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A SIMPLIFIED METHODOLOGY FOR COMPUTING CHEMICAL HAZARD DISTANCES

by

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Systems Assessment Office

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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(U) A simplified methodology is developed for solution to the Gaussian diffusion model when affected by an inversion cap. The Pasquill stability categories are used to characterize atmospheric stability. Distance assessment is made for a specified dosage from a point source release at ground level. Fortran and pocket calculator programs are included.

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PREFACE

This task is part of the Chemical Systems Laboratory's support of the arsenals by providing methodology for chemical hazard prediction. The methodology is submitted as an extension of Department of Defense Explosives Safety Board Technical Paper No. 10, which is current approved methodology for making chemical hazard predictions.

This work originated in the Hazards Analysis Group of Systems Assessment Office. The report was requested by the DARCOM Field Safety Activity in Charlestown, Indiana. The work was authorized under Project 72801211000, Attendant Central Supply Services, and was performed from September to November 1977.

The use of trade names in this report does not constitute an official endorsement or approval of the use of such commercial hardware or software. This report may not be cited for purposes of advertisement.

CONTENTS

A SIMPLIFIED METHODOLOGY FOR COMPUTING CHEMICAL HAZARD DISTANCES

1. SCOPE

1.1 Objective. It is the objective of this task to develop a methodology for the solution of the Gaussian diffusion model which is simple enough to be performed on a pocket calculator. It is intended that this would include the effect of the bounded mixing layer[1] and the 2-minute dosage correction[2] as employed with the G and V agents.

1.2 Background. The Methodology for Chemical Hazard Predictions, which was agreed upon by the Technical Advisor to the Chemical Standards Working Group of the Department of Defense Explosives Safety Board in 1974, was published as DODESB Technical Paper No. 10[3] in March 1975. The mathematical representation of this methodology was stated in very general form and its inherent complexity prevented its immediate adoption for field work.

In 1976, a system of graphic aids was prepared by the Systems Assessment Office, Chemical Systems Laboratory, and was published by DARCOM in March, 1977, as a Handbook for Chemical Hazard Prediction.[1] In June 1977, ARCSL-TR-77049[4] was published by Systems Assessment Office to document a complete computer program of this methodology.

Since the Handbook[1] was developed as the basic implementing document of this methodology, it was presented in generalized form which attempted to portray all the variables of the model over the ranges of interest. This document was large, containing some 170 graphs, but still treated many variables as factor corrections to a first estimate.

The computer program, documented as ARCSL-TR-77049, was also developed as a basic tool and attempted to cover all of the methodology in the most concise manner. As a result, the program is made up of eight subroutines containing some 1000 Fortran statements. The program is fast, relatively easy to use, and will be maintained on the ARRADCOM Univac 1108 computer at Aberdeen Proving Ground, Maryland, for remote use through the telephone.

There remained, however, an area of quick field applications which neither of these approaches satisfied completely. An approach was sought which would approximate some of the more complex procedures in the methodology and lead to simple statements which could be programmed on the pocket calculator.

1.3 Approach. Once the complete methodology was available on a high-speed computer, investigation began as to how some of the more complex operations could be approximated. The transition from the Gaussian to the Box Model* was of prime concern since this had not been fully covered by the graphic solutions presented in the handbook. From the many curves in the handbook, it was evident that this transition occurred over a relatively short distance and an approach was sought to define this zone as a function of stability and height of the mixing layer. Once the transition zone was defined, the dosage-versus-distance curve would be approximated by three line segments representing the Gaussian Model, mixing-layer transition, and Box Model.

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* Diffusion under an inversion cap with vertical distribution uniform.

In order to simplify the 2-minute-corrected methodology as developed for ORG 40[2] and reproduced in Technical Paper No. 10,[3] the full iterative program was executed and the final dosage correction factor at each distance was converted to an effective time of exposure. This effective time was then fitted as a function of stability, windspeed, and distance, and a simple algebraic statement of the 2-minute corrections was substituted into the diffusion equation and solved directly for distance.

Finally, the mixing layer and 2-minute corrections were combined to complete the model. Simple algebraic expressions were used to approximate these unknown functions with the condition that deviations would be biased to produce a safe-sided estimate of the hazard distance.

2. METHODOLOGY

2.1 Effect of the Mixing Layer. When a Gaussian cloud encounters a physical boundary such as the ground surface or an elevated-inversion cap,[1] the fraction of the cloud reaching the boundary is reflected back to reinforce the concentration and increase the dosage within this mixing layer. A model based on multiple reflections from these bounding surfaces was outlined in ORG 17[5] in 1958. This approach was reproduced in Technical Paper No. 10[3] indicating that the factor which augments the dosage at any downwind distance can be expressed as follows:

$$F_R = \frac{1}{2}\sum_{i=1}^{\infty}\left[\exp\left[-\frac{1}{2}\left(\frac{2iH_m - H - Z}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{2iH_m - H + Z}{\sigma_z}\right)^2\right]\right.$$

$$\left. + \exp\left[-\frac{1}{2}\left(\frac{2iH_m + H - Z}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{2iH_m + H + Z}{\sigma_z}\right)^2\right]\right] \qquad (1)$$

where

F_R is the reflective contribution to the dosage at distance, x

H_m is the height of the mixing layer (m)

H is the height of the source (m)

Z is the height of the sampler (m)

$\sigma_z = \sigma_{zr}\left(\frac{x}{x_{zr}}\right)_1^{\beta}$, the vertical distribution of the cloud as defined in the handbook[1] (m)

When one is interested in dosages near the ground, Z can be taken as zero and the expression simplifies to the following:

$$F_R = \sum_{i=1}^{\infty}\left[\exp\left[-\frac{1}{2}\left(\frac{2iH_m + H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{2iH_m - H}{\sigma_z}\right)^2\right]\right] \qquad (2)$$

With reasonable values of H and H_m, this expression equals zero for small values of x and then increases with x, approaching:

$$\text{Limit } F_R = \sqrt{\frac{\pi}{2}} \cdot \frac{\sigma_z}{H_m} - 1$$

From this information, the beginning of the transition zone, x_1, can be defined as the value of x corresponding to $F_R = 0 + \Delta E$, where ΔE is some specified small difference. In like manner, the extent of the transition zone, x_2, can be defined as the value of x corresponding to $F_R = \sqrt{\frac{\pi}{2}} \cdot \frac{\sigma_z}{H_m} - 1 + \Delta E$. This limit is also the distance where the Gaussian Model, with reflection, differs from the Box Model by ΔE.

