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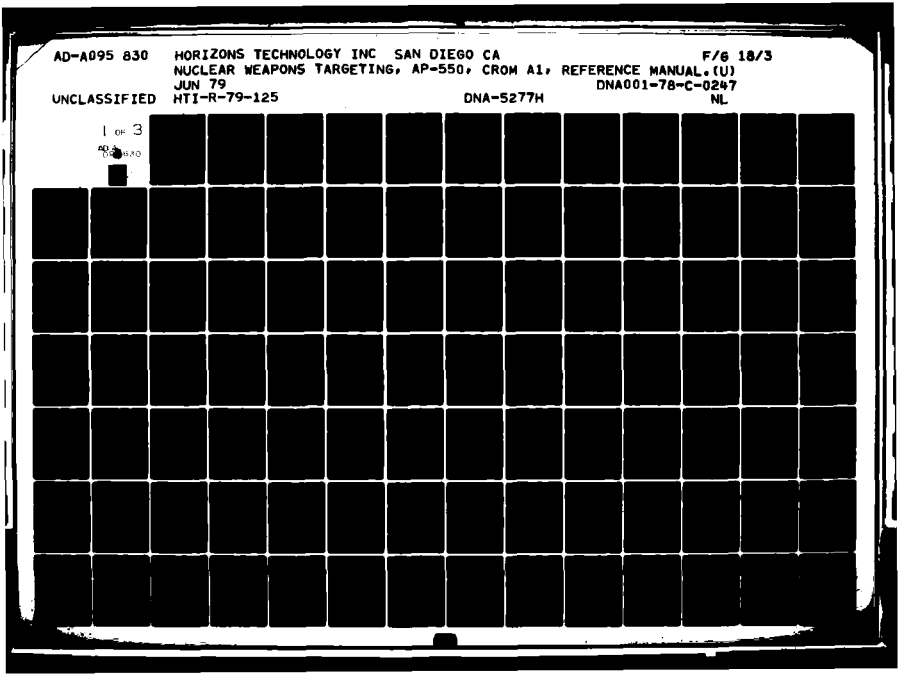

DNA 5277H

NUCLEAR WEAPONS TARGETING, AP-550 CROM A1

Reference Manual

Horizons Technology, Inc.
7830 Clairemont Mesa Boulevard
San Diego, California 92111

1 June 1979

Handbook

CONTRACT No. DNA 001-78-C-0247

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Probability of Damage

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document is a reference document and user's guide for a solid state module programmed to reproduce various targeting calculations, using a hand-held calculator. The calculations are based on methods and data from DIA's Physical Vulnerability Handbook - Nuclear Weapons. AP-550-1-2-60-INT, June 1, 1969, Unpublished.

(Continued)

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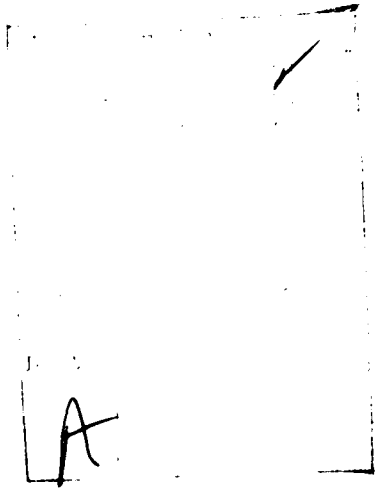
20. ABSTRACT (Continued)

The module is designed for use in the Texas Instruments programmable calculator, TI-59, with its associated PC-100 printer.

The calculator with module is capable of calculating weapon radii and probabilities of damage based on VNs, cratering phenomena, minimum safe distances, and many other calculations.

This document contains instructions for use of the module, plus annotated program listings and equations used.



CONVERSION FACTORS FOR U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

To Convert From	To	Multiply By
angstrom	meters (m)	1.000 000 X E -10
atmosphere (normal)	kilo pascal (kPa)	1.013 25 X E +2
bar	kilo pascal (kPa)	1.000 000 X E +2
barn	meter^2 (m^2)	1.000 000 X E -28
British thermal unit (thermochemical)	joule (J)	1.054 350 X E +3
calorie (thermochemical)	joule (J)	4.184 000
cal (thermochemical)/cm^2	mega joule/m^2 (MJ/m^2)	4.184 000 X E -2
curie	giga becquerel (GBq)*	3.700 000 X E +1
degree (angle)	radian (rad)	1.745 329 X E -2
degree Fahrenheit	degree kelvin (K)	$T_K = (t° f + 459.67)/1.8$
electron volt	joule (J)	1.602 19 X E -19
erg	joule (J)	1.000 000 X E -7
erg/second	watt (W)	1.000 000 X E -7
foot	meter (m)	3.048 000 X E -1
foot-pound-force	joule (J)	1.355 818
gallon (U.S. liquid)	meter^3 (m^3)	3.785 412 X E -3
inch	meter (m)	2.540 000 X E -2
jerk	joule (J)	1.000 000 X E +9
joule/kilogram (J/kg) (radiation dose absorbed)	Gray (Gy)**	1.000 000
kilotons	terajoules	4.183
kip (1000 lbf)	newton (N)	4.448 222 X E +3
kip/inch^2 (ksi)	kilo pascal (kPa)	6.894 757 X E +3
ktap	newton-second/m^2 ($N-s/m^2$)	1.000 000 X E +2
micron	meter (m)	1.000 000 X E -6
mil	meter (m)	2.540 000 X E -5
mile (international)	meter (m)	1.609 344 X E +3
ounce	kilogram (kg)	2.834 952 X E -2
pound-force (lbf avoirdupois)	newton (N)	4.448 222
pound-force inch	newton-meter (N·m)	1.129 848 X E -1
pound-force/inch	newton/meter (N/m)	1.751 268 X E +2
pound-force/foot^2	kilo pascal (kPa)	4.788 026 X E -2
pound-force/inch^2 (psi)	kilo pascal (kPa)	6.894 757
pound-mass (lbm avoirdupois)	kilogram (kg)	4.535 924 X E -1
pound-mass-foot^2 (moment of inertia)	kilogram-meter^2 ($kg·m^2$)	4.214 011 X E -2
pound-mass/foot^3	kilogram/meter^3 (kg/m^3)	1.601 846 X E +1
rad (radiation dose absorbed)	Gray (Gy)**	1.000 000 X E -2
roentgen	coulomb/kilogram (C/kg)	2.579 760 X E -4
shake	second (s)	1.000 000 X E -8
slug	kilogram (kg)	1.459 390 X E +1
torr (mm Hg, 0° C)	kilo pascal (kPa)	1.333 22 X E -1

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (Gy) is the SI unit of absorbed radiation.

A more complete listing of conversions may be found in "Metric Practice Guide E 380-74," American Society for Testing and Materials.

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GENERAL USER INSTRUCTIONS

The documentation contained in this report consists of specific user instructions, equations and program listings for nuclear weapons targeting calculations using the Texas Instruments TI-59 hand-held programmable calculator with the DNA/AP-550 CROM A1 installed. The programs were developed by Horizons Technology, Inc. (HTI) under contract with the Defense Nuclear Agency, Contract No. DNA 001-78-C-0247

These instructions were prepared for users who have a working knowledge of the TI-59 calculators. Less experienced users will find detailed operating instructions in the TI-59 Owner's Manual.

After the instructions for each calculation, this document includes a section describing the equations used in that calculation and a section cc aining annotated program listings.

Additional program development is being continued. The purpose of this CROM and associated documentation is to examine the utility and convenience of this equipment and these programs. Selected sections of the referenced document were programmed to provide the ability to run various types of calculations. Omission of other types of calculations does not imply that they are not important or will not also be programmed in the future. Similarly, the normal test and review procedures are still in process. Issuance of these CROMs and documents prior to completion of test and review permits the possibility of programming errors. The calculated results are developed from variuos numerical representations of the available data. Two accuracy statements are required. The precision with which the referenced data are represented is typically ±5% with occasional differences of as much as ±15%. The references used claim accuracies of ±15% to 25%. The user is cautioned to refer to the referenced documents for more complete descriptions of uncertainties in data and methodologies. The approximations made in generating these data are discussed only to the extent necessary to explain the equations used. These approximations can be complex and, if not understood, can lead an inexperienced user to erroneous conclusions. These data are also valid only within limited ranges. Limits have

been imposed in most of the HTI programs to confine them within the limits of the basic data or within reasonable limits if no other restrictions pertain. The user is warned by a flashing display and termination of input printing when the limits have been exceeded.

To insert the CROM module into the calculator, follow these instructions:

1. Turn the calculator off. Replacing a module with the calculator on may cause the keyboard or display to lock out. Shorting the contacts can damage the module or the calculator.

2. Slide out the small panel covering the module compartment at the bottom on the back of the calculator. Be sure to eliminate all static charges before handling the module.

3. Remove the module initially in the calculator. The calculator may be turned over to allow the module to fall into the user's hand.

4. Insert the new module, notched end first, with the contact side down into the compartment. The module should slip effortlessly into place.

5. Replace the cover panel, securing the module against the contacts.

Descriptions of the auxiliary magnetic card programs for this CROM module are given as appendices to this document. These programs run in the turn-on state of the calculator, program 00, and call the CROM programs as subroutines. They are referred to as control programs. There are four types of control programs described in Appendices A through D.

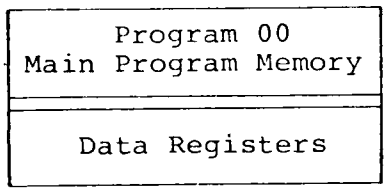
Appendix A is a demonstration code than runs CROM programs sequentially with one set of input parameters.

Appendix B provides for repetitive calculations with varying inputs, for parametric studies.

Appendix C provides for inversions of several of the CROM calculations.

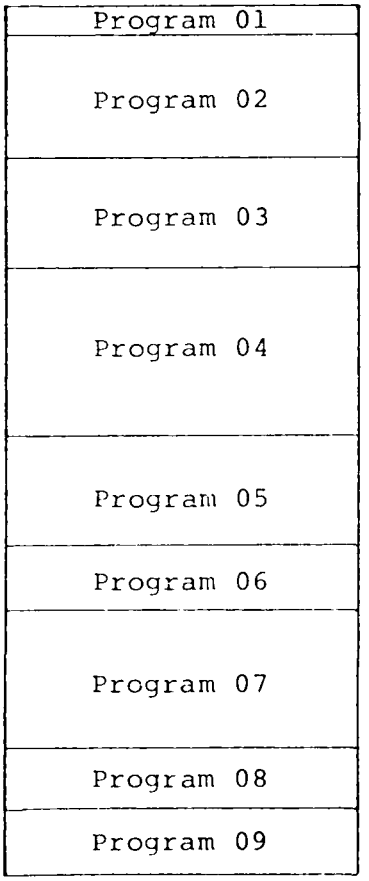
Appendix D is a program that will calculate probability of damage to rectangular, triangular, and elliptical targets.

These auxiliary programs expand the versatility of the basic CROM module by adding interesting features that would otherwise be excluded because of memory constraints and input/output considerations. A control program can reside in calculator memory, and the CROM module is still immediately accessible to the user.



Main Calculator Memory

The boxes to the right are proportional to the sizes of the different memories required in the CROM. Magnetic card programs are read into the main calculator memory illustrated above. A CROM program on the right can be selected and run independently. The data registers, however, are shared by all programs. Any program is able to call a subroutine of another program for execution. Thus a control program residing in the main program memory can call and execute a CROM program as a subroutine.



CROM Program Memory

Operation of the CROM is described in section 1, "General Description." Every code is accessed and run through the universal input routine, program 01, which is also described in section 1. The example problems shown in each section are designed to illustrate the use of the PC-100 printer with the calculator. In cases where intermediate results are printed but not displayed, the storage registers for these results are given so that they may be recalled when using the calculator in the hand-held mode. Storage registers 6-9 and 30-59 are always available to the user and have no effect on CROM program operation.

The inputs necessary to perform the calculations programmed in this CROM are briefly defined in each program section of this document. The user is referred to the Defense Intelligence Agency's Physical Vulnerability Handbook - Nuclear Weapons (U), AP-550-1-2-60-INT, June 1, 1969, CONFIDENTIAL, for further information.

At the top of the first page of every program section of this document is an image titled "AP-550 PROMPT A1". These are images of non-magnetic "prompt" cards that slip into the card holder on the front of the TI-59 calculator. The purpose of these cards is to provide an input guide for the user. No magnetic data is or can be stored on these cards.

Section 1

CROM Operation: General Input Routine and Calculational Capabilities.

AP-550 CROM A1 - GENERAL INPUT ROUTINE AND DESCRIPTION

To facilitate both versatility and ease of use, the DNA/AP-550 CROM A1 was designed to operate entirely through program 01, the universal input routine. To ensure that the AP-550 CROM is installed in the calculator, enter the keystrokes 2nd Pgm 01 SBR 2nd Write. The PC-100 printer will then print:

DNA/AP-550.

Once program 01 has been selected, the calculator can be left in that mode. The universal input program automatically selects all programs and stores all inputs.

Inputs are entered into keys A through E and 2nd A' through 2nd D' in accordance with the input label plan shown in Figure 1. Inputs may be entered in any order, except that in the Equivalent Target Area code, programs 6.0 and 6.1, the length VN and length k-factor must be entered successively into key D, as: length VN, D; length k-factor, D. The same applies to the width VN and k-factor in key E. The offset and radius of safety must also be entered successively into key D when executing program 5.1. Other than these special cases, all inputs can be independently entered before program execution. All inputs are saved (with the exception of environment classification in the Personnel Vulnerability program) during the course of execution and do not need to be re-entered when another calculation is initiated.

To run a calculation, first enter the data with the appropriate keys (as shown in Fig. 1), and then enter a two-digit code number of the form a.b with key 2nd E'. This number selects the primary calculation and subcalculation to be run. All the calculations that may be run, and their associated code numbers, are shown in Table 1. Once a calculation is selected, the code number for that calculation need not be re-entered if a repeat calculation is desired. Pressing R/S will initiate the previous keyed-in calculation even if the inputs are changed.

Programs 2.0 through 2.7

CEP	TARGET RADIUS	OFFSET	DAMAGE SIGMA	
YIELD	HOB		VN	K-FACTOR

Weapon Radius, P and Q Targets; Pd to circular normal targets

Programs 3.0 through 3.2

CEP	TARGET RADIUS	OFFSET	DAMAGE SIGMA	
		WR		

Pd to point and circular targets, normal and uniform dist.

Programs 4.0 and 4.1

YIELD	HOB	ENVIR.		

Personnel Vulnerability

Programs 5.0 through 5.3

TROOP DISP.	VULN.	RISK	DESIRED ASSUR.	
YIELD	HOB	CEP	OFFSET; R.S.	PEH

Minimum Safe Dist., Fallout-Safe HOB

Programs 6.0 and 6.1

CEP	LENGTH	WIDTH	AIM POINT	
YIELD	HOB		LENGTH VN,K	WIDTH VN, K

Prob. of Damage, ETA, VN System

Program 6.2

CEP	LENGTH	WIDTH	AIM POINT	
YIELD	HOB	MEDIUM	LENGTH CRM	WIDTH CRM

Prob. of Damage, ETA, crater radius method

Program 6.3

CEP	LENGTH	WIDTH	AIM POINT	
			LENGTH WR	WIDTH WR

Prob. of Damage, ETA, weapon radius method

Programs 7.0 through 7.4

YIELD	HOB	MEDIUM	RADIUS	

Cratering

Figure 1. An assignment of variables to user-defined keys for each program in AP-550 CROM A1. The lower rows of rectangles for each program type represent Keys A through E. The upper rows represent Keys 2nd A' through 2nd E'.

Table 1. A complete list of calculations available with AP-550 CROM A1.

CODE	DESCRIPTION
2.0	Weapon radius and probability of damage, P-target*
2.1	Weapon radius and probability of damage, Q-target*
2.2	Weapon radius and probability of damage at optimum HOB, P-target*
2.3	Weapon radius and probability of damage at optimum HOB, Q-target*
2.4	Weapon radius, P-target
2.5	Weapon radius, Q-target
2.6	Weapon radius at optimum HOB, P-target
2.7	Weapon radius at optimum HOB, Q-target
3.0	Probability of damage - point target
3.1	Probability of damage - circular normal distribution
3.2	Probability of damage - circular uniform distribution
4.0	Personnel weapon radius, any HOB
4.1	Personnel weapon radius, optimum HOB
5.0	Radius of safety and minimum safe distance
5.1	Probability of not exceeding acceptable weapons effects
5.2	The minimum HOB which has a certain probability of being fallout-safe
5.3	The probability that a certain HOB is fallout-safe
6.0	Probability of damage, ETA, VN method, P-target
6.1	Probability of damage, ETA, VN method, Q-target
6.2	Probability of damage, ETA, crater radius method
6.3	Prob. of damage, ETA, length and width weapon radii specified
7.0	Crater radius, depth and volume
7.1	Invert for HOB
7.2	Invert for yield
7.3	Calculate optimum HOB for maximum crater radius
7.4	Calculate optimum HOB and minimum yield for given crater radius

*circular normal distributions only.

The running calculation prints the calculation code number first, the inputs second, and then pauses until the solution is found and printed. During the input printing cycle, inputs are checked to determine if they are within an acceptable range, if limited by the program. These automatic limits are specified at the end of each program description. If a value falls outside the allowed data range, the calculator sets an error condition, prints the exceeded input, and stops execution with the exceeded limit flashing in the display. The input value itself is in the t-register for inspection. The procedure for correcting the error is to press CLR, re-enter a new input value with the appropriate key, and press R/S to start the calculation over.

Should it become necessary to stop the calculator while a CROM program is running, the reset key, RST, can be pressed to return program control to the keyboard. Pressing the R/S key has no effect when the calculator is running in CROM memory. The RST key also takes the calculator out of any CROM program and leaves the pointer in program 00, which is the program the machine is in when it is turned on or when it is running a magnetic card program. To use the CROM, program 01 must be selected again. For this reason, consider the RST key only as an emergency halt command.

When running the example problems in the following programs, it is useful to note that steps 1 and 2 are always the same: 1) turn off, then on, and 2) select program 01. If the calculator is already on and in program 01, these steps need not be repeated between examples. However, it is important to enter all the inputs required for a particular calculation, otherwise values previously entered will be stored in memory and can be misused. Table 2 lists the inputs and outputs and their corresponding printer alphanumerics for each of the main CROM programs. Note that Table 2 includes the same information presented graphically in Figure 1.

Table 2. Inputs and outputs for each of the main CROM programs and their corresponding printer alphanumerics.

INPUTS	KEY	ALPHA	OUTPUTS	ALPHA
Program 02 (see note at end of table)				
Yield	A	Y	Weapon Radius	W
Height of burst	B	H	Optimum height of burst	H
Vulnerability number	D	V	(printed with inputs)	
k-factor	E	K	Probability of damage	P
Program 03				
Weapon radius	C	W	Probability of Damage	P
Circular error probable	A'	C		
Target radius	B'	T		
Offset	C'	X		
Damage sigma	D'	S		
Program 04				
Yield	A	Y	Weapon radius	W
Height of burst	B	H	Damage sigma	S
Environment	C	E	Optimum height of burst	H
			(printed with inputs)	
Program 05				
Yield	A	Y	Radius of safety	RS
Height of burst	B	H	Minimum safe distance	M
Circular error probable	C	C	Probability	P
Offset	D	X	Height of burst	H
Radius of safety	E	RS		
Circular error probable	F	PH		
Troop disposition	A'	D		
Vulnerability condition	B'	V		
Acceptable risk	C'	R		
Command probability	D'	P		
Program 06				
Yield	A	Y	Length weapon radius	LW
Height of burst	B	H	Width weapon radius	WW
Length Yield	D	LY		
Width Yield	E	WY		
Length k-factor	D	LK		
Width k-factor	E	WK		
Circular error probable	A'	C		
Length	B'	L		
Width	C'	W		
Aim point	D'	A		
Soil medium	C	M		

Table 2. (Continued)

INPUTS	KEY	ALPHA	OUTPUTS	ALPHA
Program 06 (continued)				
Length crater radius multiplier	D	LM		
Width crater radius multiplier	E	WM		
Length weapon radius	D	LW		
Width weapon radius	E	WW		
Program 07				
Yield	A	Y	Radius	R
Height of burst	B	H	Depth	D
Soil Medium	C	M	Volume*	none
Radius	D	R	Yield (also minimum yield)	Y
			Height of burst (also optimum height of burst)	H

* Volume will appear in the display after pressing 2nd x.

Note on Program 02: Programs 2.0 through 2.3 calculate probability of damage to circular normal targets in addition to weapon radii. This is made possible by an internal command that automatically transfers the calculated weapon radii to program 03. Therefore, to calculate a probability of damage utilizing program 02., i.e., to invoke calculations 2.0 through 2.3, the inputs listed for program 03 must also be entered with the exception of weapon radius.

The appendices to this document contain magnetic card auxiliary programs that use the CROM module's programs as subroutines. The auxiliary programs are designed to enhance the CROM's versatility by providing inversion routines for the CROM's main program, iteration routines for parameter studies and special case considerations. A list of calculations possible when the auxiliary program magnetic cards are used in conjunction with the AP-550 CROM AI is given in Table 3.

Table 3. A list of auxiliary magnetic card programs given in the appendices of this document.

CONTROL CARD CALCULATIONS

Appendix A - Demonstration Program

(a) will run a number of CROM programs in a single execution, with parameters defaulting to programmed values. Inputs can be changed at the option of the user.

Appendix B - Iterations

(a) Appendix B1 will increment up to five different inputs through a specified range to perform large numbers of calculations in a single execution.

(b) Appendix B2 is similar to Appendix B1, except that the values of the input parameter being changed are explicitly specified.

Appendix C - Inversions

(a) Appendix C1 inverts the VNTK System for yield.

(b) Appendix C2 inverts the Personnel vulnerability code for yield.

(c) Appendix C3 inverts the Cratering code for the deeper depth of burst.

Appendix D - Probability of Damage

(a) Will calculate probability of damage to rectangular, elliptical and triangular targets by the method shown in AP-550.

PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
AUTOMATIC	07	exceeded limit flag (reset in this program, set by called programs)		

LIBRARY MODULE: CROM A-1 (Program 1)

DATA REGISTERS FOR EXAMPLE _____

DATA	REG.	COMMENTS	STEP	CODE	LABELS KEY	COMMENTS
		Program in use	001	14	D	→R13, R19
		Line for SBR call	003	14	7	formatting
		Reg. no. for input in use	010	15	E	→R14, R20
		used by called program	030	1	A	→R10
			035	1	B	→R11
			042	1	C	→R12
			048	1	D'	→R15
			051	1	E'	→R16
			056	1	A'	→R17
			060	1	B'	→R18
		Input, key A	071	1	D	advance paper
		Input, key B	080	1	E'	initiate calc
		Input, key C	1	1	E	header
		Last input, key D				
		Last input, key E				
		Input, key A'				
		Input, key B'				
		Input, key C'				
		Input, key D'				
		Next to last input, key D				
		Next to last input, key E				
		Used by called program				

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	76	LBL	If one input: Input → R13
001	14	D	
002	48	EXC	D
003	13	13	
004	42	STO	If two inputs: 1st input → R19
005	19	19	2nd input → R13
006	43	RCL	
007	13	13	
008	76	LBL	
009	34	fX	
010	09	FIX	
011	09	09	
012	13	INV	
013	57	ENG	
014	32	RTN	
015	43	RCL	Initiate calculation on R/S
016	00	00	
017	61	GTO	
018	10	E'	
019	76	LBL	If one input: Input → R14
020	15	E	
021	48	EXC	E
022	14	14	
023	42	STO	If two inputs: 1st input → R20
024	20	20	2nd input → R14
025	43	RCL	
026	14	14	
027	61	GTO	
028	34	fX	
029	76	LBL	
030	11	A	Input → R10
031	42	STO	A
032	10	10	
033	61	GTO	
034	34	fX	
035	76	LBL	
036	12	B	Input → R11
037	42	STO	B
038	11	11	
039	61	GTO	
040	34	fX	
041	76	LBL	
042	13	C	Input → R12
043	42	STO	C
044	12	12	
045	61	GTO	
046	34	fX	

STEP	CODE	KEY	COMMENTS
047	76	LBL	A' Input → R15
048	16	A'	
049	42	STO	
050	15	15	
051	61	GTO	
052	34	fX	
053	76	LBL	B' Input → R16
054	17	B'	
055	42	STO	
056	16	16	
057	61	GTO	
058	34	fX	
059	76	LBL	C' Input → R17
060	18	C'	
061	42	STO	
062	17	17	
063	61	GTO	
064	34	fX	
065	76	LBL	D' Input → R18
066	19	D'	
067	42	STO	
068	18	18	
069	61	GTO	
070	34	fX	
071	76	LBL	Return after calculation
072	31	R/S	
073	38	ADV	
074	93	ADV	
075	38	ADV	
076	32	RTN	
077	43	RCL	Same calculation R/S
078	00	00	
079	76	LBL	Label E'. Initiate CROM calc. (Pgm)
080	10	E'	
081	42	STO	
082	00	00	
083	35	CLR	
084	32	RTN	
085	35	CLR	
086	01	01	
087	48	EXC	
088	00	00	
089	01	1	
090	00	0	
091	42	STO	Used to recall input values with RCL IND 02
092	02	02	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
094	65	×	
095	43	RCL	
096	00	00	
097	33	PRT	
098	22	INV	For directing pointer to proper label
099	39	INT	
100	55	÷	
101	03	X≠T	
102	04	4	
103	22	INV	If frac(R00) ≥ .4 (P-target)
104	17	GE	
105	01	01	
106	18	18	
107	65	×	
108	03	X≠T	
109	85	+	
110	01	1	
111	02	2	
112	07	7	
113	95	=	
114	42	STO	
115	01	01	
116	43	GO+	Will go to appropriate *subroutine call*
117	01	01	
118	02	2	Re-adjust program pointer when frac(R00) > .4
119	00	0	
120	44	+/-	
121	32	HIR	
122	01	31	
123	04	4	
124	41	GTO	
125	01	01	
126	07	07	
127	02	PG*	x.0
128	00	00	
129	.1	A	
130	41	GTO	
131	91	R/S	
132	02	PG*	x.1, x.5
133	00	00	
134	.2	B	
135	41	GTO	
136	91	R/S	
137	02	PG*	x.2, x.6
138	00	00	
139	.3	C	
140	41	GTO	

STEP	CODE	KEY	COMMENTS
141	91	R/S	
142	02	PG*	x.3, x.7
143	00	00	
144	.4	D	
145	61	GTO	
146	91	R/S	
147	02	PG*	x.4, x.8
148	00	00	
149	71	SBR	
150	16	PAU	
151	61	GTO	
152	91	R/S	
153	76	LBL	Label WRITE: HEADER (identify CROM)
154	36	WRT	
155	44	OP	Print:
156	00	00	
157	98	ADV	
158	01	1	
159	06	6	
160	03	3	
161	01	1	"DNA/AP-550"
162	01	1	
163	03	3	
164	06	6	
165	03	3	
166	01	1	
167	03	3	
168	44	OP	
169	02	02	
170	03	3	
171	00	3	
172	02	2	
173	00	0	
174	00	0	
175	00	0	
176	00	0	
177	00	0	
178	01	1	
179	44	OP	
180	03	03	
181	44	OP	
182	05	05	
183	98	ADV	
184	98	ADV	
185	98	ADV	
186	25	CLR	
187	32	RTN	

PARTITION

AUTOMATIC

LIBRARY MODULE

CROM A-1 (Program 9)

FLAG	COMMENTS	FLAG	COMMENTS
00	Prevents limit checks from halting on error	09	Used in other programs; reset in case of error to turn off trace mode
01	Suppresses printing		
07	Set if limit exceeded		

DATA REGISTERS FOR EXAMPLE _____

DATA REG.	COMMENTS
00	
01	
02	Register number for input in use
03	
04	
05	
06	
07	
08	
09	Used by PGM 7 segment
10	Used by PGM 7 segment
11	Used by PGM 7 segment
12	
13	
14	
15	Used by PGM 7 segment
16	
17	
18	Used by PGM 7 segment
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	
31	
32	
33	
34	
35	
36	
37	
38	
39	
40	

LABELS

STEP	CODE	KEY	COMMENTS
001	12	B	Round and print outputs
015	14	B'	
024	13	C	Check and print inputs
032	11	A	
059	16	A'	
075	18	C'	
109	15	E	Overflow from PGM 7

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	76	LBL	Label B. Rounds argument to 3 significant digits and prints (outputs)
001	12	B	
002	32	EE	
003	53	FIX	
004	02	02	
005	32	EE	
006	53	FIX	
007	09	09	
008	85	+	
009	32	X↕T	
010	23	INV	
011	32	EE	
012	61	GTO	
013	11	A	
014	76	LBL	Label B'. Takes lower limit for Y in display and checks and prints Y (if R02=10)
015	17	B'	
016	85	+	
017	04	4	
018	05	5	
019	32	X↕T	
020	03	3	
021	32	EE	
022	04	4	
023	76	LBL	Label C.
024	13	C	
025	65	×	Checks limits on RC*2 (used in sequential inputs)
026	73	RC*	
027	02	02	
028	69	OP	
029	22	22	
030	32	X↕T	
031	76	LBL	Label A. Check limits on input, entered with: input, x ↕ t, Σo + hi x alpha
032	11	A	
033	69	OP	
034	04	04	
035	25	CLR	
036	92	HIR	
037	11	11	
038	67	EQ	
039	00	00	If x = Σo then skip rest of checks
040	50	50	
041	73	GE	
042	00	00	
043	86	86	Error routine if x<Σo
044	92	HIR	
045	12	12	
046	22	INV	
047	73	GE	
048	00	00	Error routine if x > hi
049	86	86	
050	32	X↕T	
051	87	IFF	
052	01	01	Printing suppressed if flag 1 set
053	00	00	
054	57	57	
055	69	OP	
056	06	06	
057	92	RTN	
058	76	LBL	Label A'. Integerize RC*2 (as input), check limits and print. Entered by the sequence: alpha x ↕ t hi
059	16	A'	
060	92	HIR	
061	02	02	
062	01	1	
063	95	+	
064	73	RC*	
065	02	02	
066	59	INT	
067	72	ST*	
068	02	02	
069	69	OP	
070	22	22	
071	32	X↕T	
072	61	GTO	
073	11	A	
074	76	LBL	Label C'. Replaces input RC*2 by its absolute value and prints. (lower limit implicitly 0). Entered with alphanumeric in display.
075	18	C'	
076	32	X↕T	
077	73	RC*	
078	02	02	
079	50	I×I	
080	73	ST*	
081	02	02	
082	85	+	
083	61	GTO	
084	00	00	
085	28	28	
086	98	ADV	Error handling:
087	69	OP	
088	88	88	Set error
089	71	SBR	
090	00	00	
091	50	50	Print with error
092	22	INV	
093	86	STF	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
094	09	09	
095	22	INV	
096	37	IFF	Stop on error unless
097	00	00	flag 0 is set
098	01	01	
099	05	05	
100	36	STF	
101	07	07	Error has occurred
102	36	STF	
103	01	01	Suppress further
104	32	RTN	printing
105	33	X≠T	
106	21	GTO	
107	35	CLR	(nonexistent label)
108	16	LBL	Label E is called from
109	15	E	program 4, step 869
110	55	÷	
111	04	4	
112	75	-	b
113	43	RCL	
114	12	12	Environment
115	33	X≠T	
116	43	RCL	
117	10	10	Y
118	95	=	
119	94	+/-	
120	45	Y^x	
121	53	(	
122	01	1	
123	03	3	
124	00	0	
125	02	2	More packed data,
126	07	7	class 19
127	04	4	
128	06	6	
129	43	STO	
130	13	13	
131	01	1	
132	09	9	
133	67	EQ	
134	01	01	
135	56	56	Eq. 29, Pgm. 4
136	55	÷	
137	01	1	
138	08	8	
139	93	.	
140	03	3	

STEP	CODE	KEY	COMMENTS
141	65	×	
142	01	1	
143	04	4	
144	00	0	More packed data,
145	02	2	class 20
146	00	0	
147	03	3	
148	07	7	
149	42	STO	
150	13	13	
151	01	1	
152	01	1	Data for class 19,
153	00	0	Eq. 27
154	00	0	
155	93	.	
156	06	6	Data for class 20,
157	06	6	Eq. 27
158	07	7	
159	33	X≠T	
160	93	.	
161	04	4	Eq. 29, Pgm. 4
162	04	4	
163	05	5	
164	94	+/-	
165	95	=	$(Y-b)^P$
166	55	÷	
167	01	1	
168	52	EE	Compensates for 10^3,
169	03	3	
170	65	×	
171	53	(	
172	43	RCL	Eq. 27, Pgm 4
173	28	28	
174	65	×	
175	93	.	
176	01	1	
177	49	PRD	
178	03	03	2-digit coefficient
179	55	÷	
180	43	RCL	
181	12	12	
182	42	STO	
183	10	10	Environment
184	32	X≠T	1100,667 or 667
185	35	+	
186	92	RTN	
187	04	4	Radius and depth coeffs, Pgm. 7

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
188	04	4	h Equation 5 - Dry Rock Coeff.
189	07	7	
190	01	1	
191	08	8	g
192	04	4	
193	07	7	f
194	04	4	
195	02	2	
196	42	STO	
197	21	21	
198	01	1	d Equation 4 coeff.
199	06	6	
200	00	0	c
201	02	2	
202	03	3	
203	07	7	b
204	00	0	
205	01	1	
206	05	5	a
207	00	0	
208	92	RTN	
209	04	4	Equation 5 -
210	06	6	h Wet Rock
211	07	7	
212	01	1	
213	07	7	g
214	03	3	
215	07	7	f
216	01	1	
217	06	6	
218	42	STO	
219	21	21	
220	05	5	Equation 4
221	01	1	c
222	05	5	
223	03	3	
224	06	6	b
225	00	0	
226	01	1	
227	05	5	a
228	03	3	
229	92	RTN	
230	01	1	j Equation 5
231	05	5	Dry Soil and Wet Soil
232	06	6	
233	08	8	
234	01	1	h

STEP	CODE	KEY	COMMENTS
235	03	3	g
236	00	0	
237	05	5	
238	06	6	f
239	00	0	
240	42	STO	
241	21	21	
242	05	5	Equation 4
243	00	0	c Dry Soil
244	07	7	
245	03	3	
246	05	5	b
247	00	0	
248	01	1	
249	01	1	a
250	07	7	
251	92	RTN	
252	43	MOF	Equation 5 Wet Soil
253	71	SBR	
254	02	02	
255	30	30	
256	03	3	d Equation 4
257	08	8	
258	03	3	c
259	05	5	
260	02	2	
261	09	9	b
262	00	0	
263	01	1	
264	02	2	
265	08	8	
266	85	+	a
267	93	.	
268	03	3	
269	95	=	
270	92	RTN	
271	02	2	n Equation 3 - Wet Soil
272	07	7	
273	03	3	p
274	03	3	
275	00	0	m
276	08	8	
277	42	STO	
278	21	21	
279	71	SBR	k = 11
280	02	02	
281	99	99	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
282	04	4	Equation 2
283	03	3	s
284	04	4	t
285	05	5	
286	03	3	q
287	03	3	
288	03	3	
289	07	7	
290	02	RTN	
291	05	5	n Equation 3
292	01	1	Dry Soil
293	07	7	p
294	03	3	
295	02	2	
296	05	5	m
297	42	STO	
298	21	21	
299	01	1	k
300	01	1	
301	42	STO	
302	22	22	
303	06	6	s Equation 2
304	04	4	
305	09	9	t
306	04	4	
307	03	3	q
308	08	8	
309	02	RTN	
310	48	NOP	
311	02	2	n Equation 3
312	01	1	Wet Rock
313	01	1	
314	05	5	p
315	00	0	
316	08	8	m
317	42	STO	
318	21	21	
319	07	7	
320	02	2	k
321	05	5	
322	42	STO	
323	22	22	
324	03	3	
325	09	9	s Equation 2
326	02	2	t
327	07	7	
328	02	2	q

STEP	CODE	KEY	COMMENTS
329	07	7	
330	02	RTN	
331	03	3	
332	09	9	n Equation 3
333	02	2	Dry Rock
334	05	5	p
335	04	4	
336	00	0	m
337	42	STO	
338	11	11	
339	05	5	
340	03	3	k
341	05	5	
342	42	STO	
343	22	22	
344	09	9	s Equation 2
345	02	2	
346	01	1	t
347	05	5	
348	03	3	q
349	04	4	
350	03	3	
351	02	2	
352	02	RTN	
353	03	3	HOB COEFFICIENTS
354	04	4	
355	02	2	
356	06	6	Wet
357	05	5	Soil
358	03	3	
359	05	5	
360	02	RTN	
361	02	2	
362	04	4	
363	08	8	Dry
364	04	4	Soil
365	09	9	
366	03	3	
367	05	5	
368	02	RTN	
369	01	1	
370	04	4	
371	00	0	Wet
372	05	5	Rock
373	03	3	
374	03	3	
375	02	2	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS	STEP	CODE	KEY	COMMENTS
376	92	RTN					
377	03	3	γ				
378	03	3	Dry				
379	04	4	β Rock				
380	06	6					
381	02	2					
382	03	8	α				
383	92	RTN					
384	01	1	YIELD				
385	06	6	COEFFICIENTS				
386	04	4					
387	00	0	w Dry				
388	05	5	Rock				
389	92	RTN					
390	01	1	z				
391	09	9	Wet				
392	04	4	Rock				
393	02	2	w				
394	05	5					
395	92	RTN					
396	01	1	z				
397	09	9	Dry				
398	04	4	Soil				
399	06	6	x				
400	08	8					
401	92	RTN					
402	02	2	z				
403	05	5	Wet				
404	04	4	Soil				
405	04	4	w				
406	02	2					
407	92	RTN					

Section 2: Programs 2.0 - 2.7

Weapon Radius Determination for P-type and Q-type Targets.
Probability of Damage to Point and Circular Targets With
Normal Target Element Distributions.

DNA	AP-550 PROMPT AI			HTI
WEAPON RADIUS, P and Q TARGETS; Pd to CIRCULAR TARGETS (NORM)				
CEP (ft)	TARGET RADIUS (ft)	OFFSET (ft)	DAMAGE SIGMA	2.n - WR,Pd
YIELD (KT)	HOB (ft)		VN	K-FACTOR

SOURCE OF DATA:

Defense Intelligence Agency, Physical Vulnerability Handbook-Nuclear Weapons (U), AP-550-1-2-60-INT, June 1, 1969, Part I, Section B; Part IV, Section A.

DESCRIPTION:

A. Objective

The main objective of this set of eight programs is to calculate weapon radii, (WR), utilizing the VNTK system. Four of the programs provide an option that enables the user to calculate the probability of damage, (Pd), to point targets or to circular area targets with normal target element distributions, using the previously calculated weapon radius. This option is essentially an internal transfer by the calculator to program set 03 and therefore the user is referred to the program 03 documentation for details concerning the probability of damage calculations.

The calculated weapon radius, as defined in AP-550, is: "a circle centered at ground zero, within which, on the average, there are as many targets damaged to a lesser degree than specified as there are targets damaged to the specified degree outside the circle." A more precise definition relates weapon radius to the radius of damage at which there is a 50% probability (RD_{50}) of achieving the desired damage; $WR=RD_{50}/(1-\sigma_d^2)$, where σ_d is the damage sigma. The P-type target weapon radius calculation assumes a damage sigma of 0.2 and the Q-type target weapon radius calculation assumes a damage sigma of 0.3. The user is cautioned that when performing the optional probability of damage calculation, the appropriate damage sigma must be entered to obtain valid results.

B. Inputs-Outputs

The eight calculations comprising this program set and their necessary inputs are as follows:

Program 2.0: WR and Pd - P-type targets,

Inputs:

Yield (KT)	CEP (ft)
HOB (ft)	Target radius (ft)
VN	Offset (ft)
k-factor	Damage sigma, σ_d = 0.2 for P-type targets

Program 2.1: WR and Pd - Q-type targets,

Inputs: Same as program 2.0 with the exception that σ_d=0.3

Program 2.2: WR and Pd at optimum HOB - P-type targets,

Inputs: Same as program 2.0 with the exception that no HOB is entered, σ_d = 0.2

Program 2.3: WR and Pd at optimum HOB - Q-type targets,

Inputs: Same as program 2.2 with the exception σ_d= 0.3

Program 2.4: WR - P-type targets,

Inputs:

Yield (KT)	VN
HOB (ft)	k-factor

Program 2.5: WR - Q-type targets,

Inputs: Same as program 2.4

Program 2.6: WR at optimum HOB - P-type targets,

Inputs: Same as program 2.4 with the exception of HOB.

Program 2.7: WR at optimum HOB - Q-type targets,

Inputs: Same as program 2.4 with the exception of HOB.

C. Limits

Yield: $0.1 \text{ KT} \leq Y \leq 30 \text{ MT}$

HOB: $0 \text{ ft} \leq \text{HOB}/Y^{1/3} \leq \text{HOB}_{max}$

where:

$\text{HOB}_{max} = 2308\ Y^{1/3} \exp(-AJVN/15)$ for P-targets

HOB_{max} = the minimum of:

$$\left.\begin{array}{l} 900Y^{1/3} \\ 2308Y^{1/3} \exp(-AJVN/15) \end{array}\right\} \text{Q-targets}$$

where AJVN = adjusted vulnerability number.

VN:	$0 \leq AJVN \leq 54$, P-target
	$0 \leq AJVN \leq 34$, Q-target
k-factor:	$0 \leq k \leq 9$
CEP:	CEP ≥ 0 ft.
Target Radius (TR):	TR ≥ 0 ft.
Offset (x):	$x \geq 0$ ft.
Damage sigma (σ):	$0.1 \leq \sigma \leq 0.5$

D. Data Storage Locations and Printer Alphanumerics

The user can find the following information stored in the indicated registers (R):

Variables	Registers	Alphanumerics
Yield (KT)	R10	Y
HOB (ft)	R11	H
VN	R13	V
k-factor	R14	K
CEP (ft)	R15	C
Target Radius (ft)	R16	T
Offset (ft)	R17	X
Damage Sigma	R18	S
Weapon radius	R12	W
Prob. of Damage	only in display	P

E. Additional Information

Information pertaining to the target VNTK descriptions and damage sigmas can be found in the classified version of this document and AP-550.

Pressing R/S will initiate the previously keyed-in type of calculation even if the inputs are changed.

EXAMPLE 2.0, 2.1, 2.3

Given the following information, calculate the weapon radius and corresponding probability of damage to an area target with a normal target element distribution.

target type	= P-type	damage sigma	= 0.2
VN number	= 15	offset	= 500 ft
k-factor	= 3	CEP	= 200 ft
Yield	= 100 KT	target radius	= 10,000 ft
HOB	= 4000 ft		

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off, then on			0	
2	Select program 01		2nd Pgm 01	0.	
3	Enter yield (KT)	100	A	100.	
4	Enter HOB (ft)	4000	B	4000.	
5	Enter VN	15	D	15.	
6	Enter k-factor	3	E	3.	
7	Enter CEP (ft)	200	2nd A'	200.	
8	Enter target radius (ft)	10000	2nd B'	10000.	
9	Enter offset (ft)	500	2nd C'	500.	
10	Enter damage sigma	.2	2nd D'	0.2	
11	Calc. WR and Pd - P-type	2.0	2nd E'		2.
					100. Y
					15. V
					3. K
					4000. H
					3870. W
					200. C
					10000. T
					500. X
					0.2 S
				0.341	0.341 P

EXAMPLE 2.0, 2.1, 2.3 (cont.)

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
12	Perform same calculation for Q-type target with same VN and k-factor.				
13	Enter Q-type target damage sigma	.3	2nd D'	0.3	
14	Begin calculation	2.1	2nd E'		2.1 100. Y 15. V 3. K 4000. H 3550. W 200. C 10000. T 500. X 0.3 S
				0.283	0.283 P
15	Repeat calculation described in Step 12 for the optimum HOB case	2.3	2nd E'		2.3 100. Y 15. V 3. K
16	Note optimum HOB = 2220 ft.				2220. H 4650. W 200. C 10000. T 500. X 0.3 S
				0.43	0.43 P

EXAMPLE 2.4, 2.5:

Given the following information, calculate the weapon radius for the given HOB.

target type = P-type
VN = 6
k-factor = 0
yield = 1.0 KT
HOB = 400 ft

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off, then on			0	
2	Select program 01		2nd Pgm 01	0.	
3	Enter yield (KT)	1	A	1.	
4	Enter HOB (ft)	400	B	400.	
5	Enter VN	6	D	6.	
6	Enter k-factor	0	E	0.	
7	Calc. WR - P-type	2.4	2nd E'		2.4 1. Y 6. V 0. K 400. H
				2480.	2480. W
8	Perform same calculation for Q-type target with same VN & K.				
9	Enter Q-type target damage sigma	.3	2nd D'	0.3	
10	Begin calculation	2.5	2nd E'		2.5 1. Y 6. V 0. K 400. H
				2580.	2580. W

EQUATIONS

Definitions

Y = Yield (KT)
HOB = Height of burst (ft)
VN = Vulnerability number
K = K-factor
$\hat{H}$ = scaled HOB = $HOB/Y^{1/3}$
x_0 = scaled optimum HOB
WR = Weapon radius
$\hat{WR}$ = Scaled weapon radius
x' = Scaled HOB at which $\hat{WR}=1$
AV = Adjusted VN (ADJVN)

Calculation of AV:

$$AV = VN + C\ell nR \tag{1}$$

where for P-targets,

$$C = 11$$

$$R = \frac{1}{2}\left(\frac{K}{10}\right)\left(\frac{20}{Y}\right)^{1/3} + \sqrt{\left[\frac{1}{2}\left(\frac{K}{10}\right)\left(\frac{20}{Y}\right)^{1/3}\right]^2 + \left(1 - \frac{K}{10}\right)}, \tag{2}$$

and for Q-targets,

$$C = 8.2$$

R satisfies the equation, $R^3 - \frac{K}{10}\left(\frac{20}{Y}\right)^{1/3} R + \frac{K}{10} - 1 = 0$, (3)

which is solved iteratively.

