  1600  0069
          FAD  ONEPI   SINET              127    1600    32  1004  0081
 SINET    STU  THETA                      128    0081    21  0086  0189
          RSU   8003                      129    0189    61  8003  0997
          STU  TERMM                      130    0997    21  0002  0055
          STU  FUNKT                      131    0055    21  0060  0163
          LDD  FPONE                      132    0163    69  0242  0145
          STO  ENN     NEGST              133    0145    24  0017  0020
 NEGST    RAU  ENN                        134    0020    60  0017  0271
          FAD  FPONE                      135    0271    32  0242  0119
          STU  NPONE                      136    0119    21  0224  0077
          FAD  FPONE                      137    0077    32  0242  0169
          STU  ENN                        138    0169    21  0017  0070
          RSU  TERMM                      139    0070    61  0002  0207
          FMP  THETA                      140    0207    39  0086  0136
          FMP  THETA                      141    0136    39  0086  0186
          FDV  NPONE                      142    0186    34  0224  0274
          FDV  ENN                        143    0274    34  0017  0067
          STU  TERMM                      144    0067    21  0002  0155
          RAM  FUNKT                      145    0155    67  0060  0265
          STL  FMAG                       146    0265    20  0219  0022
          RAM  TERMM                      147    0022    67  0002  0257
          RAU   8002                      148    0257    60  8002  0915
          FDV  FMAG                       149    0915    34  0219  0269
          FSB  SIZES                      150    0269    33  0072  0049
          BMI  ENUFF                      151    0049    46  0052  0253
          RAU  FUNKT                      152    0253    60  0060  0965
          FAD  TERMM                      153    0965    32  0002  0129
          STU  FUNKT   NEGST              154    0129    21  0060  0020
ENUFF     RAL  FUNKT   EXIT               155    0052    65  0060  0203
SIZES      10   0000    0043              156    0072    10  0000  0043
TWOPI      62   8318    5351              157    0221    62  8318  5351
ONEPI      31   4159    2751              158    1004    31  4159  2751
FPONE      10   0000    0051              159    0242    10  0000  0051
LNX01     STO  LNX08                      160    1650    24  0903  1006
          NZE          LNX14              161    1006    45  0110  0911
          BMI  LNX14                      162    0110    46  0911  0064
          STU  LNX09                      163    0064    21  0918  0921
          RSL  FPONE                      164    0921    66  0242  1047
          STO  LNX10                      165    1047    24  1700  0953
          STL  LNX02                      166    0953    20  0907  0160
          RAU  LNX09                      167    0160    60  0918  0073
          STL  LNX05                      168    0073    20  0127  0130
          STL  LNX11                      169    0130    20  0185  0038
          SLT   0008                      170    0038    35  0008  0957
          SUP  FIFTY                      171    0957    11  0210  1015
          NZE          LNX04              172    1015    45  0968  0919
          BMI          LNX03              173    0968    46  0971  0122
          RSU   8003                      174    0971    61  8003  0179
          LDD  FPONE                      175    0179    69  0242  0195
          STO  LNX02   LNX03              176    0195    24  0907  0122
LNX03     SRT   0008                      177    0122    30  0008  0041
          SCT   0000                      178    0041    36  0000  0213
          AUP  SIXTY                      179    0213    10  0016  1021
          SUP   8002                      180    1021    11  8002  0229
          RAU   8003                      181    0229    60  8003  0137
          FMP  LNX02                      182    0137    39  0907  1007
          FMP  LNTEN                      183    1007    39  0260  0910
          STU  LNX05   LNX04              184    0910    21  0127  0919
LNX04     RAL  LNX09                      185    0919    65  0918  0123
          SRT   0002                      186    0123    30  0002  0279
          RAU   8002                      187    0279    60  8002  0187
          ALO  FIFTY                      188    0187    15  0210  1065
          SLT   0002                      189    1065    35  0002  1071
          FAD  FPONE                      190    1071    32  0242  0969
          STU  LNX09                      191    0969    21  0918  1121
          FSB  FPTWO                      192    1121    33  0924  0901
          FDV  LNX09                      193    0901    34  0918  1018
          STU  LNX13                      194    1018    21  0172  0025
          STO  LNX12                      195    0025    24  0028  0131
          STO  LNX11                      196    0131    24  0185  0088
          FMP   8001                      197    0088    39  8001  0091
          STU  FACTR   LNX06              198    0091    21  0046  0099
LNX06     RAU  LNX10                      199    0099    60  1700  0205
          FAD  FPTWO                      200    0205    32  0924  0951
          STU  LNX10                      201    0951    21  1700  1003
          RAU  LNX13                      202    1003    60  0172  0177
          FMP  FACTR                      203    0177    39  0046  0096
          FDV  LNX10                      204    0096    34  1700  1750
          STU  LNX13                      205    1750    21  0172  0075
          FAD  LNX12                      206    0075    32  0028  0255
```

```
        STU  LNX12                           207    0255    21  0028  0181
        FSB  LNX11                           208    0181    33  0185  0961
        FDV  LNX11                           209    0961    34  0185  0235
        RAM   8003                           210    0235    67  8003  0043
        RAU   8002                           211    0043    60  8002  1001
        FSB  SIZE7                           212    1001    33  1054  0231
        BMI  LNX07                           213    0231    46  0084  0285
        LDD  LNX12                           214    0285    69  0028  0281
        STD  LNX11                           215    0281    24  0185  0138
        RAU  LNX13                           216    0138    60  0172  0227
        FMP  LNX10                           217    0227    39  1700  1800
        STU  LNX13   LNX06                   218    1800    21  0172  0099
LNX07   RAU  LNX12                           219    0084    60  0028  0083
        FMP  FPTWO                           220    0083    39  0924  0974
        FSB  LNX05   LNX08                   221    0974    33  0127  0903
FPONE    10   0000  0051                     222    0242    10  0000  0051
FPTWO    20   0000  0051                     223    0924    20  0000  0051
SIZE7    10   0000  0043                     224    1054    10  0000  0043
LNTEN    23   0258  5151                     225    0260    23  0258  5151
FIFTY    50   0000  0000                     226    0210    50  0000  0000
SIXTY    00   0000  0060                     227    0016    00  0000  0060
LNX14    01   2345  6789                     228    0911    01  2345  6789
EOOEA   STD  AAA1            EXIT INSTR      229    1850    24  1053  1056
        STL  AAA2             STORE X        230    1056    20  1011  0114
        RAM  AAA2                            231    0114    67  1011  1115
        STL  AAA3            X FOR CALC      232    1115    20  1019  0222
        RAU  AAA3                            233    0222    60  1019  0173
        FMP  AAA16                           234    0173    39  0026  0076
        FAD  AAA15                           235    0076    32  0929  0905
        FMP  AAA3                            236    0905    39  1019  1069
        FAD  AAA14                           237    1069    32  0272  0149
        FMP  AAA3                            238    0149    39  1019  1119
        FAD  AAA13                           239    1119    32  0922  0199
        FMP  AAA3                            240    0199    39  1019  1169
        FAD  AAA12                           241    1169    32  0972  0249
        FMP  AAA3                            242    0249    39  1019  1219
        FAD  AAA11                           243    1219    32  1022  0299
        FMP  AAA3                            244    0299    39  1019  1269
        FAD  AAA10                           245    1269    32  1072  0949
        STU  AAA4                            246    0949    21  1104  1057
        FMP  AAA4                            247    1057    39  1104  1154
        STU  AAA4                            248    1154    21  1104  1107
        FMP  AAA4                            249    1107    39  1104  1204
        STU  AAA4                            250    1204    21  1104  1157
        RAU  AAA2                            251    1157    60  1011  1165
        BMI  AAA5    AAA6                    252    1165    46  1068  1319
AAA5    RAU  AAA10                           253    1068    60  1072  0277
        FDV  AAA4                            254    0277    34  1104  1254
        STU  AAA4    AAA6                    255    1254    21  1104  1319
AAA6    RAL  AAA4    AAA1                    256    1319    65  1104  1053
AAA10    10   0000   0051                    257    1072    10  0000  0051
AAA11    24   9998   6850                    258    1022    24  9998  6850
AAA12    31   2575   8349                    259    0972    31  2575  8349
AAA13    25   9137   1248                    260    0922    25  9137  1248
AAA14    17   1562   0047                    261    0272    17  1562  0047
AAA15    54   3020   0045                    262    0929    54  3020  0045
AAA16    69   0600   0044                    263    0026    69  0600  0044
START   LDD  FIRST           INITIAL         264    1999    69  0100  1103
        STD  GAM11   LOOP6   GAMMA           265    1103    24  1106  0259
LOOP6   LDD  POINT           DATA POINT      266    0259    69  0101  1304
        RAA   8001                           267    1304    80  8001  0960
        LDD  ZERO                            268    0960    69  0000  1153
        STD  CEHCF                           269    1153    24  1156  0909
        STD  ALPHA                           270    0909    24  0018  1215
        STD  BETA                            271    1215    24  1118  1171
        RAU  GAM11                           272    1171    60  1106  1061
        FMP  GAM11                           273    1061    39  1106  1206
        STU  GAMSQ           GAMMA SQD       274    1206    21  1010  0263
        RAU  PI                              275    0263    60  0150  0955
        FDV  A                               276    0955    34  0103  1203
        STU  TEMP1                           277    1203    21  0258  1111
        FMP  TEMP1                           278    1111    39  0258  0908
        STU  ALPH2           ALPHA SQD       279    0908    21  0062  1265
        RAU  PI                              280    1265    60  0150  1005
        FDV  B                               281    1005    34  0104  1354
        STU  TEMP1                           282    1354    21  0258  1161
        FMP  TEMP1                           283    1161    39  0258  0958
        STU  BETA2           BETA SQD        284    0958    21  0112  1315
        RAU  GAMSQ                           285    1315    60  1010  1365
        FSB  ALPH2                           286    1365    33  0062  0239
        FSB  BETA2                           287    0239    33  0112  0289
        STU  KAPSQ   LOOP3   KAPPA SQD       288    0289    21  0044  1097
LOOP3   LDD  ZERO                            289    1097    69  0000  1253
        STD  CEHCF                           290    1253    24  1156  0959
        RAU  C                               291    0959    60  0105  1009
        FSB  Z       A                       292    1009    33  2300  0927
        FMP  GAM11                           293    0927    39  1106  1256
        FMP  MTWO                            294    1256    39  0050  1900
        RAL   8003                           295    1900    65  8003  1207
        LDD          EOOEA                   296    1207    69  1060  1850
        STL  TEMP1                           297    1060    20  0258  1211
        RAU  ONE                             298    1211    60  0200  1055
        FSB  TEMP1                           299    1055    33  0258  0935
        STU  TEMP1                           300    0935    21  0258  1261
        RAU  C                               301    1261    60  0105  1059
        FMP  GAM11                           302    1059    39  1106  1306
        FMP  MTWO                            303    1306    39  0050  1051
        RAL   8003                           304    1051    65  8003  1109
        LDD          EOOEA                   305    1109    69  0162  1850
        STL  TEMP2                           306    0162    20  0117  0120
        RAU  ONE                             307    0120    60  0200  1105
        FSB  TEMP2                           308    1105    33  0117  0093
        STU  TEMP2           FUNDAMENTA      309    0093    21  0117  0170
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          RAU TEMP1               MODE END    310    0170    60 0258 0913
          FDV TEMP2               CORRECTION  311    0913    34 0117 0167
          STU FMECF               FACTOR      312    0167    21 1122 0125
          RAU Z      A                        313    0125    60 2300 1155
          FMP GAM11                           314    1155    39 1106 1356
          RAL  8003                           315    1356    65 8003 0963
          LDD            EOOEA                316    0963    69 0066 1850
          STL TEMP1                           317    0066    20 0258 1311
          RAU X                               318    1311    60 0106 1361
          FMP PI                              319    1361    39 0150 1101
          FDV A                               320    1101    34 0103 1303
          RAL  8003                           321    1303    65 8003 1411
          LDD            EOOCR                322    1411    69 0164 1350
          STL TEMP2                           323    0164    20 0117 0220
          RAU Y                               324    0220    60 0107 1461
          FMP PI                              325    1461    39 0150 1151
          FDV B                               326    1151    34 0104 1404
          RAL  8003                           327    1404    65 8003 1511
          LDD            EOOCR                328    1511    69 0214 1350
          STL TEMP3                           329    0214    20 1369 1172
          RAU TEMP1               CALCULATE   330    1172    60 0258 1013
          FDV TEMP2               CONSTANT    331    1013    34 0117 0217
          FDV TEMP3               TERM FOR    332    0217    34 1369 1419
          FDV FMECF               CEHCF       333    1419    34 1122 1222
          STU CONST                           334    1222    21 0126 0979
          RAU THREE                           335    0979    60 0950 1205
          STU M                               336    1205    21 1110 1063
          RAU ONE                             337    1063    60 0200 1255
          STU N          LOOP2                338    1255    21 0500 1353
LOOP2     RAU N                               339    1353    60 0500 1305
          FMP PI                              340    1305    39 0150 1201
          FMP Y                               341    1201    39 0107 1257
          FDV B                               342    1257    34 0104 1454
          RAL  8003                           343    1454    65 8003 1561
          LDD            EOOCR    Y COSINE    344    1561    69 0264 1350
          STL TEMP2      LOOP1    TERM        345    0264    20 0117 0270
LOOP1     RAU M                               346    0270    60 1110 1415
          FMP PI                              347    1415    39 0150 1251
          FMP X                               348    1251    39 0106 1406
          FDV A                               349    1406    34 0103 1403
          RAL  8003                           350    1403    65 8003 1611
          LDD            EOOCR    X COSINE    351    1611    69 0914 1350
          STL TEMP1               TERM        352    0914    20 0258 1661
          RAU M                               353    1661    60 1110 1465
          FMP PI                              354    1465    39 0150 1301
          FDV A                               355    1301    34 0103 1453
          STU ALMSO                           356    1453    21 1008 1711
          FMP ALMSO               ALPHA M     357    1711    39 1008 1058
          STU ALMSO               SQUARED     358    1058    21 1008 1761
          RAU N                               359    1761    60 0500 1355
          FMP PI                              360    1355    39 0150 1351
          FDV B                               361    1351    34 0104 1504
          WTU BENSO                           362    1504    21 1108 1811
          FMP BENSO               BETA N      363    1811    39 1108 1158
          STU BENSO               SQUARED     364    1158    21 1108 1861
          FAD ALMSO                           365    1861    32 1008 0985
          FAD KAPSO                           366    0985    32 0044 1221
          LDD            EOOAU                367    1221    69 1024 1500
          STU GAMMN               GAMMA MN    368    1024    21 0078 0931
          RAU M                               369    0931    60 1110 1515
          FAD N                               370    1515    32 0500 0977
          FAD TWO                             371    0977    32 0250 1027
          FDV TWO        LOOP7                372    1027    34 0250 1401
LOOP7     FSB TWO                             373    1401    33 0250 1077
          NZE            LOOP4                374    1077    45 0180 0981
          BMI            LOOP7                375    0180    46 0133 1401
          RSU ONE                             376    0133    61 0200 1405
          STU SIGN       LOOP5                377    1405    21 1160 1113
LOOP4     RAU ONE                             378    0981    60 0200 1455
          STU SIGN       LOOP5                379    1455    21 1160 1113
LOOP5     RAU C                               380    1113    60 0105 1159
          FSB Z      A                        381    1159    33 2300 1127
          FMP GAMMN                           382    1127    39 0078 0128
          FMP MTWO                            383    0128    39 0050 1451
          RAL  8003                           384    1451    65 8003 1209
          LDD            EOOEA                385    1209    69 0212 1850
          RSU  8002                           386    0212    61 8002 1271
          FAD ONE                             387    1271    32 0200 1177
          STU TEMP3                           388    1177    21 1369 1272
          RAU C                               389    1272    60 0105 1259
          FMP GAMMN                           390    1259    39 0078 0178
          FMP MTWO                            391    0178    39 0050 1501
          RAL  8003                           392    1501    65 8003 1309
          LDD            EOOEA                393    1309    69 0262 1850
          RWU  8002                           394    0262    61 8002 1321
          FAD ONE                             395    1321    32 0200 1227
          STU TEMP4                           396    1227    21 0082 1035
          RAU Z      A                        397    1035    60 2300 1505
          FMP GAMMN                           398    1505    39 0078 0228
          RAL  8003                           399    0228    65 8003 1085
          LDD            EOOEA                400    1085    69 0188 1850
          STL TEMP5                           401    0188    20 0143 0146
          RAU SIGN                            402    0146    60 1160 1565
          FDV M                               403    1565    34 1110 1210
          FDV N                               404    1210    34 0500 1551
          FDV TEMP5                           405    1551    34 0143 0193
          FMP TEMP3                           406    0193    39 1369 1469
          FDV TEMP4                           407    1469    34 0082 0132
          STU TEMP3                           408    0132    21 1369 1322
          RAU TEMP1                           409    1322    60 0258 1163
          FMP TEMP2                           410    1163    39 0117 0267
          FMP TEMP3                           411    0267    39 1369 1519
          WTU TEMP3                           412    1519    21 1369 1372
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          RAU  CENCF                             413   1372   60 1156 1911
          FAD  TEMP3                             414   1911   32 1369 0245
          STU  CENCF                             415   0245   21 1156 1359
          RAU  SEVEN                             416   1359   60 1000 1555
          FSB  M                                 417   1555   33 1110 0237
          NZE  CONT1     CONT2                   418   0237   45 0090 0141
CONT1     RAU  M                                 419   0090   60 1110 1615
          FAD  TWO                               420   1615   32 0250 1277
          STU  M         LOOP1                   421   1277   21 1110 0270
CONT8     RAU  N                                 422   0141   60 0500 1605
          FSB  SEVEN                             423   1605   33 1000 1327
          NZE  CONT3     CONT4                   424   1327   45 0230 1031
CONT3     RAU  ONE                               425   0230   60 0200 1655
          STU  M                                 426   1655   21 1110 1213
          RAU  N                                 427   1213   60 0500 1705
          FAD  TWO                 COMPOSITE     428   1705   32 0250 1377
          STU  N         LOOP2     END           429   1377   21 0500 1353
CONT4     RAU  CENCF               HARMONIC      430   1031   60 1156 0912
          FMP  CONST               CORRECTION    431   0912   39 0126 0176
          FAD  ONE                 FACTOR        432   0176   32 0200 1427
          STU  CENCF                             433   1427   21 1156 1409
          RAU  N       A                         434   1409   60 2500 1755
          FDV  FMECF                             435   1755   34 1122 1422
          FDV  CENCF                             436   1422   34 1156 1456
          STU  NCOR    A                         437   1456   21 2700 1503
          LDD  Z       A                         438   1503   69 2300 1553
          STD   1977                             439   1553   24 1977 0280
          LDD  N       A                         440   0280   69 2500 1603
          STD   1978                             441   1603   24 1978 1081
          LDD  NCOR    A                         442   1081   69 2700 1653
          STD   1979                             443   1653   24 1979 0182
          LDD  CEHCF                             444   0182   69 1156 1459
          STD   1980                             445   1459   24 1980 0183
          LDD  FMECF                             446   0183   69 1122 0175
          STD   1981                             447   0175   24 1981 0134
          PCH   1977                             448   0134   71 1977 1477
          SXA   0001                             449   1477   51 0001 0233
          NZA  LOOP3     CONT5                   450   0233   40 1097 0287
CONT5     LDD  ZERO                              451   0287   69 0000 1703
          STD  SUMZ                              452   1703   24 1506 1509
          STD  SMLNA                             453   1509   24 0962 1665
          STD  SMZLA                             454   1665   24 1168 1371
          STD  SUMZ2                             455   1371   24 1074 1527
          LDD  POINT                             456   1527   69 0101 1554
          RAA   8001     CONT6                   457   1554   80 8001 1260
CONT6     RAU  Z       A                         458   1260   60 2300 1805
          FAD  SUMZ                              459   1805   32 1506 0283
          STU  SUMZ                              460   0283   21 1506 1559
          RAU  Z       A                         461   1559   60 2300 1855
          FMP  Z       A                         462   1855   39 2300 1601
          FAD  SUMZ2                             463   1601   32 1074 1651
          STU  SUMZ2                             464   1651   21 1074 1577
          RAU  NCOR    A                         465   1577   60 2700 1905
          LDD            LNX01                   466   1905   69 1208 1650
          FAD  SMLNA                             467   1208   32 0962 0939
          STU  SMLNA                             468   0939   21 0962 1715
          RAU  NCOR    A                         469   1715   60 2700 1556
          LDD            LNX01                   470   1556   69 1609 1650
          FMP  Z       A                         471   1609   39 2300 1701
          FAD  SMZLA                             472   1701   32 1168 0295
          STU  SMZLA                             473   0295   21 1168 1421
          SXA   0001                             474   1421   51 0001 1627
          NZA  CONT6                             475   1627   40 1260 1131
          RAU  SUMZ                              476   1131   60 1506 1012
          FMP  SMLNA                             477   1012   39 0962 1062
          STU  TEMP1                             478   1062   21 0258 1112
          RAU  OATPT                             479   1112   60 0102 1307
          FMP  SMZLA                             480   1307   39 1168 1218
          STU  TEMP2                             481   1218   21 0117 0920
          RAU  DATPT                             482   0920   60 0102 1357
          FMP  SUMZ2                             483   1357   39 1074 1124
          STU  TEMP3                             484   1124   21 1369 1472
          RAU  SUMZ                              485   1472   60 1506 1162
          FMP  SUMZ                              486   1162   39 1506 1606
          STU  TEMP4                             487   1606   21 0082 1135
          RAU  TEMP1                             488   1135   60 0258 1263
          FSB  TEMP2                             489   1263   33 0117 0243
          STU  TEMP1                             490   0243   21 0258 1212
          RAU  TEMP3                             491   1212   60 1369 0223
          FSB  TEMP4               LEAST         492   0223   33 0082 1659
          STU  TEMP2               SQUARES       493   1659   21 0117 0970
          RAU  TEMP1               SOLUTION      494   0970   60 0258 1313
          FDV  TEMP2               FOR           495   1313   34 0117 0917
          STU  NWOAM               GAMMA         496   0917   21 1522 0225
          FSB  GAM11                             497   0225   33 1106 0933
          STU  TEMP1                             498   0933   21 0258 1262
          SMI  NEG       POS                     499   1262   46 1765 0116
NEG       RAU  GAM11                             500   1765   60 1106 1312
          FDV  10000                             501   1312   34 1050 1751
          FAD  TEMP1                             502   1751   32 0258 1185
          SMI            CONT7                   503   1185   46 0238 0989
          RAU  NWGAM                             504   0238   60 1522 1677
          STU  GAM11     LOOP6                   505   1677   21 1106 0259
POS       RAU  GAM11                             506   0116   60 1106 1362
          FDV  10000                             507   1362   34 1050 1801
          FSB  TEMP1                             508   1801   33 0258 1235
          SMI            CONT7                   509   1235   46 0288 0989
          RAU  NWGAM                             510   0288   60 1522 1727
          STU  GAM11     LOOP6                   511   1727   21 1106 0259
CONT7     RAU  PI                                512   0989   60 0150 1656
          FDV  A                                 513   1656   34 0103 1753
          STU  TEMP1                             514   1753   21 0258 1412
```

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FMP  TEMP1                              515    1412    39  0258  1258
STU  ALPH2                              516    1258    21  0062  1815
RAU  PI                                 517    1815    60  0150  1706
FDV  8                                  518    1706    34  0104  1604
STU  TEMP1                              519    1604    21  0258  1462
FMP  TEMP1                              520    1462    39  0258  1308
STU  ALPH2                              521    1308    21  0062  1865
RAU  PI                                 522    1865    60  0150  1756
FDV  8                                  523    1756    34  0104  1654
STU  TEMP1                              524    1654    21  0258  1512
FMP  TEMP1                              525    1512    39  0258  1358
STU  BETA2                              526    1358    21  0112  1918
RAU  NWGAM                              527    1915    60  1522  1777
FMP  NWGAM                              528    1777    39  1522  1572
STU  GAM82                              529    1572    21  1010  1363
RSU  ALPH2                              530    1363    61  0062  0967
FSB  BETA2                              531    0967    33  0112  1039
FAD  GAM82                              532    1039    32  1010  0937
LDD             E00AU                   533    0937    69  0140  1500
STU  KAPPA                              534    0140    21  0094  1147
RAU  ONE                  CALCULATE     535    1147    60  0200  1806
FDV  KAPPA                DIFFUSION     536    1806    34  0094  0144
FMP  CONVT                LENGTH        537    0144    39  1150  1851
STU  DL                                 538    1851    21  1856  1709
LDD  NWGAM                              539    1709    69  1522  0275
STD   1977                              540    0275    24  1977  0930
LDD  GAM11                              541    0930    69  1106  1759
STD   1978                              542    1759    24  1978  1181
LDD  FIRST                              543    1181    69  0100  1803
STD   1979                              544    1803    24  1979  0232
LDD  POINT                              545    0232    69  0101  1704
STD   1980                              546    1704    24  1980  0983
LDD  DL                                 547    0983    69  1856  1809
STD   1981                              548    1809    24  1981  0184
PCH   1977       8000                   549    0184    71  1977  8000
```

APPENDIX E

IBM 650 Programs for Diffusion Length, Ratio Method

The first of these programs was written to avaluate the double integral function

$$F_{11}(z) = \int_{-a/2}^{a/2} \int_{-b/2}^{b/2} \phi\,(x, y, z) \cos \frac{\pi x}{a} \cos \frac{\pi y}{b}\, dx\, dy$$

The program was written in SOAP II and floating point form. The object program and a logic diagram are listed in this section.

The program was written to accommodate as many data points as were desired. The data was taken in the manner described in the section entitled "EXPERIMENTAL PROCEDURE". An odd number of data points is required in each of the horizontal traverses making up one set of data. This is to accommodate Simpson's rule, which is used for the major portion of the integration. The trapezoidal rule is used to evaluate the integral over the area between the fifth horizontal traverse and the extrapolated boundary.

Input constants and data input forms are listed in Table 23. Flux data should be stored in descending order of traverse, the outermost traverse, the extrapolated boundary, being first. Each traverse should be listed with its outermost point first. One card of form one is needed for each set of data. The output form is listed in Table 24.

The approximate time for evaluation of the integral using 54 data points is three minutes.

The second program was written to determine the diffusion

Table 23. Input forms for double integral evaluation program.

Symbol	Explanation	Drum Storage Location
A	Extrapolated x-dimension	0000
B	Extrapolated z-dimension	0001
BPRIM	Distance from center of pile to outermost fuel port	0002

Word	1	2	3
Form 1	Number of Data Points (IR Form)	z Elevation of Data	
Form 2	Count Rate	x co-ordinate	y co-ordinate

Table 24. Output forms for double integral evaluation program.

Word	1	2	3
	Integral	Elevation z	Number of Data Points

length by the ratio method. It was written in SOAP II and floating point form. The object program and a logic diagram are included in this section.

An initial trial value of γ_{11} is determined by

$$\gamma_{11} = \frac{1}{(z_2 - z_1)} \ell n \frac{F_1}{F_2}$$

Input constants and data input forms are listed in Table 25. In the notation used, z_1 should always be greater than z_2.

Table 25. Input forms for ratio method program.

Symbol	Explanation	Drum Storage Location
A	Extrapolated x-dimension	0100
B	Extrapolated y-dimension	0101
C	Extrapolated z-dimension	0102

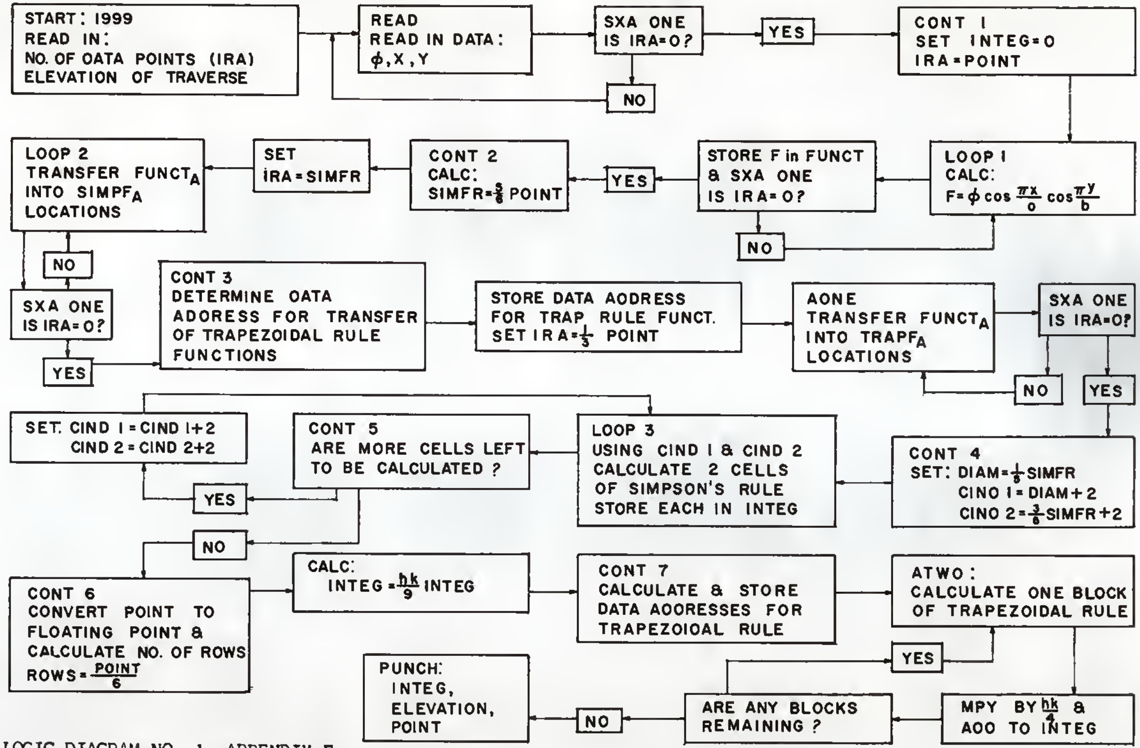
Word	1	2	3	4
Form 1	z_1	z_2	F_1	F_2

The two output forms for the ratio method program are listed in Table 26. One card of form one is punched for each trial. Operating time is between 20 and 30 seconds for one calculation of diffusion length.

Table 26. Output forms for ratio method program.

Word 1	2	3	4	5	6
Form 1:					
Gamma	Error				
Form 2:					
z_1	z_2	Gamma	Diffusion Length	Ratio	Number of Trials

IBM 650 PROGRAM FOR $\iint \phi \cos\frac{\pi x}{a} \cos\frac{\pi y}{b}\, dx\,dy$



LOGIC DIAGRAM NO. 1, APPENDIX E

```
         BLR  1951       1958                         1   0000   00 0000 0000
         BLR  1977       1984                         2   0000   00 0000 0000
         BLR  0100       0650                         3   0000   00 0000 0000
         SYN  FLUX       0100                         4   0000   00 0000 0000
         SYN  X          0200                         5   0000   00 0000 0000
         SYN  Y          0300                         6   0000   00 0000 0000
         SYN  FUNCT      0400                         7   0000   00 0000 0000
         SYN  SIMPF      0500                         8   0000   00 0000 0000
         SYN  TRAPF      0600                         9   0000   00 0000 0000
         SYN  A          0000                        10   0000   00 0000 0000
         SYN  B          0001                        11   0000   00 0000 0000
         SYN  BPRIM      0002                        12   0000   00 0000 0000
         SYN  STANT      1999                        13   0000   00 0000 0000
ZERO     00   0000       0000                        14   0050   00 0000 0000
ONE      00   0000       0001                        15   0700   00 0000 0001
TWO      00   0000       0002                        16   0750   00 0000 0002
THREE    00   0000       0003                        17   0800   00 0000 0003
FIVE     00   0000       0005                        18   0850   00 0000 0005
SIX      00   0000       0006                        19   0900   00 0000 0006
EIGHT    00   0000       0008                        20   0950   00 0000 0008
TEN      00   0000       0010                        21   1000   00 0000 0010
SIXTY    00   0000       0060                        22   1050   00 0000 0060
FP1      10   0000       0051                        23   1100   10 0000 0051
FP2      20   0000       0051                        24   1150   20 0000 0051
PI       31   4159       0051                        25   1200   31 4159 0051
FP4      40   0000       0051                        26   1250   40 0000 0051
FP6      60   0000       0051                        27   1300   60 0000 0051
FP8      80   0000       0051                        28   1350   80 0000 0051
FP9      90   0000       0051                        29   1400   90 0000 0051
FP16     16   0000       0052                        30   1450   16 0000 0052
INOXA    00   2400       0000                        31   1500   00 2400 0000
INDA     00   2600       0000                        32   1550   00 2600 0000
INOR     00   4600       0000                        33   1600   00 4600 0000
EUOCH    STD  EXIT                                   34   1650   24 0003 0006
         RAU  8002                                   35   0006   60 8002 0015
         BMI  NEGAT      REDOC                       36   0015   46 0018 0019
NEGAT    FAD  TWOPI                                  37   0018   32 0021 0047
         BMI  NEGAT                                  38   0047   46 0018 0051
         FSB  ONEPI      COSIO                       39   0051   33 0004 0031
REDOC    FSB  TWOPI                                  40   0019   33 0021 0097
         BMI             REDOC                       41   0097   46 1700 0019
         FAD  ONEPI      COSIO                       42   1700   32 0004 0031
COSIO    STU  THETA                                  43   0031   21 0036 0039
         RSU  FPONE                                  44   0039   61 0042 0697
         STU  TERMM                                  45   0697   21 0052 0005
         STU  FONKT                                  46   0005   21 0010 0013
         STL  ENNN       NEGST                       47   0013   20 0017 0020
EOUSH    STD  EXIT                                   48   1750   24 0003 0056
         RAU  8002                                   49   0056   60 8002 0065
         BMI  NEGAY      REDOD                       50   0065   46 0068 0069
NEGAY    FAD  TWOPI                                  51   0068   32 0021 0747
         BMI  NEGAY                                  52   0747   46 0068 0651
         FSB  ONEPI      SINET                       53   0651   33 0004 0081
REDOD    FSB  TWOPI                                  54   0069   33 0021 0797
         BMI             REDOD                       55   0797   46 1000 0069
         FAD  ONEPI      SINLT                       56   1800   32 0004 0081
SINLT    STU  THETA                                  57   0081   21 0036 0089
         RSU  8003                                   58   0089   61 8003 0847
         STU  TERMM                                  59   0847   21 0052 0055
         STU  FONKT                                  60   0055   21 0010 0063
         LDD  FPONE                                  61   0063   69 0048 0045
         STD  ENNN       NEGST                       62   0045   24 0017 0020
NEGST    RAU  ENNN                                   63   0020   60 0017 0071
         FAD  FPONE                                  64   0071   32 0042 0669
         STU  NPONE                                  65   0669   21 0024 0027
         FAD  FPONE                                  66   0027   32 0042 0719
         STU  ENNN                                   67   0719   21 0017 0070
         RSU  TERMM                                  68   0070   61 0052 0007
         FMP  THETA                                  69   0007   39 0036 0086
         FMP  THETA                                  70   0086   39 0036 0686
         FDV  NPONE                                  71   0686   34 0024 0074
         FDV  ENNN                                   72   0074   34 0017 0067
         STU  TERMM                                  73   0067   21 0052 0655
         RAM  FONKT                                  74   0655   67 0010 0665
         STL  FMAG                                   75   0665   20 0769 0022
         RAM  TERMM                                  76   0022   67 0052 0057
         RAU  8002                                   77   0057   60 8002 0715
         FDV  FMAG                                   78   0715   34 0769 0819
         FSB  SIZEB                                  79   0819   33 0072 0049
         BMI  ENOFF                                  80   0049   46 0652 0053
         RAU  FONKT                                  81   0053   60 0010 0765
         FAD  TERMM                                  82   0765   32 0058 0029
         STU  FONKT      NEGST                       83   0029   21 0010 0020
ENOFF    RAL  FONKT      EXIT                        84   0652   65 0010 0003
SIZEB    10   0000        0043                       85   0072   10 0000 0043
TWOPI    62   8318        5351                       86   0021   62 8318 5351
ONEPI    31   4159        8751                       87   0004   31 4159 2751
FPONE    10   0000        0051                       88   0042   10 0000 0051
START    RCD  1951                                   89   1999   70 1951 0701
         LDD  1951                                   90   0701   69 1951 0054
         STD  POINT                 DATA POINT       91   0054   24 0657 0060
         LDD  1952                                   92   0060   69 1952 0705
         STD  ELEV                                   93   0705   24 0008 0011
         LDD  POINT                                  94   0011   69 0657 0660
         RAA  8001       READ                        95   0660   80 8001 0016
READ     RCD  1951                                   96   0016   70 1951 0751
         LDD  1951                                   97   0751   69 1951 0654
         STD  0100  A               FLUX             98   0654   24 2100 0653
         LDD  1952                                   99   0653   69 1952 0755
         STD  0200  A               X               100   0755   24 2200 0703
         LDD  1953                                  101   0703   69 1953 0656
         STD  0300  A               Y               102   0656   24 2300 0753
         SXA  0001                                  103   0753   51 0001 0009
```

