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TECHNICAL REPORT ARCSL-TR-78010

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**A SIMPLIFIED METHODOLOGY FOR COMPUTING
CHEMICAL HAZARD DISTANCES**

by

C. Glenvil Whitacre

Systems Assessment Office

January 1978

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARCSL-TR-78010	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A SIMPLIFIED METHODOLOGY FOR COMPUTING CHEMICAL HAZARD DISTANCES		5. TYPE OF REPORT & PERIOD COVERED Technical Report September-November 1977
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) C. Glenvil Whitacre		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Director, Chemical Systems Laboratory Attn: DRDAR-CLY-A Aberdeen Proving Ground, Maryland 21010		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 72801211000
11. CONTROLLING OFFICE NAME AND ADDRESS Director, Chemical Systems Laboratory Attn: DRDAR-CLJ-R Aberdeen Proving Ground, Maryland 21010		12. REPORT DATE January 1978
14. MONITORING AGENCY NAME & ADDRESS (If different from Controlling Office)		13. NUMBER OF PAGES 38
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA
16. DISTRIBUTION STATEMENT (of this Report) Distribution limited to US Government agencies only because of test and evaluation; January 1978. Other requests for this document must be referred to Director, Chemical Systems Laboratory, Attn: DRDAR-CLJ-R, Aberdeen Proving Ground, Maryland 21010.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) (U) Hazards analysis Chemical hazard Cloud diffusion		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (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.		

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.

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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 layer¹ and the 2-minute dosage correction² 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. 10³ 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-77049⁴ was published by Systems Assessment Office to document a complete computer program of this methodology.

Since the Handbook¹ 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.

* Diffusion under an inversion cap with vertical distribution uniform.

In order to simplify the 2-minute-corrected methodology as developed for ORG 40² 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 17⁵ in 1958. This approach was reproduced in Technical Paper No. 10³ indicating that the factor which augments the dosage at any downwind distance can be expressed as follows:

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

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)

$\sigma_z = \sigma_{zr} \left(\frac{x}{x_{zr}} \right)^{\beta}$, the vertical distribution of the cloud as defined in the handbook¹ (m)

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

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

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:

$$x_1 = C_1 H_m^{1/\beta} \quad (3)$$

$$x_2 = C_2 H_m^{1/\beta} \quad (4)$$

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:

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

where

$D(x)$ is the total dosage at x (mg-min/m³)

Q is the source strength (mg)

u is the windspeed (m/sec)

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

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

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

$$D(x) = \frac{Q}{60\pi \sigma_{y1} \sigma_{z1} u x^{\alpha + \beta}} \quad (6)$$

where

$$\sigma_{y1} = \sigma_{yR} (x_{yR})^{-\alpha}$$

$$\sigma_{z1} = \sigma_{zR} (x_{zR})^{-\beta}$$

or the inverse solution:

$$x = \left[\frac{Q}{60\pi \sigma_{y1} \sigma_{z1} D u} \right]^{1/\alpha + \beta} \quad x < x_1 \quad (7)$$

where D is the dosage of interest (mg-min/m³).

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

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

$$D(x) = \frac{Q}{60 \sqrt{2\pi} \sigma_{y1} H_m x^\alpha} \quad (8)$$

or

$$x = \left[\frac{Q}{60 \sqrt{2\pi} \sigma_{y1} D H_m} \right]^{1/\alpha} \quad x > x_2 \quad (9)$$

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,

$$D_1 = \frac{Q}{188.5 \sigma_{y1} \sigma_{z1} u x_1^{\alpha + \beta}} \quad (10)$$

$$D_2 = \frac{Q}{150.4 \sigma_{y1} H_m u x_2^\alpha} \quad (11)$$

then

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

and

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

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-77049⁴ 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.

$$t_e = \frac{0.005 x^{0.9294}}{u} \quad (14)$$

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 dosage² to compute the effective dosage at any distance.

