Appendix F

Additional Calculations

This appendix gives more detailed procedures for working radiological fallout and decay problems discussed in Chapter 6.

Determining Decay Rate

Pocket Calculator Method

Assume that you are required to find the logarithm of 12.85. Reading down Column A in Table 6-4, you find that a value exists for 12.8 and 12.9, but not 12.85. How do you find the log of 12. 85?

Set the problem up like this: 12.85 log = 1.109 enter 12.85 hit log = 1.109.

Graphical Method

When a sequence of dose rates (NBC 4 nuclear series reports) from one location is plotted on log-log graph paper, the decay rate of the contamination causes the line plotted to be a straight line, inclined at a slope (n) to the axes of the graph.

Suppose you have readings from a set of NBC 4 nuclear series reports (Table F-1) are received for decay-rate determination. H-hour is known or determined to be 0930.

Figure F-1 (next page) shows this data plotted on log-log graph paper. The time is used as the number of hours past H-hour. Three lines are drawn through the points. The slope of these three parallel lines is n, the decay exponent.

Remember, this is an example to demonstrate a procedure. In actual practice, the points will not likely fall exactly in straight lines. In actual practice, the best straight line is fitted to the points. The value of n may then be determined for each location and an average n determined as follows:

Table F-1. Example dose-rate readings.

Location	Time of Reading				
	1000	1030	1100	1130	1200
	Dose Rate (cGyph)				
A	40	21	14	11	9
B		12	8	6	5
C			79	60	50

Place a piece of acetate, overlay paper, or other transparent material over Figure F-2 (page F-2) and trace it. Next, orient the transparent material over the log-log paper. Position the arrow on the transparent device at the point where the slope intersects the x-axis. Holding this position, align the y-axis indicator so that it is parallel with the y-axis of the log-log paper.

Note which slope on the transparency most closely matches the slope on the log-log paper. The slope which most closely matches has an n value printed along the left side of the transparency. This is the decay rate for these plotted dose rates.

Decay rate may be calculated from the plotted slope by measuring each axis in centimeters and using the formula

$n = \frac{\text{Delta } Y}{\text{Delta } X}$. **(Greek letter Delta = percent of change.)**

Once the decay rate (n) is determined, the radiological reading may be normalized to H + 1 readings. This reading is commonly referred to as the R_1 reading. This is nothing more than determining, mathematically what the dose rate reading was at any given location, one hour after the burst. Survey teams and monitors enter an area and take readings at various times after the burst (H-hour). These readings may be 15 minutes or 10 hours after the burst.

Any reading that is not recorded 1 hour (H + 1) after a burst is commonly referred to as an Rt reading. To perform radiological calculations and make decisions on the nuclear battlefield, all readings must be represented using the same time reference. If this is not done, the radioactive elements will decay and a true representation of the hazard, past and present, cannot be made.

Determining Dose Rates

Situation 1: A monitor reports a dose rate of 100 cGyph 5 hours after the burst. The decay rate is unknown so the monitor assumes standard decay (n = 1.2). What was the dose rate at the monitor's location at H + ?

This can be determined mathematically, using a hand-held pocket calculator that as a power function, which is represented by a button labeled either “Y^x” or "X^y".