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          NZA  READ        CONT1                       104   0009   40 0016 0663
CONT1     LDD  ZERO                                    105   0663   69 0050 0803
          STD  INTEG                                   106   0803   24 0706 0059
          LDD  POINT                                   107   0059   69 0657 0710
          RAA   8001       LOOP1                       108   0710   80 8001 0066
LOOP1     RAU  X        A                              109   0066   60 2200 0805
          FMP  PI                                      110   0805   39 1200 1850
          FDV  A                                       111   1850   34 0000 1900
          RAL   8003                                   112   1900   65 8003 0707
          LDD              EODCH                       113   0707   69 0760 1650
          STL  TEMP1                                   114   0760   20 0815 0668
          RAU  Y        A                              115   0668   60 2300 0855
          FMP  PI                                      116   0855   39 1200 1950
          FDV  B                                       117   1950   34 0001 0801
          RAL   8003                                   118   0801   65 8003 0659
          LDD              EODCH                       119   0659   69 0012 1650
          RAU   8002                                   120   0012   60 8002 0671
          FMP  TEMP1                                   121   0671   39 0815 0865
          FMP  FLUX     A              CALCULATE       122   0865   39 2100 0851
          STU  FUNCT    A              FUNCTIONS       123   0851   21 2400 0853
          SXA   0001                                   124   0853   51 0001 0709
          NZA  LOOP1       CONT2                       125   0709   40 0066 0713
CONT2     RAU  POINT                                   126   0713   60 0657 0061
          MPY  FIVE                                    127   0061   19 0850 0670
          DIV  SIX                                     128   0670   14 0900 0810
          STL  SIMFR                                   129   0810   20 0915 0718
          LDD  SIMFR                                   130   0718   69 0915 0768
          RAA   8001       LOOP2                       131   0768   80 8001 0674
LOOP2     LDD  FUNCT    A              DISTRIBUTE      132   0674   69 2400 0903
          STD  SIMPF    A              SIMPSON         133   0903   24 2500 0953
          SXA   0001                   FUNCTIONS       134   0953   51 0001 0759
          NZA  LOOP2       CONT3                       135   0759   40 0674 0763
CONT3     RAU  SIMFR                                   136   0763   60 0915 0869
          MPY  EIGHT                                   137   0869   19 0950 0720
          DIV  TEN                                     138   0720   14 1000 0860
          SLT   0004                                   139   0860   35 0004 0721
          ALO  INDXA                                   140   0721   15 1500 0905
          LDD  AONE                                    141   0905   69 0058 0661
          SDA  AONE                                    142   0661   22 0058 0711
          RAU  POINT                                   143   0711   60 0657 0761
          MPY  TWO                                     144   0761   19 0750 0770
          DIV  SIX                                     145   0770   14 0900 0910
          LDD   8002                                   146   0910   69 8002 0667
          RAA   8001       AONE                        147   0667   80 8001 0058
AONE      LDD   9999                   DISTRIBUTE      148   0058   69 9999 0702
          STD  TRAPF    A              TRAP RULE       149   0702   24 2600 1003
          SXA   0001                   FUNCTIONS       150   1003   51 0001 0809
          NZA  AONE        CONT4                       151   0809   40 0058 0813
CONT4     RAL  SIMFR                                   152   0013   65 0915 0919
          DIV  FIVE                                    153   0919   14 0850 0960
          STL  DIAM                                    154   0960   20 0965 0818
          ALO  TWO                                     155   0818   15 0750 0955
          STL  CINO1                                   156   0955   20 0059 0062
          RAU  SIMFR                   SET INDEX       157   0062   60 0915 0969
          MPY  THREE                   REGISTERS       158   0969   19 0000 0820
          DIV  FIVE                    FOR             159   0820   14 0850 1010
          ALO  TWO                     SIMPSONS        160   1010   15 0750 1005
          STL  CINO2                   RULE            161   1005   20 0909 0662
          RAL  POINT                                   162   0662   65 0657 0811
          DIV  SIX                                     163   0811   14 0900 1060
          SLO  ONE                                     164   1060   16 0700 1055
          STL  CELLS                                   165   1055   20 0959 0712
          LDD  CINO1       LOOP3                       166  '0712   69 0859 0762
LOOP3     RAA   8001                                   167   0762   80 8001 0868
          RAU  SIMPF    A                              168   0868   60 2500 1105
          FMP  FP16                                    169   1105   39 1450 0901
          FAD  INTEG                                   170   0901   32 0706 0033
          STU  INTEG                                   171   0033   21 0706 1009
          SXA   0001                                   172   1009   51 0001 1015
          RAU  SIMPF    A                              173   1015   60 2500 1155
          AXA   0002                                   174   1155   50 0002 0861
          FAD  SIMPF    A                              175   0861   32 2500 0077
          SXA   0001                                   176   0077   51 0001 0083
          LDD  DIAM                                    177   0083   69 0965 0918
          SXA   8001                                   178   0918   51 8001 0724
          FAD  SIMPF    A                              179   0724   32 2500 0677
          LDD  DIAM                                    180   0677   69 0965 0968
          AXA   8001                                   181   0968   50 8001 0774
          AXA   8001                                   182   0774   50 8001 0030
          FAD  SIMPF    A                              183   0030   32 2500 0727
          FMP  FP4                                     184   0727   39 1250 0951
          FAD  INTEG                                   185   0951   32 0706 0683
          STU  INTEG                                   186   0683   21 0706 1059
          AXA   0001                                   187   1059   50 0001 1065
          RAU  SIMPF    A                              188   1065   60 2500 1205
          SXA   0002                                   189   1205   51 0002 0911
          FAD  SIMPF    A                              190   0911   32 2500 0777
          LDD  DIAM                                    191   0777   69 0965 1018
          SXA   8001                                   192   1018   51 8001 0824
          SXA   8001                                   193   0824   51 8001 0080
          FAD  SIMPF    A              CELL            194   0080   32 2500 0827
          AXA   0002                   CALCULATNS      195   0827   50 0002 0733
          FAD  SIMPF    A              FOR             196   0733   32 2500 0877
          FAD  INTEG                   SIMPSONS        197   0877   32 0706 0783
          STU  INTEG                   RULE            198   0783   21 0706 1109
          LDD  DIAM                                    199   1109   69 0965 1068
          SXA   8001                   CHECK           200   1068   51 8001 0874
          SXA   0001                   CELLS           201   0074   51 0001 0680
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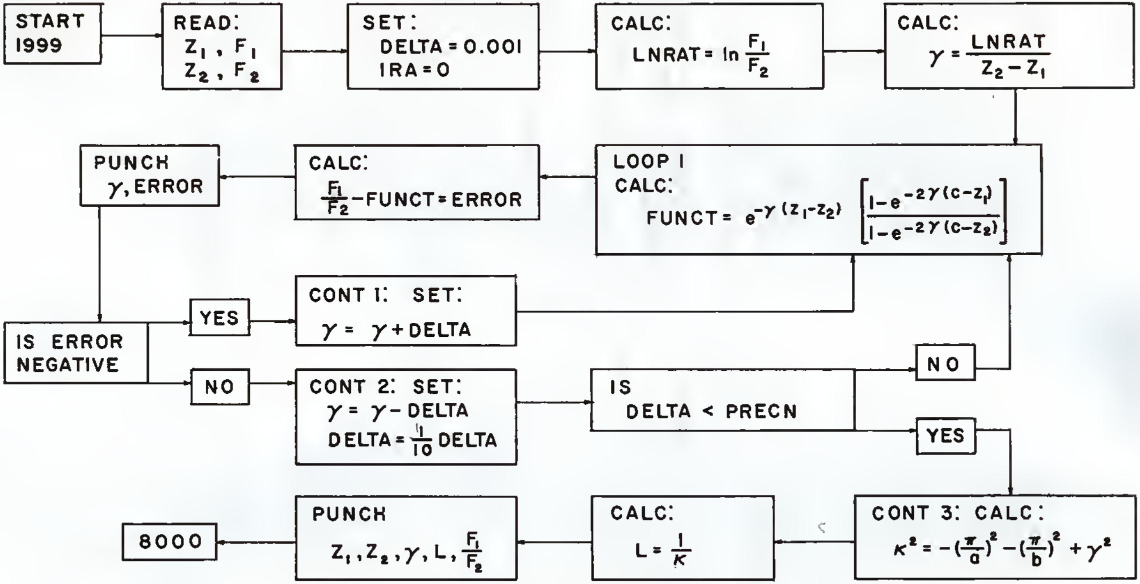
         BMA            CONT5     REMAINING    202    0680    41 0833 0034
         LDD  CIN02     LOOP3                  203    0833    69 0909 0762
CONT5    RAL  CELL8                            204    0034    65 0959 0863
         SLO  TWO                              205    0863    16 0750 1255
         STL  CELL8                            206    1255    20 0959 0812
         NZE            CONT6                  207    0812    45 0666 0717
         RAL  CIN01                            208    0666    65 0859 0913
         ALO  TWO                              209    0913    15 0750 1305
         STL  CIN01               ADJUST TO    210    1305    20 0859 0862
         RAL  CIN02               NEXT CELL    211    0862    65 0909 0963
         ALO  TWO                 SET          212    0963    15 0750 1355
         STL  CIN02                            213    1355    20 0909 0912
         LDD  CIN01     LOOP3                  214    0912    69 0859 0762
CONT6    RAU  POINT                            215    0717    60 0657 0961
         SCT   0000                            216    0961    36 0000 0883
         STL  TEMP1               CONVERT      217    0883    20 0815 1118
         RAL   8003               ROWS TO      218    1118    65 8003 0025
         ALO  SIXTY               FLOATING     219    0025    15 1050 1405
         SLO  TEMP1               POINT        220    1405    16 0815 1019
         RAU   8002                            221    1019    60 8002 0927
         FDV  FP6                              222    0927    34 1300 1001
         FSB  FP1                              223    1001    33 1100 0977
         STU  ROWS                             224    0977    21 0032 0035
         RAU  A                                225    0035    60 0000 1455
         FDV  FP2                              226    1455    34 1150 1051
         FDV  ROWS                             227    1051    34 0032 0082
         FMP  FP0                              228    0082    39 1350 1101
         FDV  FP9                              229    1101    34 1400 1151
         FMP  INTEG                            230    1151    39 0706 0756
         STU  INTEG     CONT7                  231    0756    21 0706 1159
CONT7    RAL  POINT                            232    1159    65 0657 1011
         DIV  SIX                              233    1011    14 0900 1110
         STL `INDEX               SET          234    1110    20 1115 1168
         SLT   0004               DATA         235    1168    35 0004 0079
         ALO  INOA                ADDRESSES    236    0079    15 1550 1505
         LDD  ATWO                FOR          237    1505    69 0658 1061
         SDA  ATWO                TRAP RULE    238    1061    22 0658 1111
         LDD  ATREE                            239    1111    69 0014 0767
         SDA  ATREE                            240    0767    22 0014 0817
         RAL  INDO                             241    0817    65 1600 1555
         LDD  BONE                             242    1555    69 0708 1161
         SDA  BONE                             243    1161    22 0708 1211
         LDD  BTWO                             244    1211    69 0064 0867
         SDA  BTWO                             245    0867    22 0064 0917
         RAU  B                                246    0917    60 0001 1605
         FDV  FP2                              247    1605    34 1150 1201
         FSB  RPRIM                            248    1201    33 0002 0679
         FMP  ROWS                             249    0679    39 0032 0682
         FDV  FP4                              250    0682    34 1250 1251
         STU  FACTR                            251    1251    21 0006 1209
         LDD  INDEX                            252    1209    69 1115 1218
         RAA   8001                            253    1218    80 8001 0924
         RAB   8001     ATWO                   254    0924    82 8001 0658
ATWO     RAU   9999     BONE                   255    0658    60 9999 0708
BONE     FAD   9999                            256    0708    32 9999 0075
         SXA   0001               CALCULATE    257    0075    51 0001 0681
         SXB   0001               TRAP RULE    258    0681    53 0001 0037
         NZA  ATREE     CONTN     INTEGRAL     259    0037    40 0014 0041
ATREE    FAD   9999     BTWO                   260    0014    32 9999 0064
BTWO     FAD   9999                            261    0064    32 9999 0675
         FMP  FACTR                            262    0675    39 0806 0856
         FAD  INTEG                            263    0856    32 0706 0933
         STU  INTEG     ATWO                   264    0933    21 0706 0658
CONTN    LDD  INTEG                            265    0041    69 0706 1259
         STD   1977                            266    1259    24 1977 0730
         LDD  ELEV                             267    0730    69 0008 1261
         STD   1978                            268    1261    24 1978 0731
         LDD  POINT                            269    0731    69 0657 1160
         STD   1979                            270    1160    24 1979 0732
         PCH   1977      8000     START        271    0732    71 1977 1999
```

LOGIC DIAGRAM FOR IBM 650 PROGRAM FOR RATIO METHOD



LOGIC DIAGRAM NO. 2, APPENDIX E

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          BLN  1951     1958                     1   0000   00 0000 0000
          BLN  1977     1984                     2   0000   00 0000 0000
          SYN  A        0100                     3   0000   00 0000 0000
          SYN  B        0101                     4   0000   00 0000 0000
          SYN  C        0102                     5   0000   00 0000 0000
          SYN  STANT    1999                     6   0000   00 0000 0000
ONE        10  0000     0051                     7   0000   10 0000 0051
MONE   -   10  0000     0051                     8   0050   10 0000 0051
MTWO   -   20  0000     0051                     9   0150   20 0000 0051
PI         31  4159     0051                    10   0200   31 4159 0051
CONVT      25  3600     0051                    11   0250   25 3600 0051
TEN        10  0000     0052                    12   0300   10 0000 0052
PRECN      20  0000     0045                    13   0350   20 0000 0045
INCRT      10  0000     0048                    14   0400   10 0000 0048
EOOCL     STD  ZZZ1                             15   0450   24 0053 0006
          LDD  ZZZ10                            16   0006   69 0009 0012
          STD  1977                             17   0012   24 1977 0030
          STD  1978                             18   0030   24 1978 0031
          STD  1979                             19   0031   24 1979 0032
          STD  1980                             20   0032   24 1980 0033
          STD  1981                             21   0033   24 1981 0034
          STD  1982                             22   0034   24 1982 0035
          STD  1983                             23   0035   24 1983 0036
          STD  1984     ZZZ1                    24   0036   24 1984 0053
ZZZ10      00  0000     0000                    25   0009   00 0000 0000
EOOAU     STD  SEXT                         1   26   0500   24 0103 0056
          BMI  SERR                         2   27   0056   46 0059 0010
          NZE           SEXT                3   28   0010   45 0014 0103
          STU  SA                           4   29   0014   21 0018 0021
          FAD  S10                          5   30   0021   32 0024 0001
          FMP  SHAF     SB                  6   31   0001   39 0004 0054
SB        STU  SSAV     SAB                 7   32   0054   21 0008 0011
SAB       RAU  SA              S CAPT A     8   33   0011   60 0018 0023
          FDV  SSAV                         9   34   0023   34 0008 0058
          FAD  SSAV                        10   35   0058   32 0008 0085
          FMP  SHAF                        11   36   0085   39 0004 0104
          FSB  SSAV                        12   37   0104   33 0008 0135
          NZU           SR                 13   38   0135   44 0039 0040
          BMI           SR                 14   39   0039   46 0042 0040
          FAD  SSAV                        15   40   0042   32 0008 0185
          STU  SSAV     SAB                16   41   0185   21 0008 0011
SR        RAU  SSAV     SEXT               17   42   0040   60 0008 0103
SERR      HLT  0000     SEXT               18   43   0059   01 0000 0103
SHAF       50  0000     0050               19   44   0004   50 0000 0050
S10        10  0000     0051               20   45   0024   10 0000 0051
LNX01     STD  LNX08                            46   0550   24 0153 0106
          NZE           LNX14                   47   0106   45 0060 0061
          BMI  LNX14                            48   0060   46 0061 0064
          STU  LNX09                            49   0064   21 0068 0071
          RSL  FPONE                            50   0071   66 0074 0029
          STD  LNX10                            51   0029   24 0082 0235
          STL  LNX02                            52   0235   20 0089 0092
          RAU  LNX09                            53   0092   60 0068 0073
          STL  LNX05                            54   0073   20 0027 0080
          STL  LNX11                            55   0080   20 0285 0038
          SLT  0008                             56   0038   35 0008 0007
          SUP  FIFTY                            57   0007   11 0110 0015
          NZE           LNX04                   58   0015   45 0118 0019
          BMI           LNX03                   59   0118   46 0121 0022
          RSU  8003                             60   0121   61 8003 0079
          LDD  FPONE                            61   0079   69 0074 0077
          STD  LNX02    LNX03                   62   0077   24 0089 0022
LNX03     SRT  0008                             63   0022   30 0008 0041
          SCT  0000                             64   0041   36 0000 0013
          AUP  SIXTY                            65   0013   10 0016 0171
          SUP  8002                             66   0171   11 8002 0129
          RAU  8003                             67   0129   60 8003 0037
          FMP  LNX02                            68   0037   39 0089 0139
          FMP  LNTEN                            69   0139   39 0142 0192
          STU  LNX05    LNX04                   70   0192   21 0027 0019
LNX04     RAL  LNX09                            71   0019   65 0068 0123
          SRT  0002                             72   0123   30 0002 0179
          RAU  8002                             73   0179   60 8002 0087
          ALO  FIFTY                            74   0087   15 0110 0065
          SLT  0002                             75   0065   35 0002 0221
          FAD  FPONE                            76   0221   32 0074 0051
          STU  LNX09                            77   0051   21 0068 0271
          FSB  FPTWO                            78   0271   33 0124 0151
          FDV  LNX09                            79   0151   34 0068 0168
          STU  LNX13                            80   0168   21 0072 0025
          STD  LNX12                            81   0025   24 0028 0081
          STD  LNX11                            82   0081   24 0285 0088
          FMP  8001                             83   0088   39 8001 0091
          STU  FACTN    LNX06                   84   0091   21 0046 0049
LNX06     RAU  LNX10                            85   0049   60 0082 0137
          FAD  FPTWO                            86   0137   32 0124 0201
          STU  LNX10                            87   0201   21 0082 0335
          RAU  LNX13                            88   0335   60 0072 0127
          FMP  FACTN                            89   0127   39 0046 0096
          FDV  LNX10                            90   0096   34 0082 0132
          STU  LNX13                            91   0132   21 0072 0075
          FAD  LNX12                            92   0075   32 0028 0005
          STU  LNX12                            93   0005   21 0028 0131
          FSB  LNX11                            94   0131   33 0285 0111
          FDV  LNX11                            95   0111   34 0285 0385
          RAM  8003                             96   0385   67 8003 0043
          RAU  8002                             97   0043   60 8002 0251
          FSB  SIZE7                            98   0251   33 0154 0181
          BMI  LNX07                            99   0181   46 0084 0435
          LDD  LNX12                           100   0435   69 0028 0231
          STD  LNX11                           101   0231   24 0285 0138
          RAU  LNX13                           102   0138   60 0072 0177
          FMP  LNX10                           103   0177   39 0082 0182
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         STU LNX13   LNX06                   104   0182   21 0072 0049
LNX07    RAU LNX12                           105   0084   60 0028 0083
         FMP FPTWO                           106   0083   39 0124 0174
         FSB LNX05   LNX08                   107   0174   33 0027 0153
FPONE     10  0000    0051                   108   0074   10 0000 0051
FPTWO     20  0000    0051                   109   0124   20 0000 0051
SIZE7     10  0000    0043                   110   0154   10 0000 0043
LNTEN     23  0258    5151                   111   0142   23 0258 5151
FIFTY     50  0000    0000                   112   0110   50 0000 0000
SIXTY     00  0000    0060                   113   0016   00 0000 0060
LNX14     01  2345    67N9                   114   0061   01 2345 6789
EOOEA    STD AAA1                EXIT INSTR  115   0600   24 0203 0156
         STL AAA2                 STORE X    116   0156   20 0161 0114
         RAM AAA2                            117   0114   67 0161 0115
         STL AAA3                X FOR CALC  118   0115   20 0069 0122
         RAU AAA3                            119   0122   60 0069 0173
         FMP AAA16                           120   0173   39 0026 0076
         FAD AAA15                           121   0076   32 0229 0055
         FMP AAA3                            122   0055   39 0069 0119
         FAD AAA14                           123   0119   32 0172 0099
         FMP AAA3                            124   0099   39 0069 0169
         FAD AAA13                           125   0169   32 0222 0149
         FMP AAA3                            126   0149   39 0069 0219
         FAD AAA12                           127   0219   32 0272 0199
         FMP AAA3                            128   0199   39 0069 0269
         FAD AAA11                           129   0269   32 0322 0249
         FMP AAA3                            130   0249   39 0069 0319
         FAD AAA10                           131   0319   32 0372 0299
         STU AAA4                            132   0299   21 0204 0057
         FMP AAA4                            133   0057   39 0204 0254
         STU AAA4                            134   0254   21 0204 0107
         FMP AAA4                            135   0107   39 0204 0304
         STU AAA4                            136   0304   21 0204 0157
         RAU AAA2                            137   0157   60 0161 0165
         BMI AAA5    AAA6                    138   0165   46 0218 0369
AAA5     RAU AAA10                           139   0218   60 0372 0227
         FDV AAA4                            140   0227   34 0204 0354
         STU AAA4    AAA6                    141   0354   21 0204 0369
AAA6     RAL AAA4    AAA1                    142   0369   65 0204 0203
AAA10     10  0000    0051                   143   0372   10 0000 0051
AAA11     24  9998    6850                   144   0322   24 9998 6850
AAA12     31  2575    8349                   145   0272   31 2575 8349
AAA13     25  9137    1248                   146   0222   25 9137 1248
AAA14     17  1562    0047                   147   0172   17 1562 0047
AAA15     54  3020    0045                   148   0229   54 3020 0045
AAA16     69  0600    0044                   149   0026   69 0600 0044
START    RCD  1951                           150   1999   70 1951 0301
         LDD  1951                           151   0301   69 1951 0404
         STU ZONE                READ        152   0404   24 0207 0160
         LDD  1952                           153   0160   69 1952 0105
         STD FONE                IN          154   0105   24 0108 0211
         LDD  1953                           155   0211   69 1953 0206
         STU ZTWO                DATA        156   0206   24 0109 0062
         LDD  1954                           157   0062   69 1954 0257
         STD FTWO                            158   0257   24 0210 0063
         LDD INCRT                           159   0063   69 0400 0253
         STD DELTA                           160   0253   24 0256 0159
         RAA  0000                           161   0159   80 0000 0215
         RAU FONE                            162   0215   60 0108 0113
         FDV FTWO                            163   0113   34 0210 0260
         STU RATIO                           164   0260   21 0164 0017
         LDD         LNX01                   165   0017   69 0020 0550
         STU LNRAT                           166   0020   21 0224 0277
         RAU ZTWO                            167   0277   60 0109 0163
         FSB ZONE                            168   0163   33 0207 0133
         STU TEMP1                           169   0133   21 0188 0141
         RAU LNRAT               CALCULATE   170   0141   60 0224 0279
         FDV TEMP1               INITIAL     171   0279   34 0188 0238
         STU GAMMA   LOOP1       GAMMA       172   0238   21 0242 0045
LOOP1    AXA  0001                           173   0045   50 0001 0351
         RAU ZONE                            174   0351   60 0207 0261
         FSB ZTWO                            175   0261   33 0109 0485
         FMP GAMMA                           176   0485   39 0242 0292
         FMP MONE                            177   0292   39 0050 0650
         RAL  8003                           178   0650   65 8003 0307
         LDD         EOOEA                   179   0307   69 0310 0600
         STL TEMP1                           180   0310   20 0188 0191
         RAU C                               181   0191   60 0102 0357
         FSB ZONE                            182   0357   33 0207 0183
         FMP GAMMA                           183   0183   39 0242 0342
         FMP MTWO                            184   0342   39 0150 0700
         RAL  8003                           185   0700   65 8003 0407
         LDD         EOOEA                   186   0407   69 0360 0600
         STL TEMP2                           187   0360   20 0265 0268
         RAU ONE                             188   0268   60 0000 0155
         FSB TEMP2                           189   0155   33 0265 0241
         STU TEMP2                           190   0241   21 0265 0318
         RAU C                               191   0318   60 0102 0457
         FSB ZTWO                            192   0457   33 0109 0535
         FMP GAMMA                           193   0535   39 0242 0392
         FMP MTWO                            194   0392   39 0150 0750
         RAL  8003                           195   0750   65 8003 0507
         LDD         EOOEA                   196   0507   69 0410 0600
         STL TEMP3                           197   0410   20 0315 0368
         RAU ONE                             198   0368   60 0000 0205
         FSB TEMP3                           199   0205   33 0315 0291
         STU TEMP3                           200   0291   21 0315 0418
         RAU TEMP1                           201   0418   60 0188 0093
         FMP TEMP2               CALCULATE   202   0093   39 0265 0365
         FDV TEMP3               FUNCTION    203   0365   34 0315 0415
         STU FUNCT                           204   0415   21 0070 0223
         RAU RATIO                           205   0223   60 0164 0419
```

```
        FSB  FUNCT            CHECK        206    0419    33 0070 0047
        STU  ERROR            ERROR        207    0047    21 0002 0265
        LDD         EOOCL                  208    0255    69 0158 0450
        LDD  GAMMA                         209    0158    69 0242 0095
        STD   1977                         210    0096    24 1977 0130
        LDD  ERROR                         211    0130    69 0002 0305
        STD   1978            PUNCH        212    0305    24 1978 0281
        PCH   1977            TRIAL        213    0281    71 1977 0327
        RAU  ERROR                         214    0327    60 0002 0557
        BMI  CONT1  CONT2                  215    0557    46 0460 0311
CONT1   RAU  GAMMA                         216    0460    60 0242 0097
        FAD  DELTA                         217    0097    32 0256 0233
        STU  GAMMA  LOOP1                  218    0233    21 0242 0045
CONT2   RAU  GAMMA                         219    0311    60 0242 0147
        FSB  DELTA                         220    0147    33 0256 0283
        STU  GAMMA                         221    0223    21 0242 0145
        RAU  DELTA                         222    0145    60 0256 0361
        FDV  TEN                           223    0361    34 0300 0800
        STU  DELTA                         224    0800    21 0256 0809
        FSB  PRECN            CHECK        225    0809    33 0350 0377
        BMI  CONT3  LOOP1     PRECISION    226    0377    46 0120 0045
CONT3   RAU  PI                            227    0120    60 0200 0355
        FDV  A                             228    0355    34 0100 0850
        STU  ALPH2                         229    0850    21 0454 0607
        FMP  ALPH2            ALPHA        230    0607    39 0454 0504
        STU  ALPH2            SQUARED      231    0504    21 0454 0657
        RAU  PI                            232    0657    60 0200 0405
        FDV  B                             233    0405    34 0101 0401
        STU  BETA2                         234    0401    21 0306 0259
        FMP  BETA2            BETA         235    0259    39 0306 0356
        STU  BETA2            SQUARED      236    0356    21 0306 0309
        RAU  GAMMA            GAMMA        237    0309    60 0242 0197
        FMP  GAMMA            SQUARED      238    0197    39 0242 0442
        FSB  ALPH2                         239    0442    33 0454 0331
        FSB  BETA2                         240    0331    33 0306 0333
        LDD         EOOAU                  241    0333    69 0086 0500
        STU  KAPPA            KAPPA        242    0086    21 0090 0143
        RAU  ONE                           243    0143    60 0000 0456
        FDV  KAPPA            DIFFUSION    244    0455    34 0090 0140
        FMP  CONVT                         245    0140    39 0250 0900
        STU  DL               LENGTH       246    0900    21 0554 0707
        LDD  ZONE                          247    0707    69 0807 0510
        STD   1977                         248    0510    24 1977 0830
        LDD  ZT00                          249    0230    69 0109 0112
        STD   1978                         250    0112    24 1978 0381
        LDD  GAMMA                         251    0321    69 0248 0195
        STD   1979                         252    0195    24 1979 0232
        LDD  DL                            253    0232    69 0554 0757
        STD   1980                         254    0757    24 1980 0383
        LDD  RATIO                         255    0383    69 0164 0067
        STD   1981                         256    0067    24 1981 0134
        LDD   8006                         257    0134    69 8005 0341
        STD   1982                         258    0341    24 1982 0585
        PCH   1977   8000                  259    0585    71 1977 8000
```

APPENDIX F

IBM 650 Program for Diffusion Length Double Iteration Method

This program was written to evaluate the diffusion length by the double iteration technique. It was written in SOAP II and floating point form. The object program and a logic diagram are included in this section.

A detailed description of the double iteration process can be found in the THEORY. The constants A_{mn} are determined by the equation

$$A_{mn} = \frac{4\,F_{mn}}{ab \sinh \gamma_{mn} (c - z_o)}$$

where z_o is the elevation at which the functions F_{mn}, determined by

$$F_{mn} = \int_{-a/2}^{a/2} \int_{-b/2}^{b/2} \phi\,(x, y, z) \cos \frac{m\,\pi x}{a} \cos \frac{n\,\pi y}{b}\, dx\, dy$$

are evaluated. The first portion of this program, which calculates the F_{mn}'s is an adaptation of the double integral evaluation program described in Appendix E. The remainder of the program performs the double iteration analysis. Several determinations may be desired with one set of F_{mn}'s. If this is the case, the data for each additional determination should be followed by a transfer card which sends the machine to the CON11 location. This will avoid unnecessary recalculation of the F_{mn}'s. The correction factors used are listed in Table 1.

Input to this program is partially in the form of one word load cards. Certain parameters, plus the data for the vertical traverse are of this form. This input, listed in Table 27, should be followed by a transfer card and the data for evaluation of the double integral functions. The data for the evaluation of these functions is exactly the same as the input to the double integral program described in Appendix E, forms one and two.

Table 27. One word load input for double iteration program.

Symbol	Explanation	Drum Storage Location
A	Extrapolated x-dimension	0000
B	Extrapolated y-dimension	0001
BPRIM	Distance from center of pile to outermost fuel port	0002
HARM	Number of highest harmonic, floating point form	0003
FIRST	Initial Estimate of Gamma	0004
POINT	Number of Data Points (vert. traverse) in form 00 0000 00xx	0005
DATPT	Number of Data Points (vert. traverse) in floating point form	0006
C	Extrapolated z-dimension	0007
N	Count Rates for vertical traverse, stored consecutively starting at	0650
z	Co-ordinates of vertical traverse data, stored consecutively starting at	0675

The capacity of the program is 25 data points in the vertical traverse and 100 data points in the horizontal mesh. The program capable of using up to the ninth harmonic.

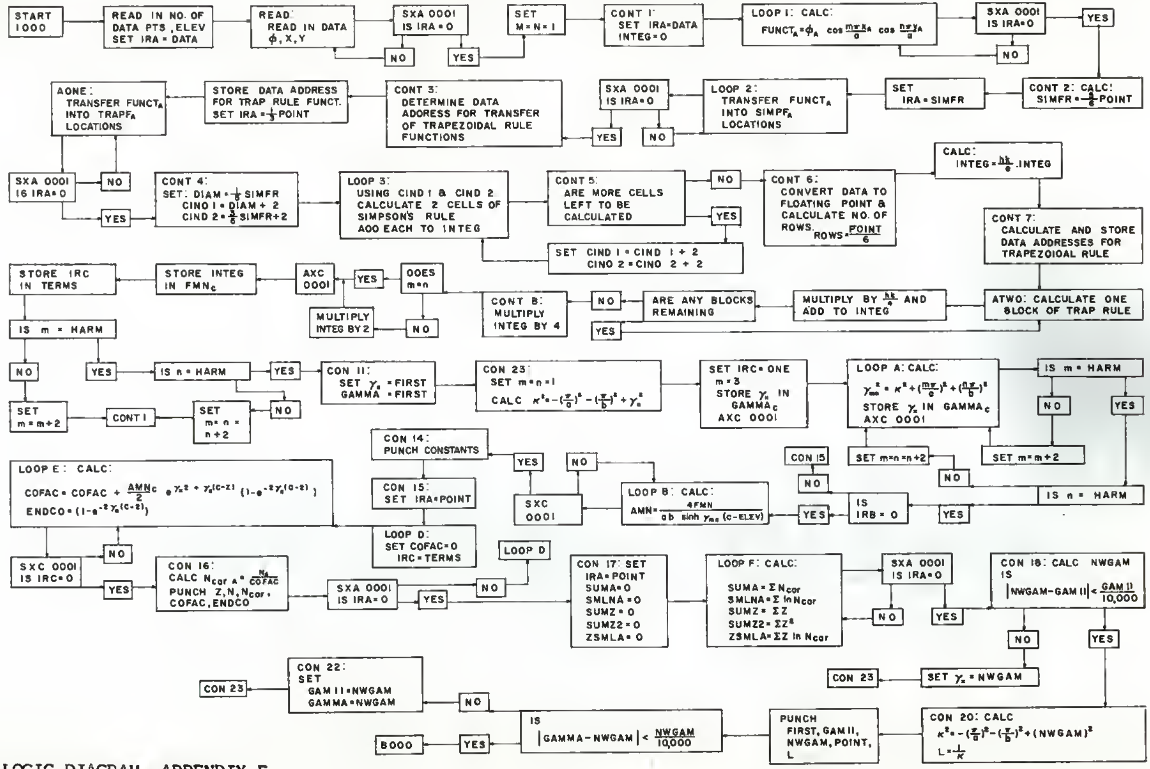
There are three output forms, listed in Table 28. The first lists the constants and may use two cards. The A_{mn}'s are listed in the order A_{11}, $2A_{13}$, $2A_{15}$, ... A_{33}, $2A_{35}$, ... A_{55}, etc.. Where m and n are not equal, the constant is multiplied by two to account for both the mn and nm terms at once. This can be done because of the symmetry of the pile. Form two is the standard correction factor output, and form three is a final output form. Form three is punched after the completion of each correction factor iteration.

Table 28. Output forms for double iteration program.

Word 1	2	3	4	5	6	7	8
Form 1: (3 harmonics)							
A_{11}	$2A_{13}$	$2A_{15}$	A_{33}	$2A_{35}$	A_{55}	-	-
Form 2:							
z	N	N_{corr}	C_H	C_E	-	-	-
Form 3:							
FIRST	Next to last γ	Last γ	Data Points	Diffusion Length	-	-	-

Five to ten minutes are required for complete double iteration analysis using 10 data points. An additional three minutes is required for evaluation of each F_{mn} used.

