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INTEGRATED BATTLEFIELD EFFECTS RESEARCH FOR THE NATIONAL TRAINING CENTER

Appendix C—NTC Chemical Model Algorithm Description

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Research performed to evaluate and develop enhancements for integrated battlefield training at the U.S. Army National Training Center is described. These enhancements had been identified and concepts developed for their application in earlier phases of this research. The report consists of the basic volume summarizing the research tasks, approach, results, conclusions, and recommendations; plus twelve appendices which provide details on the nine major tasks into which the research was divided. Research performed and the associated appendices are as follows:

Development of nuclear and chemical environmental and effects software:
- Analysis of nuclear algorithms — Appendix A
- Requirements specification for nuclear and chemical model algorithms at the NTC — Appendix B
- Chemical model algorithm description — Appendix C

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Topics in this appendix include: Chemical model, Chemical hazard prediction, Casualty computations. Keywords: Army training; Military doctrine; Army facilities; California.

19. ABSTRACT (Continued)

Demonstration of the system for combining live and notional battalions for training higher level staffs in integrated battlefield (IB) command and control:

Functional requirements analysis for IB command and control simulation	Appendix D
Report on the demonstration	Appendix E

Analysis and design of field simulators for nuclear and chemical warfare:

Technical and operational impacts of field simulators	Appendix F
Capability of off-the-shelf paging system to communicate at Ft. Irwin	Appendix G
Designs of field simulators	Appendix H

Adaptation of nuclear and chemical software to other Army training models:

Feasibility of transferring ARTBASS Code from Perkin-Elmer to VAX	Appendix I
Division/Corps training simulation functional analysis	Appendix J
ARTBASS conversion to VAX	Appendix K
Requirements specification for adding nuclear and chemical models to ARTBASS	Appendix L

This research provided the following products:

Software which models nuclear and chemical environment and effects with appropriate fidelity and timing for training and which is ready for installation on NTC computers.

A demonstrated capability for combining actions of real battalions with computer simulated notional battalions for training brigade/division commanders and staffs.

An analysis of the impacts of using field simulators at the NTC for nuclear and chemical warfare training, and the designs of the selected simulators (i.e., common control system, radiacmeters, dosimeters, chemical detectors).

Analysis of the application of nuclear and chemical models to other Army battalion training models; conversion of the ARTBASS model to operate on the VAX 11/780; incorporation of the nuclear and chemical models into ARTBASS; and demonstration of the nuclear and chemical models using ARTBASS.

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
cal (thermochemical)/cm^2	mega joule/m^2 (MJ/m^2)	4.184 000 X E -2
calorie (thermochemical)	joule (J)	4.184 000
calorie (thermochemical)/g	joule per kilogram (J/kg)*	4.184 000 X E +3
curie	giga becquerel (GBq) †	3.700 000 X E +1
degree Celsius	degree kelvin (K)	$t_K = t°_C + 273.15$
degree (angle)	radian (rad)	1.745 329 X E -2
degree Farenheit	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)	1.061 846 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 gray (Gy) is the accepted SI unit equivalent to the energy imparted by ionizing radiation to a mass and corresponds to one joule/kilogram.

†The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.

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SECTION 1
CHEMICAL MODEL

The chemical model is activated every 15 seconds (approximately). The time step need not be fixed or uniform, the time increment is computed internally. Because of the different types of agents involved, each mission must be treated independently. Two different models of chemical behavior are used; the Sutton-Calder model for nonpersistent (vapor cloud, no ground contamination), and the Porton model for persistent (liquid droplets, ground contamination with secondary vapor) chemicals.

1.1 NONPERSISTENT

For each nonpersistent event, the position and dimensions of the cloud are computed in a standard fashion. The cloud is always asumed to be ellipsoidal in shape. The current location and size is computed using the original mission values so that the previous time step value is not required. Information for graphics output is generated in the form of the two ellipse foci locations and the major diameter. In addition, for each unit within the defined cloud, the concentration of agent at that location is calculated. The cloud limit is defined to be the concentration required to trigger an alarm. The chemical concentration produced by a mission is saved for later accumulation.

Note: If center of mass of unit is outside area, but an assigned player is inside, concentration is computed.

After computing all concentrations, the event is examined for possible removal from the active mission list (projected concentration at center less than alarm sensitivity).

1.2 PERSISTENT

For each persistent event, the position and center of the ground contamination are computed using the Porton gravitational settling model. After this is done, the downwind vapor affected area is computed. As in the nonpersistent case, all areas are elliptical in shape, with a gaussian falloff of concentration versus distance from the center. Ellipse parameters covering the ground contamination and downwind vapor is transmitted as the location of the two foci and the major diameter. The limits of the ellipse are the concentration required to trigger the alarm; as with nonpersistent, the concentration of agent is computed for each unit location within the affected areas. If an assigned player is in the area, a value for the unit is computed even if its center of mass is outside the area.