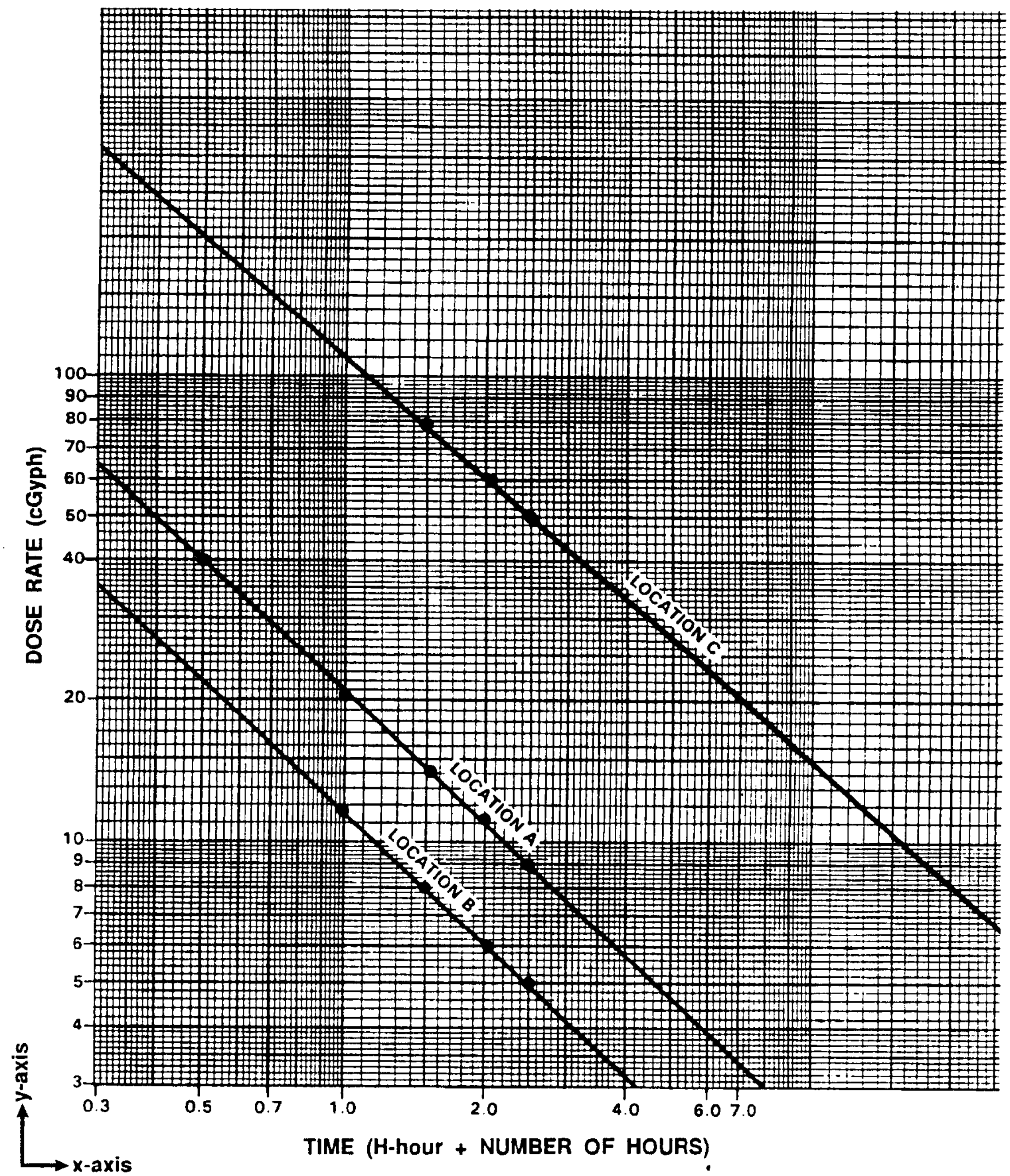

Figure F-1. Example of decay rate determination by slope measurement.

The following formula is used to solve the problem mathematically:
$R_1 = Rt \div t (Y^x) n +/-$.
(R_1 may be calculated by $R_1 = R_t x\ ty^{xn}$.
Step 1. Turn on calculator; and punch in the R_t reading of 100 cGyph; press the ÷ key.

Step 2. Push 5 (for H + 5 when the reading was taken). Push Y^x or X^y fiction key, then the n value of 1.2.
Step 3. Press the +/- key, and then the equals (=) key. The answer should be 689.86, or 690 cGyph.
This method is the most accurate. The answer may be slightly different from that found using the nomogram

