

A

0 8 3

Technical Report

RADIATION SLIDE RULE FOR
ATOMIC FALLOUT PROBLEMS



U. S. NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

This document has been approved for public release
and sale; its distribution is unlimited. *HGL*

11 DEC 1974

RADIATION SLIDE RULE FOR ATOMIC
FALLOUT PROBLEMS

Y-F011-05-401

Type C
Final Report

24 May 1960

by

J. C. LeDoux

U. S. NAVAL CIVIL ENGINEERING
LABORATORY
Port Hueneme, California

OBJECT OF TASK

Studies and reports which translate atomic warfare information into a form suitable for Bureau planning and design use and for operations in the field.

ABSTRACT

A nuclear weapon explosion results in earth and bomb debris which has become contaminated with fission products, residual radiation or fallout. The problem of decontaminating an area depends largely on the radiation intensity and the rate of decay of the fission products.

Previous methods of determining dose to personnel during decontamination operations used tables or graphs to determine the total dose which would be received at a certain location over a specified period of time. Except for values used in the tables the desired value must be obtained by interpolation.

This report presents the theory, construction, and use of a circular slide rule which is designed to solve passive defense problems dealing with residual radiation. The rule is based on the $t^{-1.2}$ law of radioactive decay. The slide rule can be used to solve an infinite number of individual problems without the necessity of interpolation in tables or construction of graphic plots. A number of typical problems are worked with the slide rule to indicate its method of use.

CONTENTS

	page
INTRODUCTION	1
THEORY	1
CONSTRUCTION OF SLIDE RULE AND OPERATION	3
COMPARISON OF SLIDE RULE TO SOME TEST RESULTS	7
TYPICAL PROBLEMS	15
USE OF RULE FOR MULTIPLICATION AND DIVISION	18
CONCLUSIONS	18
RECOMMENDATIONS	19
REFERENCES	20
DISTRIBUTION LIST	21
LIBRARY CATALOG CARD	27

TABLES		page
IA - Accumulated Dose Table, $t^{-1.2}$		10
IB - Accumulated Dose Table, NRDL		11
IIA - Dose Accumulated During Stay Time Interval, $t^{-1.2}$		12
IIB - Dose Accumulated During Stay Time Interval, NRDL.		13
III - Difference Between $t^{-1.2}$ Law and NRDL (Table IIA - IIB)		14

ILLUSTRATIONS		page
figure		
1 - Dose Rate (\dot{D}) and Total Dose (D_{∞}) for Problem $\dot{D} = 200$ r/hr at 3 hr . . .		4
2 - Radiation Computer with Dose Rate, Total Dose, and Time Scales . . .		5
3 - Plastic Overlay with Time Conversion Factors		6
4 - Movable Cursor Arm		7
5 - Comparison of 1.2 Law and NRDL Data		9

INTRODUCTION

In this nuclear age, warfare and defense problems have become increasingly scientific. It is, therefore, important that scientific devices be developed to help solve these problems. Giant electronic computers, for example, solve problems which are essentially unsolvable by other means. On a much simpler scale, problems associated with radioactive fallout and decontamination of fallout areas can be solved with a nuclear radiation slide rule. This report presents the theory, development, construction, and operation of such a radiation slide rule, and, for those engaged in Atomic Defense Engineering, a 4-in. plastic model of the slide rule has been inserted in the back cover flap of this report.

THEORY

An atomic bomb releases many radiation products from fissioning U^{235} or Pu^{239} . Most of these fission products are radioactive, and they decay according to their individual rates. By statistical methods, Way and Wigner¹ derived a decay scheme applicable to the combined fission products. Their decay scheme is expressed by the following formula:

$$P = P_0 k t^{-1.2} \dots \dots \dots (1)$$

where P is the power generation due to beta or gamma rays,

- P_0 is the total power generated during irradiation,
- k is the constant of proportionality
- t is the time after irradiation, sec.

This same decay scheme has been applied to residual or fallout radiation, since this residual radiation is made up of the fission products from either U^{235} or Pu^{239} . This decay scheme gives a good approximation of the actual results of a number of bomb tests.² The expression is changed slightly to give the answer in terms of dose rate (\dot{D}) instead of power. Thus

$$\dot{D} = \dot{D}_1 t^{-1.2} \dots \dots \dots (2)$$

where \dot{D} is the dose rate at any time, t ,

\dot{D}_1 is the dose rate at $H + 1$, one hour after the bomb detonation
 t is the time expressed in hours after bomb detonation.

In most cases the total dose received over a specified time is more important than the dose rate at a particular instant. Equation (2) is then integrated over the period of time involved:

$$D = \dot{D}_1 \int_{t_1}^{t_2} t^{-1.2} dt \dots \dots \dots (3)$$

where D is the total dose received from t_1 to t_2 .