As before, the event is then examined for removal from the active mission list.

1.3 CASUALTIES

Once every active mission has been treated to determine its current limits and status, and the concentration of agent for the units computed, the casualty computation can be done. First of all, for each agent the concentrations of that agent generated by all missions that used it are summed to get a total concentration of the agent for the unit. This concentration is then integrated over the time step to give a dose received, and the probit function used to compute the casualty contribution for the agent. When this has been done for each agent in use, the final casualty level is obtained using the chemicals casualty summation model. The individual casualty contributions are functions of MOPP and protection status. The final casualty level is set to be at least 10% if any exposure has occurred.

In the case of persistent chemicals, any unit/player within the affected area is defined to be contaminated to the level of the ground contamination (the highest value reached). An estimate of the time at which the protective unit becomes ineffective is made and the MOPP level is set to 0 for casualty computations at that time. Decontamination will reduce or eliminate the chemical concentration on the equipment. The higher of the values for contamination and environment is used to determine the concentration the player/unit is exposed to.

The model generates a list of players and units in the affected area, players and units contaminated, and a set of recommended casualty percentages by MOPP and posture for each affected unit. Current and previous recommendations are supplied.

1.4 MISSION DEFINITION:

The mission is defined by entering the attack and weather information. Immediately prior to execution, the mission is entered into the active mission table. Up to 20 missions may be active at any one time; missions that would increase the total to more than 20 are ignored. Missions can be cancelled prior to entry into the active table, and can be removed from the table after execution. Missions to be measured can be specified by operator input, or by model computations indicating no further effects exist for the mission.

With the information on the mission supplied by the operator, all other necessary parameters are obtained from tables of data stored in the program.

1.4.1 Mission Definition Inputs

1. Location of target center (Xo, Yo)
2. Weapon type index number
3. Agent index number
4. Attack type index number
5. Number of rounds (bombs, tanks)
6. Upwind direction
7. Wind speed
8. Stability index number
9. Temperature

1.4.2 Mission Definition Algorithm

Given the type of attack and number of rounds used, the target radius is computed by extracting the radius per round from Table 2, 3, or 4 (depending on the type of attack) and multiplying by the square root of the number of rounds:

$$Ro = Rw \; SQRT(N)$$

N = number of rounds

Rw = radius of coverage per round from Table #2

Ro = initial attack radius (initial cloud)

The cloud expansion parameters (alpha, beta, sig x100, sig z100) are obtained from Table 5, using the stability index supplied as input. The amount of agent delivered in the attack is obtained by multiplying the amount of agent per round (obtained from Table 6) by the number of rounds delivered:

$$QD = Qo \quad N$$

$\bar{Q}o$ = amount of material per round

QD = amount of material in attack

Note that table 6 gives the amount of agent in pounds, this must be converted to milligrams for use in the model.

The initial vertical cloud distance (ho) is obtained from Table 7, which was constructed using the shellburst radius values. This value is independent of the number of rounds.

Table 1. Type "A" attack downwind distance of hazard area

MEANS OF DELIVERY	DISTANCE FROM CENTER OF ATTACK AREA ALONG DOWNWIND AXIS, WHEN STABILITY CONDITION IS:		
	U (Unstable)	N (Neutral)	S (Stable)
Artillery, Bomblets and Mortars	10 km	30 km	50 km
Multiple Rocket Launchers, Missiles and Bombs	15 km	30 km	50 km

Table 2. Harrassment radius.

RADIUS(meters)/shell (Rw)

	Agent type:	1 (AC)	2 (GB)	3 (VX)	4 (HD)
	Weapon type:				
1.	Aircraft Spray	NA	250	250	NA
2.	Bombs	23	85	85	85
3.	105 mm BLUEFOR	7	25	25	25
4.	155 mm BLUEFOR	11	40	40	40
5.	107 mm BLUEFOR	7	25	25	25
	175 mm BLUEFOR	12	45	45	45
6.	8" BLUEFOR	12	45	45	45
7.	122 mm OPFOR	5	18	18	18
	130 mm OPFOR	7	25	25	25
8.	152 mm OPFOR (HOW)	10	35	35	35
	152 mm OPFOR (GUN)	10	35	35	35
9.	Rocket (MRL)	20	70	70	70
10.	FROG	NA	250	250	250

Note: These radii are not burst radii; they represent a mean radius of coverage per round assuming an attack using multiple rounds.

Table 3. Obstacle radius.