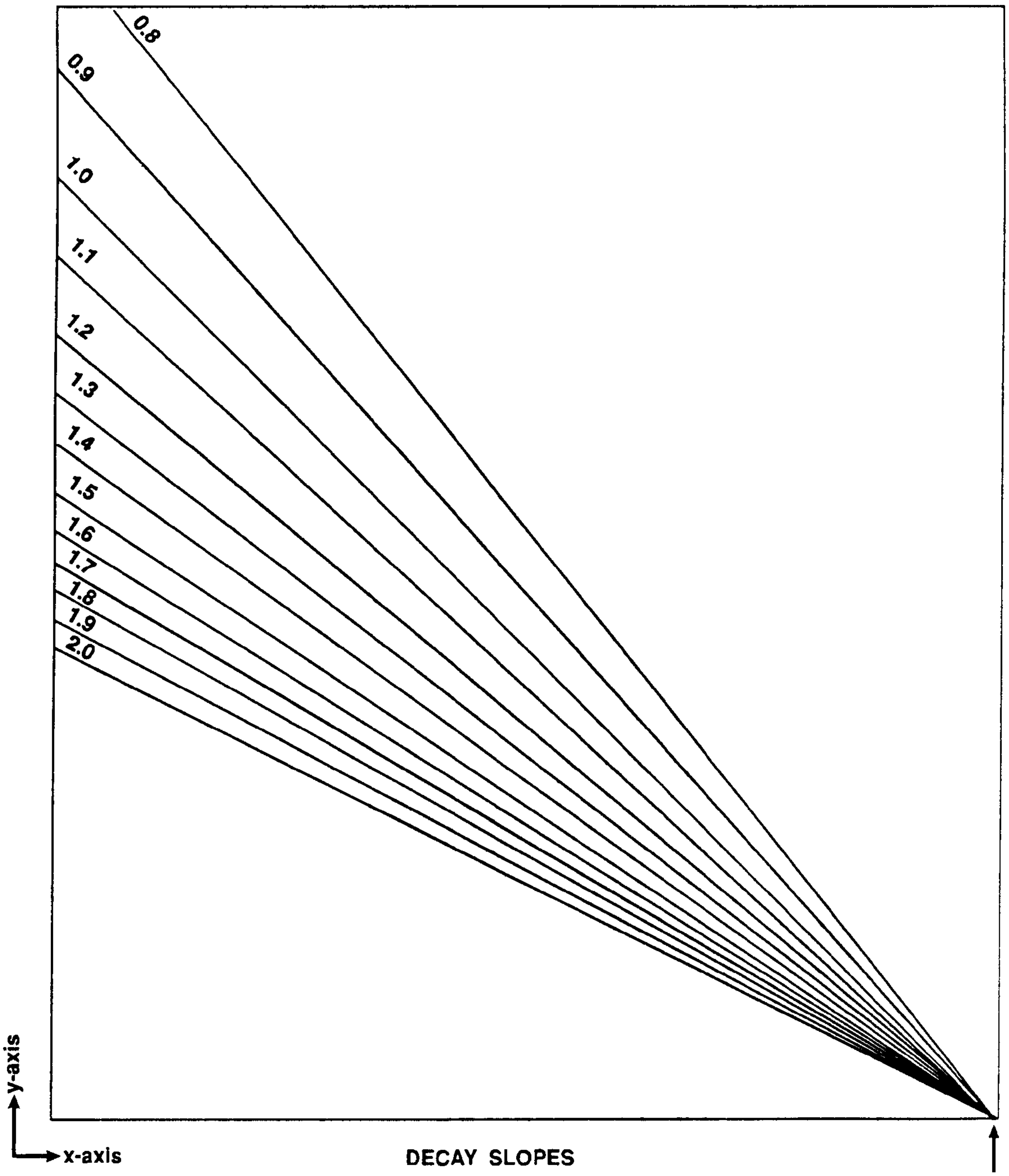

Figure F-2. Decay slopes.

method discussed in Chapter 6. That is because nomograms are subject to operator error and interpretation.

Situation 2. Further monitoring determines the decay rate to be 0.9. The monitor's reading, using the procedure of Situation 1, is normalized to a new R_1 (H + 1) of 426 cGyph. The commander wants to know what the reading will be at the monitor's location at H + 8 hours.

The formula used in Situation 1 also can be written or used as–$R_t = R_1 \times t (Y^x)$ n (+/-).