A computer program was written to select values of x_1 and x_2 for different stabilities and heights of the mixing layer. These results are shown in tables 1 and 2 for $\Delta E = 0.01$.

TABLE 1. VALUE OF x_1 AS A FUNCTION OF STABILITY AND H_m

H_m (m)	A	B	C	D	E	F
100	282	550	1023	2138	3548	7079
200	468	1096	2188	4786	8511	17783
300	617	1660	3467	7762	14125	30903
400	759	2188	4786	10965	19953	44668
600	1023	3311	7413	17783	33113	77624
800	1259	4467	10233	24547	47863	112201
1000	1479	5495	13188	32359	63095	151355
2000	2399	10965	28840	72443	151355	380188

TABLE 2. VALUE OF x_2 AS A FUNCTION OF STABILITY AND H_m

H_m (m)	A	B	C	D	E	F
100	427	955	1862	4074	6918	14454
200	692	1905	4074	9120	16596	36308
300	933	2884	6310	14791	27542	63095
400	1148	3802	8710	20893	39811	91201
600	1514	5754	13804	33113	66069	158489
800	1862	7586	19055	46773	93325	234422
1000	2188	9550	23988	60256	123026	316226
2000	3631	19055	52481	138038	295119	794324

It was found that the data shown in tables 1 and 2 could be fitted by expressions of the following form:

$$x_1 = C_1 H_m^{1/\beta} \tag{3}$$

$$x_2 = C_2 H_m^{1/\beta} \tag{4}$$

where

x_1 and x_2 defines the transition zone (m)

C_1 and C_2 are constants for each stability

β is the slope of the sigma Z curve

Given equations 3 and 4, one may now define three segments to represent the dosage-distance relationship:

Segment 1	$x < x_1$	$F_R = 0$
Segment 2	$x_1 < x < x_2$	F_R is variable
Segment 3	$x_2 < x$	$F_R = \sqrt{\frac{\pi}{2}} \cdot \frac{\sigma_z}{H_m} - 1$

The derived values of C_1 and C_2 are listed in table 3 as a function of stability. The diffusion parameters, as taken or derived from Technical Paper No. 10,[3] are also tabulated for use in the equations 5 and 6. The reference σ values have been transformed to one meter as will be discussed under equation 6. Values of σ_y are given for both instantaneous (ins) and continuous (con) sources as discussed in the handbook.[1]

TABLE 3. METEOROLOGICAL PARAMETERS

Parameter	A	B	C	D	E	F
σ_{yl} (ins)*	0.09	0.0633	0.048	0.0634	0.0754	0.0796
σ_{yl} (con)**	0.27	0.1899	0.125	0.1268	0.1508	0.1592
σ_{zl}	0.0222	0.11	0.119	0.0898	0.0879	0.0791
α	1.	1.	1.	0.9	0.8	0.7
β	1.4	1.	0.9	0.85	0.8	0.75
C_1	10.5	5.5	6.13	9.49	11.2	15.3
C_2	15.9	9.55	11.2	18.1	21.9	31.1

*ins = instantaneous

**con = continuous

2.2 Total Dosage: Segment 1, $x < x_1$

If one considers total dosage near the ground from a point source release near the ground, the dosage-distance relationship is defined as follows:

$$D(x) = \frac{Q}{60\pi\, \sigma_y(x)\, \sigma_z(x)\, u} \tag{5}$$

where

D(x) is the total dosage at x (mg-min/m^3)

Q is the source strength (mg)

u is the windspeed (m/sec)

$$\sigma_y(x) = \sigma_{yr} \left(\frac{x}{x_{yr}} \right)^{\alpha} \text{ (m)}$$

$$\sigma_z(x) = \sigma_{zr} \left(\frac{x}{x_{zr}} \right)^{\beta} \text{ (m)}$$

By transferring the reference distances, x_{yr} and x_{zr}, to one meter, this is further simplified to:

$$D(x) = \frac{Q}{60\pi\, \sigma_{yl}\, \sigma_{zl}\, u\, x^{\alpha+\beta}} \tag{6}$$

where

$$\sigma_{yl} = \sigma_{yr}\, (x_{yr})^{-\alpha}$$

$$\sigma_{zl} = \sigma_{zr}\, (x_{zr})^{-\beta}$$

or the inverse solution:

$$x = \left[\frac{Q}{60\pi\, \sigma_{yl}\, \sigma_{zl}\, D\, u}\right]^{1/\alpha+\beta} \qquad x < x_1 \tag{7}$$

where D is the dosage of interest (mg-min/m^3).

2.3 Total Dosage: Segment 3, $x > x_2$

The total dosage in segment 3 can be calculated from the following:

$$D(x) = \frac{Q}{60\sqrt{2\pi}\, \sigma_{yl}\, H_m\, x^{\alpha}} \tag{8}$$

or

$$x = \left[\frac{Q}{60\sqrt{2\pi}\, \sigma_{yl}\, D\, H_m}\right]^{1/\alpha} \qquad x > x_2 \tag{9}$$

2.4 Total Dosage: Segment 2, $x_1 < x < x_2$

Considering that the distance between x_1 and x_2 is relatively small, it was decided to approximate this segment as a log-log straight line between points (D_1, x_1) and (D_2, x_2). The value, D_1, is taken at x_1 on segment 1 and D_2 is taken at x_2 on segment 3. A straight line segment will slightly overestimate the dosage in this region and thus provide a conservative (safe-sided) estimate of the distance.