The quantity $20^{1/3} = 2.7144...$ is approximated with $e = 2.718...$

For both P and Q targets,

$$WR = \left(\frac{\hat{WR}-2 + |\hat{WR}-2|}{2}\right) Y^{1/3} \quad \text{(presents WR < 2 as WR = 0)} \tag{4}$$

P-target equations:

$$\hat{WR} = a\left(1 + a\left(\frac{\hat{H}}{x_0}\right)^P\right), \text{ for } \hat{H} \leq x_0 \tag{5}$$

$$= a\left(1 + a\left(\frac{\hat{H}}{x_0}\right)^P\right)\exp\left[-\ell n(a(1+a))\left(\frac{(\hat{H}/x_0)-1}{(x'/x_0)-1}\right)^\gamma\right] \text{ for } \hat{H} > x_0 \tag{5'}$$

where:

$$\alpha = \exp\left(7.63 - \frac{AV}{6}\right) + \exp\ 7.37 - \frac{AV}{16} \tag{6}$$

$$a = \frac{(26-AV)^4}{1890 + 31(26-AV)^3}\ ,\ \text{for } AV \leq 26 \tag{7}$$

$$= \frac{(AV-26)}{160}\ ,\ \text{for } AV > 26 \tag{8}$$

$$P = .6 + \exp[-(.393AV - 9.5\ell n(.393AV) + 3.3^2)] \tag{9}$$

$$x_0 = \exp(6 + \sqrt{2} - AV/15.7) \tag{10}$$

$$x' = 4.5 \times 10^9/(26 + AV)^4 \tag{11}$$

$$\gamma = \exp(.1 + AV/37) \tag{12}$$

Q-target equations:

$$\hat{WR} = \alpha\left(1 + a\left(\frac{\hat{H}}{x_0}\right)^P\right)\ ,\ \hat{H} \leq x_0 \tag{13}$$

$$= \alpha\left(1 + a\left(\frac{\hat{H}}{x_0}\right)^P\right) \exp\left[b\left(1 - \frac{\hat{H}}{x_0}\right)\right]\ ,\ \hat{H} > x_0 \tag{14}$$

where:

$$\alpha = [\exp(133 - 1.82\ AV) + \exp(128 - 1.4\ AV)]^{\frac{1}{16}} \tag{15}$$

$$\alpha(a+1) = [\exp(158 - 1.4\ AV) + \exp(177 - 2.7\ AV)]^{\frac{1}{20}} \tag{16}$$

$$P = \left[1 + (AV/33)^8\right]^{-1} \tag{17}$$

$$x_0 = [\exp(-.24^2\ AV)]^{\frac{1}{2}} \left\{960 - 410\left[\frac{\exp(.27AV^{1.2} - 6.5)}{1+\exp(.27AV^{1.2}-6.5)}\right]\right\} \tag{18}$$

$$b = .03AV + 4.6(9 + (AV-24)^2)^{-1} \tag{19}$$

PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
AUTOMATIC	07	test for limit check error		
LIBRARY MODULE: CROM A-1 (Program 2)	09	set - P target not set - Q target		

DATA REGISTERS FOR EXAMPLE 2.0

DATA	REG.	COMMENTS
2.	00	# of Pgm originally called
.8045060006	01	} scratch
19.	02	
4810.405388	03	
500.	04	scaled WR
.1802558265	05	scratch
0.	06	} not used
0.	07	
0.	08	
0.	09	
100.	10	Y
4000.	11	HOB, Opt. HOB
3870.	12	Scratch; calculated WR
15.	13	VN
3.	14	k
200.	15	CEP
10000.	16	Target radius
500.	17	Offset
0.2	18	Damage sigma
0.	19	} not used
1.2103539997	20	
-.8045060006	21	AJVN
-.9107730409	22	
16.2454833	23	
.0003541857	24	
.5487635763	25	
-.4592145161	26	
-.5643088943	27	

LABELS

STEP	CODE	KEY	COMMENTS
001	15	E	} common code
012	10	E'	
020	18	C'	} choose coeff.
026	28	NOF	
029	16	A'	calculate α
056	17	B'	calculate W_{max}
082	19	D'	calculate x_0
106	94	+/-	adjust VN
197	4	D	Q target opt.H
200	3	C	P target opt.H
260	12	B	Q target
263	46	PAU	} P target
265	11	A	
285	89	f	main calc.

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	76	LBL	Label E.
001	15	E	Common to subroutines
002	00	0	A' and B'
003	43	FIX	AJVN
004	01	01	
005	04	4	
006	43	INV	
007	03	LN	
008	65	×	
009	43	(	
010	32	RTN	
011	76	LBL	Label E'.
012	15	E'	Common to subroutines
013	15	E	A' and B'
014	00	0	
015	55	÷	
016	43	INV	
017	49	Y^x	
018	43	RTN	
019	76	LBL	Label C'.
020	13	C'	Select coefficient for
021	43	IFF	P- or Q-target
022	01	01	
023	09	09	
024	43	NOP	
025	22	Y^1/x	
026	76	LBL	Label NOP
027	43	NOP	
028	43	RTN	
029	76	LBL	Label A'.
030	11	A'	
031	43	IFF	Calculates α
032	01	01	
033	04	04	
034	86	STF	·P-target calc.
035	01	1	
036	00	0	
037	00	0	
038	55	÷	
039	01	1	
040	00	0	
041	00	0	
042	00	0	
043	00	0	
044	00	0	
045	00	0	
046	55	÷	

STEP	CODE	KEY	COMMENTS
047	01	1	
048	53	)	
049	04	4	
050	00	E'	
051	01	1	
052	00	0	
053	55	÷	α for Q target (eq. 15)
054	32	RTN	
055	76	LBL	Label B'.
056	12	B'	
057	43	IFF	Calculates $\alpha(a+1)=\hat{W}$ max
058	00	00	
059	04	04	·P-target calculation
060	86	STF	
061	01	1	
062	05	5	
063	00	0	
064	50	×	
065	01	1	
066	53	)	
067	04	4	
068	55	÷	
069	01	1	
070	53	)	
071	04	4	
072	65	×	
073	53	(	
074	53	(	
075	01	1	
076	55	÷	
077	53	(	
078	01	1	
079	05	5	
080	32	RTN	$\hat{W}$ max for Q target (eq. 16)
081	76	LBL	Label D'.
082	14	D'	
083	43	RCL	Calculates x_0=optimum H
084	01	01	
085	04	04	
086	22	INV	
087	43	IFF	
088	00	00	
089	05	05	
090	00	00	
091	55	÷	
092	01	1	
093	05	5	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
094	43	.	
095	01	1	
096	05	+	
097	01	1	
098	11	A	
099	05	+	
100	00	0	
101	45	=	
102	22	INV	
103	23	LNX	x_0 for P target (Eq.10)
104	32	RTN	
105	76	LBL	Label +/-
106	84	+/-	
107	75	-	
108	01	1	
109	00	0	Check and print VN, K;
110	00	0	calculate AJVN → R_{21},
111	65	+	HOB limits
112	04	4	
113	02	2	
114	85	=	
115	42	STO	
116	01	01	Alphanumeric
117	43	RCL	
118	14	14	K Calculate VN
119	55	-	adjustment factor
120	01	1	
121	00	0	
122	55	-	
123	42	STO	
124	04	04	
125	69	OP	
126	34	34	R04 ← $\frac{K}{10} - 1$
127	53	(	
128	43	RCL	
129	10	10	Y
130	22	INV	
131	45	Y^x	
132	03	3	
133	84	+/-	
134	65	×	
135	42	STO	Stores $Y^{-1/3}$ in R03
136	03	03	
137	01	1	
138	22	INV	
139	23	LNX	
140	85	=	

STEP	CODE	KEY	COMMENTS
141	42	STO	R05 ← $\frac{K}{10} eY^{1/3}$
142	05	05	
143	55	-	
144	03	3	
145	22	INV	
146	59	EE	
147	05	05	→P target calc.
148	00	0	
149	85	=	Calculate R for AJVN,
150	24	CE	Q target
151	85	=	(Eq. 3)
152	93	.	
153	00	0	
154	00	0	
155	05	5	ε = .005 allowed error
156	03	X=T	
157	01	1	
158	85	=	
159	42	STO	Estimate for R → R21
160	21	21	
161	65	×	Iteration loop
162	53	(	
163	43	RCL	
164	05	05	
165	43	RCL	$\frac{K}{10} eY^{-1/3}$
166	03	03	
167	54	)	
168	65	×	
169	43	RCL	$\frac{K}{10} - 1$
170	14	14	
171	75	-	
172	01	1	
173	95	=	
174	42	STO	
175	11	A	
176	43	RCL	
177	11	11	
178	93	.	Jump to rest of calcu-
179	05	5	lations
180	43	RCL	
181	21	21	Estimate for R
182	85	=	
183	03	3	
184	55	-	
185	43	RCL	$\frac{K}{10} eY^{-1/3}$
186	05	05	
187	85	=	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
188	22	INV	
189	14	SUM	
190	11	A	
191	43	RCL	
192	11	A	Improved R
193	01	GTO	
194	01	01	
195	61	GTO	
196	76	LBL	Label D.
197	14	D	
198	42	STO	Q target, opt. H
199	76	LBL	Label C.
200	13	C	
201	44	SUM	P target, opt. H
202	14	D	
203	91	R/S	Check and print Y, VN, K
204	48	EXC	
205	13	C	
206	91	R/S	Return without calculating WR if limit error occurred.
207	22	INV	
208	58	FIX	
209	04	04	
210	65	×	
211	03	03	
212	02	02	
213	75	-	
214	16	A'	Calculate $\hat{W}$ (needed for P target $\hat{W}$ max)
215	42	STO	
216	12	B	
217	14	D	Calculate $\hat{H}$ opt. = x_0
218	42	STO	
219	04	04	
220	75	-	$Y^{-1/3}$ is in R_{03} from SBR +/-
221	13	C	
222	01	1	
223	55	÷	
224	03	3	
225	34	FIX	Print optimum H
226	03	03	
227	65	×	
228	43	RCL	
229	04	04	
230	85	+	
231	01	1	
232	16	A'	Calculate $\hat{W}$ max
233	55	÷	
234	02	2	
235	75	-	Make W max > 2
236	01	1	.0
237	85	+	(Eq. 4)

STEP	CODE	KEY	COMMENTS
238	50	I×I	
239	95	=	
240	42	STO	
241	04	04	Modified $\hat{W}$
242	65	×	
243	22	INV	t register = WR
244	86	STF	
245	09	09	
246	43	RCL	
247	00	00	
248	28	INT	Which program was called
249	03	X≠T	
250	42	STO	
251	12	B	WR
252	02	2	
253	57	EQ	Continue calculation
254	05	05	2 in Pgm 3
255	01	01	
256	43	RCL	Return without printing
257	11	A	WR if call was not to
258	03	X≠T	program 2 (being used
259	43	RCL	as subroutine)
260	12	B	
261	92	RTN	
262	76	LBL	Label B.
263	12	B	Q target
264	22	INV	
265	76	LBL	Label PAU (same as A)
266	66	PAU	
267	76	LBL	Label A.
268	11	A	P target
269	86	STF	
270	09	09	
271	91	R/S	Check and print V, VN, K
272	55	÷	
273	03	3	
274	00	0	
275	85	+	
276	43	RCL	
277	11	11	H
278	03	X≠T	
279	02	2	
280	03	3	Check & print H
281	34	FIX	
282	04	04	
283	11	A	
284	87	IFF	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
282	07	07	Return if bad limit check
283	68	NOP	
284	76	LBL	Label π WR calculation for P and Q
285	99	π	
286	16	A'	Calc. α targets (STF 9 for P target); R03 should contain $\gamma^{-1/3}$
287	42	STO	
288	04	04	
289	43	RCL	
290	11	11	H
291	29	CP	
292	67	EQ	
293	04	04	$\hat{W} = \alpha$ for H=0.
294	61	61	
295	43	RCL	
296	21	21	AJVN
297	87	IFF	
298	09	09	
299	03	03	
300	14	14	
301	55	÷	p for Q target (Eq. 17)
302	03	3	
303	03	3	
304	95	=	
305	45	YX	
306	08	8	
307	85	+	
308	01	1	
309	95	=	
310	35	1/X	
311	61	GTO	
312	03	03	
313	38	38	
314	55	÷	p for P target (Eq. 9)
315	93	.	
316	03	3	
317	03	3	
318	03	3	
319	75	-	
320	33	LNX	
321	65	×	
322	04	4	
323	93	.	
324	05	5	
325	85	+	
326	03	3	
327	93	.	
328	03	3	

STEP	CODE	KEY	COMMENTS
329	33	X²	
330	95	=	
331	94	+/-	
332	23	INV	
333	33	LNX	
334	85	+	
335	93	.	
336	06	6	
337	95	=	
338	42	STO	p
339	05	05	
340	19	D'	Calculate $x_0 = \hat{H}$ opt.
341	42	STO	
342	01	01	
343	43	RCL	H
344	11	11	
345	55	÷	
346	59	INT	$x_0 y^{1/3}$ = H opt.
347	95	=	
348	45	YX	
349	48	EXC	p; R05 $\leftarrow \frac{H}{x_0 y^{1/3}}$ $\frac{H}{H_0}$
350	05	05	
351	95	=	
352	48	EXC	$\left(\frac{H}{x_0 y^{1/3}}\right)^P$
353	04	04	
354	42	STO	α
355	12	12	
356	17	B'	Calculate $\alpha(a+1)$
357	55	÷	
358	22	INT	
359	43	RCL	α
360	12	12	
361	75	-	
362	01	1	
363	95	=	a
364	49	PRD	
365	04	04	
366	83	DP	$R_{04} = 1+a\left(\frac{H}{H_0}\right)^P$
367	24	24	
368	43	RCL	H
369	05	05	H_0
370	22	INT	$\alpha(a+1)$
371	48	EXC	α
372	12	12	
373	49	PRD	$R_{04} = \alpha\left(1+a\left(\frac{H}{H_0}\right)^P\right)$
374	04	04	
375	01	1	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
376	77	GE	Continue if
377	04	04	$1 < \frac{H}{H_0}$
378	61	61	
379	69	OP	
380	35	35	$R_{05} = \frac{H}{H_0} - 1$
381	43	RCL	
382	21	21	AJVN
383	87	IFF	
384	09	09	
385	04	04	
386	14	14	
387	75	-	Calculate b for Q
388	02	2	target (Eq. 19)
389	04	4	
390	95	=	
391	33	X^2	
392	85	+	
393	09	9	
394	95	=	
395	35	1/X	
396	65	×	
397	04	4	
398	83	.	
399	06	6	
400	55	+	
401	93	.	
402	00	0	
403	03	3	
404	65	×	
405	43	RCL	
406	21	21	
407	95	=	b
408	65	×	
409	43	RCL	$\frac{H}{H_0} - 1$
410	05	05	
411	61	GTO	
412	04	04	
413	55	55	
414	85	+	
415	02	2	Calculate x' for P
416	06	6	target (Eq. 11)
417	95	=	
418	45	YX	
419	04	4	
420	55	÷	
421	04	4	
422	05	5	

STEP	CODE	KEY	COMMENTS
423	53	EE	
424	00	0	
425	95	=	
426	35	1/X	
427	55	÷	
428	43	RCL	$\hat{H}$ opt
429	01	01	
430	75	-	
431	01	1	
432	95	=	
433	02	INV	
434	44	PRD	$R_{05} = \frac{\frac{H}{H_0} - 1}{\frac{H'}{H_0} - 1}$
435	05	05	
436	43	RCL	
437	05	05	
438	45	YX	
439	53	(	
440	93	.	Calculate γ (Eq. 12)
441	01	1	
442	55	÷	
443	43	RCL	AJVN
444	21	21	
445	55	÷	
446	03	3	
447	07	7	
448	54	)	
449	02	INV	
450	03	LNX	$\left(\frac{H/H_0 - 1}{H'/H_0 - 1}\right)^{\gamma}$
451	65	×	
452	43	RCL	
453	13	13	$\hat{W}_{max}$
454	03	LNX	
455	95	=	
456	14	+/-	
457	02	INV	
458	03	LNX	
459	44	PRD	(Eq. 5)
460	04	04	
461	43	RCL	$\hat{WR}$
462	04	04	
463	61	GTO	
464	02	02	
465	30	30	
466	07	7	Calculate ε for P
467	93	.	target (Eq. 6)
468	06	6	
469	03	3	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
470	75	-	
471	06	6	
472	35	1/X	
473	15	E	
474	07	7	
475	93	.	
476	09	9	
477	07	7	
478	75	-	
479	01	1	
480	06	6	
481	35	1/X	
482	15	E	
483	00	0	
484	95	=	α
485	92	RTN	
486	43	RCL	Calculate Ŵ max for P target
487	21	21	
488	75	-	
489	02	2	
490	06	6	
491	95	=	
492	23	CP	
493	77	GE	
494	25	05	
495	15	15	
496	35	1/X	
497	53	(	
498	44	CE	
499	65	×	
500	33	X²	
501	55	÷	
502	53	(	
503	44	+ / -	
504	55	÷	
505	03	3	
506	01	1	
507	85	+	
508	01	1	
509	00	0	
510	04	4	
511	00	0	
512	21	GTO	
513	05	05	
514	15	15	
515	55	÷	
516	01	1	

STEP	CODE	KEY	COMMENTS
517	06	6	
518	00	0	
519	95	=	a (Eqs. 7, 8)
520	85	+	
521	01	1	
522	95	=	
523	65	×	
524	43	RCL	
525	12	12	α
526	95	=	
527	92	RTN	$\hat{W}_{max}$
528	65	×	Calculate x_0 for Q (Eq. 18)
529	93	.	
530	02	2	
531	04	4	
532	33	X²	
533	95	=	
534	22	INV	
535	23	LNX	
536	34	FX	
537	65	×	
538	53	(	
539	09	9	
540	06	6	
541	00	0	
542	75	-	
543	04	4	
544	01	1	
545	00	0	
546	65	×	
547	53	(	
548	53	(	
549	93	.	
550	02	2	
551	07	7	
552	65	×	
553	43	RCL	AJVN
554	21	21	
555	45	YX	
556	01	1	
557	93	.	
558	02	2	
559	75	-	
560	06	6	
561	93	.	
562	05	5	
563	54	)	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
564	22	INV	
565	33	LNX	
566	55	÷	
567	53	(	
568	34	CE	
569	35	+	
570	01	1	
571	95	=	
572	92	RTN	x_0
573	36	PGM	Check & print
574	01	1	Y, VN, K;
575	36	PGM	Calculate AJVN, max HOB
576	09	09	
577	17	B'	
578	00	0	
579	61	GTO	
580	94	+/-	
581	98	ADV	Go to Page 3 to
582	36	PGM	print WR, calc. P_d
583	03	03	
584	12	B	
585	92	RTN	
586	85	+	VN adjustment factor,R,
587	53	(	for P target (Eq. 2)
588	33	X²	
589	75	-	
590	43	RCL	
591	04	04	$\frac{K}{10} - 1$
592	54	)	
593	34	FX	
594	95	=	
595	42	STO	R
596	21	21	
597	35	CLR	Continuation of SBR +/-
598	43	RCL	
599	21	21	
600	33	LNX	ℓnR
601	55	÷	
602	03	3	
603	93	.	C for Q target
604	02	2	
605	32	X↑T	
606	11	1	C for P target
607	01	1	
608	53	(	
609	85	+	
610	42	STO	

STEP	CODE	KEY	COMMENTS
611	05	05	AJVN-VN = C(ℓnR) → R05
612	43	RCL	
613	13	13	VN
614	95	=	
615	42	STO	AJVN
616	21	21	
617	01	1	
618	03	3	Initialize for printing
619	42	STO	routines in Pgm 9
620	02	02	
621	43	RCL	
622	05	05	k(ℓnR)
623	75	-	
624	50	I×I	
625	95	=	
626	94	+/-	Lower limit on VN =
627	55	÷	
628	02	2	max {0,-C(ℓnR)}
629	85	+	
630	53	(	
631	03	3	Upper limit for Q target
632	04	4	= 34 - C(ℓnR)
633	32	X↑T	
634	05	5	Upper limit for P target
635	06	6	= 56 - C(ℓnR)
636	18	C'	
637	75	-	
638	43	RCL	Given alphanumeric
639	01	01	(step 115)
640	32	X↑T	
641	43	RCL	
642	05	05	C(ℓnR)
643	54	)	
644	36	PGM	Check and print VN
645	09	09	
646	13	C	
647	43	RCL	
648	01	01	Given alphanumeric
649	75	-	
650	01	1	
651	06	6	
652	95	=	Alpha for K
653	32	X↑T	
654	00	0	
655	85	+	
656	09	9	
657	36	PGM	Check & print K

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS	STEP	CODE	KEY	COMMENTS
658	09	09					
659	13	C	----------				
660	01	1					
661	04	4	Calculate H max, the				
662	32	X:T	upper limit on HOB				
663	43	RCL	AJVN				
664	21	21					
665	87	IFF					
666	09	09					
667	06	06					
668	78	78	----------				
669	77	GE	Q target calc.				
670	06	06					
671	78	78					
672	09	9					
673	00	0					
674	00	0					
675	61	GTO					
676	06	06					
677	90	90	----------				
678	55	÷	P target calc.				
679	01	1					
680	05	5					
681	94	+/-					
682	95	=					
683	22	INV					
684	23	LNX					
685	65	×					
686	02	2					
687	03	3					
688	00	0					
689	08	8					
690	55	÷	$\gamma^{-1/3}$				
691	43	RCL					
692	03	03					
693	95	=					
694	32	HIR	H max ⎫ set up to				
695	02	02	⎭ use in				
696	00	0	H min = 0 ⎫ printing				
697	32	HIR	⎭ routines				
698	01	01					
699	92	RTN					

Section 3: Programs 3.0 - 3.2

Probability of Damage to Point and Circular Targets
With Normal or Uniform Target Element Distributions.

DNA	AP-550 PROMPT AI			HTI
Pd to POINT and CIRCULAR TARGETS, NORMAL and UNIFORM DIST.				
CEP (ft)	Target Radius (ft)	Offset (ft)	Damage Sigma	3.n · Pd
		Weapon Radius (ft)		

SOURCES OF DATA:

Defense Intelligence Agency, Physical Vulnerability Handbook-Nuclear Weapons (U), AP-550-1-2-60-INT, June 1, 1969, Part IV, Section A.

DESCRIPTION:

A. Objective

The objective of this set of 3 programs is to calculate the probability of damage (Pd) to point and circular area targets. Normal and uniform target element distributions are considered. For area targets, the probability of damage is equivalent to the expected proportion of the target to be damaged. The adjusted CEP methodology is utilized to compute the Pd to circular targets. Auxiliary magnetic card programs for computing Pd to area targets of geometries other than circular by the weighted average point method are given in Appendix D.

B. Inputs-Outputs

The three calculations comprising this program set and their necessary inputs are as follows:

Program 3.0: Pd to point targets,

Inputs: Weapon radius (ft)
CEP (ft)
Offset (ft)
Damage sigma

Program 3.1: Pd to circular normal targets,

Inputs: same as 3.0 with the addition of target radius (ft)

Program 3.2: Pd to circular uniform targets.

Inputs: same as 3.1

C. Limits

Weapon radius (WR): $WR \geq 0$ ft

CEP: $CEP \geq 0$ ft

Target radius (TR): $TR \geq 0$ ft

Offset (x): $x \geq 0$ ft

Damage sigma (σ): $0.1 \leq \sigma \leq 0.5$

D. Data Storage Locations, Printer Alphanumerics

The user can find the following information stored in the indicated registers (R):

Variables	Registers	Alphanumerics
Weapon radius (ft)	R12	W
CEP (ft)	R15	C
Target radius (ft)	R16	T
Offset (ft)	R17	X
Damage sigma	R18	S
Prob. of Damage	only in display	P

E. Additional Information

Pressing R/S will initiate the previously keyed-in type of calculation even if the inputs are changed. Several CROM programs require an input of target radius (TR). If one of these programs is run prior to the point target calculation and the calculator is not turned off, then on, the value of the target radius previously entered will be printed when the point target calculation is initiated. At all times, however, a target radius of zero will be used internally for the point target calculation.

EXAMPLE 3.0, 3.1, 3.2

Given the following information, calculate the probability of damage to a point target, circular target of normal distribution and radius of 500 ft and a circular target of uniform distribution and radius of 1000 ft.

Weapon radius = 8500 ft
Damage sigma = 0.2
Offset distance = 6000 ft
CEP = 1000 ft

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off, then on			0	
2	Select program 01		2nd Pgm 01	0.	
3	Enter weapon radius (ft)	8500	C	8500.	
4	Enter CEP (ft)	1000	2nd A'	1000.	
5	Enter offset (ft)	6000	2nd C'	6000.	
6	Enter damage sigma	.2	2nd D'	0.2	
7	Calc. Pd - point target	3.0	2nd E'		3. 8500. W 1000. C 0. T 6000. X 0.2 S
				0.9	0.9 P
8	Enter Target 2 radius (ft)	500	2nd B'	500.	
9	Calc. Pd - circular target normal distribution	3.1	2nd E'		3.1 8500. W 1000. C 500. T 6000. X 0.2 S
				0.899	0.899 P

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
10	Enter Target 3 radius (ft)	1000	2nd B'	1000.	
11	Calc. Pd - circular target uniform distribution	3.2	2nd E'		3.2 8500. W 1000. C 1000. T 6000. X 0.2 S
				0.889	0.889 P

EQUATIONS

Definitions

P = probability of damage
WR = weapon radius
CEP = circular error probable
TR = target radius
X = offset
σ = damage sigma
CEP_a = adjusted CEP
$\hat{W} = WR/CEP_a$
$\hat{x} = X/CEP_a$
ε = offset at which P = .5
ε' = offset at which P = .98

Calculation of adjusted CEP:

$$CEP_a = \sqrt{CEP^2 + K \times TR^2} \tag{1}$$

where

K = 0, for point targets
K = .231, for normally distributed area targets

For uniform target distributions,

K = .4, if $WR + CEP + X \geq TR$
= .5 otherwise.

Calculation of probability:

$P = (1 + \exp(R))^{-1}$, where $R = R(\hat{x}, \hat{W}, \sigma)$: (2)

For $\hat{W} > 30$, $R = -.07Z^3 - 1.6Z$, where $Z = \frac{\ln[(1-\sigma^2)WR/X]}{\sqrt{-\ln(1-\sigma^2)}}$ (3)

For $\hat{W} \leq 30$,

$R = R'$, if $\hat{x} \geq 2$ (4)

$= R' + \cos(45\hat{x})(R_0 + \frac{\hat{x}}{.9} - R')$, if $\hat{x} < 2$ (5)

where

$$R' = a(\hat{W},\sigma)\frac{L(\hat{x},\hat{W},\sigma)}{L'} + [1-a(\hat{W},\sigma)]\frac{T(\hat{x},\hat{W},\sigma)}{T'} \quad (6)$$

$$R_0 = (3.6\sigma-2)\hat{W} - (1.3+1.1\sigma)\ell n[\hat{W}(.24+\sigma)] \quad (7)$$

$$a(W,\sigma) = \exp\left[-\left(\frac{1339\exp(-42\sigma) - 2\sigma + 3.7}{W}\right)^{(.71\exp(\frac{\sigma}{.3}))}\right] - (\gamma + |\gamma'|) \quad (8)$$

$$\gamma = 7000\sigma^{5.6}\exp(-21\sigma)(\hat{W} - 5.5) \quad (9)$$

$$T(x,W,\sigma) = q\tan(90) \quad , \text{ if } b(\hat{x}-\varepsilon) > 90 \quad (10)$$

$$= q\tan(-90) \quad , \text{ if } b(\hat{x}-\varepsilon) < -90$$

$$= q\tan(b(\hat{x}-\varepsilon)), \text{ otherwise}$$

$$T' = \tan(b(\varepsilon'-\varepsilon)) \quad (11)$$

$$L = q\ell n\left[\max\left\{\frac{\hat{x}-\varepsilon'+2}{\varepsilon-\varepsilon'+2}, 0\right\} + 10^{-5}\right] \quad (12)$$

$$L' = \ell n\left[\max\left\{\frac{2}{\varepsilon-\varepsilon'+2}, 0\right\} + 10^{-5}\right] \quad (13)$$

$$q = \ell n\left(\frac{1}{.98} - 1\right) \simeq -3.89 \quad (14)$$

$$\varepsilon = \hat{W} - .2 - (\gamma + |\gamma'|) \quad (15)$$

$$\gamma = .61(\hat{W} + 4\sigma - 3.2)(\sigma^{2.23} + 10^{-5}\sigma^{-2.23}) \quad (16)$$

$$\varepsilon' = \ell n\left\{.6\sigma + \left[\frac{1}{1.2}\exp(10\sigma - 1.1\hat{W})\right.\right.$$
$$\left.\left. + \frac{1}{299}\exp\left(-\frac{W}{.9}\exp(2.69\sigma) - 2.7\sigma + 9.47\sigma\right)\right]^{-1}\right\} \quad (17)$$

$$b = 26\exp(-2.1\sigma - W/16) \quad (18)$$

All trigonometric arguments are in degrees.

PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
AUTOMATIC	02	Suppresses printing of probability		
LIBRARY MODULE: CROM A-1 (Program 3)	07	Test for limit check error		

DATA REGISTERS FOR EXAMPLE 3.0

DATA	REG.	COMMENTS
3.	00	Code for called program
0.5	01	WR, W, $\sigma^2 - 1$
19.	02	indirect recall (Pgm 9)
1000.	03	CEP$_a$
10000.	04	D_i, x
0.	05	alphanumeric for D_i
0.	06	(calc. 3.3)
0.	07	not used
0.	08	
0.	09	
0.	10	
0.	11	HOB (from Pgm 2)
3500.	12	WR
	13	not used
	14	
1000.	15	CEP
	16	Target radius
1000.	17	Offset
0.3	18	Damage sigma
0.	19	not used
1.1006144433	20	x, R'
-0.0217133834	21	-s
-1.8018194092	22	s'
1.0437125533	23	b
0.8034346112	24	a
-1.1855110111	25	R_0
-1.1357054552	26	T
-1.4515264419	27	L'
	28	P_i (for calc. 3.3)

LABELS STEP	CODE	KEY	COMMENTS
001	16	A'	e^{-x}
012	16	B'	e
040	16	C'	tangent func.
060	16	E'	log function
078	16	D'	R-P
087	16	A	used by LBL D
179	16	-	calc. P
805	16	E	calc. 3.2
814	16	B	calc. 3.1
907	16	D	calc. 3.0
948	16	E	calc. 3.3
			calc. coeffs.

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	76	LBL	Label A'.
001	[illegible]	A'	
002	[illegible]	[illegible]	
003	[illegible]	RCL	
004	[illegible]	[illegible]	
005	[illegible]	[illegible]	$e^{-(\ x)}$ ...
006	[illegible]	-	
007	[illegible]	INV	
008	[illegible]	LNX	
009	[illegible]	[illegible]	
010	[illegible]	RTN	
011	[illegible]	LBL	Label B'.
012	[illegible]	B'	x = display (x or ε')
013	[illegible]	-	
014	[illegible]	[illegible]	
015	43	RCL	-
016	[illegible]	31	
017	[illegible]	=	
018	[illegible]	[illegible]	
019	43	RCL	b
020	[illegible]	13	
021	[illegible]	=	
022	[illegible]	[illegible]	
023	[illegible]	9	
024	[illegible]	0	
025	[illegible]	EE	
026	[illegible]	00	
027	[illegible]	33	If b(x-) > 90, set=90
028	[illegible]	[illegible]	
029	[illegible]	+/-	If b(x-ε) ≤ -90, set=-90
030	[illegible]	INV	
031	[illegible]	EE	
032	[illegible]	00	
033	[illegible]	35	
034	[illegible]	[illegible]	
035	[illegible]	[illegible]	
036	[illegible]	DEG	
037	[illegible]	TAN	tan[b(x-)]
038	[illegible]	RTN	
039	76	LBL	Label C'.
040	[illegible]	C'	
041	[illegible]	2	
042	45	=	$\frac{\ldots + 2}{(2+ \ - \ ')}$
043	55	-	
044	[illegible]	[illegible]	
045	02	2	
046	75	-	

STEP	CODE	KEY	COMMENTS
047	43	RCL	→
048	31	31	
049	75	-	
050	43	RCL	
051	32	32	'
052	95	=	
053	55	÷	
054	02	2	
055	85	+	
056	50	I x I	
057	85	+	
058	01	1	
059	52	EE	(if 0 set to 10^{-5})
060	05	5	
061	94	+/-	(guard digit)
062	95	=	
063	23	LNX	
064	92	RTN	
065	76	LBL	Label E'.
066	10	E'	
067	00	0	
068	95	=	
069	94	+/-	
070	22	INV	
071	23	LNX	
072	85	+	$\frac{1}{e^{-x}+1}$
073	01	1	
074	95	=	
075	35	1/x	
076	92	RTN	
077	76	LBL	Label D'.
078	19	D'	
079	44	SUM	ΣP_i (for option 2.3)
080	38	38	
081	69	OP	
082	15	15	
083	43	RCL	
084	15	15	Alphanumerics for D_i
085	36	PGM	
086	19	19	
087	18	C'	
088	42	STO	
089	04	04	D_i
090	87	IFF	(if WR CEP 30)
091	07	07	
092	05	05	
093	85	85	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
094	79	9	
095	32	X:T	$D_i/CEP_a = \hat{D}_i$
096	76	LBL	Label ADV
097	33	ADV	
098	44	STO	Offset=x ($\hat{x}$ or $\hat{D}_i$)
099	00	00	
100	17	B'	Tangent part of R
101	32	X:T	
102	43	RCL	
103	00	00	
104	95	+	
105	43	RCL	
106	02	02	ε'
107	85	+	
108	13	C'	Logarithmic part of R
109	32	X:T	
110	84	-	
111	43	RCL	T'
112	00	00	
113	85	+	
114	43	RCL	
115	04	04	
116	55	÷	
117	32	X:T	
118	85	+	
119	43	RCL	L'
120	01	01	
121	55	÷	
122	43	RCL	a
123	04	04	
124	65	×	
125	32	X:T	
126	01	1	
127	00	0	
128	00	0	-q
129	84	-	
130	01	1	$-R' = -q \frac{T}{T'} - \frac{L}{L'}$
131	00	0	
132	65	×	-R'+x
133	43	RCL	
134	00	00	
135	75	-	
136	01	1	If x > 2:
137	00	0	(
138	00	0	
139	00	0	
140	04	04	
141	55	÷	x/.9
142	32	X:T	
143	85	+	+
144	43	RCL	
145	00	00	
146	43	RCL	R_0
147	00	00	
148	85	+	-
149	43	RCL	
150	00	00	R'
151	54	)	)
152	00	0	
153	00	0	
154	00	0	
155	04	4	
156	05	5	...cos(45x) ...
157	00	0	
158	00	0	
159	32	X:T	
160	00	0	
161	00	0	
162	00	0	
163	14	E'	Calculate P from R
164	00	00	
165	00	00	
166	00	00	
167	00	00	(return without printing if flag 2 set)
168	00	00	
169	32	X:T	
170	00	00	"P"
171	00	00	
172	00	00	
173	00	00	
174	00	00	
175	00	00	
176	00	00	
177	00	00	
178	00	00	
179	00	00	
180	14	E'	Print Probability
181	00	00	
182	00	00	
183	76	LBL	Label C.
184	00	00	
185	00	00	Pd for Circular Uniform Targets
186	43	RCL	
187	00	00	
188	85	+	
189	43	RCL	
190	00	00	
191	85	+	
192	43	RCL	
193	00	00	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
188	85	+	
189	43	RCL	If WR + CEP + x ≥ TR,
190	17	17	then K = .4
191	95	=	
192	17	GE	
193	01	01	
194	00	00	
195	00		
196	01	1	
197	85	+	
198	00		
199	04	4	
200	95	=	
201	61	GTO	
202	02	02	(K in display)
203	16	16	
204	16	LBL	Label B.
205	12	B	Pd for Circular Normal
			Targets
			K for normally
			distributed area
			targets
		GTO	
		LBL	Label A.
		A	Pd for Point Targets
		C.P	K for point targets
			Labels A,B,C start here
		GTE	Label D starts here
		D	
		RCL	TR
		+	
		RCL	CEP
		=	
		STO	$CEP_a = \sqrt{CEP^2 + K \cdot TR^2}$
		4	"W"
34	43	RCL	

STEP	CODE	KEY	COMMENTS
235	12	12	
236	50	I×I	WR ≥ 0
237	36	PGM	
238	00	00	WR (round to 3 signif-
239	13	B	icant digits)
240	42	STO	
241	12	12	
242	42	STO	
243	01	01	(set up for $\bar{x}$)
244	00	.	
245	04	4	
246	32	X:T	
247	43	RCL	Return after
248	00	00	printing WR if
249	12	12	Frac(R00) ≥ .4
250	44	SUM	
251	11	11	
252	42	STO	
253	08	08	Set up automatic
254	44	SUM	increment for
255	12	12	printing parameters.
256	00	0	
257	00	0	
258	00	0	
259	00	0	
260	00	0	
261	00	0	
262	00	0	
263	00	0	
264	00	0	
265	00	0	
266	00	0	
267	00	0	
268	00	0	
269	00	0	
270	00	0	
271	00	0	
272	00	0	
273	00	0	
274	00	0	
275	00	0	
276	00	0	
277	00	0	
278	00	0	
279	00	0	
280	85	+	
281	00	.	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
282	05	5	$.1 \leq \sigma \leq .5$
283	36	PGM	
284	09	09	
285	13	C	Print sigma
286	33	X^2	σ^2
287	75	-	
288	53	(	
289	71	X	WR/CEP_a
290	75	-	
291	03	3	
292	00	0	
293	54	)	
294	32	X↑T	
295	00	0	
296	22	INV	
297	73	GE	} (if $\frac{WR}{CEP_a} > 30$)
298	05	05	
299	80	80	
300	25	CLR	Otherwise, CLEAR and start fit
301	15	E	
302	71	X	X/CEP_a
303	32	X↑T	
304	41	GTO	
305	38	ADV	
306	76	LBL	Label D.
307	14	D	
308	25	CLR	Calculates probability of damage to rectangular targets
309	42	STO	
310	28	28	
311	71	SBR	
312	02	02	
313	17	17	
314	55	÷	
315	01	1	
316	00	0	
317	42	STO	
318	28	28	
319	01	1	
320	00	0	
321	00	0	
322	01	1	
323	42	STO	
324	05	05	
325	55	÷	
326	03	3	
327	14	D	
328	14	D	

STEP	CODE	KEY	COMMENTS
329	69	DP	
330	22	22	
331	14	D	
332	14	D	
333	65	×	
334	43	RCL	
335	28	28	
336	55	÷	
337	55	÷	
338	01	1	
339	00	0	
340	95	=	
341	22	INV	
342	88	DSZ	
343	02	02	
344	41	GTO	
345	01	01	
346	06	06	
347	76	LBL	Label E.
348	15	E	Calculate $\bar{x}$, $\bar{y}$, a, b, R_0
349	71	X	
350	42	STO	$\hat{W} = WR/CEP_a$
351	01	01	
352	55	÷	Calculate b (Eq. 18)
353	01	1	
354	06	6	
355	85	+	
356	02	2	
357	00	0	
358	01	1	
359	69	DP	
360	22	22	
361	55	÷	
362	43	RCL	
363	28	28	
364	04	4	Calculate a (Eq. 8)
365	65	×	
366	43	RCL	
367	01	01	
368	75	-	
369	43	RCL	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
			$\frac{1339\, e^{-42c} - 2c + 3.7}{W}$
			$.71 \exp\left(\frac{1}{.3}\right)$
			Calculate , (Eq. 9)
			W

STEP	CODE	KEY	COMMENTS
			, + ,
			a
			Calculate S_0 (Eq. 17)

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
470	18	18	
471	85	=	
472	42	STO	R_0
473	00	00	
474	43	RCL	
475	18	18	Calculate -ε (Eq. 15)
476	55	÷	
477	02	2	
478	93	.	
479	02	2	
480	03	3	
481	85	+	
482	35	1/X	
483	55	÷	
484	01	1	
485	00	EE	
486	05	5	
487	85	=	
488	65	×	
489	93	.	
490	06	6	
491	01	1	
492	65	×	
493	53	(	
494	43	RCL	
495	01	01	
496	85	+	
497	04	4	
498	54	)	
499	65	×	
500	16	16	
501	75	-	
502	03	3	
503	93	.	
504	02	2	
505	85	=	P
506	85	+	
507	53	(	$P_0 + (p'$
508	85	+	
509	93	.	
510	02	2	
511	75	-	
512	43	RCL	
513	01	01	
514	85	=	
515	42	STO	
516	21	21	(-)

STEP	CODE	KEY	COMMENTS
517	02	2	Calculate ε' (Eq. 17)
518	93	.	
519	06	6	
520	04	4	
521	16	A'	
522	43	RCL	
523	01	01	W
524	55	÷	
525	93	.	
526	09	9	
527	85	+	
528	02	2	
529	93	.	
530	01	1	
531	55	÷	
532	43	RCL	
533	18	18	
534	23	LNX	2.7·n·
535	55	÷	
536	03	3	
537	93	.	
538	04	4	
539	07	7	
540	16	A'	
541	02	2	
542	09	9	
543	09	9	
544	35	1/X	$299\exp\left[\frac{-W}{.9}e^{-2.69\cdot} - 2.7\cdot n\cdot + 9.47\cdot\right]$
545	85	+	
546	53	(	
547	01	1	
548	93	.	
549	01	1	
550	55	÷	
551	43	RCL	
552	01	01	
553	75	-	
554	01	1	
555	54	)	
556	16	A'	exp[10·-1.1WR]
557	02	2	
558	93	.	
559	02	2	
560	55	÷	
561	85	=	
562	35	1/X	
563	85	+	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
			$\tan[b(\quad)]$ Coefficient for tangent function, T' $\ln\left[\max\left\{0,\frac{2}{2+\quad}\right\}+10^{-5}\right]$ Coefficient for logarithm function, L'
			Case for $\frac{WR}{CEP_a} > 30$ $^2-1$ WR x $^2-1$ $\ln^{(1-\quad^2)WR}$ $\sqrt{-\ln(1-\quad^2)}$ (Note: $\ln x = \ln(-x)$ and $\sqrt{x} = \sqrt{-x}$ to the calculator.)
			$P = [\exp(-.07z^3-1.6z)+1]^{-1}$ (Eq. 3) Flag 7 set for $\hat{W} > 30$
			When Frac(ROO) > .4, put HOB into t register, and WR in display and return (to Pgm 2).

Section 4: Programs 4.0 and 4.1

Personnel Vulnerability, Weapon Radius Determination.

DNA	AP-550 PROMPT AI			HTI
PERSONNEL VULNERABILITY				
				4.n ▸ WR
Yield (KT)	HOB (ft)	Environment Select		

SOURCE OF DATA:

Defense Intelligence Agency, Physical Vulnerability Handbook-Nuclear Weapons (U), AP-550-1-2-60-INT, June 1, 1969, Part III, Section A.

DESCRIPTION:

A. Objective

The objective of this set of two programs is to evaluate weapon radii for fatalities or incapacitating casualties to unwarned personnel in various environments. Program 4.0 calculates weapon radii and presents damage sigmas for any HOB and program 4.1 calculates weapon radii and damage sigmas generated by detonation at the near-optimum HOB. Airblast and nuclear radiation effects weapon radii are combined in the manner described on page III-2 of AP-550 to form a combined weapon radius. Thermal radiation effects are considered only for exposed personnel taking no evasive action.

B. Inputs-Outputs

The two calculations comprising this program set and their necessary inputs are as follows:

Program 4.0: Weapon radius and damage sigma - any HOB

Inputs: Yield (KT)
HOB (ft)
Environment (see subsection E below)

Program 4.1: Weapon radius and damage sigma - near-optimum HOB

Inputs: Yield (KT)
Environment (see subsection E below)

C. Limits

Yield: $0.1 \text{ KT} \leq Y \leq 30 \text{ MT}$

HOB: $0 \text{ ft/KT}^{1/3} \leq \text{SHOB} \leq 1000 \text{ ft/KT}^{1/3}$

where

SHOB = scaled HOB

Environment: Env. = 1,2,3,...20

D. Data Storage Locations, Printer Alphanumerics

The user can find the following information stored in the indicated registers (R):

Variables	Registers	Alphanumerics
Yield	R10	Y
HOB (pgm. 4.0)	R11	H
Environment	not retained	E
Weapon radius	only in display	W
Optimum HOB (pgm. 4.1)	R11	H
Damage Sigma	R18	S

E. Personnel Environments

The following personnel and environment indices are to be used in conjunction with the personnel vulnerability programs. The index number associated with each environment description is to be entered with key C when executing these programs.