This integrated to:

$$D = 5 \dot{D}_1 (t_1^{-0.2} - t_2^{-0.2}) \dots \dots \dots (4)$$

If a person remained in a contaminated area from time of entry (t_1) forever and no decontamination took place, the total dose he received would be:

$$D_\infty = 5 \dot{D}_1 t_1^{-0.2} \dots \dots \dots (5)$$

where D_∞ has been termed the dose to infinity.

If equation (2) and (5) are expressed as logarithmic functions, and then plotted on log-log paper, they would plot as straight lines, with slopes of -1.2 and -0.2, respectively.

Equation (2) thus becomes:

$$\text{Ln}(\dot{D}/\dot{D}_1) = -1.2 \text{ Ln } t \dots \dots \dots (6)$$

Equation (5) thus becomes:

$$\text{Ln} (D_\infty / 5\dot{D}_1) = -0.2 \text{ Ln } t \dots \dots \dots (7)$$

From equations (2) and (5), we find that the dose to infinity and dose rate (D_∞ and \dot{D}) are numerically equal, when $t=0.2$ hr. This information is required to plot the functions on log-log paper and also to operate the slide rule, since it allows aligning the total dose scale from a given dose rate.

It is interesting to note that equations (6) and (7) can only be plotted on log-log paper for a specific problem. Figure 1 is a typical example for the case of $\dot{D} = 200\text{r/hr}$ at $t = 3$ hrs. The plot can be made by calculating two points on the curve from equations (2) and (5), or by using the slope through one point. It is emphasized again, that a plot made like Figure 1 is only valid for a single location, or a single problem; it is limited by the size of the graph paper used and by the accuracy of the plot made.

The main virtue of a slide rule based on the general equations (2) and (5) is that it can be used for any problem; its accuracy is built into the constructed scales; it quickly solves any given problems; and finally it can be constructed so that it is independent of any set number of log cycles for the parameters of time, dose-rate, and total dose.

CONSTRUCTION OF SLIDE RULE AND OPERATION

In order to construct a useful slide rule, a closer look at the basic equations is required. Since the slide rule will be logarithmic, the relation between the three parameters of time, dose rate, and total dose must be known. Equations (2) and (5) reveal that the log cycle ratio between total dose, time and dose rate is:

$$D:t:\dot{D} = 10:10^5:10^6$$

where total dose and dose rate decrease as time increases. Thus, it is a simple matter to construct a circular slide rule based on these ratios. Since time is the common factor between total dose and dose rate, the time scale is placed between the total dose and dose rate scales. Figure 2 is the result of this construction. The dose rate scale is on the outside with values from 10,000 r/hr to 0.01 r/hr. The time scale is next and runs from 0.01 hr to 1000 hr. The inside scale is the total dose scale and it is a single log cycle from 1 to 10 r.

Since each scale has an integral number of log cycles, the rule is independent of the number of log cycles required. If the problem at hand produces a number beyond the values shown on the rule, all that has to be done is a simple change of the decimal point. For instance: if the dose rate became less than 0.01 r/hr, the 10,000 r/hr would become 0.01 r/hr. However, for most practical problems, the values listed will suffice. Since the total dose reading depends on the dose rate at 0.2 hrs, the proper decimal point locations for the total dose will depend upon the problem. This will be illustrated in the typical problems.