Step 1. Turn on calculator, and punch in the R_1 reading of 426 cGyph; press the multiplication key (x).

Step 2. Push 8 (for H + 8). Press the Y^x or X^y key, and enter the n value of 0.9.

Step 3. Press the +/- key and then equals (=). The answer should be 66 cGyph.

Normalizing Factors

To compute normalizing factors without using the table of values method discussed in Chapter 6, use either the mathematical or graphical method.

Mathematical Method

The normalizing factor is the ratio of the ground dose rate at a reference time to the ground dose rate at any other known time. It can be expressed as–

$$NF = \frac{\text{ground dose rate at ref time } (R_1)}{\text{ground dose rate at any other time } (R_2)}$$

The normalizing factor is computed using the Kaufman equation, $R_1T_1n = R_2T_2n$. This is the mathematical method. Subscript 1 denotes the reference time, and subscript 2 denotes any other known time a dose rate is determined.

Since:

a. NF = $(T_2)^n$, when the reference time is H + 1.

b. $NF = \frac{(T_2)^n}{(T_1)^n}$ when the reference time is H + 48.

Graphical Method

The graphical method is used when it is necessary to determine a large number of normalizing factors or to extend the time scope of an existing table. You have to know both n and H-hour.

Figure F-3 (page F-4) shows NF plots for H + 1 and H + 48 hours. To use these plots, enter the bottom of the plot with time the dose rate was measured. Read up to the appropriate decay slope. At this intersection, read left to the left-hand scale for the NF.

Multiple Burst Procedures

Calculating Fallout of One Burst

Fallout has been received from two detonations, one at 0800Z and one at 1100Z, resulting in the readings shown in Figure F-4.

Predict the dose rates for the 0800Z burst at this location 24 hours after the burst. Sufficient data is available to separate the two bursts.

Time	Dose Rate (cGyph)
0900	100 Peak
0930	61
1000	44
1030	33
1100	27
1130	451 Peak
1200	219
1300	108

Figure F-4. Sample dose-rate

Calculator Method

Use this method if your calculator has a logarithm function, or log button and a power key, or X^y, or Y' button.

Step 1. Calculate the decay exponent for the first burst. Divide 100 by 27 and push the log button on your calculator. Store this information in memory. Divide 3 by 1; push the log button. Divide the log of 100 ÷ 27 (stored in memory) by the log of 3 ÷ 1. The answer is 1.1918.

Step 2. Determine the decay rate for the second burst. First determine the contribution of the first burst dose rate to the 1200 hour reading of 219 cGyph. This is determined with the formula $R_1 \div ty^x n = R_t$:

R_1 = H + 1 reading for the first burst

t = time in hours from the H = 1 value of the first burst to H + 1 for the second burst

n = decay rate for the first burst calculated in Step 1

Y^x = power button on calculator

100 ÷ $4Y^X$ 1.2 = 1.9 cGyph.