LOGIC DIAGRAM FOR IBM 650 PROGRAM FOR DOUBLE ITERATION METHOD



LOGIC DIAGRAM, APPENDIX F

```
           BLR   1951     1960                    1   0000    00 0000 0000
           BLR   1977     1984                    2   0000    00 0000 0000
           BLR   1900     1999                    3   0000    00 0000 0000
           BLR   0100     0790                    4   0000    00 0000 0000
           SYN FLUX       0100                    5   0000    00 0000 0000
           SYN X          0200                    6   0000    00 0000 0000
           SYN Y          0300                    7   0000    00 0000 0000
           SYN FUNCT      0400                    8   0000    00 0000 0000
           SYN SIMPF      0500                    9   0000    00 0000 0000
           SYN TRAPF      0600                   10   0000    00 0000 0000
           SYN Z          0650                   11   0000    00 0000 0000
           SYN N          0675                   12   0000    00 0000 0000
           SYN NCOR       0700                   13   0000    00 0000 0000
           SYN GAMMA      0730                   14   0000    00 0000 0000
           SYN AMN        0750                   15   0000    00 0000 0000
           SYN FMN        0770                   16   0000    00 0000 0000
           SYN A          0000                   17   0000    00 0000 0000
           SYN B          0001                   18   0000    00 0000 0000
           SYN BPRIM      0002                   19   0000    00 0000 0000
           SYN HARM       0003                   20   0000    00 0000 0000
           SYN FIRST      0004                   21   0000    00 0000 0000
           SYN POINT      0005                   22   0000    00 0000 0000
           SYN DATPT      0006                   23   0000    00 0000 0000
           SYN C          0007                   24   0000    00 0000 0000
           SYN START      1000                   25   0000    00 0000 0000
ZERO        00   0000     0000                   26   0050    00 0000 0000
ONE         00   0000     0001                   27   0800    00 0000 0001
TWO         00   0000     0002                   28   0850    00 0000 0002
THREE       00   0000     0003                   29   0900    00 0000 0003
FIVE        00   0000     0005                   30   0950    00 0000 0005
SIX         00   0000     0006                   31   1050    00 0000 0006
EIGHT       00   0000     0008                   32   1100    00 0000 0008
TEN         00   0000     0010                   33   1150    00 0000 0010
SIXTY       00   0000     0060                   34   1200    00 0000 0060
FP1         10   0000     0051                   35   1250    10 0000 0051
FP8         20   0000     0051                   36   1300    20 0000 0051
PI          31   4159     0051                   37   1350    31 4159 0051
FP4         40   0000     0051                   38   1400    40 0000 0051
FP6         60   0000     0051                   39   1450    60 0000 0051
FP8         80   0000     0051                   40   1500    80 0000 0051
FP9         90   0000     0051                   41   1550    90 0000 0051
FP16        16   0000     0052                   42   1600    16 0000 0052
CONVT       25   3600     0051                   43   1650    25 3600 0051
10000       10   0000     0055                   44   1700    10 0000 0055
INDXA       00   2400     0000                   45   1750    00 2400 0000
INDA        00   2600     0000                   46   1800    00 2600 0000
INDB        00   4600     0000                   47   1850    00 4600 0000
EOOEA      STD AAA1                EXIT INSTR    48   0051    24 0054 0057
           STL AAA14               STORE ARO     49   0057    20 0011 0014
           RAU AAA16               ZERO          50   0014    60 0017 0021
           FAM AAA14                             51   0021    37 0011 0037
           STU AAA2                              52   0037    21 0042 0045
           RAU AAA3                ONE           53   0045    60 0048 0053
           STU AAA4       AAA8     COEFF         54   0053    21 0008 0061
AAA8       RAU AAA2                              55   0061    60 0042 0047
           FSB AAA5                FIVE          56   0047    33 0801 0027
           BMI AAA6                              57   0027    46 0030 0031
           STU AAA2                              58   0031    21 0042 0095
           RAU AAA4                              59   0095    60 0008 0013
           FMP AAA7                E TO 5        60   0013    39 0016 0066
           STU AAA4       AAA8                   61   0066    21 0008 0061
AAA6       RAU AAA2                              62   0030    60 0042 0097
           FSB AAA3                ONE           63   0097    33 0048 0025
           BMI AAA28                             64   0025    46 0028 0029
           STU AAA2                              65   0029    21 0042 0795
           RAU AAA4                              66   0795    60 0008 0063
           FMP AAA9                E TO 1        67   0063    39 0816 0866
           STU AAA4       AAA6                   68   0866    21 0008 0030
AAA28      RAU AAA2                              69   0028    60 0042 0797
           FSB AAA10               POINT TWO     70   0797    33 0851 0077
           BMI AAA11                             71   0077    46 0080 0081
           STU AAA2                              72   0081    21 0042 0845
           RAU AAA4                              73   0845    60 0008 0813
           FMP AAA12               E TO PT 2     74   0813    39 0916 0966
           STU AAA4       AAA2R                  75   0966    21 0008 0028
AAA11      RAU AAA2                              76   0080    60 0042 0847
           LDD            AAA17                  77   0847    69 0901 0R04
           FMP AAA4                              78   0901    39 0008 0058
           STU AAA13                             79   0058    21 0012 0015
           RAU AAA14                             80   0015    60 0011 0065
           BMI AAA18                             81   0065    46 0018 0019
           RAL AAA13      AAA1                   82   0019    65 0012 0054
AAA15      RAU AAA3                              83   0018    60 0048 0803
           FDV AAA13                             84   0803    34 0012 0062
           RAL  8003      AAA1                   85   0062    65 8003 0054
AAA17      STD AAA18               EXIT INSTR    86   0804    24 0807 0010
           RAU AAA3                ONE           87   0010    60 0048 0853
           FAD AAA2                              88   0853    32 0042 0069
           STU AAA19                             89   0069    21 0024 0827
           RAU AAA27               TWO           90   0827    60 0830 0035
           STU AAA20               N             91   0035    21 0040 0043
           STU AAA21               DENOM         92   0043    21 0098 0951
           RAU AAA2                              93   0951    60 0042 0897
           FMP AAA2                              94   0897    39 0042 0092
           STU AAA23      AAA22    NUMERATOR     95   0092    21 0046 0049
AAA22      FDV AAA21                             96   0049    34 0098 0798
           STU AAA24               NTH TERM      97   0798    21 0052 0055
           FAD AAA19                             98   0055    32 0024 1001
           STU AAA19               TOTAL         99   1001    21 0024 0877
           RAU AAA24                            100   0877    60 0052 0857
           FDV AAA19                            101   0857    34 0024 0074
           FSB AAA25               CRITERIA     102   0074    33 0927 0903
           BMI            AAA26                 103   0903    46 0056 0907
           RAU AAA19      AAA18                 104   0056    60 0024 0807
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AAA26    RAU  AAA20                                   105   0907   60 0040 0895
         FAO  AAA3                                    106   0895   32 0048 0075
         STU  AAA20              NEW N                107   0075   21 0040 0093
         FMP  AAA21                                   108   0093   39 0098 0848
         STU  AAA21              NEW DENOM            109   0848   21 0098 1051
         RAU  AAA23                                   110   1051   60 0046 1101
         FMP  AAA2                                    111   1101   39 0042 0792
         STU  AAA23     AAA22                         112   0792   21 0046 0049
AAA3      10   0000      0051    ONE                  113   0048   10 0000 0051
AAA5      50   0000      0051    FIVE                 114   0801   50 0000 0051
AAA7      14   8413      1653    E TO 5               115   0016   14 8413 1653
AAA9      27   1828      1851    E                    116   0816   27 1828 1851
AAA10     20   0000      0050    POINT TWO            117   0851   20 0000 0050
AAA12     12   2140      2851    E TO PT 2            118   0916   12 2140 2851
AAA16     00   0000      0000    ZERO                 119   0017   00 0000 0000
AAA28     10   0000      0047    CRITERIA             120   0927   10 0000 0047
AAA27     20   0000      0051    TWO                  121   0830   20 0000 0051
E00CL    STO  ZZZ1                                    122   1151   24 0854 0957
         LDD  ZZZ10                                   123   0957   69 0060 0863
         STO   1977                                   124   0863   24 1977 0880
         STO   1978                                   125   0880   24 1978 0831
         STO   1979                                   126   0831   24 1979 0032
         STO   1980                                   127   0032   24 1980 0033
         STO   1981                                   128   0033   24 1981 0034
         STO   1982                                   129   0034   24 1982 0035
         STO   1983                                   130   0035   24 1983 0036
         STO   1984     ZZZ1                          131   0036   24 1984 0854
ZZZ10     00   0000      0000                         132   0060   00 0000 0000
E00CR    STO  EXIT                                    133   1201   24 0904 1007
         RAU   8002                                   134   1007   60 8002 0815
         BMI  NEGAT     REDUC                         135   0818   46 0068 0819
NEGAT    FAO  TWOPI                                   136   0068   32 0071 0947
         BMI  NEGAT                                   137   0947   46 0068 1251
         FSB  ONEPI     COSIO                         138   1251   33 0954 0881
REDUC    FSB  TWOPI                                   139   0819   33 0071 0997
         BMI            REDUC                         140   0997   46 1301 0819
         FAD  ONEPI     COSIO                         141   1301   32 0954 0881
COSIO    STU  THETA                                   142   0881   21 0086 0039
         RSU  FPONE                                   143   0039   61 0842 1047
         STU  TERMM                                   144   1047   21 0802 0805
         STU  FUNKT                                   145   0805   21 0810 0913
         STL  ENNN      NEGST                         146   0913   20 0067 0020
E00SR    STO  EXIT                                    147   1351   24 0904 1057
         RAU   8002                                   148   1057   60 8002 0865
         BMI  NEGAV     REDUO                         149   0865   46 0818 0869
NEGAV    FAO  TWOPI                                   150   0818   32 0071 1097
         BMI  NEGAV                                   151   1097   46 0818 1401
         FSB  ONEPI     SINET                         152   1401   33 0954 0931
REDUO    FSB  TWOPI                                   153   0869   33 0071 1147
         BMI            REDUO                         154   1147   46 1451 0869
         FAD  ONEPI     SINET                         155   1451   32 0954 0931
SINET    STU  THETA                                   156   0931   21 0086 0089
         RSU   8003                                   157   0089   61 8003 1197
         STU  TERMM                                   158   1197   21 0802 0855
         STU  FUNKT                                   159   0855   21 0810 0963
         LDD  FPONE                                   160   0963   69 0842 0945
         STD  ENNN      NEGST                         161   0945   24 0067 0020
NEGST    RAU  ENNN                                    162   0020   60 0067 0821
         FAD  FPONE                                   163   0821   32 0842 0919
         STU  NPONE                                   164   0919   21 0824 0977
         FAU  FPONE                                   165   0977   32 0842 0969
         STU  ENNN                                    166   0969   21 0067 0070
         RSU  TERMM                                   167   0070   61 0802 1107
         FMP  THETA                                   168   1107   39 0086 0836
         FMP  THETA                                   169   0836   39 0086 0886
         FDV  NPONE                                   170   0886   34 0824 0874
         FDV  ENNN                                    171   0874   34 0067 0817
         STU  TERMM                                   172   0817   21 0802 0905
         RAM  FUNKT                                   173   0905   67 0810 0915
         STL  FMAG                                    174   0915   20 1019 0022
         RAM  TERMM                                   175   0022   67 0802 1157
         RAU   8002                                   176   1157   60 8002 0965
         FDV  FMAG                                    177   0965   34 1019 1069
         FSB  SIZES                                   178   1069   33 0072 0099
         BMI  ENUFF                                   179   0099   46 0852 0953
         RAU  FUNKT                                   180   0953   60 0810 1015
         FAD  TERMM                                   181   1015   32 0802 0079
         STU  FUNKT     NEGST                         182   0079   21 0810 0020
ENUFF    RAL  FUNKT     EXIT                          183   0852   65 0810 0904
SIZES     10   0000      0043                         184   0072   10 0000 0043
TWOPI     62   8318      5351                         185   0071   62 8318 5351
ONEPI     31   4159      2751                         186   0954   31 4159 2751
FPONE     10   0000      0051                         187   0842   10 0000 0051
E00AU    STD  SEXT                                 1  188   1501   24 1004 1207
         BMI  SERR                                 2  189   1207   46 0860 0811
         NZE            SEXT                       3  190   0811   45 0064 1004
         STU  SA                                   4  191   0064   21 0868 0871
         FAD  S10                                  5  192   0871   32 0924 1551
         FMP  SHAF      SB                         6  193   1551   39 1054 1104
SB       STU  SSAV      SAB                        7  194   1104   21 0808 0861
SAB      RAU  SA                 S CAPT A          8  195   0861   60 0868 0023
         FDV  SSAV                                 9  196   0023   34 0808 0858
         FAD  SSAV                                10  197   0858   32 0808 0835
         FMP  SNAF                                11  198   0835   39 1054 1154
         FSB  SSAV                                12  199   1154   33 0808 0885
         NZU            SR                        13  200   0885   44 0839 0090
         BMI            SR                        14  201   0839   46 0898 0090
         FAD  SSAV                                15  202   0892   32 0808 0935
         STU  SSAV      SAB                       16  203   0935   21 0808 0861
SR       RAU  SSAV      SEXT                      17  204   0090   60 0808 1004
SERR     NLT   0000     SEXT                      18  205   0860   01 0000 1004
SNAF      50   0000      0050                     19  206   1054   50 0000 0050
S10       10   0000      0051                     20  207   0924   10 0000 0051
LNX01    STO  LNX08                                   208   1601   24 1204 1257
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        NZE           LNX14               209   1257   45 0910 0911
        BMI  LNX14                        210   0910   46 0911 0814
        STU  LNX09                        211   0814   21 0918 0921
        RSL  FPONE                        212   0921   66 0842 1247
        STD  LNX10                        213   1247   24 1651 1254
        STL  LNX02                        214   1254   20 0009 0812
        RAU  LNX09                        215   0812   60 0918 0073
        STL  LNX05                        216   0073   20 1027 0930
        STL  LNX11                        217   0930   20 0985 0038
        SLT   0008                        218   0038   35 0008 1307
        SUP  FIFTY                        219   1307   11 0960 1065
        NZE           LNX04               220   1065   45 0968 1119
        BMI           LNX03               221   0968   46 0971 0822
        RSU   8003                        222   0971   61 8003 0829
        LDD  FPONE                        223   0829   69 0842 0995
        STD  LNX02    LNX03               224   0995   24 0009 0822
LNX03   SRT   0008                        225   0822   30 0008 0041
        SCT   0000                        226   0041   36 0000 1013
        AUP  SIXTY                        227   1013   10 1200 0955
        SUP   8002                        228   0955   11 8002 1063
        RAU   8003                        229   1063   60 8003 1021
        FMP  LNX02                        230   1021   39 0009 0059
        FMP  LNTEN                        231   0059   39 0862 0912
        STU  LNX05    LNX04               232   0912   21 1027 1119
LNX04   RAL  LNX09                        233   1119   65 0918 0823
        SRT   0002                        234   0823   30 0002 0879
        RAU   8002                        235   0879   60 8002 0087
        ALO  FIFTY                        236   0087   15 0960 1115
        SLT   0002                        237   1115   35 0002 1071
        FAD  FPONE                        238   1071   32 0842 1169
        STU  LNX09                        239   1169   21 0918 1121
        FSB  FPTWO                        240   1121   33 0974 1701
        FDV  LNX09                        241   1701   34 0918 1018
        STU  LNX13                        242   1018   21 0872 0825
        STD  LNX12                        243   0825   24 0078 0981
        STD  LNX11                        244   0981   24 0985 0088
        FMP   8001                        245   0088   39 8001 0091
        STU  FACTR    LNX06               246   0091   21 0096 0799
LNX06   RAU  LNX10                        247   0799   60 1651 1005
        FAD  FPTWO                        248   1005   32 0974 1751
        STU  LNX10                        249   1751   21 1651 1304
        RAU  LNX13                        250   1304   60 0872 1077
        FMP  FACTR                        251   1077   39 0096 0796
        FDV  LNX10                        252   0796   34 1651 1801
        STU  LNX13                        253   1801   21 0872 0875
        FAD  LNX12                        254   0875   32 0078 1055
        STU  LNX12                        255   1055   21 0078 1031
        FSB  LNX11                        256   1031   33 0985 0961
        FDV  LNX11                        257   0961   34 0985 1035
        RAM   8003                        258   1035   67 8003 0793
        RAU   8002                        259   0793   60 8002 1851
        FSB  SIZE7                        260   1851   33 1354 1081
        BMI  LNX07                        261   1081   46 0084 1085
        LDD  LNX12                        262   1085   69 0078 1131
        STD  LNX11                        263   1131   24 0985 0838
        RAU  LNX13                        264   0838   60 0872 1127
        FMP  LNX10                        265   1127   39 1651 0902
        STU  LNX13    LNX06               266   0902   21 0872 0799
LNX07   RAU  LNX12                        267   0084   60 0078 0083
        FMP  FPTWO                        268   0083   39 0974 1024
        FSB  LNX05    LNX08               269   1024   33 1027 1204
FPONE    10   0000     0051               270   0842   10 0000 0051
FPTWO    20   0000     0051               271   0974   20 0000 0051
SIZE7    10   0000     0043               272   1354   10 0000 0043
LNTEN    23   0258     5151               273   0862   23 0258 5151
FIFTY    50   0000     0000               274   0960   50 0000 0000
SIXTY    00   0000     0060               275   1200   00 0000 0060
LNX14    01   2345     6789               276   0911   01 2345 6789
START   RCD   1951                        277   1000   70 1951 0952
        LDD   1951                        278   0952   69 1951 1404
        STD  DATA                DATA POINT 279 1404   24 1357 1010
        LDD   1952                        280   1010   69 1952 1105
        STD  ELEV                         281   1105   24 0908 1011
        RAC   0000                        282   1011   88 0000 0867
        LDD  DATA                         283   0867   69 1357 1060
        RAA   8001    READ                284   1060   80 8001 1016
READ    RCD   1951                        285   1016   70 1951 1002
        LDD   1951                        286   1002   69 1951 1454
        STD   0100  A            FLUX     287   1454   24 2100 1003
        LDD   1952                        288   1003   69 1952 1155
        STD   0200  A            X        289   1155   24 2200 1053
        LDD   1953                        290   1053   69 1953 0806
        STD   0300  A            Y        291   0806   24 2300 1103
        SXA   0001                        292   1103   51 0001 0809
        NZA  READ                         293   0809   40 1016 1113
        LDD  FP1                          294   1113   69 1250 1153
        STD  M                            295   1153   24 0856 0859
        STD  N        CONT1               296   0859   24 0675 0828
CONT1   LDD  ZERO                         297   0828   69 0050 1203
        STD  INTEG                        298   1203   24 0906 0909
        LDD  DATA                         299   0909   69 1357 1110
        RAA   8001    LOOP1               300   1110   80 8001 1066
LOOP1   RAU  X      A                     301   1066   60 2200 1805
        FMP  M                            302   1805   39 0856 0956
        FMP  PI                           303   0956   39 1350 1052
        FDV  A                            304   1052   34 0000 1102
        RAL   8003                        305   1102   65 8003 0959
        LDD           E00CR               306   0959   69 0962 1201
        STL  TEMP1                        307   0962   20 0917 0820
        RAU  Y      A                     308   0820   60 2300 1255
        FMP  N                            309   1255   39 0675 0925
        FMP  PI                           310   0925   39 1350 1152
        FDV  B                            311   1152   34 0001 1202
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        RAL  8003                                   312  1202  65 8003 1009
        LDD              EUOCN                      313  1009  69 1012 1201
        RAU  8002                                   314  1012  60 8002 1171
        FMP  TEMP1                                  315  1171  39 0917 0967
        FMP  FLUX   A           CALCULATE           316  0967  39 2100 1252
        STU  FUNCT  A           FUNCTIONS           317  1252  21 2400 1253
        SXA  0001                                   318  1253  51 0001 1059
        NZA  LOOP1       CONT2                      319  1059  40 1066 1163
CONT2   RAU  DATA                                   320  1163  60 1357 1061
        MPY  FIVE                                   321  1061  19 0950 0870
        DIV  SIX                                    322  0870  14 1050 1160
        STL  SIUFR                                  323  1160  20 1165 1068
        LDD  SIMFR                                  324  1068  69 1165 1118
        RAA  8001        LOOP2                      325  1118  80 8001 1074
LOOP2   LDD  FUNCT  A           DISTRIBUTE          326  1074  69 2400 1303
        STD  SIMPF  A           SIMPSON             327  1303  24 2500 1353
        SXA  0001               FUNCTIONS           328  1353  51 0001 1109
        NZA  LOOP2       CONT3                      329  1109  40 1074 1213
CONT3   RAU  SIMFR                                  330  1213  60 1165 1219
        MPY  EIGHT                                  331  1219  19 1100 0920
        DIV  TEN                                    332  0920  14 1150 1210
        SLT  0004                                   333  1210  35 0004 1221
        ALO  INDXA                                  334  1221  15 1750 1305
        LDD  AONE                                   335  1305  69 0958 1111
        SDA  AONE                                   336  1111  22 0958 1161
        RAU  DATA                                   337  1161  60 1357 1211
        MPY  TWO                                    338  1211  19 0850 0970
        DIV  SIX                                    339  0970  14 1050 1260
        LDD  8002                                   340  1260  69 8002 1017
        RAA  8001        AONE                       341  1017  80 8001 0958
AONE    LDD  9999               DISTRIBUTE          342  0958  69 9999 1302
        STD  TRAPF  A           TRAP RULE           343  1302  24 2600 1403
        SXA  0001               FUNCTIONS           344  1403  51 0001 1159
        NZA  ADNE        CONT4                      345  1159  40 0958 1263
CONT4   RAL  SIMFR                                  346  1263  65 1165 1269
        DIV  FIVE                                   347  1269  14 0950 1310
        STL  DIAM                                   348  1310  20 1215 1168
        ALO  TWO                                    349  1168  15 0850 1355
        STL  CIND1                                  350  1355  20 1209 1062
        RAU  SIUFR              SET INDEX           351  1062  60 1165 1319
        MPY  THREE              REGISTERS           352  1319  19 0900 1020
        DIV  FIVE .             FOR                 353  1020  14 0950 1360
        ALO  TWO                SIMPSONS            354  1360  15 0850 1405
        STL  CIND2              RULE                355  1405  20 1259 1112
        RAL  DATA                                   356  1112  65 1357 1261
        DIV  SIX                                    357  1261  14 1050 1410
        SLO  ONE                                    358  1410  16 0800 1455
        STL  CELLS                                  359  1455  20 1309 1162
        LDD  CIND1       LOOP3                      360  1162  69 1209 1212
LOOP3   RAA  8001                                   361  1212  80 8001 1218
        RAU  SIMPF  A                               362  1218  60 2500 1505
        FMP  FP16                                   363  1505  39 1600 1352
        FAD  INTEG                                  364  1352  32 0906 0833
        STU  INTEG                                  365  0833  21 0906 1359
        SXA  0001                                   366  1359  51 0001 1265
        RAU  SIMPF  A                               367  1865  60 2500 1555
        AXA  0002                                   368  1555  50 0002 1311
        FAD  SIMPF  A                               369  1311  32 2500 1177
        SXA  0001                                   370  1177  51 0001 0883
        LDD  DIAM                                   371  0883  69 1215 1268
        SXA  8001                                   372  1268  51 8001 1124
        FAD  SIUPF  A                               373  1124  32 2500 1227
        LDD  DIAM                                   374  1227  69 1215 1318
        AXA  8001                                   375  1318  50 8001 1174
        AXA  8001                                   376  1174  50 8001 0980
        FAD  SIMPF  A                               377  0980  32 2500 1277
        FMP  FP4                                    378  1277  39 1400 1402
        FAD  INTEC                                  379  1402  32 0906 0933
        STU  INTEG                                  380  0933  21 0906 1409
        AXA  0001                                   381  1409  50 0001 1315
        RAU  SIMPF  A                               382  1315  60 2500 1605
        SXA  0002                                   383  1605  51 0002 1361
        FAD  SIMPF  A                               384  1361  32 2500 1327
        LDD  DIAM                                   385  1327  69 1215 1368
        SXA  8001                                   386  1368  51 8001 1224
        SXA  8001                                   387  1224  51 8001 1030
        FAD  SIMPF  A           CELL                388  1030  32 2500 1377
        AXA  0002               CALCULATNG          389  1377  50 0008 0983
        FAD  SIMPF  A           FOR                 390  0983  32 2500 1427
        FAD  INTEG              SIMPSONS            391  1427  32 0906 1033
        STU  INTEG              RULE                392  1033  21 0906 1459
        LDD  DIAM                                   393  1459  69 1215 1418
        SXA  8001               CHECK               394  1418  51 8001 1274
        SXA  0001               CELLS               395  1874  51 0001 1080
        SMA              CONT5  REMAININC           396  1080  41 1083 0834
        LDD  CIND2       LOOP3                      397  1083  69 1259 1212
CONT5   RAL  CELLS                                  398  0834  65 1309 1313
        SLO  TWO                                    399  1313  16 0850 1655
        STL  CELLS                                  400  1655  20 1309 1262
        NZE              CONT6                      401  1262  45 1116 1067
        RAL  CIND1                                  402  1116  65 1209 1363
        ALO  TWO                                    403  1363  15 0850 1705
        STL  CIND1              ADJUST TO           404  1705  20 1209 1312
        RAL  CIND2              NEXT CELL           405  1312  65 1259 1413
        ALO  TWO                SET                 406  1413  15 0850 1755
        STL  CIND2                                  407  1755  20 1259 1362
        LDD  CIND1       LOOP3                      408  1362  69 1209 1212
CONT6   RAU  DATA                                   409  1067  60 1357 1411
        SCT  0000                                   410  1411  36 0000 1133
        STL  TEMP1              CONVERT             411  1133  20 0917 1070
        RAL  8003               ROWS TO             412  1070  65 8003 1477
        ALO  SIXTY              FLOATING            413  1477  15 1200 1805
        SLO  TEMP1              POINT               414  1808  16 0917 1271
        RAU  8002                                   415  1271  60 8002 0929
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         FDV FP6                       416   0929   34 1450 1452
         FSB FP1                       417   1452   33 1250 1527
         STU ROWS                      418   1527   21 0082 1135
         RAU A                         419   1135   60 0000 1855
         FDV FP2                       420   1855   34 1300 1502
         FDV ROWS                      421   1502   34 0082 0832
         FMP FP8                       422   0832   39 1500 1552
         FDV FP9                       423   1552   34 1550 1608
         FMP INTEG                     424   1602   39 0906 1006
         STU INTEG  CONT7              425   1006   21 0906 1509
CONT7    RAL DATA                      426   1509   65 1357 1461
         DIV SIX                       427   1461   14 1050 1460
         STL INDEX           SET       428   1460   20 1365 1468
         2LT  0004           DATA      429   1468   35 0004 0979
         ALO INDA            ADDRESSES 430   0979   15 1800 1056
         LDD ATWO            FOR       431   1066   69 1559 1412
         SDA ATWO            TRAP RULE 432   1412   22 1559 1462
         LDD ATREE                     433   1462   69 1415 1518
         SDA ATREE                     434   1518   82 1415 1568
         RAL INDB                      435   1568   65 1850 1106
         LDD BONE                      436   1106   69 1609 1512
         WDA BONE                      437   1512   22 1609 1568
         LDD BTWO                      438   1562   69 1465 1618
         SDA BTWO                      439   1618   22 1465 1668
         RAU B                         440   1668   60 0001 1156
         FDV FP2                       441   1156   34 1300 1652
         FSB BPRIM                     442   1652   33 0008 1029
         FMP ROWS                      443   1029   39 0082 0888
         FDV FP4                       444   0882   34 1400 1702
         2TU FACTR                     445   1702   21 0096 0849
         LDD INDEX                     446   0849   69 1365 1718
         RAA  8001                     447   1718   80 8001 1324
         RAB  8001  ATWO               448   1324   82 8001 1559
ATWO     RAU  9999  BONE               449   1559   60 9999 1609
BONE     FAD  9999                     450   1609   32 9999 0975
         SXA  0001           CALCULATE 451   0975   51 0001 1181
         SXB  0001           TRAP RULE 452   1181   53 0001 0837
         NZA ATREE  CONT8    INTEGRAL  453   0837   40 1415 0791
ATREE    FAD  9999  BTWO               454   1415   32 9999 1465
BTWO     FAD  9999                     455   1465   32 9999 1025
         FMP FACTR                     456   1025   39 0096 0846
         FAD INTEG                     457   0846   32 0906 1183
         STU INTEG  ATWO               458   1183   21 0906 1559
CONT8    RAU INTEG                     459   0791   60 0906 1511
         FMP FP4                       460   1511   39 1400 1752
         STU INTEC                     461   1752   21 0906 1669
         RAU M                         462   1659   60 0856 1561
         FSB N                         463   1561   33 0675 1808
         NZE        CONT9              464   1802   45 1206 1407
         RAU INTEG                     465   1206   60 0906 1611
         FMP FP2                       466   1611   39 1300 1852
         STU INTEG  CONT9              467   1852   21 0906 1407
CONT9    AXC  0001                     468   1407   58 0001 1463
         LDD INTEC                     469   1463   69 0906 1709
         STD FMN    C                  470   1709   24 6770 0873
         LDD  8007           COUNT     471   0873   69 8007 1079
         STD TERMS           TERMS     472   1079   24 0932 1185
         RAU NARM                      473   1185   60 0003 1457
         FSB M                         474   1457   33 0856 1233
         NZE        CON10              475   1233   45 0936 0887
         RAU M                         476   0936   60 0856 1661
         FAD FP2             ADJUST    477   1661   32 1300 1577
         STU M      CONT1    M ANU N   478   1577   21 0856 0828
CON10    RAU HARM                      479   0887   60 0003 1507
         FSB N                         480   1507   33 0675 1453
         NZE        CON11              481   1453   45 1256 1557
         RAU N                         482   1256   60 0675 1129
         FAD FP2                       483   1129   32 1300 1627
         WTU M                         484   1627   21 0856 1759
         STU N      CONT1              485   1759   21 0675 0828
CON11    LDD FIRST                     486   1557   69 0004 1607
         STD GAM11                     487   1607   24 1510 1513
         STD GAMMA  CON23              488   1513   24 0730 1283
CON23    LDD FP1                       489   1283   69 1250 1503
         STD M                         490   1503   24 0856 1809
         STD N                         491   1809   24 0675 0878
         RAU PI                        492   0878   60 1350 1306
         FDV A                         493   1306   34 0000 1553
         FMP  8003                     494   1553   39 8003 1657
         STU ALPH2                     495   1657   21 1612 1515
         RAU PI                        496   1515   60 1350 1356
         FDV B                         497   1356   34 0001 1603
         FMP  8003                     498   1603   39 8003 1707
         STU BETA2                     499   1707   21 1662 1565
         RAU GAM11                     500   1565   60 1510 1615
         FMP  8003                     501   1615   39 8003 1369
         FSB ALPH2           CALCULATE 502   1369   33 1612 0889
         FSB BETA2           KAPPA     503   0889   33 1662 0939
         STU KAPSQ           SQUARED   504   0939   21 0044 1297
         RAC  0001                     505   1297   88 0001 1653
         LDD GAM11                     506   1653   69 1510 1563
         STD GAMMA  C                  507   1563   24 6730 1333
         AXC  0001                     508   1333   58 0001 0989
         RAU M                         509   0989   60 0856 1711
         FAD FP2    LOOPA              510   1711   32 1300 1677
LOOPA    FMP PI                        511   1677   39 1350 1703
         FDV A                         512   1703   34 0000 1753
         FMP  8003                     513   1753   39 8003 1757
         STU ALPN2                     514   1757   21 1612 1665
         RAU N                         515   1665   60 0675 1179
         FMP PI                        516   1179   39 1350 1803
         FDV B                         517   1803   34 0001 1853
         FMP  8003                     518   1853   39 8003 1807
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        FAD  KAPSQ                           519   1807   32 0044 1321
        FAD  ALPH2                           520   1321   32 1612 1039
        LDD            EOOAU  CALCULATE      521   1039   69 0942 1501
        STU  GAMMA   C        GAMMA MN       522   0942   21 6730 1383
        AXC   0001                           523   1383   58 0001 1089
        RAU  NARM                            524   1089   60 0003 1857
        FSB  M                               525   1857   33 0856 1433
        NZE            CON12                 526   1433   45 0986 0937
        RAU  M                               527   0986   60 0856 1761
        FAD  FP2                             528   1761   32 1300 1727
        STU  M         LOOPA                 529   1727   21 0856 1677
CON12   RAU  HARM                            530   0937   60 0003 1008
        FSB  N                               531   1008   33 0675 1504
        NZE            CON13                 532   1504   45 1058 1859
        RAU  N                               533   1058   60 0675 1229
        FAD  FP2                             534   1229   32 1300 1777
        STU  M                               535   1777   21 0856 1560
        STU  N         LOOPA                 536   1560   21 0675 1677
CON13   NZB  CON15                           537   1859   42 1712 1613
        LDD  TERMS                           538   1613   69 0932 1235
        RAC   8001     LOOPB                 539   1235   88 8001 0841
LOOPB   RSU  C                               540   0841   61 0007 1811
        FAD  ELEV                            541   1811   32 0908 1285
        FMP  GAMMA   C                       542   1285   39 6730 1130
        STU  ARG                             543   1130   21 0884 0987
        RAL  ARG                             544   0987   65 0884 1139
        LDD            EOOEA                 545   1139   69 0992 0051
        STL  TEMP1                           546   0992   20 0917 1120
        RAM  ARG                             547   1120   67 0884 1189
        LDD            EOOEA                 548   1189   69 1042 0051
        RAU   8002                           549   1048   60 8002 1554
        FSB  TEMP1                           550   1554   33 0917 0843
        FMP  A                               551   0843   39 0000 1604
        FMP  B                               552   1604   39 0001 1654
        STU  TEMP1                           553   1654   21 0917 1170
        RAU  FPB                             554   1170   60 1500 1406
        FMP  FMN     C                       555   1406   39 6770 1220
        FDV  TEMP1            CALCULATE      556   1220   34 0917 1117
        STU  AMN     C        AMN            557   1117   21 6750 1704
        SXC   0001                           558   1704   59 0001 1610
        NZC  LOOPB     CON14                 559   1610   48 0841 0864
CON14   RAC   0008                           560   0864   88 0008 1270
        LDD  LOOPC     EOOCL                 561   1270   69 0923 1151
LOOPC   LDD  AMN     C                       562   0923   69 6750 1754
        STD   1976   C                       563   1754   24 7976 1279
        SXC   0001                           564   1279   59 0001 1335
        NZC  LOOPC            PUNCN          565   1335   48 0923 1239
        PCH   1977            CONSTANTS      566   1239   71 1977 1827
        RAL  TERMS                           567   1827   65 0932 1037
        SLO  EIGHT                           568   1037   16 1100 1456
        BMI  CON1S                           569   1456   46 1712 1660
        LDD  TERMS                           570   1660   69 0932 1385
        RAC   8001     CON25                 571   1385   88 8001 0891
CON25   LDD  AMN     C                       572   0891   69 6750 1804
        STD   1968   C                       573   1804   24 7968 1371
        SXC   0009                           574   1371   59 0009 1877
        NZC  CON24                           575   1877   48 1180 1231
        PCN   1977     CON15                 576   1231   71 1977 1712
CON24   AXC   0008     CON25                 577   1180   58 0008 0891
CON15   LDD  POINT                           578   1712   69 0005 1108
        RAA   8001                           579   1108   80 8001 0914
        RAB   0001     LOOPD                 580   0914   82 0001 1320
LOOPD   LDD  TERMS                           581   1320   69 0932 1435
        RAC   8001                           582   1435   88 8001 0941
        LDD  ZERO                            583   0941   69 0050 1854
        STD  COFAC     LOOPE                 584   1854   24 1158 1861
LOOPE   RAU  GAM11                           585   1861   60 1510 1715
        FMP  Z       A                       586   1715   39 2650 1506
        STU  TEMP1                           587   1506   21 0917 1370
        RAU  C                               588   1370   60 0007 1762
        FSB  Z       A                       589   1762   33 2650 0928
        FMP  GAMMA   C                       590   0928   39 6730 1230
        FAD  TEMP1                           591   1230   32 0917 0893
        RAL   8003                           592   0893   65 8003 1556
        LDD            EOOEA                 593   1556   69 1710 0051
        RAU   8002                           594   1710   60 8002 1419
        FMP  AMN     C                       595   1419   39 6750 1606
        FDV  FP2                             596   1606   34 1300 1656
        STU  TEMP1                           597   1656   21 0917 1420
        RSU  C                               598   1420   61 0007 1812
        FAD  Z       A                       599   1812   32 2650 0978
        FMP  GAMMA   C                       600   0978   39 6730 1280
        FMP  FP2                             601   1280   39 1300 1706
        RAL   8003                           602   1706   65 8003 1663
        LDD            EOOEA                 603   1663   69 1166 0051
        RSU   8002                           604   1166   61 8002 1075
        FAD  FP1              CALCULATE      605   1075   32 1250 1028
        STU  ENDCO            END  AND       606   1028   21 0982 1485
        FMP  TEMP1            HARMONIC       607   1485   39 0917 1167
        FAD  COFAC            CORRECTION     608   1167   32 1158 1535
        STU  COFAC            FACTOR         609   1535   21 1158 1862
        SXC   0001                           610   1862   59 0001 1768
        NZC  LOOPE     CON16                 611   1768   48 1861 0922
CON16   RAU  N       A        CALCULATE      612   0922   60 2675 1329
        FDV  COFAC            CORRECTED      613   1329   34 1158 1208
        STU  NCOR    A        DATA           614   1208   21 2700 1756
        LDD            EOOCL                 615   1756   69 1760 1151
        LDD  Z       A                       616   1760   69 2650 1806
        STD   1977                           617   1806   24 1977 1330
        LDD  N       A                       618   1330   69 2675 1078
        STD   1978            PUNCH DATA     619   1078   24 1978 1281
        LDD  NCOR    A        AND            620   1281   69 2700 1856
        STD   1979            CORRECTION     621   1856   24 1979 1032
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          L88  C8FAC                       FACTOR        622   1032   69  1158  1713
          8TO   1980                                     623   1713   24  1980  1483
          L88  EN8C8                                     624   1483   69  0988  1585
          8T8   1981                                     625   1585   24  1981  0934
          PCN   1977                                     626   8934   71  1977  1128
          8XA   0801                                     627   1128   51  0881  0984
          NZA  L8OP8       C8N17                         628   0984   40  1320  0888
CON17     L08  POINT                                     629   0888   69  8085  1258
          RAA   8001                                     638   1258   88  8001  0964
          L88  ZER8                                      631   0964   69  0050  1308
          8T8  8UMA                                      632   1308   24  1763  1216
          WT8  8MLNA                                     633   1216   84  1469  0972
          8T8  8UMZ                                      634   0972   24  1125  1178
          8T8  8UMZ8                                     635   1178   24  1331  1034
          8TO  Z8MLA       L08PF                         636   1034   24  1087  0840
L08PF     WAU  NCOR    A                                 637   0840   68  2708  1358
          FA8  WUMA                                      638   1358   32  1763  1289
          8TU  8UMA                                      639   1889   81  1763  1266
          RAU  NC8R    A                                 640   1266   60  2700  1488
          L08              LNX01                         641   1408   69  1813  1601
          FA8  8MLNA                                     642   1813   32  1469  1045
          8TU  8MLNA                                     643   1045   21  1469  1822
          WAU  Z       A               FORM 8UM8         644   1028   68  2658  1458
          FA8  8UMZ                    FOR LEA8T         645   1458   32  1125  1588
          8TU  8UMZ                    8OUARE8           646   1508   21  1125  1228
          RAU  Z       A               ANALY818          647   1228   68  2658  1558
          FMP  Z       A                                 648   1558   39  2650  1608
          FAD  8UMZ2                                     649   1688   32  1331  1658
          8TU  8UMZ8                                     650   1658   21  1331  1084
          RAU  NC8R    A                                 651   1084   60  2700  1788
          L88              LNX01                         658   1708   69  1863  1681
          FMP  Z       A                                 653   1863   39  2650  1758
          FAD  Z8MLA                                     654   1758   32  1087  1814
          8TU  Z8MLA                                     655   1814   21  1887  0890
          8XA   0001                                     656   0890   51  8881  0896
          NZA  L88PF       CON1H                         657   0896   40  0840  1888
C8N18     RAU  8MLNA                                     658   1888   68  1469  8973
          FMP  8UMZ                                      659   0973   39  1128  1175
          8TU  TEMP1                                     660   1175   21  0917  1478
          WAU  8ATPT                                     661   1478   60  0086  1864
          FMP  Z8MLA                                     662   1064   39  1087  1137
          8TU  TEMP2                                     663   1137   21  1098  1095
          RAU  OATPT                                     664   1095   60  0006  1114
          FMP  8UMZ2                                     665   1114   39  1331  1381
          8TU  TEMP3                                     666   1381   21  1036  1339
          RAU  8UMZ                                      667   1339   60  1125  1379
          FMP  8UMZ                                      668   1379   39  1125  1225
          8TU  TEMP4                                     669   1225   21  1388  1533
          RAU  TEMP3                                     678   1533   68  1036  0991
          F88  TEMP4                                     671   8991   33  1388  1858
          8TU  TEMP3                                     672   1858   21  1036  1389
          RAU  TEMP1                                     673   1389   60  8917  1421
          F88  TEMP2                                     674   1421   33  1092  1519
          F8V  TEMP3                                     675   1519   34  1836  1086
          8TU  NWCAM                                     676   1886   21  0940  8943
          FOV  10000                                     677   8943   34  1700  1810
          8TU  PREC                                      678   1810   21  1164  1217
          RAU  CAM11                                     679   1217   60  1510  1765
          F88  NWCAM                                     680   1765   33  0940  1267
          RAM   8003                                     681   1267   67  8883  1275
          RAU   8082                                     682   1275   60  8082  1583
          F88  PREC                                      683   1583   33  1164  1841
          8MI  C8N20       C8N19                         684   1041   46  0094  1145
CON19     RAU  NWCAM                                     685   1145   60  0940  1195
          WTU  CAM11       CON23                         686   1195   21  1510  1283
C8N28     WAU  NWCAM                                     687   0894   68  0940  1245
          FMP  NWCAM                   CAMMA             688   1245   39  0940  0998
          8TU  CAM80                   8OUARE8           689   0990   21  0794  1347
          WAU  PI                                        690   1347   60  1350  1860
          FOV  A                                         691   1860   34  0080  1214
          FMP   8003                   ALPHA             692   1214   39  8003  1317
          8TU  ALPN2                   8OUARE8           693   1317   21  1612  1815
          RAU  PI                                        694   1815   60  1350  1264
          F8V  8                                         695   1864   34  0001  1314
          FMP   8003                   8ETA              696   1314   39  8003  1367
          WTU  8ETA2                   WOUARED           697   1367   21  1662  1865
          RAU  CAM80                                     698   1865   60  0794  0899
          F88  ALPN2                   KAPPA             699   0899   33  1612  1439
          F88  8ETA2                   8OUARE0           700   1439   33  1662  1489
          L80              E00AU                         701   1489   69  1142  1501
          8TU  KAPPA                                     702   1148   21  0946  0949
          RAU  FP1                                       783   0949   60  1250  1364
          FOV  KAPPA                                     704   1364   34  0946  0996
          FMP  CONVT                   8IFFU8I8N         785   0996   39  1650  1414
          8TU  OL                      LENGTH            706   1414   21  1818  1471
          RA8   0000                                     707   1471   82  0000  1278
          L08              E08CL                         708   1278   69  1431  1151
          L08  FIR8T                                     789   1431   69  0004  1464
          8TO   1977                                     710   1464   84  1977  1430
          L08  GAM11                                     711   1430   69  1510  1514
          8TO   1978                                     712   1514   24  1978  1481
          LOD  NWGAM-                                    713   1481   69  0940  0993
          8T8   1979                                     714   0993   24  1979  1082
          L08  POINT                                     715   1082   69  0005  1564
          8T8   1980                                     716   1564   24  1980  1633
          L8D  OL                                        717   1633   69  1818  1521
          8TO   1981                                     718   1521   24  1981  1134
          PCH   1977       C8N21                         719   1134   71  1977  1328
CON21     WAU  NWGAM                                     720   1328   80  0948  1295
          F8V  10000                                     721   1295   34  1780  1614
          8TU  PREC                                      722   1614   21  1164  1417
          RAU  CAMMA                                     783   1417   60  0730  1635
          F88  NWCAM                                     784   1635   33  0940  1467
```

```
           RAM  8003                     725   1467   67 8003 1325
           RAU  8002                     726   1325   60 8002 1683
           FSB PREC                      727   1683   33 1164 1091
           BMI  8000    CON22            728   1091   46 8000 1345
CON22      LDD NWGAM                     729   1345   69 0940 1043
           STD GAM11                     730   1043   24 1510 1664
           STD GAMMA    CON23            731   1664   24 0730 1283
```

APPENDIX G

IBM 650 Program for Experimental Determination of Effective Pile Size

This program was written to determine the effective pile size by an experimental analysis of data taken in a horizontal traverse. The program was written in SOAP II and floating point form. The object program and a logic diagram are included in this section.

The program is based upon the equation

$$\phi(x) = \sum_{m=1}^{\infty} A_m \cos \frac{m\pi x}{a} \qquad \text{(G-1)}$$

and proceeds as follows:

1. Using an assumed initial value for the effective pile size, a, the constants A_m are evaluated using a least squares analysis.

2. The least squares error is calculated using the equation

$$E^2 = \sum_{i=1}^{N} \left[A_1 \cos \frac{\pi x_i}{a} + A_3 \cos \frac{3\pi x_i}{a} + \cdots - N_i\right]^2.$$

3. The value of a is increased by an increment Δa and a new set of A_m's is calculated.

4. A new E^2 is calculated and compared with the old E^2. If E^2 is found to be decreasing, a is increased again by Δa.

5. If E^2 is increasing, a is decreased by Δa and Δa is divided by two. This process is repeated until Δa is less than a specified precision. The last value of a is then the desired value of extrapolated pile size.

The criterion for determination of a is that E^2, described above, should be minimized. Input to this program is entirely on one-word load cards and is listed in Table 29.

Table 29. Input to IBM 650 code for determination of effective size.

Symbol	Explanation	Drum Storage Location
AINIT	Initial value of a	1000
DELA	Increment Δa	1001
INDXA	Number of Data Points form - 00 0000 00xx	1002
ENN	Number of Harmonics form - 00 0000 000x (2, 3, 4, or 5)	1003
N	BF_3 Count Rates - to be stored consecutively starting with location	0301
X	Co-ordinates of count rates, to be stored consecutively in location	0201

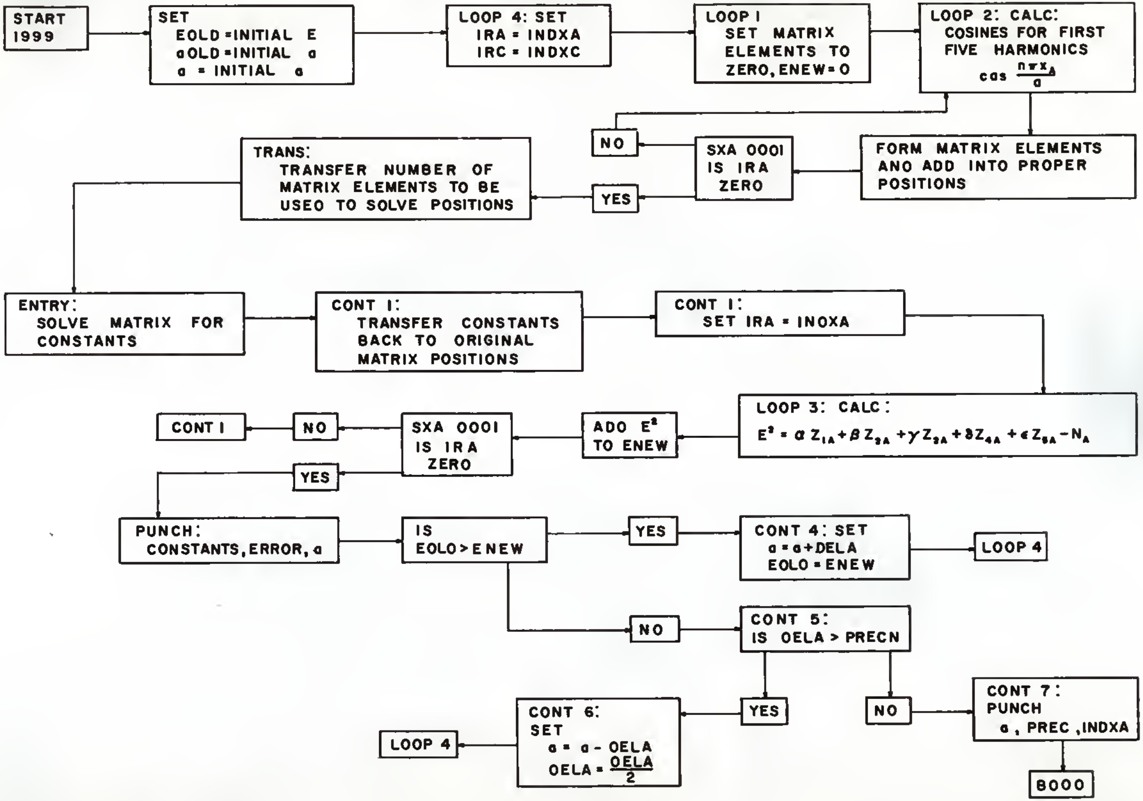
The capacity of this program is 100 data points. It will perform the analysis using from two to five terms of Eq. (G-1). Output forms for this program are listed in Table 30. Form one is punched after each trial and form two is the final output.

Table 30. Output forms for IBM 650 program for effective pile size.

Word 1	2	3	4	5	6	7
Form 1:						
A_1	A_3	A_5	A_7	A_9	E^2	a
Form 2:						
a	Precision	Number of Data Points				

The initial estimate of a should always be less than the final answer or the program will not converge. Therefore, the actual size is recommended as an initial estimate since this will always be less than the extrapolated size. Approximately 45 seconds is required for one trial using nine data points.