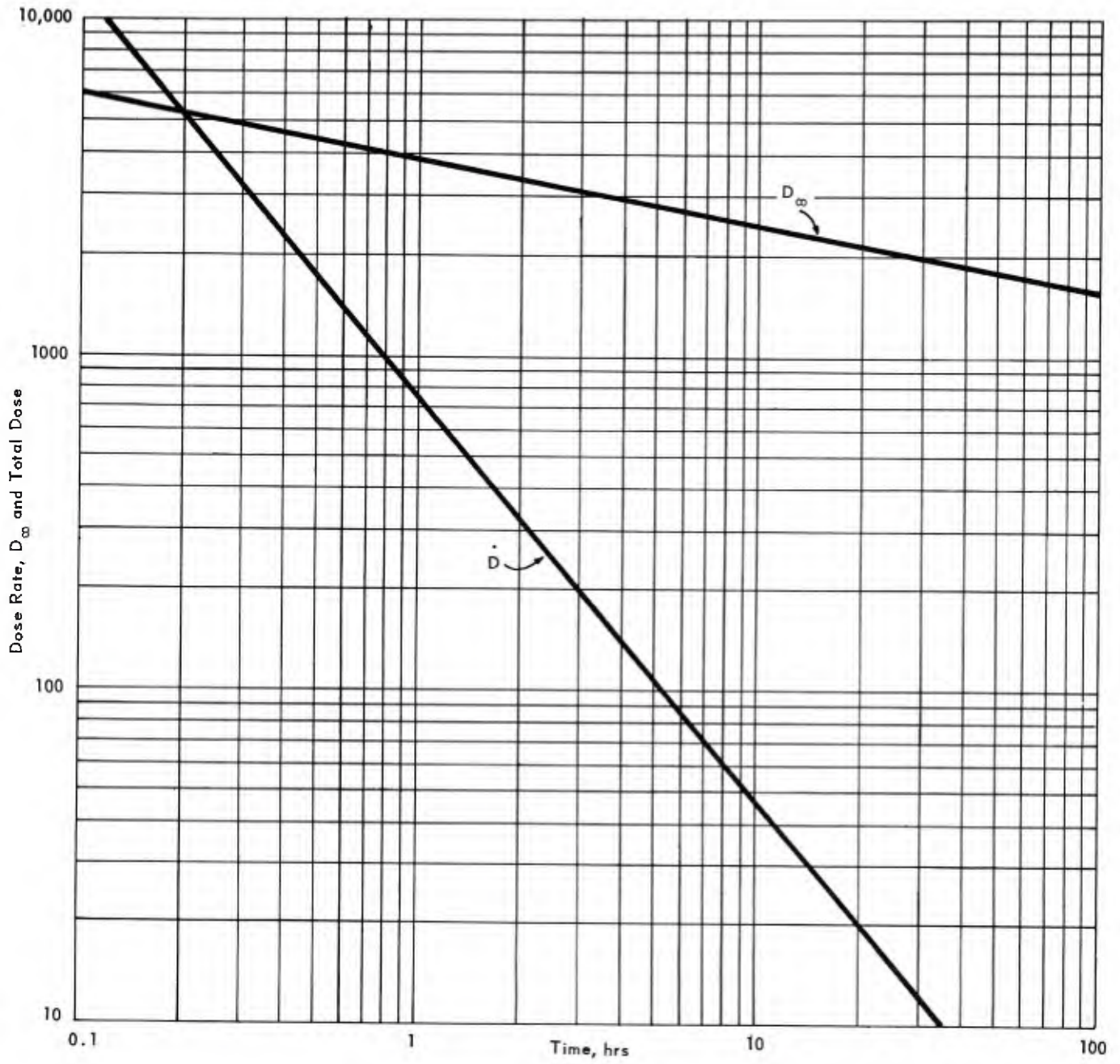


Figure 1. Dose Rate (\dot{D}) and Total Dose (D_{∞}) for Problem $\dot{D} = 200$ r/hr at 3 hr.

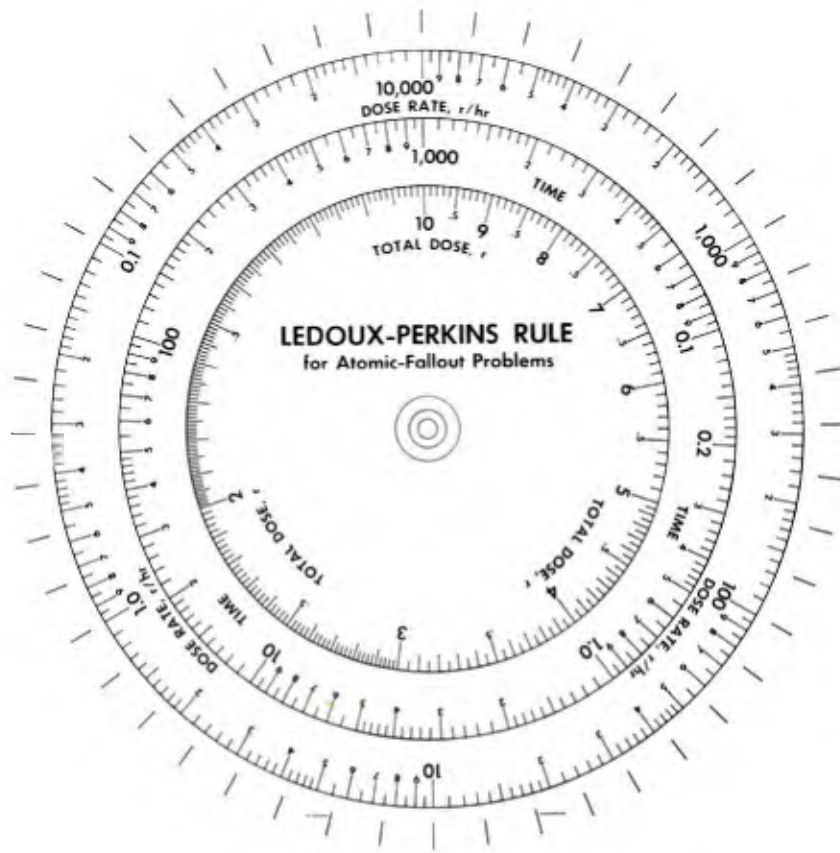


Figure 2. Radiation Computer with Dose Rate, Total Dose, and Time Scales.