Employing equations 6 and 8,

$$D_1 = \frac{Q}{188.5\, \sigma_{yl}\, \sigma_{zl}\, u\, x_1^{\alpha+\beta}} \tag{10}$$

$$D_2 = \frac{Q}{150.4\,\sigma_{y1}\,H_m\,u\,x_2^{\alpha}} \tag{11}$$

then

$$S = \frac{\ln (x_2/x_1)}{\ln (D_2/D_1)} \tag{12}$$

and

$$x = x_1\left(\frac{D}{D_1}\right)^S \tag{13}$$

3. TWO-MINUTE CORRECTION

3.1 Instantaneous Sources with 2-Minute Correction. A copy of the program for computing dosage with the 2-minute correction for G and V agents, as defined in ARCSL-TR-77049[4] was modified to output the effective time, t_e, of dosage accumulation as a function of downwind distance. Data were generated for a variety of conditions and fitted to a general equation.

$$t_e = \frac{0.005\,x^{0.9294}}{u} \tag{14}$$

where

t_e is the effective time of dosage accumulation (min)

0.9294 is the slope of the sigma-x curve

Given this effective time of exposure, one can then consider the time correction factor for the dosage[2] to compute the effective dosage at any distance.

$$M = 0.827\,t^{0.274} \quad t > 2 \text{ min} \tag{15}$$

where

M is the factor by which the required dosage is increased

t is the time of dosage accumulation (min)

3.1.1 Two-Minute Corrected Dosage: Segment 1, $x < x_1$

By setting $t = t_e$ and multiplying D by the factor M (combining equations 7, 14, and 15), the following equation can be used to calculate distance in segment 1. This equation is also subject to the condition that

$$x > [400\,u]^{1.076}$$

which represents the distance at which the time of dosage accumulation will exceed 2 minutes as calculated from equation 14.

$$x = \left[\frac{Q}{36.51\,\sigma_{y1}\,\sigma_{z1}\,D\,u^{0.726}} \right]^{1/\alpha + \beta + 0.255} \quad \text{for } x_1 > x > x_T \tag{16}$$

where $x_T = (400\,u)^{1.076}$.

For $x < x_1$ and x_T, use equation 7

3.1.2 Two-Minute Corrected Dosage: Segment 3, $x > x_2$

By combining equations 9, 14, and 15, the 2-minute correction in segment 3 can be computed subject to the same restriction in t_e.

$$x = \left[\frac{Q}{29.13\,\sigma_{y1}\,H_m\,D\,u^{0.726}} \right]^{1/\alpha + 0.255} \quad x > x_2 \text{ and } x_T \tag{17}$$

3.1.3 Two-Minute Correction of Dosage: Segment 2, $x_1 < x < x_2$

Following the same approach outlined above, when $x > x_T$,

$$D_1 = \frac{Q}{36.51\,\sigma_{y1}\,\sigma_{z1}\,u^{0.726}\,x_1^{\alpha + \beta + 0.255}} \tag{18}$$

$$D_2 = \frac{Q}{29.13\,\sigma_{y1}\,H_m\,u^{0.726}\,x_2^{\alpha + 0.255}} \tag{19}$$

The distance is then computed using equations 12 and 13. If $x < x_T$, then equations 10 and 11 are used instead of equations 18 and 19.

3.2 Semicontinuous Source with 2-Minute Correction. The special computer program referred to in section 3.1 was executed for a range of release times to provide estimates of t_e for the semicontinuous release. These data were fitted to a generalized model as follows:

$$t_e = \left[0.281\,t_s^2 + \frac{0.000025}{u^2}\,x^{1.8588} \right]^{1/2} \tag{20}$$

where t_s is the source release time (min).

For small values of x, equation 20 takes on a constant value based on the value of t_s. At large values of x, the values are the same as those obtained from equation 14. In the transition between these two extremes, the value of t_e is underestimated slightly which in turn provides a safe-sided estimate of hazard distance.

3.2.1 Semicontinuous Source with 2-Minute Correction. Segment 1

Following the approach outlined in section 3.1.1, the equation for the hazard distance to dosage, D, from source, Q, is as follows:

$$\left[0.281\, t_s^2 + \frac{0.000025}{u^2}\, x^{1.8588}\right]^{0.137} x^{\alpha+\beta} = \frac{Q}{155.9\, \sigma_{y1}\, \sigma_{z1}\, u\, D} \qquad x_1 > x > x_{TS} \qquad (21)$$

where

$$x_{TS} = \left[\frac{(4 - 0.281\, t_s^2)\, u^2}{0.000025}\right]^{0.538} \qquad (22)$$

For values of $x < x_1$ and X_T, equation 7 is used.

It is noted that equation 21 is not solved for the downwind distance, x. Due to the form of the equation, it was decided to arrive at a value of x by successive approximation. This approach is practical on a programmable electronic calculator of the pocket-size variety. (Experience has shown that some solutions can take a minute or more, but it's automatic and it does get there.)

3.2.2 Semicontinuous Source with 2-Minute Correction. Segment 3

Distances that fall in segment 3 are computed in a similar manner using the following:

$$\left[0.281\, t_s^2 + \frac{0.000025\, x^{1.8588}}{u^2}\right]^{0.137} x^{\alpha} = \frac{Q}{124.4\, \sigma_{y1}\, H_m\, D\, u} \qquad x > x_2 \text{ and } x_{TS} \qquad (23)$$

3.2.3 Semicontinuous Source with 2-Minute Correction: Segment 2, $x > x_{TS}$,

The values of D_1 and D_2 are computed in segment 2 from the following equations.

$$D_1 = \frac{Q}{155.9\, \sigma_{y1}\, \sigma_{z1}\, u\, x^{\alpha+\beta}} \left[0.281\, t_s^2 + \frac{0.000025}{u^2}\, x_1^{1.8588}\right]^{-0.137} \qquad (24)$$

$$D_2 = \frac{Q}{124.4\, \sigma_{y1}\, H_m\, u\, x^{\alpha}} \left[0.281\, t_s^2 + \frac{0.000025}{u^2}\, x_2^{1.8588}\right]^{-0.137} \qquad (25)$$

4. ACCURACY OF THE SIMPLIFIED METHODOLOGY

The methodology has been tested against that programmed in ARCSL-TR-77049 over a wide range of input parameters. The estimated distances are always found to equal or exceed the reference values as planned. These differences are generally below 3% with some few ranging as high as 5%.