RADIUS (meters)/shell (Rw)

	Agent type:	1 (AC)	2 (GB)	3 (VX)	4 (HD)
	Weapon type:				
1.	Aircraft spray	NA	NA	200	NA
2.	Bombs	NA	NA	65	65
3.	105 mm BLUEFOR	NA	NA	20	20
4.	155 mm BLUEFOR	NA	NA	30	30
5.	107 mm BLUEFOR	NA	NA	20	20
	175 mm BLUEFOR	NA	NA	35	35
6.	8" BLUEFOR	NA	NA	35	35
7.	122 mm OPFOR 130 mm OPFOR	NA	NA	12	12
8.	152 mm OPFOR (HOW)	NA	NA	25	25
	152 mm OPFOR (GUN)			25	25
9.	Rocket (MRL)	NA	NA	50	50
10.	FROG	NA	NA	180	180

Note: These radii are not burst radii; they represent a mean radii of coverage per round assuming an attack using multiple rounds.

Table 4 Casualty radius.

RADIUS (meters)/shell (Rw)

	Agent type:	1 (AC)	2 (GB)	3 (VX)	4 (HD)
	Weapon type:				
1.	Aircraft spray	NA	150	150	NA
2.	Bombs	13	50	50	5
3.	105 mm BLUEFOR	4	15	15	15
4.	155 mm BLUEFOR	7	25	25	25
5.	107 mm BLUEFOR	4	15	15	15
	175 mm BLUEFOR	8	27	27	27
6.	8" BLUEFOR	9	30	30	30
7.	122 mm OPFOR	3	10	10	10
	130 mm OPFOR	4	12	12	12
8.	152 mm OPFOR (HOW)	6	20	20	20
	152 mm OPFOR (GUN)	6	20	20	20
9.	Rocket (MRL)	11	40	40	40
10.	FROG	NA	150	150	150

Note: These radii are not burst radii; they represent a mean radius of coverage per round assuming an attack using multiple rounds.

Table 5. Cloud expansion parameters.

Stability Class	Unstable (U)	Neutral (N)	Stable (S)
Stability Index	1	2	3
Parameter			
alpha	1.2	0.88	0.75
beta	1.2	0.88	0.75
sigx100	3.41	3.41	3.41
sigz100	9.02	5.56	4.44

Table 6. Amount of material per shell (bomb, tank) (Qo) (pounds).

Agent type: / Weapon type:	1 AC (Blood)	2 GB (Nerve) Nonpersistent	3 VX (Nerve) Persistent	4 HD (Blister)
1. Aircraft spray	0.	260.0	240.0	0.
2. Bombs	155.0	250.0	230.0	350.0
3. 105 mm BLUEFOR	0.	1.8	0.	3.1
4. 155 mm BLUEFOR	0.	6.5	6.5	9.7
5. 107 mm BLUEFOR	0.	4.0	4.0	6.0
175 mm BLUEFOR	0.	10.0	10.0	0.0
6. 8" BLUEFOR	0.	15.8	14.1	0.
7. 122 mm OPFOR	1.1	1.8	1.8	3.1
130 mm OPFOR	2.5	4.0	4.0	5.0
8. 152 mm OPFOR (HOW)	4.0	6.5	6.5	9.7
152 mm OPFOR (GUN)	4.0	6.5	6.5	9.7
9. MRL (rocket)	7.0	11.0	10.0	15.0
10. FROG	450.0	750.0	700.0	1000.0

Table 7. Vertical cloud radius.

Agent type: / Weapon type:	1 AC (Blood)	2 GB (Nerve) Nonpersistent	3 VX (Nerve) Persistent	4 HD (Blister)
1. Aircraft spray	--	150	150	--
2. Bombs	20	80	80	80
3. 105 mm BLUEFOR	5	25	25	5
4. 155 mm BLUEFOR	10	40	40	10
5. 107 mm BLUEFOR	5	25	25	5
175 mm BLUEFOR	10	40	40	10
6. 8" BLUEFOR	10	40	40	10
7. 122 mm OPFOR	5	25	25	5
130 mm OPFOR	7	33	33	7
8. 152 mm OPFOR (HOW)	10	40	40	10
152 mm OPFOR (GUN)	10	40	40	10
9. MRL (rocket)	15	60	60	60
10. FROG	--	150	150	150

1.5 NONPERSISTENT AGENT CLOUD BEHAVIOR

(Includes 1 = AC, 2 = GB)

The equations are set up so as to allow for an elliptical shape for the cloud (as seen from above), but at present the cloud will be circular.