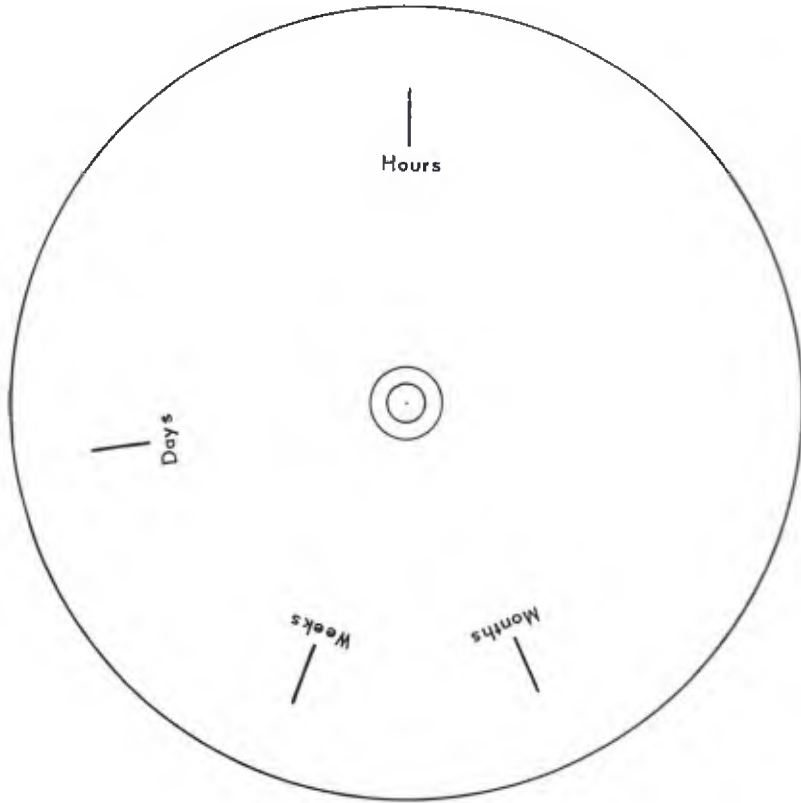


Figure 3. Plastic Overlay with Time Conversion Factors.

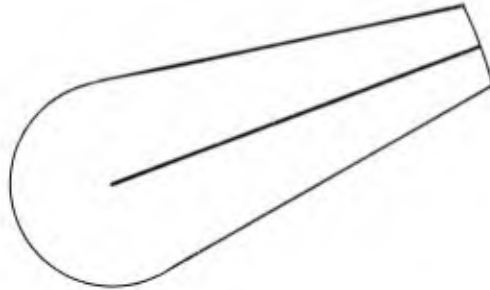


Figure 4. Movable Cursor Arm.

Figure 2 is the basic rule. Over this is placed a clear plastic overlay (Figure 3). To preserve the log cycle ratio, the time scale of the basic rule is in hours. The plastic overlay has conversion indices for days, weeks and months. Their use will be illustrated in the problems. Finally a movable cursor arm (Figure 4) is placed over the plastic overlay for use with the dose rate and total dose scales. Between the plastic overlay and the cursor is a friction bearing to prevent slippage. The cursor can be moved independently of the plastic overlay, but the cursor must move whenever the plastic overlay is moved to retain the problem being worked.

COMPARISON OF SLIDE RULE TO SOME TEST RESULTS

Since the slide rule is based on the theoretical decay law constant of -1.2 , the values that the slide rule will yield should be compared to those of known results. Actual test results have yielded decay exponents from -1.0 to -1.4 for the same shot at different locations. However decay by the 1.2 law is generally accepted as the most representative.

The most extensive work on the compilation of test results for fallout decay has been done by the Naval Radiological Defense Laboratory (NRDL) and their results appear in tabular form in Reference 4. The slide rule will be compared to these results in order to evaluate its usefulness as a planning device for passive defense recovery operations.

Figure 5 shows a plot of the decay scheme given in Table 3.9 of Reference 4 and a plot of the decay by the 1.2 law. These plots are both on an $H+1$ value of 1000 r/hr. It can be seen that, for early times, the NRDL data gives dose rates that exceed those of the 1.2 law. However, the difference between the two curves is always less than a factor of 2. For times of practical interest, from a decontamination viewpoint from a few days to six months, the two curves compare favorably. Decay curves based on exponents of -1.0 and -1.4 are also plotted for comparison purposes.