Environment		Index
Personnel in wood frame, wall bearing and adobe buildings, and forests		
	Fatalities	1
	Incapacitating casualties	2
Personnel in multistory residential, commercial or industrial buildings. Steel or reinforced concrete framed		
	Fatalities	3
	Incapacitating casualties	4
Personnel in basements		
	Fatalities	5
	Incapacitating casualties	6

Personnel in foxholes		
	Fatalities	7
	Incapacitating casualties	8
Personnel in tanks		
	Fatalities	9
	Incapacitating casualties	10
Personnel in deliberate underground shelters (2 ft. earth cover).		
	Fatalities	11
	Incapacitating casualties	13
Personnel in expedient underground shelters (2 ft. earth cover).		
	Fatalities	12
	Incapacitating casualties	14
Personnel in underground command posts		
	Fatalities and Incapacitating casualties	15
Personnel in open rural and open urban areas		
	Fatalities	16
	Incapacitating casualties	17
Personnel in urban areas		
	Any injury	18
Exposed personnel taking no evasive action		
	Thermal fatalities	19
	Thermal incapacitating casualties	20

F. Special Features

The environment index number is not stored during program execution; therefore, it must be re-entered each time programs 4.0 or 4.1 are run.

EXAMPLE 4.0, 4.1

Given the following information, calculate the weapon radii and damage sigmas for a contact burst and a near-optimum height of burst.

Yield = 100 KT

Environment: Index number = 1.

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off - then on			0	
2	Select program 01		2nd Pgm 01	0.	
3	Enter yield (KT)	100	A	100.	
4	Enter HOB (ft)	0	B	0.	
5	Enter environment index	1	C	1.	
6	Calculate weapon radius and damage sigma	4.0	2nd E'		4. 100. Y 1. E 0. H 0.318 S 7070. 7070. W
7	Calculate weapon radius and damage sigma for near-optimum HOB				
8	Re-enter environment index	1	C		
9	Initiate calculation	4.1	2nd E'		4.1 100. Y 1. E 3713.* H 0.392 S 9830. 9830. W
	Note: The near-optimum HOB is printed with the inputs in an unrounded format.				
	*prints as 3713.271067				

EQUATIONS

Definitions

Y = yield (KT)

HOB = height of burst, feet

$\hat{H}$ = scaled HOB = $HOB/Y^{1/3}$

E = environment category

WR = weapon radius

σ = damage sigma (calculated by the CROM)

Q(x) = approximation to the complement of the cumulative normal distribution

V, M, K, x_0, σ_B, σ_R, are parameters for the first 18 environment categories that are stored in look-up tables in the CROM.

E	V	$100y_1$	10K	$.01x_0$	$10\sigma_B$	$10\sigma_R$
1	12	20	62	8	4	2
2	5	28	43	10	5	2
3	14	26	62	7	3	3
4	5	33	43	10	4	3
5	16	28	62	7	4	5
6	7	36	33	9	4	5
7	21	14	0	0	2	3
8	16	23	0	5	3	3
9	21	21	0	0	3	3
10	17	29	0	0	3	3
11	27	0	20	0	5	5
12	21	0	0	0	4	5
13	16	12	0	5	4	5
14	10	12	0	8	4	5
15	31	0	30	0	3	3
16	10	25	54	9	5	2
17	7	33	62	9	5	2
18	4	41	50	9	5	3

Table 4.1. Parameters for the first 18 environment categories.

For the first 18 categories, WR is calculated by combining a blast weapon radius with a radiation weapon radius:

$$WR = \left[WR_B^2 \, Q\left(\frac{1}{\beta} \ln\left(\frac{WR_R}{WR_B}\right) - \beta\right) + WR_R^2 \, Q\left(\frac{1}{\beta} \ln\left(\frac{WR_B}{WR_R}\right) - \beta\right)\right]^{\frac{1}{2}} \tag{1}$$

$$\langle r \rangle = \langle r_B \rangle Q\left(\frac{1}{\beta} \ln\left(\frac{WR_R}{WR_B}\right) - \frac{\beta_R^2}{\beta}\right) + \langle r_R \rangle Q\left(\frac{1}{\beta} \ln\left(\frac{WR_B}{WR_R}\right) - \frac{\beta_B^2}{\beta}\right) \tag{2}$$

$$\beta = \left[1 - \frac{\langle r \rangle^2}{WR^2}\right]^{\frac{1}{2}} \tag{3}$$

where:

$$Q(x) = 1 - \left[1 + \exp(-x(1.6 + .07x^2))\right]^{-1}, \tag{4}$$

$$\beta_R^2 = -\ln(1 - \sigma_R^2), \quad \beta_B^2 = -\ln(1 - \sigma_B^2), \quad \beta^2 = \beta_B^2 + \beta_R^2, \tag{5}$$

$$\langle r_R \rangle = WR_R \exp\left(\frac{-1}{2}\beta_R^2\right), \tag{6}$$

$$\langle r_B \rangle = r_{50}(\text{blast}) \exp\left(\frac{1}{2}\beta_B^2\right), \tag{7}$$

$$WR_B = \langle r_B \rangle \exp\left(\frac{1}{2}\beta_B^2\right) \text{ and} \tag{8}$$

r_{50}(blast) is obtained from calculating WR from the P-target code (which assumes $\sigma_B = .2$), and converting it to r_{50}(blast) by

$$r_{50}(\text{blast}) = (1 - \sigma_B^2) WR(\text{blast}) = .96 WR(\text{blast}). \tag{9}$$

The radiation component of the weapon radius is calculated as follows:

$$WR_R = WR_0 \exp\left\{-.01 \exp\left(-\frac{.01}{Y^2} - \frac{1}{H}\right)\left[W_H + W_{\cdot} + W_y\right]\right\} \tag{10}$$

The four parameters, WR_0, W_H, $W_{\cdot}$, W_y, are calculated as functions of yield and HOB:

$$y_0 = -180 + 10^{(3+y_1)} \tag{11}$$

$$y_0' = y_0\left\{1 + \exp\left[-\sqrt{\frac{124}{\hat{H}}} - .6 - \frac{y_0}{50^2} - .8\left(\frac{\hat{H}}{y_0}\right)^2\right]\right\} \quad (12)$$

$$m = \log\left(\frac{670}{y_0'} + \sqrt{1.6}\right) \quad (13)$$

$$W_0 = \frac{a\exp[1.3(y-y_c)]}{1+\exp[1.3(y-y_c)]} \exp(-2/Y^4) \quad (14)$$

where:

$$y = \log Y, \quad (15)$$

$$a = \frac{-1}{4}\left(p - .6 + |p-.6|\right) + .11 + \frac{277\cdot10^3}{y_0'}, \text{ and} \quad (16)$$

$$y_c = 1 + a/.38. \quad (17)$$

$$WR_0 = y_0' \, 10^{(m-1)W_0} Y^m \quad (18)$$

$$W_H = \frac{255 - .18\hat{H} + 161q}{(p+|p|)^{(2.8+q)}}, \text{ for } \hat{H} \leq 700 \quad (19)$$

$$W_H = \frac{255 - .18\hat{H}}{(p+|p|)^{(2.8+q)}}, \text{ for } \hat{H} > 700 \quad (20)$$

where:

$$q = \frac{4}{3}\cos(.9\hat{H})\exp\left(\frac{-.9\hat{H}}{331}\right) \text{and} \quad (21)$$

$$p = 8.5 - 2\ln H - \frac{1}{2}\log Y. \quad (22)$$

(Trigonometric argument is in degrees.)

$$W_1 = \left[1 + \left(\frac{\hat{H}}{620}\right)^2\right]\log Y - 7, \text{ if } r_R = .5 \quad (23)$$

$$= 0, \text{ otherwise}$$

$$W_Y = \ln\left[1 + \exp\left\{13\log Y - 30 + \left(\frac{\hat{H}}{169}\right)^2\right\}\right]\left(.8 + 10^{-24}y_0^8\right)^{-1} \quad (24)$$

For environment categories 19 and 20,

$$WR = [a + c(Y-b)^p]^{-1} \text{ where } a, c, b, p \text{ are:} \quad (25)$$

Coefficient	Class 19	Class 20	
$\frac{8 \times 10^{-6}}{a}$	$.8 + .3\exp\left(\frac{\hat{H}}{334}\right)$	$.4 + .7\exp\left(\frac{\hat{H}}{530}\right)$	(26)
$10^{3}\alpha$	$\frac{.1\hat{H}}{667} + .46 + .27\exp\left(\frac{-\hat{H}}{130}\right)$	$\frac{.1\hat{H}}{1100.667} + .37 + .20\exp\left(\frac{-\hat{H}}{140}\right)$	(27)
4b	$.006\exp\left(\frac{\hat{H}}{306}\right)$	$.005\exp\left(\frac{\hat{H}}{340}\right)$	(28)
p	-.445	$\left(\frac{19}{18.3}\right)(-.445)$	(29)

PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
AUTOMATIC	02	Supress printing temporarily (copies flag 1)		
LIBRARY MODULE: CROM A-1 (Program 4)	09	Distinguish calc. 4.1 from 4.0		

DATA REGISTERS FOR EXAMPLE 4.0

DATA	REG.	COMMENTS
4.	00	
140531 31931	01	
11.	02	# digits in coefficients
0.215443468	03	Y-1.3
1251.811488	04	
-2.127211953	05	used by Pgm 2
0.	06	
0.	07	
0.	08	
0.	09	
100	10	Yield
0.	11	HOB
0.	12	Environment
13.	13	packed coefficients
6.3	14	K
0.	15	
0.	16	
0.	17	
.1134544844	18	
0.	19	V_0
0.	20	
4.877171304	21	AJVN
0.	22	
0.	23	
0.	24	H, scratch
0.	25	.9H, scratch
.	26	WR, scratch
[illegible]	27	, scratch
[illegible]	28	$-R^2$, scratch
0.5124114944	29	$-B^2$, scratch
5235.931161	30	R, scratch

LABELS

STEP	CODE	KEY	COMMENTS
001	16	A'	data unpacking
015	16	B'	e^{-x}
022	16	C'	x·logY+1
031	16	D'	x·Q(x)
056	16	E'	shift from r to WR
063	15		Print HOB
084	14		calc. Y1/3
100	12		calc. 4.1
103	11		calc. 4.0

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	76	LBL	Label A'.
001	16	A'	
002	43	RCL	Data unpacking:
003	43	RCL	
004	00	00	
005	85	+	
006	43	RCL	Shift decimal by
007	02	02	log(R02) places
008	85	+	
009	84	INT	
010	42	STO	Store remainder
011	03	03	
012	44	×	log(R02) digits
013	32	RTN	Retrieve in .xxx form
014	76	LBL	Label B'.
015	11	B'	
016	84	×	
017	44	+/-	e^{-x}
018	22	INV	
019	23	LNX	
020	32	RTN	
021	76	LBL	Label C'.
022	13	C'	
023	00	00	
024	43	RCL	
025	10	10	
026	23	LOG	...log Y+1
027	85	+	
028	01	1	
029	32	RTN	
030	76	LBL	Label D'.
031	14	D'	
032	85	=	
033	85	=	Calculate Q(x)
034	85	=	(approximation to
035	85	=	complement of the
036	85	=	cumulative normal
037	85	=	dist.)
038	00	0	
039	00	0	
040	85	+	
041	01	1	
042	85	+	
043	01	1	
044	85	+	
045	11	E'	
046	85	+	

STEP	CODE	KEY	COMMENTS
047	01	1	
048	85	=	
049	35	1/X	
050	94	+/-	
051	85	+	
052	01	1	
053	85	=	
054	32	RTN	Q(x)
055	76	LBL	Label E'.
056	12	E'	
057	84	×	Used in combining algorithm.
058	42	STO	
059	12	12	$.96r_{50} \cdot (r_B)$
060	84	×	
061	43	RCL	
062	08	08	$-r_B^2$
063	85	+	
064	02	2	
065	71	GTO	
066	11	B'	
067	76	LBL	Label E.
068	15	E	Check and print HOB
069	00	0	
070	85	+	
071	01	1	
072	01	1	
073	42	STO	for indirect RCL (Pgm 9)
074	00	00	
075	02	2	
076	03	3	"H"
077	43	RCL	
078	01	01	
079	32	EE	
080	03	3	
081	85	+	
082	43	RCL	$10^3 Y^{1/3}$
083	00	00	($R03 = Y^{-1/3}$ from Pgm 2
084	42	STO	call)
085	00	00	Print HOB
086	01	1	
087	32	RTN	
088	76	LBL	Label D.
089	14	D	
090	43	RCL	Calculate $Y^{1/3}$
091	00	00	
092	22	INV	
093	45	Y^x	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
094	03	3	
095	95	=	
096	43	ENG	... $Y^{1/3}$; ÷ HOB
097	11	11	
098	32	RTN	
099	76	LBL	Label B.
100	12	B	Opt. HOB
101	23	INV	
102	76	LBL	Label A.
103	11	A	given HOB
104	36	STF	Flag 9 up → normal (*i.e.* 2.0)
105	09	09	
106	23	INV	Flag 9 down → use opt. HOB
107	36	STF	
108	02	02	Initialize flag used to suppress printing temporarily
109	00	0	
110	01	1	
111	36	PGM	
112	09	09	
113	17	B'	Print Y
114	39	DP	Skip register pointer to R12 = environment
115	22	22	
116	01	1	
117	07	7	"E"
118	32	X≠T	
119	03	3	
120	10	10	Upper limit
121	36	PGM	
122	09	09	Print environment category
123	14	A'	
124	05	5	
125	03	3	
126	01	1	
127	55	×	
128	43	FIX	
129	12	12	E
130	01	1	
131	07	7	
132	34	FIX	
133	02	02	Number of digits for data unpacking
134	95	=	
135	44	STO	Program step location for packed coefficients
136	13	13	
137	71	SBR	
140	40	IND	

STEP	CODE	KEY	COMMENTS
141	13	13	
142	42	STO	
143	13	13	Retrieve packed coefficients
144	01	1	
145	08	8	
146	32	[illegible]	
147	[illegible]	GE	If E = 18,
148	18	08	print results
149	04	34	(calculation is already complete)
150	14	A'	
151	42	STO	
152	00	00	$\dot{}_R$
153	00	[illegible]	
154	[illegible]		
155	01	1	
156	95	=	
157	[illegible]		
158	[illegible]		$\ln(1-\dot{}_R^2) = -\dot{}_R^2$
159	[illegible]		
160	[illegible]	A'	$\dot{}_B$
161	[illegible]	[illegible]	
162	[illegible]	-	
163	[illegible]		
164	[illegible]		
165	[illegible]	=	$\dot{}W = 1$ in case HOB = 0
166	[illegible]		
167	[illegible]	[illegible]	
168	[illegible]	STO	$\ln(1-\dot{}_B^2) = \dot{}_B^2$
169	[illegible]	[illegible]	
170	[illegible]	[illegible]	
171	[illegible]	[illegible]	
172	[illegible]	[illegible]	$-\dot{}_R^2$
173	[illegible]	[illegible]	
174	[illegible]	[illegible]	
175	[illegible]	[illegible]	
176	[illegible]	[illegible]	
177	[illegible]	[illegible]	
178	[illegible]	[illegible]	; see Eq.5
179	[illegible]	[illegible]	
180	[illegible]	[illegible]	
181	[illegible]	[illegible]	
182	[illegible]	[illegible]	
183	[illegible]	[illegible]	(If E=15, then skip radiation contribution)
184	[illegible]	[illegible]	
185	[illegible]	[illegible]	
186	[illegible]	A'	(Opt. HOB·10^3) = x_D
187	[illegible]	[illegible]	
188	[illegible]	[illegible]	
189	[illegible]	[illegible]	
190	[illegible]	[illegible]	(Opt. HOB = opt. HOB)
191	02	02	
192	55	÷	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
188	32	X⇄T	
189	93	.	
190	01	1	Case for HOB_{OPT}=1000
191	22	INV	
192	67	EQ	
193	01	01	
194	96	96	
195	55	÷	
196	01	1	
197	52	EE	
198	03	3	
199	94	+/-	
200	65	×	
201	14	D	Store HOB optimum in R11
202	71	SBR	
203	08	08	Calculate AJVN; Print HOB
204	94	94	
205	48	EXC	HOB ⇄ y_0
206	19	19	
207	42	STO	y_0
208	12	12	
209	43	RCL	HOB'
210	11	11	
211	65	×	
212	43	RCL	$Y^{-1/3}$ (from Pgm 2)
213	[illegible]	03	
214	95	=	
215	42	STO	$\dot{H}$
216	[illegible]	[illegible]	
217	[illegible]	CP	
218	[illegible]	EQ	If HOB=0, skip W_H, W., W_y, ΔW
219	[illegible]	[illegible]	
220	[illegible]	[illegible]	
221	[illegible]	[illegible]	q: see Eq. 21
222	[illegible]	.	
223	[illegible]	[illegible]	
224	[illegible]	[illegible]	
225	[illegible]	STO	
226	[illegible]	[illegible]	
227	[illegible]	[illegible]	
228	[illegible]	[illegible]	
229	[illegible]	[illegible]	
230	[illegible]	[illegible]	
231	[illegible]	[illegible]	
232	[illegible]	[illegible]	H:.9
233	[illegible]	14	
234	[illegible]	DEG	

STEP	CODE	KEY	COMMENTS
235	39	COS	Eq. 21 (cont.)
236	55	÷	
237	93	.	
238	07	7	
239	05	5	
240	85	+	
241	02	2	q
242	93	.	
243	08	8	
244	95	=	
245	48	EXC	q + 2.8 ⇄ 0.9H
246	24	24	
247	32	X⇄T	
248	06	6	
249	03	3	
250	00	0	
251	22	INV	
252	[illegible]	GE	If $\dot{H}$ · 700 skip factor at 161q in W_H
253	02	02	
254	[illegible]	[illegible]	
255	[illegible]	HIR	
256	11	11	q
257	[illegible]	[illegible]	
258	01	1	W_H: see Eq. 19
259	[illegible]	[illegible]	
260	[illegible]	1	
261	[illegible]	+	
262	[illegible]	[illegible]	
263	[illegible]	[illegible]	
264	[illegible]	[illegible]	
265	[illegible]	[illegible]	
266	[illegible]	[illegible]	
267	[illegible]	[illegible]	
268	[illegible]	[illegible]	.9H
269	[illegible]	[illegible]	
270	[illegible]	[illegible]	
271	[illegible]	[illegible]	
272	[illegible]	[illegible]	
273	[illegible]	[illegible]	
274	[illegible]	[illegible]	
275	[illegible]	[illegible]	
276	[illegible]	[illegible]	
277	[illegible]	[illegible]	
278	[illegible]	[illegible]	H p: see Eq. 2?
279	[illegible]	[illegible]	
280	[illegible]	LNX	
281	[illegible]	-	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
			Eq. 22 (cont.)
			P
			q+2.8 } Eq. 19
			W_H ↓↑ r_R
			If $r_R \neq .5$, skip W_0
			H
			W_0: see Eq. 23
			W_0
			$W_0 + W_H$ in R29
			H
			y_0': see Eq. 12
			y_0

STEP	CODE	KEY	COMMENTS
			H } Eq. 12 (cont.)
			y_0
			y_0
			y_0' in R12, y_0 in display
			$.8+10^{-24}y_0^8 \cdot H$ W_y: see Eq. 24

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
			Eq. 24 (cont.)
			$10^{-24} y_0^8 + .8$
			W_y
			$W_0 + W_H + W_Y$
			Y
			H
			$\therefore W = \frac{WR_R}{WR_0}$
			WR_R: see Eq. 10
			Start of surface burst case
			a: see Eq. 16

STEP	CODE	KEY	COMMENTS
			Eq. 16 (cont.)
			y_0'
			a
			y_c: see Eq. 17
			y_c - logY
			exp[1.3(y-y_c)]
			a
			$\therefore W_0$
			W_0: see Eq. 14

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
470	12	12	ΔW_0 ↓↑ y_0'
471	35	1/X	
472	65	×	
473	28	LOG	
474	44	SUM	
475	12	12	ΔW_0 - log y_0' in R12
476	06	6	
477	07	7	
478	00	0	m: see Eq. 13
479	85	+	
480	01	1	
481	93	.	
482	06	6	
483	34	fX	
484	95	=	
485	28	LOG	m
486	85	+	
487	24	CE	
488	18	C'	
489	43	RCL	
490	12	12	WR_0: see Eq. 18
491	84	+/-	
492	95	=	m+mlogY - ΔW_0+logy_0'
493	32	INV	
494	28	LOG	
495	65	×	
496	43	RCL	ΔW
497	25	25	WR_R: see Eq. 10
498	95	=	
499	42	STO	
500	29	29	WR_R
501	36	PGM	
502	02	02	WR (blast): see Eq.9
503	11	SBR	(stored in R12)
504	99	^	
505	95	=	
506	93	.	
507	04	4	
508	06	6	$\cdot r_{50}$(blast)
509	10	E'	$\cdot r_B$ (Eq. 7)
510	10	E'	
511	55	÷	$\cdot WR_B$ (Eq.8); $\cdot r_B$ in R12
512	42	STO	
513	18	18	WR_B
514	43	RCL	
515	29	29	WR_R
516	95	=	

STEP	CODE	KEY	COMMENTS
517	33	LNX	
518	55	÷	
519	43	RCL	
520	26	26	F
521	85	+	
522	48	EXC	$\frac{1}{\beta}\ln\left(\frac{WR_B}{WR_R}\right)$↓↑ $-\beta_B^2$
523	28	28	
524	55	÷	
525	43	RCL	F
526	26	26	
527	19	D'	
528	48	EXC	$Q\left(\frac{1}{\beta}\ln\left(\frac{WR_B}{WR_R}\right)-\frac{\beta_B^2}{\beta}\right)$↓↑ β_R^2
529	27	27	
530	55	÷	
531	32	X↑T	
532	02	2	
533	84	+/-	
534	17	B'	$e^{-\frac{1}{2}\beta_R^2}$
535	49	PRD	
536	27	27	
537	43	RCL	
538	28	28	
539	75	-	
540	43	RCL	
541	26	26	
542	19	D'	$Q\left(\frac{1}{\beta}\ln\left(\frac{WR_B}{WR_R}\right)-\beta\right)$
543	65	×	
544	43	RCL	
545	29	29	WR_R
546	49	PRD	
547	27	27	
548	32	X↑	
549	95	=	$WR^2Q\left(\frac{1}{\beta}\cdot\ln\left(\frac{WR_B}{WR_R}\right)+\beta\right)-\beta_R^2$
550	32	X↑T	
551	55	÷	
552	43	RCL	
553	26	26	β
554	75	-	
555	43	RCL	$-\beta_R^2/\beta$
556	28	28	
557	19	D'	
558	53	(	$Q\left(-\frac{\beta_R^2}{\beta}-\frac{1}{\beta}\cdot\ln\left(\frac{WR_B}{WR_R}\right)\right)$··
559	43	RCL	
560	24	CE	
561	75	-	
562	43	RCL	$\frac{1}{\beta}\cdot\ln\left(\frac{WR_B}{WR_R}\right)$
563	28	28	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
564	19	D'	$Q\left(\frac{1}{?}\ln\left(\frac{WR_R}{WR_B}\right) - ?\right)$
565	65	×	
566	43	RCL	
567	18	18	W_{RB}
568	33	X²	
569	85	+	
570	[illegible]	[illegible]	
571	95	=	WR^2
572	55	÷	
573	53	(	
574	34	[illegible]	
575	43	E[illegible]	
576	12	12	WR [illegible] r_D
577	65	×	
578	43	RCL	
579	26	26	
580	85	+	
581	43	RCL	
582	27	27	
583	54	)	[illegible] (Eq. 2)
584	33	X²	
585	95	=	
586	35	1/[illegible]	
587	94	+/-	
588	85	+	
589	01	1	
590	95	=	
591	[illegible]	[illegible]	
592	42	STO	[illegible] (Eq. 3)
593	13	13	
594	[illegible]	AD'	Print results
595	[illegible]	[illegible]	
596	[illegible]	[illegible]	"S"
597	[illegible]	[illegible]	
598	[illegible]	RCL	
599	[illegible]	12	
600	[illegible]	PGM	
601	[illegible]	09	
602	[illegible]	E	Print [illegible]
603	[illegible]	4	"W"
604	[illegible]	[illegible]	
605	[illegible]	[illegible]	
606	[illegible]	RCL	
607	[illegible]	19	Environment [illegible] WR
608	4[illegible]	E[illegible]	
609	12	12	
610	36	PGM	

STEP	CODE	KEY	COMMENTS
611	09	09	
612	12	B	Print WR
613	22	INV	
614	86	STF	
615	09	09	
616	92	RTN	
617	16	A'	Case for E=15
618	87	IFF	
619	09	09	
620	06	06	
621	25	25	
622	25	CLR	When HOB_{opt} is selected
623	42	STO	
624	11	11	HOB
625	71	SBR	
626	08	08	
627	94	94	Calculate AJVN
628	61	GTO	
629	05	05	
630	01	01	
631	01	1	} V
632	02	2	
633	02	2	} Y_1
634	00	0	Class 1
635	06	6	} K
636	02	2	
637	03	3	$-H_{opt}$
638	04	4	$-B$
639	02	2	$-R$
640	92	RTN	
641	00	0	
642	05	5	
643	01	1	
644	03	3	
645	04	4	Class 2
646	03	3	
647	01	1	
648	05	5	
649	02	2	
650	92	RTN	
651	[illegible]	[illegible]	
652	04	4	
653	02	2	
654	[illegible]	[illegible]	
655	[illegible]	[illegible]	
656	02	2	Class 3
657	07	[illegible]	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
655	03	3	Class 4
656	03	3	
657	42	RTN	
658	00	0	
659	05	5	
660	03	3	
661	03	3	
662	04	4	
663	03	3	
664	01	1	
665	04	4	
666	03	3	
667	42	RTN	
668	01	1	Class 5
669	00	0	
670	02	2	
671	04	4	
672	00	0	
673	00	0	
674	04	4	
675	42	RTN	
676	01	1	Class 6
677	00	0	
678	03	3	
679	04	4	
680	05	5	
681	00	0	
682	04	4	
683	42	RTN	
684	01	1	Class 7
685	00	0	
686	03	3	
687	04	4	
688	05	5	
689	00	0	
690	04	4	
691	42	RTN	
700	01	1	
701	00	0	
702	02	2	
703	02	2	
704	03	3	

STEP	CODE	KEY	COMMENTS
705	00	0	Class 8
706	02	2	
707	05	5	
708	03	3	
709	03	3	
710	42	RTN	
711	01	1	Class 9
712	01	1	
713	02	2	
714	01	1	
715	00	0	
716	00	0	
717	00	0	
718	03	3	
719	03	3	
720	42	RTN	
721	01	1	Class 10
722	03	3	
723	04	4	
724	00	0	
725	00	0	
726	00	0	
727	00	0	
728	42	RTN	
729	01	1	Class 11
730	01	1	
731	04	4	
732	00	0	
733	00	0	
734	00	0	
735	00	0	
736	42	RTN	
737	01	1	Class 12
738	04	4	
739	05	5	
740	02	2	
741	00	0	
742	00	0	
743	00	0	
744	00	0	
745	42	RTN	
746	01	1	
747	04	4	
748	05	5	
749	02	2	
750	42	RTN	
751	01	1	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
			Class 13
			Class 14
			Class 15
			Class 16
			Class 17

STEP	CODE	KEY	COMMENTS
			Class 18
			E=19 to b (Eq. 28)
			to a (Eq. 26)
			E=20 to b (Eq. 28)
			to a (Eq. 26)
			For environment categories 19 and 20: $y^{1/3}$ → HOB in R11
			If not flag 9, want HOB_{OPT}
			$y^{1/3}$

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
846	11	11	$1000Y^{1/3}$;· $Y^{1/3}$ in R11
847	35	1/x	
848	42	STO	
849	03	03	$Y^{-1/3}$
850	95	=	
851	42	STO	
852	33	33	HOB
853	15	E	Print HOB
854	71	SBR	
855	39	39	
856	39	39	
857	94	+/-	
858	17	B'	a: see Eq. 26
859	95	=	
860	42	STO	$\frac{8 \cdot 10^{-6}}{a}$
861	34	34	
862	71	SBR	
863	39	39	
864	44	44	
865	94	+/-	b: see Eq. 28
866	17	B'	
867	[illegible]	[illegible]	
868	[illegible]	A'	
869	[illegible]	[illegible]	4b
870	[illegible]	[illegible]	
871	[illegible]	E	
872	[illegible]	SBR	
873	[illegible]	[illegible]	
874	[illegible]	[illegible]	
875	[illegible]	E'	
876	[illegible]	=	$\cdot(Y-b)^P$
877	[illegible]	+	
878	[illegible]	[illegible]	
879	[illegible]	EE	
880	[illegible]	÷	a: see Eq. 26
881	[illegible]	+/-	
882	[illegible]	[illegible]	
883	[illegible]	[illegible]	
884	[illegible]	[illegible]	
885	[illegible]	[illegible]	
886	[illegible]	[illegible]	
887	[illegible]	[illegible]	WR (Eq. 25)
888	[illegible]	[illegible]	
889	[illegible]	.	
890	[illegible]	[illegible]	
891	42	STO	=.3 for classes 19 and 20
892	18	18	

STEP	CODE	KEY	COMMENTS
893	92	RTN	
894	[illegible]	1	Calculation of ADVN with printing suppressed.
895	[illegible]	0	
896	43	RCL	
897	02	02	2 digit coefficients
898	55	÷	
899	16	A'	unpack K/10
900	95	=	
901	42	STO	
902	14	14	K
903	16	A'	unpack y_1
904	85	+	
905	03	3	
906	95	=	
907	22	INV	
908	28	LOG	
909	75	-	
910	01	1	
911	08	8	
912	00	0	
913	95	=	
914	42	STO	
915	13	13	y_0 - See Eq. 11
916	86	STF	
917	03	03	For P target
918	87	IFF	
919	[illegible]	01	
920	39	39	
921	34	34	
922	86	STF	Set if flag 1 was not originally set
923	[illegible]	02	
924	86	STF	
925	[illegible]	01	Suppress printing
926	[illegible]	FIX	
927	[illegible]	02	
928	[illegible]	SBR	
929	94	+/-	Calculate ADVN → R21
930	22	INV	
931	87	IFF	
932	[illegible]	[illegible]	
933	15	E	
934	[illegible]	INV	Restore original condition of flag 1
935	[illegible]	STF	
936	[illegible]	[illegible]	
937	[illegible]	STO	
938	15	E	←
939	16	A'	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS	STEP	CODE	KEY	COMMENTS
440	55	+					
441	16	R/S					
442	00	0					
443	00	0					
444	43	RCL	H Subroutine used by environment categories 19 and 20. (Next coefficient has 3 digits)				
445	00	0					
446	01	1					
447	03	3					
448	00	0					
449	00	0					
450	00	0					
451	00	0					
452	55	+					
453	16	R/S					
454	32	RTN	NOTE: Overflow from this program is in Pgm 9, steps 108 through 186, located at page 1-17.				

Section 5a: Programs 5.0 and 5.1

Radius of Safety and Minimum Safe Distance Calculations.

DNA	AP-550 PROMPT AI			HTI
MINIMUM SAFE DISTANCE				
Troop Disposition	Vulnerability State	Acceptable Risk	Desired Assurance	5.n · RS,MSD
Yield (KT)	HOB (ft)	CEP (ft)	Offset, Rad. of Safety	PEH (ft)

SOURCE OF DATA:

Defense Intelligence Agency, Physical Vulnerability Handbook-Nuclear Weapons (U), AP-550-1-2-60-INT, June 1, 1969, Part III, Section C.

DESCRIPTION:

A. Objective

The objective of this set of two programs is to calculate the radius of safety (RS) and the associated minimum safe distance. The radius of safety is treated as a function of desired height of burst, yield, troop vulnerability condition, the acceptable risk category (see subsection E), and vertical delivery error, i.e., the probable error in height of burst (PEH). Considering the PEH in the radius of safety calculation requires that the user also define the confidence level he desires. For example, if the user desires a 99% assurance level value for the HOB used in the radius of safety calculation, 3.5 × PEH will be subtracted from the entered HOB. After the radius of safety calculation the program proceeds to calculate the minimum safe distance (MSD). The MSD is the sum of the RS and a buffer distance. The value of the buffer distance is a function of both a multiple of the circular error probable (CEP) and the troop disposition (see subsection E). The multiple of the CEP used is a function of the desired assurance that the acceptable weapons effects will not be exceeded.

An inversion of the above buffer distance calculation is also provided which allows the user to determine the probability that a population located some distance greater than the radius of safety from the desired ground zero will experience no greater than the acceptable weapons effects.

B. Inputs-Outputs

The two calculations comprising this program set and their necessary inputs are as follows:

Program 5.0: Radius of safety and minimum safe distance.

Inputs: Yield (KT)
HOB (ft)
CEP (ft)
PEH (ft)
Troop disposition (see subsection E)
Vulnerability condition (see subsection E)
Acceptable risk (see subsection E)
Desired Assurance Level

Program 5.1: Probability of not exceeding the acceptable weapons effects.

Inputs: CEP (ft)
Offset (ft)
Radius of safety (ft)
Troop disposition (see subsection E)

C. Limits

Yield: $0.01 \text{ KT} \leq Y \leq 30 \text{ MT}$

HOB: $\text{HOB} \geq 0$ ft

CEP: $\text{CEP} \geq 0$ ft

PEH: $\text{PEH} \geq 0$ ft

Troop disposition: 1, 2, 3, or 4
Vulnerability condition: 1, 2, or 3
Acceptable risk: 1, 2, or 3
} See subsection E

Desired assurance: $0.6 \leq P \leq 0.99$

D. Data Storage Locations, Printer Alphanumerics

The user can find the following information stored in the indicated registers (R):

Variables	Registers	Alphanumerics
Yield (KT)	R10	Y
HOB (ft)	R11	H
CEP (ft)	R12	C
Offset (ft)	R19	X
Radius of Safety (ft)	R13	RS
PEH (ft)	R14	PH
Troop disposition	R15	D
Vulnerability	R16	V
Acceptable risk	R17	R
Desired assurance	R18	P
Minimum safe distance	only in display	M
Probability of not exceeding acceptable weapons effects	only in display	P

E. Troop Disposition, Vulnerability Condition, and Degree of Risk Categories and Associated Index Numbers

1. Troop dispositions:	Indices
Linear	1
Quarter-circular	2
Semicircular	3
Circular	4

2. Vulnerability conditions:	
Unwarned exposed	1
Warned exposed	2
Warned protected	3

3. Risk categories	
Negligible	1
Moderate	2
Emergency	3

F. Additional Information

Further definition of these terms can be found in AP-550, Part III, pages 64 and 65. Pressing R/S will initiate the previously keyed-in type of calculation even if the inputs are changed.

EXAMPLE 5.0

Given the following information, calculate the radius of safety and minimum safe distance.

Yield = 10 KT	troop disposition = linear
HOB = 1000 ft	vulnerability = unwarned exposed
CEP = 500 ft	acceptable risk = negligible
PEH = 100 ft	desired assurance = 99%

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off - then on			0	
2	Select program 01		2nd Pgm 01	0.	
3	Enter yield (KT)	10	A	10.	
4	Enter HOB (ft)	1000	B	1000.	
5	Enter CEP (ft)	500	C	500.	
6	Enter PEH (ft)	100	E	100.	
7	Enter troop disposition	1	2nd A'	1.	
8	Enter vulnerability condition	1	2nd B'	1.	
9	Enter acceptable risk	1	2nd C'	1.	
10	Enter desired assurance	.99	2nd D'	0.99	
11	Calculate radius of safety and minimum safe distance	5.0	2nd E'		5. R 10. Y 1000. H 500. C 100. PH 1. D 1. V 1. R 0.99 P 15900. RS 16900. M

EXAMPLE #5.1:

Given the following information, calculate the probability of not exceeding the acceptable weapons effects.

distance from troops to desired ground zero, i.e., offset = 8200 ft
radius of safety = 7000 ft
circular error probable (CEP) = 500 ft
troop disposition = semicircular

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off, then on			0	
2	Select program 01		2nd Pgm 01	0.	
3	Enter CEP (ft)	500	C	500.	
4	Enter offset (ft)	8200	D	8200.	
5	Enter radius of safety (ft)	7000	D	7000.	
	NOTE: Offset and radius of safety must always be entered in the above order. If one is to be changed, both values must be re-entered.				
6	Enter troop disposition (see subsection E)	2	2nd A'	2.	
7	Calculate probability of not exceeding acceptable weapons effects	5.1	2nd E'		5.1 500. C 8200. D 7000. E 2. F
				0.993	0.993 P

Equations and listings for programs 5.0 and 5.1 are included with those for programs 5.2 and 5.3.

Section 5b: Programs 5.2 and 5.3

Fallout-Safe Height of Burst Calculations

DNA	AP-550 PROMPT AI				HTI
FALLOUT SAFE HEIGHT OF BURST					
			Desired Assurance	5.n → Prob., HOB	
Yield (KT)	HOB (ft)			PEH (ft)	

SOURCE OF DATA:

Defense Intelligence Agency, Physical Vulnerability Handbook - Nuclear Weapons (U), AP-550-1-2-60-INT, June 1, 1969, Part III, Section C.

DESCRIPTION:

A. Objective

The objective of this set of two programs is to calculate the minimum fallout-safe height of burst, or alternatively the probability that a selected HOB will result in an actual HOB which is fallout-safe. The calculation for minimum fallout-safe HOB is based upon fireball size and the uncertainty in actual HOB (i.e., PEH) due to delivery system characteristics; therefore, the user must specify the assurance level he desires.

To find the minimum actual HOB which will be fallout-safe, program 5.2 should be run with PEH = 0.

B. Inputs-Outputs

Program 5.2: Fallout-safe height of burst.

Inputs: Yield (KT)
PEH (ft)
Desired assurance

Program 5.3: Probability of achieving a fallout-safe HOB.

Inputs: Yield (KT)
PEH (ft)
HOB (ft)

C. Limits

Yield: 0.01KT ≤ Y ≤ 50MT

HOB: HOB ≥ 0 ft

PEH: PEH ≥ 0 ft

Desired assurance: 0.6 ≤ P ≤ 0.99

D. Data Storage Locations, Printer Alphanumerics

The user can find the following information stored in the indicated registers (R):

Variables	Registers	Alphanumerics
Yield (KT)	R10	Y
HOB (ft)	R11	H
PEH (ft)	R14	PH
Desired assurance	R18	P
Fallout-safe HOB	only in display	H
Probability that HOB is fallout-safe	only in display	P

E. Special Features

Pressing R/S will initiate the previously keyed-in type of calculation even if the inputs are changed.

EXAMPLE 5.2, 5.3

Given the following information, calculate the fallout-safe heights of burst corresponding to the two desired assurances; then invert the calculation using the HOB calculated for the second given desired assurance.

Yield = 10 KT

PEH = 100 ft

Desired assurances = 99%, 75%

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off - then on			0	
2	Select program 01		2nd Pgm 01	0.	
3	Enter yield (KT)	10	A	10.	
4	Enter PEH (ft)	100	E	100.	
5	Enter first desired assurance	.99	2nd D'	0.99	
6	Calculate fallout-safe HOB (ft)	5.2	2nd E'		5.2 10. Y 100. PH 0.99 P 651. H
7	Enter 2nd desired assurance	.75	2nd D'	0.75	
8	Calculate fallout-safe HOB (ft)		R/S		5.2 10. Y 100. PH 0.75 P 347. H
9	Enter HOB obtained in last calc.	347	B	347.	
10	Calc. probability of a fallout-safe HOB	5.3	2nd E'		5.3 10. Y 100. PH 347. H 0.751 P

EQUATIONS

Definitions

Y = Yield
HOB = Height of burst
CEP = Circular error probable
RS = Radius of safety
X = Offset
PEH = Probable error in height
V = Vulnerability state
R = Acceptable risk
P = Desired assurance (probability)
RS_{SR} = Slant range radius of safety
B = Buffer distance
MSD = Minimum safe distance

Calculate RS and MSD:

A slant range radius of safety is calculated as a function of Y, $RS_{SR}(Y)$, and the actual (ground range) radius of safety is calculated as:

$$RS = \left[RS_{SR}^2 - HOB'^2 \right]^{1/2}, \tag{1}$$

and the minimum safe distance is calculated as:

$$MSD = RS + B \tag{2}$$

where B and HOB' are functions of the error distributions:

$$HOB' = HOB + \frac{PEH}{1.15} \ln\left(\frac{1}{P} - 1\right) \tag{3}$$

$$B = CEP\left[b - \frac{1}{a} \ln\left(\frac{1}{P} - 1\right)\right] \tag{4}$$

where a and b are functions of troop disposition (see Table 5.1).

Calculation of RS_{SR}:

N = RS_{SR} (negligible risk)
M = RS_{SR} (moderate risk)
E = RS_{SR} (emergency risk)

For VUL = 1, (5)

$$N = \begin{cases} 7000(Y-.005)^{.13} & \text{for} \quad .01 \leq Y < 1 \\ 6250(Y+.3)^{.4} & \text{for} \quad 1 \leq Y \leq 10^5 \end{cases}$$

$$M = \begin{cases} N/1.22 & \text{for} \quad .01 \leq Y < 1 \\ N/1.2 & \text{for} \quad 1 \leq Y \leq 10^5 \end{cases}$$

$$E = \begin{cases} M/1.35 & \text{for} \quad .01 \leq Y < 1 \\ M/1.27 & \text{for} \quad 1 \leq Y \leq 10^5 \end{cases}$$

For VUL = 2,

$$N = \begin{cases} 7000(Y-.005)^{.13} & \text{for} \quad .01 \leq Y < 1 \\ 5000(Y+1.5)^{.36} & \text{for} \quad 1 \leq Y \leq 10^5 \end{cases}$$

$$M = \begin{cases} N/1.22 & \text{for} \quad .01 \leq Y < 1 \\ N/1.2 & \text{for} \quad 1 \leq Y \leq 10^5 \end{cases}$$

$$E = \begin{cases} M/1.35 & \text{for} \quad .01 \leq Y < 1 \\ M/1.27 & \text{for} \quad 1 \leq Y \leq 10^5 \end{cases}$$

For VUL = 3,

$$N = \begin{cases} 8576Y^{.2} & \text{for} \quad .01 \leq Y \leq .1 \\ 7332(Y-.05)^{.11} & \text{for} \quad .1 \leq Y \leq 30 \\ 3308Y^{.34} & \text{for} \quad 30 \leq Y \leq 10^5 \end{cases}$$

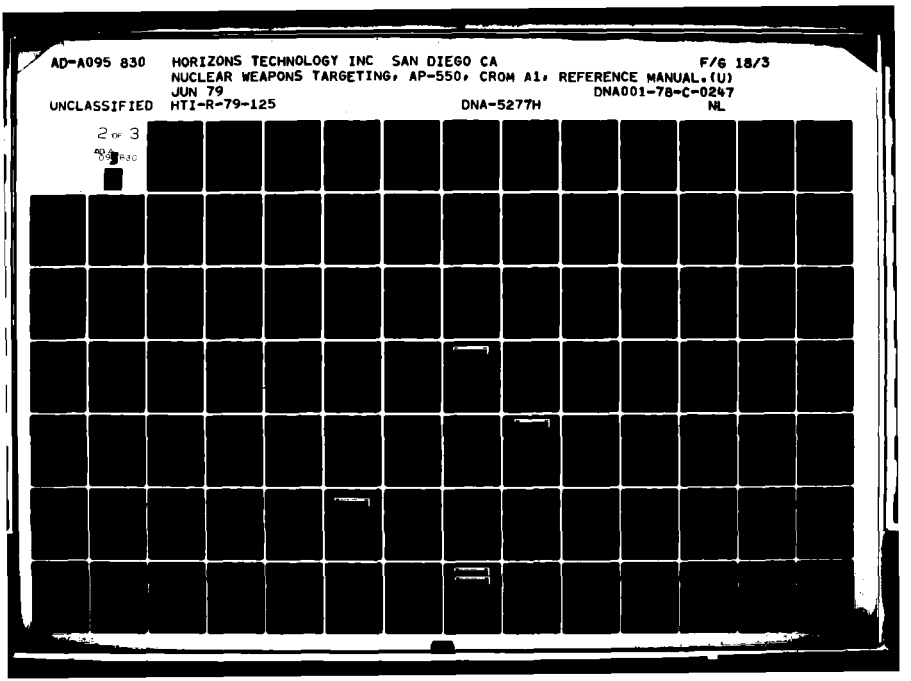
$$M = \begin{cases} N/1.4 & \text{for} \quad .01 \leq Y < .1 \\ 6069(Y-.075)^{.11} & \text{for} \quad .1 \leq Y < 90 \\ 2179Y^{.34} & \text{for} \quad 90 \leq Y < 300 \\ N/1.5 & \text{for} \quad 300 \leq Y \leq 10^5 \end{cases}$$

$$E = \begin{cases} M/1.38 & \text{for} \quad .01 \leq Y < .1 \\ 4341(Y-.[illegible])^{.15} & \text{for} \quad .1 \leq Y < 300 \\ N/1.47 & \text{for} \quad 300 \leq Y \leq 10^5 \end{cases}$$

Calculation of probability of not exceeding acceptable weapons effects:

$$B = X - RS, \text{ and} \tag{6}$$

$$P = [1 + \exp a(b - B/CEP)]^{-1}, \text{ where } a \text{ and } b \text{ are given as} \tag{7}$$
in table 5.1.