LOGIC DIAGRAM FOR IBM 650 PROGRAM FOR EFFECTIVE PILE SIZE



LOGIC DIAGRAM, APPENDIX G

```
         BLR  0000   0030            1   0000   00 0000 0000
         BLR  0101   0131            2   0000   00 0000 0000
         BLR  0200   0900            3   0000   00 0000 0000
         BLR  1951   1960            4   0000   00 0000 0000
         BLR  1977   1985            5   0000   00 0000 0000
         SYN  Y11    0101            6   0000   00 0000 0000
         SYN  Y12    0102            7   0000   00 0000 0000
         SYN  Y13    0103            8   0000   00 0000 0000
         SYN  Y14    0104            9   0000   00 0000 0000
         SYN  Y15    0105           10   0000   00 0000 0000
         SYN  Y21    0106           11   0000   00 0000 0000
         SYN  Y22    0107           12   0000   00 0000 0000
         SYN  Y23    0108           13   0000   00 0000 0000
         SYN  Y24    0109           14   0000   00 0000 0000
         SYN  Y25    0110           15   0000   00 0000 0000
         SYN  Y31    0111           16   0000   00 0000 0000
         SYN  Y32    0112           17   0000   00 0000 0000
         SYN  Y33    0113           18   0000   00 0000 0000
         SYN  Y34    0114           19   0000   00 0000 0000
         SYN  Y35    0115           20   0000   00 0000 0000
         SYN  Y41    0116           21   0000   00 0000 0000
         SYN  Y42    0117           22   0000   00 0000 0000
         SYN  Y43    0118           23   0000   00 0000 0000
         SYN  Y44    0119           24   0000   00 0000 0000
         SYN  Y45    0120           25   0000   00 0000 0000
         SYN  Y51    0121           26   0000   00 0000 0000
         SYN  Y52    0122           27   0000   00 0000 0000
         SYN  Y53    0123           28   0000   00 0000 0000
         SYN  Y54    0124           29   0000   00 0000 0000
         SYN  Y55    0125           30   0000   00 0000 0000
         SYN  Z1     0126           31   0000   00 0000 0000
         SYN  Z2     0127           32   0000   00 0000 0000
         SYN  Z3     0128           33   0000   00 0000 0000
         SYN  Z4     0129           34   0000   00 0000 0000
         SYN  Z5     0130           35   0000   00 0000 0000
         SYN  ALPHA  0400           36   0000   00 0000 0000
         SYN  BETA   0500           37   0000   00 0000 0000
         SYN  GAMMA  0600           38   0000   00 0000 0000
         SYN  DELTA  0700           39   0000   00 0000 0000
         SYN  EPSIL  0800           40   0000   00 0000 0000
         SYN  N      0300           41   0000   00 0000 0000
         SYN  X      0200           42   0000   00 0000 0000
         SYN  AINIT  1000           43   0000   00 0000 0000
         SYN  DELA   1001           44   0000   00 0000 0000
         SYN  INDXA  1002           45   0000   00 0000 0000
         SYN  ENN    1003           46   0000   00 0000 0000
         SYN  START  1999           47   0000   00 0000 0000
ZERO      00  0000   0000           48   0050   00 0000 0000
TWO       20  0000   0051           49   0100   20 0000 0051
THREE     30  0000   0051           50   0150   30 0000 0051
PI        31  4159   0051           51   0950   31 4159 0051
FIVE      50  0000   0051           52   1050   50 0000 0051
SEVEN     70  0000   0051           53   1100   70 0000 0051
NINE      90  0000   0052           54   1150   90 0000 0052
FINIT     10  0000   0075           55   1200   10 0000 0075
PREC      10  0000   0048           56   1250   10 0000 0048
INDXC     00  0000   0030           57   1300   00 0000 0030
EQUCH    STD  EXIT                  58   1350   24 0053 0056
         RAU  8002                  59   0056   60 8002 0065
         BMI  NEGAT  REDUC          60   0065   46 0068 0069
NEGAT    FAD  TWOPI                 61   0068   32 0071 0047
         BMI  NEGAT                 62   0047   46 0068 0051
         FSB  ONEPI  COSIO          63   0051   33 0154 0031
REDUC    FSB  TWOPI                 64   0069   33 0071 0097
         BMI         REDUC          65   0097   46 1400 0069
         FAD  ONEPI  COSIO          66   1400   32 0154 0031
COSIO    STU  THETA                 67   0031   21 0036 0039
         RSU  FPONE                 68   0039   61 0042 0147
         STU  TERMM                 69   0147   21 0052 0055
         STU  FUNKT                 70   0055   21 0060 0063
         STL  ENNN   NEGST          71   0063   20 0067 0070
EQUSR    STD  EXIT                  72   1450   24 0053 0156
         RAU  8002                  73   0156   60 8002 0165
         BMI  NEGAV  REDUD          74   0165   46 0168 0169
NEGAV    FAD  TWOPI                 75   0168   32 0071 0197
         BMI  NEGAV                 76   0197   46 0168 0151
         FSB  ONEPI  SINET          77   0151   33 0154 0081
REDUD    FSB  TWOPI                 78   0169   33 0071 0947
         BMI         REDUD          79   0947   46 1500 0169
         FAD  ONEPI  SINET          80   1500   32 0154 0081
SINET    STU  THETA                 81   0081   21 0036 0089
         RSU  8003                  82   0089   61 8003 0997
         STU  TERMM                 83   0997   21 0052 0155
         STU  FUNKT                 84   0155   21 0060 0163
         LDD  FPONE                 85   0163   69 0042 0045
         STD  ENNN   NEGST          86   0045   24 0067 0070
NEGST    RAU  ENNN                  87   0070   60 0067 0171
         FAD  FPONE                 88   0171   32 0042 0919
         STU  NPONE                 89   0919   21 0074 0077
         FAD  FPONE                 90   0077   32 0042 0969
         STU  ENNN                  91   0969   21 0067 0170
         RSU  TERMM                 92   0170   61 0052 0057
         FMP  THETA                 93   0057   39 0036 0086
         FMP  THETA                 94   0086   39 0036 0136
         FDV  NPONE                 95   0136   34 0074 0174
         FDV  ENNN                  96   0174   34 0067 0167
         STU  TERMM                 97   0167   21 0052 0905
         RAM  FUNKT                 98   0905   67 0060 0915
         STL  FMAG                  99   0915   20 1019 0072
         RAM  TERMM                100   0072   67 0052 0157
         RAU  8002                 101   0157   60 8002 0965
         FDV  FMAG                 102   0965   34 1019 1069
```

```
        FSB  SIZEB                               103    1069    33 0172 0049
        BMI  ENUFF                               104    0049    46 0152 0153
        RAU  FUNKT                               105    0153    60 0060 1015
        FAD  TERMM                               106    1015    32 0052 0079
        STU  FUNKT     NEGST                     107    0079    21 0060 0070
ENUFF   RAL  FUNKT     EXIT                      108    0152    65 0060 0053
SIZEB    10   0000      0043                     109    0172    10 0000 0043
TWOPI    62   8318      5351                     110    0071    62 8318 5351
ONEPI    31   4159      2751                     111    0154    31 4159 2751
FPONE    10   0000      0051                     112    0042    10 0000 0051
EQUCL   STD  ZZZ1                                113    1550    24 0903 0906
        LDD  ZZZ10                               114    0906    69 0059 0062
        STD   1977                               115    0062    24 1977 0080
        STD   1978                               116    0080    24 1978 0181
        STD   1979                               117    0181    24 1979 0032
        STD   1980                               118    0032    24 1980 0033
        STD   1981                               119    0033    24 1981 0034
        STD   1982                               120    0034    24 1982 0035
        STD   1983                               121    0035    24 1983 0186
        STD   1984     ZZZ1                      122    0186    24 1984 0903
ZZZ10    00   0000      0000                     123    0059    00 0000 0000
START   LDD  AINIT               SET UP          124    1999    69 1000 0953
        STD  AOLD                INITIAL         125    0953    24 0956 0159
        LDD  EINIT               CONDITION       126    0159    69 1200 1053
        STD  EOLD                                127    1053    24 1006 0909
        LDD  AINIT                               128    0909    69 1000 1103
        STD  A         LOOP4                     129    1103    24 1056 0959
LOOP4   LDD  INDXA               SET             130    0959    69 1002 0955
        RAA   8001               INDEX           131    0955    80 8001 0061
        LDD  INDXC               REGISTERS       132    0061    69 1300 1153
        RAC   8001                               133    1153    88 8001 1009
        LDD  ZERO      LOOP1                     134    1009    69 0050 1203
LOOP1   STD   0100 C             CLEAR           135    1203    24 6100 1253
        STD   0000 C             ALL             136    1253    24 6000 1303
        SXC   0001               MATRIX          137    1303    59 0001 1059
        NZC  LOOP1     CONTB     ELEMENTS        138    1059    48 1203 0913
CONTB   STD  ENEW      LOOP2                     139    0913    24 0066 1119
LOOP2   RAU  PI                  FORM            140    1119    60 0950 1005
        FMP  X     A             COSINE          141    1005    39 2200 1600
        FDV  A                   TERMS           142    1600    34 1056 1106
        STU  TEMP1               1               143    1106    21 0160 0963
        FMP  THREE                               144    0963    39 0150 1650
        STU  TEMP2               3               145    1650    21 0904 0907
        RAU  TEMP1                               146    0907    60 0160 1065
        FMP  FIVE                                147    1065    39 1050 1700
        STU  TEMP3               5               148    1700    21 0954 0957
        RAU  TEMP1                               149    0957    60 0160 1115
        FMP  SEVEN                               150    1115    39 1100 1750
        STU  TEMP4               7               151    1750    21 1004 1007
        RAU  TEMP1                               152    1007    60 0160 1165
        FMP  NINE                                153    1165    39 1150 1800
        STU  TEMP5               9               154    1800    21 1054 1057
        RAL  TEMP1                               155    1057    65 0160 1215
        LDD            EQUCH                     156    1215    69 0918 1350
        STL  ALPHA A             1               157    0918    20 2400 1353
        RAL  TEMP2                               158    1353    65 0904 1109
        LDD            EQUCH                     159    1109    69 0162 1350
        STL  BETA  A             3               160    0162    20 2500 1403
        RAL  TEMP3                               161    1403    65 0954 1159
        LDD            EQUCR                     162    1159    69 0912 1350
        STL  GAMMA A             5               163    0912    20 2600 1453
        RAL  TEMP4                               164    1453    65 1004 1209
        LDD            EQUCR                     165    1209    69 0962 1350
        STL  DELTA A             7               166    0962    20 2700 1503
        RAL  TEMP5                               167    1503    65 1054 1259
        LDD            EQUCH                     168    1259    69 1012 1350
        STL  EPSIL A             9               169    1012    20 2800 1553
        RAU  ALPHA A             FORM            170    1553    60 2400 1055
        FMP  ALPHA A             MATRIX          171    1055    39 2400 1850
        FAD  Y11                 ELEMENTS        172    1050    32 0101 0177
        STU  Y11                 11              173    0177    21 0101 1104
        RAU  ALPHA A                             174    1104    60 2400 1105
        FMP  BETA  A                             175    1105    39 2500 1900
        FAD  Y12                                 176    1900    32 0102 0179
        STU  Y12                 12              177    0179    21 0102 1155
        STU  Y21                 21              178    1155    21 0106 1309
        RAU  ALPHA A                             179    1309    60 2400 1205
        FMP  GAMMA A                             180    1205    39 2600 1950
        FAD  Y13                                 181    1950    32 0103 0929
        STU  Y13                 13              182    0929    21 0103 1156
        STU  Y31                 31              183    1156    21 0111 0064
        RAU  ALPHA A                             184    0064    60 2400 1255
        FMP  DELTA A                             185    1255    39 2700 0901
        FAD  Y14                                 186    0901    32 0104 0931
        STU  Y14                 14              187    0931    21 0104 1107
        STU  Y41                 41              188    1107    21 0116 1169
        RAU  ALPHA A                             189    1169    60 2400 1305
        FMP  EPSIL A                             190    1305    39 2800 0951
        FAD  Y15                                 191    0951    32 0105 0981
        STU  Y15                 15              192    0981    21 0105 0058
        STU  Y51                 51              193    0058    21 0121 0924
        RAU  BETA  A                             194    0924    60 2500 1355
        FMP  BETA  A                             195    1355    39 2500 1051
        FAD  Y22                                 196    1051    32 0107 0083
        STU  Y22                 22              197    0083    21 0107 0910
        RAU  BETA  A                             198    0910    60 2500 1405
        FMP  GAMMA A                             199    1405    39 2600 1101
        FAD  Y23                                 200    1101    32 0108 0085
        STU  Y23                 23              201    0085    21 0108 0161
        STU  Y32                 32              202    0161    21 0112 1265
        RAU  BETA  A                             203    1265    60 2500 1455
        FMP  DELTA A                             204    1455    39 2700 1151
        FAD  Y24                                 205    1151    32 0109 0135
```

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          STU  Y24                    24     206  0135  21 0109 1062
          STU  Y42                    42     207  1062  21 0117 0920
          RAU  BETA   A                      208  0920  60 2500 1505
          FMP  EPSIL  A                      209  1505  39 2800 1201
          FAD  Y25                           210  1201  32 0110 0037
          STU  Y25                    25     211  0037  21 0110 1013
          STU  Y52                    52     212  1013  21 0122 0075
          RAU  GAMMA  A                      213  0075  60 2600 1555
          FMP  GAMMA  A                      214  1555  39 2600 1251
          FAD  Y33                           215  1251  32 0113 0139
          STU  Y33                    33     216  0139  21 0113 0166
          RAU  GAMMA  A                      217  0166  60 2600 1605
          FMP  DELTA  A                      218  1605  39 2700 1301
          FAD  Y34                           219  1301  32 0114 0041
          STU  Y34                    34     220  0041  21 0114 0917
          STU  Y43                    43     221  0917  21 0118 0921
          RAU  GAMMA  A                      222  0921  60 2600 1655
          FMP  EPSIL  A                      223  1655  39 2800 1351
          FAD  Y35                           224  1351  32 0115 0091
          STU  Y35                    35     225  0091  21 0115 0968
          STU  Y53                    53     226  0968  21 0123 0076
          RAU  DELTA  A                      227  0076  60 2700 1705
          FMP  DELTA  A                      228  1705  39 2700 1401
          FAD  Y44                           229  1401  32 0119 0095
          STU  Y44                    44     230  0095  21 0119 0922
          RAU  DELTA  A                      231  0922  60 2700 1755
          FMP  EPSIL  A                      232  1755  39 2800 1451
          FAD  Y45                           233  1451  32 0120 1047
          STU  Y45                    45     234  1047  21 0120 0073
          STU  Y54                    54     235  0073  21 0124 0927
          RAU  EPSIL  A                      236  0927  60 2800 1805
          FMP  EPSIL  A                      237  1805  39 2800 1501
          FAD  Y55                           238  1501  32 0125 1551
          STU  Y55                    55     239  1551  21 0125 0078
          RAU  ALPHA  A                      240  0078  60 2400 1855
          FMP  N      A                      241  1855  39 2300 1601
          FAD  Z1                            242  1601  32 0126 1603
          STU  Z1                     Z1     243  1603  21 0126 0979
          RAU  BETA   A                      244  0979  60 2500 1905
          FMP  N      A                      245  1905  39 2300 1651
          FAD  Z2                            246  1651  32 0127 1653
          STU  Z2                     Z2     247  1653  21 0127 0180
          RAU  GAMMA  A                      248  0180  60 2600 1206
          FMP  N      A                      249  1206  39 2300 1701
          FAD  Z3                            250  1701  32 0128 1256
          STU  Z3                     Z3     251  1256  21 0128 1031
          RAU  DELTA  A                      252  1031  60 2700 1306
          FMP  N      A                      253  1306  39 2300 1751
          FAD  Z4                            254  1751  32 0129 1356
          STU  Z4                     Z4     255  1356  21 0129 0082
          RAU  EPSIL  A                      256  0082  60 2800 1406
          FMP  N      A                      257  1406  39 2300 1801
          FAD  Z5                            258  1001  32 0130 1157
          STU  Z5                     Z5     259  1157  21 0130 0133
          SXA   0001                         260  0133  51 0001 0189
          NZA  LOOP2     TRANS               261  0189  40 1119 0043
TRANS     RAA   0001                         262  0043  80 0001 0099
          RAB   0001                         263  0099  82 0001 1456
          RAC   0001                         264  1456  88 0001 1112
          LDD  ENN                           265  1112  69 1003 1506
          STD  ENNO      LOOPX               266  1506  24 1359 1162
LOOPX     LDD   0100  A                      267  1162  69 2100 1703
          STD   0000  C                      268  1703  24 6000 1753
          LDD  ENNO                          269  1753  69 1359 1212
          SXC   8001                         270  1212  59 8001 1018
          NZC            CONTY               271  1018  48 0971 0972
          AXC   8001                         272  0971  58 8001 0977
          AXA   0001                         273  0977  50 0001 0183
          AXC   0001     LOOPX               274  0183  58 0001 1162
CONTY     AXC   8001                         275  0972  58 8001 0178
          RAU   8001                         276  0178  60 8001 0185
          SUP  ENN                           277  0185  11 1003 1207
          NZU            BFC2                278  1207  44 0911 1262
          SUP  ENN                           279  0911  11 1003 1257
          NZU            BFC3                280  1257  44 0961 1312
          SUP  ENN                           281  0961  11 1003 1307
          NZU            BFC4                282  1307  44 1011 1362
          SUP  ENN                           283  1011  11 1003 1357
          NZU  COLZ      BFC5                284  1357  44 1061 1412
BFC2      LDD  ENN                           285  1262  69 1003 1556
          SXB   8001                         286  1556  53 8001 1462
          NZB            COLZ                287  1462  42 1315 1061
          AXB   8001                         288  1315  52 8001 1021
          AXB   0001                         289  1021  52 0001 1027
          RAA   0006                         290  1027  80 0006 0933
          LDD  ENN                           291  0933  69 1003 1606
          RAC   8001                         292  1606  88 8001 1512
          AXC   0001                         293  1512  58 0001 1068
          RAU  ENN                           294  1068  60 1003 1407
          AUP  ENN                           295  1407  10 1003 1457
          STU  ENNO      LOOPX               296  1457  21 1359 1162
BFC3      LDD  ENN                           297  1312  69 1003 1656
          SXB   8001                         298  1656  53 8001 1562
          NZB            COLZ                299  1562  42 1365 1061
          AXB   8001                         300  1365  52 8001 1071
          AXB   0001                         301  1071  52 0001 1077
          RAA   0011                         302  1077  80 0011 0983
          LDD  ENNO                          303  0983  69 1359 1612
          RAC   8001                         304  1612  88 8001 1118
          AXC   0001                         305  1118  58 0001 0974
          RAU  ENNO                          306  0974  60 1359 1063
          AUP  ENN                           307  1063  10 1003 1507
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          SXB   8001                                     310   1706   53 8001 1662
          NZB          COLZ                              311   1662   42 1415 1061
          AXB   8001                                     312   1415   62 8001 1121
          AXB   0001                                     313   1121   52 0001 1127
          RAA   0016                                     314   1127   80 0016 1033
          LOU ENNO                                       315   1033   69 1359 1712
          RAC   8001                                     316   1712   88 8001 1168
          AXC   0001                                     317   1168   58 0U01 1024
          RAU ENNO                                       318   1024   60 1359 1113
          AUP ENN                                        319   1113   10 1003 1557
          STU ENNO     LOOPX                             320   1557   21 1359 1168
SFC5      LOO ENN                                        321   1412   69 1003 1756
          SXB   8001                                     322   1756   53 8001 1762
          NZB          COLZ                              323   1762   42 1465 1061
          RAA   0021                                     324   1465   80 0021 1171
          LUU ENNO                                       325   1171   69 1359 1812
          RAC   8001                                     326   1818   88 8001 1218
          AXC   0001                                     327   1218   88 0001 1074
          RAU ENNO                                       328   1074   60 1359 1163
          AUP ENN                                        329   1163   10 1003 1607
          STU ENNO     LOOPX                             330   1607   81 1359 1162
COLZ      LOD ENNO                                       331   1061   69 1359 1862
          RAC   8001                                     332   1862   88 8001 1268
          AXC   0U01                                     333   1268   58 0001 1124
          RAA   0001   LUOPZ                             334   1124   80 0001 0930
LOUPZ     LOD   0125 A                                   335   0930   69 2185 0928
          STO   0000 C                                   336   0928   24 6000 1803
          LOO ENN                                        337   1803   89 1003 1806
          SXA   8001                                     338   1806   51 8001 1912
          NZA          CONT1                             339   1912   40 1515 0916
          AXA   8001                                     340   1515   50 8001 1221
          AXA   0001                                     341   1221   50 0001 1177
          AXC   0001   LOOPZ                             342   1177   58 0001 0930
CONT1     LOO          ENTHY                             343   0916   69 1219 1022
          RAU ENN                                        344   1219   60 1003 1657
          MPY ENN                                        345   1657   19 1003 1174
          ALO UNITY                                      346   1174   15 1227 1081
          STL ENN2                                       347   1081   20 0935 0038
          RAA   0001                                     348   0038   80 0001 0044
          LOD ENN2                                       349   0044   69 0935 0088
          RAC   8001   LOOPY                             350   0088   88 8001 0094
LOOPY     LDO   0000 C                                   351   0094   69 6000 1853
          STO   0125 A                                   352   1853   24 2125 0978
          SXA   0005                                     353   0978   51 0005 0084
          NZA          CON1                              354   0084   40 0087 0138
          AXA   0006                                     355   0087   50 0006 0093
          AXC   0001   LOOPY                             356   0093   58 0001 0094
CON1      LDD INDXA                                      357   0138   69 1002 1856
          RAA   8001   LOOP3                             358   1856   80 8001 1962
LOOP3     RAU Z1                 CALCULATE               359   1962   60 0126 1131
          FMP ALPHA  A           ERROR                   360   1131   39 2400 1851
          STU TEMP1              SQUAREU                 361   1851   21 0160 1213
          RAU Z2                                         362   1213   60 0127 1181
          FMP HETA   A                                   363   1181   39 2500 1901
          STU TEMP2                                      364   1901   21 0904 1707
          RAU Z3                                         365   1707   60 0128 1083
          FMP GAMMA  A                                   366   1083   39 2600 0902
          STU TEMP3                                      367   0902   21 0954 1757
          RAU Z4                                         368   1757   60 0129 1133
          FMP DELTA  A                                   369   1133   39 2700 0952
          STU TEMP4                                      370   0952   21 1004 1807
          HAU Z5                                         371   1807   60 0130 0985
          FMP EPSIL  A                                   372   0985   39 2800 1052
          FAD TEMP1                                      373   1052   32 0160 0137
          FAD TEMP2                                      374   0137   32 0904 1231
          FAU TEMP3                                      375   1231   32 0954 1281
          FAD TEMP4                                      376   1281   32 1004 1331
          FSB N      A                                   377   1331   33 2300 1277
          STU TEMP1                                      378   1277   21 0160 1263
          FMP TEMP1                                      379   1263   39 0160 0960
          FAD ENEW                                       380   0960   32 0066 0143
          STU ENEW                                       381   0143   21 0066 1269
          SXA   0001                                     382   1269   51 0001 0175
          NZA LOOP3   CONT3                              383   0175   40 1962 1029
CONT3     LOO         EUOCL                              384   1029   69 0132 1550
          LOO Z1                                         385   0132   69 0186 1079
          STO   1977                                     386   1079   24 1977 0980
          LOO Z2                                         387   0980   69 0127 1030
          STO   1978                                     388   1030   24 1978 1381
          LOO Z3                                         389   1381   69 0128 1431
          STO   1979                                     390   1431   24 1979 0182
          LOO Z4                                         391   0182   69 0129 0932
          STO   1980                                     392   0932   24 1980 1183
          LOO Z5                                         393   1183   69 0130 1233
          STO   1981                                     394   1233   24 1981 0134
          LOU ENEW                                       395   0134   89 0086 1319
          STU   1982                                     396   1319   24 1982 1035
          LOO A                                          397   1035   69 1056 1409
          STO   1983                                     398   1409   24 1983 0938
          PCN   1977                                     399   0938   71 1977 1327
          RAU EOLO                                       400   1327   60 1006 1111
          FSB ENEW                                       401   1111   33 0066 0193
          BMI CONT5   CONT4                              402   0193   46 0046 1097
CONT4     RAU A                                          403   1097   80 1056 1161
          FAD DELA                                       404   1161   32 1001 1377
          STU A                                          405   1377   21 1056 1459
          LOO ENEW                                       406   1459   89 0086 1369
          STO EOLO                                       407   1369   24 1006 1509
          LOO ZERO                                       408   1509   69 0050 1903
          STO ENEW    LOOP4                              409   1903   24 0086 0959
CONT5     RAU DELA                                       410   0046   60 1001 1906
          FSB PREC                                       411   1906   33 1250 1427
          BMI CONT7   CONT6                              412   1427   48 1080 1481
CONT6     RAU DELA                                       413   1481   60 1001 1857
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          FDV  TWO                        414     1857     34 0100 1102
          STU  DELA                       415     1102     21 1001 1154
          RAU  A                          416     1154     60 1056 1211
          FSB  DELA                       417     1211     33 1001 1477
          STU  A              LOOP4       418     1477     21 1056 0955
CONT7     LDD                 E00CL       419     1080     69 1283 1550
          LDD  A                          420     1283     69 1056 1559
          STD   1977                      421     1559     24 1977 1130
          LDD  PREC                       422     1130     69 1250 1204
          STD   1978                      423     1204     24 1978 1531
          LDD  INDXA                      424     1531     69 1002 1907
          STD   1979                      425     1907     24 1979 0982
          PCH   1977           8000       426     0982     71 1977 8000
ENTRY     STD  EXIT                       427     1028     24 0053 0158
          RAU  ENN                        428     0158     60 1003 0908
          SUP  UNITY                      429     0908     11 1227 1581
          STU  UNLES                      430     1581     21 0986 0939
          RAU  ENN                        431     0939     60 1003 0958
          AUP  UNITY                      432     0958     10 1227 1631
          STU  ENPLU                      433     1631     21 1036 0989
          MPY  ENN                        434     0989     19 1003 1224
          STL  NSPEN                      435     1224     20 1129 1032
          SLT   0004                      436     1032     35 0004 0943
          ALO  INDA                       437     0943     15 0096 1152
          LDD  AONE                       438     1152     69 1008 1261
          SDA  AONE                       439     1261     22 1008 1311
          LDD  LOOPB                      440     1311     69 0164 0967
          SDA  LOOPB                      441     0967     22 0164 1017
          LDD  ATWO                       442     1017     69 0970 0173
          SDA  ATWO                       443     0173     22 0970 0923
          LDD  ATREE                      444     0923     69 0176 1179
          SDA  ATREE                      445     1179     22 0176 1229
          LDD  AFOUR                      446     1229     69 1082 1085
          SDA  AFOUR                      447     1085     22 1082 1135
          LDD  LOOPF                      448     1135     69 0188 0141
          SDA  LOOPF                      449     0141     22 0188 0191
          LDD  LOADC                      450     0191     69 0144 1147
          SDA  LOADC                      451     1147     22 0144 1197
          LDD  AFIVE                      452     1197     69 1202 1058
          SDA  AFIVE                      453     1058     22 1202 1108
          ALO  INDB                       454     1108     15 1361 1565
          LDD  CONE                       455     1565     69 1318 1271
          SDA  CONE                       456     1271     22 1318 1321
          LDD  CTWO                       457     1321     69 1274 1527
          SDA  CTWO                       458     1527     22 1274 1577
          LDD  CTREE                      459     1577     69 1180 1333
          SDA  CTREE                      460     1333     22 1180 1383
          LDD  CFOUR                      461     1383     69 1086 1039
          SDA  CFOUR                      462     1039     22 1086 1089
          LDD  CFIVE                      463     1089     69 0092 0145
          SDA  CFIVE                      464     0145     22 0092 0195
          RAC   0000                      465     0195     88 0000 1252
          LDD   8007                      466     1252     69 8007 1158
          STD  CTEMP                      467     1158     24 1411 0914
          RSL  NSPEN                      468     0914     66 1129 1433
          RAA   8002                      469     1433     80 8002 0941
          STL  ATEMP          LOOPA       470     0941     20 0945 0048
LOOPA     RSL  UNLES                      471     0048     66 0986 0991
          RAB   8002                      472     0991     82 8002 0149
          STL  BTEMP          AONE        473     0149     20 1254 1008
AONE      RAL   9999                      474     1008     65 9999 1304
          NZE  NORMA          NEPLA       475     1304     45 1200 1609
NORMA     STL  DTEMP          LOOPB       476     1208     20 1313 0164
LOOPB     RAU   9999                      477     0164     60 9999 1354
          FDV  BTEMP          ATWO        478     1354     34 1313 0970
ATWO      STU   9999                      479     0970     21 9999 1302
          RAL  ENN                        480     1302     65 1003 1258
          AXA   8002                      481     1258     50 8002 1067
          BMA  LOOPB                      482     1067     41 0164 1371
          RAL  ATEMP                      483     1371     65 0945 0199
          RAA   8002          LOOPC       484     0199     80 8002 1308
LOOPC     NZC                 BHKIP       485     1308     48 1461 1363
          RAL   8007                      486     1461     65 8007 1419
          ALO   8005                      487     1419     15 8005 1627
          RAC   8002          CONE        488     1627     88 8002 1318
CONE      RSU   9999                      489     1318     61 9999 1404
          NZE                 NXSBT       490     1404     45 1358 1659
          STU  ETEMP          LOOPD       491     1358     21 1413 0966
LOOPD     RAU  ETEMP          ATREE       492     0966     60 1413 0176
ATREE     FMP   9999          CTWO        493     0176     39 9999 1274
CTWO      FAD   9999          CTREE       494     1274     32 9999 1180
CTREE     STU   9999                      495     1180     21 9999 1352
          RAL  ENN                        496     1352     65 1003 1408
          AXA   8002                      497     1408     50 8002 1117
          AXC   8002                      498     1117     58 8002 0925
          BMA  LOOPD          NXSBT       499     0925     41 0966 1659
NXSBT     AXB   0001                      500     1659     52 0001 1615
          NZB  NEWST                      501     1615     42 1368 1469
          LDD  CTEMP                      502     1469     69 1411 0964
          RAC   8001                      503     0964     88 8001 1020
          LDD  ATEMP                      504     1020     69 0945 0098
          RAA   8001                      505     0098     80 8001 1454
          LDD  ENPLU                      506     1454     69 1036 1139
          AXA   8001                      507     1139     50 8001 0995
          LDD   8005                      508     0995     69 8005 1402
          STD  ATEMP                      509     1402     24 0945 0148
          BMA                 EXIT        510     0148     41 1452 0053
          SXC   0001                      511     1452     59 0001 1458
          LDD   8007                      512     1458     69 8007 1014
          STD  CTEMP                      513     1014     24 1411 1064
          STD  KTEMP          LOOPA       514     1064     24 1167 0048
NEWST     LDD  ATEMP                      515     1368     69 0945 0198
          RAA   8001                      516     0198     80 8001 1504
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          LDD  KTEMP                         517     1504     69 1167 1070
          RAC   8001      SHKIP              518     1070     88 8001 1363
SHKIP     AXC   0001                         519     1363     58 0001 1519
          LDD   8007                         520     1519     69 8007 0975
          STD  KTEMP      LOOPC              521     0975     24 1167 1308
NEPLA     LDD  UNLES                         522     1609     69 0986 1189
          AXC   8001      LOOPE              523     1189     58 8001 1045
LOOPE     AXC   0001                         524     1045     58 0001 1502
          SXC   0001      AFOUR              525     1502     59 0001 1082
AFOUR     RAL   9999                         526     1082     65 9999 1554
          NZE             ZEERO              527     1554     45 1508 1709
          RSL  UNLES                         528     1508     66 0986 1041
          AXC   8002                         529     1041     58 8002 0949
          RAL   8007                         530     0949     65 8007 1558
          ALO   8005                         531     1558     15 8005 1665
          RAC   8002      LOOPF              532     1665     88 8002 0188
LOOPF     RAL   9999      CFOUR              533     0188     65 9999 1086
CFOUR     LDD   9999      AFIVE              534     1086     69 9999 1202
AFIVE     STD   9999      CFIVE              535     1202     24 9999 0092
CFIVE     STL   9999                         536     0092     20 9999 1552
          LDD  ENN                           537     1552     69 1003 1608
          AXC   8001                         538     1608     58 8001 1114
          AXA   8001                         539     1114     50 8001 1120
          BMI  LOOPF                         540     1120     46 0188 1324
          LDD  ATEMP                         541     1324     69 0945 0948
          RAA   8001                         542     0948     80 8001 1604
          LDD  CTEMP                         543     1604     69 1411 1164
          RAC   8001      NORMA              544     1164     88 8001 1808
ZEERO     NZC  LOOPF      STOPP              545     1709     48 1045 1463
PUNCN     LDD  ENN                           546     1602     69 1003 1658
          RSA   8001                         547     1658     81 8001 1214
          RSC   0008      LOADC              548     1814     89 0008 0144
LOADC     LDD   9999                         549     0144     69 9999 1652
          STD   1985  C                      550     1652     24 7985 0938
          AXC   0001                         551     0938     58 0001 0194
          NZC  INCXA                         552     0194     48 1247 0998
          PCH   1977                         553     0998     71 1977 1677
          RSC   0008      INCXA              554     1677     89 0008 1847
INCXA     AXA   0001                         555     1247     50 0001 1654
          NZA  LOADC                         556     1654     40 0144 1708
          PCH   1977                         557     1708     71 1977 1727
          RAU  NSPEN                         558     1727     60 1129 1483
          RSB   8001                         559     1483     83 8001 1239
          RAA   0000      ZEERE              560     1239     80 0000 1095
ZEERE     NZB              N000              561     1095     42 1048 0000
          AXB   0001                         562     1048     52 0001 1704
          STL   0001  A                      563     1704     20 2001 1754
          AXA   0001      ZEERE              564     1754     50 0001 1095
UNITY     00    0000       0001              565     1227     00 0000 0001
INOA      00    2001       0000              566     0096     00 2001 0000
INOR      00    4000       0000              567     1361     00 4000 0000
STOPP     01    5555       5555              568     1463     01 5555 5555
```

APPENDIX H

IBM 650 Program for Diffusion Length, Monoenergetic Fast Source

This code was written to determine an experimental value of diffusion length based upon the assumption of a monoenergetic source of fast neutrons. The program was written in SOAP II and floating point form. The object program and a logic diagram are given in this section.

The solution to this problem is based upon the equation

$$\phi = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{Q_o}{ab\, D\gamma_{mn}} e^{-\kappa^2 \tau} \left[e^{-\gamma_{mn} z} \left[1 + \mathrm{erf}\left(\frac{z}{2\sqrt{\tau}} - \gamma_{mn}\sqrt{\tau}\right)\right] + e^{\gamma_{mn} z} \left[1 - \mathrm{erf}\left(\frac{z}{2\sqrt{\tau}} + \gamma_{mn}\sqrt{\tau}\right)\right]\right] \left(1 - e^{-2\gamma_{mn}(c-z)}\right).$$

An iteration procedure similar to that used in the point thermal and constant thermal source programs was used.

Input parameters and data are listed in Table 31. All input should be punched on one word load cards and read into the machine with the object deck.

Output from this program is in two forms, as shown in Table 32. Form one is punched after the calculation of each individual correction factor. Form two is the final result and gives the last value of γ_{11} as well as the diffusion length.

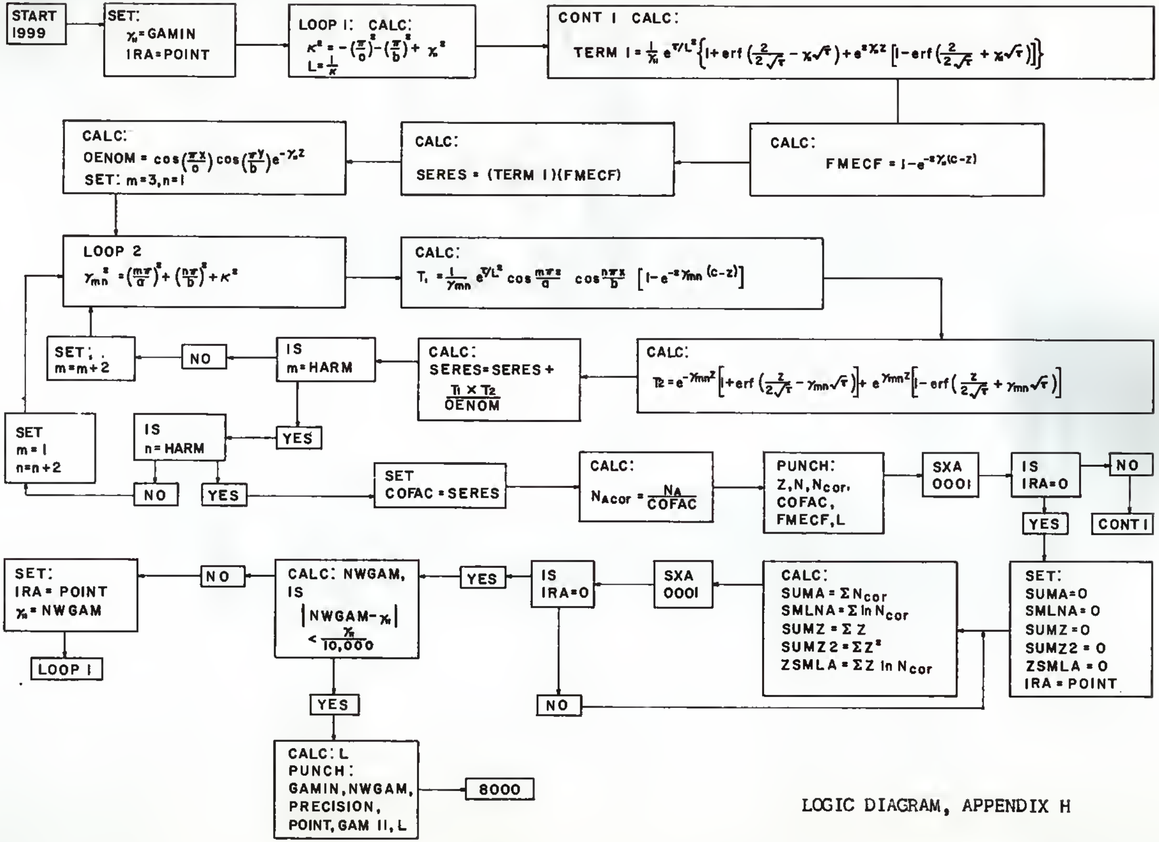
The operating time for the calculation of one correction factor using four harmonics is approximately 40 seconds. The capacity of the program is 200 data points.

Table 31. Input to IBM 650 program for diffusion length, monoenergetic fast source.

Symbol	Explanation	Drum Storage Location
FIRST	Initial estimate of γ_{11}	0100
POINT	Number of Data Points, in form 00 0000 00xx	0101
DATPT	Number of Data Points, in floating point form	0102
A	Extrapolated x-dimension	0103
B	Extrapolated y-dimension	0104
C	Extrapolated z-dimension	0105
X	X co-ordinate of data	0106
Y	y co-ordinate of data	0107
TAU	Fermi age of source neutrons	0108
HARM	Magnitude of highest harmonic used.	0109

Table 32. Output forms for IBM 650 program for diffusion length, monoenergetic fast source.

Word No. 1	2	3	4	5	6
Form One:					
z co-ordinate	data	corrected data	Harmonic correction	End correction	Diffusion Length
Form Two:					
γ_{11}, initial value	γ_{11} last value	Precision	POINT	γ_{11}, next to last value	Diffusion Length



LOGIC DIAGRAM, APPENDIX H