Table IA, Accumulated Dose Table, is similar to Table 3.9 in Reference 4. Table IB is a portion of Table 3.9 using the same time references as Table IA. Table IA was computed using the dose rate at entry as listed in Table IB since this is presumably the value that would be read on a monitoring instrument upon entering the contaminated area. Table IIA, Dose Accumulated During Stay Time Interval, is the dose difference between successive column entries from Table IA. Thus, it is the dose accumulated during that period. Table IIB is the same information from the NRDL data, Table IB. Finally, Table III is the tabular difference between Table IIA and IIB, or between the 1.2 law and the NRDL data. It is interesting to note that in all cases except five, the 1.2 law predicts doses which are on the conservative side. For the one and two day entry times and the first week of stay time, the prediction is lower than the NRDL data by 21 per cent and 44 per cent, respectively. Both methods indicate lethal doses for one day entries. The other three instances of low values are only 7, 3, and 2 r less than NRDL and therefore not significant. It should be kept in mind that these are planning doses only. In an actual case, continuous monitoring would be used and adjustments made for future predictions which would tend to bring the results even closer together.

Since the slide rule is designed primarily as a planning device, it appears from the above comparison that it can be used with safety since it predicts doses on the conservative side (compared to NRDL data) for cases of practical interest; i.e. for entry times after two days. Reference 5 states, "the fission process found in nuclear weapons may differ from these data, but probably not by more than a factor of two, which is of minor consequence when considering the over-all uncertainties connected with the hazard to man". This comment is appropriate, since the slide rule will predict dose rates, total dose, times of exposure, and decontamination factors well within a factor of two not only of the NRDL data, but known test results as well.

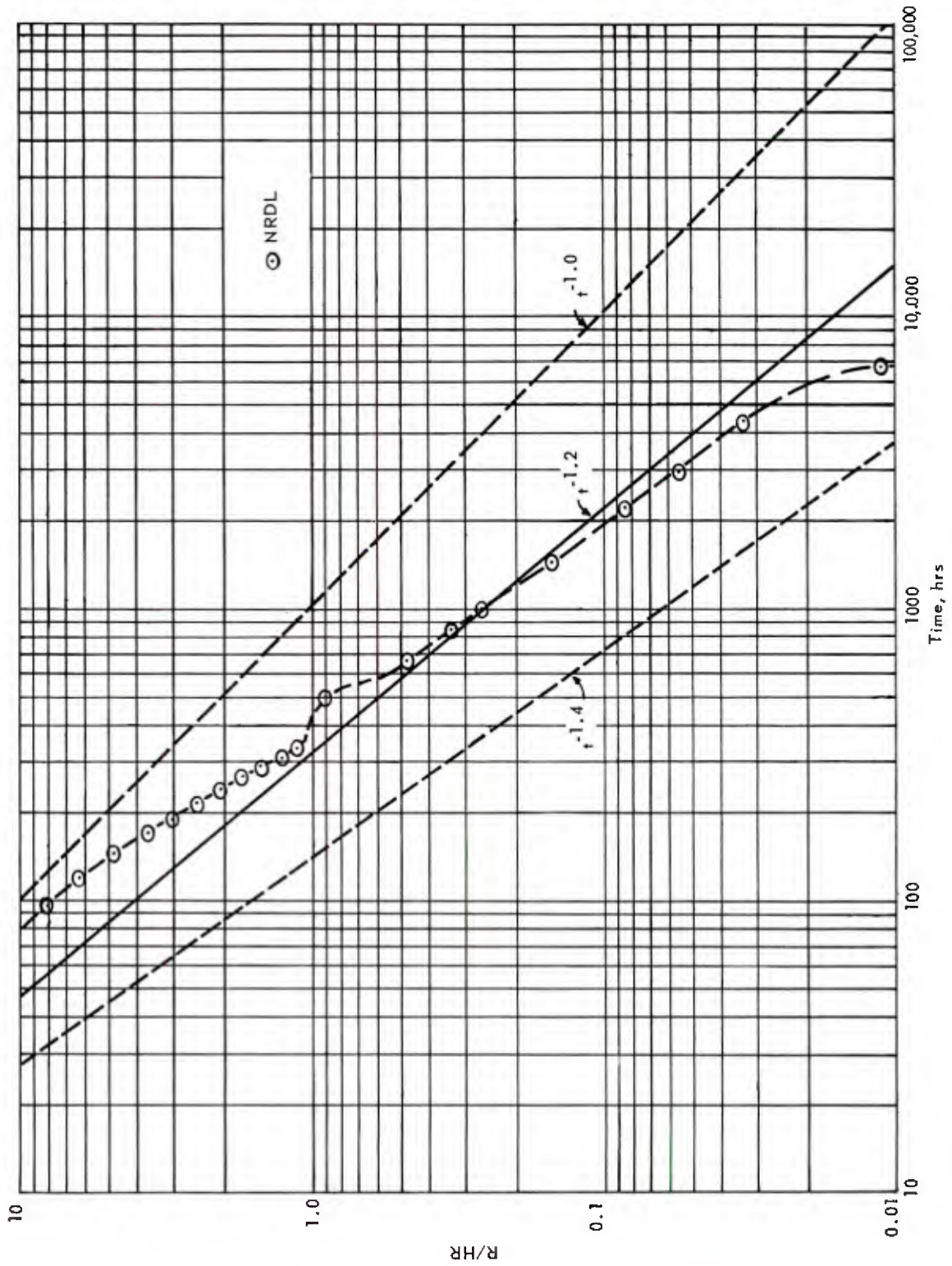


Figure 5. Comparison of 1.2 Law and NRD L Data.