Ro, QD, alpha, beta, SIGx100, SIGz100, ho, Xo, Yo are as defined above. A volatilization factor (f) is defined:

Agent #1 (=AC) $f = 1.0$

Agent #2 (=GB) $f = 0.414337 + 0.002096\ T + 0.00001814\ T^2$

where T is temperature. Using this factor, the amount of airborne material in the cloud (Q) is:

$$Q = QD\ f\ Cpmg$$

where Cpmg is the conversion factor from pounds mass to milligrams (Cpmg = 453592.37).

Given that the cloud has three initial size parameters a = semi- major ellipse axis, b = semiminor ellipse axis, and ho = semi- vertical axis, the initial gaussian cloud values are computed

$SIGAo = a/1.5$ (= Ro/1.5)

$SIGBo = b/1.5$ (= Ro/1.5)

$SIGZo = ho/1.5$

and the "point source" distance parameters are

$$Da = 100\ (SIGAo/SIGx100)^{1/alpha}$$

$$Db = 100\ (SIGBo/SIGx100)^{1/alpha}$$

$$Dz = 100\ (SIGZo/SIGz100)^{1/beta}$$

These parameters need be computed only once per mission.

Defining the wind speed to be Vw, the downwind direction, THETAw, and the ellipse orientation THETAel, the cloud motion and growth are computed:

Cloud center motion:

$$Xc = Xo + Vw\,(t-to)\,\sin\ THETAw$$

$$Yc = Yo + Vw\,(t-to)\,\cos\ THETAw$$

where

t = current time

to = time of attack

Xc, Yc = coordinates of cloud center

Cloud growth:

$$SIGA = SIGx100\,((Da + D)/100)^{alpha}$$

$$SIGB = SIGx100\,((Db + D)/100)^{alpha}$$

$$SIGZ = SIGz100\,((Dz + D)/100)^{beta}$$

with

$$D = Vw\,(t-to)$$

1.6 DISPLAY OF CLOUD BOUNDARY:

The concentration of agent at the center of the cloud is:

$$Cc = 2\,Q/((2\pi)^{3/2}\ SIGA\ SIGB\ SIGZ)$$

This is compared to the limit concentration for the boundary (either the concentration triggering an alarm or a casualty criterion). This value (Cd) is read from Table 8. If Cc is less than Cd, the cloud no longer exists and is removed from the list of active missions. If Cc is greater than Cd, the cloud display is computed.

$$At = SIGA\,(-2\ \ln\,(Cd/Cc))^{1/2}$$

$$Bt = SIGB\,(-2\ \ln\,(Cd/Cc))^{1/2}$$

where At and Bt are the semimajor and semiminor axes of the display ellipse. The ellipse foci are obtained

$$X1 = Xc + SQRT(At^2 - Bt^2) \sin THETAel$$

$$Y1 = Yc + SQRT(At^2 - Bt^2) \cos THETAel$$

$$X2 = Xc - SQRT(At^2 - Bt^2) \sin THETAel$$

$$Y2 = Yc - SQRT(At^2 - Bt^2) \cos THETAel$$

where X1, Y1 and X2, Y2 are the coordinates of the two ellipse foci. The model transmits the foci coordinates and the major diameter (= 2 At) to the graphics processor. (Note that, as stated previously, the current situation will generate a circle).

1.7 LEVELS AT UNIT LOCATIONS

The current concentration of agent at any location is given by:

$$C = Cc \exp(-1/2 \, (Ra/SIGA)^2)$$

$$\exp(-1/2 \, (Rb/SIGB)^2)$$

$$\exp(-1/2 \, (Zc/SIGZ)^2)$$

where Zc is the height of the cloud center, Ra and Rb are the distances from the center in the directiion of the major and minor axes respectively. It is asumed that the location has an altitude of zero; and in most cases the cloud center altitude Zc will also be zero. The offset distances are:

$$Ra = (X-Xc) \sin THETAel + (Y-Yc) \cos THETAel$$

$$Rb = (X-Xc) \cos THETAel - (Y-Yc) \sin THETAel$$

Table 8. Boundary concentration levels.

(mg/m^3)

1 - AC	0.2
2 - GB	0.2
3 - VX	0.4
4 - HD	4.0

SECTION 2
CHEMICAL HAZARD PREDICTION

This is done a the time the mission is defined; it should be retained until the mission is removed from the list of future or currently active missions. It need be done only once for any given mission. The output is used only for display purposes. The procedure will follow the one in the NATO report ATP-45, Part IV, Chapter 12. (Note: It will be assumed that a very large attack will actually be composed of several smaller ones that overlap, so the type "B", case "c" need not be handled).