```
          BLR   1951  1958                 1   0000   00 0000 0000
          BLR   1977  1984                 2   0000   00 0000 0000
          BLR   0300  0900                 3   0000   00 0000 0000
          SYN  Z      0300                 4   0000   00 0000 0000
          SYN  N      0500                 5   0000   00 0000 0000
          SYN  NCOR   0700                 6   0000   00 0000 0000
          SYN  GAMIN  0100                 7   0000   00 0000 0000
          SYN  POINT  0101   INDEX FORM    8   0000   00 0000 0000
          SYN  DATPT  0102   DATA FORM     9   0000   00 0000 0000
          SYN  A      0103   X DIMEN      10   0000   00 0000 0000
          SYN  B      0104   Y DIMEN      11   0000   00 0000 0000
          SYN  C      0105   Z DIMEN      12   0000   00 0000 0000
          SYN  X      0106      DATA      13   0000   00 0000 0000
          SYN  Y      0107   COORDINATE   14   0000   00 0000 0000
          SYN  TAU    0108                15   0000   00 0000 0000
          SYN  HARM   0109                16   0000   00 0000 0000
          SYN  START  1999                17   0000   00 0000 0000
ZERO       00   0000  0000                18   0000   00 0000 0000
ONE        10   0000  0051                19   0050   10 0000 0051
THREE      30   0000  0051                20   0150   30 0000 0051
PI         31   4159  0051                21   0200   31 4159 0051
CONVT      25   3600  0051                22   0250   25 3600 0051
10000      10   0000  0055                23   0950   10 0000 0055
TWO        20   0000  0051                24   1000   20 0000 0051
EDERF     STD  OUT                        25   1050   24 0003 0006
          BMI  NGTVE  PSTVE               26   0006   46 0009 0010
NGTVE     STU  TEM1                       27   0009   21 0014 0017
          RAM  TEM1                       28   0017   67 0014 0019
          RAU   8002                      29   0019   60 8002 0027
          STU  ARGG                       30   0027   21 0032 0035
          LDD  MUNIT                      31   0035   69 0038 0041
          STD  COEFF  APPRO               32   0041   24 0044 0047
PSTVE     STU  ARGG                       33   0010   21 0032 0085
          LDD  UNIT                       34   0085   69 0088 0091
          STD  COEFF  APPRO               35   0091   24 0044 0047
APPRO     RAU  ARGG                       36   0047   60 0032 0037
          FMP  A6AA                       37   0037   39 0040 0090
          FAD  A5AA                       38   0090   32 0043 0069
          FMP  ARGG                       39   0069   39 0032 0082
          FAD  A4AA                       40   0082   32 0135 0011
          FMP  ARGG                       41   0011   39 0032 0132
          FAD  A3AA                       42   0132   32 0185 0061
          FMP  ARGG                       43   0061   39 0032 0182
          FAD  A2AA                       44   0182   32 0235 0111
          FMP  ARGG                       45   0111   39 0032 0232
          FAD  A1AA                       46   0232   32 0285 0161
          FMP  ARGG                       47   0161   39 0032 0282
          FAD  UNIT                       48   0282   32 0088 0015
          FMP   8003                      49   0015   39 8003 0119
          FMP   8003                      50   0119   39 8003 0023
          FMP   8003                      51   0023   39 8003 0077
          FMP   8003                      52   0077   39 8003 0031
          STU  TEM1                       53   0031   21 0014 0067
          RAU  UNIT                       54   0067   60 0088 0093
          FDV  TEM1                       55   0093   34 0014 0064
          STU  TEM1                       56   0064   21 0014 0117
          RAU  UNIT                       57   0117   60 0088 0143
          FSB  TEM1                       58   0143   33 0014 0141
          FMP  COEFF  OUT                 59   0141   39 0044 0003
A1AA       70   5230  7849                60   0285   70 5230 7849
A2AA       42   2820  1249                61   0235   42 2820 1249
A3AA       92   7052  7248                62   0185   92 7052 7248
A4AA       15   2014  3047                63   0135   15 2014 3047
A5AA       27   6567  2047                64   0043   27 6567 2047
A6AA       43   0638  0046                65   0040   43 0638 0046
UNIT       10   0000  0051                66   0088   10 0000 0051
MUNIT   -  10   0000  0051                67   0038   10 0000 0051
LNX01     STD  LNX08                      68   1100   24 0053 0056
          NZE         LNX14               69   0056   45 0060 0211
          BMI  LNX14                      70   0060   46 0211 0114
          STU  LNX09                      71   0114   21 0018 0021
          RSL  FPONE                      72   0021   66 0024 0029
          STD  LNX10                      73   0029   24 0932 0935
          STL  LNX02                      74   0935   20 0039 0042
          RAU  LNX09                      75   0042   60 0018 0073
          STL  LNX05                      76   0073   20 0127 0030
          STL  LNX11                      77   0030   20 0985 0138
          SLT   0008                      78   0138   35 0008 0007
          SUP  FIFTY                      79   0007   11 0110 0065
          NZE         LNX04               80   0065   45 0068 0169
          BMI         LNX03               81   0068   46 0071 0022
          RSU   8003                      82   0071   61 8003 0079
          LDD  FPONE                      83   0079   69 0024 0177
          STD  LNX02  LNX03               84   0177   24 0039 0022
LNX03     SRT   0008                      85   0022   30 0008 0191
          SCT   0000                      86   0191   36 0000 0013
          AUP  SIXTY                      87   0013   10 0016 0121
          SUP   8002                      88   0121   11 8002 0129
          RAU   8003                      89   0129   60 8003 0087
          FMP  LNX02                      90   0087   39 0039 0089
          FMP  LNTEN                      91   0089   39 0092 0142
          STU  LNX05  LNX04               92   0142   21 0127 0169
LNX04     RAL  LNX09                      93   0169   65 0018 0123
          SRT   0002                      94   0123   30 0002 0179
          RAU   8002                      95   0179   60 8002 0137
          ALO  FIFTY                      96   0137   15 0110 0115
          SLT   0002                      97   0115   35 0002 0171
          FAD  FPONE                      98   0171   32 0024 0001
          STU  LNX09                      99   0001   21 0018 0221
          FSB  FPTWO                     100   0221   33 0074 0051
          FDV  LNX09                     101   0051   34 0018 0118
          STU  LNX13                     102   0118   21 0072 0025
          STD  LNX12                     103   0025   24 0028 0081
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          STD  LNX11                         104  0081  24 0985 0188
          FMP   8001                         105  0188  39 8001 0241
          STU  FACT8    LNX06                106  0241  21 0046 0049
LNX06     RAU  LNX10                         107  0049  60 0932 0187
          FAD  FPTWO                         108  0187  32 0074 0151
          STU  LNX10                         109  0151  21 0932 1035
          RAU  LNX13                         110  1035  60 0072 0227
          FMP  FACT8                         111  0827  39 0046 0096
          FDV  LNX10                         112  0096  34 0932 0982
          STU  LNX13                         113  0982  21 0072 0075
          FAD  LNX12                         114  0075  32 0088 0005
          STU  LNX12                         115  0005  21 0028 0131
          FSB  LNX11                         116  0131  33 0985 0261
          FDV  LNX11                         117  0261  34 0985 1085
          RAM   8003                         118  1085  67 8003 0193
          RAU   8002                         119  0193  60 8002 0201
          FSB  SIZE7                         120  0201  33 0004 0181
          BMI  LNX07                         121  0181  46 0034 1135
          LDD  LNX12                         122  1135  69 0028 0231
          STD  LNX11                         123  0231  24 0985 0838
          RAU  LNX13                         124  0238  60 0072 0277
          FMP  LNX10                         125  0277  39 0932 1032
          STU  LNX13    LNX06                126  1038  21 0072 0049
LNX07     RAU  LNX12                         127  0034  60 0028 0033
          FMP  FPTWO                         128  0033  39 0074 0184
          FSB  LNX05    LNX08                129  0124  33 0127 0053
FPONE      10  0000      0051                130  0084  10 0000 0051
FPTWO      20  0000      0051                131  0074  20 0000 0051
SIZE7      10  0000      0043                132  0004  10 0000 0043
LNTEN      23  0258      5151                133  0092  23 0258 5151
FIFTY      50  0000      0000                134  0110  50 0000 0000
SIXTY      00  0000      0060                135  0016  00 0000 0060
LNX14      01  2345      6789                136  0211  01 2345 6789
EDDCR     STD  EXIT                          137  1150  24 0153 0156
          RAU   8002                         138  0156  60 8002 0165
          BMI  NEGAT    REDUC                139  0165  46 0168 0219
NEGAT     FAD  TWOPI                         140  0168  32 0271 0097
          BMI  NEGAT                         141  0097  46 0168 0251
          FSB  ONEPI    COSIO                142  0251  33 0054 0281
REDUC     FSB  TWOPI                         143  0219  33 0271 0147
          BMI           REDUC                144  0147  46 1200 0219
          FAD  ONEPI    COSIO                145  1200  32 0054 0281
COSIO     STU  THETA                         146  0281  21 0036 0139
          RSU  FPONE                         147  0139  61 0024 0229
          STU  TERMM                         14R  0229  21 0084 0237
          STU  FUNKT                         149  0237  21 0198 0045
          STL  ENNN     NEGST                150  0045  20 0099 0002
EDDBR     STD  EXIT                          151  1250  24 0153 0206
          RAU   8002                         152  0206  60 8002 0215
          BMI  NEGAV    REDUO                153  0215  46 0218 0269
NEGAV     FAD  TWOPI                         154  0218  32 0271 0197
          BMI  NEGAV                         155  0197  46 0218 0901
          FSB  ONEPI    SINET                156  0901  33 0054 0931
REDUO     FSB  TWOPI                         157  0269  33 0271 0247
          BMI           REDUO                158  0247  46 1300 0269
          FAD  ONEPI    SINET                159  1300  32 0054 0931
SINET     STU  THETA                         160  0931  21 0036 0189
          RSU   8003                         161  0189  61 8003 0297
          STU  TERMM                         162  0297  21 0084 0287
          STU  FUNKT                         163  0287  21 0192 0095
          LDD  FPONE                         164  0095  69 0024 0927
          STD  ENNN     NEGST                165  0927  24 0099 0002
NEGST     RAU  ENNN                          166  0002  60 0099 0203
          FAD  FPONE                         167  0203  32 0024 0951
          STU  NPONE                         160  0951  21 0256 0059
          FAU  FPONE                         169  0059  32 0024 1001
          STU  ENNN                          170  1001  21 0099 0052
          RSU  TERMM                         171  0052  61 0084 0239
          FMP  THETA                         172  0239  39 0036 0086
          FMP  THETA                         173  0086  39 0036 0136
          FDV  NPONE                         174  0136  34 0256 0906
          FDV  ENNN                          175  0906  34 0099 0149
          STU  TERMM                         176  0149  21 0084 0937
          RAM  FUNKT                         177  0937  67 0192 0947
          STL  FMAG                          178  0947  20 1051 0154
          RAM  TENMM                         179  0154  67 0084 0289
          RAU   8002                         180  0289  60 8002 0997
          FDV  FMAG                          181  0997  34 1051 1101
          FSB  SIZE8                         182  1101  33 0204 0981
          BMI  ENUFF                         183  0981  46 0134 1185
          RAU  FUNKT                         184  1185  60 0192 1047
          FAD  TERMM                         105  1047  32 0084 0911
          STU  FUNKT    NEGST                186  0911  21 0192 0002
ENUFF     RAL  FUNKT    EXIT                 187  0134  65 0192 0153
SIZE8      10  0000      0043                188  0204  10 0000 0043
TWOPI      62  8318      5351                189  0271  62 8318 5351
ONEPI      31  4159      2751                190  0054  31 4159 2751
FPONE      10  0000      0051                191  0024  10 0000 0051
EDDEA     STD  AAA1              EXIT INSTR  192  1350  24 0253 0956
          STL  AAA2               STORE X    193  0956  20 0961 0164
          RAM  AAA2                          194  0164  67 0961 0265
          STL  AAA3              X FOR CALC  195  0265  20 0919 0122
          RAU  AAA3                          196  0122  60 0919 0173
          FMP  AAA16                         197  0173  39 0026 0076
          FAD  AAA15                         198  0076  32 0279 0055
          FMP  AAA3                          199  0055  39 0919 0969
          FAD  AAA14                         200  0969  32 0172 0199
          FMP  AAA3                          201  0199  39 0919 1019
          FAD  AAA13                         202  1019  32 0222 0249
          FMP  AAA3                          203  0249  39 0919 1069
          FAD  AAA12                         204  1069  32 0272 0299
          FMP  AAA3                          205  0299  39 0919 1119
          FAD  AAA11                         206  1119  32 0922 0949
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          FMP  AAA3                                  207   0949    39 0919 1169
          FAD  AAA10                                 208   1169    32 0972 0999
          STU  AAA4                                  209   0999    21 0254 0057
          FMP  AAA4                                  210   0057    39 0254 0904
          STU  AAA4                                  211   0904    21 0254 U157
          FMP  AAA4                                  212   0157    39 0254 0954
          STU  AAA4                                  213   0954    21 0254 0207
          RAU  AAA2                                  214   0207    60 0961 0915
          BMI  AAA5       AAA6                       215   0915    46 0268 1219
AAA5      RAU  AAA10                                 216   0268    60 0972 0977
          FDV  AAA4                                  217   0977    34 0254 1004
          STU  AAA4       AAA6                       218   1004    21 0254 1219
AAA6      RAL  AAA4       AAA1                       219   1219    65 0254 0253
AAA10      10   0000       0051                      220   0972    10 0000 0051
AAA11      24   9998       6850                      221   0922    24 9998 6850
AAA12      31   2575       8349                      222   0272    31 2575 8349
AAA13      25   9137       1248                      223   0222    25 9137 1248
AAA14      17   1562       0047                      224   0172    17 1562 0047
AAA15      54   3020       0045                      225   0279    54 3020 0045
AAA16      69   0600       0044                      226   0026    69 0600 0044
EOOAU     STD  SEXT                                1 227   1400    24 0903 1006
          BMI  SERR                                2 228   1006    46 0159 0160
          NZE             SEXT                     3 229   0160    45 0214 0903
          STU  SA                                  4 230   0214    21 0918 0921
          FAD  S10                                 5 231   0921    32 0174 1151
          FMP  SHAF       SB                       6 232   1151    39 1054 1104
SB        STU  SSAV       SAH                      7 233   1104    21 0008 1011
SAH       RAU  SA                   S CAPT  A      8 234   1011    60 0918 0223
          FDV  SSAV                                9 235   0223    34 0008 0058
          FAD  SSAV                               10 236   0058    32 0008 1235
          FMP  SHAF                               11 237   1235    39 1054 1154
          FSB  SSAV                               12 238   1154    33 0008 1285
          NZU             SR                      13 239   1285    44 0939 0140
          BMI             SR                      14 240   0939    46 0242 0140
          FAD  SSAV                               15 241   0242    32 0008 1335
          STU  SSAV       SAH                     16 242   1335    21 0008 1011
SR        RAU  SSAV       SEXT                    17 243   0140    60 0008 0903
SERR      HLT   0000      SEXT                    18 244   0159    01 0000 0903
SHAF       50   0000       0050                   19 245   1054    50 0000 0050
S10        10   0000       0051                   20 246   0174    10 0000 0051
START     LDD  GAMIN                                 247   1999    69 0100 0953
          STD  GAM11      LOOP1                      248   0953    24 1056 0209
LOOP1     RAU  PI                                    249   0209    60 0200 0155
          FDV  A                                     250   0155    34 0103 1003
          STU  TEMP1                                 251   1003    21 0158 1061
          FMP  TEMP1                                 252   1061    39 0158 0208
          STU  TEMP1                                 253   0208    21 0158 1111
          RAU  PI                                    254   1111    60 0200 0205
          FDV  B                                     255   0205    34 0104 1204
          STU  TEMP2                                 256   1204    21 0258 1161
          FMP  TEMP2                                 257   1161    39 0258 0908
          STU  TEMP2                                 258   0908    21 0258 1211
          RAU  GAM11                                 259   1211    60 1056 1261
          FMP  GAM11                                 260   1261    39 1056 1106
          FSB  TEMP1                                 261   1106    33 0158 1385
          FSB  TEMP2                CALCULATE        262   1385    33 0258 1435
          STU  KAPSQ                KAPPA            263   1435    21 0190 0243
          LDD             EOOAU     SQUARED          264   0243    69 0146 1400
          STU  KAPPA                                 265   0146    21 1450 1053
          RAU  ONE                  CALCULATE        266   1053    60 0050 0255
          FDV  KAPPA                DIFFUSION        267   0255    34 1450 1500
          STU  DL                   LENGTH           268   1500    21 1254 0257
          LDD  POINT                                 269   0257    69 0101 1304
          RAA   8001      CONT1                      270   1304    80 8001 0210
CONT1     RAU  TAU                                   271   0210    60 0108 0063
          FDV  DL                                    272   0063    34 1254 1354
          FDV  DL                                    273   1354    34 1254 1404
          RAL   8003                                 274   1404    65 8003 1311
          LDD             EOOEA                      275   1311    69 0264 1350
          RAU   8002                                 276   0264    60 8002 0273
          FDV  GAM11                                 277   0273    34 1056 1156
          STU  TEMP1                                 278   1156    21 0158 1361
          RAU  Z          A                          279   1361    60 2300 0905
          FMP  GAM11                                 280   0905    39 1056 1206
          FMP  TWO                                   281   1206    39 1000 1550
          RAL   8003                                 282   1550    65 8003 0907
          LDD             EOOEA                      283   0907    69 0260 1350
          STL  TEMP2                                 284   0260    20 0258 1411
          RAU  TAU                                   285   1411    60 0108 0113
          LDD             EOOAU                      286   0113    69 0066 1400
          STU  RTTAU                                 287   0066    21 0020 0923
          RAU  Z          A                          288   0923    60 2300 0955
          FDV  TWO                                   289   0955    34 1000 1600
          FDV  RTTAU                                 290   1600    34 0020 0070
          STU  PART1                                 291   0070    21 0224 1027
          RAU  RTTAU                                 292   1027    60 0020 0125
          FMP  GAM11                                 293   0125    39 1056 1256
          STU  PART2                                 294   1256    21 0910 0163
          RAU  PART1                                 295   0163    60 0224 0929
          FSB  PART2                                 296   0929    33 0910 0987
          LDD             EOERF                      297   0987    69 0240 1050
          FAD  ONE                                   298   0240    32 0050 1077
          STU  TEMP3                                 299   1077    21 1082 1485
          RAU  PART1                                 300   1485    60 0224 0979
          FAD  PART2                                 301   0979    32 0910 1037
          LDD             EOERF                      302   1037    69 0290 1050
          STU  TEMP4                                 303   0290    21 0094 1097
          RAU  ONE                                   304   1097    60 0050 1005
          FSB  TEMP4                                 305   1005    33 0094 0971
          FMP  TEMP2                                 306   0971    39 0258 0958
          STU  TEMP2                                 307   0958    21 0258 1461
          FAD  TEMP3                                 308   1461    32 1082 0259
          FMP  TEMP1                                 309   0259    39 0158 1008
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         STU TERM1                                 310   1008    21 0012 0965
         RAU Z       A                             311   0965    60 2300 1055
         FSB C                                     312   1055    33 0105 1031
         FMP GAM11                                 313   1031    39 1056 1306
         FMP TWO                                   314   1306    39 1000 1650
         RAL  8003                                 315   1650    65 8003 0957
         LDD            E00EA                      316   0957    69 0960 1350
         STL TEMP1                                 317   0960    20 0158 1511
         RSU C                                     318   1511    61 0105 0909
         FMP GAM11                                 319   0909    39 1056 1356
         FMP TWO                                   320   1356    39 1000 1700
         RAL  8003                                 321   1700    65 8003 1007
         LDD            E00EA                      322   1007    69 1010 1350
         RAU  8002                                 323   1010    60 8002 1269
         FAD ONE                                   324   1269    32 0050 1127
         STU TEMP2                                 325   1127    21 0258 1561
         RAU ONE                                   326   1561    60 0050 1105
         FSB TEMP1                                 327   1105    33 0158 1535
         FDV TEMP2                                 328   1535    34 0258 1058
         STU FMECF               CALCULATE         329   1058    21 0062 1015
         FMP TERM1               TERM ONE          330   1015    39 0012 0112
         STU SERES               OF SERIES         331   0112    21 0116 1319
         RAU PI                                    332   1319    60 0200 1155
         FDV A                                     333   1155    34 0103 1103
         FMP X                                     334   1103    39 0106 1406
         RAL  8003                                 335   1406    65 8003 0213
         LDD            E00CR                      336   0213    69 0166 1150
         STL TEMP1                                 337   0166    20 0158 1611
         RAU PI                                    338   1611    60 0200 1205
         FDV B                                     339   1205    34 0104 1454
         FMP Y                                     340   1454    39 0107 1057
         RAL  8003                                 341   1057    65 8003 1065
         LDD            E00CR                      342   1065    69 0968 1150
         STL TEMP2                                 343   0968    20 0258 1661
         RSU Z       A                             344   1661    61 2300 1255
         FMP GAM11                                 345   1255    39 1056 1456
         RAL  8003               CALCULATE         346   1456    65 8003 0263
         LDD            E00EA    DENOMINATR        347   0263    69 0216 1350
         RAU  8002               FOR               348   0216    60 8002 0175
         FMP TEMP1               SUCCEEDING        349   0175    39 0158 1108
         FMP TEMP2               SERIES            350   1108    39 0258 1158
         STU DENOM               TERMS             351   1158    21 0162 1115
         RAU HARM                                  352   1115    60 0109 0913
         RAU THREE               SET  M  N         353   0913    60 0150 1305
         STU M                   FOR SECOND        354   1305    21 1060 0963
         RAU ONE                 SERIES            355   0963    60 0050 1355
         STU N          LOOP2    TERM              356   1355    21 0500 1153
LOOP2    RAU M                                     357   1153    60 1060 1165
         FMP PI                                    358   1165    39 0200 1750
         FDV A                                     359   1750    34 0103 1203
         STU TEMP1                                 360   1803    21 0158 1711
         FMP TEMP1                                 361   1711    39 0158 1208
         STU TEMP1                                 362   1208    21 0158 1761
         RAM N                                     363   1761    60 0500 1405
         FMP PI                                    364   1405    39 0200 1800
         FDV B                                     365   1800    34 0104 1504
         STU TEMP2                                 366   1504    21 0258 1811
         FMP TEMP2                                 367   1811    39 0258 1258
         STM TEMP2                                 368   1258    21 0258 1861
         RAU KAPSO                                 369   1861    60 0190 0145
         FAD TEMP1                                 370   0145    32 0158 1585
         FAD TEMP2                                 371   1585    32 0258 1635
         LDD            E00AU    CALCULATE         372   1635    69 0288 1400
         STU GAMMA               GAMMA  MN         373   0288    21 0292 0195
         RAU TAU                                   374   0195    60 0108 1013
         FDV OL                                    375   1013    34 1254 1554
         FDV OL                                    376   1554    34 1254 1604
         RAL  8003                                 377   1604    65 8003 1911
         LDD            E00EA                      378   1911    69 0914 1350
         RAM  8002                                 379   0914    60 8002 0973
         FDV GAMMA                                 380   0973    34 0292 0942
         STU TEMP1                                 381   0942    21 0158 1961
         RAM M                                     382   1961    60 1060 1215
         FMP PI                                    383   1215    39 0200 1850
         FDV A                                     384   1850    34 0103 1253
         FMP X                                     385   1253    39 0106 1506
         RAL  8003                                 386   1506    65 8003 1063
         LDD            E00CR                      387   1063    69 0266 1150
         STL TEMP2                                 388   0266    20 0258 0212
         RAM N                                     389   0212    60 0500 1455
         FMP PI                  CALCULATE         390   1455    39 0200 1900
         FDV B                   TERM              391   1900    34 0104 1654
         FMP X                   OF                392   1654    39 0106 1556
         RAL  8003               SERIES            393   1556    65 8003 1113
         LDD            E00CR                      394   1113    69 0916 1150
         STL TEMP3                                 395   0916    20 1082 1685
         RAU Z       A                             396   1685    60 2300 1505
         FSB C                                     397   1505    33 0105 1081
         FMP GAMMA                                 398   1081    39 0292 0992
         FMP TWO                                   399   0992    39 1000 1950
         RAL  8003                                 400   1950    65 8003 1107
         LDD            E00EA                      401   1107    69 1110 1350
         STL TEMP4                                 402   1110    20 0094 1147
         RSU C                                     403   1147    61 0105 0959
         FMP GAMMA                                 404   0959    39 0292 1042
         FMP TWO                                   405   1042    39 1000 1201
         RAL  8003                                 406   1201    65 8003 1009
         LDD            E00EA                      407   1009    69 0262 1350
         RAU  8002                                 408   0262    60 8002 1021
         FAD ONE                                   409   1021    32 0050 1177
         STU TEMP5                                 410   1177    21 1132 1735
         RAU ONE                                   411   1735    60 0050 1555
         FSB TEMP4                                 412   1555    33 0094 1071
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          FDV TEMP5                          413  1071  34 1132 1182
          FMP TEMP1                          414  1182  39 0158 1308
          FMP TEMP2                          415  1308  39 0258 1358
          FMP TEMP3                          416  1358  39 1082 1232
          STU TEMP1                          417  1232  21 0158 0912
          RAU RTTAU                          418  0912  60 0020 0225
          FMP GAMMA                          419  0225  39 0292 1092
          STU PART2                          420  1092  21 0910 1163
          RAU PART1                          421  1163  60 0224 1029
          FSB PART2                          422  1029  33 0910 1087
          LDD           EDERF                423  1087  69 0940 1050
          FAD ONE                            424  0940  32 0050 1227
          STU TEMP2                          425  1227  21 0258 0962
          RAU PART1                          426  0962  60 0224 1079
          FAD PART2                          427  1079  32 0910 1137
          LDD           EDERF                428  1137  69 0990 1050
          STU TEMP3                          429  0990  21 1082 1785
          RAU ONE                            430  1785  60 0050 1605
          FSB TEMP3                          431  1605  33 1082 1059
          STU TEMP3                          432  1059  21 1082 1835
          RAU GAMMA                          433  1835  60 0292 1197
          FMP Z       A                      434  1197  39 2300 1251
          RAL  8003                          435  1251  65 8003 1109
          LDD           EDDEA                436  1109  69 1012 1350
          RAU  8002                          437  1012  60 8002 1121
          FMP TEMP3                          438  1121  39 1082 1282
          STU TEMP3                          439  1282  21 1082 1885
          RSU GAMMA                          440  1885  61 0292 1247
          FMP Z       A                      441  1247  39 2300 1301
          RAL  8003                          442  1301  65 8003 1159
          LDD           EDDEA                443  1159  69 1062 1350
          RAU  8002                          444  1062  60 8002 1171
          FMP TEMP2                          445  1171  39 0258 1408
          FAD TEMP3                          446  1408  32 1082 1209
          FMP TEMP1                          447  1209  39 0158 1458
          FDV DENOM             ADD TERM     448  1458  34 0162 1112
          FAD SERES             TO           449  1112  32 0116 0293
          STU SERES             SERIES       450  0293  21 0116 1369
          RAU HARM                           451  1369  60 0109 1213
          FSB M                              452  1213  33 1060 1187
          NZE CONT3     CONT2                453  1187  45 1040 0291
CONT2     RAU ONE               ADJUST       454  0291  60 0050 1655
          STU M                 M AND N      455  1655  21 1060 1263
          RAU HARM              FOR          456  1263  60 0109 1313
          FSB N                 NEXT TERM    457  1313  33 0500 1277
          NZE           CONT4                458  1277  45 0080 1131
          RAU N                              459  0080  60 0500 1705
          FAD TWO                            460  1705  32 1000 1327
          STU N         LOOP2                461  1327  21 0500 1153
CONT3     RAU M                              462  1040  60 1060 1265
          FAD TWO                            463  1265  32 1000 1377
          STU M         LOOP2                464  1377  21 1060 1153
CONT4     RAU SERES                          465  1131  60 0116 0989
          STU COFAC                          467  0989  21 0144 1297
          RAU N       A                      468  1297  60 2500 1755
          FDV COFAC                          469  1755  34 0144 0194
          STU NCOR    A                      470  0194  21 2700 1303
          LDD Z       A                      471  1303  69 2300 1353
          STD  1977                          472  1353  24 1977 0130
          LDD N       A                      473  0130  69 2500 1403
          STD  1978                          474  1403  24 1978 1181
          LDD NCOR    A                      475  1181  69 2700 1453
          STD  1979                          476  1453  24 1979 1332
          LDD COFAC                          477  1332  69 0144 1347
          STD  1980                          478  1347  24 1980 0083
          LDD FMECF                          479  0083  69 0062 1315
          STD  1981                          480  1315  24 1981 0184
          LDD OL                             481  0184  69 1254 1157
          STD  1982                          482  1157  24 1982 1935
          PCH  1977                          483  1935  71 1977 1427
          SXA  0001                          484  1427  51 0001 0133
          NZA CONT1     CONT5                485  0133  40 0210 1237
CONT5     LDD POINT                          486  1237  69 0101 1704
          RAA  8001                          487  1704  80 8001 1160
          LDD ZERO                           488  1160  69 0000 1503
          STD SUMA                           489  1503  24 1606 1259
          STD SMLNA                          490  1259  24 1162 1365
          STD SUMZ                           491  1365  24 1018 1271
          STD SUMZ2                          492  1271  24 0274 1477
          STD ZSMLA     LOOP3                493  1477  24 0180 0183
LOOP3     RAU NCOR    A                      494  0183  60 2700 1805
          FAD SUMA                           495  1805  32 1606 0233
          STU SUMA                           496  0233  21 1606 1309
          RAU NCOR    A                      497  1309  60 2700 1855
          LDD           LNX01                498  1855  69 1508 1100
          FAD SMLNA                          499  1508  32 1162 1039
          STU SMLNA                          500  1039  21 1162 1415
          RAU Z       A         FORM SUMS    501  1415  60 2300 1905
          FAD SUMZ              FOR LEAST    502  1905  32 1018 0245
          STU SUMZ              SQUARES      503  0245  21 1018 1321
          RAU Z       A         ANALYSIS     504  1321  60 2300 1656
          FMP Z       A                      505  1656  39 2300 1351
          FAD SUMZ2                          506  1351  32 0274 1401
          STU SUMZ2                          507  1401  21 0274 1527
          RAU NCOR    A                      508  1527  60 2700 1706
          LDD           LNX01                509  1706  69 1359 1100
          FMP Z       A                      510  1359  39 2300 1451
          FAD ZSMLA                          511  1451  32 0180 1207
          STU ZSMLA                          512  1207  21 0180 0283
          SXA  0001                          513  0283  51 0001 1089
          NZA LOOP3     CONT6                514  1089  40 0183 0943
CONT6     RAU SMLNA                          515  0943  60 1162 0167
          FMP SUMZ                           516  0167  39 1018 1068
```

```
         STU  TEMP1                         517   1068   21 0158 1218
         RAU  OATPT                         518   1218   60 0102 1257
         FMP  Z8MLA                         519   1257   39 0180 0230
         STU  TEMP2                         520   0230   21 0258 1268
         RAU  OATPT                         521   1268   60 0102 1307
         FMP  SUMZ2                         522   1307   39 0274 0924
         STU  TEMP3                         523   0924   21 1082 1985
         RAU  SUMZ                          524   1988   60 1018 1023
         FMP  SUMZ                          525   1023   39 1018 1118
         STU  TEMP4                         526   1118   21 0094 1397
         RAU  TEMP3                         527   1397   60 1082 1287
         FSB  TEMP4                         528   1287   33 0094 1371
         STU  TEMP3                         529   1371   21 1082 0186
         RAU  TEMP1                         530   0186   60 0158 1363
         FSB  TEMP2                         531   1363   33 0258 0236
         FDV  TEMP3                         532   0236   34 1082 1388
         STU  NWGAM                         533   1388   21 0286 1139
         FDV  10000                         534   1139   34 0950 1501
         STU  PREC                          535   1501   21 1756 1409
         RAU  GAM11                         536   1409   60 1056 1312
         FSB  NWGAM                         537   1312   33 0286 1413
         RAM   8003                         538   1413   67 8003 1421
         RAU   8002                         539   1421   60 8002 1129
         FSB  PREC                          540   1129   33 1756 0933
         BMI  CONT8   CONT7                 541   0933   46 0936 1337
CONT7    RAU  NWGAM                         542   1337   60 0286 0941
         STU  GAM11                         543   0941   21 1056 1459
         LDD  ZERO                          544   1459   69 0000 1553
         STD  SERES   LOOP1                 545   1553   24 0116 0209
CONT8    RAU  NWGAM                         546   0936   60 0286 0991
         FMP  NWGAM           GAMMA         547   0991   39 0286 0986
         STU  GAMSQ           SQUARED       548   0986   21 1090 0993
         RAU  PI                            549   0993   60 0200 1806
         FDV  A                             550   1806   34 0103 1603
         STU  ALPH2                         551   1603   21 1558 1362
         FMP  ALPH2           ALPHA         552   1362   39 1558 1608
         STU  ALPH2           SQUARED       553   1608   21 1558 1412
         RAU  PI                            554   1412   60 0200 1856
         FDV  B                             555   1856   34 0104 1754
         STU  BETA2                         556   1754   21 1658 1462
         FMP  BETA2           BETA          557   1462   39 1658 1708
         STU  BETA2           SQUARED       558   1708   21 1658 1512
         RAU  GAMSQ                         559   1512   60 1090 0295
         FSB  ALPH2           KAPPA         560   0295   33 1558 1036
         FSB  BETA2           SQUARED       561   1036   33 1658 1086
         LDD          EOOAU                 562   1086   69 1189 1400
         STU  KAPPA                         563   1189   21 1450 1653
         RAU  ONE                           564   1653   60 0050 1906
         FDV  KAPPA                         565   1906   34 1450 1551
         FMP  CONVT           DIFFUSION     566   1551   39 0250 1601
         STU  DL              LENGTH        567   1601   21 1254 1357
         LDD  GAMIN                         568   1357   69 0100 1703
         STD   1977                         569   1703   24 1977 0280
         LDD  NWGAM                         570   0280   69 0286 1239
         STD   1978                         571   1239   24 1978 1231
         LDD  PREC                          572   1231   69 1756 1509
         STD   1979                         573   1509   24 1979 1432
         LDD  POINT                         574   1438   69 0101 1804
         STD   1980                         575   1804   24 1980 0983
         LDD  GAM11                         576   0983   69 1056 1559
         STD   1981                         577   1559   24 1981 0834
         LDD  DL                            578   0234   69 1254 1407
         STD   1982                         579   1407   24 1982 1136
         PCH   1977   8000                  580   1136   71 1977 8000
```

APPENDIX I

IBM 650 Program for Diffusion Length, Gaussian Range Empirical Source

This program was written to determine the diffusion length based upon an empirically determined source of high energy neutrons. The program was written in SOAP II and floating point form. The object program and a logic diagram are included in this section.

The solution to this problem is based upon the equation

$$\phi(x,y,z) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{f_i Q_o}{ab D \gamma_{mn}} e^{\frac{\kappa^2 r_i^2}{4}} \left[e^{-\gamma_{mn} z} \left[1 + \operatorname{erf}\left(\frac{z}{r_i} - \frac{\gamma_{mn} r_i}{2} \right) \right] + e^{+\gamma_{mn} z} \left[1 - \operatorname{erf}\left(\frac{z}{r_i} + \frac{\gamma_{mn} r_i}{2} \right) \right] \right] \left(1 - e^{-2\gamma_{mn}(c-z)}\right) .$$

Correction factors C_E and C_H derived from this equation are listed in Table 1. A correction factor iteration, such as has been described previously, is used to obtain an accurate value of γ_{11} and hence the diffusion length.

Input parameters and data are listed in Table 33. All input should be punched on one word load cards and read into the machine with the object deck.

Output forms are listed in Table 34. Form one is punched after calculation of each individual correction factor. Form two gives the end result of the analysis.

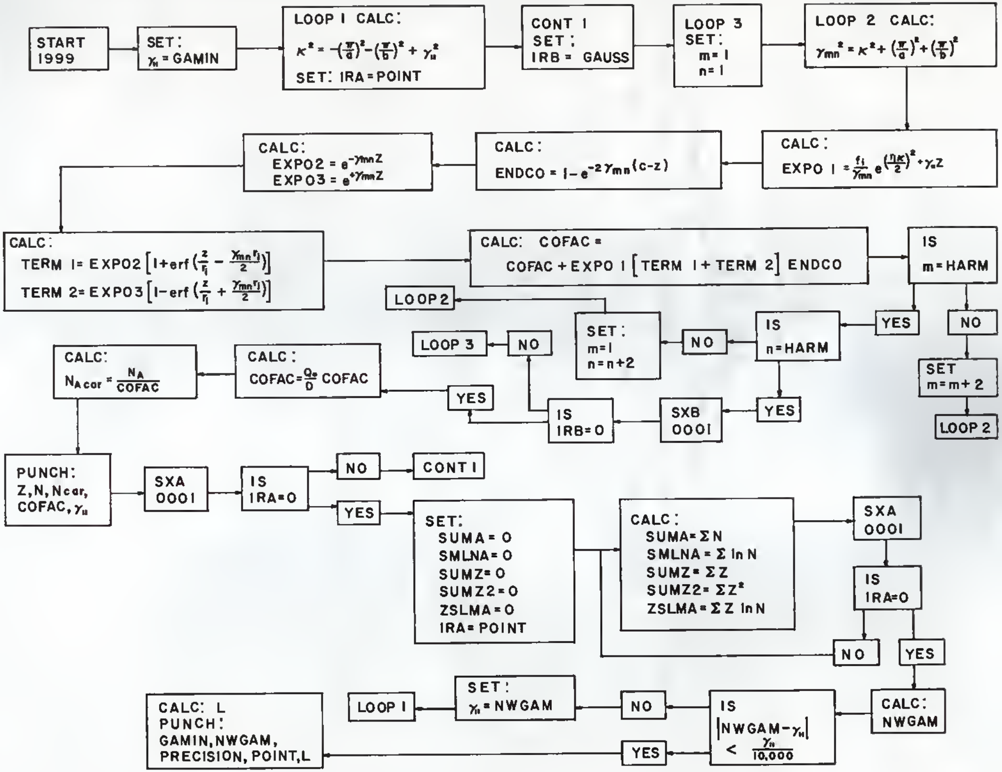
The operating time for the calculation of one correction factor using four harmonics is approximately one minute and 30 seconds. The data capacity of the program is 200 data points. As many as five sets of Gaussian ranges and fractions may be used.

Table 33. Input parameters and data for IBM 650 program for diffusion length, empirical source method.

Symbol	Explanation	Drum Storage Location
GAMIN	Initial Estimate of γ_{11}	0100
POINT	No. of Data Points, form 00 0000 00xx	0101
DATPT	No. of Data Points, floating point form	0102
A	Extrapolated x-dimension	0103
B	Extrapolated y-dimension	0104
C	Extrapolated z-dimension	0105
HARM	No. of highest harmonic, floating point form	0106
GAUSS	No. of Gaussian Ranges used, form 00 0000 000x	0107
QO	Source strength	0108
DIFCO	Diffusion Coefficient	0109
RI	Gaussian Range, stored consecutively starting at	0901
FI	Range Fractions, stored consecutively starting at	0906
N	Count Rates, stored consecutively starting at	0501
z	Data co-ordinates, stored consecutively starting at	0301

Table 34. Output forms for IBM 650 program for determination of diffusion lenth, empirical source method.

WORD 1	2	3	4	5
Form 1:				
z	N	N (corrected)	Combined correction	γ_{11}
Form 2:				
Gamin	γ_{11}, last value	Precision	No. of Data Points	Diffusion Length



LOGIC DIAGRAM, APPENDIX I

```
         BLR  1951      1961                        1    0000
         BLR  1977      1984                        2    0000
         SLR  0300      0910                        3    0000
         SYN  Z         0300                        4    0000
         SYN  N         0500                        5    0000
         SYN  NCOR      0700                        6    0000
         SYN  RI        0900                        7    0000
         SYN  FI        0905                        8    0000
         SYN  CAMIN     0100                        9    0000
         SYN  POINT     0101      INDEX FORM       10    0000
         SYN  DATPT     0102      DATA FORM        11    0000
         SYN  A         0103      X DIMEN          12    0000
         SYN  B         0104      Y DIMEN          13    0000
         SYN  C         0105      Z DIMEN          14    0000
         SYN  HARM      0106                       15    0000
         SYN  GAUSS     0107      GAUSSIANS        16    0000
         SYN  DD        0108      SOURCE           17    0000
         SYN  DIFCO     0109                       18    0000
         SYN  START     1999                       19    0000
ZERO      00  0000      0000                       20    0000
ONE       10  0000      0051                       21    0050    10 0000 0051
TWO       20  0000      0051                       22    0150    20 0000 0051
THREE     30  0000      0051                       23    0200    30 0000 0051
PI        31  4159      0051                       24    0250    31 4159 0051
CONVT     25  3600      0051                       25    0950    25 3600 0051
10000     10  0000      0055                       26    1000    10 0000 0055
EOOEA    STD  AAA1                EXIT INSTR       27    1050    24 0003 0006
         STL  AAA2                 STORE X         28    0006    20 0011 0014
         RAM  AAA2                                 29    0014    67 0011 0015
         STL  AAA3                X FOR CALC       30    0015    80 0019 0028
         RAU  AAA3                                 31    0022    60 0019 0023
         FMP  AAA16                                32    0023    39 0026 0076
         FAD  AAA15                                33    0076    32 0029 0005
         FMP  AAA3                                 34    0005    39 0019 0069
         FAD  AAA14                                35    0069    32 0072 0049
         FMP  AAA3                                 36    0049    39 0019 0119
         FAD  AAA13                                37    0119    32 0122 0099
         FMP  AAA3                                 38    0099    39 0019 0169
         FAD  AAA12                                39    0169    32 0172 0149
         FMP  AAA3                                 40    0149    39 0019 0219
         FAD  AAA11                                41    0219    32 0222 0199
         FMP  AAA3                                 42    0199    39 0019 0269
         FAD  AAA10                                43    0269    32 0272 0249
         STU  AAA4                                 44    0249    21 0004 0007
         FMP  AAA4                                 45    0007    39 0004 0054
         STU  AAA4                                 46    0054    21 0004 0057
         FMP  AAA4                                 47    0057    39 0004 0154
         STU  AAA4                                 48    0154    21 0004 0157
         RAU  AAA2                                 49    0157    60 0011 0065
         BMI  AAA5      AAA6                       50    0065    46 0018 0919
AAA5     RAU  AAA10                                51    0018    60 0272 0027
         FDV  AAA4                                 52    0027    34 0004 0204
         STU  AAA4      AAA6                       53    0204    21 0004 0919
AAA6     RAL  AAA4      AAA1                       54    0919    65 0004 0003
AAA10     10  0000      0051                       55    0272    10 0000 0051
AAA11     24  9990      6850                       56    0222    24 9998 6850
AAA12     31  2575      8349                       57    0172    31 2575 8349
AAA13     25  9137      1248                       58    0122    25 9137 1248
AAA14     17  1562      0047                       59    0072    17 1568 0047
AAA15     54  3020      0045                       60    0029    54 3020 0045
AAA16     69  0600      0044                       61    0026    69 0600 0044
LNX01    STD  LNX08                                62    1100    24 0053 0056
         NZE            LNX14                      63    0056    45 0010 0061
         BMI  LNX14                                64    0010    46 0061 0064
         STU  LNX09                                65    0064    21 0068 0021
         RSL  FPONE                                66    0021    66 0024 0079
         STD  LNX10                                67    0079    24 0032 0035
         STL  LNX02                                68    0035    20 0039 0042
         RAU  LNX09                                69    0042    60 0068 0073
         STL  LNX05                                70    0073    20 0077 0030
         STL  LNX11                                71    0030    20 0085 0038
         SLT  0008                                 72    0038    35 0008 0207
         SUP  FIFTY                                73    0207    11 0060 0115
         NZE            LNX04                      74    0115    45 0118 0969
         BMI            LNX03                      75    0118    46 0071 0922
         RSU  8003                                 76    0071    61 8003 0129
         LDD  FPONE                                77    0129    69 0024 0127
         STD  LNX02     LNX03                      78    0127    24 0039 0922
LNX03    SRT  0008                                 79    0922    30 0008 0041
         SCT  0000                                 80    0041    36 0000 0013
         AUP  SIXTY                                81    0013    10 0016 0121
         SUP  8002                                 82    0121    11 8008 0179
         RAU  8003                                 83    0179    60 8003 0037
         FMP  LNX02                                84    0037    39 0039 0089
         FMP  LNTEN                                85    0089    39 0092 0142
         STU  LNX05     LNX04                      86    0142    21 0077 0969
LNX04    RAL  LNX09                                87    0969    65 0068 0123
         SRT  0002                                 88    0123    30 0002 0229
         RAU  8002                                 89    0229    60 8002 0087
         ALO  FIFTY                                90    0087    15 0060 0165
         SLT  0002                                 91    0165    35 0002 0171
         FAD  FPONE                                92    0171    32 0024 0001
         STU  LNX09                                93    0001    21 0068 0221
         FSB  FPTWO                                94    0221    33 0074 0051
         FDV  LNX09                                95    0051    34 0068 0168
         STU  LNX13                                96    0168    21 0972 0025
         STD  LNX12                                97    0025    24 0028 0031
         STD  LNX11                                98    0031    24 0085 0088
         FMP  8001                                 99    0088    39 8001 0091
         STU  FACTR     LNX06                     100    0091    21 0046 0299
LNX06    RAU  LNX10                               101    0299    60 0032 0137
         FAD  FPTWO                               102    0137    32 0074 0151
         STU  LNX10                               103    0151    21 0032 0135
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          RAU  LNX13                               104   0135   60 0972 0177
          FMP  FACTR                               105   0177   39 0046 0096
          FOV  LNX10                               106   0096   34 0032 0082
          STU  LNX13                               107   0082   21 0972 0075
          FAD  LNX12                               108   0075   32 0028 0055
          STU  LNX12                               109   0055   21 0028 0081
          FSB  LNX11                               110   0081   33 0085 0111
          FOV  LNX11                               111   0111   34 0085 0185
          RAM   8003                               112   0185   67 8003 0043
          RAU   8002                               113   0043   60 8002 0201
          FSB  SIZE7                               114   0201   33 0254 0131
          BMI  LNX07                               115   0131   46 0034 0235
          LDD  LNX12                               116   0235   69 0028 0181
          STO  LNX11                               117   0181   24 0085 0138
          RAU  LNX13                               118   0138   60 0972 0227
          FMP  LNX10                               119   0227   39 0032 0132
          STU  LNX13   LNX06                       120   0132   21 0972 0299
LNX07     RAU  LNX12                               121   0034   60 0028 0033
          FMP  FPTWO                               122   0033   39 0074 0124
          FSB  LNX05   LNX08                       123   0124   33 0077 0053
FPONE      10   0000    0051                       124   0024   10 0000 0051
FPTWO      20   0000    0051                       125   0074   20 0000 0051
SIZE7      10   0000    0043                       126   0254   10 0000 0043
LNTEN      23   0258    5151                       127   0092   23 0258 5151
FIFTY      50   0000    0000                       128   0060   50 0000 0000
SIXTY      00   0000    0060                       129   0016              60
LNX14      01   2345    6789                       130   0061    1 2345 6789
EOOCR     STO  EXIT                                131   1150   24 0153 0156
          RAU   8002                               132   0156   60 8002 0215
          BMI  NEGAT   REDUC                       133   0215   46 0218 1019
NEGAT     FAD  TWOPI                               134   0218   32 0271 0047
          BMI  NEGAT                               135   0047   46 0218 0251
          FSB  ONEPI   COSIO                       136   0251   33 0954 0231
REDUC     FSB  TWOPI                               137   1019   33 0271 0097
          BMI          REDUC                       138   0097   46 1200 1019
          FAD  ONEPI   COSIO                       139   1200   32 0954 0231
COSIO     STU  THETA                               140   0231   21 0036 0139
          RSU  FPONE                               141   0139   61 0024 0279
          STU  TERMM                               142   0279   21 0084 0187
          STU  FUNKT                               143   0187   21 0192 0045
          STL  ENNN    NEGST                       144   0045   20 0949 0002
EOOSR     STO  EXIT                                145   1250   24 0153 0206
          RAU   8002                               146   0206   60 8002 0265
          BMI  NEGAV   REDUO                       147   0265   46 0268 1069
NEGAV     FAD  TWOPI                               148   0268   32 0271 0147
          BMI  NEGAV                               149   0147   46 0268 0951
          FSB  ONEPI   SINET                       150   0951   33 0954 0281
REDUO     FSB  TWOPI                               151   1069   33 0271 0197
          BMI          REDUO                       152   0197   46 1300 1069
          FAD  ONEPI   SINET                       153   1300   32 0954 0281
SINET     STU  THETA                               154   0281   21 0036 0189
          RSU   8003                               155   0189   61 8003 0247
          STU  TERMM                               156   0247   21 0084 0237
          STU  FUNKT                               157   0237   21 0192 0095
          LDD  FPONE                               158   0095   69 0024 0277
          STO  ENNN    NEGST                       159   0277   24 0949 0002
NEGST     RAU  ENNN                                160   0002   60 0949 0203
          FAD  FPONE                               161   0203   32 0024 1001
          STU  NPONE                               162   1001   21 0256 0009
          FAD  FPONE                               163   0009   32 0024 1051
          STU  ENNN                                164   1051   21 0949 0052
          RSU  TERMM                               165   0052   61 0084 0239
          FMP  TNETA                               166   0239   39 0036 0086
          FMP  THETA                               167   0086   39 0036 0136
          FOV  NPONE                               168   0136   34 0256 0956
          FOV  ENNN                                169   0956   34 0949 0999
          STU  TERMM                               170   0999   21 0084 0287
          RAM  FUNKT                               171   0287   67 0192 0297
          STL  FMAG                                172   0297   20 1101 1004
          RAM  TERMM                               173   1004   67 0084 0289
          RAU   8002                               174   0289   60 8002 0947
          FOV  FMAG                                175   0947   34 1101 1151
          FSB  SIZE8                               176   1151   33 1054 0931
          BMI  ENUFF                               177   0931   46 0134 0285
          RAU  FUNKT                               178   0285   60 0192 0997
          FAD  TERMM                               179   0997   32 0084 0161
          STU  FUNKT   NEGST                       180   0161   21 0192 0002
ENUFF     RAL  FUNKT   EXIT                        181   0134   65 0192 0153
SIZE8      10   0000    0043                       182   1054   10 0000 0043
TWOPI      62   8318    5351                       183   0271   62 8318 5351
ONEPI      31   4159    2751                       184   0954   31 4159 2751
FPONE      10   0000    0051                       185   0024   10 0000 0051
EOOAU     STO  SEXT                             1  186   1350   24 0253 1006
          BMI  SERR                             2  187   1006   46 0059 0110
          NZE          SEXT                     3  188   0110   45 0114 0253
          STU  SA                               4  189   0114   21 0918 0921
          FAD  S10                              5  190   0921   32 0174 1201
          FMP  SNAF    SB                       6  191   1201   39 1104 1154
SB        STU  SSAV    SAS                      7  192   1154   21 0008 0211
SAS       RAU  SA               B  CAPT  A      8  193   0211   60 0918 0173
          FOV  SSAV                             9  194   0173   34 0008 0058
          FAD  SSAV                            10  195   0058   32 0008 0935
          FMP  SHAF                            11  196   0935   39 1104 1204
          FSB  SSAV                            12  197   1204   33 0008 0985
          NZU          SR                      13  198   0985   44 0939 0040
          SMI          SR                      14  199   0939   46 0242 0040
          FAD  SSAV                            15  200   0242   32 0008 1035
          STU  SSAV    SAS                     16  201   1035   21 0008 0211
SR        RAU  SSAV    SEXT                    17  202   0040   60 0008 0253
SERR      HLT   0000   SEXT                    18  203   0059    1 0000 0253
SNAF       50   0000    0050                   19  204   1104   50 0000 0050
S10        10   0000    0051                   20  205   0174   10 0000 0051
EOERF     STO  OUT                                 206   1400   24 0953 1056
```