AD-A095 830
HORIZONS TECHNOLOGY INC SAN DIEGO CA
F/6 18/3
NUCLEAR WEAPONS TARGETING, AP-550, CROM A1, REFERENCE MANUAL.(U)
JUN 79
DNA001-78-C-0247
UNCLASSIFIED
HTI-R-79-125
DNA-5277H
NL
2 OF 3
AD A095830

Calculation of the minimum HOB which has a given probability of being fallout-safe:

$$HOB = 100Y^{.4} - \frac{PEH}{1.15} \ln\left(\frac{1}{P} - 1\right) \tag{8}$$

Calculation of the probability that a given HOB is fallout-safe:

$$P = \left\{1 + \exp\left[\frac{1.15}{PEH}\left(100Y^{.4} - HOB\right)\right]\right\}^{-1} \tag{9}$$

Disposition	a	b
1	2.6	.2
2	2.6	.5
3	3	.8
4	3	1

Table 5.1

PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
AUTOMATIC	07	Marks exceeded limit		

LIBRARY MODULE: CROM A-1 (Program 5)

DATA REGISTERS FOR EXAMPLE 5.2

DATA	REG.	COMMENTS
5.2	00	
137.	01	scratch
15.	02	indirect register RCL
0.	03	(Pgm 9)
0.	04	
0.	05	
0.	06	
0.	07	
0.	08	
0.	09	
10.	10	Y
0.	11	HOB
0.	12	CEP
0.	13	RS
100.	14	PEH
0.	15	Troop disposition
0.	16	Vulnerability state
0.	17	Risk
0.99	18	Assurance %
0.	19	Offset

LABELS

STEP	CODE	KEY	COMMENTS
001	81	RST	return on error
025	10	E'	input printing
031	16	A'	used in RS_{SR}
055	15	E	Print Y, PEH
072	17	B'	correct for risk cat.
085	18	C'	FSH, 50%
098	19	D'	used in RS_{SR}
111	11	A	calc. 5.0
191	97	DSZ	used in RS_{SR}
209	98	ADV	calc. RS, MSD
274	14	D	calc. 5.3
295	13	C	calc. 5.2
317	12	B	calc. 5.1

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	76	LBL	
001	81	RST	(Return on error)
002	92	RTN	
003	68	NOP	
004	68	NOP	
005	68	NOP	
006	03	3	
007	85	+	Coefficients for probability of damage for 4 troop configurations.
008	68	NOP	
009	03	3	
010	85	+	
011	32	X:T	
012	32	X:T	
013	02	2	
014	85	+	
015	32	X:T	
016	32	X:T	
017	00	0	
018	95	=	
019	55	÷	
020	01	1	
021	00	0	
022	95	=	b; a is in t register
023	92	RTN	
024	76	LBL	
025	10	E'	Prints inputs which have a lower limit of 0.
026	36	PGM	
027	09	09	
028	18	C'	
029	92	RTN	
030	76	LBL	
031	16	A'	Used in SR radius of safety:
032	94	+/-	
033	45	Y^x	Push operand into HIR stack
034	01	1	
035	52	EE	t = t register
036	03	3	x = display
037	94	+/-	
038	32	HIR	$\frac{-x}{1000}$
039	42	42	
040	43	RCL	
041	10	10	
042	32	HIR	$\left(\frac{-x}{1000}+Y\right)$
043	32	32	
044	53	(	
045	32	X:T	
046	55	-	
047	01	1	
048	00	0	(t/100)
049	00	0	
050	95	=	$\ldots\left(\frac{-x}{1000}+Y\right)^{(t/100)}$
051	42	STO	
052	01	01	
053	92	RTN	
054	76	LBL	
055	15	E	
056	93	.	
057	00	0	Print Y
058	01	1	
059	36	PGM	
060	09	09	
061	17	B'	
062	03	3	Print PEH as "PH"
063	44	SUM	
064	02	02	
065	03	3	
066	03	3	
067	02	2	
068	03	3	
069	61	GTO	
070	10	E'	
071	76	LBL	Used in RS_{SR} corrections for moderate and emergency risks
072	17	B'	
073	55	÷	
074	01	1	
075	00	0	
076	00	0	
077	85	+	
078	01	1	
079	95	=	
080	22	INV	
081	49	PRD	
082	01	01	
083	92	RTN	
084	76	LBL	FSH, 50% probability
085	18	C'	
086	01	1	
087	00	0	
088	00	0	
089	65	×	
090	43	RCL	
091	10	10	
092	45	Y^x	
093	93	.	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
094	04	4	FSH, 50% (cont.)
095	95	=	
096	92	RTN	
097	76	LBL	
098	19	D'	
099	03	3	
100	03	3	
101	00	0	
102	08	8	Used in radius of safety, SR VUL = 3
103	65	×	
104	03	3	
105	04	4	
106	32	X↕T	
107	00	0	
108	16	A'	
109	92	RTN	
110	76	LBL	Label A. Calculation 5.0
111	11	A	
112	93	.	
113	00	0	
114	01	1	Print Y
115	36	PGM	
116	09	09	
117	17	B'	
118	02	2	
119	03	3	Print HOB
120	10	E'	
121	01	1	
122	05	5	Print CEP
123	10	E'	
124	69	DP	
125	22	22	
126	03	3	
127	03	3	Print PEH
128	02	2	
129	03	3	
130	10	E'	
131	01	1	
132	06	6	
133	32	X↕T	Print DISP
134	04	4	
135	36	PGM	
136	09	09	
137	16	A'	
138	04	4	
139	02	2	Print VUL
140	32	X↕T	
141	03	3	
142	36	PGM	Print VUL (cont.)
143	09	09	
144	16	A'	
145	03	3	
146	05	5	
147	32	X↕T	Print RISK
148	03	3	
149	36	PGM	
150	09	09	
151	16	A'	
152	71	SBR	
153	04	04	Print P_c, desired probability
154	08	08	
155	87	IFF	
156	07	07	Return on error
157	81	RST	
158	43	RCL	Calculate SR radius of safety
159	10	10	
160	28	LOG	logY
161	85	+	
162	43	RCL	
163	16	16	VUL
164	32	X↕T	
165	03	3	
166	67	EQ	
167	04	04	If VUL=3
168	80	80	
169	00	0	
170	95	=	
171	29	CP	If log Y > 0
172	77	GE	
173	04	04	(if Y ≥ 1)
174	36	36	
175	07	7	Otherwise VUL=1 or 2,
176	52	EE	
177	03	3	and Y < 1:
178	65	×	
179	01	1	
180	03	3	
181	32	X↕T	
182	05	5	(see Eq. 5)
183	16	A'	$7000(Y-.005)^{.13} = N$
184	02	2	
185	02	2	Correction for moderate risk
186	85	+	
187	03	3	Correction for emergency risk

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
188	05	5	
189	65	×	
190	76	LBL	Label DSZ: distinguish risks
191	97	DSZ	
192	25	CLR	
193	43	RCL	
194	17	17	Risk
195	32	X:T	
196	01	1	
197	67	EQ	} If Risk = 1, no correction (negligible)
198	98	ADV	
199	82	HIR	
200	11	11	
201	17	B'	
202	02	2	} If Risk = 2 (moderate)
203	67	EQ	
204	98	ADV	
205	82	HIR	
206	12	12	Case for Risk = 3:
207	17	B'	
208	76	LBL	Label ADV
209	98	ADV	
210	71	SBR	RS_{SR} in R01
211	04	04	
212	24	24	$\frac{1.15}{PEH}$ in t register
213	25	CLR	
214	43	RCL	
215	11	11	HOB + ...
216	85	+	
217	71	SBR	
218	06	06	$\frac{PEH}{1.15} \ln\left(\frac{1}{p} - 1\right) = HOB'$
219	00	00	
220	33	X²	(Eq. 3)
221	75	-	
222	43	RCL	
223	01	01	RS_{SR}
224	33	X²	
225	95	=	
226	94	+/-	RS^2, Ground range (Eq. 1)
227	29	CP	
228	77	GE	
229	02	02	
230	32	32	
231	25	CLR	
232	34	FX	RS
233	32	X:T	} Print RS
234	03	3	
235	05	5	"R"
236	03	3	
237	06	6	"S"
238	98	ADV	} Print RS
239	32	X:T	
240	36	PGM	
241	09	09	
242	12	B	
243	42	STO	RS
244	13	13	
245	43	RCL	Disposition
246	15	15	
247	71	SBR	
248	03	03	Get coefficient for MSD
249	92	92	
250	32	X:T	a
251	55	÷	
252	43	RCL	
253	12	12	
254	95	=	$\frac{a}{CEP}$
255	32	X:T	b
256	65	×	x
257	43	RCL	CEP
258	12	12	
259	85	+	
260	43	RCL	RS
261	13	13	
262	75	-	
263	03	3	
264	00	0	"M"
265	71	SBR	
266	03	03	Print MSD
267	08	08	
268	32	X:T	
269	43	RCL	
270	13	13	RS→t
271	32	X:T	
272	92	RTN	MSD in display
273	76	LBL	Label D. Calculation 5.3
274	14	D	
275	15	E	Print Y, PEH
276	01	1	} Print H
277	01	1	
279	42	STO	
279	02	02	
280	02	2	
281	03	3	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
282	10	E'	
283	87	IFF	Return on error
284	07	07	
285	81	RST	
286	71	SBR	
287	04	04	$100Y^{.4}$; $\frac{1.15}{PEH}$ in t reg.
288	24	24	
289	43	RCL	
290	11	11	
291	61	GTO	$100Y^{.4}$ - HOB
292	03	03	
293	74	74	Print P (Eq. 9)
294	76	LBL	Label C. Calculation 5.2
295	13	C	
296	15	E	Print Y, PEH
297	71	SBR	
298	04	04	Print P
299	08	08	
300	87	IFF	Return on error
301	07	07	
302	81	RST	
303	71	SBR	
304	04	04	$100Y^{.4} - \frac{1.15}{PEH}$ in t reg.
305	24	24	
306	02	2	
307	03	3	"H"
308	71	SBR	
309	06	06	(Eq. 8)
310	00	00	
311	36	PGM	
312	09	09	Print distance
313	12	B	(FSH or MSD)
314	98	ADV	
315	92	RTN	.
316	76	LBL	Label B. Calculation 5.1
317	12	B	
318	02	2	
319	44	SUM	
320	02	02	
321	01	1	"C" Print CEP
322	05	5	
323	10	E'	
324	43	RCL	X
325	19	19	
326	32	X:T	CEP
327	65	×	
328	93	.	

STEP	CODE	KEY	COMMENTS
329	06	6	Lower limit = .9 CEP + RS
330	85	+	
331	43	RCL	RS
332	13	13	
333	85	+	
334	09	9	Print offset (cont.)
335	52	EE	
336	09	9	
337	65	×	
338	04	4	"X"
339	04	4	
340	36	PGM	
341	09	09	
342	11	A	
343	03	3	"R" Print radius of safety
344	05	5	
345	03	3	
346	06	6	"S"
347	10	E'	
348	69	DP	
349	22	22	
350	01	1	"D" Print disposition
351	06	6	
352	32	X:T	
353	04	4	
354	36	PGM	
355	09	09	
356	16	A'	
357	87	IFF	Return on error
358	07	07	
359	81	RST	
360	71	SBR	
361	03	03	
362	92	92	b
363	75	-	
364	53	(	
365	43	RCL	
366	19	19	(X
367	75	-	-
368	43	RCL	RS)/CEP
369	13	13	
370	54	)	
371	55	÷	
372	43	RCL	
373	12	12	
374	95	=	
375	65	×	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
376	32	X↕T	$a\left(\frac{1.15}{PEH}\right.$ for calc. 5.3$\left.\right)$
377	95	=	
378	22	INV	
379	23	LNX	
380	85	+	
381	03	3	"P"
382	03	3	
383	32	X↕T	
384	01	1	
385	95	=	
386	35	1/X	P (Eq. 7)
387	98	ADV	
388	36	PGM	
389	09	09	Print "P"
390	12	B	
391	92	RTN	
392	65	×	Disposition
393	02	2	
394	93	.	
395	06	6	Used for retrieval
396	32	X↕T	of coefficients
397	04	4	for 4 risk
398	95	=	categories -
399	42	STO	See note on
400	01	01	coefficient
401	01	1	retrieval
402	00	0	For
403	75	-	Disp: R01:
404	53	(	1 004
405	03	3	2 008
406	83	GO*	3 012
407	01	01	4 016
408	43	RCL	P Print P
409	18	18	
410	32	X↕T	
411	93	.	Print "P"
412	06	6	Low
413	85	+	
414	93	.	
415	09	9	
416	09	9	High
417	65	×	
418	03	3	
419	03	3	"P"
420	36	PGM	
421	09	09	
422	11	A	
423	92	RTN	
424	01	1	
425	93	.	
426	01	1	
427	05	5	
428	55	÷	
429	43	RCL	
430	14	14	
431	95	=	$\frac{1.15}{PEH}$
432	32	X↕T	
433	18	C'	$100Y^{.4}$
434	75	-	
435	92	RTN	
436	43	RCL	Case for VUL≠3, $Y \geq 1$
437	16	16	
438	32	X↕T	
439	02	2	
440	67	EQ	
441	04	04	If VUL=2
442	59	59	
443	04	4	Case for VUL=1,
444	00	0	$Y \geq 1$
445	32	X↕T	
446	06	6	
447	02	2	
448	05	5	
449	00	0	$6250(Y+.3)^{.4}$
450	65	×	
451	03	3	
452	00	0	
453	00	0	
454	94	+/-	
455	16	A'	
456	61	GTO	
457	04	04	
458	72	72	
459	03	3	Case for VUL = 2, $Y \geq 1$
460	06	6	
461	32	X↕T	
462	05	5	
463	52	EE	
464	03	3	
465	65	×	
466	01	1	
467	05	5	
468	00	0	
469	00	0	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
470	94	+/-	
471	16	A'	$(1.5+Y)^{.36}$ x 5000
472	02	2	
473	00	0	Corrections to negligible risk, for moderate and emergency risk
474	85	+	
475	02	2	
476	07	7	
477	65	×	
478	61	GTO	
479	97	DSZ	
480	04	4	Case for VUL=3
481	95	=	
482	22	INV	&logY + 4, t reg = 3
483	77	GE	
484	05	05	If Y < .1
485	82	82	
486	75	-	
487	03	3	
488	52	EE	
489	03	3	
490	28	LOG	
491	95	=	
492	77	GE	
493	05	05	If Y ≥ 300
494	73	73	
495	85	+	
496	01	1	otherwise .1 ≤ Y ≤ 300
497	75	-	
498	53	(	
499	43	RCL	
500	17	17	
501	67	EQ	
502	05	05	If RISK = 3
503	59	59	
504	85	+	
505	01	1	
506	54	)	
507	67	EQ	
508	05	05	If RISK = 2
509	28	28	
510	00	0	
511	95	=	
512	77	GE	
513	05	05	
514	47	47	If Y ≥ 30
515	01	1	
516	01	1	Start of Case for VUL=3, RISK=1
517	32	X:T	.1 ≤ Y < 30
518	07	7	
519	03	3	
520	03	3	
521	02	2	
522	65	×	
523	05	5	
524	00	0	
525	16	A'	$(Y-.05)^{.11}$
526	61	GTO	
527	98	ADV	
528	03	3	Case for VUL=3, RISK=2
529	28	LOG	
530	95	=	
531	77	GE	
532	05	05	If Y ≥ 90
533	50	50	
534	01	1	Case for VUL=3, RISK=2,
535	01	1	.1 ≤ Y < 90
536	32	X:T	
537	06	6	
538	00	0	
539	06	6	
540	09	9	
541	65	×	
542	07	7	
543	05	5	
544	16	A'	$6069(Y-.075)^{.11}$
545	61	GTO	
546	98	ADV	
547	19	D'	
548	61	GTO	$3308Y^{.34}$ Case for VUL=3; RISK=1; 30 ≤ Y < 300
549	98	ADV	
550	02	2	
551	01	1	Case for VUL=3; RISK=2;
552	07	7	90 ≤ Y < 300
553	09	9	
554	71	SBR	
555	01	01	
556	03	03	$2179Y^{.34}$
557	61	GTO	
558	98	ADV	
559	25	CLR	Case for VUL=3; RISK=3
560	01	1	
561	05	5	
562	32	X:T	
563	04	4	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS	STEP	CODE	KEY	COMMENTS
564	03	3		611	95	=	$\frac{CEP}{a}\ln\left(\frac{1}{p}-1\right)$
565	04	4		612	92	RTN	
566	01	1					
567	65	×					
568	05	5					
569	05	5					
570	16	A'	$4341x(Y-.055)^{.15}$				
571	61	GTO					
572	98	ADV					
573	19	D'	Case for VUL=3; Y > 300				
574	05	5	$3308Y^{.34}$				
575	00	0	Corrections to negligible risk for moderate and emergency risk categories.				
576	85	+					
577	04	4					
578	07	7					
579	65	×					
580	61	GTO					
581	97	DSZ					
582	02	2	Case for VUL=3; Y < .1				
583	00	0					
584	32	X:T					
585	08	8					
586	05	5					
587	07	7					
588	06	6					
589	65	×					
590	00	0					
591	16	A'	$8576Y^{.2}$				
592	04	4	Corrections to negligible risk for moderate and emergency categories.				
593	00	0					
594	85	+					
595	03	3					
596	08	8					
597	65	×					
598	61	GTO					
599	97	DSZ					
600	32	X:T					
601	35	1/X	$\frac{CEP}{a}$ or $\frac{PEH}{1.15}$				
602	65	×					
603	53	(					
604	43	RCL	p				
605	18	18					
606	35	1/X					
607	75	-					
608	01	1					
609	54	)					
610	23	LNX					

Section 6: Programs 6.0 - 6.3

Probability of Damage Utilizing
Equivalent Target Areas

DNA	AP-550 PROMPT AI			HTI
PROBABILITY OF DAMAGE - EQUIVALENT TARGET AREA - VN SYSTEM				
CEP (ft)	TARGET LENGTH (ft)	TARGET WIDTH (ft)	SELECT AIMPOINT	6.n → Pd
YIELD (KT)	HOB (ft)		LENGTH VN, K	WIDTH VN, K

DNA	AP-550 PROMPT AI			HTI
PROBABILITY OF DAMAGE - ETA, CRATER RADIUS METHOD				
CEP (ft)	TARGET LENGTH (ft)	TARGET WIDTH (ft)	SELECT AIMPOINT	6.2 → Pd
YIELD (KT)	HOB (ft)	MEDIUM	LENGTH C.R.MULT.	WIDTH C.R.MULT.

DNA	AP-550 PROMPT AI			HTI
PROBABILITY OF DAMAGE - ETA, WEAPON RADII SPECIFIED				
CEP (ft)	TARGET LENGTH (ft)	TARGET WIDTH (ft)	SELECT AIMPOINT	6.3 → Pd
			LENGTH WR (ft)	WIDTH WR (ft)

SOURCE OF DATA:

Defense Intelligence Agency, Physical Vulnerability Handbook-Nuclear Weapons (U), AP-550-1-2-69-INT, 1 June 1969, Ch. 4, pages 28, 30-33, 37.

DESCRIPTION:

A. Objective

This program calculates the probability of damage to rectangular targets using the Equivalent Target Area (ETA) method. The ETA is an area such that the probability of placing the ground zero position within the area is equal to the probability of doing the desired damage to the target. Given the target dimensions, the circular error probable, CEP, and the weapon radii for both dimensions, the program will calculate the ETA dimensions and the probability of doing the desired damage.

The program sets offers four calculations. Program 6.0 uses the VN system to calculate the length and width weapon radii for P-type targets, those most sensitive to shock overpressure. Program 6.1 does the same for Q-type targets, those most sensitive

to dynamic pressure. Program 6.2 calculates the crater radius and then uses it to calculate the weapon radii. For cases when the weapon radii are known, program 6.3 allows the user to enter these values and proceed with the probability of damage calculations. Once the weapon radii are obtained, the program uses the same calculation for the probability of damage in all four routines.

B. Inputs-Outputs

The CEP, target length, target width and aim point (1 for center of target, 2 for longer dimension edge) are entered in all four calculations. The other entries for each program are:

6.0: Yield, HOB, Length VN, Length k-factor, Width VN, Width k-factor.

6.1: Same as 6.0

6.2: Yield, HOB, Medium (1 = dry rock, 2 = wet rock, 3 = dry soil, 4 = wet soil), Length Crater Radius Multiplier, Width Crater Radius Multiplier.

6.3: Length Weapon Radius, Width Weapon Radius.

A negative HOB is interpreted as that distance below the ground. Programs 6.0, 6.1 and 6.2 calculate the weapon radii and all four programs display the probability of damage.

C. Limits

The following limits are the same for all the programs:

Yield: $0.1 \text{ KT} \leq Y \leq 30 \text{ MT}$

Length: $L \geq$ Width

Width: $W \geq 5$ ft.

Aimpoint: AP = 1 or 2

Program 6.0

VN: $0 \leq \text{AJVN} \leq 54$

k-factor: $0 \leq k \leq 9$

HOB: $0 \leq \text{HOB} \leq 2308\ Y^{1/3} \exp(-\text{AJVN}/15)$ ft.

AJVN = Adjusted Vulnerability Number (for width and length)

Program 6.1

VN: $0 \leq AJVN \leq 34$

k-factor: $0 \leq k \leq 9$

HOB: $0 \leq HOB \leq HOB_{max}(Y)^{1/3}$ ft.

where HOB_{max} is the minimum of:

$900\ Y^{1/3}$ ft.

$2308\ Y^{1/3}\ \exp(-AJVN/15)$ ft.

Program 6.2

HOB: $-200(Y)^{0.3} \leq HOB \leq 20(Y)^{0.3}$ ft.

Medium no.: $M = 1,2,3,4$

Crater Radius Mult.: $1 \leq$ Length CRM ≤ 3

$1 \leq$ Width CRM ≤ 3

D. Data Storage Locations, Printer Alphanumerics

The user can find the following information stored in the indicated registers (R).

Variable	Registers	Alphanumerics
Yield	R10	Y
HOB	R11	H
CEP	R15	C
Length	R16	L
Width	R17	W
Aim Point	R18	A
Width Weapon Radius	R27	WW
Length Weapon Radius	R29	LW

(continued)

Variable	Registers	Alphanumerics
For Programs 6.0 and 6.1		
Length k-factor	R13	LK
Width k-factor	R14	WK
Length VN	R19	LV
Width VN	R20	WV
For Program 6.2		
Medium	R12	M
Length CRM	R13	LM
Width CRM	R14	WM
For Program 6.3		
Length Weapon Radius	R13	LW
Width Weapon Radius	R14	WW

EXAMPLE 6.0, 6.1 (P and Q Target Options)

Calculate the probability of damage to a 500- by 50-ft bridge from the dynamic pressure (Q-type target) effect of a 0.5 KT weapon which bursts 100 ft. above the bridge. Assume the relevant quantities are:

CEP = 500 ft	Aim Point = Target Center
Length VN = 18	Width VN = 14
Length k = 9	Width k = 9

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off - then on			0	
2	Select program 01		2nd Pgm 01	0.	
3	Enter the target length, L(ft)	500	2nd B'	500.	
4	Enter the target width, W(ft)	50	2nd C'	50.	
5	Enter the weapon yield, Y(KT)	.5	A	0.5	
6	Enter the HOB(ft)	100	B	100.	
7	Enter the CEP(ft)	500	2nd A'	500.	
8	Enter the aim point (1 = target center, 2 = edge of longer dimension)	1	2nd D'	1.	
9	Enter the length VN, LV	18	D	18.	
10	Enter the length k factor, LK	9	D	9.	
11	Enter the width VN, WV	14	E	14.	
12	Enter the width k factor, WK	9	E	9.	
13	Calculate the probability of damage to the bridge from dynamic pressure. Note: If this were a P-type target, step 13 "Input Data" would be 6.0 and the resulting probability of damage (P) would be 0.347.	6.1	2nd E'	0.651	6.1 0.5 Y 18. LV 9. LK 14. WV 9. WK 100. H 375. LW 505. WW 500. C 500. L 50. W 1. A 0.651 P

EXAMPLE 6.2, 6.3 (Cratering and WR Input Options)

A solid arch concrete bridge 1000 ft long and 70 ft wide is to be attacked by a 10-KT weapon which will burst on contact with the bridge. The weapon, which is aimed towards the center of the target, has a CEP of 500 ft. Assuming the length and width crater radius multipliers are 1.25 and 1.5 respectively, calculate the probability of damage to the target. See AP-550, tables I-5, I-6, I-7, and I-10 for source of crater radius multipliers.

Change the length and width weapon radii to 350 ft and 300 ft and recalculate the probability of damage to the bridge.

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off - then on			0	
2	Select program 01.		2nd Pgm 01	0.	
3	Enter the weapon yield, Y(KT)	10	A	10.	
4	Enter the HOB(ft)	0	B	0.	
5	Enter the medium (1 = dry rock, 2 = wet rock, 3 = dry soil, 4 = wet soil)	1	C	1.	
6	Enter the target length, L(ft)	1000	2nd B'	1000.	
7	Enter the target width, W(ft)	70	2nd C'	70.	
8	Enter the weapon CEP(ft)	500	2nd A'	500.	
9	Enter the aim point (A = 1 center of target, A = 2 at longest dimension edge)	1	2nd D'	1.	
10	Enter the length multiplier, LM	1.25	D	1.25	
11	Enter the width multiplier, WM	1.5	E	1.5	
12	Calculate the probability of damage to the bridge utilizing the crater radius method.	6.2	2nd E'		6.2 10. Y 0. H 1. M 1.25 LM 1.5 WM 142. LW 171. WW 500. C 1000. L 70. W 1. A
				0.298	0.298 P

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
13	Enter the new length weapon radius, LW(ft)	350	D	350.	
14	Enter the new width weapon radius, WW(ft)	300	E	300.	
15	Calculate the probability of damage to the bridge from a weapon that produced these weapon radii.	6.3	2nd E'		6.3 350. LW 300. WW 500. C 1000. L 70. W 1. A
				0.536	0.536 P

EQUATIONS (Note all distances in feet)

Definitions

CR = Crater Radius
LM = Crater Radius Multiplier for Length
WM = Crater Radius Multiplier for Width
RL = Radius of Disruption for Length
RW = Radius of Disruption for Width
LW = Length Weapon Radius
WW = Width Weapon Radius
CEP = Circular Error Probable
$LCEP_a$ = Adjusted Circular Error Probable for Length
$WCEP_a$ = Adjusted Circular Error Probable for Width
L = Target Length
W = Target Width
LETA = Length Equivalent Target Area
WETA = Width Equivalent Target Area
AP = Aim Point (1=Center of Target, 2=Edge of Target) (dgz)
P = Probability of Damage
, , , and are intermediate calculation values

For Calculation 6.2 (CR Method):

RL = CR × LM (1)
RW = CR × WM (2)
LW = 1.1 × RL (3)
WW = 1.1 × RW (4)

For calculations 6.0, 6.1 and 6.3 (The weapon radii are either calculated or entered)

RL = LW (5)
RW = WW (6)

The following 8 values are then used in the probability calculation: CEP, L, W, AP, RL, RW, WL and WW.

$LCEP_a = (CEP^2 + 0.125LE)^{1/2}$ (7)

$WCEP_a = (CEP^2 + 0.125WE)^{1/2}$ (8)

LETA = L + 2RL (9)

WETA = W + 2RW (10)

= LETA × $LCEP_a$ (11)

= WETA × $WCEP_a$ (12)

$$\gamma = (W+RW) \div WCEP_a \tag{13}$$

$$\delta = RW \div WCEP_a \tag{14}$$

Case 1: $\beta \leq 4$

$$P = \left|1 - \exp\left(-0.221\beta^2\right)\right|^{1/2} \times \left|1 - \exp\left(-0.221\alpha^2\right)\right|^{1/2} \tag{15}$$

Case 2: $\beta > 4$ and AP = 1 (center of target)

$$P = \left|1 - \exp\left(-0.221\alpha^2\right)\right|^{1/2} \tag{16}$$

Case 3: $\beta > 4$ and AP = 2 (edge of target)

$$P = \frac{\left|1 - \exp\left(-0.88\delta^2\right)\right|^{1/2} + \left|1 - \exp\left(-0.88\gamma^2\right)\right|^{1/2}}{2} \tag{17}$$

PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
AUTOMATIC	07	Marks limit check error		
LIBRARY MODULE: CROM A-1 (Program 6)	09	Distinguish P-target from Q-target		

DATA REGISTERS FOR EXAMPLE 6.1

DATA	REG.	COMMENTS
6.1	00	
0.221	01	
19.	02	indirect RCL (Pgm 9)
1.153821105	03	
6.01130929	04	
.9255558333	05	
0.	06	
0.	07	
0.	08	
0.	09	
0.5	10	Y
100.	11	HOB
504.8018854	12	Soil medium: 1,2,3,4
0.	13	Length WR, CRM, or K
0.	14	Width WR, CRM, or K
500.	15	CEP
500.	16	Target length
50	17	Target width
1.	18	Aimpoint: 0,1
19.	19	Length VN
14.	20	Width VN
19.5801854	21	
0.	22	
0.	23	
403.5984119	24	
0.	25	
504.8018854	26	
504.8018854	27	
4.655010331	28	
4.655010331	29	

LABELS STEP	CODE	KEY	COMMENTS
001			CEP_a calc.
015			calc. eq.15-17
038			6.3 calc.
051			6.2 calc.
064			6.1 calc.
077			6.0 calc.

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	15	LBL	Label C'.
001	18	C'	
002	53	(	Calculation of adjusted CEP for width or length see Eqs. 7 and 8
003	32	X2	
004	55	-	
005	43	RCL	
006	15	15	
007	32	X2	
010	54	)	
011	44	+	
012	43	RCL	
013	01	01	
014	33	√x	
015	15	LBL	Label D'.
016	19	D'	
017	53	(	Calculation of a part of Eqs. 15, 16, or 17.
020	53	(	
021	43	RCL	
022	00	00	
023	43	RCL	
024	01	01	
025	54	)	
026	44	+	
027	43	RCL	
030	02	02	
031	54	)	
032	44	+	
033	43	RCL	
034	03	03	
035	54	)	
036	55	÷	
037	43	RCL	
040	04	04	
041	54	)	
042	33	√x	
043	15	LBL	Label D.
044	14	D	
045	43	RCL	Input Weapon Radii
046	00	00	
047	28	LOG	
050	04	4	
051	03	3	
052	04	4	"LW"
053	03	3	Print entered Length
054	36	PGM	Weapon Radius
055	04	04	
056	18	C'	
057	42	STO	R28=RL=LW
060	28	LOG	
061	01	1	
062	05	5	
063	42	STO	See Eq. 5
064	00	00	R29=LW
065	36	PGM	
066	04	04	
067	18	C'	
070	42	STO	
071	43	RCL	
072	11	11	
073	55	÷	
074	04	4	
075	53	EE	
076	09	9	
077	36	PGM	
100	04	04	
101	04	4	
102	03	3	
103	04	4	"WW"
104	03	3	Print entered
105	36	PGM	Width Weapon Radius
106	04	04	
107	18	C'	
110	42	STO	See Eq. 6
111	26	26	R26=RW=WW
112	42	STO	R27=WW
113	27	27	
114	01	1	
115	05	5	"C"
116	42	STO	
117	02	02	Print
120	36	PGM	CEP
121	04	04	
122	18	C'	
123	01	1	
124	01	1	"L"
125	33	√x	Check and
126	43	RCL	print
127	11	11	Length
130	55	÷	
131	04	4	
132	53	EE	Lower Limit = W
133	09	9	Upper Limit = 9E9
134	36	PGM	
135	04	04	
136	04	4	"W"
137	03	3	
140	33	√x	Check and
141	05	5	print W
142	36	PGM	
143	04	04	Lower limit = 5
144	55	÷	
145	02	2	
146	01	1	"A"
147	03	3	
150	33	√x	Check and print aim
151	01	1	point
152	36	PGM	
153	04	04	
154	16	A'	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
094	87	IFF	If Flag 7
095	07	07	is set,
096	03	03	go to 370
097	70	70	
098	43	RCL	
099	29	29	
100	65	×	If LW x WW = 0,
101	43	RCL	
102	27	27	
103	95	=	then P = 0 and
104	29	CP	
105	67	EQ	
106	03	03	go to 362
107	62	62	
108	43	RCL	Calculate
109	39	29	$LCEP_a$
110	18	C'	See Eq. 7
111	53	(	
112	02	2	
113	65	×	Calculate
114	43	RCL	LETA
115	28	28	See Eq. 9
116	85	+	
117	43	RCL	
118	16	16	
119	85	=	Calculate
120	32	X↑T	β
121	83	.	See Eq. 11
122	03	3	
123	32	2	ROI = 0.221
124	01	1	Put β in t reg
125	42	STO	
126	01	01	
127	04	4	If 4 ≥ P,
128	77	GE	Case 1
129	03	03	Go to Step 344
130	44	44	See Eq. 15
131	43	RCL	If Aim Point=1
132	18	18	(center of target),
133	32	X↑T	
134	01	1	Case 2
135	67	EQ	Go to Step 347
136	03	03	See Eq. 16
137	47	47	
138	83	.	Case 3
139	08	8	ROI=0.88
140	08	8	

STEP	CODE	KEY	COMMENTS
141	42	STO	
142	01	01	
143	43	RCL	Calculate
144	27	27	$WCEP_a$
145	18	C'	See Eq. 8
146	43	RCL	
147	26	26	Calculate
148	95	=	WETA
149	19	D'	See Eq. 10
150	55	÷	Calculate 1st
151	02	2	half of Eq. 17
152	85	+	
153	83	.	
154	05	5	Prepare to
155	49	PRD	calculate
156	26	26	last part
157	65	×	of Eq. 17
158	61	GTO	
159	03	03	Go to 347
160	47	47	
161	76	LBL	Label C.
162	13	C	
163	36	PGM	CR-WR
164	07	07	Call cratering
165	71	SBR	Code to check
166	33	PRT	Limits and print
167	02	2	Yield and HOB
168	07	7	
169	03	3	"LM"
170	00	0	
171	32	X↑T	
172	01	1	1=Lower Limit
173	85	+	
174	03	3	3=Upper Limit
175	36	PGM	Check and print
176	09	09	Length Multiplier
177	13	C	
178	04	4	
179	03	3	"WM"
180	03	3	
181	00	0	
182	32	X↑T	1=Lower Limit
183	01	1	
184	36	PGM	3=Upper Limit
185	09	09	Check and print
186	13	C	Width Multiplier
187	36	PGM	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
188	07	07	Call cratering
189	71	SBR	code to
190	95	=	calculate
191	79	x²	crater radius
192	32	X:T	
193	65	×	
194	32	X:T	CR x WM = RW
195	43	RCL	See Eq. 2
196	14	14	
197	95	=	
198	42	STO	R26= RW
199	26	26	
200	42	STO	R27=WW
201	27	27	See Eq. 4
202	32	X:T	CR x LM = LW
203	65	×	
204	43	RCL	See Eq. 1
205	13	13	
206	65	×	
207	42	STO	R28=RL
208	28	28	
209	01	1	
210	93	.	
211	01	1	R29 = LW
212	49	PRD	See Eq. 3
213	27	27	
214	95	=	
215	42	STO	
216	29	29	Go to 321
217	98	ADV	to print
218	61	GTO	LW and WW
219	03	03	
220	21	21	
221	76	LBL	Label B.
222	12	B	Q-target WR
223	22	INV	
224	76	LBL	Label A.
225	11	A	P-target WR
226	86	STF	
227	09	09	
228	43	RCL	LK, WK, LV: put LV=R_{13}, LK=R_{14}
229	13	13	
230	48	EXC	
231	14	14	
232	48	EXC	
233	19	19	for Page 2
234	42	STO	

STEP	CODE	KEY	COMMENTS
235	13	13	
236	93	.	
237	01	1	
238	36	PGM	
239	09	09	
240	17	B'	Check and print Y
241	02	2	
242	07	7	"L"
243	36	PGM	
244	02	02	
245	71	SBR	
246	94	+/-	Check and print LV, LK
247	83	HIR	
248	12	12	Max H for LV, LK
249	42	STO	
250	24	24	
251	36	PGM	
252	02	02	
253	71	SBR	Calculate LW
254	89	π	
255	42	STO	R28=RL=LW
256	28	28	See Eq. 5
257	42	STO	R29=LW
258	29	29	
259	43	RCL	LV, WK, LK, WV: put WV=R_{13}, WK=R_{14}
260	13	13	
261	48	EXC	
262	19	19	
263	48	EXC	
264	14	14	
265	48	EXC	
266	20	20	
267	42	STO	
268	13	13	
269	43	RCL	
270	00	00	Page calculation
271	32	INV	
272	59	INT	
273	29	CP	
274	22	INV	(Flag 9 cleared by
275	67	EQ	page 2)
276	02	02	
277	80	80	
278	86	STF	Set flag 9 again for
279	09	09	P-target (6.0)
280	04	4	
281	03	3	"W"

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
282	36	PGM	Check WV, WK
283	02	02	
284	71	SBR	
285	94	+/-	
286	92	HIR	Max H for WV, WK
287	12	12	
288	32	X:T	
289	43	RCL	
290	24	24	
291	77	GE	
292	02	02	Max H=min{L-max H,
293	95	95	W-max H}
294	32	X:T	
295	00	0	
296	85	+	
297	43	RCL	
298	11	11	
299	32	X:T	
300	65	×	
301	02	2	"H"
302	03	3	
303	36	PGM	Check and print H
304	09	09	
305	11	A	
306	98	ADV	
307	36	PGM	
308	02	02	Calculate WW
309	71	SBR	
310	89	π	
311	42	STO	R26=RW=WW
312	26	26	See Eq. 6
313	42	STO	
314	27	27	
315	43	RCL	WV } Replace to
316	13	13	} original register
317	48	EXC	LK } positions
318	20	20	
319	42	STO	
320	13	13	
321	02	2	
322	07	7	
323	04	4	Print LW
324	03	3	
325	32	X:T	
326	43	RCL	
327	29	29	
328	36	PGM	
329	09	09	
330	12	B	
331	04	4	
332	03	3	Print WW
333	04	4	
334	03	3	
335	32	X:T	
336	43	RCL	
337	27	27	
338	36	PGM	
339	09	09	
340	12	B	
341	61	GTO	Go to beginning of calculation
342	00	00	
343	61	61	
344	32	X:T	Begins calculation for Case 1; See Eq. 15 (step 345 calculates the 1st half of Eq. 15)
345	19	D'	
346	65	×	
347	53	(	
348	43	RCL	Begins calculation for 2nd part of Eq. 15 or all of Eq. 16 or the 2nd part of Eq. 17.
349	27	27	
350	18	C'	
351	53	(	
352	02	2	See Eq. 8
353	65	×	Calculation of γ or γ see Eqns. 12 or 13
354	43	RCL	
355	26	26	
356	85	+	
357	43	RCL	
358	17	17	
359	54	)	
360	54	)	
361	19	D'	Call D' to complete calculation of P
362	98	ADV	
363	32	X:T	
364	03	3	"P"
365	03	3	
366	32	X:T	Print out Probability
367	36	PGM	
368	09	09	
369	12	B	
370	92	RTN	

Section 7: Programs 7.0 - 7.4

Cratering Calculations

DNA	AP-550 PROMPT AI				HTI
CRATERING CALCULATIONS					
				7.n → CALC.	
YIELD (KT)	HOB (ft)	SELECT MEDIUM	RADIUS (ft)		

SOURCES OF DATA:

1. Defense Intelligence Agency, Physical Vulnerability Handbook - Nuclear Weapons (U), AP-550-1-2-69-INT, 1 June 1969 (C Int), Part II, pages II-1 through II-8.
2. Horizons Technology, Inc., Nuclear Weapons Effects Programs, DNA-1 CROM-1, 3 November 1978, Programs 8 and A-1.

DESCRIPTION:

A. Objective

Given any two of the following three values, crater radius (R), height of burst (HOB), or weapon yield (Y), this program will calculate the third. Programs are also included that calculate the optimum HOB and corresponding crater radius given a yield, or optimum HOB and minimum yield given a crater radius.

Results are provided for four different surface medium categories:

Medium 1: Dry Rock (less than 3% moisture content)
Medium 2: Wet Rock (more than 3% moisture content)
Medium 3: Dry Soil (less than 10% moisture content)
Medium 4: Wet Soil (more than 10% moisture content)

A negative height of burst is interpreted as a distance below ground. Crater dimensions are estimated in the referenced documents within ±15%. In layered media or in the presence of an intersecting water table the accuracy is estimated to be reduced to ±25%.

B. Inputs-Outputs

The medium number is used in all five program calculations. The following other values are used in each program:

Program 7.0: Crater radius, depth and volume

Inputs: Yield (KT)
HOB (ft)

Program 7.1: Less than optimum depth of burst

Inputs: Yield (KT)
Crater radius (ft)

Program 7.2: Necessary yield

Inputs: Crater radius (ft)
Height of burst (ft)

Program 7.3: Maximum crater radius, optimum HOB

Inputs: Yield (KT)

Program 7.4: Minimum yield, optimum HOB

Inputs: Crater radius (ft)

A rough estimate of the following crater dimensions can be calculated from the output values:

Radius of the crater from the top of the lip = 1.25 R

Depth of the crater from the top of the lip = 1.25 D
(depth from surface)

Radius of the ejecta material = 2.5 R

C. Limits

Yield: $1 \text{ KT} \leq Y \leq 30 \text{ MT}$

Medium: M = 1,2,3,4

M = Medium
(1=dry rock, 2=wet rock,
3=dry soil, 4=wet soil)

For Program 7.0

HOB: $-200(Y)^{0.3} \leq \text{HOB} \leq 20(Y)^{0.3}$ ft

(a negative HOB denotes a depth of burst)

For Program 7.1

Crater radius: $0 \leq R \leq$ U.L. (Upper Limit)

where

$\text{U.L.} = 151.8(Y)^{0.3}$ for dry rock
$\text{U.L.} = 174.9(Y)^{0.3}$ for wet rock
$\text{U.L.} = 161.7(Y)^{0.3}$ for dry soil
$\text{U.L.} = 214.5(Y)^{0.3}$ for wet soil

For Program 7.2

HOB: $-3000 \leq HOB \leq 300$ ft

Crater radius: $L.L. \leq R \leq 4 \exp\left(A + .7 \ln\left|\frac{HOB}{442.2} + 1\right|\right)$ ft

where L.L. is the lower limit, and:

A = 5.77 for dry rock
A = 5.94 for wet rock
A = 5.94 for dry soil
A = 6.21 for wet soil

For HOB > 0

L.L. = 3.7

For HOB $\leq$ 0

$$L.L. = 3.7 \exp\left[B + \ln\left(\frac{-HOB}{3.3}\right)\right]$$

where

B = -1.27 for dry rock
B = -1.30 for wet rock
B = -1.73 for dry soil
B = -1.20 for wet soil

D. Special Features

The program leaves the calculator in the radian mode.

Pressing R/S will initiate the previously keyed-in type of calculation even if the inputs are changed.

E. Data Storage Locations, Printer Alphanumerics

Variables	Registers	Alphanumerics
Yield	R10	Y
HOB or optimum HOB	R11	H
Medium	R12	M
Radius	R13	R

EXAMPLE 7.0, 7.1, 7.2 (General Calculation and Inversions)

Calculate the crater radius, depth and volume produced by a weapon of yield 10 KT set 240 feet below the surface in dry rock. Then find, for the same weapon, the HOB that will produce a crater radius of 150 feet in wet soil. Finally, find the yield of a weapon which produces a 100-foot crafter radius when set 20 feet below the surface in wet rock.

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off - then on			0	
2	Select program 01		2nd Pgm 01	0.	
3	Enter weapon yield, Y(KT)	10	A	10.	
4	Enter HOB (ft)	-240	B	-240.	
	(Note that a negative HOB means a distance below ground)				
5	Enter the medium	1	C	1.	
	(1 = dry rock, 2 = wet rock, 3 = dry soil, 4 = wet soil)				
6	Calculate the crater radius and depth	7.0	2nd E'		7. 10. Y -240. H 1. M 301. R 173. D
7	Display the crater volume (ft^3)		2nd $\bar{x}$	3.01 02 2.462 07	
8	Enter crater radius, R(ft)	150	D	150.	
9	Enter the new medium value	4	C	4.	
10	Calculate the HOB (ft)	7.1	2nd E'		7.1 10. Y 4. M 150. R
				3.28	3.28 H

EXAMPLE 7.0, 7.1, 7.2 (cont.)