Table IA. Accumulated Dose Table, $t^{-1.2}$

Entry time, t_e	Dose rate at t_e	1 week	2 weeks	1 month	3 months	6 months	1 year	2 years
1 day	29.2	1180	1460	1750	2080	2270	2420	2560
2 days	16.2	1000	1310	1660	2080	2300	2505	2680
3 days	11.1	850	1160	1530	1980	2230	2450	2640
5 days	6.15	590	850	1180	1630	1890	2115	2315
10 days	2.06	250	400	600	910	1100	1270	1420
2 weeks	1.13	150	245	385	630	780	915	1040
4 weeks	0.47	70	120	210	395	525	647	762
2 months	0.15	30	45	85	185	266	355	441
6 months	0.032	5	10	19	52	88	136	192
1 year	0.0058	1	2	5	7	20	33	50

Table IB. Accumulated Dose Table, NRDL

Entry time, t_e	Dose rate at t_e	1 week	2 weeks	1 month	3 months	6 months	1 year	2 years
1 day	29.2	1490	1765	2000	2243	2355	2414	2434
2 days	16.2	1046	1279	1504	1739	1849	1908	1928
3 days	11.1	788	993	1198	1430	1539	1597	1617
5 days	6.15	499	650	838	1056	1162	1219	1239
10 days	2.06	200	317	462	653	752	808	827
2 weeks	1.13	137	230	354	528	621	675	694
4 weeks	0.47	63	112	185	322	402	447	464
2 months	0.15	27	49	82	167	225	259	275
6 months	0.032	4	7	19	43	60	67	73
1 year	0.0058	1	2	4	8	13	20	23

Table IIA. Dose Accumulated During Stay Time Interval, $t^{-1.2}$

Entry time	1 week	1 week — 2 weeks	2 weeks — 1 month	1 month — 3 months	3 months — 6 months	6 months — 1 year	1 year — 2 years
1 day	1180	280	290	330	190	150	140
2 days	1000	310	350	420	220	205	175
3 days	850	310	370	450	250	220	190
5 days	590	260	330	480	260	225	200
10 days	250	150	200	310	190	170	150
2 weeks	150	95	140	245	150	135	125
4 weeks	70	50	90	185	130	122	115
2 months	30	15	40	100	81	89	86
6 months	5	5	9	33	36	48	56
1 year	1	1	3	2	13	13	17

Table IIB. Dose Accumulated During Stay Time Interval, NRDL

Entry time	1 week	1 week - 2 weeks	2 weeks - 1 month	1 month - 3 months	3 months - 6 months	6 months - 1 year	1 year - 2 years
1 day	1490	275	235	243	112	59	20
2 days	1046	233	225	235	110	59	20
3 days	788	205	205	232	109	58	20
5 days	499	151	188	310	106	57	20
10 days	200	117	145	191	99	56	19
2 weeks	137	93	124	174	93	54	19
4 weeks	63	49	73	137	80	45	17
2 months	27	22	33	85	58	34	16
6 months	4	3	12	24	17	7	6
1 year	1	1	2	4	5	7	3

Table III. Difference Between $t^{-1.2}$ Law and NRDL (Table IIA - IIB)

Entry time	1 week	1 week - 2 weeks	2 weeks - 1 month	1 month - 3 months	3 months - 6 months	6 months - 1 year	1 year - 2 years
1 day	- 310	+ 5	+ 55	+ 87	+ 78	+ 91	+ 120
2 days	- 46	+ 77	+ 125	+ 185	+ 110	+ 146	+ 155
3 days	+ 62	+ 105	+ 165	+ 218	+ 141	+ 162	+ 170
5 days	+ 91	109	142	170	154	168	180
10 days	+ 50	33	55	119	91	114	131
2 weeks	+ 13	2	16	71	57	81	106
4 weeks	+ 7	1	17	48	50	77	98
2 months	+ 3	- 7	7	15	23	55	70
6 months	+ 1	2	- 3	9	19	41	50
1 year	0	0	1	- 2	8	6	14

TYPICAL PROBLEMS

The slide rule can be used to solve five basic problems; they are:

- (1) Dose rate at any time from dose rate at given time,
- (2) Dose to infinity at any entry time from dose rate at given time,
- (3) Total dose received between entry and exit times,
- (4) Time of entry for given allowed dose and mission time,
- (5) Decontamination required for entry at specified time for a given mission duration.