```
          BMI NGTVE    PSTVE                 207   1056   46 0159 0160
NGTVE     STU TEM1                           208   0159   21 0164 0017
          RAM TEM1                           209   0017   67 0164 1119
          RAU   8002                         210   1119   60 8002 0927
          STU ARGG                           211   0927   21 0182 1085
          LDD MUNIT                          212   1085   69 0188 0141
          STD COEFF    APPRO                 213   0141   24 0044 1047
PSTVE     STU ARGG                           214   0160   21 0182 1135
          LDD UNIT                           215   1135   69 0238 0191
          STD COEFF    APPRO                 216   0191   24 0044 1047
APPRO     RAU ARGG                           217   1047   60 0182 0937
          FMP A6AA                           218   0937   39 0090 0140
          FAD A5AA                           219   0140   32 0093 1169
          FMP ARGG                           220   1169   39 0182 0232
          FAD A4AA                           221   0232   32 1185 0261
          FMP ARGG                           222   0261   39 0182 0282
          FAD A3AA                           223   0282   32 1235 0911
          FMP ARGG                           224   0911   39 0182 0932
          FAD A2AA                           225   0932   32 1285 0961
          FMP ARGG                           226   0961   39 0182 0982
          FAD A1AA                           227   0982   32 1335 1011
          FMP ARGG                           228   1011   39 0182 1032
          FAD UNIT                           229   1032   32 0238 0915
          FMP   8003                         230   0915   39 8003 1219
          FMP   8003                         231   1219   39 8003 0223
          FMP   8003                         232   0223   39 8003 0977
          FMP   8003                         233   0977   39 8003 0981
          STU TEM1                           234   0981   21 0164 0067
          RAU UNIT                           235   0067   60 0238 0143
          FDV TEM1                           236   0143   34 0164 0214
          STU TEM1                           237   0214   21 0164 0117
          RAU UNIT                           238   0117   60 0238 0193
          FSB TEM1                           239   0193   33 0164 0241
          FMP COEFF    OUT                   240   0241   39 0044 0953
A1AA       70   5230    7849                 241   1335   70 5230 7849
A2AA       42   2820    1249                 242   1285   42 2820 1249
A3AA       92   7052    7248                 243   1235   92 7052 7248
A4AA       15   2014    3047                 244   1185   15 2014 3047
A5AA       27   6567    2047                 245   0093   27 6567 2047
A6AA       43   0638    0046                 246   0090   43 0638 0046
UNIT       10   0000    0051                 247   0238   10 0000 0051
MUNIT  -   10   0000    0051                 248   0188   10 0000 0051
START     LDD GAMIN                          249   1999   69 0100 1003
          STD GAM11    LOOP1                 250   1003   24 1106 0209
LOOP1     RAU PI                             251   0209   60 0250 0155
          FDV A                              252   0155   34 0103 1053
          FMP   8003                         253   1053   39 8003 0257
          STU TEMP1                          254   0257   21 0012 0965
          RAU PI                             255   0965   60 0250 0205
          FDV B                              256   0205   34 0104 1254
          FMP   8003                         257   1254   39 8003 0957
          STU TEMP2                          258   0957   21 0062 1015
          RAU GAM11                          259   1015   60 1106 1061
          FMP   8003                         260   1061   39 8003 1065
          FSB TEMP1              CALCULATE   261   1065   33 0012 0989
          FSB TEMP2              KAPPA       262   0989   33 0062 1039
          STU KAPSQ              SQUARED     263   1039   21 0094 1097
          LDD POINT                          264   1097   69 0101 1304
          RAA   8001   CONT1                 265   1304   80 8001 0210
CONT1     LDD GAUSS                          266   0210   69 0107 0260
          RAB   8001   LOOP3                 267   0260   82 8001 0066
LOOP3     LDD ONE                            268   0066   69 0050 1103
          STD M                              269   1103   24 1156 0259
          STD N        LOOP2                 270   0259   24 0500 1153
LOOP2     RAU M                              271   1153   60 1156 1111
          FMP PI                             272   1111   39 0250 1450
          FDV A                              273   1450   34 0103 1203
          FMP   8003                         274   1203   39 8003 1007
          STU ALPH2                          275   1007   21 0112 1115
          RAU N                              276   1115   60 0500 0255
          FMP PI                             277   0255   39 0250 1500
          FDV B                              278   1500   34 0104 1354
          FMP   8003                         279   1354   39 8003 1057
          STU BETA2                          280   1057   21 0162 1165
          FAD ALPH2                          281   1165   32 0112 1089
          FAD KAPSQ                          282   1089   32 0094 0971
          LDD          EOOAU     CALCULATE   283   0971   69 0224 1350
          STU GAMMN              GAMMA MN    284   0224   21 0078 1031
          RAU RI     B                       285   1031   60 4900 0955
          FDV TWO                            286   0955   34 0150 1550
          FMP   8003                         287   1550   39 8003 1253
          FMP KAPSQ                          288   1253   39 0094 0144
          STU TEMP1                          289   0144   21 0012 1215
          RAU Z      A                       290   1215   60 2300 1005
          FMP GAM11                          291   1005   39 1106 1206
          FAD TEMP1                          292   1206   32 0012 1139
          RAL   8003                         293   1139   65 8003 1147
          LDD          EOOEA                 294   1147   69 1600 1050
          RAU   8002                         295   1600   60 8002 0959
          FMP FI     B                       296   0959   39 4905 1055
          FDV GAMMN                          297   1055   34 0078 0128
          STU EXPO1                          298   0128   21 1082 1385
          RAU Z      A                       299   1385   60 2300 1105
          FSB C                              300   1105   33 0105 1081
          FMP TWO                            301   1081   39 0150 1850
          FMP GAMMN                          302   1650   39 0078 0178
          RAL   8003                         303   0178   65 8003 1435
          LDD          EOOEA                 304   1435   69 0288 1050
          RSU   8002                         305   0288   61 8002 1197
          FAD ONE                            306   1197   32 0050 1027
          STU TEMP1                          307   1027   21 0012 1265
          RSU C                              308   1265   61 0105 1009
          FMP TWO                            309   1009   39 0150 1700
          FMP GAMMN                          310   1700   39 0078 0228
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          RAL  8003                             311    0228    65 8003 1485
          LDD              EOOEA                312    1485    69 0938 1050
          RAU  8002                             313    0938    60 8002 1247
          FAD  ONE                              314    1247    32 0050 1077
          STU  TEMP2                            315    1077    21 0062 1315
          RAU  TEMP1                END         316    1315    60 0012 0167
          FDV  TEMP2                CORRECTION  317    0167    34 0062 0212
          STU  ENDCO                FACTOR      318    0212    21 0116 1269
          RSU  Z       A                        319    1269    61 2300 1155
          FMP  GAMMN                            320    1155    39 0078 0278
          STU  ARG                              321    0278    21 1132 1535
          RAL  ARG                              322    1535    65 1132 0987
          LDD              EOOEA                323    0987    69 0190 1050
          STL  EXP02                            324    0190    20 0145 0048
          RAM  ARG                              325    0048    67 1132 1037
          LDD              EOOEA                326    1037    69 0240 1050
          STL  EXP03                            327    0240    20 0195 0098
          RAU  Z       A                        328    0098    60 2300 1205
          FDV  HI      B                        329    1205    34 4900 1750
          STU  TEMP1                            330    1750    21 0012 1365
          RAU  RI      B                        331    1365    60 4900 1255
          FMP  GAMMN                            332    1255    39 0078 0920
          FDV  TWO                              333    0928    34 0150 1800
          STU  TEMP2                            334    1800    21 0062 1415
          RAU  TEMP1                            335    1415    60 0012 0217
          FSR  TEMP2                            336    0217    33 0062 1189
          LDD              EOERF                337    1189    69 0292 1400
          FAD  ONE                              338    0292    32 0050 1127
          FMP  EXP02                            339    1127    39 0145 0245
          STU  TERM1                            340    0245    21 1850 1303
          RAU  TEMP1                            341    1303    60 0012 0267
          FAD  TEMP2                            342    0267    32 0062 1239
          LDD              EOERF                343    1239    69 0942 1400
          STU  TEMP1                            344    0942    21 0012 1465
          RAU  ONE                              345    1465    60 0050 1305
          FSR  TEMP1                            346    1305    33 0012 1289
          FMP  EXP03                            347    1289    39 0195 0295
          FAD  TERM1                            348    0295    32 1850 1177
          FMP  EXP01                            349    1177    39 1082 1182
          FMP  ENDCO                            350    1182    39 0116 0166
          FAD  COFAC                CORRECTION  351    0166    32 1319 0945
          STU  COFAC                FACTOR      352    0945    21 1319 1022
          RAU  HARM                             353    1022    60 0106 1161
          FSB  M                                354    1161    33 1156 0083
          NZE              CONT2                355    0083    45 0186 1087
          RAU  M                                356    0186    60 1156 1211
          FAD  TWO                              357    1211    32 0150 1227
          STU  M           LOOP2                358    1227    21 1156 1153
CONT2     RAU  HARM                             359    1087    60 0106 1261
          FSB  N                                360    1261    33 0500 1277
          NZE              CONT3                361    1277    45 0080 1131
          RAU  N                                362    0080    60 0500 1355
          FAD  TWO                              363    1355    32 0150 1327
          STU  N           LOOP2                364    1327    21 0500 1153
CONT3     SXB  0001                             365    1131    53 0001 1137
          NZB  LOOP3                            366    1137    42 0066 0291
          RAU  00                               367    0291    60 0108 0063
          FDV  DIFCO                            368    0063    34 0109 1059
          FDV  A                                369    1059    34 0103 1353
          FDV  B                                370    1353    34 0104 1404
          FMP  COFAC                            371    1404    39 1319 1369
          STU  COFAC                            372    1369    21 1319 1072
          RAU  N       A            CALCULATE   373    1072    60 2500 1405
          FDV  COFAC                CORRECTED   374    1405    34 1319 1419
          STU  NCOR    A            DATA        375    1419    21 2700 1403
          LDD  Z       A                        376    1403    69 2300 1453
          STD  1977                             377    1453    24 1977 0130
          LDD  N       A                        378    0130    69 2500 1503
          STD  1978                             379    1503    24 1978 1181
          LDD  NCOR    A                        380    1181    69 2700 1553
          STD  1979                             381    1553    24 1979 1232
          LDD  COFAC                            382    1232    69 1319 1122
          STD  1980                             383    1122    24 1980 0133
          LDD  GAM11                            384    0133    69 1106 1109
          STD  1981                             385    1109    24 1981 0184
          PCH  1977                             386    0184    71 1977 1377
          LDD  ZERO                             387    1377    69 0000 1603
          STD  COFAC                            388    1603    24 1319 1172
          SXA  0001                             389    1172    51 0001 0978
          NZA  CONT1       CONT5                390    0978    40 0210 1282
CONT5     LDD  POINT                            391    1282    69 0101 1454
          RAA  8001                             392    1454    80 8001 0960
          LDD  ZERO                             393    0960    69 0000 1653
          STD  SUMA                             394    1653    24 1256 1159
          STD  SMLNA                            395    1159    24 0262 1515
          STD  SUMZ                             396    1515    24 0968 1021
          STD  SUMZ2                            397    1021    24 0274 1427
          STD  ZSMLA       LOOP4                398    1427    24 0180 0183
LOOP4     RAU  NCOR    A                        399    0183    60 2700 1455
          FAD  SUMA                             400    1455    32 1256 0233
          STU  SUMA                             401    0233    21 1256 1209
          RAU  NCOR    A                        402    1209    60 2700 1505
          LDD              LNX01                403    1505    69 0158 1100
          FAD  SMLNA                            404    0158    32 0262 1339
          STU  SMLNA                            405    1339    21 0262 1565
          RAU  Z       A            FORM SUMS   406    1565    60 2300 1555
          FAD  SUMZ                 FOR LEAST   407    1555    32 0968 0995
          STU  SUMZ                 SQUARES     408    0995    21 0968 1071
          RAU  Z       A            ANALYSIS    409    1071    60 2300 1605
          FMP  Z       A                        410    1605    39 2300 1900
          FAD  SUMZ2                            411    1900    32 0274 1251
          STU  SUMZ2                            412    1251    21 0274 1477
```

```
          RAU NCOR  A                          413   1477   60 2700 1655
          LDD           LNK01                  414   1655   69 0208 1100
          FMP Z     A                          415   0208   39 2300 1950
          FAD ZSMLA                            416   1950   30 0180 1107
          STU ZSMLA                            417   1107   01 0180 0283
          SXA  0001                            418   0083   51 0001 1389
          NZA LOOP4     CONT6                  419   1389   40 0183 0243
CONT6     RAU SMLNA                            480   0043   60 0262 0917
          FMP SUMZ                             401   0917   39 0968 1018
          STU TEMP1                            422   1018   01 0012 1615
          RAU DATPT                            423   1615   60 0100 1157
          FMP ZSMLA                            424   1157   39 0180 0230
          STU TEMPO                            425   0230   21 0062 1665
          RAU DATPT                            426   1665   60 0102 1007
          FMP SUMZ2                            407   1007   39 0074 0924
          STU TEMP3                            428   0924   21 1028 1031
          RAU SUMZ                             489   1031   60 0968 0073
          FMP SUMZ                             430   0273   39 0968 1068
          STU TEMP4                            431   1068   01 1022 0125
          RAU TEMP3                            432   0125   60 1028 0933
          FSB TEMP4                            433   0933   33 1228 1049
          STU TEMP3                            434   1049   21 1008 1281
          RAU TEMP1                            435   1081   60 0012 0967
          FSB TEMP2                            436   0967   33 0060 1439
          FDV TEMP3                            437   1439   34 1028 1078
          STU NWGAM                            438   1078   21 1332 1585
          FDV 10000                            439   1585   34 1000 1301
          STU PREC                             440   1301   21 1306 1259
          RAU GAM11                            441   1859   60 1106 1311
          FSB NWGAM                            442   1311   33 1332 1309
          RAM  8003                            443   1309   67 8003 1017
          RAU  8002                            444   1017   60 8002 0175
          FSB PREC                             445   0175   33 1306 0983
          BMI CONT8     CONT7                  446   0983   46 0036 1187
CONT7     RAU NWGAM                            447   1187   60 1332 1037
          STU GAM11     LOOP1                  448   1237   21 1106 0209
CONT8     RAU NWGAM                            449   0236   60 1332 1287
          FMP NWGAM           GAMMA            450   1287   39 1332 1382
          STU GAMSQ           SQUARED          451   1380   01 0286 1489
          RAU PI                               452   1489   60 0250 1705
          FDV A                                453   1705   34 0103 1703
          STU ALPH2                            454   1703   21 0112 1715
          FMP ALPH2           ALPHA            455   1715   39 0118 0910
          STU ALPHQ           SQUARED          456   0912   21 0112 1765
          RAU PI                               457   1765   60 0250 1755
          FDV B                                458   1755   34 0104 1504
          STU BETAQ                            459   1504   01 0162 1815
          FMP BETA2           BETA             460   1815   39 0162 0968
          STU BETAQ           SQUARED          461   0962   21 0162 1865
          RAU GAMSQ                            462   1865   60 0086 0941
          FSB ALPHQ           KAPPA            463   0941   33 0112 1539
          FSB BETA2           SQUARED          464   1539   33 0160 1589
          LDD           EDDAU                  465   1589   69 0992 1350
          STU KAPPA                            466   0990   01 0146 1099
          RAU ONE                              467   1099   60 0050 1805
          FDV KAPPA                            468   1805   34 0146 0196
          FMP CONVT           DIFFUSION        469   0196   39 0950 1361
          STU DL              LENGTH           470   1351   21 1356 1359
          LDD GAMIN                            471   1359   69 0100 1753
          STD  1977                            472   1753   24 1977 0280
          LDD NWGAM                            473   0080   69 1332 1635
          STD  1978                            474   1635   24 1978 1331
          LDD PREC                             475   1331   69 1306 1409
          STD  1979                            476   1409   24 1979 1432
          LDD POINT                            477   1430   69 0101 1554
          STD  1980                            478   1554   04 1980 1033
          LDD DL                               479   1033   69 1356 1459
          STD  1981                            480   1459   24 1981 0034
          PCH  1977      8000                  481   0034   71 1977 8000
```

APPENDIX J

IBM 650 Program for Determination of Material Buckling and Effective Multiplication Factor

This code was written to determine the material buckling, B_m^2, and the effective multiplication factor, k_{eff}, in the KSU exponential pile. The program was written in SOAP II and floating point form. The object program and a logic diagram are included in this section.

The program is based upon the point thermal source solution to the thermal diffusion equation. An accurate value of γ_{11} is determined by the iteration procedure outlined previously using the correction factors listed in Table 1. B_m^2 is calculated from the equation

$$B_m^2 = \left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{b}\right)^2 - \gamma_{11}^2 .$$

The program then calculates the infinite multiplication factor, k_∞, from

$$k_\infty = 1 + B_m^2 \, (L_t^2 + \tau).$$

The effective multiplication factor, k_{eff}, can then be calculated from

$$k_{eff} = \frac{k_\infty \, e^{-B_G^2 \tau}}{1 + B_G^2 \, L_t^2}$$

where B_G^2 is the geometric buckling. By increasing the effective dimensions of the multiplying medium, k_{eff} can be extrapolated to critical pile size. This is done by reading in new values for a, b, and d and starting the program over at CON11 by means of a transfer card.

Input forms for this program are given in Table 35. All input should be in the form of one word load cards.

Table 35. Input forms for IBM 650 program for material buckling and effective multiplication factor.

Symbol	Explanation	Drum Storage Location
FIRST	Initial estimate of γ_{11}	0100
POINT	Number of Data Points, form 00 0000 00xx	0101
DATPT	Number of Data Points, floating point form	0102
A	Extrapolated x-dimension	0103
B	Extrapolated y-dimension	0104
C	Extrapolated z-dimension	0105
X	x co-ord of data	0106
Y	y co-ord of data	0107
L	Lattice diffusion length	0108
TAU	Fermi age	0109
D	z dimension of active lattice	0110
N	Count Rates, to be stored consecutively, starting at	0501
z	Data co-ordinates, to be stored consecutively, starting at	0301

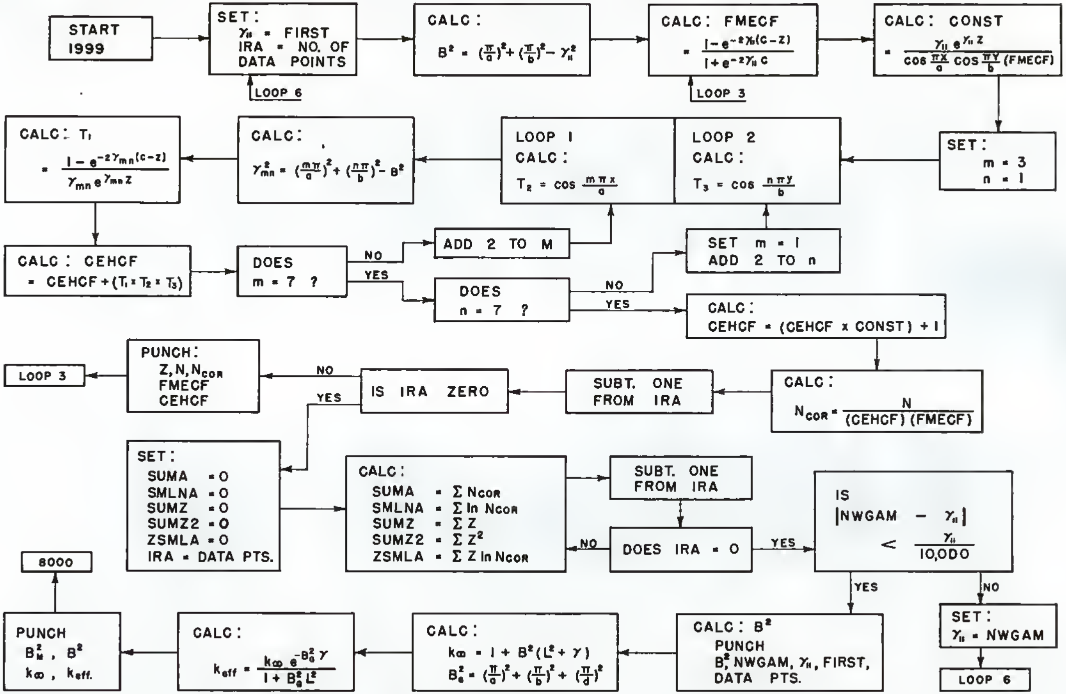
Output from this program is in three forms. Form one is punched after calculation of each correction factor. Form two is the results of the buckling calculation. Form three gives the buckling and the multiplication factors. Table 36 lists the output forms.

Table 36. Output forms for IBM 650 program for material buckling and effective multiplication factor.

WORD 1	2	3	4	5
Form 1:				
z	N	N (corrected)	C_H	C_E
Form 2:				
B_m^2	γ_{11}, last value	γ_{11}, next to last value	γ_{11}, initial value	No. of Data Points
Form 3:				
B_m^2	B_G^2	k_∞	k_{eff}	--

The operating time necessary to calculate the correction factor for one data point using four harmonics is approximately 45 seconds. The capacity of the program is 200 data points.

Logic Diagram for I.B.M. 650 Program for Material Buckling, B_m^2, and Multiplication Factor, k_{eff}.



LOGIC DIAGRAM, APPENDIX J