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
11	Enter new crater radius, R (ft)	100	D	100.	
12	Enter the HOB (ft)	-20	B	-20.	
13	Enter the new medium value	2	C	2.	
14	Calculate the weapon yield (KT)	7.2	2nd E'		7.2 -20. H 2. M 100. R
				0.49	0.49 Y

EXAMPLE #7.3, 7.4 (Optimized HOB Routines)

Calculate the maximum radius that a 1-KT yield bomb can produce in dry soil and the optimum HOB that the weapon should be set at to produce this radius. Compare this to the maximum radius produced by the same weapon in dry rock.

Then calculate the smallest yield that a weapon must have to produce a crater radius of 200 feet in wet soil and the optimum HOB that the weapon must be set at to produce this crater.

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off - then on			0	
2	Select program 01		2nd Pgm 01	0.	
3	Enter weapon yield, Y(KT)	1	A	1.	
4	Enter the medium (1 = dry rock, 2 = wet rock, 3 = dry soil, 4 = wet soil)	3	C	3.	
5	Calculate the maximum radius (ft) and the optimum HOB (ft)	7.3	2nd E'		7.3 1. Y 3. M 162. R -158. H
6	Change the medium to dry rock	1	C	1.	
7	Repeat the same calculation		R/S		7.3 1. Y 1. M 152. R -109. H
8	Enter the crater radius, R(ft)	200	D	200.	
9	Enter the new medium	4	C	4.	
10	Calculate the minimum yield (KT) and the optimum HOB (ft)	7.4	2nd E'		7.4 4. M 200. R 0.792 Y -129. H

EQUATIONS

Definitions

Y = Yield (KT)
HOB_1 = Height of burst for the equivalent 1 KT explosion
HOB = Height of burst
R_1 = Crater radius for the equivalent 1 KT explosion
R = Crater radius
D_1 = Crater depth for the equivalent 1 KT explosion
D = Crater depth
V = Crater volume
OPT HOB = Optimal Height of Burst

Routine 7.0:

$$HOB_1 = \frac{HOB}{3.3Y^{0.3}} \tag{1}$$

For $HOB_1 \geq -4$

$$R_1 = 3.3(k-HOB_1)^{s}\exp\left|-q(k-HOB_1)-t\right| \tag{2}$$

$$D_1 = 3.3(k-HOB_1)^{n}\exp\left|-m(k-HOB_1)-p\right| \tag{3}$$

For $HOB_1 < -4$

$$R_1 = \exp\left\{c\sin\left|\left(a-b\ell n(-HOB_1)\right)^{0.15}\right| - d\right\} \tag{4}$$

$$D_1 = \exp\left\{h\sin\left|\left(f-g\ell n(-HOB_1)\right)^{0.2}\right| - j\right\}^{*} \tag{5}$$

$$R = R_1(Y)^{0.3} \tag{6}$$

$$D = D_1(Y)^{0.3} \tag{7}$$

$$V = \frac{\pi R^2 D}{2} \tag{8}$$

*For a Dry Soil Medium:

$$D_1 = \exp\left\{h\sin\left|\left(f-g\ell n(-HOB_1)\right)^{0.2}\right| - j\right\}: 3 \tag{9}$$

The coefficients for the radius calculation are:

Coefficient	Dry Rock	Wet Rock	Dry Soil	Wet Soil
f	74.2	71.6	56.0	56.0
g	18.4	17.3	13.0	13.0
h	4.47	4.67	5.68	5.68
j	0.0	0.0	0.0	1.0
a	150.0	153.0	117.0	128.3
b	37.0	36.0	25.0	29.0
c	6.02	5.15	5.07	8.35
d	1.0	0.0	0.0	3.0
k	5.5	7.5	11.0	11.0
s	3.6	3.8	6.9	4.3
q	.342	.27	.38	.237
t	1.5	2.7	9.4	4.5
n	3.9	2.1	5.1	2.7
m	0.4	0.08	0.25	0.08
p	2.5	1.5	7.3	3.3

Routine 7.1

This routine uses the false position method to calculate the HOB given R and Y.

$$R_s = \frac{R}{3.3Y^{0.3}} \quad \text{(radius for a 1 KT explosion, in meters)} \tag{10}$$

$$H_{new}(1) = -\frac{r_1H_1 - r_2H_2}{r_1 - r_2} \quad \text{1st Iteration} \tag{11}$$

where:

for $R_s < \alpha$,	for $R_s \geq \alpha$,
$r_1 = \alpha - R_s$	$r_1 = \alpha - R_s$
$r_2 = (\beta - R_s)$	$r_2 = 2(\beta - R_s)$
$H_1 = -5$	$H_1 = \gamma$
$H_2 = 4$	$H_2 = 4$

(12)

(See table below for the coefficients α, β, γ, δ.)

H_1 and H_2 represent scaled depths of burst.

Using $H_{new}(1)$ as HOB_1, R_1 is calculated, using equation (2) for $R_s < \alpha$, and equation (4) for $R_s \geq \alpha$.

For $R_s \geq \alpha$, $r_2 = \frac{1}{2}r_2$. (13)

(This increases the accuracy of the false position routine).

$$R_{new} = \frac{R_1 \left| H_{new}(1) \right|}{3.3} - R_s \qquad (14)$$

for $(R_{new} \times r_1) < 0$	for $(R_{new} \times r_1) \geq 0$
$r_2 = R_{new}$	$r_1 = r_2$
$H_1 = H_{new}(1)$	$H_2 = H_1$
	$r_2 = R_{new}$
	$H_1 = H_{new}(1)$

(15)

Now a second H_{new} can be found using equation 11:

$$H_{new}(2) = \frac{r_1 H_1 - r_2 H_2}{r_1 - r_2} \qquad (16)$$

$$HOB = -3.3 \; H_{new}(2) \; (Y)^{0.3} \qquad (17)$$

The coefficients for the HOB calculation are:

Coefficient	Dry Rock	Wet Rock	Dry Soil	Wet Soil
α[1]	28	32	35	35
β[2]	46	53	49	65
γ[3]	33	40	48	42
δ[4]	0	1	2	6

[1] α is the radius for HOB = -4 meters and Y = 1 KT

[2] Maximum R_1 in meters

[3] Depth of Burst for this Max R_1 in meters

[4] δ = radius for HOB = 5 meters, Y = 1 KT

Routine 7.2

This routine uses the false position method to calculate the yield from a given HOB and radius.

$$R_L = \ell n\left(\frac{R}{3.3}\right) \qquad (18)$$

$$H_m = \frac{HOB}{3.3} \qquad (19)$$

$$Y_{new}(1) = \frac{r_1 Y_1 - r_2 Y_2}{r_1 - r_2} \qquad (20)$$

where:

$$Y_1 = 10.3$$

$$r_2 = \ell nz + 3 + .7\ell n\left(1 - \frac{H_m}{134}\right) - R_L \qquad (21)$$

and

for $H_m > 0$

$$r_1 = R_L \div 2$$

$$Y_2 = \left(\ell n(H_m) - \ell n(4+\text{Medium})\right) \div 3$$

for $H_m \leq 0$

$$r_1 = \left(\ell nz - w + \ell n(-H_m) - R_L\right) \div 2$$

$$Y_2 = \left(\ell n(-H_m) - w\right) \div 3$$

(see below for a table of coefficients w and z)

Now $Y_{new}(1)$ is substituted into equation 1 and then either equation 2 for $HOB_1 \geq -4$ or equation 4 for $HOB_1 < -4$ is calculated to produce a new:

$$R_1\left(\exp\left|Y_{new}(1)\right|\right)$$

$$r_1 = .8r_1 \qquad (22)$$

Now an iterative routine is performed twice:

$$R_{new} = \ell n\left[\frac{R_1\left(\exp\left|Y_{new}(i)\right|\right)}{3.3}\right] - R_L \qquad i = 1 \text{ or } 2 \qquad (23)$$

for $(R_{new} - r_1) < 0$	for $(R_{new} - r_1) \geq 0$
$r_2 = R_{new}$	$r_1 = r_2$
$Y_1 = Y_{new}(i)$	$Y_2 = Y_1$
	$r_2 = R_{new}$
	$Y_1 = Y_{new}(i)$

(24)

$$Y_{new}(i+1) = \frac{r_1 Y_1 - r_2 Y_2}{r_1 - r_2} \quad (25)$$

when i+1 = 3 (2 iterations of equations 23-25)

then $Y = \exp\left|Y_{new}(3)\right|$ (26)

The coefficients for the yield calculation are:

Coefficient	Dry Rock	Wet Rock	Dry Soil	Wet Soil
z^1	16	19	19	25
w	4.05	4.25	4.68	4.42

[1]Radius for HOB = 0, Y = 1

Routine 7.3

The maximum radius R is:

$$R = 3.3\beta(Y)^{0.3} \quad (27)$$

$$OPT.\ HOB = 3.3\gamma(Y)^{0.3} \quad (28)$$

Routine 7.4

The minimum yield Y is:

$$Y = \left[\frac{R}{3.3\beta}\right]^{10/3} \quad (29)$$

$$OPT.\ HOB = 3.3\gamma(Y)^{0.3} \quad (30)$$

where Y is the value from equation 29.

PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
AUTOMATIC	07	Marks limit check error		
LIBRARY MODULE: CROM A-1 (Program 7)	09	Set for depth calculation		

DATA REGISTERS FOR EXAMPLE 7.1

DATA	REG.	COMMENTS
7.1	00	
22.78123789	01	
2.	02	
-.9830327986	03	
2.630196229	04	
.2079703803	05	
0.	06	
0.	07	
0.	08	
0.	09	
10.	10	Y
3.28	11	HOB
4.	12	Soil medium: 1,2,3,4
100.	13	Radius
0.	14	
0.	15	
0.	16	
0.	17	
0.	18	
301.	19	
0.	20	
273308.	21	
11.	22	
0.	23	
-16.78123789	24	
.2079703803	25	
2.630196229	26	
-5.	27	

LABELS

STEP	CODE	KEY	COMMENTS
001	16	A'	Coeff. unpacker
021	42	RTN	Return
024	10	E'	Feet/Meters
031	18	C'	Retrieve HOB coeff.
038	17	B'	Retrieve coeff.
054	15	E	Yield scaling
066	85	=	R or D calc.
124	45	Y<	Y limit checks
132	99	PRT	Y, HOB, M lim.
151	47	CMS	M limit check
161	14	D	R_{max}, OPT HOB
195	66	PAU	Y_{min}, OPT HOB
236	19	D'	R_{max} or OPT HOB
256	11	A	R, D, V calc.
347	12	B	HOB calc.
426	13	C	Yield calc.

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	76	LBL	Label A'.
001	16	A'	Unpacker routine
002	53	(	for coefficients
003	32	INV	Display = Value in dis-
004	28	LOG	play when A' called
005	65	×	Takes
006	53	(	{Fraction $\left[\frac{R23}{10^{R02}}\right]$
007	43	RCL	
008	23	23	$\times 10^{(Display)}$}
009	55	÷	and puts it in the
010	43	RCL	display
011	02	02	
012	22	INV	Takes
013	23	LOG	integer $\left\lvert\frac{R23}{10^{R02}}\right\rvert$
014	75	-	
015	59	INT	
016	42	STO	and puts it in R23
017	23	23	
018	54	)	
019	54	)	
020	76	LBL	Label RTN
021	92	RTN	
022	92	RTN	
023	76	LBL	Label E'.
024	10	E'	
025	03	3	
026	93	.	3.3
027	03	3	
028	95	=	
029	92	RTN	
030	76	LBL	Label C'.
031	18	C'	
032	03	3	
033	08	8	Routine to retrieve
034	05	5	HOB coefficients
035	75	-	
036	08	8	
037	76	LBL	Label B'
038	17	B'	
039	65	×	General
040	43	RCL	coefficient
041	12	12	string routine
042	95	=	
043	42	STO	
044	21	21	
045	36	PGM	Pgm 9
046	09	09	SBR Ind 21 returns
047	71	SBR	with string in the
048	40	IND	display
049	21	21	
050	42	STO	Store string in R23
051	23	23	
052	92	RTN	
053	76	LBL	Label E.
054	15	E	
055	43	RCL	
056	10	10	
057	45	Y^x	$Y^{0.3}$
058	93	.	Scaling factor
059	03	3	
060	94	+/-	$R03=\frac{1}{Y^{0.3}}$
061	65	×	
062	42	STO	
063	03	03	
064	92	RTN	
065	76	LBL	Label =.
066	95	=	
067	04	4	Routine to calculate
068	32	X:T	crater radius
069	03	3	
070	42	STO	See Eq. 1
071	02	02	
072	15	E	$HOB_1=\frac{HOB}{3.3Y^{0.3}}$
073	43	RCL	
074	11	11	
075	94	+/-	
076	55	÷	
077	10	E'	
078	42	STO	$R05 = -HOB_1$
079	05	05	
080	77	GE	
081	05	05	If $-HOB_1 \geq 4$,
082	01	01	go to 501
083	69	DP	Calculation of CR for
084	32	32	$-HOB_1 > 4$
085	03	3	
086	05	5	
087	01	1	
088	75	-	Get coefficient
089	02	2	string
090	02	0	
091	17	B'	Store it in R23
092	43	RCL	
093	22	22	K

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
094	85	+	+
095	43	RCL	$-HOB_1$
096	05	05	
097	95	=	=
098	65	×	
099	32	X:T	
100	00	0	
101	77	GE	
102	01	01	
103	19	19	
104	16	A'	Recall q or m
105	94	+/-	
106	75	-	
107	01	1	
108	16	A'	Recall t or p
109	95	=	
110	22	INV	
111	23	LNX	
112	65	×	
113	32	X:T	
114	45	Y×	
115	01	1	
116	16	A'	Recall s or n
117	65	×	
118	10	E'	
119	95	=	
120	42	STO	
121	04	04	Store R_1 or D_1 in R04
122	92	RTN	
123	76	LBL	Label Y^X.
124	45	Y×	
125	93	.	Check and print Yield
126	01	1	
127	36	PGM	
128	09	09	
129	17	B'	
130	92	RTN	
131	76	LBL	Label PRT.
132	99	PRT	
133	71	SBR	Call yield
134	45	Y×	check
135	02	2	HOB
136	00	0	
137	55	÷	Limit check
138	15	E	and print
139	32	X:T	routine
140	01	1	

STEP	CODE	KEY	COMMENTS
141	00	0	
142	94	+/-	
143	85	+	
144	02	2	"H"
145	03	3	
146	32	X:T	
147	36	PGM	
148	09	09	
149	13	C	
150	76	LBL	Label CMS
151	47	CMS	
152	03	3	"M"
153	00	0	
154	32	X:T	Check and print
155	04	4	medium number
156	36	PGM	
157	09	09	
158	16	A'	
159	92	RTN	
160	76	LBL	Label D.
161	14	D	Calculation of R_{max} and OPT HOB.
162	71	SBR	Check and print
163	45	Y×	yield
164	69	OP	
165	22	22	
166	71	SBR	Check and print medium
167	47	CMS	
168	97	IFF	If flag 7 set, go to
169	07	07	Label RTN
170	92	RTN	
171	99	ADV	
172	16	C'	Recall HOB
173	02	2	coefficients
174	42	STO	
175	02	02	
176	16	A'	
177	86	STF	See Eq. 27
178	07	07	
179	16	D'	Calculation of R_{max}
180	32	X:T	
181	03	3	"R"
182	05	5	
183	32	X:T	
184	36	PGM	Print radius
185	09	09	
186	12	B	
187	42	STO	R13=R

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
188	13	13	
189	02	2	
190	03	3	
191	04	4	
192	05	5	
193	06	GTO	Go to D' to calculate OPT HOB
194	14	D'	
195	76	LBL	Label PAU.
196	66	PAU	Calculation of Y_{min} and OPT HOB
197	02	2	
198	44	SUM	
199	02	02	
200	71	SBR	Check and print medium
201	67	CMS	
202	03	3	"R"
203	05	5	Print radius
204	36	PGM	
205	09	09	
206	13	C'	
207	87	IFF	If flag 7 set, go to Label RTN
208	07	07	
209	92	RTN	
210	18	C'	
211	02	2	
212	42	STO	Calculation of minimum yield
213	02	02	
214	16	A'	
215	43	RCL	See Eq. 29
216	13	13	
217	55	÷	
218	02	2	
219	16	A'	
220	55	÷	
221	10	E'	
222	22	INV	
223	45	Y^x	
224	04	4	"Y"
225	05	5	
226	32	X↔T	
227	43	RCL	
228	03	3	
229	95	=	
230	98	ADV	
231	36	PGM	Print
232	09	09	Yield
233	12	B	R10=Y
234	42	STO	
235	10	10	

STEP	CODE	KEY	COMMENTS
235	76	LBL	Label D'
236	14	D'	
237	02	2	
238	16	A'	Calculation of OPT
239	55	÷	HOB or max R.
240	02	2	See Eq. 28 or 30
241	03	3	
242	32	X↔T	
243	15	E	
244	10	E'	
245	87	IFF	
246	07	07	
247	92	RTN	
248	94	+/-	Print OPT HOB
249	36	PGM	
250	09	09	
251	12	B	
252	42	STO	
253	11	11	R11 = OPT HOB
254	92	RTN	
255	76	LBL	Label A.
256	11	A	Calculation of P, D & V
257	71	SBR	Call Y, HOB, M
258	99	PRT	
259	87	IFF	
260	07	07	If Flag 7 set,
261	92	RTN	go to RTN
262	98	ADV	
263	71	SBR	Call
264	95	=	radius calculation
265	79	R/S	Return with R_1 in R04
266	03	3	"R"
267	05	5	
268	32	X↔T	Print crater radius
269	36	PGM	
270	09	09	
271	12	B	
272	42	STO	
273	13	13	
274	86	STF	Set Flag 9
275	09	09	
276	04	4	Prepare for depth
277	01	1	calculation
278	07	7	
279	65	×	
280	43	RCL	
281	02	02	Get proper address to

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
282	75	-	calculate depth
283	07	7	
284	04	4	
285	03	2	
286	95	=	
287	48	EXC	Put address in R01
288	01	01	
289	42	STO	
290	23	23	
291	02	2	Go to depth calculation
292	71	SBR	
293	40	IND	
294	21	21	
295	43	RCL	Return with D in R04
296	12	12	
297	65	×	
298	43	RCL	If special case of
299	02	02	Eq. 9, then
300	95	=	
301	34	FX	
302	32	X↑T	$R_1 = \frac{R_1}{3}$
303	03	3	
304	22	INV	
305	87	EQ	
306	03	03	
307	10	10	
308	43	RCL	
309	03	03	Put R in t reg
310	79	X	
311	22	INV	
312	86	STF	Remove flag 9
313	09	09	
314	01	1	"D"
315	06	6	
316	32	X↑T	Print depth
317	36	PGM	
318	09	09	
319	12	B	
320	65	×	Calculate volume
321	43	RCL	
322	13	13	
323	33	X²	See Eq. 8
324	65	×	
325	89	π	
326	55	÷	
327	02	2	Set up volume such
328	95	=	that pressing x̄ puts

STEP	CODE	KEY	COMMENTS
329	52	EE	volume in display
330	59	FIX	(truncate volume
331	03	03	to 3 decimal places)
332	52	EE	
333	58	FIX	
334	09	09	
335	42	STO	
336	01	01	
337	01	1	
338	48	EXC	
339	03	03	
340	22	INV	
341	49	PRD	
342	04	04	
343	43	RCL	Recall R
344	13	13	
345	32	RTN	
346	76	LBL	Label B.
347	12	B	Calculation of HOB in-
348	71	SBR	sion. Check and print Yield
349	45	YX	
350	00	OP	
351	32	22	
352	71	SBR	Check and print medium
353	47	CMS	
354	18	C'	Call string of coeffi-
355	04	4	cients
356	42	STO	
357	27	27	R27 = H_2 = 4
358	02	2	
359	42	STO	Recall α
360	02	02	
361	16	A'	
362	42	STO	
363	24	24	R24 = r_1 = α
364	02	2	
365	16	A'	
366	42	STO	R26 = r_2 = β
367	26	26	
368	55	÷	See Eq. 12
369	15	E	
370	10	E'	
371	32	X↑T	Check limits
372	00	0	and print
373	85	+	radius
374	43	RCL	
375	13	13	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
376	32	X:T	
377	65	×	
378	03	3	"R"
379	05	5	
380	36	PGM	
381	09	09	
382	11	A	
383	87	IFF	If flag 7 set, go to
384	07	07	Label RTN
385	92	RTN	
386	48	ADV	
387	32	X:T	
388	15	E	$Y^{-0.3}$
389	43	RCL	
390	24	24	
391	32	X:T	$R_S=\left\lvert\frac{(R)}{3.3Y^{0.3}}\right\rvert$
392	55	÷	
393	10	E'	
394	42	STO	STO 01
395	01	01	If
396	77	GE	$R_S \geq \alpha$
397	06	06	
398	66	66	Go to Step 666
399	94	+/-	
400	42	STO	$r_2=-R_S$
401	26	26	
402	44	SUM	$\alpha-R_S=R24$
403	24	24	
404	00	0	
405	16	A'	
406	43	RCL	
407	23	23	$r_2=-R_S+\delta$
408	44	SUM	
409	26	26	
410	05	5	
411	94	+/-	$R25=H_1=-5$
412	42	STO	
413	25	25	
414	71	SBR	
415	07	07	$H_{new}=\frac{r_1H_1-r_2H_2}{r_1-r_2}$
416	47	47	
417	42	STO	
418	05	05	$R05=H_{new}$
419	71	SBR	Calculation of
420	00	00	Eq. 12
421	85	85	to get
422	61	GTO	$R_1\{H_{new}\}$
423	06	06	Go to 690
424	90	90	
425	76	LBL	Label C.
426	13	C	Calculation of Yield
427	43	RCL	inversion
428	13	13	See Eq. 18
429	55	÷	Calculation
430	10	E'	of R_L
431	23	LNX	See Eq. 18
432	42	STO	$R01=R_L$
433	01	01	
434	69	OP	
435	22	22	
436	03	3	
437	00	0	Limit check for HOB
438	00	0	and medium
439	65	×	
440	71	SBR	
441	01	01	See Eq. 19
442	39	39	
443	43	RCL	$H_m=\frac{HOB}{3.3}$
444	11	11	
445	55	÷	
446	10	E'	
447	42	STO	$R28=H_m$
448	28	28	
449	03	3	
450	07	7	
451	08	8	
452	85	+	
453	06	6	Get coefficient
454	17	B'	string from Pgm 9
455	55	÷	
456	01	1	
457	52	EE	
458	03	3	
459	75	-	
460	59	INT	
461	23	LNX	
462	42	STO	
463	24	24	$R24=r_1=$ Onz
464	42	STO	
465	26	26	$R26=r_2=$ Onz
466	22	INV	
467	23	LNX	
468	95	=	
469	65	×	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
470	01	1	
471	00	0	
472	42	STO	R25=Y_1=10
473	25	25	
474	94	+/-	-W
475	85	+	
476	43	RCL	
477	28	28	
478	94	+/-	
479	29	CP	If $-H_m \geq 0$
480	77	GE	
481	05	05	Go to 551
482	51	51	
483	25	CLR	
484	42	STO	R24=r_1=0
485	24	24	
486	43	RCL	
487	28	28	
488	23	LNX	
489	75	-	
490	53	(	$\phi = \ell n(H_m) - \ell n\left(4+\frac{\text{Medium}}{\text{No.}}\right)$
491	04	4	
492	85	+	
493	43	RCL	
494	12	12	
495	54	)	
496	23	LNX	
497	95	=	
498	61	GTO	Go to step 559
499	05	05	
500	59	59	
501	01	1	Calculation of Radius or Depth for $-HOB \geq 4$
502	06	6	
503	05	5	
504	85	+	
505	02	2	See Eqs. 4 and 5
506	02	2	
507	17	B'	Get coefficient string
508	03	3	Recall
509	16	A'	a or f
510	75	-	
511	02	2	Recall
512	16	A'	b or g
513	65	×	
514	43	RCL	$-HOB_1$
515	05	05	
516	23	LNX	
517	95	=	
518	29	CP	
519	77	GE	If
520	05	05	$a-b \cdot \ell n(-HOB_1)$
521	26	26	is < 0
522	00	0	
523	42	STO	R04 = 0 = R_1 or D_1
524	04	04	
525	92	RTN	RTN
526	45	YX	
527	93	.	
528	02	2	
529	87	IFF	Flag 9 set when depth
530	09	09	calculated
531	05	05	
532	36	36	
533	93	.	
534	01	1	
535	05	5	
536	95	=	
537	70	RAD	
538	38	SIN	
539	65	×	
540	01	1	Recall
541	16	A'	c or n
542	75	-	
543	03	3	Recall
544	16	A'	d or j
545	95	=	
546	22	INV	
547	23	LNX	
548	42	STO	Store R_1 or D_1
549	04	04	in R04
550	92	RTN	
551	23	LNX	Continuation of yield inversion
552	95	=	
553	44	SUM	R24=$\ell n z$
554	24	24	
555	32	X:T	$+[-w+\ell n(-H_m)]$
556	43	RCL	See Eq. 21
557	24	24	
558	32	X:T	
559	55	÷	
560	93	.	
561	03	3	
562	44	SUM	R25=Y_1=10.3
563	25	25	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
564	95	=	
565	42	STO	$R27=Y_2$
566	27	27	
567	43	RCL	$Y_2=\phi:.3$
568	28	28	for $-Hm < 0$ or
569	55	÷	$Y_2=\frac{[-w+\ell n(-H_m)]}{.3}$
570	01	1	
571	03	3	for $-H_m \geq 0$
572	04	4	
573	75	-	
574	01	1	
575	95	=	
576	23	LNX	
577	65	×	
578	93	.	$R26=\ell nz+3+.7\left\lvert \ell n\left(\frac{H_m}{134}-1\right)\right\rvert$
579	07	7	
580	85	+	
581	03	3	
582	95	=	
583	44	SUM	
584	26	26	
585	43	RCL	Limit check and print radius
586	13	13	
587	32	X:T	
588	22	INV	
589	23	LNX	
590	65	×	
591	03	3	
592	93	.	
593	07	7	
594	85	+	
595	43	RCL	
596	26	26	
597	22	INV	
598	23	LNX	
599	65	×	
600	04	4	
601	65	×	
602	03	3	"R"
603	05	5	
604	36	PGM	
605	09	09	
606	11	A	
607	87	IFF	If flag 7 set,
608	07	07	go to Label RTN
609	92	RTN	
610	71	SBR	

STEP	CODE	KEY	COMMENTS
611	07	07	$R26=R26-R_L$
612	08	08	
613	93	.	Calculation of R_{new}
614	05	5	and Y_{new}
615	49	PRD	$R24=\frac{R24-R_L}{2}$
616	24	24	
617	71	SBR	
618	07	07	
619	47	47	$Y_{new(1)}=\frac{r_1Y_1-r_2Y_2}{r_1-r_2}$
620	22	INV	
621	23	LNX	
622	42	STO	$R10=\exp(Y_{new(1)})$
623	10	10	
624	93	.	
625	08	8	See Eq. 21
626	49	PRD	R24 = .8(R24)
627	24	24	1st time through set
628	22	INV	flag 7 (i=1)
629	23	LNX	2nd time through reset
630	86	STF	flag 7 (i=2)
631	07	07	
632	71	SBR	Use equations 2 or 4
633	95	=	to calculation a new
634	43	RCL	R_1 $Y_{new(i)}$
635	10	10	
636	23	LNX	
637	42	STO	
638	05	05	$R05=Y_{new(i)}$
639	79	-	
640	32	X:T	
641	55	-	
642	10	E'	$\ell n\left\lvert\frac{R_1 Y_{new(i)}}{3.3}\right\rvert$
643	23	LNX	
644	71	SBR	Calculation
645	07	07	of new
646	16	16	$Y_{new(i)}$
647	22	INV	
648	23	LNX	
649	42	STO	$R10=Y_{new(i)}$
650	10	10	
651	87	IFF	
652	07	07	If flag 7 is set
653	06	06	go to 629
654	29	29	
655	98	ADV	
656	32	X:T	
657	04	4	Print calculated

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
658	05	5	
659	32	X:T	Yield value
660	36	PGM	
661	09	09	
662	12	B	
663	42	STO	
664	10	10	
665	92	RTN	
666	02	2	
667	16	A'	Recall γ Continuation of HOB inversion
668	42	STO	
669	25	25	R25=γ
670	71	SBR	
671	07	07	R24=α-R_S
672	08	08	
673	02	2	R26=β-R_S
674	49	PRD	
675	26	26	R26=2(β-R_S)
676	71	SBR	
677	07	07	$H_{new}=\frac{r_1H_1-r_2H_2}{r_1-r_2}$
678	47	47	
679	42	STO	
680	05	05	R05=H_N
681	02	2	
682	22	INV	
683	49	PRD	$R24=\frac{\alpha-R_S}{2}$
684	24	24	
685	69	OP	
686	22	22	R02=R02+1
687	71	SBR	See Eq. 4
688	05	05	$R_1\{H_{new}\}$
689	01	01	
690	55	÷	$R_1\{H_{new}\}$
691	10	E'	
692	71	SBR	Set new values
693	07	07	
694	16	16	
695	55	÷	
696	02	2	
697	03	3	"H"
698	32	X:T	
699	15	E	Finished calculation
700	10	E'	Print and
701	94	+/-	store HOB
702	36	PGM	
703	09	09	
704	12	B	

STEP	CODE	KEY	COMMENTS
705	42	STO	
706	11	11	
707	92	RTN	
708	43	RCL	
709	01	01	
710	94	+/-	
711	44	SUM	R24=R24-R01
712	24	24	
713	44	SUM	R26=R26-R01
714	26	26	
715	92	RTN	
716	75	-	False position
717	43	RCL	routine to set
718	01	01	new iterative values
719	95	=	
720	42	STO	
721	04	04	
722	65	×	
723	43	RCL	
724	24	24	
725	95	=	
726	69	OP	
727	22	INV	
728	77	GE	
729	07	07	
730	39	39	
731	43	RCL	
732	26	26	
733	42	STO	
734	24	24	
735	43	RCL	
736	25	25	
737	42	STO	
738	27	27	
739	43	RCL	
740	04	04	
741	42	STO	
742	26	26	
743	43	RCL	
744	05	05	
745	42	STO	
746	25	25	
747	43	RCL	False position
748	24	24	calculation of new
749	65	×	intermediate value
750	43	RCL	$\frac{(R24)(R25)-(R26)(R27)}{(R24-R26)}$
751	25	25	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS	STEP	CODE	KEY	COMMENTS
752	75	-					
753	43	RCL					
754	27	27					
755	65	×					
756	43	RCL					
757	26	26					
758	95	=					
759	55	÷					
760	53	(					
761	43	RCL					
762	24	24					
763	75	-					
764	43	RCL					
765	26	26					
766	95	=					
767	92	RTN	NOTE: Overflow from this program is in Pgm 9, step 187 et seq., located at page 1-17.				

Appendix A: CROM A1 Demonstration

1	DNA AP-550 CONTROL A1 HTI			2
DEMONSTRATION PROGRAM (RST, R/S)				
SOIL MEDIUM	WEAPON RADIUS	OFFSET	SKIP	→ START
YIELD	HOB	VN, K	ENVIRONMENT	PROBABILITY

SOURCE OF DATA:

Defense Intelligence Agency, Physical Vulnerability Handbook-Nuclear Weapons (U), AP-550-2-2-69-INT, June 1, 1969, Part IV.

DESCRIPTION:

A. Objective

The objective of this magnetic card auxiliary program is to provide a quick demonstration of the AP-550 CROM A1's calculational capabilities. The PC-100 printer must be attached for execution of this program. After program initiation, the five representative calculations given below are performed consecutively without pause.

1. Probability of damage and weapon radius to a circular normal P-target at the optimum height of burst, or if the user inputs a height of burst, probability of damage and weapon radius at a given height of burst; or the probability of damage to a circular uniform target if the user inputs a weapon radius.
2. Weapon radius for personnel targets at a specified height of burst.
3. Minimum Safe Distance for troops or, if an offset is provided, probability of not exceeding the acceptable weapons effects.
4. Crater radius at the optimum height of burst.
5. Weapon radius and probability of damage - ETA, crater radius method.

B. Inputs-Outputs

This program may be executed without entering any of the input data (see example). If the user chooses this option, the default values listed

in Table 4 will be used. These values can be changed by entering data in the appropriate override keys also listed in Table 4.

C. Limits

Limits can be found in the descriptions of the programs run.

D. Special Features

Up to two calculations can be skipped by entering their numbers on key 2nd D'. Numbers can be entered in any order. The numbering scheme is one through five, with one being the first calculation run, five the last.

Table 4. List of default values and override keys.

Input	Used in Calculations	Alpha-numeric	Default Value	Stored in Register	Override Key
Yield	1,2,3,4,5	Y	30 KT	10	Key A
Height of burst	1	H	Optimum	__*	Key B *
Vulnerability number	1	V	16	30	Key C +
k-factor	1	K	3	31	Key C +
Circular error probable	1,2,3,5	C	800	32	None
Target radius	1	T	2000	33	None
Offset (for P-target damage prob.)	1	X	800	34	None
Damage sigma	1	S	.2	35	None
Weapon radius	1	W	None	__*	Key 2nd B'*
Environment number	2	E	8	36	Key D
Height of burst	2,3	H	1600	37	None
Probable error in height	3	PH	20	38	None
Troop disposition	3	D	2	39	None
Troop vulnerability	3	V	2	40	None
Acceptable risk	3	R	3	41	None
Desired assurance	3	P	.95	42	Key E
Offset (for troop safety prob.)	3	X	None	__*	Key 2nd C' *
Soil medium	4,5	M	1	43	Key 2nd A'
Height of burst (for cratering damage prob.)	5	H	0	44	None
Length crater radius mult.	5	LC	2	45	None
Width crater radius mult.	5	WC	1.5	46	None
Length	5	L	800	47	None
Width	5	W	200	48	None
Aim point	5	A	1	49	None

* See next page for footnotes

* Keys B, 2nd B', and 2nd C' change the calculations performed as follows. A height of burst entered on key B will cause the weapon radius for the first calculation to be calculated at this height of burst rather than the optimum height of burst. A weapon radius entered on key 2nd B' will cause the weapon radius calculation to be bypassed in the first calculation. An offset entered on key 2nd C' will cause the probability of not exceeding acceptable weapon effects to be calculated rather than the minimum safe distance.

+ VN and k must both be entered, VN first, k second, both using key C.

EXAMPLE #1:

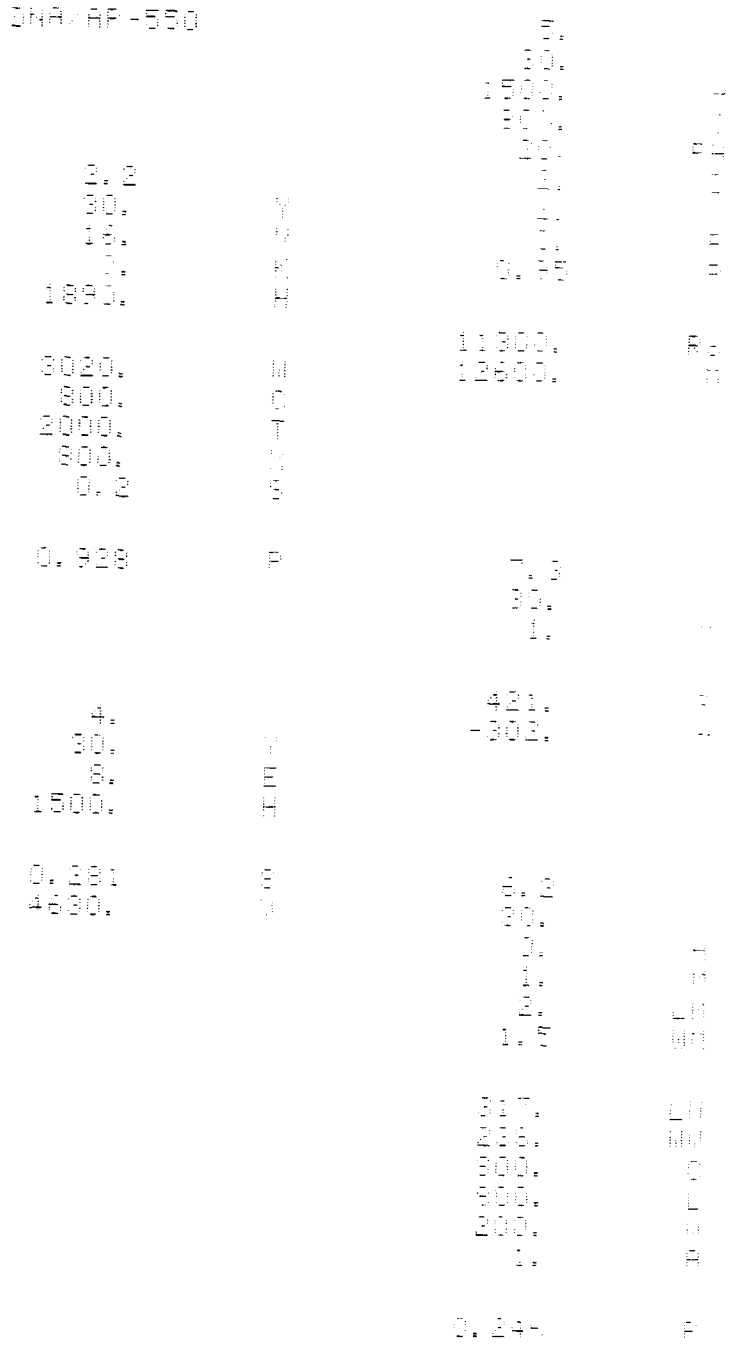
(a) Run the entire demonstration program using the default values.

(b) Run the demonstration program using a height of burst of 300 feet for the first calculation. Omit the fourth calculation.

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off, then on			0.	
2	Read sides 1 and 2 of card			1.,2.	
3	Initialize program (stores default values)		RST R/S	0.	
4	Run demonstration		2nd E'		see printer output (a)
5	Enter new height of burst (feet). This input overrides the optimum height of burst calculation in the 1st calculation.	300	B	300.	
6	Omit the fourth calculation. Two calculations may be skipped. Both should be entered using 2nd D'.	4	2nd D'	4.	
7	Run demonstration		2nd E'		see printer output (b)

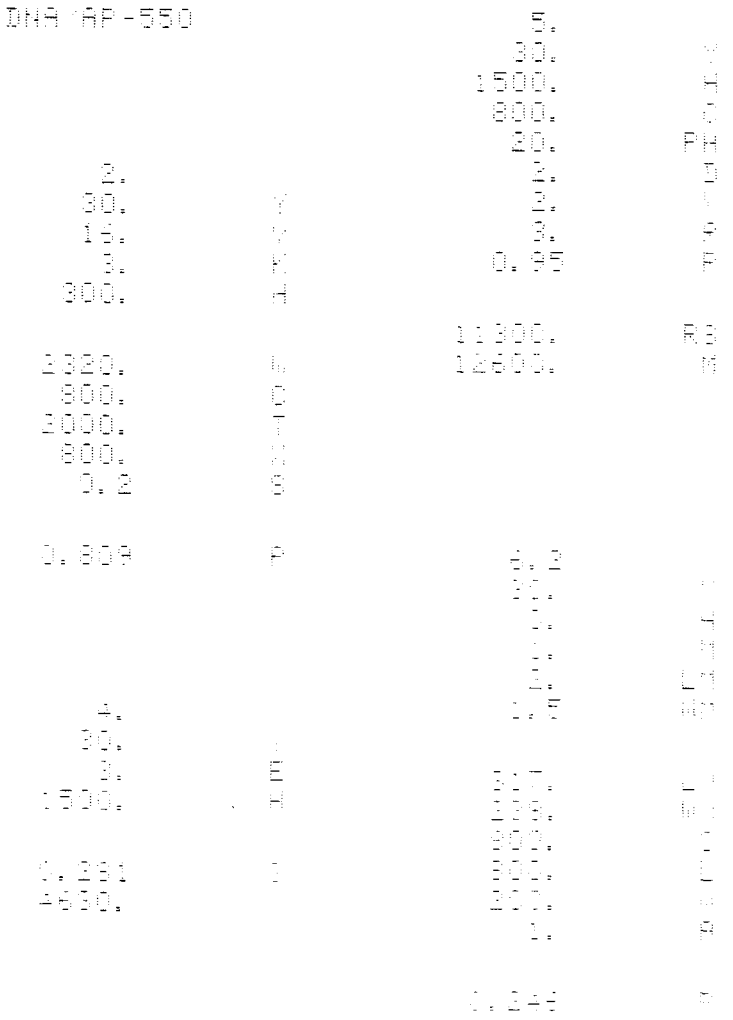
PRINTER OUTPUT FOR EXAMPLE 1:

(a)



PRINTER OUTPUT FOR EXAMPLE 1:

(b)



PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
479:59 AUTOMATIC LIBRARY MODULE CROM A-1	0, 1, 2, 7, 9 1	Used by CROM. Suppresses CROM's printing.	3 4 5	Used by control program to demonstrate different capabilities of the CROM.