To illustrate the use of the slide rule, each problem will have the following initial conditions: Dose rate = 200 r/hr at 3 hours after bomb time.

(1) For problems of the first type, set the plastic overlay over the proper time; set the hour index over 3; and now move the cursor arm until it is set over the proper dose rate--200 on the outer dose rate scale. Determine the dose rates at the following times: 1 hour, 10 hours, 3 days, 5 weeks, 3 months, and 1 year.

(a) 1 hour: move the plastic overlay until the Hour Index is over 1, read the value under the cursor: 748 r/hr

(b) 10 hours: move the plastic overlay until the Hour Index is over 10, read the value under the cursor: 48 r/hr

(c) 3 days: move the plastic overlay until the Day Index is over the value 3, read the value under the cursor: 4.5 r/hr

(d) 5 weeks: $D = 0.23$ r/hr

(e) 3 months: $D = 0.075$ r/hr

(f) 1 year: Place the plastic overlay so that the Month Index is over 12, read 0.014 r/hr under the cursor.

It should be noted that once the cursor is set relative to the plastic overlay, any time unit can be used on the time scale and the correct value will appear under the cursor.

(2) For problems of the second type, the cursor must be set to read the proper value on the Total Dose Scale. To do this, move the plastic overlay until the Hour Index is over 0.2, read the value of the dose rate now under the cursor.

(The cursor is still set with the initial conditions.) The value for the given problem is 5200 r/hr. As indicated previously, (page 2), the dose rate at 0.2 hrs and dose to infinity are numerically equal. To set the cursor then for total dose problems, determine the dose rate at 0.2 hrs and set this value on the Total Dose Scale by moving the cursor over the same value on the Total Dose Scale. For the given problem, move the cursor arm until it is over the value of 5.2 on the Total Dose Scale. It must be remembered that 5.2 is actually 5200 r.

Now determine the dose to infinity for the same entry times given in Problem 1.

- (a) 1 hour: $D_{\infty} = 3770$ r
- (b) 10 hours: $D_{\infty} = 2380$ r
- (c) 3 days: $D_{\infty} = 1600$ r
- (d) 5 weeks: $D_{\infty} = 980$ r
- (e) 3 months: $D_{\infty} = 815$ r
- (f) 1 year: $D_{\infty} = 615$ r

(3) For problems of the third type, the dose to infinity problem as in (b) above is merely worked for both the entry and exit times. The answer desired is the difference between the two. The following problems illustrate the technique:

Entry	Exit	D(entry)		D(exit)	D(Total Dose)
1 hour	12 hours	3770 r	-	2290 r	1480 r
1 day	7 days	2000 r	-	1350 r	650 r
7 days	5 weeks	1350 r	-	980 r	370 r
2 months	5 months	880 r	-	735 r	145 r
1 year	3 years	615 r	-	495 r	120 r

The above type problem is sometimes worked in reverse. We know the entry time and the total dose to be allowed and would like to know the exit time. This is done by setting the rule on the entry time, the allowed dose is then subtracted and the exit time read off. The total time allowed in the area then is the difference between the exit and entry times. The following illustrates this type of problem: Allowed dose is 150 r in all cases.

ENTRY	EXIT	MISSION TIME
1 hour	1.22 hours	13 minutes
1 day	1.48 days	11 hours
2 weeks	3.8 weeks	12 days
3 months	8.2 months	5 months

(4) For problems of the fourth type, the duration of the stay time in a contaminated area is known, the total allowed dose is specified, and the problem is to determine when a contaminated area can be entered. The initial conditions are the same as before: 200 r/hr at 3 hours; 48-hour work week in the contaminated area; a total allowed dose of 200 r for a mission lasting 1 year. Find the entry time.

Since the slide rule is based on continuous exposure, the first item to be determined is the total dose received by someone staying in the area continuously instead of only 48 hours per week. This dose would be:

$$D = 200 \times \frac{168}{48} = 700 \text{ r}$$

A first approximation for a 1-year mission, determine the exit dose at one year. This is:

$$D (1 \text{ yr}) = 615 \text{ r}$$

Since the allowed dose for this problem for continuous exposure is 700 r, the dose to infinity at entry would be 615 r + 700 r or 1315 r. The entry time for this value is 8 days. In this case the first approximation is close enough, since the exit dose at 373 days is 611 r and the adjusted entry time is 8.2 days. Hence, our answer would be 8 days.

(5) Supposing that the 8 days entry time is unsatisfactory and that the area must be entered at 1 day after the bomb explosion; how much decontamination must be effected, so that the total dose received still remains 200 r for the first year?

The dose to infinity at 1 day is 2000 r. The dose to infinity at exit time (1 yr) is 615 r. Therefore, the total dose received during this period would be 1385 r.