To determine the reference or peak reading of the second burst–

219 cGyph - 19 cGyph = 200 cGyph at 1200 from the second burst

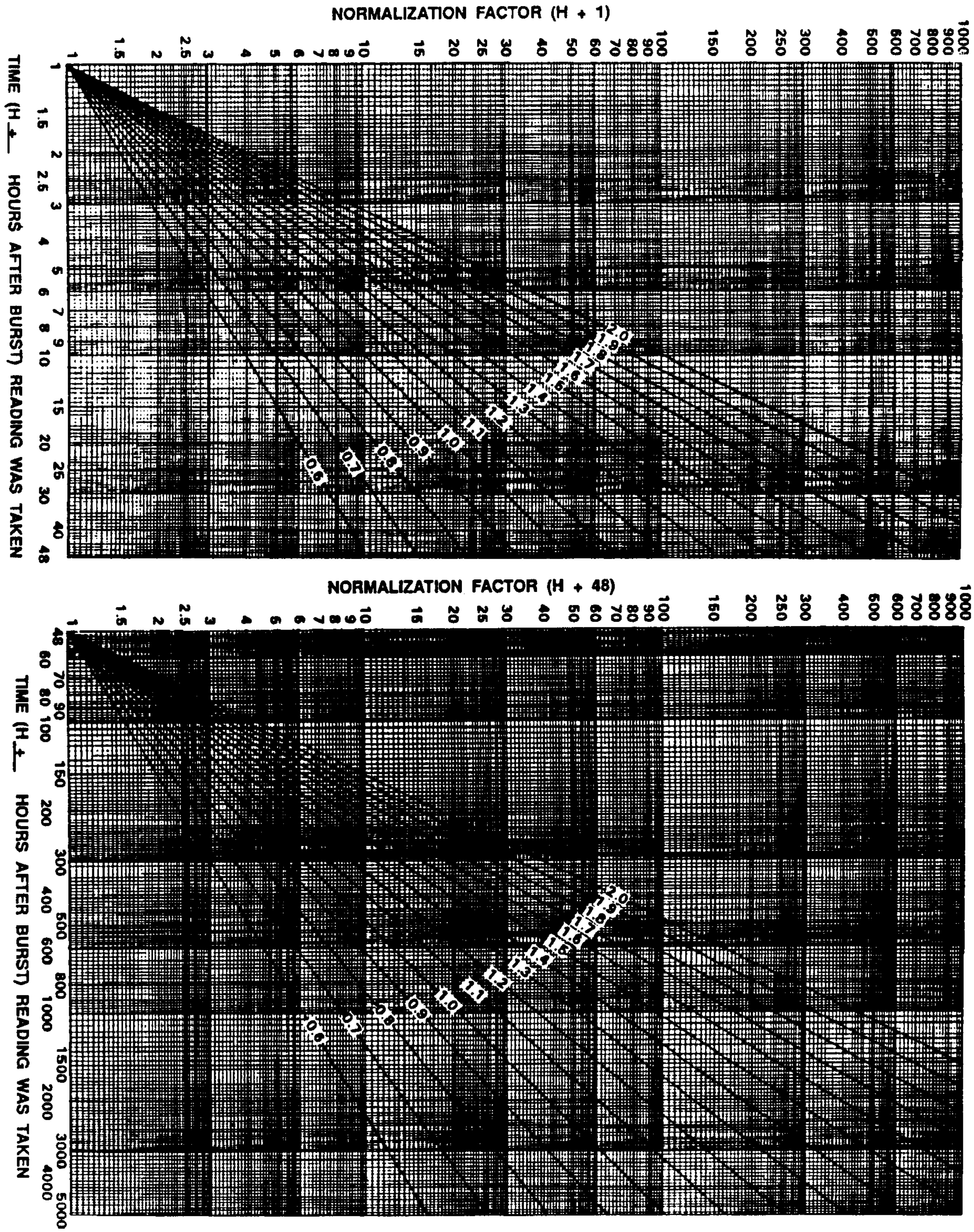

Figure F-3. Graphical method for determining normalization factor.

$$\frac{\log\left(\frac{R_a}{R_b}\right)}{\log\left(\frac{T_b}{T_a}\right)}$$

R_a = H + 1 reading of second burst

R_b = Last reading minus contribution from first burst

T_b = Time, in hours, of last reading from detonation time of second burst

T_a = Time, in hours, of reference reading for second burst

$$\frac{\log\frac{200}{108 - R_t}}{\log\frac{2}{1}}$$

R_t value for the first burst: $R_t = (R_1 \div ty^x n)$
$= (100 \div 5y^x 1.2)$
$= R_t = 14.5$ cGyph.

The R_1 value in this case is 100 cGyph. Use the value of 5 hours for t, because the reading of 108 cGyph occurred at 1300, which is 5 hours after the first burst. Push the y^x power key on the calculator, then the decay rate of 1.2 for the first burst. The answer, in this case, is 14.5 cGyph contribution from the first burst.

$$\frac{\log\left(\frac{200}{108 - 14.5}\right)}{\log\left(\frac{2}{1}\right)} = \frac{\log(2.1390)}{\log(2)}$$

Using the log button on the calculator, find the log of the top and bottom numbers, then divide 0.3302 by 0.3010; and your answer is 1.097, or 1.1.