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

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

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

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

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

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

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 .

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

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

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

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

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

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:

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

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:

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

where

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

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:

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

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.

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

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

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.

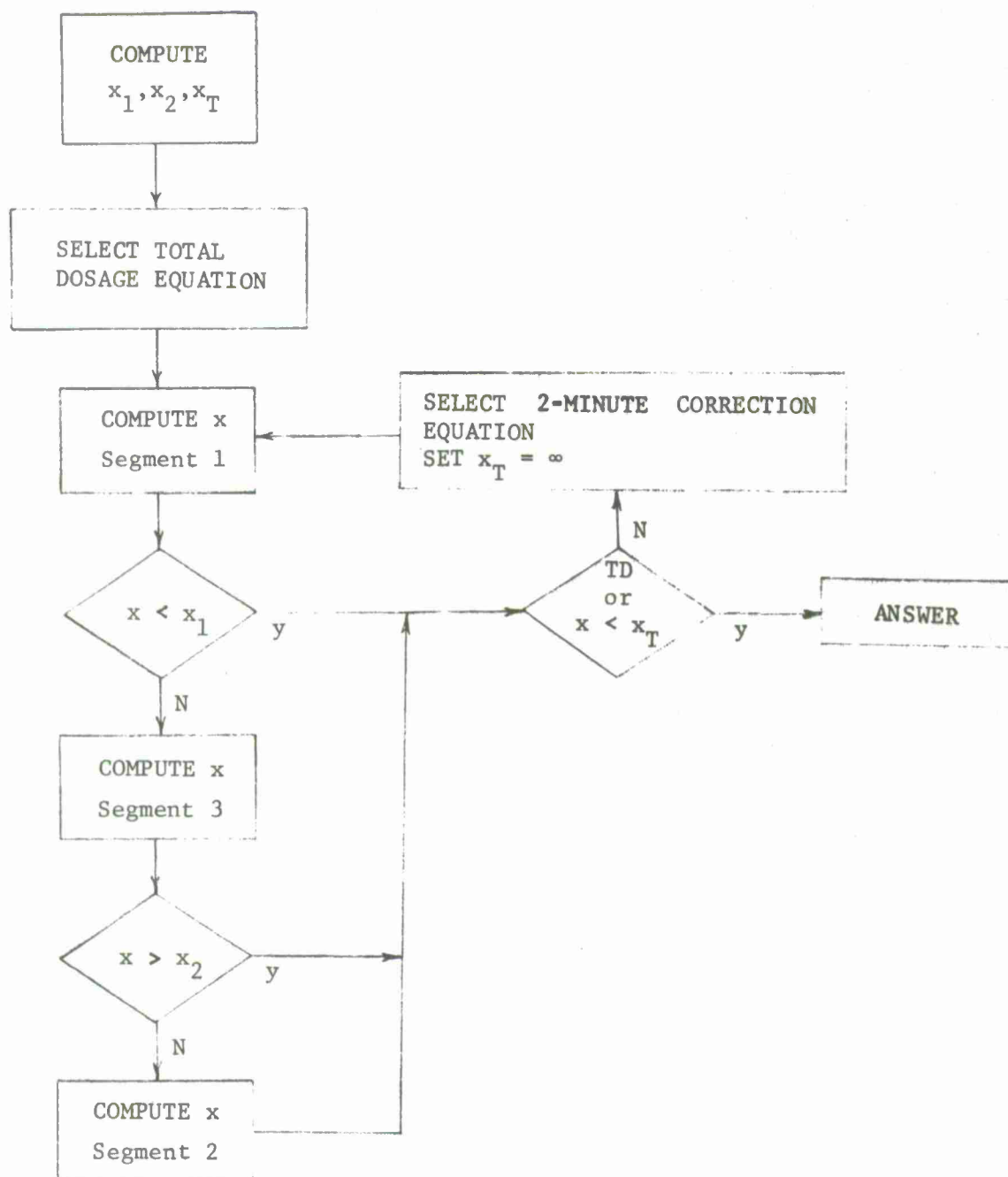


Figure. Logic for Determining Proper Segment

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_y , σ_z , 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 40² and Technical Paper No. 10³ 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-77049⁴ should still be used for reference and for special applications not treated in this report.