2.1 CHEMICAL HAZARD PREDICTION ALGORITHMS.

1. If the wind speed is less than or equal to 10 km/hr, the hazard area is defined to be a circle 10 km in radius.

2. If the wind speed is greater than 10 km/hr, the persistent and nonpersistent algorithms are different.

   a. Nonpersistent:

      upwind - 1 km circle arc to 60 degrees each side of upwind direction

      downwind - distance limit from table 1

      side bounds - tangents from 1 km arc extended to downwind limit line

      See Figure 1.

   b. Persistent:

      In the case of persistent chemicals, it is first necessary to determine the size of the attack area. This is done by looking up in Table 2, 3, or 4 as determined by the type of attack the value for the individual delivery systems and multiplying this value by the square root of the number of units delivered (rounds, bombs, tanks). Thus

$$R = Rw\ SQRT(N)$$

The result divides the hazard computations into 3 classes:

1. R less or equal 1 km: The maximum downwind distance is 10 km. The remainder of the algorithm matches case a. nonpersistent. See Figure 1.

2. 1 km less than R less than 2 km: The upwind arc has a 2 km radius; the maximum downwind distance is 10 km; side bounds 30 degrees tangents.

3. R greater than 2 km.

   This case will not be treated for NTC since it is assumed the attack will be divided into smaller events for processing.

SECTION 3
CASUALTY COMPUTATION

3.1 CASUALTY COMPUTATION ALGORITHM

It is assumed that the time interval between calls is sufficiently small to permit the use of a linear approximation over the time step for the variation of concentration with time for a unit.

For each unit:

1. Assume all mission data (i.e., cloud movement, etc.) has been updated to the current time, giving a concentration of agent produced by each mission at the unit location (Ci, where i is the index representing the mission).

2. Execute steps 3 through 10 for each agent (index = j)

3. Sum the concentrations of all missions with agent type j:

$$C_j = \Sigma_i C_i \quad \text{such that mission i used agent j}$$

4. Determine the incremental dose dDj of agent j:

$$dDj = 1/2\ (Cj + Cj^o)\ (t - t^o) \qquad j = 2, 3, 4$$

where Cj^o is the concentration Cj from the previous call

t is current time

t^o is time of previous call

. . . .

$$dDj = 1/2\ (Cj + Cj^o) \qquad j = 1$$

and the accumulated total dose Dj:

$$Dj = Dj^o + dDj \qquad j = 2, 3, 4$$

$$DJ = dDj \qquad j = 1$$

5. Compare the accumulated dose Dj with the threshold dose of the agent DTj. (DTj is in Table 9). If the dose is below the threshold level, no casualties are assessed as a result of this agent. If the dose exceeds the threshold level, the final integrated casualty level must be set to a minimum of 10%.

   Special computation for Agent 1

   Whenever the current dose D1 is above the threshold dose DT1, and the previous dose D1 was below the threshold level, an exposure counter (NE) must be incremented. This counter starts at zero and has an upper limit of 4. The value of NE for the unit from the previous time step is used in computations for all agents, not just agent 1.

6. If Dj exceeds DTj, compute an effective dose (DIjk) based upon posture category k:

$$DIjk = Dj\ Pjk$$

   where Pjk is a posture and agent dependent effectiveness facts from Table 10.

   Steps 7, 8, 9, 10, and 11 must be done for each posture and each MOPP:

7. a safety time (ts)

$$ts = tE + (1 - NE/4)\ ts^{o}$$

   where tso is obtained from Table 11. tE represents the exposure time - the first time since decontamination (if any) the unit was exposed to the agent. For persistent agents, ts represents a deadline for decontamination and can never be increased unless decontamination occurs. For non persistent agents, ts represents a time period within which MOPP must be upgraded for safety.

8. Compute a time of casualty effect (tc)

   persistent:

   tc1 = tE + dtc   t less than ts

   tc2 = ts + dtc   t greater than or equal to ts nonpersistent:

$$tc = ts + dtc$$

values for the time delay dtc are obtained from Table 12.

9. When the current time reaches the time of casualty effect, compute the casualty level

$$C_F = 1 - (1-CFo)(1 - N_E/4)$$ for nonpersistent and for t less than t_{c2}, persistent

$$C_F = 1$$ for t greater or equal t_{c2}, persistent

$$D_{EFF} = C_F \; DIjk$$

$$Cas_j = 50 \; (erf \; (DSG) + 1)$$

$$DSG = 0.3070925/PRj \; \log_{10} (DEFF/D50j)$$

erf (x) is the normal error function

CFo is obtained from Table 13

PRj and D50j are obtained from Table 14

10. If full decontamination is done before time ts, immediately apply the casualty computation. Then set the values for NE and dose to zero. When this is done, further casualties are handled as increments to the current levels if new chemical exposures occur.

11. Combine the casualties produced by each agent

$$CasT = SQRT \left(\Sigma_j \; (cas_j^2)\right)$$

Note: as soon as any casualty must be reported, the minimum value of CasT is 10%. See step 5.