5. COMPUTATIONS WITH THE SIMPLIFIED METHODOLOGY

With the exception of equations 21 and 23, all of these equations can readily be solved on a pocket calculator which has a fractional power function (y^x). The only complication is the determination of the proper segment and, thus, the selection of the proper equation for x. The complete logic for making this selection is shown in the figure.

The procedure starts with a total dosage solution and then repeats the procedure using the 2-minute-corrected equations when needed. The figure represents a computer approach which is complete but nonintelligent. Once the user has a feel for the distances involved, the total dosage solution or any unneeded segment solution may be by-passed on the values of x_1, x_2, and X_T as long as the restrictions on the basic equations are complied with.

The procedure for selecting the proper segment has been explained in the development of the methodology. The X_T restriction is somewhat more subtle. The time of dosage accumulation must exceed 2 minutes before the 2-minute correction is applied. Thus, for distances less than X_T (or x_{TS}), the total dosage and 2-minute-corrected solutions are the same.

6. FORTRAN PROGRAMS

In order to test the simplified methodology and the logic in the figure, two Fortran computer programs were written. These programs contain 42 and 56 statements as compared to 334 for subroutine DOSDIS.[4] One provides solutions for instantaneous releases and the other for semicontinuous releases. Each program has the option of solving either the total dosage or 2-minute-corrected methodology. These programs are very similar and one program could provide all four solutions if provisions were made to select the proper reference sigma Y values for instantaneous and continuous solutions. The two Fortran programs are listed in appendix A, where the inputs are defined.

7. POCKET CALCULATOR PROGRAMS

In the first attempts to code this methodology on a programmable pocket calculator, a two-segment* approximation to the mixing layer was used. A segment of the instantaneous model with 2-minute correction was then programmed and finally the semicontinuous with 2-minute correction using an iterative approach to solve equation 21 was tested. Each of these was a program of about a hundred steps and was written for the Texas Instruments Model 52.

*The intersection of the Gaussian and Box Models separating the segments.

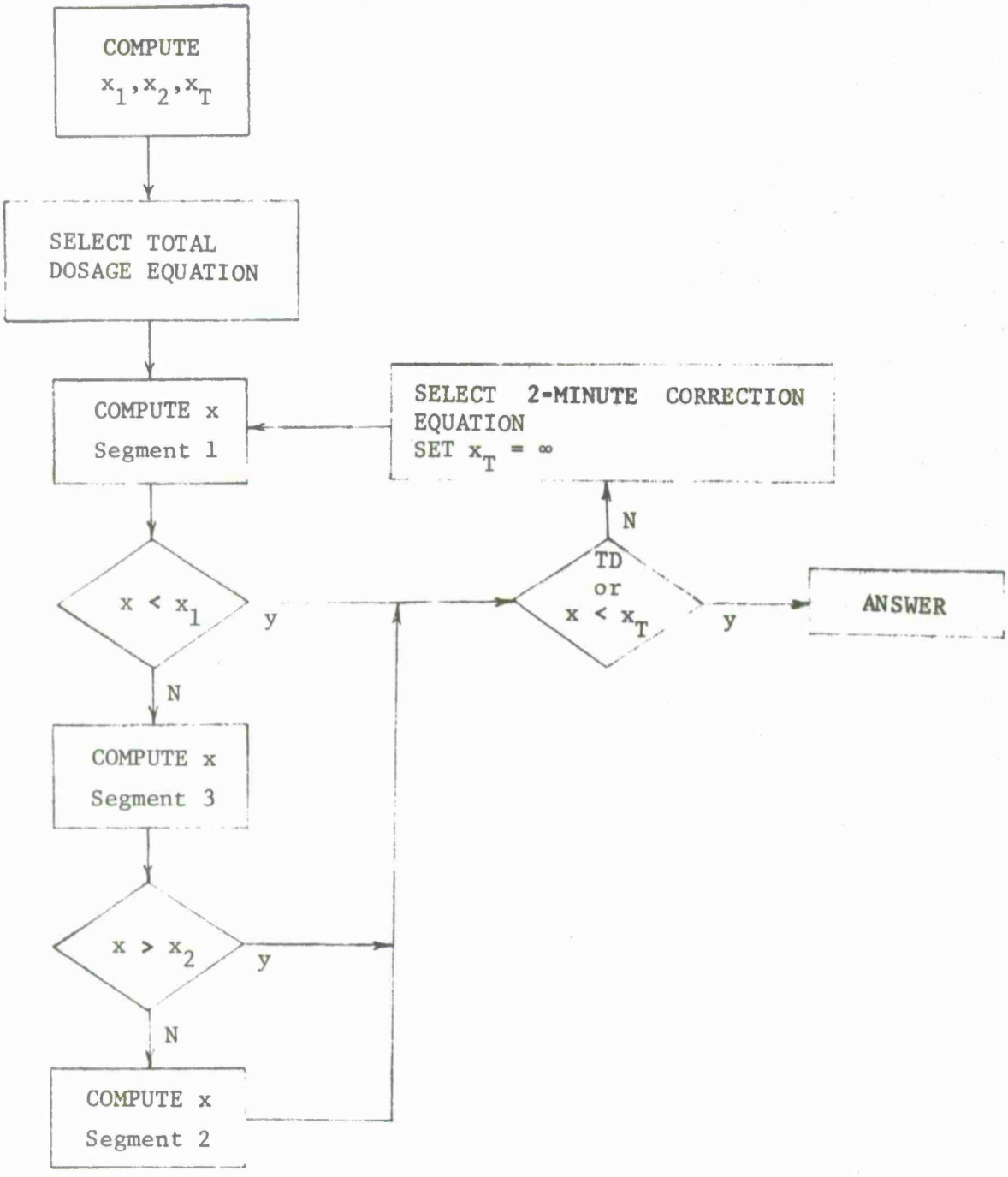

Figure. Logic for Determining Proper Segment

Once the complete logic was tested with a Fortran program, this approach was coded for the Texas Instruments Model 59. With the increased memory of the TI 59, it became possible to store the stability-dependent parameters (σ_{y1}, σ_{z1}, α, β, C_1, C_2) in memory and select the proper set by indirect addressing. The larger program size made it possible to store the three-segment logic as defined in the figure including the 2-minute corrections. Again, two programs are used, one for instantaneous and one for semicontinuous sources. These programs are discussed in appendix B.