DATA REGISTERS FOR EXAMPLE 1

DATA	REG.	COMMENTS
7.3	00	Calc. # — Registers 00 through 29 are used by the CROM. Only those registers used in the control program are noted here.
0.31	01	
19.	02	print pointer
[illegible]	03	
51.7381[illegible]	04	
0.	05	
0.	06	
0.	07	
0.	08	
0.	09	
10.	10	y
0.	11	HOB
1.	12	W, E, C, M
2.	13	VN, RS, LM
1.5	14	k, PEH, WM
500.	15	C, D
600.	16	T, V, L
100.	17	X, R, W
1.	18	S, P, A
1500.	19	X
1.0035[illegible]13	20	
192540.	21	
5.5	22	
0.	23	
1.346071652	24	
[illegible]	25	
316.12[illegible]14	26	
17.7[illegible]85	27	
375.1[illegible]19	28	
[illegible]08	29	
16.	30	VN number
3.	31	k factor
800.	32	CEP
2000.	33	Target radius
810.	34	Offset
0.2	35	Damage Sigma
8.	36	Environment
1700.	37	HOB
20.	38	PEH
2.	39	Troop disposition

LABELS

STEP	CODE	KEY	COMMENTS
[illegible]	[illegible]	[illegible]	Initializes
017	[illegible]	[illegible]	Advances
026	41	[illegible]	Optional calculations
037	42	[illegible]	
050	11	A	Stores Y
055	12	B	" HOB
062	13	C	" VN, k
071	14	D	" Env.
076	15	E	" Prob.
081	16	A'	" Soil
086	17	B'	" WR
093	18	C'	" Offset
100	19	D'	" Skip
105	65		Optional
137	35	[illegible]	Stores defaults
225	10	E'	Starts demo
240	47	CMS	Calc. #2
319	24	CE	#3
371	60	DEG	#4
394	70	RAD	#5

DATA	REG.	COMMENTS
[illegible]	40	Troop vulnerability
[illegible]	41	Acceptable risk
[illegible]	42	Desired assurance
[illegible]	43	Soil medium
[illegible]	44	HOB for ETA cratering method
[illegible]	45	Length crater radius multiplier
[illegible]	46	Width crater radius multiplier
[illegible]	47	Length
[illegible]	48	Width
[illegible]	49	Aim point
[illegible]	50	HOB for weapon radius and prob.
[illegible]	51	Weapon radius
[illegible]	52	Offset for troop safety
[illegible]	53	Omit calculation
[illegible]	54	Omit calculation
[illegible]	55	
[illegible]	56	
[illegible]	57	
[illegible]	58	
[illegible]	59	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	61	GTO	Go to 1/x
001	35	1/x	
002	76	LBL	Label CLR.
003	25	CLP	
004	25	CLP	Resets two flags
005	22	INV	used by the CROM,
006	57	ENG	stores 10 in R02
007	22	INV	for the CROM print
008	86	STF	routine.
009	01	01	
010	22	INV	
011	86	STF	
012	07	07	
013	22	INV	
014	58	FIX	
015	01	1	
016	00	0	
017	42	STO	
018	02	02	
019	76	LBL	Label ADV.
020	48	ADV	Moves paper ahead
021	48	ADV	three lines.
022	48	ADV	
023	48	ADV	
024	80	RTN	
025	76	LBL	Label RCL.
026	41	RCL	Calls the CROM weapon
027	02	2	radius and probability
028	48	ADV	of damage calculations
029	42	STO	with a user-specified
030	00	00	HOB.
031	36	PGM	
032	03	03	
033	11	A	
034	61	GTO	
035	47	CMS	
036	76	LBL	Label STO.
037	42	STO	
038	00	0	Calls the CROM
039	48	ADV	probability of damage
040	02	2	calculation with a
041	80	RTN	user-specified weapon
042	11	A	radius
043	76	LBL	
044	76	LBL	Label A.
045	11	A	
046	42	STO	Stores the yield
047	10	10	
048	80	RTN	
049	76	LBL	Label B.
050	12	B	
051	42	STO	Store a HOB for the
052	50	50	weapon radius calcu-
053	86	STF	lation.
054	03	03	
055	80	RTN	Sets flag 3
056	76	LBL	Label C.
057	13	C	
058	48	EXC	Stores VN and k
059	31	31	
060	42	STO	
061	30	30	
062	43	RCL	
063	31	31	
064	80	RTN	
065	76	LBL	Label D.
066	14	D	
067	42	STO	Stores environment
068	33	33	
069	80	RTN	
070	76	LBL	Label E.
071	15	E	
072	42	STO	Stores probability
073	34	34	
074	80	RTN	
075	76	LBL	Label A'.
076	16	A'	
077	42	STO	Stores soil medium
078	35	35	
079	80	RTN	
080	76	LBL	Label B'.
081	17	B'	
082	42	STO	Stores weapon radius
083	36	36	for damage probability
084	80	RTN	calculation
085	03	03	Sets flag 4
086	76	LBL	Label C'.
087	18	C'	
088	42	STO	Stores offset for
089	37	37	probability of

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
096	86	STF	troop safety calculation
097	05	05	Sets flag 5
098	92	RTN	
099	76	LBL	Label D'.
100	19	D'	
101	48	EXC	Stores two numbers for
102	54	54	omitting calculations.
103	42	STO	
104	53	53	
105	43	RCL	
106	54	54	
107	92	RTN	
108	76	LBL	Label X.
109	65	×	
110	86	STF	Given a user-specified
111	01	01	offset calls the CROM
112	01	1	radius of safety calc-
113	00	0	ulation, then the CROM
114	42	STO	probability of not
115	02	02	exceeding the accepta-
116	36	PGM	ble risk calculation.
117	05	05	
118	11	A	
119	71	SBR	
120	25	CLR	
121	43	RCL	
122	52	52	
123	42	STO	
124	19	19	
125	05	5	
126	83	.	
127	01	1	
128	42	STO	
129	00	00	
130	99	PRT	
131	36	PGM	
132	05	05	
133	12	B	
134	61	GTO	
135	60	DEG	
136	76	LBL	Label 1/x .
137	35	1/x	
138	25	CLR	Clears pending opera-
139	03	3	tions
140	00	0	Stores 30 as the default
141	42	STO	yield,
142	10	10	16 as the default
143	01	1	VN,

STEP	CODE	KEY	COMMENTS
144	06	6	
145	42	STO	
146	30	30	
147	03	3	3 as the k-factor and
148	42	STO	the acceptable risk
149	31	31	level,
150	42	STO	
151	41	41	
152	08	8	800 as the CEP, the
153	00	0	offset (for P-target
154	00	0	damage probability),
155	42	STO	and the length (for
156	32	32	the ETA cratering
157	42	STO	probability),
158	34	34	
159	42	STO	
160	47	47	
161	01	1	1500 as the HOB
162	05	5	(for weapon radius
163	00	0	against personnel
164	00	0	targets and radius
165	42	STO	of safety),
166	37	37	
167	02	2	200 as the width (for
168	00	0	the ETA cratering
169	00	0	probability),
170	42	STO	
171	48	48	
172	02	2	
173	52	EE	2000 as the target
174	03	3	radius,
175	42	STO	
176	33	33	
177	83	.	0.2 as the damage
178	02	2	sigma,
179	42	STO	
180	39	39	
181	08	8	8 as the environment
182	42	STO	number,
183	45	Y^x	
184	02	2	20 as the probable
185	00	0	error in height,
186	42	STO	
187	49	49	
188	02	2	2 as the troop dis-
189	42	STO	position, troop vul-
190	38	38	nerability, and length
191	42	STO	crater radius

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
192	40	40	multiplier,
193	42	STO	
194	45	45	
195	93	.	0.95 as the desired assurance,
196	09	9	
197	05	5	
198	42	STO	
199	42	42	
200	01	1	1 as the soil medium and aim point,
201	42	STO	
202	43	43	
203	42	STO	
204	49	49	
205	01	1	1.5 as the width crater radius multiplier.
206	93	.	
207	05	5	
208	42	STO	
209	46	46	
210	25	CLR	
211	42	STO	Zeros the registers for the optional inputs and the calculation skip numbers
212	50	50	
213	42	STO	
214	51	51	
215	42	STO	
216	52	52	
217	42	STO	
218	53	53	
219	42	STO	
220	54	54	Stores 0 for the HOB for cratering
221	42	STO	
222	44	44	
223	[illegible]	[illegible]	
224	76	LBL	Label E'
225	10	E'	
226	[illegible]	[illegible]	Initializes
227	[illegible]	[illegible]	
228	[illegible]	[illegible]	Prints DNA/AP-550
229	[illegible]	[illegible]	
230	[illegible]	[illegible]	
231	[illegible]	[illegible]	
232	[illegible]	[illegible]	
233	[illegible]	[illegible]	Sees if the first calculation should be omitted by comparing 1 with the contents of R53 and R54
234	[illegible]	RCL	
235	[illegible]	[illegible]	
236	[illegible]	[illegible]	
237	47	CMS	
238	43	RCL	
239	54	54	

STEP	CODE	KEY	COMMENTS
240	67	EQ	
241	47	CMS	
242	43	RCL	Stores HOB for the user-selected HOB option
243	50	50	
244	42	STO	
245	11	11	
246	43	RCL	Stores weapon radius for the user-selected WR option
247	51	51	
248	42	STO	
249	12	12	
250	43	RCL	
251	30	30	Stores VN
252	42	STO	
253	13	13	
254	43	RCL	
255	31	31	Stores k-factor
256	42	STO	
257	14	14	
258	43	RCL	
259	32	32	Stores CEP
260	42	STO	
261	15	15	
262	43	RCL	
263	33	33	Stores target radius
264	42	STO	
265	16	16	
266	43	RCL	
267	34	34	Stores offset
268	42	STO	
269	17	17	
270	43	RCL	
271	35	35	
272	42	STO	Stores damage sigma
273	18	18	
274	87	IFF	If the user input a weapon radius go directly to the probability calculation. If the user input an HOB use that rather than the OHOB. Otherwise run the weapon radius and probability program at the OHOB.
275	04	04	
276	42	STO	
277	87	IFF	
278	[illegible]	[illegible]	
279	43	RCL	
280	[illegible]	[illegible]	
281	[illegible]	[illegible]	
282	[illegible]	[illegible]	
283	[illegible]	[illegible]	
284	[illegible]	[illegible]	
285	[illegible]	[illegible]	
286	36	PGM	
287	02	02	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
288	13	C	
289	76	LBL	Label CMs.
290	47	CMS	
291	02	2	
292	32	X≠T	Sees if the second calculation should be omitted
293	43	RCL	
294	53	53	
295	67	EQ	
296	34	DE	
297	43	RCL	
298	54	54	
299	67	EQ	
300	24	CE	
301	71	SBR	Initializes
302	25	CLR	
303	43	RCL	Stores HOB
304	31	31	
305	42	STO	
306	11	11	
307	43	RCL	Stores environment
308	36	36	
309	42	STO	
310	12	12	
311	04	4	
312	42	STO	
313	00	00	Runs weapon radius calculation
314	69	PRT	
315	36	PGM	
316	04	04	
317	[illegible]	[illegible]	
318	[illegible]	LBL	Label CE.
319	24	CE	
320	03	3	Sees if the third calculation should be omitted
321	43	RCL	
322	51	51	
323	67	EQ	
324	[illegible]	[illegible]	
325	[illegible]	[illegible]	
326	[illegible]	[illegible]	
327	[illegible]	[illegible]	
328	[illegible]	[illegible]	
329	[illegible]	[illegible]	
330	[illegible]	[illegible]	Stores CEP
331	[illegible]	[illegible]	
332	12	12	
333	43	RCL	
334	38	38	

STEP	CODE	KEY	COMMENTS
335	42	STO	PEH
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
340	42	STO	Troop disposition
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
344	42	STO	Troop vulnerability
345	16	16	
346	43	RCL	
347	41	41	
348	42	STO	Acceptable risk
349	17	17	
350	43	RCL	
351	42	42	
352	42	STO	
353	18	18	Desired assurance
354	43	RCL	
[illegible]	[illegible]	[illegible]	
357	42	STO	HOB
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	If the user input an offset do a probability calculation
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	SBR	Initializes
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	Runs minimum safe distance calculation
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	LBL	Label DEG.
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	Sees if the fourth calculation should be omitted
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	RCL	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
380	70	RHI	
381	71	SBR	
382	25	CLR	Initializes

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
394	43	RCL	
395	43	43	
396	42	STO	Stores soil medium
397	12	12	
398	43	RCL	
399	43	43	
400	42	STO	Runs cratering calcu- lation
401	00	00	
402	48	PRT	
403	36	PGM	
404	07	07	
405	14	D	
406	76	LBL	Label RAD.
407	70	RAD	
408	05	5	Sees if fifth calcula- tion should be omitted
409	32	X≠T	
410	43	RCL	
411	53	53	
412	67	EQ	
413	98	ADV	
414	43	RCL	
415	54	54	
416	67	EQ	
417	98	ADV	
418	71	SBR	
419	25	CLR	Initializes
420	43	RCL	
421	43	43	
422	42	STO	Stores soil medium
423	12	12	
424	43	RCL	
425	45	45	
426	42	STO	Length crater radius multiplier
427	13	13	
428	43	RCL	
429	46	46	
430	42	STO	Width crater radius multiplier
431	14	14	
432	43	RCL	
433	43	43	
434	42	STO	
435	12	12	
436	43	RCL	
437	45	45	
438	42	STO	Target width
439	13	13	
440	43	RCL	
441	43	43	
442	42	STO	Aim
443	08	08	
444	43	RCL	
445	44	44	
446	42	STO	HOB
447	11	11	
448	05	5	
449	93	.	
450	05	5	
451	43	RCL	
452	53	53	
453	42	STO	
454	00	00	
455	48	PRT	Runs ETA cratering probability calcula- tion
456	36	PGM	
457	06	06	
458	01	1	
459	43	RCL	
460	47	STO	
461	98	ADV	

Appendix B: Iterations I and II

1 DNA AP-550 CONTROL A1 HTI 1				
ITERATIONS I (Pgm. 01, Input; RST, Input, Run)				
Δx MULT.?	Δx MULT.?	Δx MULT.?	Δx MULT.?	n.n → CALC
REG_A; x_f; Δx	REG_B; x_f; Δx	REG_C; x_f; Δx	REG_D; x_f; Δx	LOOPS

DESCRIPTION:

A. Objective

This control program provides an automated way of doing parametric studies using the programs in the CROM. Input variables may be incremented by some specified amount over any desired range, with the CROM carrying out the calculation anew for each incremented input value. Each calculation run may be set to treat as many as four variables parametrically.

With this control card, Iterations I, each parameterized input variable may be stepped either by adding an amount Δx for each calculation or by multiplying the value by a factor Δx each time, as the user wishes.

The Iterations II control program operates similarly but steps through a set of values which are explicitly entered, but which, therefore, need not vary by any fixed increment.

B. Inputs

Initial inputs (i.e., for the first of the series of calculations to be run) are entered as they are normally done, through Pgm 01, following the procedures set forth for the particular calculation in the main body of this document.

Next is entered the number of variables to be parameterized (spoken of as the number of iteration "loops"). Then, for each such variable, the following are entered: (a) the register number storing its value, (b) the maximum value, x_f, to be used for that variable in the iterations, (c) the amount, Δx, of the increment to be used, and if appropriate, (d) the choice that the increment Δx multiply the previous value rather than be added to it.

C. General Instructions for Data Entry

1. Press 2nd Pgm 01.
2. Enter initial inputs for desired calculation, following format of the particular CROM program.
3. Press RST.
4. Enter number of loops desired (i.e., number of parameters to be varied) with key E.
5. For the first variable to be parameterized, enter with key A, in order:
   a. Its storage register number, (R_A) (see Fig. 2),
   b. The maximum value to be accepted, (x_f), and
   c. The increment to be applied (Δx).
   If Δx is to be applied as a multiplier (not added), press 2nd A'.
6. Repeat step 5 for successive variables using keys B and 2nd B', C and 2nd C', etc.
7. To start, enter calculation number (n.n) with key 2nd E', exactly as is done in starting this calculation when using the CROM directly.

D. Special Features

All values, REG_i, x_f, and Δx are retained after the program has been run, and do not need to be re-entered unless they are to be changed. The number of loops desired (key E) may be changed at any time.

E. Data Storage Locations

Initial values for the various parameters are stored according to the CROM's universal input routine (Pgm 01) format. The relationship between keys and storage register numbers is shown in Fig. 2.

A' R15	B' R16	C' R17	D' R18	
A R10	B R11	C R12	D R19,R13	E R20,R14

Figure 2. Register numbers corresponding to input keys of the CROM universal input routine.

Keys D and E sometimes accept a single input (e.g., crater radius), sometimes a dual input (e.g., VN and k). If two inputs are needed, the values will be stored at the respective register numbers shown. As an example, if VN and k were entered at key D, VN would be stored in R19, k in R13. However, if only one input is entered with key D (or E), the register number corresponding to that input is the one underlined (for key D, R13; for key E, R14).

EXAMPLE #1:

Calculate the weapon radii for yields .1, 1, 10 and 100 KT for the first three environment categories of the personnel vulnerability code, for both the surface burst case and the optimum height of burst cases.

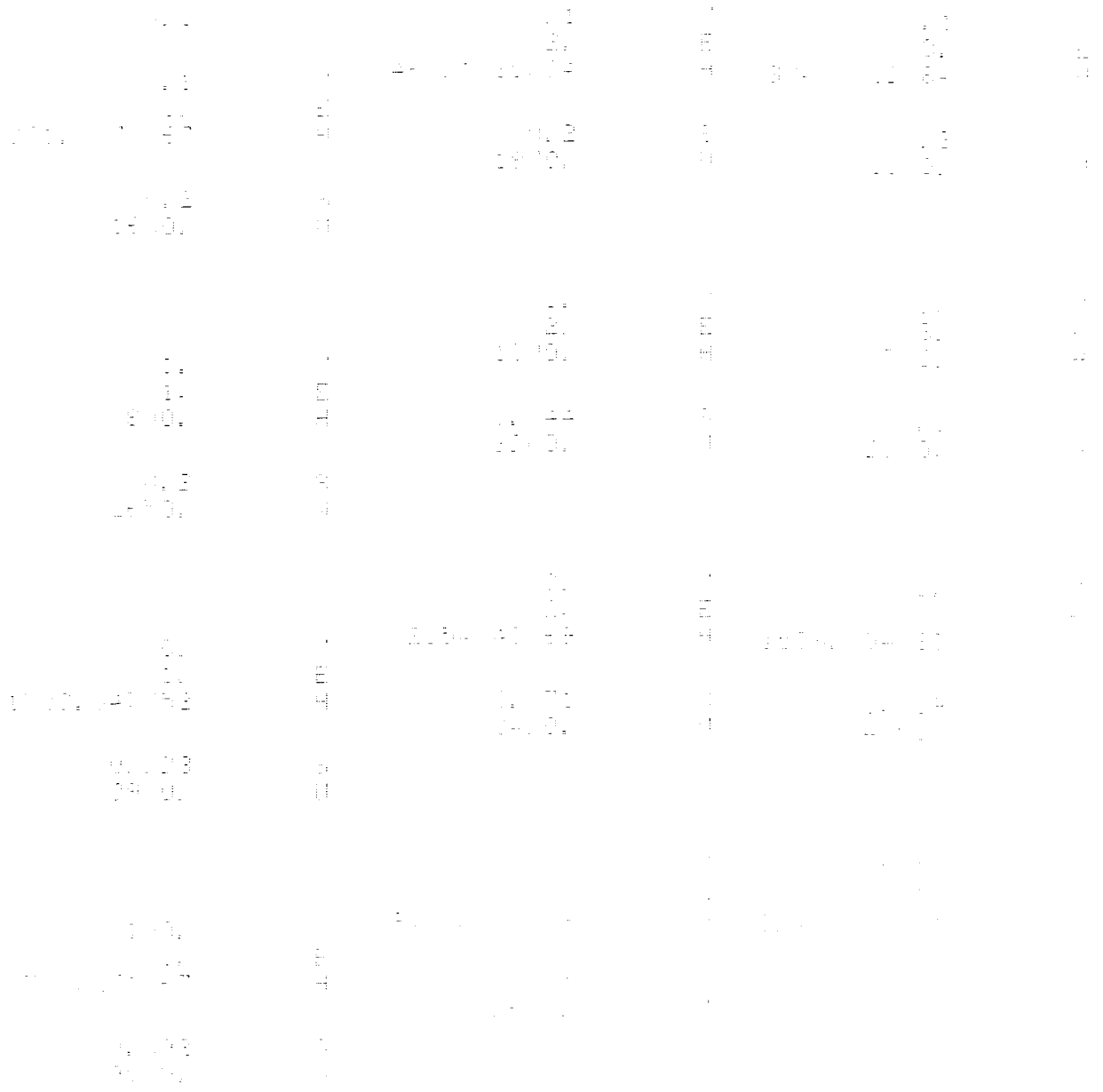
NOTES: 1. All initial values are entered through the universal input routine.

2. All product options are removed when RST is pressed. That is, after RST, all ΣX's will be added (not multiplied) unless the 2nd A', 2nd B' etc., keys are again pressed.

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off, then on			0	
2	Read either side of Iterations I card			1.	
3	Prepare to enter initial values (per universal input routine)		2nd Pgm 01	1.	
4	Enter lowest yield (KT)	1	A	0.1	
5	Enter height of burst	0	B	0.	
6	Enter first environment category	1	C	1.	
7	Return to Iterations program		RST	1.	
8	Enter number of loops desired	2	E	2.	
9	Enter register for yield (R10) (see Fig. 1) as first incrementing register	10	A	10.	
10	Enter largest desired value for yield	100	A	100.	
11	Enter increment in yield	10	A	10.	
12	Select multiplying option for first (yield) loop		2nd A'	10.	
13	Enter register for environment categories as second incrementing loop (i.e., REG_B)	12	B	12.	
14	Enter largest desired value for environment category	3	B	3.	
15	Enter increment to environment category	1	B	1.	
16	Initiate run for surface burst case	4	2nd E'	0.	see printer output
17	Initiate run for the optimum HOB case	4.1	2nd E'	0.	see printer output

PRINTER OUTPUT FOR EXAMPLE #1, STEP 16

PRINTER OUTPUT FOR EXAMPLE #1, STEP 17



PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
239.89	0,1,2,7,9 3-6	Used by CROM. Product options		

AUTOMATIC

LIBRARY MODULE

CROM A-1

DATA REGISTERS FOR EXAMPLE 1

DATA	REG.	COMMENTS	LABELS STEP	CODE	KEY	COMMENTS
		Program n.m				Set up pointer registers
		Used by CROM				Stack manipulation
						Enter initial, final, and increment values.
		Pointer registers				Number of loops
						Initiate calc.
						Set option for multiplication into registers.
		Universal input routine registers				
		Used by CROM				
		Pointers to registers to increment				
		Final values of incremented parameters				

DATA	REG.	COMMENTS
		Increment values of parameters to increment
		Temporary storage used by Program 0.

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
			Label DS7.
			R6=30+ ⎫ =: 0 for LBL A 1 for LBL B R7=34+ ⎬ 2 for LBL C 3 for LBL D ⎭ 0 in recur- R8=38+ ⎭ sions
			Label R/S.
			⎫ Stack manipulation ⎭
			Label A.
			A three-register stack:
			x↓↑R30↓↑R34↓↑R38
			Label B.
			Stack:
			x↓↑R31↓↑R35↓↑R39
			Label C.
			Stack:
			x↓↑R32↓↑R36↓↑R40
			Label D.
			Stack:
			x↓↑R33↓↑R37↓↑R41
			Label E.
			Enter loop
			Label E'.
			n.m

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
094	[illegible]	30	Copy initial values into registers 42-45
095	42	STO	
096	42	42	
097	73	RC*	
098	31	31	
099	42	STO	
100	43	43	
101	73	RC*	
102	31	31	
103	42	STO	
104	44	44	
105	73	RC*	
106	31	31	
107	42	STO	
108	45	45	
109	86	STF	
110	00	00	
111	71	SBR	
112	97	DSZ	
113	42	STO	
114	09	09	
115	22	INV	
116	86	STF	Set up and call CROM
117	01	01	
118	22	INV	
119	86	STF	
120	[illegible]	[illegible]	
121	[illegible]	[illegible]	
122	[illegible]	[illegible]	
123	[illegible]	[illegible]	
124	[illegible]	[illegible]	
125	[illegible]	[illegible]	
126	[illegible]	[illegible]	
127	[illegible]	[illegible]	
128	[illegible]	[illegible]	
129	[illegible]	[illegible]	
130	[illegible]	[illegible]	
131	[illegible]	[illegible]	
132	[illegible]	[illegible]	
133	[illegible]	[illegible]	
134	[illegible]	[illegible]	
135	[illegible]	[illegible]	
136	[illegible]	[illegible]	
137	[illegible]	[illegible]	
138	[illegible]	[illegible]	
139	[illegible]	[illegible]	
140	[illegible]	[illegible]	

STEP	CODE	KEY	COMMENTS
141	42	STO	
142	11	11	
143	73	RC*	Start of parameter manipulation
144	04	04	
145	42	STO	
146	01	01	
147	43	RCL	Set up for flg IND
148	04	04	
149	75	-	
150	01	1	
151	[illegible]	[illegible]	
152	95	=	
153	42	STO	
154	01	01	
155	73	RC*	
156	[illegible]	[illegible]	
157	44	SM*	
158	01	01	Sum Σx_i
159	22	INV	
160	87	IFF	
161	40	IND	
162	01	01	
163	01	01	
164	[illegible]	[illegible]	
165	22	INV	If appropriate flag, PROD Πx
166	[illegible]	PD*	
167	[illegible]	01	
168	[illegible]	PD*	
169	[illegible]	01	
170	73	RC*	
171	[illegible]	01	x_i
172	[illegible]	[illegible]	
173	[illegible]	RC*	
174	[illegible]	[illegible]	x_{f_i}
175	[illegible]	[illegible]	
176	[illegible]	[illegible]	If $x_i = x_{f_i}$
177	[illegible]	[illegible]	
178	[illegible]	[illegible]	
179	[illegible]	[illegible]	
180	[illegible]	[illegible]	Set $x_i = x_i$ (initial)
181	[illegible]	[illegible]	
182	[illegible]	[illegible]	
183	[illegible]	[illegible]	
184	[illegible]	[illegible]	
185	[illegible]	[illegible]	
186	[illegible]	[illegible]	
187	[illegible]	[illegible]	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS	STEP	CODE	KEY	COMMENTS
			If not end of loop, continue calculation				
			If end of loop, print "END"				
			Label A'. Set flag to multiply 'x for REG_A				
			Label B'. Set flag to multiply 'x for REG_B				
			Label C'. Set flag to multiply 'x for REG_C				
			Label D'. Set flag to multiply 'x for REG_D				

1a DNA AP-550 CONTROL A1 HTI 1b				
ITERATIONS II (1a RST, R/S, Input; 1b, RUN)				
R15	R16	R17	R18	n.n → CALC.
R10	R11	R12	R19, R13	R20, R14

DESCRIPTION:

A. Objective

This magnetic card program also provides for multiple calculations, varying selected inputs. This program more closely matches the CROMs input routine than does Iterations I. Here, the variables are specified exactly, and need not vary by some fixed increment. For example, yield can take on values of 1, 10, 50, 100 and 500 KT. When the program is selected to run, it will perform the selected calculations five times - once for each yield. To obtain the results of these calculations the calculator must be attached to the printer. If not, the program will run and simply display the results of the last calculation. All others will have been run but not recorded or stored.

Up to five different variables may be given multiple values. When the program is executed, all possible combinations of the values will be used as inputs for the calculations. The number of calculations performed rises quickly as more variables are given values. Assume that five different variables are each given four different values. The calculator will then attempt to perform a calculation for all the combinations, which equals 4^5 or 1024 calculations.

This large number requires a long calculator running time. If all these calculations are needed, it is recommended that the user time a few calculations to determine when the calculator will stop. It is prudent to select only those values necessary for the parameter study so that the calculator will run for a reasonable length of time.

The program itself is divided into two parts: card side 1a is used to set the variable inputs, and card side 1b is used to accept the additional inputs required to run the calculations. When side 1a is read into the machine, the user inputs the register number(s) of the variable(s) to be given multiple values, and the values chosen. Side 1b is then read into

the machine; at that point, the procedure for entering data and starting the calculations is exactly the same as for normal CROM operation.

B. Inputs

The inputs required for any series of calculations are those given in the main body of this document, which also describes the limits imposed by the CROM calculations.

For those inputs which will take different values in the course of these multiple calculations, the user will enter, in response to a "prompt" by the machine, the storage register number corresponding to that variable. The card face shows the required register number(s); it is shown at the key position at which that value is normally entered using the CROM's universal input routine.

Note that keys D and E sometimes accept two inputs. If two inputs (e.g., VN, k) are needed, the values will be stored at the respective register numbers. As an example, if VN and k were entered at key D, VN would be at R19, k at R13. However, if only one input is needed at key D or E, the register number corresponding to that input is the one underlined (for key D, R13, for key E, R14).

C. Limits

Limits are imposed by the CROM on any given call. When a limit is exceeded, the exceeded limit is printed with an error and execution for that particular example terminates. Control returns to the iterations program, which will resume the exercise with the next example.

D. General Instructions for Data Entry

1. Read side 1a of card
2. Press RST, then R/S, to begin data entry
3. In response to a prompt (?REG), enter register number for first variable to be assigned multiple values. Press R/S.
4. After prompt (?PTS), enter the number of values to be assigned that variable. Press R/S.
5. After prompt (?PT 1 or ?PT n), enter the value to be taken. Press R/S. Repeat for each value.

6. After those values are entered, machine will prompt again (?REG) for another variable. If another variable is to be given multiple values, repeat steps 3, 4, and 5 for that variable.
7. When all multiple-valued inputs have been entered, press CLR, read side 1b of card.
8. Turn to the section of this document that describes the calculation being performed, enter the indicated inputs and initiate the program by entering the appropriate a.b code number with key E'.

EXAMPLE #1:

Calculate the weapon radius for a 10P3 target using the iteration control program for the following combinations of inputs:

Yield (KT) = .4, 1, 4 HOB = 0, 750, 1000 (ft)

NOTES:

1. See card image at the beginning of this description for an association of registers to keys.
2. Side 1a. automatically repartitions the calculator to 239.89 for the variable input values. Side 1b. is recorded in this partition for program execution. If side 1b. is allowed to run to completion, the calculator is automatically repartitioned to 479.59 so that side 1a. can again be read. If side 1b. is stopped prematurely, an on/off sequence or manual repartition to 479.59 is necessary to read side 1a. again. However, any side, once read, may be exercised over and over without partitioning difficulties.

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off, then on			0.	
2	Read side 1a only			1.	
3	Begin program.		RST	1.	
	"1. LOOP" indicates that the calculator is receiving inputs for the first loop. Yield normally enters at key A, which according to the program card is Register 10. Only a register from 10 to 20 should be input for the prompt ?REG.		R/S	10.2	1. LOOP ?REG
4	Enter loop 1 register (yield). (See note 1)	10	R/S		10. REG
	?PTS asks for the number of loop 1 values. The 41 in the display indicates the maximum number allowed. Yield has three values in this case.			41	?PTS
5	Enter total number of values for loop 1. $1 \leq PTS \leq 41$	3	R/S		3. PTS
				1.	1. ?PT 1
6	Enter first yield value, PT 1	.4	R/S		.4 PT 1
				2.	2. ?PT 2
7	Enter second yield value, PT 2	1	R/S		1. PT 2
				3.	3. ?PT 3
8	Enter third yield value, PT 3	4	R/S		4. PT 3
9	Now the printer indicates that loop 2 is ready for values. HOB is in Register 11 from the card.			10.2	2. LOOP ?REG

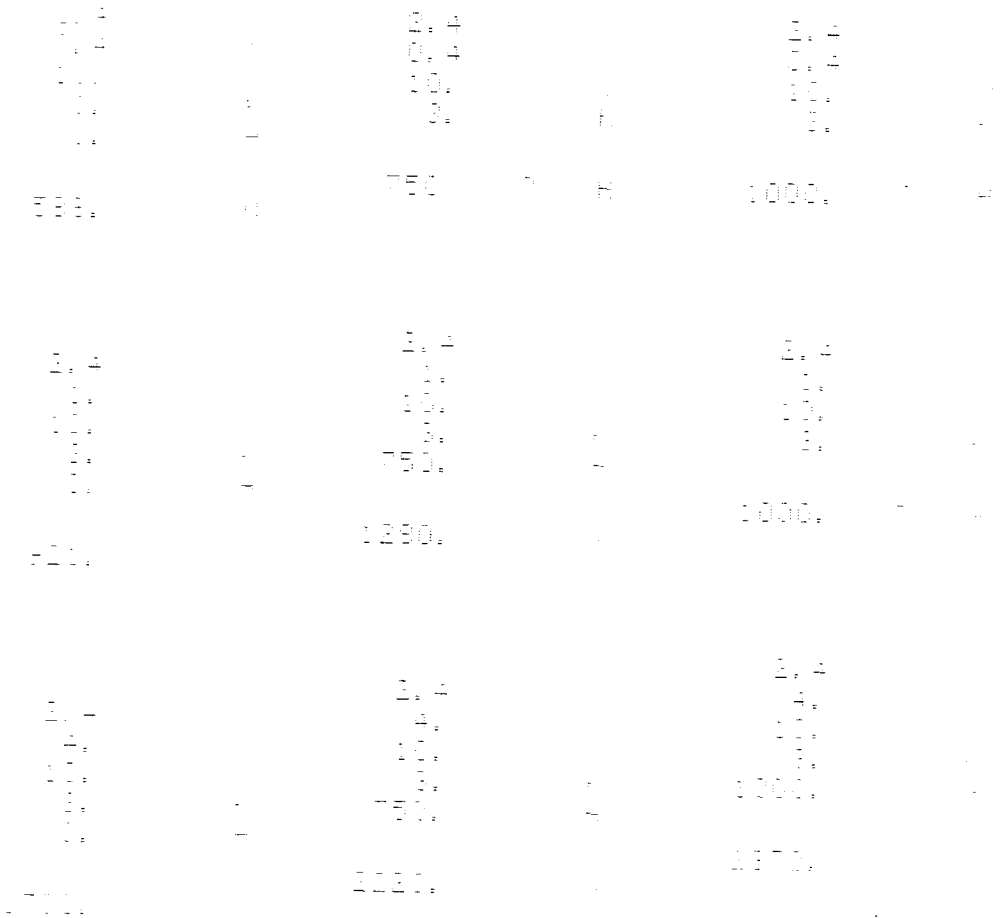
EXAMPLE #1 (continued)

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
10	Enter loop 2 register, (HOB) The 38 which appears in the display indicates the maximum number of values which may be entered for PTS.	11	R/S	38.	11. REG ?PTS
11	Enter total number of values for loop 2.	3	R/S	1.	3. PTS 1. ?PT 1
12	Enter first HOB value, PT 1	0	R/S	2.	0. PT 1 2. ?PT 2
13	Enter second HOB value, PT 2	750	R/S	3.	750. PT 2 3. PT 3
14	Enter third HOB value, PT 3	1000	R/S	10.2	1000. PT 3 3. LOOP ?REG
15	Press CLR. Read side 1b. (see note 2.) The calculator now acts as though in Pgm 01.		CLR	1.	
16	Enter VN	10	D	10.	
17	Enter k-factor	3	E	3.	
18	Initiate calculations	2.4	2nd E'		See Printer Output

PRINTER OUTPUT FOR EXAMPLE #1:

```
    1.     LOOP

          ?REG
   10.     REG

          ?PTS
    3.     PTS

    1.    ?PT 1
  0.4     PT 1

    2.    ?PT 2
    1.     PT 2

    3.    ?PT 3
    4.     PT 3

    2.     LOOP

          ?REG
   11.     REG

          ?PTS
    3.     PTS

    1.    ?PT 1
    0.     PT 1

    3.    ?PT 2
  -50.     PT 2

    4.    ?PT 3
 -100.     PT 3

    1.     LOOP

          ?REG
```

PRINTER OUTPUT FOR EXAMPLE #1 (continued):



PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
AUTOMATIC	0,1,2,7,9	Used by CROM		

LIBRARY MODULE: CROM A-1

DATA REGISTERS FOR EXAMPLE 1

DATA REG.	COMMENTS	STEP	CODE	LABELS KEY	COMMENTS
	Program n.m				Side a
	Pointer registers; also used by CROM				Parameter loop Data point loop
					Side b
					Unpacker Initiate calc.
	Universal I/O registers				5th parameter 4th parameter 3rd parameter 2nd parameter 1st parameter
	Used by CROM				Universal I/O
	Temporary storage				
	R34-R38: Pointers to registers for parameters to vary				

DATA	REG.	COMMENTS
		R39-R44: Starting location and number of values for each of five parameters
		R49-R89: Values that parameters take in increments

SIDE 1a

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS	STEP	CODE	KEY	COMMENTS
			Start				"LOOP"
			Pointer to starting location of first set of data				
			Number of free data points				
			Repartition				
			Pointer to register storing number of points and their pointer				"?REG"
			Pointer to pointers of registers to increment				
			Loop counter				
			Label x^2. Begin loop				10.2 in display Read ith register
			Pointer to data points to be stored				Store pointer to ith register
			Data point counter				

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
095	01	1	
096	09	09	
097	14	LBL	"?PTS"
098	11	A	
099	15	E	
100	36	PAU	
101	42	STO	
102	00	0	
103	14	LBL	
104	00	0	Read number of data points that are associated with ith register
105	12	B	
106	44	SUM	
107	00	00	
108	42	STO	
109	00	00	Counter to number of data points
110	44	SUM	
111	00	00	
112	44	SUM	
113	00	00	
114	55	-	
115	01	1	
116	00	0	
117	00	0	
118	48	=	
119	44	SUM	
120	04	04	Pack information
121	22	INV	
122	04	04	
123	02	2	
124	44	SUM	
125	00	00	
126	45	RCL	Store pointer to starting location of registers for next set of data.
127	00	00	
128	42	STO	
129	04	04	
130	14	LBL	Label $\sqrt{x}$.
131	34	FIX	
132	45	RCL	
133	00	00	
134	55	-	
135	45	RCL	
136	00	00	
137	48	=	
138	58	FIX	
139	55	-	
140	45	RCL	
141	04	04	
142	44	SUM	

STEP	CODE	KEY	COMMENTS
143	01	1	
144	48	=	
145	58	FIX	
146	36	PAU	
147	00	0	
148	00	0	
149	00	0	
150	00	0	
151	45	RCL	
152	00	00	
153	05	5	
154	00	0	
155	00	0	
156	00	0	
157	01	1	
158	00	00	
159	04	4	
160	35	/	Calculate alphanumerics for "PT L"
161	01	1	
162	04	04	
163	00	00	
164	GSB	CLF	
165	00	00	
166	45	RCL	
167	00	00	
168	00	00	
169	00	00	
170	00	00	
171	00	00	
172	00	00	Read ith data point
173	00	00	
174	00	00	
175	00	00	
176	00	00	
177	00	00	
178	00	00	
179	00	00	
180	00	00	
181	00	00	
182	00	00	Loop for data point
183	00	00	
184	00	00	Loop for register loop
185	00	00	
186	00	00	
187	00	00	
188	00	00	
189	00	00	
190	01	1	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS	STEP	CODE	KEY	COMMENTS
			"END"				

SIDE 1b

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	76	LBL	Label INT.
001	69	INT	
002	42	STO	Unpack number of points
003	77	INT	in nth loop
004	43	RCL	
005	01	1	
006	00	0	
007	00	0	
008	95	=	
009	92	RTN	
010	76	LBL	LABEL E'. start calc.
011	30	E'	
012	49	PRD	
013	42	STO	Pgm n.m.
014	31	31	
015	43	RCL	
016	31	31	
017	65	×	
018	43	RCL	
019	00	00	
020	95	=	
021	59	INT	
022	65	×	
023	43	RCL	
024	00	00	
025	95	=	
026	42	STO	
027	00	00	
028	76	LBL	Label LNX.
029	11	A'	
030	43	RCL	Set up fifth looping
031	00	00	register
032	65	×	
033	43	RCL	
034	01	01	
035	95	=	
036	59	INT	
037	42	STO	Store data point of
038	00	00	fifth loop
039	43	RCL	
040	01	01	
041	00	0	
042	00	0	
043	76	LBL	Label CE.
044	34	CE	
045	42	STO	Set up fourth looping
046	02	02	register
047	43	RCL	
048	02	02	
049	65	×	
050	43	RCL	
051	01	01	
052	95	=	
053	59	INT	
054	65	×	
055	43	RCL	
056	02	02	
057	00	00	
058	95	=	
059	42	STO	Store data point of
060	32	X↑I	fourth loop
061	02	02	
062	43	RCL	
063	01	01	
064	01	01	
065	95	=	
066	42	STO	
067	40	40	
068	76	LBL	Label CLR.
069	35	CLR	
070	43	RCL	Set up third looping
071	41	41	register
072	65	×	
073	43	RCL	
074	00	00	
075	95	=	
076	42	STO	
077	00	00	
078	43	RCL	Store data point of
079	41	41	third loop
080	32	X↑I	
081	00	00	
082	43	RCL	
083	01	01	
084	01	01	
085	95	=	
086	59	INT	
087	42	STO	
088	41	41	
089	76	LBL	Label LOG.
090	13	C'	
091	43	RCL	Set up second looping
092	41	41	register
093	00	00	
094	00	00	
095	95	=	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
			Store data point for second loop
			Label CP.
			Set up first looping register
			Set up data point for first loop.
			Preserve R12
			Call Pgm. n.m
			Restore R12
141	23	12	
142	23	IN"	

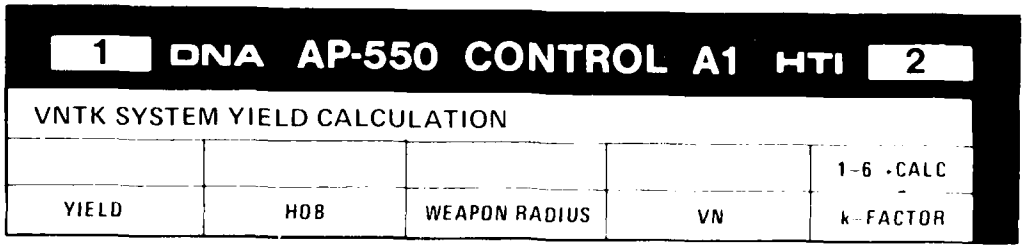
STEP	CODE	KEY	COMMENTS
			Innermost loop
			Second loop
			Third loop
			Fourth loop
			Fifth loop
			"END"
			Label A.
183	42	STO	Store 10

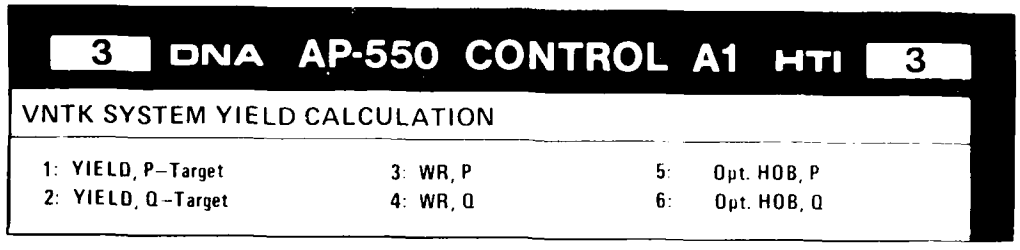
PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS	STEP	CODE	KEY	COMMENTS
							Store 18
			Label B.				
			Store 11				
			Label C.				
			Store 12				
			Label D.				
			R19 = R13 R13 = x				
			Label E.				
			R20 = R14 R14 = x				
			Label A'.				
			Store 15				
			Label B'.				
			Store 16				
			Label C'.				
			Store 17				
			Label D'.				

APPENDIX C: INVERSIONS

VNTK Weapon Radius Inversion for Yield
Personnel Weapon Radius Inversion for Yield
Cratering Second DOB Calculation





DESCRIPTION:

A. Objective

This code inverts the AP-550 CROM's VNTK program (program 02) for yield (Y), given a height of burst, a weapon radius (WR), a vulnerability number (VN), and a k-factor. Inputs are entered with keys A-E, and a calculation is initiated by entering one of six options (entered as an integer between 1 and 6) with key E'. The six options are:

1. Invert P-target weapon radius calculation for yield.
2. Invert Q-target weapon radius calculation for yield.
3. Calculate weapon radius, P-target.
4. Calculate weapon radius, Q-target.
5. Calculate optimum HOB and maximum WR, P-target.
6. Calculate optimum HOB and maximum WR, Q-target.

The weapon radius varies relatively slowly with heights of burst below the optimum height of burst. For this reason, a direct inversion of the calculation for the height of burst is not useful and has not been included. Instead, the CROM calculation of the optimum height of burst may be used to indicate the upper limit of desirable heights of burst.

B. Inputs - Outputs

Inputs: Yield (KT) (except options 1 and 2)
HOB (ft) (except options 5 and 6)

	WR (ft)	(except options 3, 4, 5, and 6)
	VN	
	k-factor	
Outputs:	Yield	(options 1 and 2)
	HOB	(options 5 and 6)
	WR	(options 3, 4, 5, and 6)

C. Limits (appropriate units are kilotons and feet)

Yield: $0.1 \text{ KT} \leq Y \leq 30 \text{ MT}$ (options 3,4,5,6)

HOB: $0 \leq \text{HOB} \leq \text{HOB}_{max}$ (options 3,4)

where:

$\text{HOB}_{max} = 2308\ Y^{1/3} \exp(-\text{AJVN}/15)$, P-target

HOB_{max} = the minimum of: $900\ Y^{1/3}$, $2308\ Y^{1/3} \exp(-\text{AJVN}/15)$ } Q-target

$0 \leq \text{HOB} \leq$ optimum HOB (options 1,2)

WR: $(0.1)^{1/3} W_1 \leq \text{WR} \leq (30{,}000)^{1/3} W_2$ (options 1,2)

where:

W_1 = scaled weapon radius at HOB = 0

W_2 = scaled weapon radius at optimum HOB

VN: $0 \leq \text{AJVN} \leq 56$, P-target

$0 \leq \text{AJVN} \leq 34$, Q-target

k-factor: $0 \leq k \leq 9$

D. Data Storage Locations, Printer Alphanumerics

Variables	Registers	Alphanumerics
Yield (KT)	R10	Y
HOB (ft)	R11	H
Weapon radius (ft)	R12	W
VN	R13	V
k-factor	R14	K

EXAMPLE #1:

Find the yield necessary to produce a weapon radius of 15,000 ft, for a target with a VNTK of 10P3. Assume a surface burst.

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off, then on			0	
2	Read sides 1, 2, 3 of cards			1,2,3	
3	Enter height of burst (ft)	0	B	0.	
4	Enter weapon radius (ft)	15000	C	15000.	
5	Enter VN	10	D	10.	
6	Enter k-factor	3	E	3.	
7	Initiate inversion for P-target	1	2nd E'		1. 10. V 3. K 0. H 15000. W
	Read yield			1170.	1170. Y
8	Verify that this yield will produce a 15,000 ft weapon radius	3	2nd E'		3. 1170. Y 10. V 0. K 15000. W

EQUATIONS

Definitions

Y = yield (KT)

H = height of burst (ft)

WR = weapon radius (ft)

VN = VN number

k = k factor

Yield inversion (calculations 1 and 2)

Using ϵ, x_0, a and p as defined below (equations 23 through 31) calculate first guess for $Y = Y_1$ as follows:

$$AJVN_0 = VN \tag{1}$$

$$\epsilon_0 = \epsilon \text{ calculated using } AJVN_0 \text{ (equations 23, 28)} \tag{2}$$

$$Y_1 = (WR/\epsilon_0)^3 \tag{3}$$

Adjust VN using equations 18-22 and Y_1 as yield to get $AJVN_1$ (4)

$$\epsilon_1 = \epsilon \text{ calculated with } AJVN_1 \text{ (equations 23, 28)} \tag{5}$$

$$W_1 = \epsilon_1 Y_1^{1/3} \tag{6}$$

$$Y_2 = (WR/\epsilon_1)^3 \tag{7}$$

Adjust VN using equations 18-22 and Y_2 as yield to get $AJVN_2$ (8)

$$\epsilon_2 = \epsilon \text{ calculated with } AJVN_2 \text{ (equations 23, 28)} \tag{9}$$

$$W_2 = \epsilon_2 Y_2^{1/3} \tag{10}$$

$$\text{Improved first guess } \hat{Y}_1 = \exp\left[\frac{\ln\left(\frac{W_2}{WR}\right)\cdot\ln Y_1 - \ln\left(\frac{W_1}{WR}\right)\cdot\ln Y_2}{\ln\left(\frac{W_2}{W_1}\right)}\right] \tag{11}$$

Adjust VN using equations 18-22 and $\tilde{Y}_1$ as yield; and calculate (12)

$$W_1 = \left[1 + a\left(\frac{H}{x_0 Y_1^{1/3}}\right)^p\right] Y_1^{1/3} \quad (13)$$

Then $\tilde{Y}_2 = \left(\frac{WR}{\tilde{W}_1}\right)^3 \tilde{Y}_1$ = improved second guess (14)

Adjust VN using equations 18-22 and $\tilde{Y}_2$ as yield; and calculate (15)

$$W_2 = \left[1 + a\left(\frac{H}{x_0 \tilde{Y}_2^{1/3}}\right)^p\right] \tilde{Y}_2^{1/3} \quad (16)$$

$$\text{Finally, } Y = \exp\left[\frac{\ln\left(\frac{W_2}{WR}\right)\ln Y_1 - \ln\left(\frac{\tilde{W}_1}{WR}\right)\ln \tilde{Y}_2}{\ln\left(\frac{W_2}{\tilde{W}_1}\right)}\right] \quad (17)$$

NOTE: If K-factor = 0, then calculations begin with equation (12), with AJVN VN.