The decay rate, therefore, after rounding to the nearest tenth, for the second burst is 1.1.

Step 3. Calculate the 0800Z dose rate 24 hours after the first burst. Remember, the T_b for 1.1 is only 5 hrs. You have to use 1.2 or get another series report.

$R24_x = R_1 \div 24Y^x 1.2$

$R24_x$ = rate 24 hours after first burst

$R_1 = R_1$ reading for first burst

Y^x = power key

$R24_x = 100 \div 24y^x 1.2$

$R24_x = 2.2067$ cGyph

$R21_y = R_1 \div y^x, 1.1$

$R21_y$ = rate of second burst at 0800Z

$R_1 = R_1$ or reference reading for the second burst

21 = 0800Z is 21 hours after the detonation time of the second burst

Y^x = power key on calculator

1.1 = decay rate for second burst

$R21_y = 7.02$ cGyph

$R21_y = 7.02$ cGyph.

Add the reading for 24 hours after the first burst to the reading 21 hours after the second burst:

2.2067 + 7.02 = 0.23, or 9 cGyph.

By using these procedures you can determine any dose rate, at any particular time with your calculator.

$R_1 = Rt\ (t)\ y^x n$

$Rt = R_1 \div ty^x n$

$t = Rt \div R_1 = \text{INV}\ {}_y{}^x n\ t/-.$

To solve for t is a little more complicated than the other procedures.

Given:

$R_t = 7$

$R_1 = 200$

n = 1.1

Find: t.

Divide 7 by 200. Push equals. Push the INV button, then 1.1, then the +/- button; then the equals button. In other words, $t = R_t \div R_1 = \text{INV}\ Y^x n + 1$ -.

Graphical Method

Use the graphical method when sufficient data is not available to separate the multiple burst readings.

Fallout has been received from two detonations. Dose-rate measurements were made at the intervals shown in Figure F-5. The time of the second burst is 0800. Time of the first burst is not known.

After receiving the measurement made at 1100, predict the dose rate at that location at 2000 on the following day (36 hours after the burst). After receiving each succeeding dose-rate measurement, update this prediction. Sufficient data are not available to separate the two bursts.

Step 1. Plot on log-graph paper the 0900 and 1100 dose-rate measurements against the time after the second burst.

Step 2. Draw a straight line through these points and extrapolate the line past H + 36 hours (see Figure F-6, next page).

Step 3. As a first approximation, determine a dose rate of 28.0 cGyph for 2000 on the day following the burst (R_{36}) directly from the graph.

Step 4. Upon receiving the 1300 measurement, plot this reading on the graph.

Step 5. Draw a new straight line through the 1100 and 1300 points; and extrapolate the line past H + 36 hours.

Step 6. As a second (and better) approximation, determine a dose rate of 20.5 cGyph for H + 36 hours directly from the second extrapolation.

Step 7. Repeat the procedure described in steps 4 through 6. Upon receipt of the

Time	Dose Rate (cGyph)
0900	360
1100	165
1300	108
1500	80
0200	30
1200	17.5

Figure F-5. Sample dose-rate readings.

1500, 0200, and 1200 measurements, update the prediction for R_{36} to 18.0, 14.5, and 12.5 cGyph, respectively.

Step 8. See Figure F-6 for an illustration of the dose-rate calculation. Reading from this figure, the true dose rate encountered at H + 36 hours at that location is 12.5 cGyph.

Calculating Overlapping Fallout

H-hour is known for each burst. At 251500, a 20-KT nuclear weapon was detonated on the surface "near" your position. Sometime later, fallout arrived on your position. At 1630, a peak dose rate of 126 cGyph was measured. Subsequent readings indicated that n = 1.4. At 251700, another weapon was detonated close to your area, and fallout arrived soon after. At 251730, a second peak dose rate of 300 cGyph was measured.

Assuming that n = 1.2 for the second weapon, what will the dose rate be at 1900? This may be calculated using Step 3 of the calculator method for determining an R_1 value.

When H-hour for each detonation is known, calculate the dose or dose rate for each event and add them together to get the total dose or dose rate received.