8. LIMITATIONS OF THE SIMPLIFIED METHODOLOGY

The simplified methodology treats only point releases at ground level as calculated from a Gaussian diffusion model with vertical boundaries. The 2-minute correction as defined in ORG 40[2] and Technical Paper No. 10[3] is included and may be applied to G and V dosages as required. The simplified methodology does not include height of release or source cloud dimensions.

Special models such as that recommended for explosive dissemination of HD and the combined inhalation and disposition of VX are not treated. These models should lend themselves to a similar treatment. However, to avoid further delay, it was decided to complete the current report at this time and follow it with further extensions as those become available.

This simplified methodology is intended as a short-cut approximation and the program reported in ARCSL-TR-77049[4] should still be used for reference and for special applications not treated in this report.

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APPENDIX A

FORTRAN PROGRAMS

Program SINST estimates the distance to a specified dosage of interest for either total dosage or 2-minute-corrected dosage.

When program SINST is executed, it will request the following information:

INPUT: Q, u, D, HML, IS, IT

where

Q is source strength (mg)

u is windspeed (m/sec)

D is dosage (mg-min/m^3)

HML is height of the mixing layer (m)

IS is one of digits 1 through 6 corresponding to stability categories A through F

IT is an indicator, IT = 0 for total dosage

IT = 1 for 2-minute correction

Variable format is followed. All real numbers are written with a decimal point and fields are separated by commas.

The program outputs x_1, x_2, and x,

where

x_1 is the distance at which reflection from the inversion cap begins

x_2 is the distance at which vertical mixing is uniform

x is the distance at which the dosage of interest occurs.

```
WRK(1).SINST
 1       C  SHØRT TØTAL DØSAGE (IT=0)/SHØRT 2-MIN CRT (IT=1)/SAØ/CGW
 2             DIMENSIØN SY1(6),ALF(6),SZ1(6),BTA(6),C1(6),C2(6)
 3             DATA SY1/.09,.0633,.048,.0634,.0754,.0796/
 4             DATA SZ1/.0222,.11,.119,.0898,.0879,.0791/
 5             DATA ALF/1.,1.,1.,.9,.8,.7/
 6             DATA BTA/1.4,1.,.9,.85,.8,.75/
 7             DATA C1/10.5,5.5,6.13,9.49,11.2,15.3/
 8             DATA C2/15.9,9.55,11.2,18.1,21.9,31.1/
 9           3 PRINT 101
10         101 FØRMAT ('INPUT: Q,U,D,HML,IS,IT')
11             READ 100,Q,U,D,HML,IS,IT
12             APB=ALF(IS)+BTA(IS)
13             HRB=HML**(1./BTA(IS))
14             ALFI=ALF(IS)
15             XT=1.E36
16             IF (IT .EQ. 1) XT=(400.*U)**1.076
17             X1=C1(IS)*HRB
18             X2=C2(IS)*HRB
19             QYZDU=Q/(188.4*SY1(IS)*SZ1(IS)*D*U)
20             QYHDU=QYZDU*1.253*SZ1(IS)/HML
21           5 X=QYZDU**(1./APB)
22             IF (X .LT. X1) GØ TØ 4
23             X=QYHDU**(1./ALFI)
24             IF (X .LT. X2) GØ TØ 2
25           4 IF (X .LT. XT) GØ TØ 1
26             UE=U**.274/.1937
27             QYZDU=QYZDU*UE
28             QYHDU=QYHDU*UE
29             APB=APB+.255
30             ALFI=ALFI+.255
31             XT=1.E36
32           GØ TØ 5
33           2 D1=QYZDU/X1**APB
34             D2=QYHDU/X2**ALFI
35             S=LØG(X2/X1)/LØG(D2/D1)
36             X=X1/D1**S
37             GØ TØ 4
38           1 PRINT 200,X1,X2,X
39             GØ TØ 3
40         100 FØRMAT ( )
41         200 FØRMAT(23X,'  X1=',1PE10.3,'  X2=',E10.3,'  X=',E10.3,' M')

42             END
>
```

Program SSCS estimates the distance to a specified dosage of interest from a semicontinuous (uniform release for a finite time) source. The estimate is made for either total dosage or 2-minute correction. When program SSCS is executed, the following input is requested:

INPUT: Q, TS, u, D, HML, IS, IT

where

TS is the release time (min)