Adjustment of VN:

For P-target, AJVN = VN + 11·nx (18)

where

$$x = \frac{1}{2}\frac{k}{10}\left(\frac{20}{Y}\right)^{1/3} + \left\{\left[\frac{1}{2}\frac{k}{10}\left(\frac{20}{Y}\right)^{1/3}\right]^2 + 1 - \frac{k}{10}\right\}^{1/2} \quad (19)$$

For Q-target, AJVN = VN + 8.2·nx, (20)

where

$$x = x_0 - \left[3x_0^2 - \frac{k}{10}\left(\frac{20}{Y}\right)^{1/3}\right]\frac{1}{6x_0} +$$

$$\left\{\left(\left[3x_0^2 - \frac{k}{10}\left(\frac{20}{Y}\right)^{1/3}\right]\frac{1}{x_0}\right)^2 - \frac{1}{3x_0}\left(x_0^3 - \frac{k}{10}\left(\frac{20}{Y}\right)^{1/3} x_0 - \frac{k}{10} - 1\right)\right\}^{1/2} \quad (21)$$

$$x_0 = \frac{k}{10}\left(\frac{20}{Y}\right)^{1/6} + 1 - \frac{k}{10} \tag{22}$$

For P-target

$$\text{[illegible]} = \exp(7.63 - AJVN/6) + \exp(7.37 - AJVN/16) \tag{23}$$

$$x_0 = \exp(6 + \text{[illegible]}^2 - VN/15.7) \tag{24}$$

$$a = \frac{(26 - AJVN)^4}{1890 + 31(26 - AJVN)^3} \text{ for AJVN} \leq 26 \tag{25}$$

$$a = \frac{(AJVN - 26)}{160} \text{ for AJVN} > 26 \tag{26}$$

$$p = .6 + \exp[-.393AJVN + 9.5\ln(.393AJVN) - 3.3^2] \tag{27}$$

For Q-target

$$\text{[illegible]} = [\exp(133 - 1.82AJVN) + \exp(128 - 1.4AJVN)]^{1/16} \tag{28}$$

$$x_0 = [\exp(-.24^2 AJVN)]^{.5}\left\{960 - 410\left[\frac{\exp(.27AJVN^{1.2} - 6.5)}{1 + \exp(.27AJVN^{1.2} - 6.5)}\right]\right\} \tag{29}$$

$$a = \frac{1}{\text{[illegible]}}[\exp(158 - 1.4AJVN) + \exp(177 - 2.7AJVN)]^{1.20} - 1 \tag{30}$$

$$p = [1 + (AJVN/33)^8]^{-1} \tag{31}$$

Calculations 3, 4, 5, and 6 use the same equations as are in the CROM (program 2).

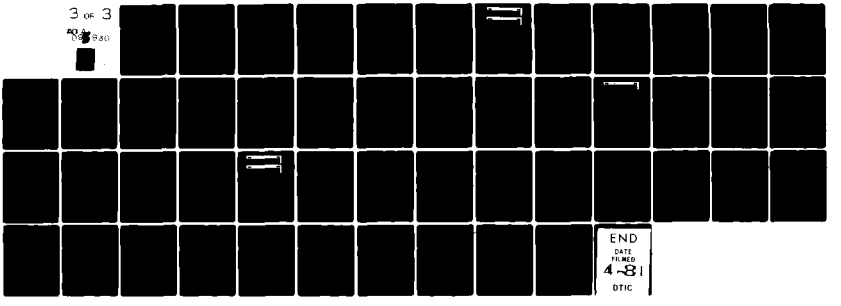
PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
559.49	0,1,2,7,9	Used by CROM	4	Set if 9 target
AUTOMATIC	3	Flags first acceleration in yield inversion		
LIBRARY MODULE				
CROM A-1				

DATA REGISTERS FOR EXAMPLE _____

DATA	REG.	COMMENTS
	0	Calc. index (used by CROM)
	1	Used by CROM
	2	-2
	3	Adjusted to VN (by CROM)
	4	Y_1
	5	W_1/WP
	6	Y_2
	7	W_2/WP
	8	Y (as finally calculated)
	9	HOB
	10	WP
	11	VN
	12	k factor
	13	WR (temporary storage)
	14	Not used
	15	ADVN
	16	Adjustment to VN (by control program)
	17	Upper limit for VN

LABELS KEY	COMMENTS
	Calc. -2
	Aitken's accel.
	Calc. guess for
	Adjust VN
	Store yield
	Store HOB
	Store WP
	Store VN
	Store k factor
	Calc. [illegible]

AD-A095 830 HORIZONS TECHNOLOGY INC SAN DIEGO CA F/G 18/3
NUCLEAR WEAPONS TARGETING, AP-550, CROM A1, REFERENCE MANUAL.(U)
JUN 79 DNA001-78-C-0247
UNCLASSIFIED HTI-R-79-125 DNA-5277H NL



PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	98	ADV	End of routines
001	98	ADV	
002	98	ADV	
003	92	RTN	
004	76	LBL	Label B'.
005	17	B'	Calculate α-2
006	87	IFF	Flag 4 set = Q target
007	04	04	
008	03	03	
009	73	73	
010	36	PGM	
011	02	02	
012	71	SBR	
013	04	04	
014	66	66	P-target α
015	61	GTO	
016	03	03	
017	76	76	
018	76	LBL	Label C'.
019	18	C'	
020	43	RCL	Aitken's acceleration
021	09	09	$\frac{W_2}{WR}$ or $\frac{\tilde{W}_2}{WR}$
022	23	LNX	
023	65	×	
024	43	RCL	Y_1
025	06	06	
026	23	LNX	
027	75	-	
028	43	RCL	$\frac{W_1}{WR}$ or $\frac{\tilde{W}_1}{WR}$
029	07	07	
030	23	LNX	
031	55	÷	
032	43	RCL	Y_2
033	08	08	
034	23	LNX	
035	95	=	
036	55	÷	
037	53	(	
038	43	RCL	
039	09	09	$\frac{W_2}{W_1}$ or $\frac{\tilde{W}_2}{\tilde{W}_1}$
040	55	÷	
041	43	RCL	
042	07	07	
043	54	)	
044	23	LNX	
045	95	=	
046	22	INV	
047	23	LNX	
048	42	STO	
049	10	10	
050	92	RTN	
051	76	LBL	Label A'.
052	16	A'	Subroutine to calculate
053	19	D'	guess for Y and associated Ws
054	22	INV	Adjust VN
055	87	IFF	Flag 3 set for first
056	03	03	accel., reset for 2nd
057	04	04	Full WR calculation
058	36	36	Calculate α
059	17	B'	
060	61	GTO	
061	05	05	
062	32	32	
063	76	LBL	Label D'.
064	19	D'	Adjust VN with present
065	43	RCL	yield
066	14	14	k
067	55	÷	
068	01	1	
069	00	0	
070	65	×	
071	42	STO	
072	01	01	
073	42	STO	
074	04	04	
075	69	DP	
076	34	34	
077	53	(	
078	43	RCL	
079	10	10	
080	22	INV	Calculation of $Y^{-1/3}$
081	45	Y^x	
082	03	3	
083	94	+/-	
084	65	×	
085	42	STO	
086	22	22	
087	01	1	
088	22	INV	
089	23	LNX	
090	55	÷	
091	87	IFF	
092	04	04	
093	03	03	
094	82	82	
095	02	2	P target

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
096	95	=	
097	85	+	
098	53	(	
099	33	X^2	
100	75	-	
101	43	RCL	
102	04	04	
103	54	)	
104	34	$\sqrt{x}$	
105	95	=	x
106	23	LNX	
107	65	×	
108	01	1	
109	01	1	
110	61	GTO	
111	04	04	
112	25	25	
113	76	LBL	Label A.
114	11	A	
115	42	STO	Input Y
116	10	10	
117	92	RTN	
118	76	LBL	Label B.
119	12	B	
120	42	STO	Input H
121	11	11	
122	92	RTN	
123	76	LBL	Label C.
124	13	C	
125	42	STO	Input WR
126	12	12	
127	92	RTN	
128	76	LBL	Label D.
129	14	D	
130	42	STO	Input VN
131	13	13	
132	92	RTN	
133	76	LBL	Label E.
134	15	E	
135	42	STO	Input k
136	14	14	
137	92	RTN	
138	76	LBL	Label E'.
139	10	E'	Enter calc. number to
140	98	ADV	begin.
141	59	INT	
142	32	X:T	
143	25	CLR	
144	01	1	
145	85	+	Check and print calcula-
146	06	6	tion number
147	42	STO	Initialize for ST*00's
148	00	00	in yield inversion
149	65	×	
150	00	0	
151	36	PGM	
152	09	09	
153	11	A	
154	55	÷	
155	32	X:T	
156	02	2	
157	85	+	
158	59	INT	
159	95	=	
160	67	EQ	
161	01	01	Set flag 4 if even
162	64	64	(Q-target calc.)
163	22	INV	
164	86	STF	
165	04	04	
166	05	5	
167	69	DP	Repartition
168	17	17	
169	43	RCL	*Remove input WR to safe*
170	12	12	place
171	42	STO	
172	15	15	
173	02	2	
174	77	GE	
175	02	02	*Yield inversion*
176	13	13	
177	93	.	
178	04	4	
179	49	PRD	R_{00} = 2.4 to get CROM
180	00	00	to tranfer to Pgm. 3,
181	01	1	print WR.
182	00	0	R_{02} = 10 WS expected by
183	42	STO	CROM.
184	02	02	
185	04	4	
186	77	GE	
187	03	03	
188	01	01	WR calculation
189	87	IFF	
190	04	04	WR optimum H calcula=
191	01	01	tion

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
192	97	97	
193	36	PGM	P target
194	02	02	
195	13	C	
196	81	RST	
197	36	PGM	WR, optimum H calculation for Q target
198	02	02	
199	14	D	
200	81	RST	
201	87	IFF	
202	04	04	
203	02	02	WR calculation
204	09	09	
205	36	PGM	
206	02	02	P target
207	11	A	
208	81	RST	
209	36	PGM	
210	02	02	Q target
211	12	B	
212	81	RST	
213	86	STF	
214	03	03	Yield inversion
215	43	RCL	
216	13	13	
217	42	STO	$AJVN_0$ = VN
218	21	21	
219	17	B'	$\alpha_0 - 2$
220	71	SBR	
221	05	05	
222	44	44	Calculate $Y_1 \rightarrow R_{10}$
223	43	RCL	
224	14	14	Skip first acceleration if k = 0
225	29	CP	
226	67	EQ	
227	02	02	
228	34	34	
229	16	A'	W_1, Y_2
230	16	A'	W_2, extraneous "Y_3"
231	18	C'	Acceleration
232	42	STO	
233	06	06	$\tilde{Y}_1$
234	22	INV	
235	86	STF	
236	03	03	
237	07	7	Reinitialize R_{00}
238	42	STO	for indirect STORES.
239	00	00	
240	16	A'	
241	16	A'	
242	18	C'	→Final Y
243	19	D'	Adjust VN with final Y
244	17	B'	Calculate α-?
245	87	IFF	
246	04	04	
247	03	03	
248	58	58	→Q-target
249	42	STO	
250	12	12	
251	43	RCL	
252	21	21	AJVN
253	94	+/-	
254	36	PGM	
255	02	02	
256	71	SBR	
257	00	00	
258	91	91	
259	42	STO	x_0
260	01	01	
261	36	PGM	
262	02	02	
263	71	SBR	
264	04	04	
265	86	86	
266	42	STO	
267	00	00	$\hat{W}_{max}$
268	05	5	
269	06	6	
270	75	-	
271	43	RCL	$\left\{\begin{matrix}11\\8.2\end{matrix}\right\}\ell nx$
272	22	22	
273	95	=	
274	42	STO	Upper limit for VN
275	23	23	
276	43	RCL	
277	15	15	
278	42	STO	Put WR back before
279	12	12	getting stuck in
280	01	1	limit checks!
281	03	3	
282	42	STO	
283	02	02	
284	04	4	
285	02	2	"V"
286	32	X:T	
287	43	RCL	

limit checks

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
288	22	22	
289	75	-	
290	50	I×I	
291	95	=	
292	55	÷	
293	02	2	
294	94	+/-	
295	44	SUM	$R_{00} = \alpha(a+1)-2$
296	00	00	
297	85	+	$\max\left\{0, -\binom{11}{8.2}\ell nx\right\}$
298	43	RCL	
299	23	23	
300	36	PGM	
301	09	09	
302	13	C	
303	02	2	"k"
304	06	6	
305	32	X:T	
306	00	0	
307	85	+	
308	09	9	
309	36	PGM	
310	09	09	
311	13	C	
312	01	1	
313	01	1	
314	42	STO	
315	02	02	
316	79	x̄	
317	32	X:T	
318	00	0	
319	85	+	
320	02	2	"H"
321	03	3	
322	32	X:T	
323	36	PGM	
324	09	09	
325	13	C	
326	04	4	"W"
327	03	3	
328	32	X:T	
329	93	.	
330	04	4	
331	06	6	$(.1)^{1/3}$
332	65	×	
333	43	RCL	
334	00	00	
335	85	+	
336	03	3	
337	01	1	$(30,000)^{1/3}$
338	93	.	
339	01	1	
340	65	×	
341	43	RCL	
342	04	04	
343	36	PGM	
344	09	09	
345	13	C	
346	98	ADV	
347	04	4	
348	05	5	
349	32	X:T	Print yield, rounded
350	43	RCL	to 3 digits
351	10	10	
352	36	PGM	
353	09	09	
354	12	B	
355	42	STO	
356	10	10	
357	81	RST	
358	36	PGM	
359	02	02	Calculation for yield
360	19	D'	inversion, limit
361	42	STO	checks, Q-target
362	01	01	$\hat{H}_{opt}$
363	36	PGM	
364	02	02	
365	17	B'	$\alpha(a+1)$
366	42	STO	
367	00	00	
368	03	3	AJVN max
369	04	4	
370	61	GTO	
371	02	02	
372	70	70	
373	36	PGM	Part of Label B'
374	02	02	
375	16	A'	
376	75	-	Q-target α
377	02	2	compensates for CROM's
378	95	=	adjustment of WR by
379	42	STO	$2Y^{1/3}$
380	04	04	
381	92	RTN	
382	49	PRD	part of Label D'
383	01	01	Q-target

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
384	34	ΓX	VN adjustment
385	54	)	
386	75	-	
387	43	RCL	
388	04	04	
389	95	=	
390	42	STO	
391	03	03	
392	55	÷	
393	02	2	
394	75	-	
395	79	x̄	
396	55	÷	
397	06	6	
398	75	-	
399	53	(	
400	33	X²	
401	75	-	
402	53	(	
403	43	RCL	
404	03	03	
405	33	X²	
406	75	-	
407	43	RCL	
408	01	01	
409	85	+	
410	32	X↕T	
411	54	)	
412	55	÷	
413	03	3	
414	54	)	
415	34	ΓX	
416	75	-	
417	43	RCL	
418	03	03	
419	95	=	x
420	23	LNX	
421	65	×	
422	08	8	
423	93	.	
424	02	2	
425	85	+	
426	48	EXC	
427	22	22	$R_{22} \leftarrow \begin{Bmatrix} 11 \\ 8.2 \end{Bmatrix}$ ℓnx
428	42	STO	
429	03	03	$R_{03} \leftarrow Y^{-1/3}$
430	43	RCL	
431	13	13	
432	95	=	
433	42	STO	
434	21	21	AJVN
435	92	RTN	
436	87	IFF	Part of Label A'
437	04	04	
438	05	05	
439	28	28	(Q-target WR calc.)
440	17	B'	
441	02	2	Calculation of P-target
442	44	SUM	WR, adapted from CROM
443	04	04	
444	43	RCL	
445	11	11	
446	29	CP	Skip
447	67	EQ	if
448	05	05	H=0
449	20	20	
450	43	RCL	
451	21	21	
452	65	×	
453	93	.	
454	03	3	
455	09	9	
456	03	3	
457	75	-	
458	23	LNX	
459	65	×	
460	09	9	
461	93	.	
462	05	5	
463	85	+	
464	03	3	
465	93	.	
466	03	3	
467	33	X²	
468	95	=	
469	94	+/-	
470	22	INV	
471	23	LNX	
472	85	+	
473	93	.	
474	06	6	
475	95	=	
476	42	STO	P
477	05	05	
478	43	RCL	
479	21	21	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
480	94	+/-	
481	36	PGM	
482	02	02	
483	71	SBR	
484	00	00	
485	91	91	
486	42	STO	
487	01	01	$\hat{H}_{opt}$
488	43	RCL	
489	11	11	
490	55	÷	
491	79	$\bar{x}$	
492	95	=	
493	45	Y^x	
494	43	RCL	
495	05	05	$\left(\frac{H}{H_{opt}}\right)^P$
496	95	=	
497	48	EXC	
498	04	04	
499	42	STO	
500	12	12	α
501	36	PGM	
502	02	02	
503	71	SBR	$\alpha(a+1)$
504	04	04	
505	86	86	
506	55	÷	
507	43	RCL	
508	12	12	
509	75	-	
510	01	1	
511	95	=	a
512	49	PRD	
513	04	04	
514	69	□P	
515	24	24	
516	43	RCL	
517	12	12	
518	49	PRD	
519	04	04	
520	36	PGM	
521	02	02	
522	71	SBR	Finish off WR calc.
523	04	04	
524	61	61	
525	61	GTO	
526	05	05	
527	32	32	
528	36	PGM	Q-target WR calc.
529	02	02	
530	71	SBR	
531	89	π	
532	79	$\bar{x}$	$Y^{-1/3}$ in R_{03}, $\hat{W}$ in R_{04}
533	43	RCL	
534	15	15	WR (given)
535	55	÷	
536	32	X↕T	W_i
537	95	=	
538	72	ST*	R_{07} or R_{09}
539	00	00	
540	69	□P	
541	20	20	
542	43	RCL	
543	04	04	
544	55	÷	Entry point for first guess Y_1
545	43	RCL	
546	15	15	WR
547	65	×	
548	33	X²	
549	95	=	$Y_{i+1} = \left(\frac{WR}{W_i}\right)^3$
550	35	1/X	
551	72	ST*	
552	00	00	R_{06} or R_{08}
553	69	□P	
554	20	20	
555	42	STO	New Y
556	10	10	
557	92	RTN	

1 DNA AP-550 CONTROL A1 HTI 2				
PERSONNEL VULNERABILITY YIELD CALCULATION				
				→ WEAPON RADIUS
YIELD	WEAPON RADIUS	ENVIRONMENT		→ YIELD

3a DNA AP-550 CONTROL A1 HTI 3b
PERSONNEL VULNERABILITY YIELD CALCULATION
Side 3a for HOB=0, Side 3b for HOB=near-optimum

SOURCE OF DATA:

Defense Intelligency Agency, Physical Vulnerability Handbook-Nuclear Weapons (U), AP-550-1-2-60-INT, June 1, 1969, Ch. 4.

DESCRIPTION:

A. Objective

This code finds the yield necessary to produce a specified personnel weapon radius for the twenty environments listed in section 4 for the surface and near-optimum HOB cases. The accuracy of this inversion of the CROMs program 04 will generally be within ±5%, although there may be a few areas with errors slightly larger.

The program uses two cards. The two sides of card one are read into banks 1 and 2 respectively. With the other card, the first side (marked 3a) is read into bank 3 for calculation of the surface burst case, and the second side (marked 3b) is read into bank 3 for the near-optimum HOB case.

For convenience, one can also, with this card, exercise the CROM Personnel Vulnerability calculation in the forward direction (i.e., finding WR, given the yield, etc.), without having to call Pgm 01. That calculation is begun through key 2nd E'; done in this way, the environment number is retained for successive calculations.

B. Inputs - Outputs

Inputs: Yield (KT) (for calculation of weapon radius)
HOB (ft)
Environment index
Weapon radius (ft) (for calculation of yield)

Outputs: Yield (KT)
HOB (optimum) (ft)
Weapon radius (ft)

C. Limits

Yield: $0.1 \leq Y \leq 30{,}000$ KT

HOB: $0 \leq HOB \leq 1000\ Y^{1/3}$ ft

Environment: Env. = 1,2,3,...20 (see section 4)

Weapon Radius: (limit is environment-dependent; maximum weapon radius corresponds to a yield of 30,000 KT, and minimum weapon radius corresponds to a yield of 0.1 KT.)

D. Data Storage

Variables	Registers	Alphanumerics
Yield	R10	Y
HOB	R11	H
Environment	R20	E
Weapon radius	R12	W

EXAMPLE #1:

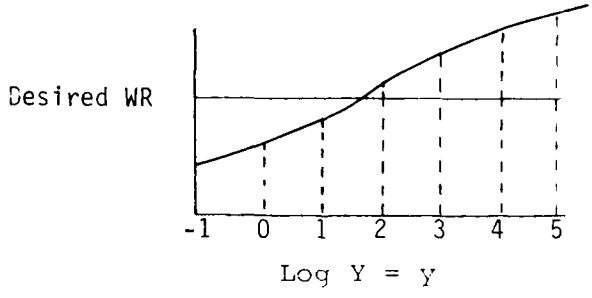
Calculate the yield that produces a weapon radius of 20,000 ft. for the near-optimum height of burst case, for the first environment category.

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off, then on			0	
2	Read both sides of first card, and second side of second card (3b) (first side is for surface burst case)		CLR	1,2,3	
3	Enter environment category	1	C	1.	
4	Enter weapon radius	20000	B	20000.	
5	Initiate calculation		E	547.	20000. W 1. E 6540. H 547. Y

EQUATIONS

The inversions for yield are done by fitting a cubic interpolating polynomial through four values of the weapon radius curve around the point to be inverted, and inverting the polynomial for the desired yield. The values for the interpolating polynomial are obtained from a lookup table, as described below.

Each of the data registers 30-47 contains (in packed form) weapon radii at every decade of yield between 1 and 10^5, for environment categories 1-18, respectively. Data on the first side of the second card are for surface bursts, and data on the reverse side are for optimum heights of burst. The weapon radius for Y = .1 KT is obtained from the lookup table in Program 4 (and is adjusted to y_0' (adjusted weapon radius) in the optimum HOB case), thus providing information for WR for values of Log Y = -1, 0, 1, 2, 3, 4 and 5. Four points that "box" the desired weapon radius are chosen, so that two are greater than the desired WR, and two are less that the desired WR.



These four points define a unique cubic polynomial, which is set up as described below. Once these four points have been obtained, an approximate solution to the cubic equation is effected by first setting up a quadratic equation that interpolates the first three points on the graph, and inverting it for a "first guess" at Y, and then expanding the cubic polynomial into a second-order Taylor series about the "first series", and solving the resulting quadratic equation. This approximate inversion to the cubic polynomial is sufficiently accurate so that there is no significant deviation from the true solution to the cubic polynomial. The polynomial itself approximates the data to $\leq$ 2%, except in the transition

region around Y = 10 KT, when it gets as high as 4-7%. This gives an error in yield of ~5% normally, and ~20% in the transition region, in some cases.

The equations for this procedure are as follows. (The cubic polynomial is in log-log space).

Calling the four points along the abscissa that box the desired weapon radius (in log-log space) y_{-1}, y_0, y_1, y_2, and the corresponding ordinate points W_{-1}, W_0, W_1, W_2, then the quadratic formula that interpolates the first three points,

$$f_q(y-y_0) = a_q\ y-y_0\ ^2 + b_q\ y-y_0\ + c_q \tag{1}$$

has coefficients

$$a_q = \frac{1}{2}(W_{-1} + W_1) - W_0 \tag{2}$$

$$b_q = \frac{1}{2}(W_1 - W_{-1}) \tag{3}$$

$$c_q = W_0 \tag{4}$$

and the cubic interpolating polynomial,

$$f_c(y - y_0) = a_c(y - y_0)^3 + b_c(y - y_0)^2 + c_c(y - y_0) + d_c \tag{5}$$

has coefficients

$$a_c = \frac{1}{6}(W_2 - 3W_1 + 3W_0 - W_{-1}) \tag{6}$$

$$b_c = \frac{1}{2}(W_{-1} + W_1) - W_0 = a_q \tag{7}$$

$$c_c = \frac{1}{6}(-2W_{-1} - 3W_0 + 6W_1 - W_2) = \frac{1}{2}(W_1 - W_{-1}) - a_c = b_q - a_c \tag{8}$$

$$d_c = W_0 = c_q \tag{9}$$

It is convenient to express these coefficients in a slightly different form:

let $\gamma = 2a_q = 2b_c$; (10)

$\beta = b_q$ (11)

$\alpha = W_0 = c_q = d_c$ (12)

$\delta = 3a_c = (\gamma + \beta) + \frac{1}{2}(W_0 - W_2)$ (13)

Calling y_q the solution to the quadratic formula, then

$$(y_q - y_o) = \frac{-\delta}{\gamma} + \text{sgn}(\gamma)\sqrt{\left(\frac{-\beta}{\gamma}\right)^2 - \frac{2(\alpha - W)}{\gamma}} \quad (14)$$

where $W = \ln WR$ (15)

and the cubic polynomial Taylor series expansion has the form

$$f(y - y_q) = f(y_q - y_0) + f'(y_q - y_0)(y - y_q) + \frac{1}{2}f''(y_q - y_0)(y - y_0)^2 \quad (16)$$

Where f' and f'' are the first and second derivatives of f, respectively.

Let $r = \frac{f'(y_q)}{f''(y_q)} = \frac{y_q(\delta y_q + \gamma) + \beta - \alpha/3}{(2\delta y_q + \gamma)}$ (17)

Then using the approximation of (16),

$$(y - y_q) = -\gamma + \text{sgn}(2\delta y_q + \gamma)\sqrt{r^2 - \frac{2(f(y_q) - W)}{(2\delta y_q + \gamma)}} \quad (18)$$

which gives the final result,

$$\text{Yield} = 10^Y \quad (19)$$

If $W > W_f$ (= ℓn WR at yield = 10^4 KT), then the yield is approximated as

$$\exp(W - W_f) = \left(\frac{Y}{10^4}\right)^{1/3} \tag{20}$$

or

$$Y = 10^4 \exp\left[-3(W_f - W)\right], \tag{21}$$

setting as an upper limit on WR

$$\exp(W - W_f) = 3^{1/3} \rightarrow WR_{max} = \exp\left(W_f + \frac{1}{3}\ell n 3\right) \tag{22}$$

The more accurate approximation calculates a weapon radius given this value of Y, and calculates a new Y (Yield) as

$$\left(\frac{Y_{new}}{Y}\right)^{1/3} = \left(\frac{WR_{new}}{WR}\right), \tag{23}$$

or

$$(Y_{new}) = Y\left(\frac{WR_{new}}{WR}\right)^3 \tag{24}$$

The last two categories can be inverted analytically for yield:

$$WR = \left[a + \alpha(Y - b)^P\right]^{-1} \quad \text{(see Program 4 equations)} \tag{25}$$

or

$$Y = \left[\frac{WR^{-1} - a}{\alpha}\right]^{-1/P} + b \tag{26}$$

The coefficients a, α, p and b are packed in registers 48 and 49, as:

	Class 19		Class 20	
	HOB = 0	HOB = optimum	HOB = 0	HOB = optimum
$\frac{1}{8} \times 10^4 a^{-1}$	110	679	1.0	502
$10^5 \alpha$	73	61	57	46
p	.445	.445	.462	.462
$10^5 b$	150	3939	125	2367

PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
559.49	1	Suppresses CROM printing		
AUTOMATIC	2	For short or long calculation		
LIBRARY MODULE				
CROM A-1				

DATA REGISTERS FOR EXAMPLE 1

DATA	REG.	COMMENTS
101.	00	Subroutine addresses
965.1679343	01	
21.	02	= 10
0.122244373	03	
2134.783554	04	
.8288712996	05	
20000.	06	
20000.	07	
0.	08	
1633.648041	09	
547.	10	Yield
6540.	11	= 0
20000.	12	Weapon radius
12.	13	Address for environment-dependent coding
6.2	14	
0.	15	
0.	16	
0.	17	
.3999999975	18	
6544.268239	19	
1.	20	Environment type
8.508009781	21	
9.904604435	22	
15.97562075	23	
2.951443219	24	
.2083570601	25	
.9999999993	26	
.0000362436	27	
5.491845105	28	
1562.250761	29	
8.6879193 11	30	
8.08291 11	31	
8.1849064 11	32	
8.08289 11	33	
7.7838452 11	34	
7.7808585 11	35	
5.5574533 11	36	
7.0785132 11	37	
4.9554335 11	38	
6.1604535 11	39	

LABELS

STEP	CODE	KEY	COMMENTS
005	18	C'	Retrieve data
010	16	A'	Retrieve R02 digits
025	17	B'	e-x
032	19	D'	→f(x),f'(x), f''(x)
057	14	D	quadratic form
085	11	A	Y→
090	12	B	WR→
095	13	C	E→
100	10	E'	→WR
203	35	=	print output
435	15	E	→Y

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	43	RDN	
001	43	RDN	End of calculation
002	43	RDN	
003	81	R/S	
004	76	LBL	Label C'. Retrieve data
005	19	D'	for environment E
006	02	2	
007	09	9	
008	85	+	
009	43	RCL	E
010	30	30	
011	95	=	
012	42	STO	
013	00	00	
014	73	RC*	
015	00	00	
016	42	STO	Data table for relevant
017	13	13	environment
018	76	LBL	Label A'. Retrieve R02
019	16	A'	digits from register
020	36	PGM	13.
021	04	04	(data unpacking)
022	16	A'	
023	32	RTN	
024	76	LBL	Label B'.
025	17	B'	
026	54	)	
027	84	+/-	Calculate e^{-x}
028	32	INV	
029	23	LNX	
030	32	RTN	
031	76	LBL	Label D'. Used in
032	19	D'	calculating f'(x) and
033	32	INV	f(x) (where f(x) is
034	49	PRD	cubic polynomial)
035	24	24	
036	43	RCL	
037	24	24	
038	84	+/-	
039	75	-	
040	43	RCL	
041	25	25	
042	85	+	
043	43	RCL	
044	01	01	
045	65	×	
046	53	(	
047	34	FX	

STEP	CODE	KEY	COMMENTS
048	65	×	Entry point for calcu-
049	43	RCL	lating f''(x)
050	24	24	
051	85	+	
052	43	RCL	
053	23	23	
054	95	=	
055	32	RTN	
056	76	LBL	Label D. Quadratic
057	14	D	formula, to invert for
058	85	+	x
059	53	(	
060	33	X²	
061	75	-	
062	02	2	2 × ...
063	65	×	
064	53	(	
065	43	RCL	(f(x) ...
066	22	22	
067	75	-	
068	43	RCL	
069	12	12	
070	23	LNX	- y) ...
071	54	)	
072	55	÷	
073	43	RCL	: f''(x)
074	23	23	
075	54	)	
076	34	FX	
077	65	×	
078	43	RCL	
079	23	23	
080	69	OP	
081	10	10	$\text{sgn}(f''(x))=\text{sgn}\left[\frac{f'(x)}{f''(x)}\right]$
082	95	=	
083	32	RTN	
084	76	LBL	Label A. Enter Yield
085	11	A	
086	42	STO	
087	10	10	
088	32	RTN	
089	76	LBL	Label B. Enter weapon
090	12	B	radius
091	42	STO	
092	12	12	
093	32	RTN	
094	76	LBL	Label C. Enter environ-
095	13	C	ment type

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
098	42	STO	
099	00	00	
100	32	RTN	
101	76	LBL	Label E'.
102	15	E'	
103	00	0	
104	00	0	
105	11	A	
106	36	PGM	
107	01	01	Calculate WR
108	00	00	
109	36	PGM	Advance paper
110	00	00	
111	76	LBL	Subroutine sets up a CROM call to calculate WR
112	00	0	
113	42	STO	
114	00	00	
115	02	2	
116	00	0	
117	36	PGM	
118	06	06	
119	51	EXC	
120	42	STO	
121	00	00	
122	44	RCL	
123	20	20	
124	51	EXC	
125	42	STO	Preserve old WR
126	06	06	
127	36	PGM	
128	04	04	
129	36	PGM	
130	00	IND	
131	00	00	
132	42	STO	
133	12	B	
134	32	RTN	
135	01	1	Case for environment category 15
136	55	=	
137	01	1	
138	44	RCL	Start of inversion for WR
139	12	B	
140	65	LN	
141	01	1	W-t
142	42	STO	
143	09	09	
144	55	=	y_0'=lower limit for WR
145	42	STO	
146	00	00	
147	01	1	
148	00	0	
149	00	0	
150	00	0	
151	00	0	
152	00	0	
153	00	0	
154	00	0	
155	00	0	
156	00	0	
157	00	0	
158	00	0	
159	00	0	
160	00	0	
161	00	0	
162	00	0	
163	00	0	
164	00	0	
165	00	0	
166	00	0	
167	00	0	
168	00	0	
169	15	E'	Calculate upper limit on WR:
170	00	0	$WR_{max}=\exp(W_f+\frac{1}{3}\ln 3)$
171	55	=	

Set up W_1

Shift W_1, W_2, W_3 until $W_3 \cdot W$

Case for $W \cdot W_f$ ($W_f = W/_{y=10^4}$)

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
192	03	3	
193	17	B'	
194	65	×	
195	01	1	
196	52	EE	
197	04	4	$Y+10^4\exp[-3(W_f-W)]$
198	87	IFF	
199	02	02	
200	03	03	Calculate WR(Y) and adjust Y
201	47	47	
202	76	LBL	Label =.
203	95	=	
204	95	=	
205	42	STO	
206	10	10	Calculated Yield.
207	32	IN^	
208	45	Y^	
209	03	3	
210	95	=	
211	49	PRD	
212	11	11	R11 = HOB = $\hat{H}\ Y^{1/3}$
213	22	IN^	
214	86	STF	
215	01	01	
216	06	6	
217	69	DP	
218	17	17	
219	43	RCL	Print WR
220	09	09	
221	85	+	
222	43	RCL	
223	12	12	
224	32	X:T	
225	65	×	
226	04	4	
227	03	3	
228	36	PGM	
229	09	09	
230	11	A	Print environment
231	01	1	
232	07	7	
233	32	X:T	
234	02	2	
235	00	0	
236	42	STO	
237	02	02	
238	36	PGM	
239	09	09	
240	16	A'	
241	02	2	
242	03	3	
243	32	X:T	
244	43	RCL	Print HOB
245	11	11	
246	36	PGM	
247	09	09	
248	12	B	
249	42	STO	
250	11	11	
251	38	ADV	
252	04	4	
253	05	5	
254	32	X:T	
255	43	RCL	Print Yield
256	10	10	
257	36	PGM	
258	09	09	
259	12	B	
260	42	STO	
261	10	10	
262	01	PST	
263	42	STO	Set up interpolating polynomial:
264	23	23	
265	16	A'	R23 = W_3
266	95	=	
267	42	STO	R24 = W_4
268	24	24	
269	43	RCL	
270	21	21	
271	75	-	
272	48	EXC	
273	23	23	
274	44	SUM	
275	23	23	
276	95	=	2β
277	44	SUM	
278	24	24	
279	55	÷	
280	43	RCL	
281	22	22	
282	94	+/-	
283	44	SUM	
284	23	23	
285	44	SUM	
286	23	23	γ in R23
287	44	SUM	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
288	24	24	
289	02	2	
290	55	÷	
291	42	STO	
292	25	25	β in R25
293	43	RCL	
294	23	23	
295	22	INV	
296	44	SUM	
297	24	24	
298	22	INV	
299	44	SUM	2δ in R24
300	24	24	
301	14	D	
302	42	STO	
303	01	01	Solve for $(y_q - Y_0)$
304	71	SBR	
305	00	00	
306	48	48	Calculate $f''(y_q - Y_0)$
307	32	X↕T	
308	03	3	
309	35	1/X	
310	65	×	
311	02	2	
312	19	D'	Calculate $f'(y_q - Y_0)$
313	94	+/-	
314	48	EXC	
315	22	22	$-f'(y_q - y_0)\downarrow\uparrow\alpha$
316	85	+	
317	02	2	
318	22	INV	
319	49	PRD	
320	23	23	
321	43	RCL	
322	01	01	
323	65	×	
324	53	(	
325	03	3	
326	19	D'	
327	48	EXC	
328	22	22	$f(y_q-y_0)\downarrow\uparrow-f'(y_q-y_0)$
329	55	÷	
330	43	RCL	
331	12	12	
332	32	X↕T	
333	42	STO	$f''(y_q-y_0)$
334	23	23	
335	14	D	
336	85	+	
337	43	RCL	
338	01	01	
339	85	+	
340	04	4	$(y-y_q)+(y_q-y_0)+4$
341	75	-	
342	43	RCL	
343	00	00	
344	95	=	$\log Y=(y-y_q)+(y_q-y_0)+$
345	22	INV	4-R00
346	28	LOG	
347	95	=	
348	42	STO	Y(obtained from cubic
349	10	10	spirals)
350	32	X↕T	
351	42	STO	
352	07	07	Store limit on WR
353	71	SBR	
354	01	01	Calculate WR at newly
355	08	08	found yield.
356	35	1/X	
357	65	×	
358	43	RCL	
359	07	07	
360	32	X↕T	
361	43	RCL	
362	06	06	
363	42	STO	
364	12	12	
365	65	×	
366	33	X^2	
367	95	=	Correction to yield
368	49	PRD	
369	10	10	
370	61	GTO	
371	02	02	
372	13	13	
373	25	CLR	Environment categories
374	01	1	19 and 20
375	06	6	
376	52	EE	
377	04	4	
378	55	-	
379	71	SBR	
380	05	05	
381	57	57	
382	32	X↕T	upper limit on WR
383	18	C'	$10^{-4}\hat{A}$

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
384	42	STO	
385	11	11	
386	01	1	
387	52	EE	
388	04	4	
389	49	PRD	$\hat{H}$ in R11
390	11	11	
391	55	÷	
392	01	1	
393	00	0	
394	42	STO	
395	09	09	
396	49	PRD	
397	09	09	Lower limit on WR
398	49	PRD	
399	02	02	(so as to retrieve 2
400	55	÷	digits at a time)
401	16	A'	
402	65	×	$\frac{1}{\alpha}$ ×...
403	53	(	
404	43	RCL	
405	12	12	
406	35	1/X	
407	75	-	
408	08	8	
409	55	÷	
410	01	1	
411	32	EE	
412	06	6	
413	55	÷	
414	01	1	
415	00	0	
416	49	PRD	
417	02	02	
418	55	÷	
419	16	A'	... $\frac{1}{WR}$ - a
420	95	=	
421	32	INV	
422	45	Y^X	
423	16	A'	
424	94	+/-	-P
425	85	+	
426	43	RCL	
427	13	13	
428	55	÷	
429	01	1	
430	52	EE	
431	05	5	b

STEP	CODE	KEY	COMMENTS
432	61	GTO	
433	95	=	
434	76	LBL	Label E.
435	15	E	
436	25	CLR	Initiate calculation
437	42	STO	
438	11	11	R11 = 0
439	36	STF	
440	02	02	
441	36	STF	
442	01	01	
443	23	INV	
444	58	FIX	
445	22	IN	
446	71	ENG	
447	05	5	
448	63	DP	Repartitions
449	17	17	
450	43	RCL	
451	20	20	Environment to t
452	22	XIT	
453	01	1	
454	00	0	
455	42	STO	R02 = 10
456	02	02	
457	65	×	
458	01	1	
459	08	8	Environment categories 19 and 20, go to 373
460	23	INV	
461	77	GE	
462	03	03	
463	73	73	
464	01	1	
465	05	5	
466	67	EQ	
467	01	01	
468	33	33	Environment category
469	22	XIT	15, go to 133
470	85	+	
471	06	6	
472	02	2	
473	01	1	
474	95	=	
475	42	STO	
476	13	13	
477	36	PGM	Retrieve data for y_0 and H_{opt}
478	04	04	
479	71	SBR	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
480	40	IND	
481	13	13	
482	55	÷	
483	01	1	Start of case for $\hat{H}_{opt}$. Listing for surface burst case is shown after listing for $\hat{H}_{opt}$ case
484	00	0	
485	00	0	
486	95	=	
487	59	INT	
488	42	STO	
489	13	13	Packed data
490	16	A'	
491	55	÷	
492	93	.	
493	01	1	
494	22	INV	
495	49	PRD	Change number of digits to be retrieved
496	02	02	
497	22	INV	
498	67	EQ	
499	05	05	
500	02	02	
501	55	÷	
502	93	.	
503	00	0	
504	00	0	
505	01	1	
506	95	=	
507	42	STO	
508	11	11	$\hat{H}$
509	16	A'	
510	16	A'	
511	85	+	
512	03	3	
513	95	=	
514	22	INV	
515	33	LOG	unpack Y_0
516	75	-	
517	01	1	
518	08	8	
519	00	0	
520	85	+	
521	34	CE	Start of calculation for y_0'
522	55	÷	
523	53	(	
524	34	CE	
525	75	-	
526	32	X↔T	
527	05	5	
528	00	0	
529	33	X²	
530	85	+	
531	93	.	
532	06	6	
533	85	+	
534	93	.	
535	08	8	
536	65	×	
537	43	RCL	
538	11	11	
539	33	X²	
540	55	÷	
541	32	X↔T	
542	33	X²	
543	85	+	
544	01	1	
545	02	2	
546	04	4	
547	55	÷	
548	43	RCL	
549	11	11	
550	55	÷	
551	34	ΠX	
552	17	B'	y_0'
553	61	GTO	
554	01	01	
555	34	34	
556	00	0	
557	01	1	Indicator to program that H_{opt} case is in memory
558	95	=	
559	32	RTN	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
479	71	SBR	Program for HOB=0
480	40	IND	
481	13	13	
482	55	÷	
483	01	1	
484	52	EE	
485	05	5	
486	95	=	
487	50	INT	
488	42	STO	Retrieve packed data
489	12	12	
490	01	1	
491	00	0	
492	44	PRD	
493	02	02	
494	16	A'	
495	35	÷	
496	03	3	
497	95	=	
498	32	INV	
499	38	LOG	
500	45	-	
501	01	1	
502	08	8	
503	00	0	
504	95	=	Unpack $y_0 = y_0'$
505	41	STO	
506	01	01	
507	35	35	
508	00	0	
509	00	0	
510	00	0	
511	00	0	
512	00	0	
513	00	0	
514	00	0	
515	00	0	
516	00	0	
517	00	0	
518	00	0	
519	00	0	
520	00	0	
521	00	0	
522	00	0	
523	00	0	
524	00	0	
525	00	0	
526	00	0	
527	00	0	
528	00	0	
529	00	0	
530	00	0	
531	00	0	
532	00	0	
533	00	0	
534	00	0	
535	00	0	
536	00	0	
537	00	0	
538	00	0	
539	00	0	
540	00	0	
541	00	0	
542	00	0	
543	00	0	
544	00	0	
545	00	0	
546	00	0	
547	00	0	
548	00	0	
549	00	0	
550	00	0	
551	00	0	
552	00	0	
553	00	0	
554	00	0	
555	00	0	
556	00	0	
557	02	2	Indicator to program that surface burst case is in memory.
558	95	=	
559	92	RTN	

1	DNA AP-550 CONTROL A1 HTI			1
CRATERING, 2nd DOB CALCULATION				
				7.n → CALC
YIELD	HOB	MEDIUM	CRATER RADIUS	→ 2nd DOB

SOURCE OF DATA:

Defense Intelligency Agency, Physical Vulnerability Handbook - Nuclear Weapons (U), AP-550-1-2-69-INT, June 1, 1969, Part II.

DESCRIPTION:

A. Objective

Program 7.1 of the AP-550 CROM calculates the upper of two depths of burst of yield Y, which will produce a crater of a specified radius, (R), in the designated earth medium, (M). This control program calculates the greater of the two depths, and, for convenience in comparison, will exercise program 07 if desired. Keeping with the convention established, a depth of burst is referred to as a negative HOB.

B. Inputs - Outputs

The user enters the weapon yield, (Y), crater radius, (R), and medium number, (M), corresponding to one of these media:

Dry rock (M=1)
Wet rock (M=2)
Dry soil (M=3)
Wet soil (M=4)

Inputs may be entered in any order.