Step 1. Find R_1 for the first detonation.

$R_1 = [R_t(t), y^x n]$

$R_1 = [126\ (1.5)\ y^x, 1.4]$

$R_1 = 222.3$ cGyph.

Step 2. Find R_t at 1730 for first fallout only.

$R_t = R_1 ÿ\ t\ Y^x n$

$R_t = 222.3 \div 2.5\ Y^x 1.4$

$R_t = 61.6$, or 62 cGyph.

Step 3. Find the dose rate contribution at 1730 from the second burst.

$Rt_a = R_t - R_{t1}$

$R_{ta} = 300$ cGyph - 62 cGyph

$R_{ta} = 238$ cGyph.

Step 4. Find R_{1a} for the second burst only.

$R_1 = R_t(t), Y^x, n$

$R_1 = 238\ (0.5), Y^x, 1.2$

$R_1 = 103.5$, or 104 cGyph.

Step 5. Find R_t at 1900 for each burst. For the first burst—

$R_1 = 222$ cGyph

t = H + 4 hours

$R_t = (R_1\ ÿ\ t, Y^x, n)$

$R_t = 222\ ÿ\ 4, Y^x, 1.4$

$R_t = 31.8$, or 32 cGyph.

For the second burst—

$R_1 = 104$ cGyph

t = H + 2

$R_t = R_1 \div t, Y^x, n$

$R_t = 104 \div 2, Y^x, 1.2$

$R_t = 45.3$, or 45 cGyph.

Step 6. Find the total dose rate at 1900. Total dose rate is the sum of dose rates at that time.

R total $= R_t + R_{t2}$

R total = 32 + 45

R total = 77 cGyph.

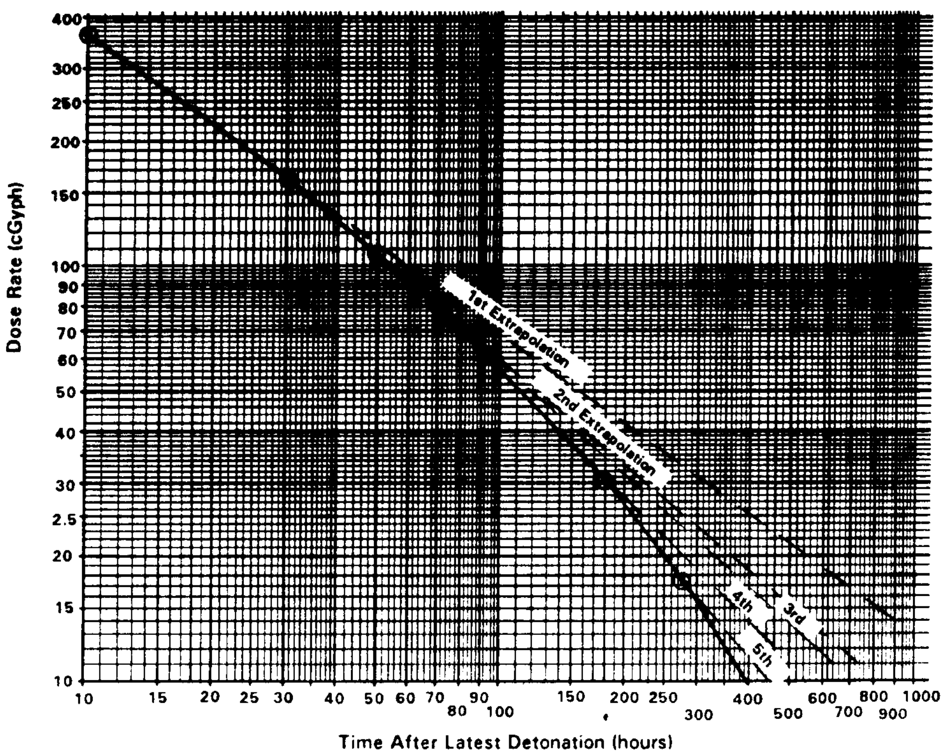

Figure F-6. Sample extrapolations with periodic revisions.