Other inputs and outputs are the same as for program SINST.

```
WRK(1).SSCS
 1      C  SHØRT SEMI-CØNT (IT=0) W/2-MIN CØRR (IT=1)/SA0/CGW
 2           DIMENSIØN SY1(6),ALF(6),SZ1(6),BTA(6),C1(6),C2(6)
 3           DATA SY1/.27,.1899,.125,.1268,.1508,.1592/
 4           DATA SZ1/.0222,.11,.119,.0898,.0879,.0791/
 5           DATA ALF/1.,1.,1.,.9,.8,.7/
 6           DATA BTA/1.4,1.,.9,.85,.8,.75/
 7           DATA C1/10.5,5.5,6.13,9.49,11.2,15.3/
 8           DATA C2/15.9,9.55,11.2,18.1,21.9,31.1/
 9           PRINT 101
10       101 FØRMAT(' INPUT: Q,TS,U,D,HML,IS,IT',6X,'X1',8X,'X2',8X,'X (M)')

11         3 READ 100,Q,TS,U,D,HML,IS,IT
12           APB=ALF(IS)+BTA(IS)
13           HRB=HML**(1./BTA(IS))
14           ALFI=ALF(IS)
15           ET=.281*TS*TS
16           RU=.000025/(U*U)
17           X1=C1(IS)*HRB
18           X2=C2(IS)*HRB
19           QYZDU=Q/(188.4*SY1(IS)*SZ1(IS)*D*U)
20           QYHDU=QYZDU*1.253*SZ1(IS)/HML
21           IF (IT .EQ. 0) GØ TØ 5
22           XT=0.
23           IF (TS .GT. 3.77) GØ TØ 6
24           XT=((4.-ET)/RU)**.538
25         5 X=QYZDU**(1./APB)
26           IF (X .LT. X1) GØ TØ 4
27           X=QYHDU**(1./ALFI)
28           IF (X .LT. X2) GØ TØ 2
29         4 IF (X .LT. XT .ØR. IT .EQ. 0) GØ TØ 1
30         6 CALL XE(QYZDU,APB)
31           IF (X .LT. X1) GØ TØ 1
32           CALL XE(QYHDU,ALFI)
33           IF (X .GT. X2) GØ TØ 1
34           QYZDU=QYZDU/(.827*(ET+RU*X1**1.8588)**.137)
35           QYHDU=QYHDU/(.827*(ET+RU*X2**1.8588)**.137)
36           XT=1.E36
37         2 D1=QYZDU/X1**APB
38           D2=QYHDU/X2**ALFI
39           S=LØG(X2/X1)/LØG(D2/D1)
40           X=X1/D1**S
41           GØ TØ 4
42         1 PRINT 200,X1,X2,X
43           GØ TØ 3
44       100 FØRMAT ( )
45       200 FØRMAT (25X,3F10.0)
46           SUBRØUTINE XE(FQ,P)
47           E=FQ/.827
48           X=0.
49           DX=1.E5
50         7 X=X+DX
51           IF (((ET+RU*X**1.8588)**.137*X**P) .LT. E) GØ TØ 7
52           X=X-DX
53           DX=DX/10.
54           IF (DX .GE. 1.) GØ TØ 7
55           RETURN
56           END
>
```

APPENDIX B

POCKET CALCULATOR PROGRAMS

The programs listed in this appendix were written for the Texas Instruments pocket calculator Model 59. The programs could readily be adapted to any calculator of similar capability. These programs use 36 words of memory to store the stability-dependent parameters and 6 words to store the indirect address references. This approach has the advantage that the stability is simply selected by the user and the parameters do not have to be keyed in with each execution. For program SINST, 12 additional words are used for intermediate storage, and program SSCS uses 18 additional words. Program SINST occupies 260 instruction cells, and SSCS occupies 419 instruction cells.

The pocket calculator programs follow the logic diagram (figure in text) and the Fortran programs listed in appendix A very closely. The user should note that the same input is used but the order is different.

For the TI 59, either program is loaded from two magnetic cards. (Systems Assessment Office will write three programs on your cards if requested.) The program is then initiated by pressing label A. The following tables will indicate the order of entry for each program.

TABLE B-1. DATA ENTRY PROGRAM SINST

Label A	IS is one of digits 1 through 6 to indicate stability, A through F
Label B	HML is height of the mixing layer (m)
Label C	Q is quantity airborne (mg)
	u is windspeed (m/sec)
	D is dosage of interest (mg-min/m^3)
	IT = 0 for total dosage
	= 1 for 2-minute correction

TABLE B-2. DATA ENTRY PROGRAM SSCS

Label A — IS is one of digits 1 through 6 to indicate stability, A through F

Label B — HML is height of the mixing layer (m)

t_s is release time (min)

Label C — Q is quantity airborne (mg)

u is windspeed (m/sec)

D is dosage of interest (mg-min/m^3)

IT = 0 for total dosage

= 1 for 2-minute correction

The program will progress from Label A to B to C automatically and return to Label C with the estimated distance. If the user does not want to restart with Q, he may restart at Label B or A.