The program includes limits for all entered values:

$0.1 \leq Y \leq 30{,}000$ KT

$1 \leq M \leq 4$

$0 \leq R \leq$ upper limit (U.L.)

$$\begin{cases} \text{U.L.} = 151(Y)^{0.3} & \text{for M=1} \\ \text{U.L.} = 172(Y)^{0.3} & \text{for M=2} \\ \text{U.L.} = 159(Y)^{0.3} & \text{for M=3} \\ \text{U.L.} = 210(Y)^{0.3} & \text{for M=4} \end{cases}$$

After the calculation is initiated, the program checks each value against its limits and prints the value. If a limit is violated, the calculator stops printing the inputs and

flashes the exceeded limit in the display. The input value is printed with a question mark and put in the t-register. To re-enter an acceptable value, press CLR and re-enter the new value into the appropriate key. Then press R/S to start the calculation over.

The calculation can be started by pressing key E or R/S after the appropriate data is entered.

C. Special Features

The five cratering calculation options given in Section 7 of this document can also be run by entering the appropriate calculation number in key 2nd E'. The program leaves the calculator in the radian angular mode.

D. Data Storage Locations and Printer Alphanumerics

The user may find the following information in the indicated registers.

Variable	Register	Alphanumerics
Yield	R10	Y
Medium	R12	M
Radius	R13	R
HOB	R11	H

EXAMPLE #1:

Find the greatest depth of burst (a negative HOB means a distance below the ground) for which a 10-KT weapon will produce a crater radius of 315 feet in wet soil.

Compare this to the DOB nearer the surface at which the same weapon will produce the same crater radius.

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off, then on			0	
2	Read one side of program card			1.	
3	Enter yield, Y (KT)	10	A	10.	
4	Enter crater radius, R (ft)	315	D	315.	
5	Enter medium number (1=dry rock, 2=wet rock, 3=dry soil, 4=wet soil)	4	C	4.	
6	Calculate the DOB (ft)		E		10. Y 4. M 315. R -447. H
7	Calculate the upper DOB (A)	7.1	2nd E'		7.1 10. Y 4. M 315. R -72.4 -72.4 H

PRINTER OUTPUT:

```
  10.      Y
   4.      M
 315.      R

-447.      H
```

```
   7.1
  10.      Y
   4.      M
 315.      R

 -72.4     H
```

EQUATIONS

Definitions

Y = Yield (kilotons)

HOB = Height of Burst (feet)

R = Crater Radius (feet)

$$\text{Define z:} \quad z = \arcsin\left[\frac{\ln \frac{R}{Y^{0.3}} + d}{c}\right] \tag{1}$$

$$\text{Then HOB} = -3.3(Y)^{0.3}\exp\left[\frac{a - (z)^{20/3}}{b}\right] \tag{2}$$

The coefficients are:

Coefficient	Dry Rock	Wet Rock	Dry Soil	Wet Soil
a	150.0	153.0	117.0	128.3
b	37.0	36.0	25.0	29.0
c	6.02	5.15	5.07	8.35
d	1.0	0.0	0.0	3.0

NOTE:

Equation (2) is an analytic inversion of the crater radius curvefit equation:

$$R = (Y)^{0.3}\exp\left\{c \sin\left|\left(a - b\ln\left(\frac{-HOB}{3.3Y^{0.3}}\right)\right)^{0.15}\right| - d\right\}$$

PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
479.59	Not used			

AUTOMATIC

LIBRARY MODULE

CROM A-1

DATA REGISTERS FOR EXAMPLE 1

DATA	REG.	COMMENTS
7.1	00	n.n
47.64059957	01	Temp
3.	02	Temp
21.93244743	03	Temp
3.0800019441	04	Temp
14.34667064	05	Temp
0.	06	
0.	07	
0.	08	
0.	09	
10.	10	Y
-72.4	11	H
4.	12	M
315.	13	R
0.	14	
0.	15	
0.	16	
0.	17	
0.	18	
0.	19	
0.	20	
156813056O.	21	Temp
0.	22	
0.	23	
-6.43083987	24	Temp
14.34667064	25	Temp
3.0800019441	26	Temp

LABELS

STEP	CODE	KEY	COMMENTS
017	16	A'	Unpacker rtne.
022	11	A	Store yield
029	13	C	Store medium
035	14	D	Store radius
039	36	INPT	Prepare for calc.
047	15	E	2nd HOB calc.
163	16	E'	CROM cratering
168	12	B	Store HOB

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	01	1	Upper Limit for radius M = 1
001	05	5	
002	01	1	
003	32	RTN	
004	01	1	Upper Limit for radius M = 2
005	07	7	
006	02	2	
007	32	RTN	
008	01	1	Upper Limit for radius M = 3
009	05	5	
010	09	9	
011	32	RTN	
012	02	2	Upper Limit for radius M = 4
013	01	1	
014	00	0	
015	32	RTN	
016	76	LBL	Label A'.
017	16	A'	
018	36	PGM	Call Pgm 7 Unpacker
019	07	07	
020	16	A'	
021	32	RTN	
022	76	LBL	Label A.
023	11	A	
024	42	STO	Store yield in R10
025	10	10	
026	81	GTO	Go to Label WRT
027	36	WRT	
028	76	LBL	Label C.
029	13	C	
030	42	STO	Store medium in R12
031	12	12	
032	81	GTO	Go to Label WRT
033	36	WRT	
034	76	LBL	Label D.
035	14	D	
036	42	STO	Store radius in R13
037	13	13	
038	76	LBL	Label WRT.
039	36	WRT	
040	32	X↕T	Remove scientific and fixed notation from display.
041	35	CLR	
042	22	INV	
043	28	FIX	
044	32	X↕T	
045	32	RTN	
046	76	LBL	Label E.
047	15	E	
048	38	ADV	
049	22	INV	Reset flags 0 and 1
050	36	STF	
051	00	00	
052	22	INV	
053	36	STF	
054	01	01	
055	01	1	Store 10 in R02
056	00	0	
057	42	STO	
058	02	02	
059	36	PGM	Call yield limit checker and printer
060	07	07	
061	71	SBR	
062	45	Y^x	
063	69	DP	Add 1 to R02
064	22	22	
065	36	PGM	Call medium limit checker and printer
066	07	07	
067	71	SBR	
068	47	CMS	
069	04	4	
070	65	×	
071	43	RCL	4 × M - 4
072	12	12	
073	75	-	Store in R21
074	04	4	
075	95	=	Limit checks for radius
076	42	STO	
077	21	21	
078	00	0	Lower Limit = 0
079	85	+	
080	03	3	
081	05	5	Alphas for "R"
082	32	X↕T	
083	71	SBR	Call radius upper limit
084	40	IND	
085	21	21	
086	55	÷	Take U.L. × $(Y)^{0.3}$
087	36	PGM	
088	07	07	
089	15	E	
090	01	1	
091	36	PGM	Check limits and print radius
092	09	09	
093	13	C	
094	38	ADV	
095	01	1	Begin calculation

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
096	06	6	165
097	05	5	
098	85	+	+
099	02	2	
100	02	2	22
101	36	PGM	Call the routine to get
102	07	07	the coefficient string
103	17	B'	containing a, b, c and
104	03	3	d
105	42	STO	
106	02	02	R02 = 3
107	16	A'	
108	42	STO	Call unpacker to get a,
109	24	24	R24 = a
110	02	2	
111	16	A'	Call unpacker to get b,
112	42	STO	
113	25	25	R25 = b
114	01	1	
115	16	A'	Call unpacker to get c,
116	32	X:T	
117	36	PGM	put c in t register
118	07	07	
119	15	E	Calculation of eq. 1
120	43	RCL	
121	13	13	
122	95	=	
123	23	LNX	
124	85	+	
125	03	3	
126	16	A'	
127	95	=	
128	55	÷	
129	32	X:T	
130	95	=	
131	70	RAD	
132	32	INV	
133	38	SIN	z in display
134	32	INV	Calculation of eq. 2
135	45	Y^x	
136	93	.	
137	01	1	
138	05	5	
139	75	-	
140	43	RCL	
141	24	24	
142	95	=	
143	94	+/-	
144	55	÷	
145	43	RCL	
146	25	25	
147	95	=	
148	32	INV	
149	23	LNX	
150	36	PGM	Call routine to finish
151	07	07	eq. 2 and print small-
152	71	SBR	er HOB
153	06	06	
154	95	95	
155	98	ADV	
156	98	ADV	
157	98	ADV	
158	92	RTN	
159	61	GTO	Will do calculation
160	15	E	again when R/S pressed.
161	76	LBL	Label E'.
162	10	E'	
163	36	PGM	Call AP550 INPUT Pgm.
164	01	01	to begin calculation.
165	10	E'	
166	92	RTN	
167	76	LBL	Label B.
168	12	B	
169	42	STO	Store HOB in R11
170	11	11	
171	92	RTN	

APPENDIX D: PROBABILITY OF DAMAGE TO IRREGULARLY SHAPED TARGETS

1	DNA AP-550 CONTROL A1	HTI	2

PROBABILITY OF DAMAGE TO IRREGULARLY SHAPED TARGETS				
CEP	TARGET RADIUS	OFFSET	DAMAGE SIGMA	3.n → CALC
ANGLE	SIDE 1	WEAPON RADIUS	LENGTH OR SIDE 2	WIDTH OR SIDE 3

3	DNA AP-550 CONTROL A1	HTI	3

PROBABILITY OF DAMAGE TO IRREGULARLY SHAPED TARGETS				

SOURCE OF DATA:

Defense Intelligence Agency, Physical Vulnerability Handbook - Nuclear Weapons (U), AP-550-1-2-69-INT, June 1, 1969, Part IV.

DESCRIPTION:

A. Objective

The objective of this program set is to provide calculations of average probability of damage for rectangular, triangular and elliptical targets with uniform target element distributions. These programs use the Probability of Damage to Point Targets CROM program as a subroutine. The weighted point method is used and therefore target size limitations must be imposed to ensure accuracy. The limitations are:

Triangular target: longest side $\leq$ CEP
Rectangular target: diagonal $\leq$ CEP
Elliptical target: major axis $\leq 2 \times$ CEP

If target dimensions are greater than the limitations imposed above then the general case method for area targets should be used to compute the Pd. This method requires that the area target be divided into small cells of equal area whose greatest dimension is less than or equal to 1/4 of the CEP. Each cell is then considered a point target and the Pd to each cell is computed using the point target program with an offset equal to the distance from the DGZ to the center of each cell. The Pd to the whole area target is then obtained by averaging the Pd

to each cell. To implement the general case method for area targets, the user must use program 3.0 and then manually compute the average Pd.

B. Inputs - Outputs

The three calculations comprising this program set and their necessary inputs are as follows. Figure 3 gives a graphical representation of the inputs.

Program 3.3: Probability of damage - rectangular targets.
Inputs: Offset of the DGZ from the target center, (x) ft.
Angle between offset line and length, (A) deg.
Target length, (L) ft.
Target width, (WD) ft.

Program 3.4: Probability of damage - triangular targets.
Inputs: Offset of the DGZ from the "offset vertex", (x) ft.
Angle between offset line and side S1, (A) deg.
Lengths of the three sides, (S1, S2, S3) ft.
Note: Sides S1, S2 and S3 are defined by moving clockwise from the "offset vertex"; which is the triangle vertex to which the offset distance (x) is measured. (see figure 3)

Program 3.5: Probability of damage - elliptical targets.
Inputs: Offset of the DGZ from the target center, (x) ft.
Angle between offset line and major axis, (A) deg.
Length of major axis, (L) ft.
Length of minor axis, (WD) ft.

C. Limits

Rectangular targets:
Length (L): $WD \leq L \leq (CEP^2 - WD^2)^{1/2}$ ft.
Width (WD): $1 \leq WD \leq L$ ft.

Triangular targets:
Longest side (S): $1 \leq S \leq CEP$ ft.

Elliptical targets:
Major axis (L): $WD \leq L \leq 2 \times CEP$ ft.
Minor axis (WD): $1 \leq WD \leq L$ ft.

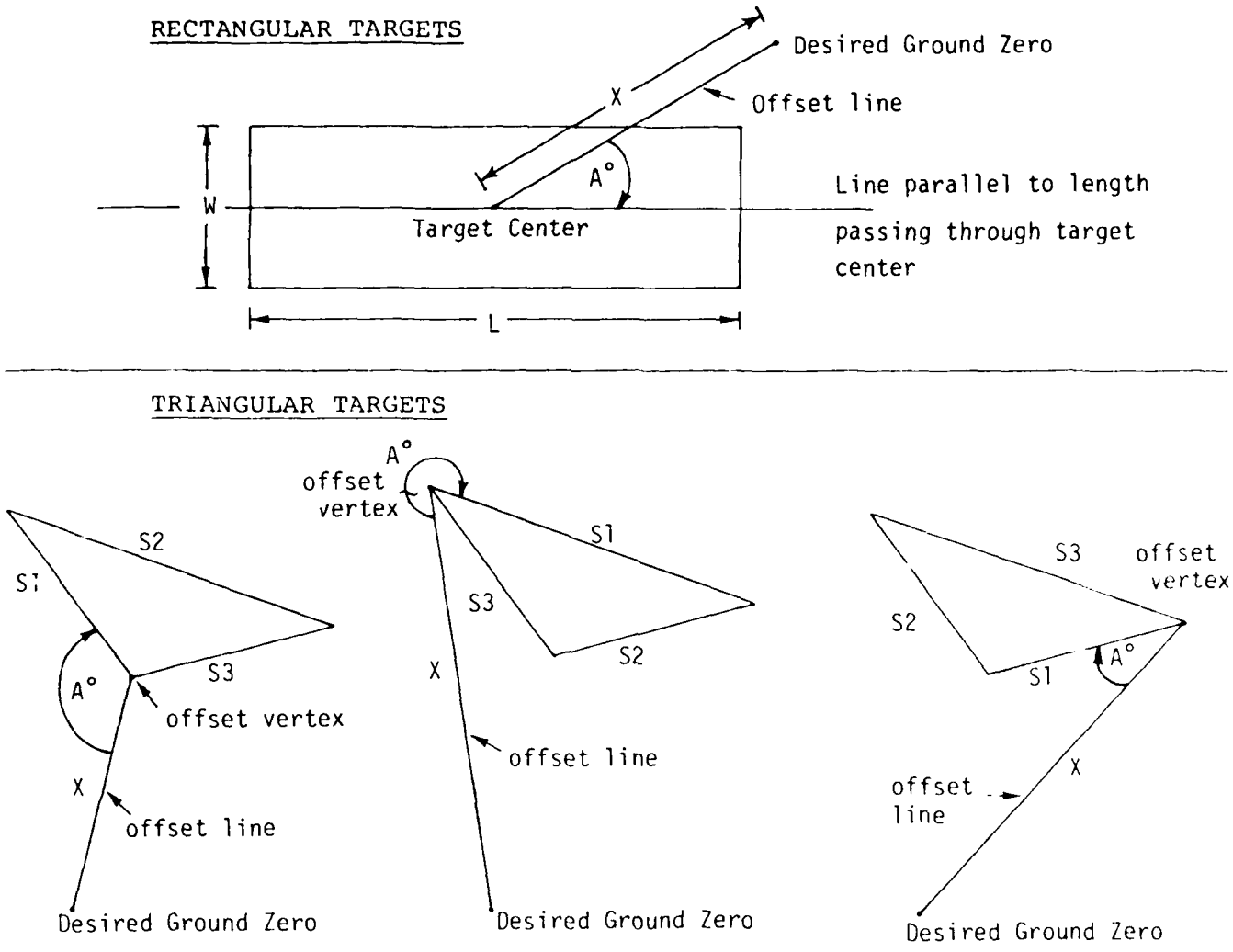


Figure 3. Definition of input dimensions for various area targets.

Input limits common to all target types:

Offset angle (A):	$A \geq 0$ deg.
Offset (x):	$x \geq 0$ ft.
CEP:	CEP ≥ 0 ft.
Damage sigma (S):	$0.1 \leq S \leq 0.5$
Weapon radius (W):	$W \geq 0$ ft.

D. Data Storage Locations and Printer Alphanumerics

The user can find the following information stored in the indicated registers.

Variables	Register	Alphanumerics
program no.	R00	--
angle	R10	A
triangle S1	R11	S1
weapon radius	R12	W
triangle S2	R13	S2
triangle S3	R14	S3
rect. length	R13	L
rect. width	R14	WD
major axis	R13	L
minor axis	R14	WD
CEP	R15	C
target radius	R16	TR
offset	R17	X
damage sigma	R18	S
Pd	R19	P

E. Special Features

The user may run the programs described in Section 3 of this documentation by entering the appropriate program designator (3.0, 3.1, or 3.2) with key 2nd E' of this control program. If this is done, a value for the target radius will be printed for all three programs even though the value is used in programs 3.1 and 3.2 only.

EXAMPLE #1: Probability of Damage to Area Targets

Given the following information:

Weapon Radius	= 400 ft	Offset	= 200 ft.
CEP	= 320 ft.	Damage sigma	= 0.4

calculate the average probability of damage for the following area targets.

(1) A 240-ft by 80-ft rectangle with a 53-degree angle between the offset and length lines.

(2) A 260-ft by 100-ft ellipse with the same angle between the offset and length (major axis) lines.

(3) A triangle with S1 = 100 ft, S2 = 100 ft, and S3 = 100 ft, and a 210-degree angle between offset line and S1 measured in the clockwise direction.

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
1	Turn off, then on			0	
2	Read both sides of card one, and one side of card two			1,2,3	
3	Enter weapon radius	400	C	400.	
4	Enter CEP	320	2nd A'	320.	
5	Enter offset	200	2nd C'	200.	
6	Enter damage sigma	.4	2nd D'	0.4	
	Target 1: Rectangle				
7	Enter target length	240	D	240.	
8	Enter target width	80	E	80.	
9	Enter angle between offset and length lines	53	A	53.	
10	Begin rectangular target calculation	3.3	2nd E'		3.3
					400. W
	(calculation takes 1.25 minutes)				320. C
					0. T
					200. X
					0.4 S
					53. A
					240. L
					80. WD
				0.432	0.432 P
	Target 2: Ellipse				
11	Enter target major axis	260	D	260.	
12	Enter target minor axis	100	E	100.	

EXAMPLE #1 (Cont.)

STEP	INSTRUCTIONS	INPUT	KEYS	DISPLAY	PRINT
13	Begin elliptical target calculation (calculation takes 1.8 minutes)	3.5	2nd E'		3.5 400. W 320. C 0. T 200. X 0.4 S 53. A 260. L 100. WD
				0.43	0.43 P
	Target 3: Triangle				
14	Enter S1	100	B	100.	
15	Enter S2	100	D	100.	
16	Enter S3	100	E	100.	
17	Enter angle corresponding to the number of degrees in the clockwise direction between the offset line and S1.	210	A	210.	
18	Begin triangular target calculation (calculation takes 1.0 minutes)	3.4	2nd E'		3.4 400. W 320. C 0. T 200. X 0.4 S 210. A 100. S1 100. S2 100. S3
				0.416	0.416 P

EQUATIONS

Definitions

WR = Weapon radius

X = Offset

σ = Damage sigma

CEP = Circular error probable

TR = Target radius

P = Probability of damage

Routines 3.0, 3.1 and 3.2

Initially the following adjusted values are calculated:

$$CEP_a = \sqrt{CEP^2 + kTR^2} \quad (1)$$

where k = 0 for point targets,

k = 0.231 for circular targets with normal distribution.

For circular targets with uniform distribution:

k = 0.4 when TR $\leq$ WR + CEP + x

k = 0.5 when TR > WR + CEP + x

$$W1 = WR \div CEP_a \quad (2)$$

For W1 $\leq$ 30, the following curvefit coefficients are calculated:

$$b = 26 \exp\left(-2.1\sigma - \frac{W1}{16}\right) \quad (3)$$

$$a = \exp\left|-\left(\frac{1339\exp(-42\sigma) - 2\sigma + 3.7}{W1}\right)^{\left[0.71\exp\left(\frac{\sigma}{0.3}\right)\right]}\right| - (\gamma + |\gamma|) \quad (4)$$

where $\gamma = 7000\sigma^{5.6}[\exp(-21\sigma)(W1-5.5)]$ (5)

$$R_0 = (3.6\sigma-2)W1 - (1.3+1.1\sigma)\ln[W1(0.24+\sigma)] \quad (6)$$

$$\varepsilon = W1 - 0.2 - (\beta + |\beta|) \tag{7}$$

$$\text{where } \beta = 0.61(W1 + 4\sigma - 3.2)\left(\sigma^{2.23} + \frac{10^{-5}}{\sigma^{2.23}}\right) \tag{8}$$

$$\varepsilon' = \ln\left[0.6\sigma + \frac{1}{\delta}\right] \tag{9}$$

$$\text{where } \delta = \frac{1}{1.2}\exp(10\sigma - 1.1W1) + \frac{1}{299}\exp\left[9.47\sigma - \frac{W1}{0.9}\exp(-2.69\sigma) - 2.7\ln\sigma\right] \tag{10}$$

$$T' = \tan[b(\varepsilon' - \varepsilon)] \tag{11}$$

$$L' = \ln[\lambda + |\ell| + 10^{-5}] \tag{12}$$

$$\text{where } \ell = \frac{1}{2+\varepsilon-\varepsilon'} \tag{13}$$

With these coefficients, the code proceeds to calculate the probability:

$$X1 = X \div CEP_a \tag{14}$$

$$R' = 3.89\left\{\frac{(1-a)}{T'}\tan[b(X1 - \varepsilon)] + \frac{a}{L'}\ln\left[\frac{X1 - \varepsilon' + 2}{\varepsilon - \varepsilon' + 2}\right]\right\} \tag{15}$$

$$\text{for } X1 \geq 2, \quad R = -R' \tag{16}$$

$$\text{for } X1 < 2, \quad R = \cos(45X1)\left(R_0 + \frac{X1}{0.9} + R'\right) - R' \tag{17}$$

For $W1 > 30$, R is given by,

$$R = -0.07z^3 - 1.6z \tag{18}$$

$$\text{where } z = \ln\left[(1-\sigma^2)\frac{WR}{X}\right] \div \sqrt{-\ln(1-\sigma^2)} \tag{19}$$

And finally to go from the transformed R space to the probability P we have

$$P = \frac{1}{1 + \exp(R)} \tag{20}$$

Routine 3.3 Average Probability of Damage to Rectangular Targets

Definitions

D_i = distance from the desired ground zero to one of the four corners of the rectangle.

A = angle between the offset line and length

L = length of rectangle

WD = width of rectangle

P_r = average Pd to the rectangular target

For i = 1 to i = 4,

$$D_i = \left[(X\cos A - 0.5gL)^2 + (X\sin A - 0.5hWD)^2\right]^{1/2} \quad (21)$$

where $g = \text{sgn}[\cos(90i+45)]$ (22)

$h = \text{sgn}[\cos(90i-45)]$ (23)

(Sgn is the signum function.)

The following table shows i, g and h:

i	g	h
1	-1	1
2	-1	-1
3	1	-1
4	1	1

For each D_i, $P(D_i)$ the probability of damage to a point target for the desired ground zero a distance D_i from the target is calculated by setting $X = D_i$ in equations 14 through 20.

$$P_r = \frac{6P(X) + P(D_1) + P(D_2) + P(D_3) + P(D_4)}{10} \quad (24)$$

Routine 3.4 Average Probability of Damage to Triangular Targets

Definitions

D_{12} = distance from the desired ground zero to the vertex of sides S1 and S2

D_{23} = distance from the desired ground zero to the vertex of sides S2 and S3

S1, S2 and S3 = 3 sides of the triangle (see figure 3, p.D-5)

D_c = distance from the desired ground zero to the centroid of the triangle

P_T = Average Pd to the triangular target

$$D_{12} = [(S1)^2 + X^2 - 2(S1)X\cos A]^{\frac{1}{2}} \quad (25)$$

$$D_{23} = [(S3)^2 + X^2 - 2(S3)X\cos(A + \ )]^{\frac{1}{2}} \quad (26)$$

$$\text{where } \ = \arccos\left[\frac{(S1)^2 + (S3)^2 - (S2)^2}{2(S1)(S3)}\right] \quad (27)$$

$$D_c = [M^2 + X^2 - 2MX\cos(A+ \ )] \quad (28)$$

$$\text{where } M = \frac{S1}{2}\,\frac{\sin(\ )}{\sin(\ +\ )} \quad (29)$$

$$\ = \arccos\left\{\frac{3(S1)^2 + (S3)^2 - (S2)^2}{(S1)\left[8(S1)^2 + 8(S3)^2 - 4(S2)^2\right]^{\frac{1}{2}}}\right\} \quad (30)$$

$$\ = \arccos\left\{\frac{(S2)^2 - (S3)^2}{(S1)\left[2(S2)^2 + 2(S3)^2 - (S1)^2\right]^{\frac{1}{2}}}\right\} \quad (31)$$

$$P_T = \frac{7P(D_c) + P(X) + P(D_{12}) + P(D_{23})}{10} \quad (32)$$

Routine 3.5 Average Probability of Damage to Elliptical Targets

Definitions

D_i = distance from the desired ground zero to the corners and midpoints of sides of an inscribed rectangle in the ellipse

A = angle between offset line and major axis

L = length of the major axis

WD = length of the minor axis

P_e = average Pd to an elliptical target

For i = 1 to i = 8

$$D_i = \left[\left(X\cos A - \frac{f\sqrt{L^2 - WD^2}}{2}\right)^2 + \left(X\sin A - j\frac{WD^2}{2L}\right)^2\right]^{\frac{1}{2}} \tag{33}$$

where $f = \text{sgn}[\cos(45i + 45)]$ (34)

$j = \text{sgn}[\cos(45i - 45)]$ (35)

The following table shows i, f and j

i	f	j
1	0	1
2	-1	1
3	-1	0
4	-1	-1
5	0	-1
6	1	-1
7	1	0
8	1	1

$$P_e = \frac{4[P(X)+P(D_1)+P(D_3)+P(D_5)+P(D_7)] + P(D_2)+P(D_4)+P(D_6)+P(D_8)}{24} \tag{36}$$

PARTITION	FLAG	COMMENTS	FLAG	COMMENTS
559.49	See Pgm. 3 A1 CROM flags			

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CROM A-1

DATA REGISTERS FOR EXAMPLE _____

DATA	REG.	COMMENTS
3.4	00	Program no.
1.25	01	W1
15.	02	Print Routine Ind. Reg.
320.	03	CEP_a
234.26553804	04	Temp
0.4	05	Temp
0.	06	Temp
30.	07	Temp
10000.	08	Temp
-10000.	09	Temp
210.	10	A
100.	11	S1
400.	12	WR
100.	13	S2 or L
100.	14	S3 or WD
320.	15	CEP
0.	16	TR
200.	17	x
0.4	18	Damage Sigma
0.416	19	P
.53497659962	20	Temp
-1.05	21	-c
-1.1413373315	22	c'
10.3809411	23	b
.00006450666	24	a
-.3117302207	25	R_0
-.4192967045	26	T'
-.73985171144	27	L'
4.1640791106	28	Temp
0.	29	Registers 29 through 49 unused
0.	30	
0.	31	
0.	32	
0.	33	
0.	34	
0.	35	
0.	36	
0.	37	
0.	38	
0.	39	

LABELS STEP	CODE	KEY	COMMENTS
001	11	A	Enter angle
005	86	MRT	Clear format
01E	34	[illegible]	Triangle calc.
028	89	DP	Limit checks
043	36	PGM	Calc. 3.0, 3.1, 3.2
058	19	COS	Cosine law
[illegible]	[illegible]	[illegible]	Distance calc.
[illegible]	[illegible]	[illegible]	Calc. $P(D_i)$
[illegible]	[illegible]	[illegible]	Limit checks
[illegible]	[illegible]	[illegible]	Rectangle calc.
[illegible]	[illegible]	[illegible]	Rectangle calc.
[illegible]	[illegible]	=	Print P
[illegible]	[illegible]	[illegible]	Ellipse calc.
[illegible]	[illegible]	[illegible]	Ellipse calc.
[illegible]	[illegible]	[illegible]	Enter S1
[illegible]	[illegible]	[illegible]	Enter WR
[illegible]	[illegible]	[illegible]	Enter SZ or L
[illegible]	[illegible]	[illegible]	Enter S3 or WD
[illegible]	[illegible]	[illegible]	Enter CEP
[illegible]	[illegible]	[illegible]	Enter TR
[illegible]	[illegible]	[illegible]	Enter Sigma
[illegible]	[illegible]	[illegible]	Enter x
[illegible]	[illegible]	[illegible]	Flag 7 check
[illegible]	[illegible]	[illegible]	Advance paper
[illegible]	[illegible]	[illegible]	Program stops here
[illegible]	[illegible]	[illegible]	Begin calc.
411	91	R/S	Print angle

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
000	76	LBL	Label A.
001	11	A	
002	42	STO	Store angle in R10
003	10	10	
004	76	LBL	Label WRT.
005	96	WRT	
006	22	INV	Remove FIX and Scien-
007	58	FIX	tific display formats
008	22	INV	
009	57	ENG	
010	92	RTN	
011	43	RCL	Option to run same
012	00	00	calculation with R/S.
013	61	GTO	Put 3.n in display
014	10	E'	Go to Label E'
015	76	LBL	Label $\sqrt{x}$.
016	34	$\sqrt{x}$	
017	43	RCL	Calculation routine for
018	11	11	triangular targets
019	33	x^2	
020	85	+	$(S1)^2 + (S3)^2 - (S2)^2$
021	43	RCL	
022	09	09	
023	75	-	
024	43	RCL	
025	08	08	
026	92	RTN	
027	76	LBL	Label OP.
028	69	OP	Printout and limit
029	69	OP	check routine for
030	27	27	triangular targets
031	43	RCL	routine
032	07	07	Recall alphanumerics
033	32	X↔T	put in t register
034	01	1	Lower Limit = 1
035	85	+	
036	43	RCL	Upper Limit = CEP
037	15	15	
038	36	PGM	Call Pgm. 9 to check
039	09	09	limits and print
040	13	C	value
041	92	RTN	
042	76	LBL	Label PGM.
043	36	PGM	
044	36	PGM	Call CROM Pgm. 1 to do
045	01	01	calculations 3.0, 3.1,
046	71	SBR	and 3.2
047	00	00	
048	90	90	See Eqs. 1 through 20
049	61	GTO	Go to Label RTN
050	92	RTN	
051	76	LBL	Label COS.
052	39	COS	Routine used in the
053	65	×	triangular targets
054	53	(	calculation to perform
055	32	X↔T	cosine law.
056	85	+	
057	43	RCL	See eqs. 25, 26 and 27
058	10	10	
059	54	)	
060	39	COS	
061	65	×	
062	03	3	
063	65	×	
064	43	RCL	
065	17	17	
066	94	+/-	
067	85	+	
068	43	RCL	
069	17	17	
070	33	x^2	
071	85	+	
072	32	X↔T	
073	33	x^2	
074	95	=	
075	34	$\sqrt{x}$	
076	61	GTO	Go to Label GTO
077	61	GTO	
078	76	LBL	Label P/R.
079	37	P/R	Routine used in the
080	04	4	rectangular and
081	05	5	elliptical targets
082	65	×	calculations to calcu-
083	43	RCL	late D_j
084	06	06	
085	85	+	
086	04	4	See eqs. 21 and 33
087	05	5	
088	75	-	
089	42	STO	Calculation of g and h
090	09	09	(see eqs. 22 and 23)
091	08	8	or f and j (see eqs.
092	00	0	34 and 35)
093	95	=	
094	39	COS	
095	69	OP	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
096	10	10	
097	55	÷	
098	02	2	
099	65	×	
100	43	RCL	
101	08	08	
102	94	+/-	
103	85	+	
104	43	RCL	
105	17	17	
106	32	X↕T	
107	43	RCL	
108	10	10	
109	37	P/R	
110	95	=	
111	32	X↕T	
112	75	-	
113	43	RCL	
114	07	07	
115	55	÷	
116	02	2	
117	65	×	
118	43	RCL	
119	09	09	
120	39	COS	
121	69	OP	
122	10	10	
123	95	=	
124	22	INV	
125	37	P/R	
126	32	X↕T	
127	76	LBL	Label GTO.
128	61	GTO	
129	36	PGM	Call Pgm. 3 to calculate $P(D_i)$
130	03	03	
131	71	SBR	
132	00	00	See eqs. 24, 32 and 36
133	88	88	
134	44	SUM	Store sum of $P(D_i)$ in R28
135	28	28	
136	92	RTN	
137	76	LBL	Label PRT.
138	99	PRT	
139	43	RCL	Limit check and print-out routine for rectangular and elliptical targets
140	15	15	
141	33	X²	
142	95	=	
143	34	√X	
144	82	HIR	Upper limit
145	02	02	
146	02	2	
147	44	SUM	
148	02	02	
149	02	2	"L" alphanumerics
150	07	7	
151	32	X↕T	
152	43	RCL	Lower limit = WD
153	14	14	
154	36	PGM	Call Pgm. 9 to check
155	09	09	limits and print out L
156	13	C	
157	42	STO	Store L in R07
158	07	07	
159	04	4	
160	03	3	"WD" alphanumerics
161	01	1	
162	06	6	
163	32	X↕T	
164	01	1	
165	36	PGM	Call Pgm. 9 to check
166	09	09	limits and print out
167	13	C	WD
168	42	STO	Store WD in R08
169	08	08	
170	92	RTN	
171	76	LBL	Label RST.
172	81	RST	
173	43	RCL	Start of rectangular
174	14	14	targets average Pd
175	33	X²	routine
176	94	+/-	
177	85	+	
178	71	SBR	Call SBR PRT to check
179	99	PRT	limits
180	06	6	
181	49	PRD	6 P(x)
182	28	28	see eq. 24
183	04	4	
184	42	STO	i = 4
185	06	06	Store i in R06
186	76	LBL	Label RAD.
187	70	RAD	
188	02	2	
189	65	×	
190	71	SBR	Call SBR P/R to calcu-
191	37	P/R	late D_i and $P(D_i)$

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
192	97	DSZ	If i > 0 subtract 1
193	06	06	from i, store i in
194	70	RAD	R06 and go to RAD
195	76	LBL	Label =.
196	95	=	
197	71	SBR	For i = 0
198	96	WRT	
199	06	6	Repartition back to
200	69	DP	normal partition
201	17	17	
202	36	PGM	Call Pgm. 3 to print
203	03	03	out P
204	71	SBR	
205	03	03	
206	34	34	
207	61	GTO	Go to Label ADV
208	98	ADV	
209	76	LBL	Label EE.
210	52	EE	
211	04	4	Start of elliptical
212	49	PRD	targets average Pd
213	28	28	routine
214	65	×	4P(x)
215	71	SBR	See Eq. 36
216	99	PRT	Call SBR PRT to check
217	33	X²	limits
218	55	÷	
219	43	RCL	
220	07	07	
221	95	=	
222	48	EXC	Store $\frac{WD^2}{L}$ in R08
223	08	08	
224	33	X²	See eq. 33
225	94	+/-	
226	85	+	
227	43	RCL	
228	07	07	
229	33	X²	
230	95	=	
231	34	FX	
232	42	STO	Store $\sqrt{L^2-WD^2}$ in R07
233	07	07	
234	08	8	See Eq. 33
235	42	STO	i = 8
236	06	06	Store i in R06
237	76	LBL	Label EXC.
238	48	EXC	Call SBR P/R to calc.
239	71	SBR	D_i and $P(D_i)$
240	37	P/R	See Eq. 36
241	69	DP	
242	36	36	Subtract 1 from i
243	71	SBR	Call SBR P/R to calcu-
244	37	P/R	late D_i and $P(D_i)$
245	65	×	
246	03	3	$4P(D_i)$ for i equal to
247	95	=	1, 3, 5 or 7
248	44	SUM	
249	28	28	
250	97	DSZ	If i > 0 subtract 1
251	06	06	from i, store i in R06
252	48	EXC	and go to EXC
253	02	2	
254	93	.	
255	04	4	Divide R28 by 2.4
256	22	INV	
257	49	PRD	
258	28	28	
259	61	GTO	Go to Label =
260	95	=	
261	76	LBL	Label B.
262	12	B	
263	42	STO	Store S1 in R11
264	11	11	
265	61	GTO	Go to Label WRT
266	96	WRT	
267	76	LBL	Label C.
268	13	C	
269	42	STO	Store WR in R12
270	12	12	
271	61	GTO	
272	96	WRT	Go to Label WRT
273	76	LBL	Label D.
274	14	D	
275	42	STO	Store either S2 or L in
276	13	13	R13
277	61	GTO	
278	96	WRT	Go to Label WRT
279	76	LBL	Label E.
280	15	E	
281	42	STO	Store either S3 or WD
282	14	14	in R14
283	61	GTO	
284	96	WRT	Go to Label WRT
285	76	LBL	Label A'.
286	16	A'	
287	42	STO	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
288	15	15	Store CEP in R15
289	61	GTO	
290	96	WRT	Go to Label WRT
291	76	LBL	Label B'.
292	17	B'	
293	43	STO	Store TR in R16
294	16	16	
295	61	GTO	Go to Label WRT
296	96	WRT	
297	76	LBL	Label D'.
298	19	D'	
299	42	STO	Store sigma in R18
300	18	18	
301	61	GTO	Go to Label WRT
302	96	WRT	
303	76	LBL	Label C'.
304	18	C'	
305	42	STO	Store x in R17
306	17	17	
307	71	SBR	
308	96	WRT	
309	92	RTN	
310	60	DEG	
311	43	RCL	
312	01	01	
313	22	CP	
314	22	22	
315	00	00	
316	42	STO	
317	00	00	
318	22	INV	
319	88	STF	
320	07	07	
321	60	DEG	
322	98	ADV	
323	22	INV	
324	55	CLR	
325	22	INV	
326	58	FIX	
327	03	3	
328	92	.	
329	04	4	
330	04	4	
331	36	PGM	
332	03	03	
333	71	SBR	
334	00	00	
335	85	85	

STEP	CODE	KEY	COMMENTS
336	42	STO	
337	28	28	
338	03	3	
339	93	.	
340	03	3	
341	32	X↑T	
342	43	RCL	
343	00	00	
344	77	GE	
345	91	R/S	
346	43	RCL	
347	28	28	
348	36	PGM	
349	03	03	
350	71	SBR	
351	01	01	
352	66	66	
353	76	LBL	Label ADV.
354	98	ADV	
355	22	INV	Reset Flag 2
356	86	STF	
357	02	02	
358	98	ADV	
359	98	ADV	
360	98	ADV	
361	76	LBL	Label RTN
362	92	RTN	
363	42	STO	Store P in R19
364	19	19	
365	92	RTN	Program stops here
366	43	RCL	Recall 3.n
367	00	00	
368	76	LBL	Label E'.
369	10	E'	
370	42	STO	Start of calculation
371	00	00	Store 3.n in R00
372	22	INV	
373	88	STF	Reset Flag 7
374	07	07	
375	60	DEG	Set degrees angular mode
376	98	ADV	
377	22	INV	
378	55	CLR	Remove pending operations
379	22	INV	
380	58	FIX	
381	03	3	
382	92	.	
383	02	2	

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
384	77	GE	If 3.n ≤ 3.2 go to
385	36	PGM	Label PGM
386	43	RCL	Recall 3.n
387	00	00	
388	99	PRT	Print 3.n
389	75	-	
390	22	INV	
391	59	INT	
392	42	STO	Store .n in R05
393	05	05	
394	95	=	
395	42	STO	Store 3 in R00
396	00	00	
397	96	STF	Set flag 2
398	02	02	
399	36	PGM	Call Pgm. 3 to print
400	03	03	and check limits on
401	71	SBR	WR, CEP, TR, S and
402	02	02	to calculate eqs. 1
403	24	24	through 20 to get P(x)
404	42	STO	
405	28	28	
406	43	RCL	
407	05	05	
408	44	SUM	Store 3.n in R00 again
409	00	00	
410	76	LBL	Label R/S.
411	91	R/S	
412	01	1	
413	00	0	
414	42	STO	
415	02	02	Call Pgm. 9 to check
416	01	1	limits and print A
417	03	3	
418	36	PGM	
419	09	09	
420	18	C'	
421	43	RCL	
422	05	05	
423	32	X:T	If 3.n = 3.3, go to
424	93	.	Label RST
425	03	3	(Rectangle calculation)
426	67	EQ	
427	81	RST	
428	93	.	If 3.n = 3.5 go to
429	05	5	Label EE (Ellipse
430	67	EQ	calculation)
431	52	EE	

STEP	CODE	KEY	COMMENTS
432	71	SBR	Remove FIX and scientif-
433	96	WRT	ic display format
434	05	5	
435	69	OP	Repartition calculator
436	17	17	to 559.49
437	03	3	
438	06	6	"S" alphanumerics
439	00	0	
440	01	1	
441	42	STO	Store in R07
442	07	07	
443	71	SBR	Call SBR OP to check
444	69	OP	limits and print S1
445	29	CP	
446	71	SBR	Call SBR COS to calcu-
447	39	COS	late D_{12} and $P(D_{12})$
448	69	OP	See eqs. 25 and 32
449	22	22	
450	71	SBR	Call SBR OP to check
451	69	OP	limits and print S2
452	33	X^2	
453	42	STO	
454	08	08	Store $(S2)^2$ in R08
455	71	SBR	Call SBR OP to check
456	69	OP	limits and print S3
457	33	X^2	
458	42	STO	Store $(S3)^2$ in R09
459	09	09	
460	71	SBR	Calculation of
461	34	[illegible]	
462	95	=	
463	55	÷	See eq. 27
464	02	2	
465	55	÷	
466	43	RCL	
467	11	11	
468	65	×	
469	43	RCL	
470	14	14	
471	95	=	
472	22	INV	
473	39	COS	
474	22	INV	Put [illegible] in t register
475	42	STO	
476	14	14	
477	71	SBR	Call SBR COS to calcu-
478	39	COS	late D_{23}
479	71	SBR	See eqs. 26 and 32

PROGRAM MEMORY (LIST)

STEP	CODE	KEY	COMMENTS
480	34	ΓX	Calculation of ϕ
481	55	÷	
482	02	2	See eq. 30
483	95	=	
484	55	÷	
485	08	8	
486	95	=	
487	34	ΓX	
488	32	X:T	
489	03	3	
490	65	×	
491	71	SBR	
492	34	ΓX	
493	95	=	
494	55	÷	
495	32	X:T	
496	55	÷	
497	43	RCL	
498	11	11	
499	95	=	
500	22	INV	
501	39	COS	
502	42	STO	Store ϕ in R07
503	07	07	
504	32	X:T	Store ϕ in t reg.
505	01	1	
506	94	+/-	Calculation of α
507	49	PRD	See eq. 31
508	03	09	
509	93	.	
510	05	5	
511	65	×	
512	71	SBR	
513	34	ΓX	
514	95	=	
515	94	+/-	
516	65	×	
517	02	2	
518	95	=	
519	34	ΓX	
520	35	1/X	
521	65	×	
522	53	(	
523	43	RCL	
524	09	09	
525	85	+	
526	43	RCL	
527	08	08	

STEP	CODE	KEY	COMMENTS
528	95	=	
529	55	÷	
530	43	RCL	
531	11	11	
532	95	=	
533	22	INV	α
534	39	COS	
535	85	+	Calculation of M
536	38	SIN	
537	32	X:T	See eq. 29
538	95	=	
539	38	SIN	
540	65	×	
541	02	2	
542	55	÷	
543	43	RCL	
544	11	11	
545	55	÷	
546	43	RCL	
547	07	07	
548	32	X:T	
549	95	=	
550	35	1/X	
551	71	SBR	Call SBR COS to calcu-
552	39	COS	late D_c and $7P(D_c)$.
553	65	×	See eqs. 28 and 32.
554	06	6	
555	95	=	
556	44	SUM	
557	28	28	
558	61	GTO	Go to Label =
559	95	=	

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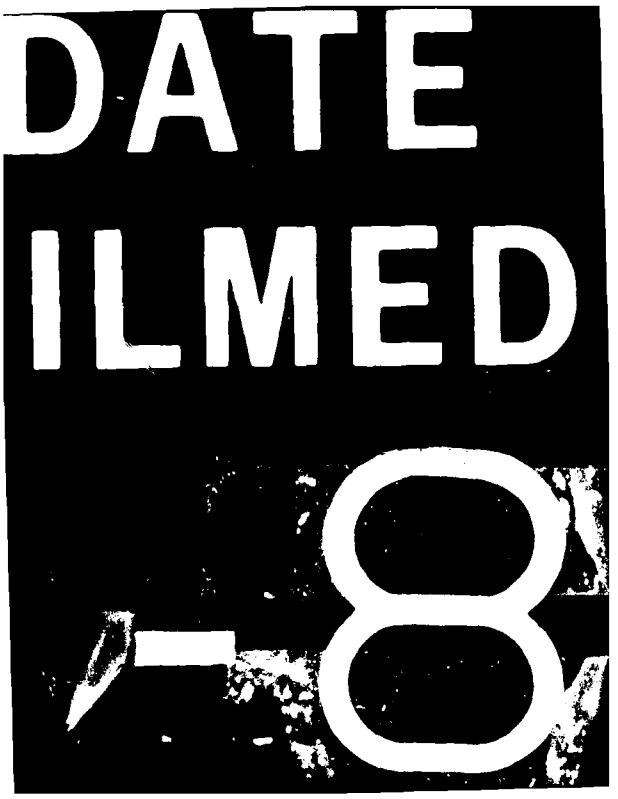
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