```
          BLR   1951      1958                       1   0000    00  0000  0000
          BLR   1977      1984                       2   0000    00  0000  0000
          BLN   0300      0900                       3   0000    00  0000  0000
          SYN  FIRST      0100                       4   0000    00  0000  0000
          SYN  POINT      0101      INDEX FORM       5   0000    00  0000  0000
          SYN  DATPT      0102      DATA FORM        6   0000    00  0000  0000
          SYN  A          0103      X DIMEN          7   0000    00  0000  0000
          SYN  B          0104      Y DIMEN          8   0000    00  0000  0000
          SYN  C          0105      Z DIMEN          9   0000    00  0000  0000
          SYN  X          0106         DATA         10   0000    00  0000  0000
          SYN  Y          0107      COORDINATE      11   0000    00  0000  0000
          SYN  L          0108      DIFFUSION       12   0000    00  0000  0000
          SYN  TAU        0109      FERMI AGE       13   0000    00  0000  0000
          SYN  D          0110                      14   0000    00  0000  0000
          SYN  Z          0300                      15   0000    00  0000  0000
          SYN  N          0500                      16   0000    00  0000  0000
          SYN  NCOR       0700                      17   0000    00  0000  0000
          SYN  START      1999                      18   0000    00  0000  0000
ZERO       00   0000      0000                      19   0000    00  0000  0000
ONE        10   0000      0051                      20   0050    10  0000  0051
TWO        20   0000      0051                      21   0150    20  0000  0051
MTWO    -  20   0000      0051                      22   0200    20  0000  0051
THREE      30   0000      0051                      23   0250    30  0000  0051
PI         31   4160      0051                      24   0950    31  4160  0051
SEVEN      70   0000      0051                      25   1000    70  0000  0051
CONVT      25   3600      0051                      26   1050    25  3600  0051
10000      10   0000      0055                      27   1100    10  0000  0055
EOOCL     STD  ZZZ1                                 28   1150    24  0003  0006
          LDD  ZZZ10                                29   0006    69  0009  0012
          STD   1977                                30   0012    24  1977  0030
          STD   1978                                31   0030    24  1978  0031
          STD   1979                                32   0031    24  1979  0032
          STD   1980                                33   0032    24  1980  0033
          STD   1981                                34   0033    24  1981  0034
          STD   1982                                35   0034    24  1982  0035
          STD   1983                                36   0035    24  1983  0036
          STD   1984      ZZZ1                      37   0036    24  1984  0003
ZZZ10      00   0000       0000                     38   0009    00  0000  0000
LNX01     STD  LNX08                                39   1200    24  0053  0056
          NZE             LNX14                     40   0056    45  0010  0011
          BMI  LNX14                                41   0010    46  0011  0014
          STU  LNX09                                42   0014    21  0018  0021
          RSL  FPONE                                43   0021    66  0024  0029
          STD  LNX10                                44   0029    24  0082  0085
          STL  LNX02                                45   0085    20  0039  0042
          RAU  LNX09                                46   0042    60  0018  0023
          STL  LNX05                                47   0023    20  0027  0080
          STL  LNX11                                48   0080    20  0135  0038
          SLT   0008                                49   0038    35  0008  0007
          SUP  FIFTY                                50   0007    11  0060  0015
          NZE             LNX04                     51   0015    45  0068  0019
          BMI             LNX03                     52   0068    46  0071  0022
          RSU   8003                                53   0071    61  8003  0079
          LDD  FPONE                                54   0079    69  0024  0077
          STD  LNX02      LNX03                     55   0077    24  0039  0022
LNX03     SRT   0008                                56   0022    30  0008  0041
          SCT   0000                                57   0041    36  0000  0013
          AUP  SIXTY                                58   0013    10  0016  0121
          SUP   8002                                59   0121    11  8002  0129
          RAU   8003                                60   0129    60  8003  0037
          FMP  LNX02                                61   0037    39  0039  0089
          FMP  LNTEN                                62   0089    39  0092  0142
          STU  LNX05      LNX04                     63   0142    21  0027  0019
LNX04     RAL  LNX09                                64   0019    65  0018  0073
          SRT   0002                                65   0073    30  0002  0179
          RAU   8002                                66   0179    60  8002  0087
          ALO  FIFTY                                67   0087    15  0060  0065
          SLT   0002                                68   0065    35  0002  0171
          FAD  FPONE                                69   0171    32  0024  0001
          STU  LNX09                                70   0001    21  0018  0221
          FSB  FPTWO                                71   0221    33  0074  0051
          FDV  LNX09                                72   0051    34  0018  0118
          STU  LNX13                                73   0118    21  0072  0025
          STD  LNX12                                74   0025    24  0028  0081
          STD  LNX11                                75   0081    24  0135  0088
          FMP   8001                                76   0088    39  8001  0091
          STU  FACTR      LNX06                     77   0091    21  0046  0049
LNX06     RAU  LNX10                                78   0049    60  0082  0137
          FAD  FPTWO                                79   0137    32  0074  0151
          STU  LNX10                                80   0151    21  0082  0165
          RAU  LNX13                                81   0165    60  0072  0127
          FMP  FACTR                                82   0127    39  0046  0096
          FDV  LNX10                                83   0096    34  0082  0132
          STU  LNX13                                84   0132    21  0072  0075
          FAD  LNX12                                85   0075    32  0028  0005
          STU  LNX12                                86   0005    21  0028  0131
          FSB  LNX11                                87   0131    33  0135  0061
          FDV  LNX11                                88   0061    34  0135  0235
          RAM   8003                                89   0235    67  8003  0043
          RAU   8002                                90   0043    60  8002  0201
          FSB  SIZE7                                91   0201    33  0004  0181
          BMI  LNX07                                92   0181    46  0084  0285
          LDD  LNX12                                93   0285    69  0028  0231
          STD  LNX11                                94   0231    24  0135  0138
          RAU  LNX13                                95   0138    60  0072  0177
          FMP  LNX10                                96   0177    39  0082  0182
          STU  LNX13      LNX06                     97   0182    21  0072  0049
LNX07     RAU  LNX12                                98   0084    60  0028  0083
          FMP  FPTWO                                99   0083    39  0074  0124
          FSB  LNX05      LNX08                    100   0124    33  0027  0053
FPONE      10   0000       0051                    101   0024    10  0000  0051
FPTWO      20   0000       0051                    102   0074    20  0000  0051
SIZE7      10   0000       0043                    103   0004    10  0000  0043
LNTEN      23   0258       5151                    104   0092    23  0258  5151
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FIFTY     50   0000    0000                    105   0060   50 0000 0000
SIXTY     00   0000    0060                    106   0016   00 0000 0060
LNX14     01   2345    6789                    107   0011   01 2345 6789
EOOCR    STD  EXIT                             108   1250   24 0153 0156
         RAU   8002                            109   0156   60 8002 0115
         BMI  NEGAT   REDUC                    110   0115   46 0168 0069
NEGAT    FAD  TWOPI                            111   0168   32 0271 0047
         BMI  NEGAT                            112   0047   46 0168 0251
         FSB  ONEPI   COSIO                    113   0251   33 0054 0281
REDUC    FSB  TWOPI                            114   0069   33 0271 0097
         BMI          REDUC                    115   0097   46 1300 0069
         FAD  ONEPI   COSIO                    116   1300   32 0054 0281
COSIO    STU  THETA                            117   0281   21 0086 0139
         RSU  FPONE                            118   0139   61 0024 0229
         STU  TERMM                            119   0229   21 0134 0187
         STU  FUNKT                            120   0187   21 0192 0045
         STL  ENNN    NEGST                    121   0045   20 0099 0002
EOOSR    STD  EXIT                             122   1350   24 0153 0206
         RAU   8002                            123   0206   60 8002 0165
         BMI  NEGAV   REDUU                    124   0165   46 0218 0119
NEGAV    FAD  TWOPI                            125   0218   32 0271 0147
         BMI  NEGAV                            126   0147   46 0218 0901
         FSB  ONEPI   SINET                    127   0901   33 0054 0931
REDUU    FSB  TWOPI                            128   0119   33 0271 0197
         BMI          REDUU                    129   0197   46 1400 0119
         FAD  ONEPI   SINET                    130   1400   32 0054 0931
SINET    STU  THETA                            131   0931   21 0086 0189
         RSU   8003                            132   0189   61 8003 0247
         STU  TERMM                            133   0247   21 0134 0237
         STU  FUNKT                            134   0237   21 0192 0095
         LDD  FPONE                            135   0095   69 0024 0227
         STD  ENNN    NEGST                    136   0227   24 0099 0002
NEGST    RAU  ENNN                             137   0002   60 0099 0203
         FAD  FPONE                            138   0203   32 0024 0951
         STU  NPONE                            139   0951   21 0256 0059
         FAD  FPONE                            140   0059   32 0024 1001
         STU  ENNN                             141   1001   21 0099 0052
         RSU  TERMM                            142   0052   61 0134 0239
         FMP  THETA                            143   0239   39 0086 0136
         FMP  THETA                            144   0136   39 0086 0186
         FDV  NPONE                            145   0186   34 0256 0906
         FDV  ENNN                             146   0906   34 0099 0149
         STU  TERMM                            147   0149   21 0134 0287
         RAM  FUNKT                            148   0287   67 0192 0297
         STL  FMAG                             149   0297   20 1051 0154
         RAM  TERMM                            150   0154   67 0134 0289
         RAU   8002                            151   0289   60 8002 0947
         FDV  FMAG                             152   0947   34 1051 1101
         FSB  SIZE8                            153   1101   33 0204 0981
         BMI  ENUFF                            154   0981   46 0184 0935
         RAU  FUNKT                            155   0935   60 0192 0997
         FAD  TERMM                            156   0997   32 0134 0111
         STU  FUNKT   NEGST                    157   0111   21 0192 0002
ENUFF    RAL  FUNKT   EXIT                     158   0184   65 0192 0153
SIZE8     10   0000    0043                    159   0204   10 0000 0043
TWOPI     62   8318    5351                    160   0271   62 8318 5351
ONEPI     31   4159    2751                    161   0054   31 4159 2751
FPONE     10   0000    0051                    162   0024   10 0000 0051
EDOEA    STD  AAA1            EXIT INSTR       163   1450   24 0253 0956
         STL  AAA2             STORE X         164   0956   20 0161 0064
         RAM  AAA2                             165   0064   67 0161 0215
         STL  AAA3            X FOR CALC       166   0215   20 0169 0122
         RAU  AAA3                             167   0122   60 0169 0123
         FMP  AAA16                            168   0123   39 0026 0076
         FAD  AAA15                            169   0076   32 0279 0055
         FMP  AAA3                             170   0055   39 0169 0219
         FAD  AAA14                            171   0219   32 0172 0199
         FMP  AAA3                             172   0199   39 0169 0269
         FAD  AAA13                            173   0269   32 0222 0249
         FMP  AAA3                             174   0249   39 0169 0919
         FAD  AAA12                            175   0919   32 0272 0299
         FMP  AAA3                             176   0299   39 0169 0969
         FAD  AAA11                            177   0969   32 0922 0949
         FMP  AAA3                             178   0949   39 0169 1019
         FAD  AAA10                            179   1019   32 0972 0999
         STU  AAA4                             180   0999   21 0254 0057
         FMP  AAA4                             181   0057   39 0254 0904
         STU  AAA4                             182   0904   21 0254 0157
         FMP  AAA4                             183   0157   39 0254 0954
         STU  AAA4                             184   0954   21 0254 0207
         RAU  AAA2                             185   0207   60 0161 0265
         BMI  AAA5    AAA6                     186   0265   46 0268 1069
AAA5     RAU  AAA10                            187   0268   60 0972 0277
         FDV  AAA4                             188   0277   34 0254 1004
         STU  AAA4    AAA6                     189   1004   21 0254 1069
AAA6     RAL  AAA4    AAA1                     190   1069   65 0254 0253
AAA10     10   0000    0051                    191   0972   10 0000 0051
AAA11     24   9998    6850                    192   0922   24 9998 6850
AAA12     31   2575    8349                    193   0272   31 2575 8349
AAA13     25   9137    1248                    194   0222   25 9137 1248
AAA14     17   1562    0047                    195   0172   17 1562 0047
AAA15     54   3020    0045                    196   0279   54 3020 0045
AAA16     69   0600    0044                    197   0026   69 0600 0044
EOOAU    STD  SEXT                           1 198   1500   24 0903 1006
         BMI  SERR                           2 199   1006   46 0159 0160
         NZE          SEXT                   3 200   0160   45 0114 0903
         STU  SA                             4 201   0114   21 0918 0921
         FAD  S10                            5 202   0921   32 0174 1151
         FMP  SHAF    SB                     6 203   1151   39 1054 1104
SB       STU  SSAV    SAB                    7 204   1104   21 0008 0211
SAB      RAU  SA              S CAPT A       8 205   0211   60 0918 0173
         FDV  SSAV                           9 206   0173   34 0008 0058
         FAD  SSAV                          10 207   0058   32 0008 0985
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          FMP SHAF                                   11 208   0985   39 1054 1154
          FSB SSAV                                   12 209   1154   33 0008 1035
          NZU            SR                          13 210   1035   44 0939 0040
          BMI            SR                          14 211   0939   46 0242 0040
          FAD SSAV                                   15 212   0242   32 0008 1085
          STU SSAV       SAV                         16 213   1085   21 0008 0211
SR        RAU SSAV       SEXT                        17 214   0040   60 0008 0903
SERR      HLT  0000      SEXT                        18 215   0159   01 0000 0903
SHAF       50  0000       0050                       19 216   1054   50 0000 0050
S10        10  0000       0051                       20 217   0174   10 0000 0051
START     LDD FIRST                 INITIAL             218   1999   69 0100 0953
          STD GAM11      LOOP6       GAMMA              219   0953   24 1056 0209
LOOP6     LDD POINT                 DATA POINT          220   0209   69 0101 1204
          RAA  8001                                     221   1204   80 8001 0210
          LDD ZERO                                      222   0210   69 0000 1003
          STD ALPHA                                     223   1003   24 1106 0259
          STD BETA                                      224   0259   24 0062 0915
          RAU GAM11                                     225   0915   60 1056 0261
          FMP GAM11                                     226   0261   39 1056 1156
          STU GAMSQ                 GAMMA SQD           227   1156   21 0260 0063
          STU TEMP1                                     228   0063   21 0968 0971
          RAU PI                                        229   0971   60 0950 0155
          FDV A                                         230   0155   34 0103 1053
          STU TEMP2                                     231   1053   21 0158 0911
          FMP TEMP2                   ALPHA             232   0911   39 0158 0208
          STU TEMP2                    SQD              233   0208   21 0158 0961
          RAU PI                                        234   0961   60 0950 0205
          FDV B                                         235   0205   34 0104 1254
          STU TEMP3                                     236   1254   21 0258 1011
          FMP TEMP3                    BETA             237   1011   39 0258 0908
          STU TEMP3                     SQD             238   0908   21 0258 1061
          RSU TEMP1                                     239   1061   61 0968 0223
          FAD TEMP2                                     240   0223   32 0158 1135
          FAD TEMP3                      R              241   1135   32 0258 1185
          STU RSQD       LOOP3          SQD             242   1185   21 0090 0093
LOOP3     LDD ZERO                                      243   0093   69 0000 1103
          STD CEHCF                                     244   1103   24 1206 0909
          RAU C                     CORRECTION          245   0909   60 0105 0959
          FSB Z         A                FOR            246   0959   33 2300 0927
          FMP GAM11                     END             247   0927   39 1056 1256
          FMP MTWO                         EFFECT       248   1256   39 0200 1550
          RAL  8003                                     249   1550   65 8003 0257
          LDD            EOOEA                          250   0257   69 0910 1450
          STL TEMP1                                     251   0910   20 0968 1021
          RAU ONE                   FUND   MODE         252   1021   60 0050 0255
          FSB TEMP1                 CORRECTION          253   0255   33 0968 0145
          STU FMECF                   FACTOR            254   0145   21 1600 1153
          RAU PI                     CALCULATE          255   1153   60 0950 0905
          FMP X                       CONSTANT          256   0905   39 0106 1306
          FDV A                         FACTOR          257   1306   34 0103 1203
          RAL  8003                 FOR CEHCF           258   1203   65 8003 1111
          LDD            EOOCH                          259   1111   69 0164 1250
          STL TEMP1                                     260   0164   20 0968 1071
          RAU PI                                        261   1071   60 0950 0955
          FDV B                                         262   0955   34 0104 1304
          FMP Y                                         263   1304   39 0107 0907
          RAL  8003                                     264   0907   65 8003 0965
          LDD            EOOCH                          265   0965   69 1018 1250
          STL TEMP2                                     266   1018   20 0158 1161
          RAU GAM11                                     267   1161   60 1056 1211
          FMP Z         A                               268   1211   39 2300 1650
          RAL  8003                                     269   1650   65 8003 0957
          LDD            EOOEA                          270   0957   69 0960 1450
          RAU  8002                                     271   0960   60 8002 1119
          FMP GAM11                                     272   1119   39 1056 1356
          FDV TEMP1                                     273   1356   34 0968 1068
          FDV TEMP2                                     274   1068   34 0158 0958
          FDV FMECF                                     275   0958   34 1600 1700
          STU CONST                  CONSTANT           276   1700   21 1354 1007
          LDD THREE                                     277   1007   69 0250 1253
          STD M                                         278   1253   24 1406 1009
          LDD ONE                                       279   1009   69 0050 1303
          STD N          LOOP2                          280   1303   24 0500 1353
LOOP2     RAU N                                         281   1353   60 0500 1005
          FMP PI                                        282   1005   39 0950 1750
          FMP Y                                         283   1750   39 0107 1057
          FDV B                                         284   1057   34 0104 1404
          RAL  8003                                     285   1404   65 8003 1261
          LDD            EOOCH                          286   1261   69 0214 1250
          STL TEMP3      LOOP1                          287   0214   20 0258 1311
LOOP1     RAU M                                         288   1311   60 1406 1361
          FMP PI                                        289   1361   39 0950 1800
          FMP X                                         290   1800   39 0106 1456
          FDV A                                         291   1456   34 0103 1403
          RAL  8003                                     292   1403   65 8003 1411
          LDD            EOOCH                          293   1411   69 0264 1250
          STL TEMP2                                     294   0264   20 0158 1461
          RAU M                                         295   1461   60 1406 1511
          FMP PI                                        296   1511   39 0950 1850
          FDV A                                         297   1850   34 0103 1453
          STU TEMP4                                     298   1453   21 1008 1561
          FMP TEMP4                                     299   1561   39 1008 1058
          STU ALPH2                                     300   1058   21 0112 1015
          RAU N                                         301   1015   60 0500 1055
          FMP PI                                        302   1055   39 0950 1900
          FDV B                                         303   1900   34 0104 1454
          STU TEMP4                                     304   1454   21 1008 1611
          FMP TEMP4                                     305   1611   39 1008 1108
          STU BETA2                                     306   1108   21 0162 1065
          FAD ALPH2                                     307   1065   32 0112 0989
          FSB RSQD                                      308   0989   33 0090 0017
          LDD            EOOAU                          309   0017   69 0020 1500
          STU GAMMA                                     310   0020   21 0224 0977
          RAU C                                         311   0977   60 0105 1059
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        RAU  C                              311  0977  60 0105 1059
        FSB  Z       A                      312  1059  33 2300 1027
        FMP  GAMMA                          313  1027  39 0224 0274
        FMP  MTWO                           314  0274  39 0200 1950
        RAL   8003                          315  1950  65 8003 1107
        LOO            EOOEA                316  1107  69 1010 1450
        STL  TEMP5                          317  1010  20 1115 1118
        RAU  GAMMA                          318  1118  60 0224 0929
        FMP  Z       A                      319  0929  39 2300 1201
        RAL   8003                          320  1201  65 8003 1109
        LOO            EOOEA                321  1109  69 0212 1450
        STL  TEMP6                          322  0212  20 0067 0070
        RAU  ONE                            323  0070  60 0050 1105
        FSB  TEMP5                          324  1105  33 1115 0141
        FOV  TEMP6                          325  0141  34 0067 0117
        FUV  CAMMA                          326  0117  34 0224 0924
        FMP  TEMP3                          327  0924  39 0258 1158
        FMP  TEMP2                          328  1158  39 0158 1208
        FAU  CEHCF                          329  1208  32 1206 0133
        STU  CENCF                          330  0133  21 1206 1159
        RAU  SEVEN                          331  1159  60 1000 1155
        FSB  M                              332  1155  33 1406 0183
        NZE  CONT1     CUNT2                333  0183  45 0236 0937
CONT1   RAU  M                              334  0236  60 1406 1661
        FAO  TWO                            335  1661  32 0150 1077
        STU  M         LOOP1                336  1077  21 1406 1311
CONT2   RAU  N                              337  0937  60 0500 1205
        FSB  SEVEN                          338  1205  33 1000 1127
        NZE  CONT3     CONT4                339  1127  45 0130 1031
CONT3   LUU  ONE                            340  0130  69 0050 1503
        STU  M                              341  1503  24 1406 1209
        RAU  N                              342  1209  60 0500 1255
        FAO  TWO                            343  1255  32 0150 1177
        STU  N         LOOP2                344  1177  21 0500 1353
CONT4   RAU  CENCF             CALC OF      345  1031  60 1206 1711
        FMP  CONST             HARMONIC     346  1711  39 1354 1504
        FAU  ONE               END          347  1504  32 0050 1227
        STU  CENCF             CORRECTION   348  1227  21 1206 1259
        RAU  N       A                      349  1259  60 2500 1305
        FOV  CEHCF                          350  1305  34 1206 1506
        FUV  FMECF                          351  1506  34 1600 1251
        STU  NCOR    A                      352  1251  21 2700 1553
        LUO  Z       A                      353  1553  69 2300 1603
        STD   1977                          354  1603  24 1977 0180
        LUO  N       A                      355  0180  69 2500 1653
        STD   1978                          356  1653  24 1978 1081
        LOU  NCOR    A                      357  1081  69 2700 1703
        STD   1979                          358  1703  24 1979 0232
        LDD  CEHCF                          359  0232  69 1206 1309
        STU   1980                          360  1309  24 1980 0233
        LUO  FMECF                          361  0233  69 1600 1753
        STO   1981                          362  1753  24 1981 0234
        PCH   1977                          363  0234  71 1977 1277
        SXA   0001                          364  1277  51 0001 0283
        NZA  LOOP3     CONT6                365  0283  40 0093 0987
CONT6   LDD  POINT                          366  0987  69 0101 1554
        RAA   8001                          367  1554  80 8001 1060
        LOO  ZERO                           368  1060  69 0000 1803
        STD  SUMA                           369  1803  24 1556 1359
        STO  SMLNA                          370  1359  24 0262 1165
        STO  SUMZ                           371  1165  24 1168 1121
        STD  SUMZ2                          372  1121  24 0974 1327
        STU  ZSMLA                          373  1327  24 0230 0933
        LOO  DATPT                          374  0933  69 0102 1355
        STO  P         LOOP5                375  1355  24 1258 1761
LOOP5   RAU  NCOR    A                      376  1761  60 2700 1405
        FAO  SUMA                           377  1405  32 1556 0983
        STU  SUMA                           378  0983  21 1556 1409
        RAU  NCOR    A                      379  1409  60 2700 1455
        LOO            LNX01                380  1455  69 1308 1200
        FAO  SMLNA                          381  1308  32 0262 1039
        STU  SMLNA                          382  1039  21 0262 1215
        RAU  Z       A                      383  1215  60 2300 1505
        FAD  SUMZ                           384  1505  32 1168 0195
        STU  SUMZ                           385  0195  81 1168 1171
        RAU  Z       A                      386  1171  60 2300 1555
        FMP  Z       A                      387  1555  39 2300 1301
        FAD  SUMZ2                          388  1301  32 0974 1351
        STU  SUMZ2                          389  1351  21 0974 1377
        RAU  NCOR    A                      390  1377  60 2700 1605
        LOD            LNX01                391  1605  69 1358 1200
        FMP  Z       A                      392  1358  39 2300 1401
        FAO  ZSMLA                          393  1401  32 0230 1157
        STU  ZSMLA                          394  1157  21 0230 1033
        SXA   0001                          395  1033  51 0001 1089
        NZA  LOOP5     CONT7                396  1089  40 1761 0143
CONT7   RAU  SMLNA                          397  0143  60 0262 0167
        FMP  SUMZ                           398  0167  39 1168 1218
        STU  TEMP1                          399  1218  21 0968 1221
        RAU  P                              400  1221  60 1258 0113
        FMP  ZSMLA                          401  0113  39 0230 0280
        STU  TEMP2                          402  0280  21 0158 1811
        RAU  P                              403  1811  60 1258 0163
        FMP  SUMZ2                          404  0163  39 0974 1024
        STU  TEMP3                          405  1024  21 0258 1861
        RAU  SUMZ                           406  1861  60 1168 0273
        FMP  SUMZ                           407  0273  39 1168 1268
        STU  TEMP4                          408  1268  21 1008 1911
        RAU  TEMP3                          409  1911  60 0258 0213
        FSB  TEMP4                          410  0213  33 1008 1235
        STU  TEMP3                          411  1235  21 0258 1961
        RAU  TEMP1                          412  1961  60 0968 0923
        FSB  TEMP2                          413  0923  33 0158 1285
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             FDV  TEMP3                                   414      1285     34  0258  1408
             STU  NWGAM                                   415      1408     21  0912  1265
             FOV  10000                                   416      1265     34  1100  1451
             STU  PREC                                    417      1451     21  1606  1459
             RAU  GAM11                                   418      1459     60  1056  0962
             FBR  NWGAM                                   419      0962     33  0912  1139
             RAM   8003                                   420      1139     67  8003  1047
             RAU   8002                                   421      1047     60  8002  1655
             FSB  PREC                                    422      1655     33  1606  1083
             BMI  CONT8     CONT9                         423      1083     46  0286  1037
CONT9        RAU  NWGAM                                   424      1037     60  0912  0217
             STU  GAM11     LOOP6                         425      0217     21  1056  0209
CONT8        RAU  PI                                      426      0286     60  0950  1705
             FOV  A                                       427      1705     34  0103  1853
             STU  ALPH2                                   428      1853     21  0112  1315
             FMP  ALPH2                                   429      1315     39  0112  1012
             STU  ALPH2                                   430      1012     21  0112  1365
             RAU  PI                                      431      1365     60  0950  1755
             FOV  B                                       432      1755     34  0104  1604
             STU  BETA2                                   433      1604     21  0162  1415
             FMP  BETA2                                   434      1415     39  0162  1062
             STU  BETA2                                   435      1062     21  0162  1465
             RSU  NWGAM                                   436      1465     61  0912  0267
             FMP  NWGAM                                   437      0267     39  0912  1112
             FAO  BETA2                                   438      1112     32  0162  1189
             FAO  ALPH2                CALCULATE          439      1189     32  0112  1239
             STU  BSQO                 MATERIAL           440      1239     21  0090  0193
             LOO  BSQO                 BUCKLING           441      0193     69  0090  0243
             STO   1977                                   442      0243     24  1977  0930
             LOO  NWGAM                                   443      0930     69  0912  1515
             STO   1978                                   444      1515     24  1978  1131
             LOO  GAM11                                   445      1131     69  1056  1509
             STD   1979                                   446      1509     24  1979  0282
             LOD  FIRST                                   447      0282     69  0100  1903
             STD   1980                                   448      1903     24  1980  1133
             LDD  POINT                                   449      1133     69  0101  1654
             STO   1981                                   450      1654     24  1981  0284
             PCH   1977     CON10                         451      0284     71  1977  1427
CON10        RAU  L                                       452      1427     60  0108  0263
             FMP  L                                       453      0263     39  0108  1458
             FAO  TAU                                     454      1458     32  0109  1335
             FMP  BSQO                 CALCULATE          455      1335     39  0090  0140
             FAO  ONE                  K INFINITY         456      0140     32  0050  1477
             STU  KINF      CON11                         457      1477     21  0932  1385
CON11        RAU  PI                                      458      1385     60  0950  1805
             FOV  A                                       459      1805     34  0103  1704
             FMP   8003                                   460      1704     39  8003  1207
             STU  ALPH2                                   461      1207     21  0112  1565
             RAU  PI                                      462      1565     60  0950  1855
             FOV  B                                       463      1855     34  0104  1754
             FMP   8003                                   464      1754     39  8003  1257
             STU  BETA2                                   465      1257     21  0162  1615
             RAU  PI                                      466      1615     60  0950  1905
             FOV  O                                       467 .    1905     34  0110  1110
             FMP   8003                                   468      1110     39  8003  0913
             FAO  ALPH2                CALCULATE          469      0913     32  0112  1289
             FAO  BETA2                GEOMETRIC          470      1289     32  0162  1339
             STU  BGSQO                BUCKLING           471      1339     21  0044  1097
             RSU  TAU                                     472      1097     61  0109  0963
             FMP  BGSQO                                   473      0963     39  0044  0094
             RAL   8003                                   474      0094     65  8003  1501
             LOO            EOOEA                         475      1501     69  1804  1450
             STL  TEMP1                                   476      1804     20  0968  1271
             RAU  BGSQO                                   477      1271     60  0044  1049
             FMP  L                                       478      1049     39  0108  1508
             FMP  L                                       479      1508     39  0108  1558
             FAO  ONE                                     480      1558     32  0050  1527
             STU  TEMP2                                   481      1527     21  0158  1162
             RAU  KINF                 CALCULATE          482      1162     60  0932  1087
             FMP  TEMP1                K                  483      1087     39  0968  1318
             FOV  TEMP2                EFFECTIVE          484      1318     34  0158  1608
             STU  KEFF                                    485      1608     21  1212  1665
             LOO            EOOGL                         486      1665     69  1368  1150
             LOO  BSQO                                    487      1368     69  0090  0293
             STO   1977                                   488      0293     24  1977  0980
             LOO  BGSQO                                   489      0980     69  0044  1147
             STO   1978                                   490      1147     24  1978  1181
             LDD  KINF                                    491      1181     69  0932  1435
             STO   1979                                   492      1435     24  1979  0982
             LOD  KEFF                                    493      0982     69  1212  1715
             STO   1980                                   494      1715     24  1980  1183
             PCH   1977      8000                         495      1183     71  1977  8000
```

APPENDIX K

IBM 650 Program for Statistical Analysis of Horizontal Traverse Date

The purpose of this program was to analyze data taken in a horizontal traverse of the KSU pile and to determine the reliability of each data point based on predicted statistical variations. The program was written in SOAP II and floating point. The object program and a logic diagram are given in this section.

The analysis performed by this program is based on the equation

$$\phi(x,y,z) = \sum_{m=1}^{\infty} A_m \cos \frac{mnx}{a}$$

where m is odd, and y and z are held constant. Care should be taken that too many harmonics are not used, as this will cause errors in the least squares calculation due to statistical noise. The 1, 3, and 5 harmonics were found sufficient in this work. In performing the analysis, the program first determines the values of A_m, for as many harmonics as are specified, by a least squares technique. It then proceeds to calculate the allowable deviation of each point in the traverse according to the formula found in Price (19)

$$\mathrm{DEV} = K\sigma = K\left(\frac{r}{t}\right)^{1/2}$$

where r = count rate in counts per minute,

t = total counting time to obtain r,

K = constant multiplier which may be varied to set the allowable deviation to include any given probability of occurrence.

Having determined the allowable deviations, the program then checks each point to determine whether or not it is within the allowable deviation of the value predicted by the least squares analysis. If not, the point is temporarily discarded. If its deviation is within the allowable limits, the point is stored in the accepted data table, designated in the program as XPRIM and NPRIM.

The accepted data are then used to calculate a new set of least squares coefficients and the same deviation check is repeated for all of the original data points using the new coefficients. The new accepted data table is then compared with the table used in the least squares calculations, previously designated X and N. If the two tables are identical, indicating that the same data points have been rejected in two successive trials, then the rejected values are replaced by least squares values in the original table, and the complete set of corrected data is punched out. If the accepted table and the least squares data do not match, the accepted table replaces the least squares table and a new least squares analysis is performed.

The final output of this program is a complete table of data with statistically invalid points replaced by values calculated from a least squares analysis of the accepted points.

Input constants and data are listed in Table 37. All input to this program should be in the form of one-word load cards.

Output of this program is in three forms as listed in Table 38. Form one contains the least squares coefficients and is punched after each least squares calculation. Form two is punched whenever a data point is rejected, there being no intermediate output of accepted data.

Form three is the final output and gives the accepted or corrected data point and its co-ordinate.

Table 37. Input to IBM 650 program for statistical analysis of horizontal traverse data.

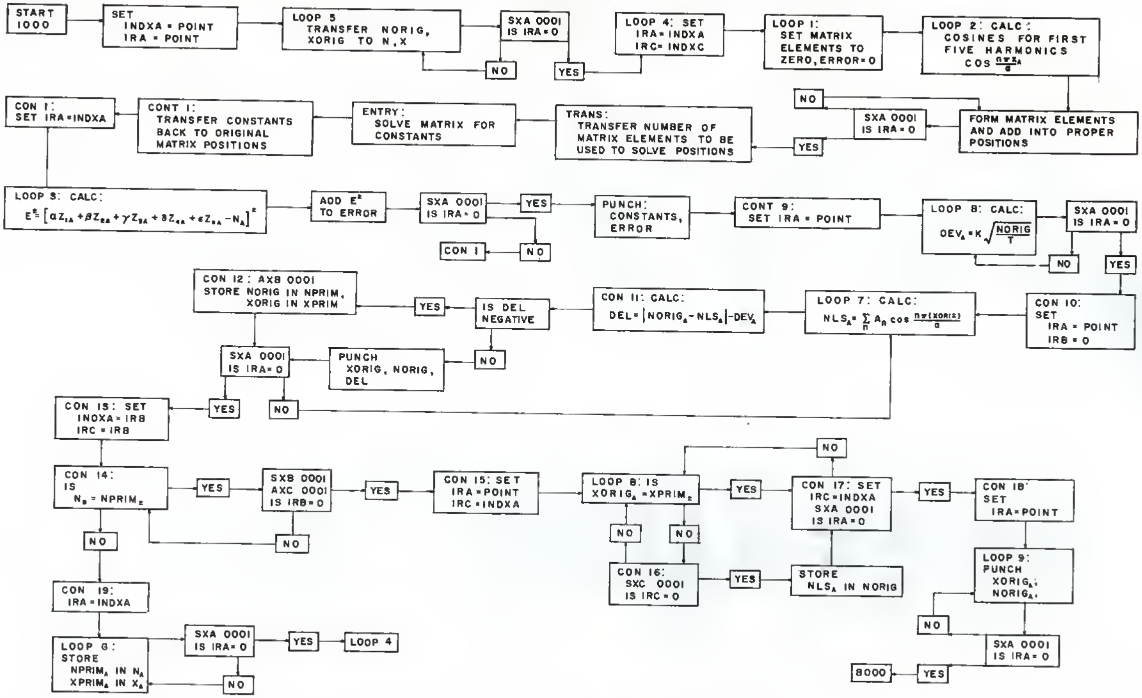
Symbol	Explanation	Drum Storage Location
A	Extrapolated x-dimension	1001
K	Sigma multiplier	1002
POINT	Number of Data Points, in form 00 0000 00xx	1003
HARM	Value of (2m + 1) for highest value of m used	1004
ENN	Number of harmonics used, in form 00 0000 000x	1005
XORIG	Position co-ordinates of data, to be stored consecutively starting as	0251
NORIG	Count rates, to be stored consecutively starting at	0201
T	Total counting times, to be stored consecutively starting at	0651

The operating time for a two-trial analysis of 10 data points is approximately three minutes. The total capacity of the program is 50 data points.

Table 38. Output forms for IBM 650 program for statistical analysis of horizontal data.

Word No.	Form One	Form Two	Form Three
1	A_o		Position co-ordinate
2	A_1		Count Rate
3	A_2		
4	A_3		
5	A_4		
6	Total error squared	Position co-ordinate	
7		Rejected Count Rate	
8		Amount by which point exceeded allowable deviation	

LOGIC DIAGRAM FOR IBM 650 PROGRAM FOR STATISTICAL ANALYSIS OF HORIZONTAL DATA TRAVERSE



LOGIC DIAGRAM, APPENDIX K

```
         SLR   0000     0030                        1    0000    00  0000  0000
         SLR   0101     0131                        2    0000    00  0000  0000
         SLR   0200     09.00                       3    0000    00  0000  0000
         SLR   1900     1999                        4    0000    00  0000  0000
         SYN  Y11       0101                        5    0000    00  0000  0000
         SYN  Y12       0102                        6    0000    00  0000  0000
         SYN  Y13       0103                        7    0000    00  0000  0000
         SYN  Y14       0104                        8    0000    00  0000  0000
         SYN  Y15       0105                        9    0000    00  0000  0000
         SYN  Y21       0106                       10    0000    00  0000  0000
         SYN  Y22       0107                       11    0000    00  0000  0000
         SYN  Y23       0108                       12    0000    00  0000  0000
         SYN  Y24       0109                       13    0000    00  0000  0000
         SYN  Y25       0110                       14    0000    00  0000  0000
         SYN  Y31       0111                       15    0000    00  0000  0000
         SYN  Y38       0112                       16    0000    00  0000  0000
         SYN  Y33       0113                       17    0000    00  0000  0000
         SYN  Y34       0114                       18    0000    00  0000  0000
         SYN  Y35       0115                       19    0000    00  0000  0000
         SYN  Y41       0116                       20    0000    00  0000  0000
         SYN  Y42       0117                       21    0000    00  0000  0000
         SYN  Y43       0118                       22    0000    00  0000  0000
         SYN  Y44       0119                       23    0000    00  0000  0000
         SYN  Y45       0120                       24    0000    00  0000  0000
         SYN  Y51       0181                       25    0000    00  0000  0000
         SYN  Y52       0122                       26    0000    00  0000  0000
         SYN  Y53       0123                       27    0000    00  0000  0000
         SYN  Y54       0124                       28    0000    00  0000  0000
         SYN  Y55       0125                       29    0000    00  0000  0000
         SYN  Z1        0126                       30    0000    00  0000  0000
         SYN  Z2        0127                       31    0000    00  0000  0000
         SYN  Z3        0128                       32    0000    00  0000  0000
         SYN  Z4        0129                       33    0000    00  0000  0000
         SYN  Z5        0130                       34    0000    00  0000  0000
         SYN  ALPHA     0400                       35    0000    00  0000  0000
         SYN  BETA      0450                       36    0000    00  0000  0000
         SYN  GAMMA     0500                       37    0000    00  0000  0000
         SYN  DELTA     0550                       38    0000    00  0000  0000
         SYN  EPSIL     0600                       39    0000    00  0000  0000
         SYN  NORIG     0200                       40    0000    00  0000  0000
         SYN  XORIG     0250                       41    0000    00  0000  0000
         SYN  N         0300                       42    0000    00  0000  0000
         SYN  X         0350                       43    0000    00  0000  0000
         SYN  T         0650                       44    0000    00  0000  0000
         SYN  NPRIM     0700                       45    0000    00  0000  0000
         SYN  XRRIM     0750                       46    0000    00  0000  0000
         SYN  NLS       0800                       47    0000    00  0000  0000
         SYN  DEV       0850                       48    0000    00  0000  0000
         SYN  A         1001                       49    0000    00  0000  0000
         SYN  K         1002                       50    0000    00  0000  0000
         SYN  POINT     1003     DATA  IN          51    0000    00  0000  0000
         SYN  HARM      1004     HARMONICS         52    0000    00  0000  0000
         SYN  ENN       1005     IR FORM           53    0000    00  0000  0000
         SYN  START     1000                       54    0000    00  0000  0000
ZERO      00   0000     0000                       55    0050    00  0000  0000
ONE       10   0000     0051                       56    0100    10  0000  0051
TWO       20   0000     0051                       57    0150    20  0000  0051
THREE     30   0000     0051                       58    0950    30  0000  0051
PI        31   4159     0051                       59    1050    31  4159  0051
FIVE      50   0000     0051                       60    1100    50  0000  0051
SEVEN     70   0000     0051                       61    1150    70  0000  0051
NINE      90   0000     0051                       62    1200    90  0000  0051
INOXC     00   0000     0030                       63    1250    00  0000  0030
EODCL    STO  ZZZ1                                 64    1300    24  0053  0056
         LOO  ZZZ10                                65    0056    69  0059  0062
         STO   1977                                66    0062    24  1977  0080
         STO   1978                                67    0080    24  1978  0031
         STO   1979                                68    0031    24  1979  0032
         STO   1980                                69    0032    24  1980  0033
         STO   1981                                70    0033    24  1981  0034
         STO   1982                                71    0034    24  1982  0035
         STO   1983                                72    0035    24  1983  0036
         STO   1984     ZZZ1                       73    0036    24  1984  0053
ZZZ10     00   0000      0000                      74    0059    00  0000  0000
EODCR    STO  EXIT                                 75    1350    24  0153  0156
         NAU   8002                                76    0156    60  8002  0065
         SMI  NEGAT     REDUG                      77    0065    46  0068  0069
NEDAT    FAO  TWOPI                                78    0068    32  0071  0047
         SMI  NEGAT                                79    0047    46  0068  0051
         FSS  ONEPI     COSIO                      80    0051    33  0054  0081
REDUC    FSS  TWOPI                                81    0069    33  0071  0097
         SMI            REDUC                      82    0097    46  1400  0069
         FAO  ONEPI     COSIO                      83    1400    32  0054  0081
COSIO    STU  THETA                                84    0081    21  0086  0039
         NSU  FPONE                                85    0039    61  0042  0147
         STU  TERMM                                86    0147    21  0052  0055
         STU  FUNKT                                87    0055    21  0060  0063
         STL  ENNN      NEGST                      88    0063    20  0067  0070
EODSR    STO  EXIT                                 89    1450    84  0153  0906
         NAU   8002                                90    0906    60  8002  0165
         SMI  NEGAV     REDUO                      91    0165    46  0168  0169
NEDAV    FAO  TWOPI                                92    0168    32  0071  0197
         SMI  NEGAV                                93    0197    46  0168  0151
         FSS  ONEPI     SINET                      94    0151    33  0054  0181
REDUD    FSS  TWOPI                                95    0169    33  0071  0947
         SMI            REDUO                      96    0947    46  1500  0169
         FAO  ONEPI     SINET                      97    1500    32  0054  0181
SINET    STU  THETA                                98    0181    21  0086  0089
         NSU   8003                                99    0089    61  8003  0997
         STU  TENMM                               100    0997    21  0052  0155
         STU  FUNKT                               101    0155    21  0060  0163
         LOO  FPONE                               102    0163    69  0042  0045
         STO  ENNN      NEDST                     103    0045    24  0067  0070
```

```
NEGST   RAU ENNN                                  104   0070   60 0067 0171
        FAD FPONE                                 105   0171   32 0042 0919
        STU NPONE                                 106   0919   21 0074 0077
        FAD FPONE                                 107   0077   32 0042 0969
        STU ENNN                                  108   0969   21 0067 0170
        RSU TERMM                                 109   0170   61 0052 0057
        FMP THETA                                 110   0057   39 0086 0136
        FMP THETA                                 111   0136   39 0086 0186
        FDV NPONE                                 112   0186   34 0074 0174
        FDV ENNN                                  113   0174   34 0067 0167
        STU TERMM                                 114   0167   21 0052 0905
        RAM FUNKT                                 115   0905   67 0060 0915
        STL FMAG                                  116   0915   20 1019 0072
        RAM TERMM                                 117   0072   67 0052 0157
        RAU  8002                                 118   0157   60 8002 0965
        FDV FMAG                                  119   0965   34 1019 1069
        FSB SIZES                                 120   1069   33 0172 0049
        SMI ENUFF                                 121   0049   46 0152 0903
        RAU FUNKT                                 122   0903 . 60 0060 1015
        FAD TERMM                                 123   1015   32 0052 0079
        STU FUNKT      NEGST                      124   0079   21 0060 0070
ENUFF   RAL FUNKT      EXIT                       125   0152   65 0060 0153
SIZES    10  0000       0043                      126   0172   10 0000 0043
TSOPI    62  8318       5351                      127   0071   62 8318 5351
ONEPI    31  4159       2751                      128   0054   31 4159 2751
FPONE    10  0000       0051                      129   0042   10 0000 0051
EOOAU   STO SEXT                                1 130   1550   24 0953 0956
        SMI SERR                                2 131   0956   46 0159 0160
        NZE            SEXT                     3 132   0160   45 0064 0953
        STU SA                                  4 133   0064   21 0918 0921
        FAD S10                                 5 134   0921   32 0924 0901
        FMP SNAF       SS                       6 135   0901   39 0154 0904
SS      STU SSAV       SAB                      7 136   0904   21 0058 0061
SAB     RAU SA                      S CAPT A    8 137   0061   60 0918 0073
        FDV SSAV                                9 138   0073   34 0058 0158
        FAD SSAV                               10 139   0158   32 0058 0085
        FMP SNAF                               11 140   0085   39 0154 0954
        FSB SSAV                               12 141   0954   33 0058 0135
        NZU            SR                      13 142   0135   44 0139 0040
        SMI            SR                      14 143   0139   46 0092 0040
        FAD SSAV                               15 144   0092   32 0058 0185
        STU SSAV       SAB                     16 145   0185   21 0058 0061
SR      RAU SSAV       SEXT                    17 146   0040   60 0058 0953
SERR    HLT  0000      SEXT                    18 147   0159   01 0000 0953
SNAF     50  0000       0050                   19 148   0154   50 0000 0050
S10      10  0000       0051                   20 149   0924   10 0000 0051
START   LDD POINT                                 150   1000   69 1003 1006
        STD INDXA                                 151   1006   24 0909 0162
        RAA  8001      LOOP5                      152   0162   80 8001 0968
LOOP5   LDD NORIG A                 PUT DATA      153   0968   69 2200 1053
        STD N     A                 IN LEAST      154   1053   24 2300 1103
        LDD XORIG A                 SQUARES       155   1103   69 2250 1153
        STD X     A                 TABLE         156   1153   24 2350 1203
        SXA  0001                                 157   1203   51 0001 0959
        NZA LOOP5      LOOP4                      158   0959   40 0968 0913
LOOP4   LDD INDXA                   SET           159   0913   69 0909 0912
        RAA  8001                   INDEX         160   0912   80 8001 1018
        LDD INDXC                   REGISTERS     161   1018   69 1250 1253
        RAC  8001                                 162   1253   88 8001 1009
        LDD ZERO       LOOP1                      163   1009   69 0050 1303
LOOP1   STD  0100 C                 CLEAR         164   1303   24 6100 1353
        STD  0000 C                 ALL           165   1353   24 6000 1403
        SXC  0001                   MATRIX        166   1403   59 0001 1059
        NZC LOOP1      CONTS        ELEMENTS      167   1059   48 1303 0963
CONTS   STD ERROR      LOOP2                      168   0963   24 0066 1119
LOOP2   RAU PI                      FORM          169   1119   60 1050 0955
        FMP X     A                 COSINE        170   0955   39 2350 1600
        FDV A                       TERMS         171   1600   34 1001 0951
        STU TEMP1                   1             172   0951   21 1056 1109
        FMP THREE                                 173   1109   39 0950 1650
        STU TEMP2                   3             174   1650   21 1054 0907
        RAU TEMP1                                 175   0907   60 1056 0161
        FMP FIVE                                  176   0161   39 1100 1700
        STU TEMP3                   5             177   1700   21 1104 0957
        RAU TEMP1                                 178   0957   60 1056 0911
        FMP SEVEN                                 179   0911   39 1150 1750
        STU TEMP4                   7             180   1750   21 1154 1007
        RAU TEMP1                                 181   1007   60 1056 0961
        FMP NINE                                  182   0961   39 1200 1800
        STU TEMP5                   9             183   1800   21 1204 1057
        RAL TEMP1                                 184   1057   65 1056 1011
        LDD            EOOCR                      185   1011   69 0164 1350
        STL ALPHA A                 1             186   0164   20 2400 1453
        RAL TEMP2                                 187   1453   65 1054 1159
        LDD            EOOCR                      188   1159   69 0962 1350
        STL BETA  A                 3             189   0962   20 2450 1503
        RAL TEMP3                                 190   1503   65 1104 1209
        LDD            EOOCR                      191   1209   69 1012 1350
        STL GAMMA A                 5             192   1012   20 2500 1553
        RAL TEMP4                                 193   1553   65 1154 1259
        LDD            EOOCR                      194   1259   69 1062 1350
        STL DELTA A                 7             195   1062   20 2550 1603
        RAL TEMP5                                 196   1603   65 1204 1309
        LDD            EOOCR                      197   1309   69 1112 1350
        STL EPSIL A                 9             198   1112   20 2600 1653
        RAU ALPHA A                 FORM          199   1653   60 2400 1055
        FMP ALPHA A                 MATRIX        200   1055   39 2400 1850
        FAD Y11                     ELEMENTS      201   1850   32 0101 0177
        STU Y11                     11            202   0177   21 0101 1254
        RAU ALPHA A                               203   1254   60 2400 1105
        FMP BETA  A                               204   1105   39 2450 1051
        FAD Y12                                   205   1051   32 0102 0179
        STU Y12                     12            206   0179   21 0102 1155
```

```
          STU  Y21                    21        207   1155   21 0106 1359
          RAU  ALPHA   A                        208   1359   60 2400 1205
          FMP  GAMMA   A                        209   1205   39 2500 1101
          FAO  Y13                              210   1101   32 0103 0989
          STU  Y13                    13        211   0989   21 0103 1106
          STU  Y31                    31        212   1106   21 0111 0914
          RAU  ALPHA   A                        213   0914   60 2400 1255
          FMP  DELTA   A                        214   1255   39 2550 1151
          FAO  Y14                              215   1151   32 0104 0931
          STU  Y14                    14        216   0931   21 0104 1107
          STU  Y41                    41        217   1107   21 0116 1169
          RAU  ALPHA   A                        218   1169   60 2400 1305
          FMP  EPSIL   A                        219   1305   39 2600 1201
          FAO  Y15                              220   1201   32 0105 0981
          STU  Y15                    15        221   0981   21 0105 0908
          STU  Y51                    51        222   0908   21 0121 0974
          RAU  BETA    A                        223   0974   60 2450 1355
          FMP  BETA    A                        224   1355   39 2450 1251
          FAO  Y22                              225   1251   32 0107 0083
          STU  Y22                    22        226   0083   21 0107 0910
          RAU  BETA    A                        227   0910   60 2450 1405
          FMP  GAMMA   A                        228   1405   39 2500 1301
          FAO  Y23                              229   1301   32 0108 0935
          STU  Y23                    23        230   0935   21 0108 1061
          STU  Y32                    32        231   1061   21 0112 1065
          RAU  BETA    A                        232   1065   60 2450 1455
          FMP  DELTA   A                        233   1455   39 2550 1351
          FAO  Y24                              234   1351   32 0109 0985
          STU  Y24                    24        235   0985   21 0109 1162
          STU  Y42                    42        236   1162   21 0117 0920
          RAU  BETA    A                        237   0920   60 2450 1505
          FMP  EPSIL   A                        238   1505   39 2600 1401
          FAO  Y25                              239   1401   32 0110 0037
          STU  Y25                    25        240   0037   21 0110 1013
          STU  Y52                    52        241   1013   21 0122 0075
          RAU  GAMMA   A                        242   0075   60 2500 1555
          FMP  GAMMA   A                        243   1555   39 2500 1451
          FAO  Y33                              244   1451   32 0113 0189
          STU  Y33                    33        245   0189   21 0113 0166
          RAU  GAMMA   A                        246   0166   60 2500 1605
          FMP  DELTA   A                        247   1605   39 2550 1501
          FAO  Y34                              248   1501   32 0114 0041
          STU  Y34                    34        249   0041   21 0114 0917
          STU  Y43                    43        250   0917   21 0118 0971
          RAU  GAMMA   A                        251   0971   60 2500 1655
          FMP  EPSIL   A                        252   1655   39 2600 1551
          FAO  Y35                              253   1551   32 0115 0091
          STU  Y35                    35        254   0091   21 0115 1068
          STU  Y53                    53        255   1068   21 0123 0076
          RAU  DELTA   A                        256   0076   60 2550 1705
          FMP  DELTA   A                        257   1705   39 2550 1601
          FAO  Y44                              258   1601   32 0119 0095
          STU  Y44                    44        259   0095   21 0119 0922
          RAU  DELTA   A                        260   0922   60 2550 1755
          FMP  EPSIL   A                        261   1755   39 2600 1651
          FAO  Y45                              262   1651   32 0120 1047
          STU  Y45                    45        263   1047   21 0120 0173
          STU  Y54                    54        264   0173   21 0124 0927
          RAU  EPSIL   A                        265   0927   60 2600 1805
          FMP  EPSIL   A                        266   1805   39 2600 1701
          FAO  Y55                              267   1701   32 0125 1751
          STU  Y55                    55        268   1751   21 0125 0078
          RAU  ALPHA   A                        269   0078   60 2400 1855
          FMP  N       A                        270   1855   39 2300 1801
          FAO  Z1                               271   1801   32 0126 1703
          STU  Z1                     Z1        272   1703   21 0126 0979
          RAU  BETA    A                        273   0979   60 2450 1156
          FMP  N       A                        274   1156   39 2300 1851
          FAO  Z2                               275   1851   32 0127 1753
          STU  Z2                     Z2        276   1753   21 0127 0180
          RAU  GAMMA   A                        277   0180   60 2500 1206
          FMP  N       A                        278   1206   39 2300 0902
          FAO  Z3                               279   0902   32 0128 1256
          STU  Z3                     Z3        280   1256   21 0128 1031
          RAU  DELTA   A                        281   1031   60 2550 1306
          FMP  N       A                        282   1306   39 2300 0952
          FAO  Z4                               283   0952   32 0129 1356
          STU  Z4                     Z4        284   1356   21 0129 0082
          RAU  EPSIL   A                        285   0082   60 2600 1406
          FMP  N       A                        286   1406   39 2300 1052
          FAO  Z5                               287   1052   32 0130 1157
          STU  Z5                     Z5        288   1157   21 0130 0133
          SXA   0001                            289   0133   51 0001 0939
          NZA  LOOP2       TRANS                290   0939   40 1119 0043
TRANS     RAA   0001                            291   0043   80 0001 0099
          RAB   0001                            292   0099   82 0001 1456
          RAC   0001                            293   1456   88 0001 1212
          LDD  ENN                              294   1212   69 1005 0958
          STD  ENND        LOOPX                295   0958   24 1111 0964
LOOPX     LDD   0100   A                        296   0964   69 2100 1803
          STD   0000   C                        297   1803   24 6000 1853
          LDD  ENND                             298   1853   69 1111 1014
          SXC   8001                            299   1014   59 8001 0970
          NZC              COMTY                300   0970   48 0923 1024
          AXC   8001                            301   0923   58 8001 1029
          AXA   0001                            302   1029   50 0001 1035
          AXC   0001       LOOPX                303   1035   58 0001 0964
COMTY     AXC   8001                            304   1024   58 8001 0930
          RAU   8001                            305   0930   60 8001 0087
          SUP  ENN                              306   0087   11 1005 1409
          NZU              SFC2                 307   1409   44 1063 1064
          SUP  ENN                              308   1063   11 1005 1459
          NZU              SFC3                 309   1459   44 1113 1114
```

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        SUP  ENN           SFC4                310   1113    11  1005  1509
        NZU                                    311   1509    44  1163  1164
        SUP  ENN                               312   1163    11  1005  1559
        NZU  COLZ          SFC5                313   1559    44  1213  1214
SFC2    LDD  ENN                               314   1064    69  1005  1008
        SXB   8001                             315   1008    53  8001  1264
        NZB                COLZ                316   1264    42  0967  1213
        AXB   8001                             317   0967    52  8001  0973
        AXB   0001                             318   0973    52  0001  1079
        RAA   0006                             319   1079    80  0006  1085
        LDD  ENN                               320   1085    69  1005  1058
        RAC   8001                             321   1058    88  8001  1314
        AXC   0001                             322   1314    58  0001  1020
        RAU  ENN                               323   1020    60  1005  1609
        AUP  ENN                               324   1609    10  1005  1659
        STU  ENND          LOOPX               325   1659    21  1111  0964
SFC3    LDD  ENN                               326   1114    69  1005  1108
        SXB   8001                             327   1108    53  8001  1364
        NZB                COLZ                328   1364    42  1017  1213
        AXB   8001                             329   1017    52  8001  1023
        AXB   0001                             330   1023    52  0001  1129
        RAA   0011                             331   1129    80  0011  1135
        LDD  ENND                              332   1135    69  1111  1414
        RAC   8001                             333   1414    88  8001  1070
        AXC   0001                             334   1070    58  0001  0176
        RAU  ENND                              335   0176    60  1111  1115
        AUP  ENN                               336   1115    10  1005  1709
        STU  ENND          LOOPX               337   1709    21  1111  0964
SFC4    LDD  ENN                               338   1164    69  1005  1158
        SXB   8001                             339   1158    53  8001  1464
        NZB                COLZ                340   1464    42  1067  1213
        AXB   8001                             341   1067    52  8001  1073
        AXB   0001                             342   1073    52  0001  1179
        RAA   0016                             343   1179    80  0016  1185
        LDD  ENND                              344   1185    69  1111  1514
        RAC   8001                             345   1514    88  8001  1120
        AXC   0001                             346   1120    58  0001  0926
        RAU  ENND                              347   0926    60  1111  1165
        AUP  ENN                               348   1165    10  1005  1759
        STU  ENND          LOOPX               349   1759    21  1111  0964
SFC5    LDD  ENN                               350   1214    69  1005  1208
        SXB   8001                             351   1208    53  8001  1564
        NZB                COLZ                352   1564    42  1117  1213
        RAA   0021                             353   1117    80  0021  1123
        LDD  ENND                              354   1123    69  1111  1614
        RAC   8001                             355   1614    88  8001  1170
        AXC   0001                             356   1170    58  0001  0976
        RAU  ENND                              357   0976    60  1111  1215
        AUP  ENN                               358   1215    10  1005  1809
        STU  ENND          LOOPX               359   1809    21  1111  0964
COLZ    LDD  ENND                              360   1213    69  1111  1664
        RAC   8001                             361   1664    88  8001  1220
        AXC   0001                             362   1220    58  0001  1026
        RAA   0001         LOOPZ               363   1026    80  0001  0132
LOOPZ   LDD   0125  A                          364   0132    69  2125  0178
        STO   0000  C                          365   0178    24  6000  1304
        LDD  ENN                               366   1304    69  1005  1258
        SXA   8001                             367   1258    51  8001  1714
        NZA                CONT1               368   1714    40  1167  1118
        AXA   8001                             369   1167    50  8001  1173
        AXA   0001                             370   1173    50  0001  1229
        AXC   0001         LOOPZ               371   1229    58  0001  0132
CONT1   LDD                ENTRY               372   1118    69  1021  1074
        RAU  ENN                               373   1021    60  1005  1859
        MPY  ENN                               374   1859    19  1005  1076
        ALO  UNITY                             375   1076    15  1279  0103
        STL  ENN2                              376   0183    20  0137  0090
        RAA   0001                             377   0090    80  0001  0046
        LDD  ENN2                              378   0046    69  0137  0140
        RAC   8001         LOOPY               379   0140    88  8001  0096
LOOPY   LDD   0000  C                          380   0096    69  6000  1354
        STO   0125  A                          381   1354    24  2125  0928
        SXA   0005                             382   0928    51  0005  0084
        NZA                CON1                383   0084    40  0187  0038
        AXA   0006                             384   0187    50  0006  0093
        AXC   0001         LOOPY               385   0093    58  0001  0096
CON1    LDD  INDXA                             386   0038    69  0909  1262
        RAA   8001         LOOP3               387   1262    80  8001  1168
LOOP3   RAU  Z1                      CALCULATE 388   1168    60  0126  1081
        FMP  ALPHA  A                ERROR     389   1081    39  2400  1102
        STU  TEMP1                   SQUARED   390   1102    21  1056  0960
        RAU  Z2                                391   0960    60  0127  1131
        FMP  BETA   A                          392   1131    39  2450  1152
        STU  TEMP2                             393   1152    21  1054  1207
        RAU  Z3                                394   1207    60  0128  0933
        FMP  GAMMA  A                          395   0933    39  2500  1202
        STU  TEMP3                             396   1202    21  1104  1257
        RAU  Z4                                397   1257    60  0129  0983
        FMP  DELTA  A                          398   0983    39  2550  1252
        STU  TEMP4                             399   1252    21  1154  1307
        RAU  Z5                                400   1307    60  0130  1235
        FMP  EPSIL  A                          401   1235    39  2600  1302
        FAD  TEMP1                             402   1302    32  1056  1033
        FAD  TEMP2                             403   1033    32  1054  1181
        FAD  TEMP3                             404   1181    32  1104  1231
        FAD  TEMP4                             405   1231    32  1154  1281
        FSB  N      A                          406   1281    33  2300  0977
        STU  TEMP1                             407   0977    21  1056  1010
        FMP  TEMP1                             408   1010    39  1056  1506
        FAD  ERROR                             409   1506    32  0066  0143
        STU  ERROR                             410   0143    21  0066  1219
        SXA   0001                             411   1219    51  0001  0175
        NZA  LOOP3         CONT3               412   0175    40  1168  1329
```