PROGRAM SINST

```
000  76 LBL
001  11  A
002  05  5
003  42 STO
004  09  09
005  00  0
006  42 STO
007  08  08
008  91 R/S   IS
009  42 STO
010  00  00
011  76 LBL
012  16 A'
013  01  1
014  00  0
015  44 SUM
016  08  08
017  43 RCL
018  08  08
019  85  +
020  43 RCL
021  00  00
022  95  =
023  72 ST*
024  08  08
025  97 DSZ
026  09  09
027  16 A'
028  76 LBL
029  12  B
030  73 RC*
031  40  40
032  42 STO
033  07  07
034  73 RC*
035  50  50
036  42 STO
037  08  08
038  91 R/S   Hm
039  42 STO
040  19  19
041  45 Y^x
042  53  (
043  73 RC*
044  30  30
045  35 1/X
046  54  )
047  95  =
048  49 PRD
049  07  07
050  49 PRD
051  08  08
052  01  1
053  93  .
054  52 EE
055  03  3
056  06  6
057  42 STO
058  09  09
059  76 LBL
060  13  C
061  73 RC*
062  20  20
063  42 STO
064  28  28
065  85  +
066  73 RC*
067  30  30
068  95  =
069  42 STO
070  27  27
071  32 X:T
072  91 R/S   Q
073  55  ÷
074  01  1
075  08  8
076  08  8
077  93  .
078  05  5
079  55  ÷
080  73 RC*
081  00  00
082  55  ÷
083  73 RC*
084  10  10
085  55  ÷
086  91 R/S   u
087  42 STO
088  37  37
089  55  ÷
090  91 R/S   D
091  95  =
092  42 STO
093  17  17
094  65  ×
095  01  1
096  93  .
097  02  2
098  05  5
099  03  3
100  65  ×
101  73 RC*
102  10  10
103  55  ÷
104  43 RCL
105  19  19
106  95  =
107  42 STO
108  18  18
109  91 R/S   IT
110  32 X:T
111  00  0
112  67  EQ
113  10 E'
114  04  4
115  00  0
116  00  0
117  65  ×
118  43 RCL
119  37  37
120  95  =
121  45 Y^x
122  01  1
123  93  .
124  00  0
125  07  7
126  06  6
127  95  =
128  42 STO
129  09  09
130  76 LBL
131  10 E'
132  43 RCL
133  17  17
134  45 Y^x
135  53  (
136  43 RCL
137  27  27
138  35 1/X
139  54  )
140  95  =
141  32 X:T
142  43 RCL
143  07  07
144  77  GE
145  19 D'
146  43 RCL
147  18  18
148  45 Y^x
149  53  (
```

```
150  43 RCL
151  28  28
152  35 1/X
153  54  )
154  95  =
155  32 X:T
156  43 RCL
157  08  08
158  77  GE
159  18 C'
160  76 LBL
161  19 D'
162  43 RCL
163  09  09
164  77  GE
165  13  C
166  43 RCL
167  37  37
168  45 Y^
169  93  .
170  02  2
171  07  7
172  04  4
173  55  ÷
174  93  .
175  01  1
176  09  9
177  03  3
178  07  7
179  95  =
180  49 PRD
181  17  17
182  49 PRD
183  18  18
184  93  .
185  02  2
186  05  5
187  05  5
188  44 SUM
189  27  27
190  44 SUM
191  28  28
192  01  1
193  93  .
194  52 EE
195  03  3
196  06  6
197  42 STO
198  09  09
199  61 GTO
200  10 E'
201  76 LBL
202  18 C'
203  43 RCL
204  17  17
205  55  ÷
206  53  (
207  43 RCL
208  07  07
209  45 Y^
210  43 RCL
211  27  27
212  54  )
213  95  =
214  42 STO
215  38  38
216  43 RCL
217  18  18
218  55  ÷
219  53  (
220  43 RCL
221  08  08
222  45 Y^
223  43 RCL
224  28  28
225  54  )
226  95  =
227  55  ÷
228  43 RCL
229  38  38
230  95  =
231  23 LNX
232  42 STO
233  48  48
234  43 RCL
235  08  08
236  55  ÷
237  43 RCL
238  07  07
239  95  =
240  23 LNX
241  55  ÷
242  43 RCL
243  48  48
244  95  =
245  42 STO
246  58  58
247  43 RCL
248  07  07
249  55  ÷
250  53  (
251  43 RCL
252  38  38
253  45 Y^
254  43 RCL
255  58  58
256  54  )
257  95  =
258  32 X:T
259  61 GTO
260  19 D'
261  00  0
262  00  0
263  00  0
264  00  0
265  00  0
266  00  0
```

MEMORY MAP SINST

0.	00	0.	30
0.09	01	1.4	31
0.0633	02	1.	32
0.048	03	0.9	33
0.0634	04	0.85	34
0.0754	05	0.8	35
0.0796	06	0.75	36
0.	07	0.	37
0.	08	0.	38
0.	09	0.	39
0.	10	0.	40
0.0222	11	10.5	41
0.11	12	5.5	42
0.119	13	6.13	43
0.0898	14	9.49	44
0.0879	15	11.2	45
0.0791	16	15.3	46
0.	17	0.	47
0.	18	0.	48
0.	19	0.	49
0.	20	0.	50
1.	21	15.9	51
1.	22	9.55	52
1.	23	11.2	53
0.9	24	18.1	54
0.8	25	21.9	55
0.7	26	31.1	56
0.	27	0.	57
0.	28	0.	58
0.	29	0.	59