If CasT at the current time is more than 20% above CasT for the previous time step, or CasT currently is 10% and the previous value was 0%, or CasT is greater than or equal to 100%, transmit old and new values.

3.2 UNIT EFFECTIVENESS ALGORITHM

$$Degj = 50\ (erf\ (DSG^{1}) + 1)$$

$$DSG^{1} = 0.3070925/PR\ \log_{10}\ (DEFF/I50j)$$

$$DEGTOT = SQRT\ (\Sigma\ (Degj)^{2})$$

EFFECTIVENESS = (1 - DEGTOT) MOPFAC

where MOPFAC is a MOPP dependent factor:

MOPP	MOPFAC
0	1.0
1	0.9
2	0.9
3	0.8 (0.98-0.05 tMOPP)
4	0.8 (0.98-0.05 tMOPP)
5	0.9

tMOPP is time spent in that MOPP.

Table 9. Threshold dose for casualty computation (DTj).

Agent		Dose ($mg\text{-}hr/m^3$)
1	AC	2.
2	GB	0.25
3	VX	0.1667
4	HD	4.167

Table 10. Posture effectiveness factor (Pjk).

	Agent:	1 AC	2 GB	3 VX	4 HD
	Posture:				
1	Open	1.0	1.0	1.0	1.0
2	Protected	0.4	0.3	0.2	0.2
3	Covered	0.2	0.1	0.01	0.01

Table 11. Safety time (tso) (hr).

MOPP	Agent: 1 AC	2 GB	3 VX	4 HD
0	0.1	0.1	0.1	0.1
1	0.1	0.1	0.3	4.0
2	inf	2.0	2.0	4.0
3	inf	4.0	3.0	6.0
4	inf	inf	6.0	8.0
5	inf	1.1	0.5	0.5

inf = infinite

Table 12. Casualty time delay (dtc) (hr).

Agent	Time (dtc)
1 AC	0.0
2 GB	0.1
3 VX	0.5
4 HD	6.0

Table 13. Casualty effectiveness coefficient (CFo).

MOPP \ Agent	1 AC	2 GB	3 VX	4 HD
0	1.0	1.0	1.0	1.0
1	1.0	1.0	0.9	0.8
2	0.1	0.2	0.5	0.6
3	0.1	0.2	0.5	0.5
4	0.1	0.1	0.1	0.1
5	0.1	0.3	0.8	0.9

Table 14. PROBIT values (PRj) and 50% lethality level (D50j).

Agent	PROBIT PRj	50% Incapacitation ($mg\text{-}hr/m^3$) I50j	50% Lethality ($mg\text{-}hr/m^3$) D50j
1 AC	0.23	16.667	16.667
2 GB	0.157	0.1667	1.167
3 VX	0.254	0.0717	1.667
4 HD	0.186	2.5	25.0

3.3 PERSISTENT AGENT BEHAVIOR

(Includes 3 - VX, 4 - HD)

Ro, QD, alpha, beta, SIGx100, SIGz100, ho, Xo, Yo are as defined previously.

The amount of material in the cloud is defined

$$Q = QD \quad Cpmg$$

where Cpmg is 453592.37 mg/lb.

The initial cloud parameters are as defined for the nonpersistent case:

$$SIGAo = a/1.5 \quad (= Ro/1.5)$$

$$SIGBo = b/1.5 \quad (= Ro/1.5)$$

$$SIGZo = ho/1.5$$

$$Da = 100 \; (SIGAo/SIGx100)^{1/alpha}$$

$$Db = 100 \; (SIGBo/SIGx100)^{1/alpha}$$

$$Dz = 100 \; (SIGZo/SIGz100)^{1/beta}$$

As before, the wind speed is Vw, the downwind direction is THETAW, and the initial ellipse orientation is THETAel.

For all types of weapons other than aircraft spray, the initial cloud center height (Zo) is assumed to be zero (ground level). For aircraft spray tanks Zo is assumed to be 100 meters.

The horizontal (X, Y) motion of the cloud center is the same as for the nonpersistent case:

$$Xc = Xo + Vw \; (t - to) \sin (THETAw)$$

$$Yc = Yo + Vw \; (t - to) \cos (THETAw)$$

$$D = Vw \; (t - to)$$

with the horizontal diffusion parameters

$$SIGA = SIGx100 \; ((Da + D)/100)^{alpha}$$

$$SIGB = SIGx100\ ((Db + D)/100)^{alpha}$$

The vertical cloud growth and cloud center height are different:

$$Zc = Zo - Vfo\ (t - to)$$

$$SIGZ = SIGZo + (VfB - VfT)\ (t - to)/3$$

The vertical cloud limits are

$$ZB = ZoB - VfB\ (t - to)$$

$$ZT = ZoT - VfT\ (t - to)$$

For aircraft spray, ZoB = ZoT = Zo. For all other weapon types ZoB = Zo = 0, ZoT = SIGZo/2. ZB and ZT represent the heights of the central location of the most rapidly descending and most slowly descending droplet sizes. Vfo is the fall velocity of the mean droplet size, VfB the velocity of the largest droplet size, and VfT the velocity of the smallest droplet size. Values for these velocities are given in Table 15. These velocities are currently assumed to be dependent only on agent type; it may be desirable later to include a weapon type dependence.