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CONT3     LDD           EOOCL       413   1329   69 0182 1300
          LDD  Z1                   414   0182   69 0126 1379
          STD   1977                415   1379   24 1977 0980
          LDD  Z2                   416   0980   69 0127 1030
          STD   1978                417   1030   24 1978 1331
          LDD  Z3                   418   1331   69 0128 1381
          STD   1979                419   1381   24 1979 0932
          LDD  Z4                   420   0932   69 0129 0982
          STD   1980                421   0982   24 1980 1083
          LDD  Z5                   422   1083   69 0130 1133
          STD   1981                423   1133   24 1981 0134
          LDD  ERROR                424   0134   69 0066 1269
          STD   1982                425   1269   24 1982 1285
          PCH   1977    CONT9       426   1285   71 1977 1027
ENTRY     STD  EXIT                 427   1074   24 0153 1556
          RAU  ENN                  428   1556   60 1005 1060
          SUP  UNITY                429   1060   11 1279 1183
          STU  UNLES                430   1183   21 0088 0141
          RAU  ENN                  431   0141   60 1005 1110
          AUP  UNITY                432   1110   10 1279 1233
          STU  ENPLU                433   1233   21 0138 0191
          MPY  ENN                  434   0191   19 1005 1126
          STL  NSPEN                435   1126   20 1431 0184
          SLT   0004                436   0184   35 0004 0145
          ALO  INOA                 437   0145   15 0048 1404
          LDD  AONE                 438   1404   69 1357 1160
          SDA  AONE                 439   1160   22 1357 1210
          LDD  LOOPB                440   1210   69 1263 0916
          SDA  LOOPB                441   0916   22 1263 0966
          LDD  ATWO                 442   0966   69 1319 0972
          SDA  ATWO                 443   0972   22 1319 1022
          LDD  ATREE                444   1022   69 0925 0978
          SDA  ATREE                445   0978   22 0925 1028
          LDD  AFOUR                446   1028   69 1481 0934
          SDA  AFOUR                447   0934   22 1481 0984
          LDD  LOOPF                448   0984   69 0937 0190
          SDA  LOOPF                449   0190   22 0937 0940
          LDD  LOADC                450   0940   69 0193 0146
          SDA  LOADC                451   0146   22 0193 0196
          LDD  AFIVE                452   0196   69 0149 1352
          SDA  AFIVE                453   1352   22 0149 1402
          ALO  INOB                 454   1402   15 1606 1161
          LDD  CONE                 455   1161   69 1764 1217
          SDA  CONE                 456   1217   22 1764 1267
          LDD  CTWO                 457   1267   69 1270 1223
          SDA  CTWO                 458   1223   22 1270 1273
          LDD  CTREE                459   1273   69 1176 1429
          SDA  CTREE                460   1429   22 1176 1479
          LDD  CFOUR                461   1479   69 1032 1335
          SDA  CFOUR                462   1335   22 1032 1385
          LDD  CFIVE                463   1385   69 0188 0941
          SDA  CFIVE                464   0941   22 0188 0991
          RAC   0000                465   0991   88 0000 1097
          LDD   8007                466   1097   69 8007 1454
          STD  CTEMP                467   1454   24 1407 1260
          RSL  NSPEN                468   1260   66 1431 1435
          RAA   8002                469   1435   80 8002 0943
          STL  ATEMP    LOOPA       470   0943   20 1147 1452
LOOPA     RSL  UNLES                471   1452   66 0088 0993
          RAB   8002                472   0993   82 8002 1502
          STL  BTEMP    AONE        473   1502   20 1457 1357
AONE      RAL   9999                474   1357   65 9999 1504
          NZE  NORMA    REPLA       475   1504   45 1308 1310
NORMA     STL  DTEMP    LOOPB       476   1308   20 1313 1263
LOOPB     RAU   9999                477   1263   60 9999 1554
          FDV  DTEMP    ATWO        478   1554   34 1313 1319
ATWO      STU   9999                479   1319   21 9999 1552
          RAL  ENN                  480   1552   65 1005 1360
          AXA   8002                481   1360   50 8002 1369
          BMA  LOOPB                482   1369   41 1263 1323
          RAL  ATEMP                483   1323   65 1147 1602
          RAA   8002    LOOPC       484   1602   80 8002 1211
LOOPC     NZC           SHKIP       485   1211   48 1814 1265
          RAL   8007                486   1814   65 8007 1071
          ALO   8005                487   1071   15 8005 1529
          RAC   8002    CONE        488   1529   88 8002 1764
CONE      RSU   9999                489   1764   61 9999 1604
          NZE           NXSST       490   1604   45 1358 1410
          STU  ETEMP    LOOPD       491   1358   21 1312 1315
LOOPD     RAU  ETEMP    ATREE       492   1315   60 1312 0925
ATREE     FMP   9999    CTWO        493   0925   39 9999 1270
CTWO      FAD   9999    CTREE       494   1270   32 9999 1176
CTREE     STU   9999                495   1176   21 9999 1652
          RAL  ENN                  496   1652   65 1005 1460
          AXA   8002                497   1460   50 8002 1419
          AXC   8002                498   1419   58 8002 1077
          BMA  LOOPD    NXSST       499   1077   41 1315 1410
NXSST     AXB   0001                500   1410   52 0001 1016
          NZB  NEWST                501   1016   42 1469 1320
          LDD  CTEMP                502   1320   69 1407 1510
          RAC   8001                503   1510   88 8001 1066
          LDD  ATEMP                504   1066   69 1147 1702
          RAA   8001                505   1702   80 8001 1408
          LDD  ENPLU                506   1408   69 0138 1041
          AXA   8001                507   1041   50 8001 1197
          LDD   8005                508   1197   69 8005 1654
          STD  ATEMP                509   1654   24 1147 1752
          BMA           EXIT        510   1752   41 1656 0153
          SXC   0001                511   1656   59 0001 1362
          LDD   8007                512   1362   69 8007 1218
          STD  CTEMP                513   1218   24 1407 1560
          STD  KTEMP    LOOPA       514   1560   24 1363 1452
NEWST     LDD  ATEMP                515   1469   69 1147 1802
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        RAA  8001                       516   1802   80  8001  1458
        LDD KTEMP                       517   1458   69  1363  1116
        RAC  8001     SHKIP             518   1116   88  8001  1265
SHKIP   AXC  0001                       519   1265   58  0001  1121
        LDD  8007                       520   1121   69  8007  1127
        STD KTEMP     LOOPC             521   1127   24  1363  1211
REPLA   LDD UNLES                       522   1310   69  0088  1091
        AXC  8001     LOOPE             523   1091   58  8001  1247
LOOPE   AXC  0001                       524   1247   58  0001  1704
        SXC  0001     AFOUR             525   1704   59  0001  1481
AFOUR   RAL  9999                       526   1481   65  9999  1754
        NZE           ZEERO             527   1754   45  1508  1610
        RSL UNLES                       528   1508   66  0088  1043
        AXC  8002                       529   1043   58  8002  1852
        RAL  8007                       530   1852   65  8007  1660
        ALO  8005                       531   1660   15  8005  1317
        RAC  8002     LOOPF             532   1317   88  8002  0937
LOOPF   RAL  9999     CFOUR             533   0937   65  9999  1032
CFOUR   LDD  9999     AFIVE             534   1032   69  9999  0149
AFIVE   STD  9999     CFIVE             535   0149   24  9999  0188
CFIVE   STL  9999                       536   0188   20  9999  1804
        LDD ENN                         537   1804   69  1005  1558
        AXC  8001                       538   1558   58  8001  1864
        AXA  8001                       539   1864   50  8001  1370
        BMI LOOPF                       540   1370   46  0937  1124
        LDD ATEMP                       541   1124   69  1147  1854
        RAA  8001                       542   1854   80  8001  1710
        LDD CTEMP                       543   1710   69  1407  1760
        RAC  8001     NORMA             544   1760   88  8001  1308
ZEERO   NZC LOOPE     STOPP             545   1610   48  1247  1365
PUNCH   LDD ENN                         546   1706   69  1005  1608
        RSA  8001                       547   1608   81  8001  1415
        RSC  0008     LOADC             548   1415   89  0008  0193
LOADC   LDD  9999                       549   0193   69  9999  1756
        STD  1985  C                    550   1756   24  7985  0938
        AXC  0001                       551   0938   58  0001  0044
        NZC INCXA                       552   0044   48  1297  0098
        PCH  1977                       553   0098   71  1977  1177
        RSC  0008     INCXA             554   1177   89  0008  1297
INCXA   AXA  0001                       555   1297   50  0001  1806
        NZA LOADC                       556   1806   40  0193  1810
        PCH  1977                       557   1810   71  1977  1227
        RAU NBPEN                       558   1227   60  1431  1485
        RSB  8001                       559   1485   83  8001  1141
        RAA  0000     ZEERE             560   1141   80  0000  1347
ZEERE   NZB            8000             561   1347   42  1856  8000
        AXB  0001                       562   1856   52  0001  1412
        STL  0001  A                    563   1412   20  2001  1507
        AXA  0001     ZEERE             564   1507   50  0001  1347
UNITY    00  0000      0001             565   1279   00  0000  0001
INDA     00  2001      0000             566   0048   00  2001  0000
INDB     00  4000      0000             567   1606   00  4000  0000
STOPP    01  5555      5555             568   1365   01  5555  5555
CONT9   LDD POINT                       569   1027   69  1003  1557
        RAA  8001     LOOP6             570   1557   80  8001  1413
LOOP6   RAU NORIG  A                    571   1413   60  2200  1607
        FDV T      A          CALCULATE 572   1607   34  2650  1657
        LDD           EODAU   ALLOWABLE 573   1657   69  1860  1550
        FMP K                 DEVIATION 574   1860   39  1002  1707
        STU DEV    A                    575   1707   21  2850  1757
        SXA  0001                       576   1757   51  0001  1463
        NZA LOOP6     CON10             577   1463   40  1413  1367
CON10   LDD POINT                       578   1367   69  1003  1807
        RAA  8001                       579   1807   80  8001  1513
        RAB  0000     LOOP7             580   1513   82  0000  1519
LOOP7   RAU PI                          581   1519   60  1050  1857
        FMP XORIG  A                    582   1857   39  2250  1658
        FDV A                           583   1658   34  1001  1708
        STU TEMP1                       584   1708   21  1056  1261
        RAL  8003                       585   1261   65  8003  1569
        LDD           EODCR             586   1569   69  1072  1350
        RAU  8002                       587   1072   60  8002  1531
        FMP Z1                          588   1531   39  0126  1226
        STU NLS    A                    589   1226   21  2800  1758
        RAU TEMP1                       590   1758   60  1056  1311
        FMP THREE                       591   1311   39  0950  1808
        RAL  8003                       592   1808   65  8003  1465
        LDD           EODCR             593   1465   69  1268  1350
        RAU  8002                       594   1268   60  8002  1277
        FMP Z2                          595   1277   39  0127  1327
        FAD NLS    A                    596   1327   32  2800  1377
        STU NLS    A                    597   1377   21  2800  1858
        RAU TEMP1                       598   1858   60  1056  1361
        FMP FIVE                        599   1361   39  1100  1411
        RAL  8003                       600   1411   65  8003  1619
        LDD           EODCR             601   1619   69  1122  1350
        RAU  8002                       602   1122   60  8002  1581
        FMP Z3                          603   1581   39  0128  1078
        FAD NLS    A                    604   1078   32  2800  1427
        STU NLS    A                    605   1427   21  2800  1461
        RAU TEMP1                       606   1461   60  1056  1511
        FMP SEVEN                       607   1511   39  1150  1561
        RAL  8003                       608   1561   65  8003  1669
        LDD           EODCR             609   1669   69  1172  1350
        RAU  8002                       610   1172   60  8002  1631
        FMP Z4                          611   1631   39  0129  1579
        FAD NLS    A                    612   1579   32  2800  1477
        STU NLS    A                    613   1477   21  2800  1611
        RAU TEMP1                       614   1611   60  1056  1661
        FMP NINE                        615   1661   39  1200  1711
        RAL  8003                       616   1711   65  8003  1719
        LDD           EODCR   CALCULATE 617   1719   69  1222  1350
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          RAU  8002             LEAST       618   1222   60 8002 1681
          FMP Z5                SQUARES     619   1681   39 0130 1080
          FAD NLS   A           DATA        620   1080   32 2800 1527
          STU NLS   A CON11                 621   1527   21 2800 1761
CON11     RAU NORIG A                       622   1761   60 2200 1811
          FSB NLS   A                       623   1811   33 2800 1577
          RAM  8003                         624   1577   67 8003 1535
          RAU  8002                         625   1535   60 8002 1093
          FSB DEV   A           CHECK       626   1093   33 2850 1627
          STU DEL               DEVIATION   627   1627   21 1082 1585
          BMI CON12                         628   1585   46 0988 0989
          LDD         EOOCL                 629   0989   69 0142 1300
          LDD XORIG A                       630   0142   69 2250 1861
          STD  1982             PUNCH       631   1861   24 1982 1635
          LDD NORIG A           REJECTED    632   1635   69 2200 1462
          STD  1983             DATA        633   1462   24 1983 0936
          LDD DEL               POINT       634   0936   69 1082 1685
          STD  1984                         635   1685   24 1984 0987
          PCH  1977                         636   0987   71 1977 1677
          SXA  0001                         637   1677   51 0001 1283
          NZA LOOP7   CON13                 638   1283   40 1519 1037
CON12     AXB  0001                         639   0988   52 0001 0094
          LDD NORIG A           FORM NEW    640   0094   69 2200 1512
          STD NPRIM B           LEAST       641   1512   24 4700 1562
          LDD XORIG A           SQUARES     642   1562   69 2250 1612
          STD XPRIM B           DATA TABLE  643   1612   24 4750 1662
          SXA  0001                         644   1662   51 0001 1318
          NZA LOOP7   CON13                 645   1318   40 1519 1037
CON13     LDD  8006                         646   1037   69 8006 1143
          STD INDXA                         647   1143   24 0909 1712
          RAC  8001   CON14                 648   1712   88 8001 1368
CON14     RAU N     B           COMPARE     649   1368   60 4300 1762
          FSB NPRIM C           NEW  OLD    650   1762   33 6700 1727
          NZE CON19             DATA        651   1727   45 1130 1731
          SXB  0001             TABLES      652   1731   53 0001 1087
          SXC  0001                         653   1087   59 0001 1193
          NZB CON14   CON15                 654   1193   42 1368 1397
CON19     LDD INDXA                         655   1130   69 0909 1812
          RAA  8001   LOOPG                 656   1812   80 8001 1418
LOOPG     LDD NPRIM A           TRANSFER    657   1418   69 2700 1862
          STD N     A           NEW DATA    658   1862   24 2300 1563
          LDD XPRIM A           TABLE FOR   659   1563   69 2750 1613
          STD X     A           LEAST       660   1613   24 2350 1663
          SXA  0001             SQUARES     661   1663   51 0001 1769
          NZA LOOPG   LOOP4     OPERATION   662   1769   40 1418 0913
CON15     LDD POINT                         663   1397   69 1003 1713
          RAA  8001                         664   1713   80 8001 1819
          LDD INDXA                         665   1819   69 0909 1763
          RAC  8001   LOOP8                 666   1763   88 8001 1869
LOOP8     RAU XORIG A           CHECK       667   1869   60 2250 1813
          FSB XPRIM C           ORIGINAL    668   1813   33 6750 1777
          NZE CON16   CON17     DATA        669   1777   45 1180 1781
CON16     SXC  0001             AND         670   1180   59 0001 0986
          NZC LOOP8             REPLACE     671   0986   48 1869 0990
          LDD NLS   A           REJECTED    672   0990   69 2800 1863
          STD NORIG A CON17     POINTS      673   1863   24 2200 1781
CON17     SXA  0001             WITH        674   1781   51 0001 1137
          LDD INDXA             LEAST       675   1137   69 0909 1515
          RAC  8001             SQUARES     676   1515   88 8001 1171
          NZA LOOP8   CON18     VALUES      677   1171   40 1869 0975
CON18     LDD POINT                         678   0975   69 1003 1565
          RAA  8001                         679   1565   80 8001 1221
          LDD LOOP9   EOOCL                 680   1221   69 1174 1300
LOOP9     LDD XORIG A           PUNCH       681   1174   69 2250 1615
          STD  1977             CORRECTED   682   1615   24 1977 1230
          LDD NORIG A           DATA        683   1230   69 2200 1665
          STD  1978                         684   1665   24 1978 1831
          PCH  1977                         685   1831   71 1977 1827
          SXA  0001                         686   1827   51 0001 1333
          NZA LOOP9    8000                 687   1333   40 1174 8000
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APPENDIX L

IBM 650 Program for Determination of Confidence Limits on Diffusion Length

This code was written to determine the confidence limits on individually determined values of diffusion length based upon the expected standard deviation of the slope of a plot of $\ell n\, \phi_{corr}$ vs. z from which L was determined. The program was written in SOAP II and floating point form. The object program and a logic diagram are presented in this section.

The method of calculation included a linear regression analysis to determine $\sigma(\gamma_{11})$, the standard deviation of γ_{11} and a propagation of errors analysis to determine $\sigma(L)$ from $\sigma(\gamma_{11})$. A description of the linear regression analysis can be found in Volk (29). The equation used was

$$\sigma^2(\gamma_{11}) = \frac{\sigma^2(\ell n\, \hat{\phi})}{\Sigma^1(z^2)} ,$$

where

$$\sigma^2(\widehat{\ell n\, \phi}) = \frac{\Sigma(\ell n\, \hat{\phi} - \ell n\, \phi)^2}{N - 2}$$

and

$$\Sigma^1(z^2) = \Sigma(z^2) - \frac{(\Sigma z)^2}{N} .$$

In the above equations $\widehat{\ell n\, \phi}$, represents the value of $\ell n\, \phi$ predicted by

$$\widehat{\ell n\, \phi} = \ell n\, \phi(0) + \gamma z$$

Since $L = 1/\kappa$, the auxiliary separation constants equation could be written

$$\frac{1}{L^2} = \gamma_{11}^2 - \alpha_1^2 - \beta_1^2 .$$

By the theory of propagation of errors,

$$\sigma^2 (L) = \left(\frac{\partial L}{\partial \gamma_{11}} \partial(\gamma_{11}) \right)^2 .$$

Writing L as a function of γ_{11},

$$L = (\gamma_{11}^2 - \alpha_1^2 - \beta_1^2)^{-\frac{1}{2}}$$

Thus,

$$\frac{\partial L}{\partial \gamma_{11}} = - \frac{1}{2} (\gamma_{11}^2 - \alpha_1^2 - \beta_1^2)^{-\frac{3}{2}} (2 \gamma_{11}).$$

Since

$$\gamma_{11}^2 - \alpha_1^2 - \beta_1^2 = \kappa^2,$$

$$\frac{\partial L}{\partial \gamma_{11}} = - \frac{\gamma_{11}}{\kappa^3}$$

Thus $\sigma(L)$, the standard deviation of L, can be written in terms of $\sigma(\gamma_{11})$, the standard deviation of γ_{11}, as

$$\sigma (L) = \pm \frac{\gamma_{11} \sigma (\gamma_{11})}{\kappa^3} .$$

Input for this code consisted of the values of z, and ϕ_{corr} obtained from the output of any given diffusion length program as well as certain parameters listed in Table 39. Data to be fed in on one-word load cards are listed first with other load forms following. One card of form two is to be used for each corrected flux value, whereas only one card of form one is required for each set of input data.

The output form is given in Table 40. One output card is produced for each set of input data. Approximately 20 seconds is required to process 12 data points. The capacity of the program is 20 data points.

Table 39. Input parameters for IBM 650 program for determination of confidence limits.

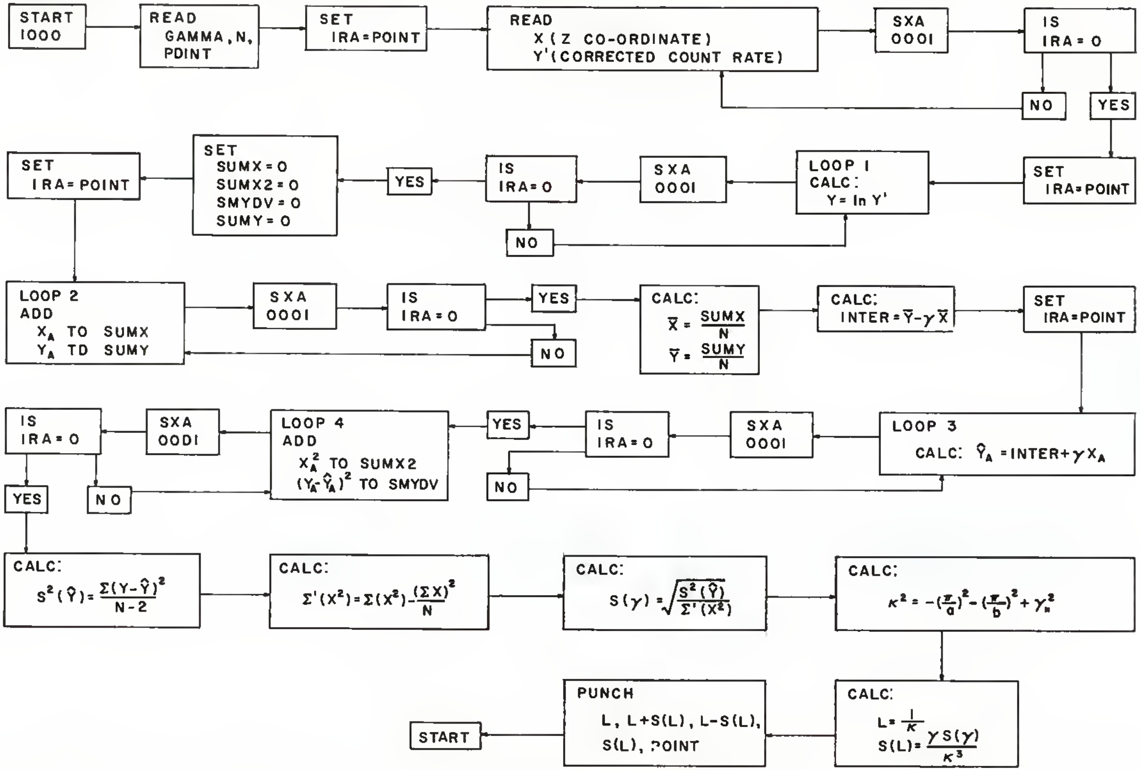
Symbol	Explanation	Drum Storage Location
A	Extrapolated x-dimension	0100
B	Extrapolated y-dimension	0101

Word No.	1	2	3
Form 1	Gamma	Number of Data Points, floating point form	Number of Data Points form 00 0000 00xx
Form 2	z-co-ordinate	Corrected count rate	---

Table 40. Output forms for IBM 650 program for determination of confidence limits.

Word No. 1	2	3	4	5
L	$L + \sigma(L)$	$L - \sigma(L)$	$\sigma(L)$	Number of Data Points

LOGIC DIAGRAM FOR IBM 650 PROGRAM FOR DETERMINATION OF CONFIDENCE LIMITS



LOGIC DIAGRAM, APPENDIX L

OBJECT PROGRAM - APPENDIX L

```
         SLR   0000    0003                        1   0000   00 0000 0000
         SLR   1951    1961                        2   0000   00 0000 0000
         SLR   1977    1987                        3   0000   00 0000 0000
         SLR   0200    0280                        4   0000   00 0000 0000
         SYN  L        0000                        5   0000   00 0000 0000
         SYN  A        0100                        6   0000   00 0000 0000
         SYN  S        0101                        7   0000   00 0000 0000
         SYN  X        0200                        8   0000   00 0000 0000
         SYN  YPRIM    0220                        9   0000   00 0000 0000
         SYN  Y        0240                       10   0000   00 0000 0000
         SYN  YHAT     0260                       11   0000   00 0000 0000
         SYN  START    1000                       12   0000   00 0000 0000
ZERO      00   0000    0000                       13   0050   00 0000 0000
ONE       10   0000    0051                       14   0150   10 0000 0051
TWO       20   0000    0051                       15   0300   20 0000 0051
CONVT     25   3600    0051                       16   0350   25 3600 0051
PI        31   4159    0051                       17   0400   31 4159 0051
EOOAU    STD  SEXT                            1   18   0450   24 0053 0006
         SMI  SERR                            2   19   0006   46 0009 0010
         NZE          SEXT                    3   20   0010   45 0014 0053
         STU  SA                              4   21   0014   21 0018 0021
         FAD  S10                             5   22   0021   32 0024 0051
         FMP  SNAF    SS                      6   23   0051   39 0004 0054
SS       STU  SSAV    SAB                     7   24   0054   21 0008 0011
SAB      RAU  SA                  S CAPT A    8   25   0011   60 0018 0023
         FDV  SSAV                            9   26   0023   34 0008 0058
         FAD  SSAV                           10   27   0058   32 0008 0035
         FMP  SNAF                           11   28   0035   39 0004 0104
         FSB  SSAV                           12   29   0104   33 0008 0085
         NZU          SR                     13   30   0085   44 0039 0040
         SMI          SR                     14   31   0039   46 0042 0040
         FAD  SSAV                           15   32   0042   32 0008 0135
         STU  SSAV    SAB                    16   33   0135   21 0008 0011
SR       RAU  SSAV    SEXT                   17   34   0040   60 0008 0053
SERR     HLT   0000   SEXT                   18   35   0009   01 0000 0053
SNAF      50   0000    0050                  19   36   0004   50 0000 0050
S10       10   0000    0051                  20   37   0024   10 0000 0051
LNX01    STD  LNX08                               38   0500   24 0103 0056
         NZE          LNX14                       39   0056   45 0060 0061
         SMI  LNX14                               40   0060   46 0061 0064
         STU  LNX09                               41   0064   21 0068 0071
         RSL  FPONE                               42   0071   66 0074 0029
         STD  LNX10                               43   0029   24 0032 0185
         STL  LNX02                               44   0185   20 0089 0092
         RAU  LNX09                               45   0092   60 0068 0073
         STL  LNX05                               46   0073   20 0027 0030
         STL  LNX11                               47   0030   20 0285 0038
         SLT   0008                               48   0038   35 0008 0007
         SUP  FIFTY                               49   0007   11 0110 0015
         NZE          LNX04                       50   0015   45 0118 0019
         SMI          LNX03                       51   0118   46 0121 0022
         RSU   8003                               52   0121   61 8003 0079
         LDD  FPONE                               53   0079   69 0074 0077
         STD  LNX02   LNX03                       54   0077   24 0089 0022
LNX03    SRT   0008                               55   0022   30 0008 0041
         SCT   0000                               56   0041   36 0000 0013
         AUP  SIXTY                               57   0013   10 0016 0171
         SUP   8002                               58   0171   11 8002 0129
         RAU   8003                               59   0129   60 8003 0037
         FMP  LNX02                               60   0037   39 0089 0139
         FMP  LNTEN                               61   0139   39 0142 0192
         STU  LNX05   LNX04                       62   0192   21 0027 0019
LNX04    RAL  LNX09                               63   0019   65 0068 0123
         SRT   0002                               64   0123   30 0002 0179
         RAU   8002                               65   0179   60 8002 0087
         ALO  FIFTY                               66   0087   15 0110 0065
         SLT   0002                               67   0065   35 0002 0321
         FAD  FPONE                               68   0321   32 0074 0151
         STU  LNX09                               69   0151   21 0068 0371
         FSB  FPTWO                               70   0371   33 0124 0301
         FDV  LNX09                               71   0301   34 0068 0168
         STU  LNX13                               72   0168   21 0072 0025
         STD  LNX12                               73   0025   24 0028 0031
         STD  LNX11                               74   0031   24 0285 0088
         FMP   8001                               75   0088   39 8001 0091
         STU  FACTR   LNX06                       76   0091   21 0046 0049
LNX06    RAU  LNX10                               77   0049   60 0032 0137
         FAD  FPTWO                               78   0137   32 0124 0351
         STU  LNX10                               79   0351   21 0032 0335
         RAU  LNX13                               80   0335   60 0072 0127
         FMP  FACTR                               81   0127   39 0046 0096
         FDV  LNX10                               82   0096   34 0032 0082
         STU  LNX13                               83   0082   21 0072 0075
         FAD  LNX12                               84   0075   32 0028 0005
         STU  LNX12                               85   0005   21 0028 0081
         FSB  LNX11                               86   0081   33 0285 0111
         FDV  LNX11                               87   0111   34 0285 0385
         RAM   8003                               88   0385   67 8003 0043
         RAU   8002                               89   0043   60 8002 0401
         FSB  SIZE7                               90   0401   33 0154 0131
         SMI  LNX07                               91   0131   46 0034 0435
         LDD  LNX12                               92   0435   69 0028 0181
         STD  LNX11                               93   0181   24 0285 0138
         RAU  LNX13                               94   0138   60 0072 0177
         FMP  LNX10                               95   0177   39 0032 0132
         STU  LNX13   LNX06                       96   0132   21 0072 0049
LNX07    RAU  LNX12                               97   0034   60 0028 0033
         FMP  FPTWO                               98   0033   39 0124 0174
         FSB  LNX05   LNX08                       99   0174   33 0027 0103
FPONE     10   0000    0051                      100   0074   10 0000 0051
FPTWO     20   0000    0051                      101   0124   20 0000 0051
SIZE7     10   0000    0043                      102   0154   10 0000 0043
LNTEN     23   0258    5151                      103   0142   23 0258 5151
```

```
FIFTY     50  0000     0000                104   0110   50 0000 0000
SIXTY     00  0000     0060                105   0016   00 0000 0060
LNX14     01  2345     6789                106   0061   01 2345 6789
START    RCD  1951                         107   1000   70 1951 0451
         LDD  1951                         108   0451   69 1951 0304
         STD  GAMMA             SLOPE      109   0304   24 0057 0160
         LDD  1952                         110   0160   69 1952 0055
         STD  N                 N          111   0055   24 0108 0161
         LDD  1953                         112   0161   69 1953 0106
         STD  POINT             IR NUMBER  113   0106   24 0059 0012
         RAA  8001     CONT1               114   0012   80 8001 0318
CONT1    RCD  1951                         115   0318   70 1951 0501
         LDD  1951                         116   0501   69 1951 0354
         STD  X      A          Z COORD    117   0354   24 2200 0153
         LDD  1952                         118   0153   69 1952 0105
         STD  YPRIM  A          CORR FLUX  119   0105   24 2220 0173
         SXA  0001                         120   0173   51 0001 0329
         NZA  CONT1                        121   0329   40 0318 0083
         LDD  POINT                        122   0083   69 0059 0062
         RAA  8001     LOOP1               123   0062   80 8001 0368
LOOP1    RAU  YPRIM  A          LOGARITHMS 124   0368   60 2220 0125
         LDD           LNX01    OF FLUXES  125   0125   69 0078 0500
         STU  Y      A                     126   0078   21 2240 0093
         SXA  0001                         127   0093   51 0001 0099
         NZA  LOOP1                        128   0099   40 0368 0303
         LDD  POINT                        129   0303   69 0059 0112
         RAA  8001                         130   0112   80 8001 0418
         LDD  ZERO                         131   0418   69 0050 0353
         STD  SUMX              SET SUMS   132   0353   24 0156 0109
         STD  SUMX2             EQUAL TO   133   0109   24 0162 0115
         STD  SMYDV             ZERO       134   0115   24 0468 0421
         STD  SUMY     LOOP2               135   0421   24 0324 0327
LOOP2    RAU  X      A                     136   0327   60 2200 0155
         FAD  SUMX              SUMMATION  137   0155   32 0156 0133
         STU  SUMX              OF X       138   0133   21 0156 0159
         RAU  Y      A                     139   0159   60 2240 0045
         FAD  SUMY              SUMMATION  140   0045   32 0324 0551
         STU  SUMY              OF Y       141   0551   21 0324 0377
         SXA  0001                         142   0377   51 0001 0183
         NZA  LOOP2                        143   0183   40 0327 0187
         RAU  SUMX                         144   0187   60 0156 0311
         FDV  N                            145   0311   34 0108 0158
         STU  XBAR              X BAR      146   0158   21 0312 0165
         RAU  SUMY                         147   0165   60 0324 0379
         FDV  N                            148   0379   34 0108 0308
         STU  YBAR              Y BAR      149   0308   21 0362 0315
         RSU  XBAR                         150   0315   61 0312 0017
         FMP  GAMMA                        151   0017   39 0057 0107
         FAD  YBAR              CALCULATE  152   0107   32 0362 0189
         STU  INTER             INTERCEPT  153   0189   21 0044 0047
         LDD  POINT                        154   0047   69 0059 0412
         RAA  8001     LOOP3               155   0412   80 8001 0518
LOOP3    RAU  X      A                     156   0518   60 2200 0305
         FMP  GAMMA             CALCULATE  157   0305   39 0057 0157
         FAD  INTER             LEAST      158   0157   32 0044 0471
         STU  YNAT   A          SQUARES Y  159   0471   21 2260 0063
         SXA  0001                         160   0063   51 0001 0069
         NZA  LOOP3                        161   0069   40 0518 0323
         LDD  POINT                        162   0323   69 0059 0462
         RAA  8001     LOOP4               163   0462   80 8001 0568
LOOP4    RAU  X      A                     164   0568   60 2200 0355
         FMP  8003              SUMMATION  165   0355   39 8003 0309
         FAD  SUMX2             OF X       166   0309   32 0162 0289
         STU  SUMX2             SQUARED    167   0289   21 0162 0365
         RAU  Y      A                     168   0365   60 2240 0095
         FSB  YNAT   A          SUMMATION  169   0095   33 2260 0287
         FMP  8003              OF Y DEV   170   0287   39 8003 0141
         FAD  SMYDV             SQUARED    171   0141   32 0468 0145
         STU  SMYDV                        172   0145   21 0468 0521
         SXA  0001                         173   0521   51 0001 0427
         NZA  LOOP4                        174   0427   40 0568 0281
         RAU  N                            175   0281   60 0108 0113
         FSB  TWO                          176   0113   33 0300 0477
         STU  TEMP1                        177   0477   21 0182 0485
         RAU  SMYDV             DEVIATION  178   0485   60 0468 0373
         FDV  TEMP1             SQUARED OF 179   0373   34 0182 0282
         STU  S2YHT             Y NAT      180   0282   21 0036 0339
         RSU  SUMX                         181   0339   61 0156 0361
         FMP  SUMX              SIGMA      182   0361   39 0156 0306
         FDV  N                 PRIME OF   183   0306   34 0108 0358
         FAD  SUMX2             X SQUARED  184   0358   32 0162 0389
         STU  SIPX2                        185   0389   21 0094 0097
         RAU  S2YHT                        186   0097   60 0036 0191
         FDV  SIPX2                        187   0191   34 0094 0144
         LDD           EODAU    DEVIATION  188   0144   69 0147 0450
         STU  GADEV             OF GAMMA   189   0147   21 0052 0405
         RAU  PI                           190   0405   60 0400 0455
         FDV  A                            191   0455   34 0100 0550
         FMP  8003              ALPHA      192   0550   39 8003 0403
         STU  ALPH2             SQUARED    193   0403   21 0408 0411
         RAU  PI                           194   0411   60 0400 0505
         FDV  B                            195   0505   34 0101 0601
         FMP  8003              BETA       196   0601   39 8003 0555
         STU  BETA2             SQUARED    197   0555   21 0310 0163
         RAU  GAMMA             GAMMA      198   0163   60 0057 0461
         FMP  GAMMA             SQUARED    199   0461   39 0057 0307
         FSB  ALPH2                        200   0307   33 0408 0535
         FSB  BETA2                        201   0535   33 0310 0337
         LDD           EODAU               202   0337   69 0090 0450
         STU  KAPPA             KAPPA      203   0090   21 0194 0197
         RSU  GAMMA                        204   0197   61 0057 0511
         FMP  GADEV                        205   0511   39 0052 0102
```

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FDV KAPPA                           206   0102    34 0194 0294
FDV KAPPA                           207   0294    34 0194 0344
FDV KAPPA                           208   0344    34 0194 0394
FMP CONVT              DEVIATION    209   0394    39 0350 0600
STU LDEV               OF L         210   0600    21 0404 0357
RAU ONE                             211   0357    60 0150 0605
FDV KAPPA                           212   0605    34 0194 0444
FMP CONVT                           213   0444    39 0350 0650
FAD LDEV                            214   0650    32 0404 0331
STU  1978              L PLUS       215   0331    21 1978 0381
FSB LDEV                            216   0381    33 0404 0431
STU  1977              L            217   0431    21 1977 0060
FSB LDEV                            218   0060    33 0404 0481
STU  1979              L MINUS      219   0481    21 1979 0332
LDD LDEV                            220   0332    69 0404 0407
STD  1980              DEVIATION    221   0407    24 1980 0283
LDD POINT                           222   0283    69 0059 0512
STD  1981              DATA POINT   223   0512    24 1981 0618
PCH  1977    START                  224   0618    71 1977 1000
```

APPENDIX M

Calculation of Thermal Utilization

The thermal utilization in the KSU pile was calculated from formulas presented in ANL 5800 (20). The lattice is eight inches square, but was converted to equivalent cylindrical cells of radius 4.52 inches for this calculation. The equation used was

$$\frac{1}{f} - 1 = \frac{b^2 - c^2}{a^2} \frac{\Sigma_{mc}}{\Sigma_{uc}} G + a \Sigma_{uc} (1 - \frac{a}{c}) + \kappa_m^2 b^2 C + \frac{b^2 - c^2}{c} \Sigma_{mc} (\frac{3}{2} \lambda - 1)$$

where

Σ_{mt} = total cross section of moderator
Σ_{mc} = capture cross section of moderator
Σ_{uc} = capture cross section of fissionable material
Σ_{ut} = total cross section of fissionable material
Σ_{us} = scattering cross section of fissionable material
κ_m^2 = $3 \Sigma_{mt} \Sigma_{mc}$

$$C = \frac{1}{2} \frac{b^2/c^2}{(b^2/c^2)-1} \ln (\frac{b}{c}) - (\frac{3}{4}) + \frac{1}{4 b^2/c^2}$$

$G = \frac{\phi(a)}{\phi_u}$ where ϕ_u is the average flux in the uranium.

The approximation used for G was

$$G = 1 + \frac{\Sigma_{uc}}{\Sigma_{ut}} A \ 1 + \alpha \frac{\Sigma_{us}}{\Sigma_{ut}} + \beta (\frac{\Sigma_{us}}{\Sigma_{ut}})^2 \quad .$$

Values of A, λ, α, and β were tabulated in ANL 5800. The radii of the fuel cooling gap and moderator region were assigned the symbols

a - fuel
b - outer radius of moderator
c - outer radius of cooling gap.

EXPERIMENTAL AND THEORETICAL INVESTIGATION OF THE DIFFUSION LENGTH OF THERMAL NEUTRONS IN GRAPHITE

by

RICHARD EDWARD KAISER

B. S., Northwestern University, 1959

AN ABSTRACT OF A MASTER'S THESIS

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requirements for the degree

MASTER OF SCIENCE

Department of Nuclear Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1962

The effect of the assumption of various mathematical models on the experimental determination of diffusion length was studied, and the diffusion length in the KSU graphite pile determined.

One-group diffusion theory was used in several forms, including an assumed constant thermal source boundary condition and an assumed point thermal source boundary condition. A method whereby the necessity of specifying a source boundary condition could be avoided was studied. A technique for the experimental evaluation of the constants A_{mn} in the thermal flux equation, and hence an equivalent thermal source boundary condition, is also presented.

Age-diffusion theory was studied in two forms, one assuming a point source of monoenergetic fast neutrons, the other an empirical fast source described in terms of Gaussian ranges and range fractions.

Criteria are established for judging the extent of validity of each method in the KSU pile. A final value of L is reported based on the method which best meets the stated criteria.