PROGRAM SSCS

```
000  76 LBL
001  11  A
002  05  5
003  42 STO
004  09  09
005  00  0
006  42 STO
007  08  08
008  91 R/S   IS
009  42 STO
010  00  00
011  76 LBL
012  16  A'
013  01  1
014  00  0
015  44 SUM
016  08  08
017  43 RCL
018  08  08
019  85  +
020  43 RCL
021  00  00
022  95  =
023  72 ST*
024  08  08
025  97 DSZ
026  09  09
027  16  A'
028  76 LBL
029  12  B
030  73 RC*
031  40  40
032  42 STO
033  07  07
034  73 RC*
035  50  50
036  42 STO
037  08  08
038  91 R/S   Hm
039  42 STO
040  19  19
041  45 Y^x
042  53  (
043  73 RC*
044  30  30
045  35 1/X
046  54  )
047  95  =
048  49 PRD
049  07  07
050  49 PRD
051  08  08
052  00  0
053  42 STO
054  29  29
055  91 R/S   ts
056  33 X²
057  65  ×
058  93  .
059  02  2
060  08  8
061  01  1
062  95  =
063  42 STO
064  47  47
065  76 LBL
066  13  C
067  73 RC*
068  20  20
069  42 STO
070  28  28
071  85  +
072  73 RC*
073  30  30
074  95  =
075  42 STO
076  27  27
077  32 X:T
078  91 R/S   Q
079  55  ÷
080  01  1
081  08  8
082  08  8
083  93  .
084  05  5
085  55  ÷
086  73 RC*
087  00  00
088  55  ÷
089  73 RC*
090  10  10
091  55  ÷
092  91 R/S   u
093  42 STO
094  37  37
095  55  ÷
096  91 R/S   D
097  95  =
098  42 STO
099  17  17
100  65  ×
101  01  1
102  93  .
103  02  2
104  05  5
105  03  3
106  65  ×
107  73 RC*
108  10  10
109  55  ÷
110  43 RCL
111  19  19
112  95  =
113  42 STO
114  18  18
115  43 RCL
116  37  37
117  33 X²
118  35 1/X
119  65  ×
120  02  2
121  05  5
122  52 EE
123  94 +/-
124  06  6
125  95  =
126  42 STO
127  57  57
128  22 INV
129  86 STF
130  01  01
131  91 R/S   IT
132  32 X:T
133  00  0
134  67  EQ
135  10  E'
136  86 STF
137  01  01
138  00  0
139  32 X:T
140  04  4
141  75  -
142  43 RCL
143  47  47
144  95  =
145  22 INV
146  77  GE
147  17  B'
148  55  ÷
149  43 RCL
```

```
150  57  57
151  95  =
152  45  Y^x
153  93  .
154  05  5
155  03  3
156  08  8
157  95  =
158  42  STO
159  29  29
160  76  LBL
161  10  E'
162  43  RCL
163  17  17
164  45  Y^x
165  53  (
166  43  RCL
167  27  27
168  35  1/X
169  54  )
170  95  =
171  32  X:T
172  43  RCL
173  07  07
174  77  GE
175  19  D'
176  43  RCL
177  18  18
178  45  Y^x
179  53  (
180  43  RCL
181  28  28
182  35  1/X
183  54  )
184  95  =
185  32  X:T
186  43  RCL
187  08  08
188  77  GE
189  18  C'
190  76  LBL
191  19  D'
192  43  RCL
193  29  29
194  77  GE
195  13  C
196  22  INV
197  87  IFF
198  01  01
199  13  C
200  76  LBL
201  17  B'
202  01  1
203  52  EE
204  03  3
205  06  6
206  42  STO
207  29  29
208  43  RCL
209  27  27
210  42  STO
211  39  39
212  43  RCL
213  17  17
214  71  SBR
215  71  SBR
216  43  RCL
217  07  07
218  77  GE
219  13  C
220  43  RCL
221  28  28
222  42  STO
223  39  39
224  43  RCL
225  18  18
226  71  SBR
227  71  SBR
228  43  RCL
229  08  08
230  22  INV
231  77  GE
232  13  C
233  43  RCL
234  07  07
235  71  SBR
236  22  INV
237  93  .
238  08  8
239  02  2
240  07  7
241  95  =
242  22  INV
243  49  PRD
244  17  17
245  43  RCL
246  08  08
247  71  SBR
248  22  INV
249  93  .
250  08  8
251  02  2
252  07  7
253  95  =
254  22  INV
255  49  PRD
256  18  18
257  76  LBL
258  18  C'
259  43  RCL
260  17  17
261  55  ÷
262  53  (
263  43  RCL
264  07  07
265  45  Y^x
266  43  RCL
267  27  27
268  54  )
269  95  =
270  42  STO
271  38  38
272  43  RCL
273  18  18
274  55  ÷
275  53  (
276  43  RCL
277  08  08
278  45  Y^x
279  43  RCL
280  28  28
281  54  )
282  95  =
283  55  ÷
284  43  RCL
285  38  38
286  95  =
287  23  LNX
288  42  STO
289  48  48
290  43  RCL
291  08  08
292  55  ÷
293  43  RCL
294  07  07
295  95  =
296  23  LNX
297  55  ÷
298  43  RCL
299  48  48
```

```
300  95  =
301  42 STO
302  58  58
303  43 RCL
304  07  07
305  55  ÷
306  53  (
307  43 RCL
308  38  38
309  45 Y^x
310  43 RCL
311  58  58
312  54  )
313  95  =
314  32 X:T
315  61 GTO
316  19 D'
317  76 LBL
318  71 SBR
319  55  ÷
320  93  .
321  08  8
322  02  2
323  07  7
324  95  =
325  32 X:T
326  00  0
327  42 STO
328  49  49
329  01  1
330  52 EE
331  05  5
332  42 STO
333  59  59
334  76 LBL
335  85  +
336  43 RCL
337  59  59
338  44 SUM
339  49  49
340  43 RCL
341  49  49
342  66 PAU
343  45 Y^x
344  01  1
345  93  .
346  08  8
347  05  5
348  08  8
349  08  8
350  65  ×
351  43 RCL
352  57  57
353  85  +
354  43 RCL
355  47  47
356  95  =
357  45 Y^x
358  93  .
359  01  1
360  03  3
361  07  7
362  65  ×
363  53  (
364  43 RCL
365  49  49
366  45 Y^x
367  43 RCL
368  39  39
369  54  )
370  95  =
371  22 INV
372  77  GE
373  85  +
374  43 RCL
375  59  59
376  22 INV
377  44 SUM
378  49  49
379  55  ÷
380  01  1
381  00  0
382  95  =
383  42 STO
384  09  09
385  42 STO
386  59  59
387  97 DSZ
388  09  09
389  85  +
390  43 RCL
391  49  49
392  32 X:T
393  92 RTN
394  76 LBL
395  22 INV
396  45 Y^x
397  01  1
398  93  .
399  08  8
400  05  5
401  08  8
402  08  8
403  65  ×
404  43 RCL
405  57  57
406  85  +
407  43 RCL
408  47  47
409  95  =
410  45 Y^x
411  93  .
412  01  1
413  03  3
414  07  7
415  65  ×
416  92 RTN
417  00  0
418  00  0
419  00  0
420  00  0
421  00  0
422  00  0
423  00  0
424  00  0
425  00  0
```

MEMORY MAP SSCS

4.		00	34.	30
0.27		01	1.4	31
0.1899		02	1.	32
0.125		03	0.9	33
0.1268		04	0.85	34
0.1508		05	0.8	35
0.1592		06	0.75	36
4834.59752		07	1.	37
9220.886735		08	1.168277898	38
0.		09	1.75	39
14.		10	44.	40
0.0222		11	10.5	41
0.11		12	5.5	42
0.119		13	6.13	43
0.0898		14	9.49	44
0.0879		15	11.2	45
0.0791		16	15.3	46
465900.3699		17	63.225	47
262.1141504		18	-.7051408062	48
200.		19	1370.	49
24.		20	54.	50
1.		21	15.9	51
1.		22	9.55	52
1.		23	11.2	53
0.9		24	18.1	54
0.8		25	21.9	55
0.7		26	31.1	56
1.75		27	0.000025	57
0.9		28	-.5884553105	58
1.	36	29	1.	59

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