3.4 GROUND CONTAMINATION

1. Do not treat any ground contamination until the height ZB is equal to (or less than) zero. Treat only the descending cloud until then.

2. After the cloud top ZT reaches zero, treat only ground contamination, no cloud effects.

3. Between the time the cloud bottom first touches ground (ZB = 0) and the top touches ground (ZT = 0), a combined cloud/ground effect must be treated.

Define tT to be the time at which the top touches ground:

$$tT = to + ZoT/VfT$$

and tB when the bottom touches ground:

$$tB = to + ZoB/VfB.$$

(tB is less than tT)

Case #1: t less than or equal to tB

There is no ground contamination. All computations are done on the basis of the cloud itself (casualty and display).

Case #2: t greater than or equal to tT

The cloud no longer exists (note that the vertical position calculation will put the center and bottom beneath the ground plane). The entire mass of material is assumed to be on the ground. Defining

$$XB = Xo + Vw\ (tB - to)\ \sin\ (THETAw)$$

$$YB = Yo + Vw\ (tB - to)\ \cos\ (THETAw)$$

and

$$XT = Xo + Vw\ (tT - to)\ \sin\ (THETAw)$$

$$YT = Yo + Vw\ (tT - to)\ \cos\ (THETAw)$$

define the ground contamination such that there is an ellipse with a center at

$$XEC = (XB + XT)/2$$

$$YEC = (YB + YT)/2\ ,$$

a major axis orientation of THETAw, a semimajor axis of

$$aGEL = 1/2\ SQRT(\ (XB - XT)^2 + (YB-YT)^2\ ) + 1.5\ SIGGA$$

and a semiminor axis of

$$bGEL = 1.5\ SIGGB$$

where

$$PHI = THETAw - THETAC$$

$$AFAC = SIN(PHI)\ COS(PHI)\ (SIGAC^2 - SIGBC^2)/$$

$$(SIGAC^2\ COS^2\ (PHI) + SIGBC^2\ SIN^2\ (PHI))$$

$$BFAC = SIN(PHI)\ cos(PHI)\ (SIGAC^2 - SIGBC^2)/$$

$$(SIGAC^2\ SIN^2\ (PHI) + SIGBC^2\ COS^2\ (PHI))$$

$$SIGGA = 1/SQRT\ (((COS(PHI) + AFAC\ SIN(PHI))/SIGAC)^2$$

$$+ ((SIN(PHI) - AFAC\ COS(PHI))/SIGBC)^2\ )$$

$$SIGGB = 1/SQRT\ (((SIN(PHI) + BFAC\ COS(PHI))/SIGAC)^2$$

$$+ ((-COS(PHI) + BFAC\ SIN(PHI))/SIGBC)^2\ )$$

THETAw = wind direction

THETAC = orientation of original cloud major axis (if not circular)

SIGAC = (SIGAB + SIGAT)/2

SIGBC = (SIGBB + SIGBT)/2

SIGAB = cloud sigma (SIGA) when ZB = 0 (tB)

SIGAT = cloud sigma (SIGA) when ZT = 0 (tT)

SIGBB = cloud sigma (SIGB) when ZB = 0 (tB)

SIGBT = cloud sigma (SIGB) when ZT = 0 (tT)

If SIGGA is less than SIGGB, set it equal to SIGGB.

The concentration (mgm/m^2) at the center of the ground ellipse is defined to be

$$Cgc = Q/(2\ \pi\ SIGAC\ SIGBC)$$

The downwind weapon hazard from this contamination is computed from the equations (t greater than tT)

$$Cv = 0.2\ Cs\ Sf\ ((DL+aGEL)/2\ aGEL)^{VFAC}\ tfac$$

V FAC = -1.13 for aGEL less than or equal to DL less than or equal to Vw (t - tT) + SIGAT

V FAC = 0.46 for -aGEL less than or equal to DL less than aGEL

CV = 0 for DL less than -aGEL or DL greater than
Vw(t - tT) + SIGAT

Cv represents the concentration downwind from the center of the ground contamination and is used to generate the display and casualty values

DL is the distance down wind from the center of ground contamination.