REFERENCES

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4. Whitacre, C. Glenvil, Robinson, Philip E., Kneas, William L., and Freeman, Alan L. ARCSL-TR-77049. Computer Program for Chemical Hazard Prediction. June 1977. UNCLASSIFIED 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/m³)

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

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

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

150 57 57
 151 95 =
 152 45 YX
 153 93 .
 154 05 5
 155 03 3
 156 08 8
 157 95 =
 158 42 STD
 159 29 29
 160 76 LBL
 161 10 E'
 162 43 RCL
 163 17 17
 164 45 YX
 165 53 (
 166 43 RCL
 167 27 27
 168 35 1/X
 169 54)
 170 95 =
 171 32 XIT
 172 43 RCL
 173 07 07
 174 77 GE
 175 19 D'
 176 43 RCL
 177 18 18
 178 45 YX
 179 53 (
 180 43 RCL
 181 28 28
 182 35 1/X
 183 54)
 184 95 =
 185 32 XIT
 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 STD
 207 29 29
 208 43 RCL
 209 27 27
 210 42 STD
 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 STD
 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 YX
 266 43 RCL
 267 27 27
 268 54)
 269 95 =
 270 42 STD
 271 38 38
 272 43 RCL
 273 18 18
 274 55 +
 275 53 (
 276 43 RCL
 277 08 08
 278 45 YX
 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 STD
 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	=	350	65	x	400	05	5
301	42	STD	351	43	RCL	401	08	8
302	58	58	352	57	57	402	08	8
303	43	RCL	353	85	+	403	65	x
304	07	07	354	43	RCL	404	43	RCL
305	55	÷	355	47	47	405	57	57
306	53	(	356	95	=	406	85	+
307	43	RCL	357	45	Yx	407	43	RCL
308	38	38	358	93	.	408	47	47
309	45	Yx	359	01	1	409	95	=
310	43	RCL	360	03	3	410	45	Yx
311	58	58	361	07	7	411	93	.
312	54	)	362	65	x	412	01	1
313	95	=	363	53	(	413	03	3
314	32	X↑T	364	43	RCL	414	07	7
315	61	GTD	365	49	49	415	65	x
316	19	D'	366	45	Yx	416	92	RTN
317	76	LBL	367	43	RCL	417	00	0
318	71	SBR	368	39	39	418	00	0
319	55	÷	369	54	)	419	00	0
320	93	.	370	95	=	420	00	0
321	08	8	371	22	INV	421	00	0
322	02	2	372	77	GE	422	00	0
323	07	7	373	85	+	423	00	0
324	95	=	374	43	RCL	424	00	0
325	32	X↑T	375	59	59	425	00	0
326	00	0	376	22	INV			
327	42	STD	377	44	SUM			
328	49	49	378	49	49			
329	01	1	379	55	÷			
330	52	EE	380	01	1			
331	05	5	381	00	0			
332	42	STD	382	95	=			
333	59	59	383	42	STD			
334	76	LBL	384	09	09			
335	85	+	385	42	STD			
336	43	RCL	386	59	59			
337	59	59	387	97	DSZ			
338	44	SUM	388	09	09			
339	49	49	389	85	+			
340	43	RCL	390	43	RCL			
341	49	49	391	49	49			
342	66	PAU	392	32	X↑T			
343	45	Yx	393	92	RTN			
344	01	1	394	76	LBL			
345	93	.	395	22	INV			
346	08	8	396	45	Yx			
347	05	5	397	01	1			
348	08	8	398	93	.			
349	08	8	399	08	8			

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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