Sf is a surface coverage factor

$$Sf = 6.E{-}5 \quad Q/Rw^2$$

Cs is the saturation vapor concentration of the material

Cs = Cso (298./(273.+ T)) exp (RHVAP(1./298.- 1./(273.+ T)))

tfac is an agent dissipation factor

tfac = exp (-(t-to)/TAU)

with TAU an agent dependent decay time

TAU = TAUO (Cso/Cs)/(1. + Vw)

TAUO, Cso, and RHVAP are agent dependent values, See Table 13.

Case #3 tB less than t less than tT

For most purposes, the cloud will take priority since it is the greater hazard. Only upwind of the cloud will a ground contamination computation be required. In general, the computations for Case 1 and Case 2 will be combined in a simple fashion (using the greater result).

.5 CONCENTRATIONS AT PLAYER/UNIT LOCATIONS

Case #1 t less than or equal to tB

The calculation is done in exactly the same way as the nonpersistent case, except that the cloud height is greater than zero.

Case #2 t greater than or equal to tT

Use the equation for the downwind vapor hazard as given in the previous discussion; then define the concentration to be:

$$C = Cv \exp(-(Dc/SIGGB)^2/2)$$

Note that DL is a downwind distance and Dc a cross wind distance:

$$DL = (Xp-XEC) \sin THETAw + (Yp-YEC) \cos THETAw$$

$$DC = (Xp-XEC) \cos THETAw - (Yp-YEC) \sin THETAw$$

Case #3 tB less than t less than tT

Combine the computations for Cases 1 and 2:

a) If downwind from cloud center, do a cloud calculation only just as in Case 1.

b) If upwind from cloud center location, do both a cloud calculation as for Case 1 and a ground vapor hazard computation as for Case 2. Use whichever of the two concentrations is the greater.

3.6 PLAYER/UNIT CONTAMINATION

a) Any player entering the ground contamination area is assumed to have a contamination level at least at the highest ground contamination level entered. The ground contamination level is obtained by

$$Cg = Cgc \exp(-1/2\ (DL/SIGGA)^2)$$

$$\exp(-1/2\ (Dc/SIGGB)^2)$$

CONTAM = maximum of CONTAM, Cg

b) Any player entering the cloud is contaminated at least to the level

CONTAM = maximum of CONTAM, CLCONT

CLCONT = 2 Dose

where DOSE is the dose received from the cloud; computed in the same way as for casualties.

c) No incremental contamination is generated from the downwind vapor.

Hazard Graphics Display

Case #1 $\quad t$ less than or equal to t_B

Only the cloud need be considered

Compute $CFAC = -(Zc/SIGZ)^2 - 2 \ln (Cd/Cc)$

where Cd and Cc are the same as for the non persistent, and Zc is the height of the cloud center defined previously.

If Cc is greater than Cd

$At = SIGA \; SQRT\,(CFAC)$

$Bt = SIGB \; SQRT\,(CFAC)$

If Cc is less than or equal to Cd

$At = Bt = 0$

Case #2 $\quad tT$ is less than or equal to t

Compute the edge concentration for the downward ground computations:

$CEDGE = 0.2\ Cs\ Sf\ tfac$

If CEDGE is greater than Cd

$At_{MAX} = aGEL\,(C_d/C_{EDGE})^{(1/VFAC)} \qquad (VFAC = -1.13)$

If At_{MAX} is greater than $(Vw(t-tT) + SIGAt + aGEL)/2$

$At = (Vw(t-tr) + SIGAt + aGEL)/2$

otherwise

$At = At_{MAX}$

$Bt = bGEL\,(At/aGEL)$

Case #3 tB is less than t is less than tT

$$At = (SIGA(SQRT(-2 \ln (C_d/C^*_o)) + SQRT(CFAC)) + SQRT((Xc-XB)^2 + (Yc-YB)^2))/2$$

$C^*_o = C_o$ at time

$t = t_B$

Bt = SIGB SQRT (CFAC)

where CFAC is as computed in Case #1.

For cases #2 and #3, the ellipse center is

XELC = XEC + (At - aGEL) SIN THETAw

YELC = YEC + (At - aGEL) COS THETAw

The ellipse foci are computed with the same equations as used in the nonpersistent case, with Xc, Yc replaced by XELC, YELC and THETAel replaced by THETAw.

Table 15. Persistent agent lookup table.

	VX	HD
Vfo (m/s)	0.6	1.2
VfB (m/s)	1.0	2.0
VFT (m/s)	0.2	0.4
Cso (mgm/m)	10.5	610.
TAUO (sec)	1.E5	2.E5
RHVAP (deg K)	9850.	7522.

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