The total allowed dose for continuous exposure is 700 r, therefore the decontamination residual number required is $700/1385$ or 0.51. This is the degree of decontamination that must be effected for entry at 1 day.

USE OF RULE FOR MULTIPLICATION AND DIVISION

Because of its logarithmic construction, the rule can be used to solve multiplication and division problems associated with decontamination problems. For instance the illustrated problem 5, contained the problem of $700/1385$. This can be worked on the rule. In most cases it is most convenient to use the inner Total Dose Scale for these arithmetic problems.

For Multiplication: Set the Hour Time Index over the first number to be multiplied. Set the movable cursor arm over 10. Move the overlay until the movable cursor arm is over the second number. Read the answer under the Hour Index.

Examples: $5.5 \times 7 = 37.5$ Set hours over 5.5; set arm over 10; move overlay until arm is over 7; read 37.5 under Hours.

For Division: Set Hour Index over numerator and the movable cursor arm over the denominator. Move the overlay until the cursor arm is over 10 and read the answer under the Hour Index.

Example: $700/1385 = 0.51$ Set hours over 700; set arm over 1385; move overlay to 10; read under hours 0.51.

CONCLUSIONS

1. The use of a slide rule for the solution of passive defense problems offers certain advantages over the use of either tables or plotted curves. They are:

- (a) Accuracy. No interpolation required; no curve plotting,
- (b) Can be made pocket size for easy use and carrying.

2. The use of the slide rule (and the 1.2 law) will usually produce conservative results. For early times, the results may be unconservative but in error at most by a factor of 2.

RECOMMENDATIONS

1. It is recommended that the Radiation Computer be made available to all passive defense teams and monitors. (A 8 in. model of slightly different design has been issued as a part of "Radiological Recovery of Fixed Military Installations" by the Bureau of Yards and Docks.)

REFERENCES

1. Way, K., and E. P. Wigner: The Rate of Decay of Fission Products, *Phys. Rev.*, 73(11): 1318-1330 (June 1, 1948).
2. Atomic Energy Commission; *Effects of Nuclear Weapons, — 1957*, Washington, D. C., June 1957
3. Jarrett, A. A., *Evaluation of Fallout Data*, NAA-SR-3972, Dec. 1959, Atomic International, Conoga Park, California.
4. Departments of the Army and the Navy: *Radiological Recovery of Fixed Military Installations*, Interim Revision. April 1958. TP-PL-13, TM-3-225.
5. Kement, Alfred W., Jr.: *A Review of Potential Radionuclides Produced in Weapons Detonations*. WASH-1024, July 30, 1959. U. S. Atomic Energy Commission.

DISTRIBUTION LIST

No. of copies	Code	
10		Chief, Bureau of Yards and Docks
212		Activities to which Public Works Officers are Assigned, as follows:
	50C	(Taiwan only)
	E4	(Wash., D. C., only); E16
	F9	(Boston, Green Cove Springs, Key West, New Orleans, Orange, San Juan, Long Beach, San Diego, Treasure Island, Tongue Point, and Rodman only)
	F17	(San Juan, San Francisco, Pearl Harbor, Adak, and Guam only)
	F21	(Saipan only); F40 (Pt. Lyautey and Kami Seya only); F41
	F42	(Oso and Cheltenham only); F43 (Londonderry only); F48 (Winter Harbor only)
	G1A	(except Johnsville, Pt. Mugu,); G1B
	G1D	(Phoenix, Monterey, Oppama, Naha, Naples, Severn River, and Azores only); G1F, G3C, G5A, G5B, G8G, G8H (except Rota); G8I; G14; G18; G19; G21, G29
	H3	(Chelsea, St. Albans, Portsmouth, Va, Beaufort, Gt. Lakes, San Diego, Oakland, Camp Pendleton, and Philadelphia only); H6
	J1	(Great Lakes and San Diego only); J3 (Virginia Beach, San Diego only); J4
	J19	(Brooklyn only); J31; J34 (Wash., D. C. only); J37 (Bainbridge only); J46; J60; J84; J90; J99
	K2A	(except Philadelphia); K2C; K2D; K5A; K5B; K5D; K7 (White Oak only)
	K8	(Yellow Water and Guam only); K10; K12; K13C; K16; K22
	L1;L7	(New London, Panama City, Carderock, and Annapolis only); L26 (Antigua, Turks Island, Barbados, San Salvador, and Eleuthera only)
	L30	(New London only); L32 (London and Naples only); L42
	M27;M28	(except Guantanamo Bay, Subic Bay, and Yokosuka); M61
	N14	
	R9;R10	(Albany and Barstow only); R20; R64; R66 (Tengan only)
		BuDocks Managed Activities, as follows:
3	N1	
42	N2	
9	N5	
7	N6	
18	N9	
		Activities Primarily Composed of CEC Officers, as follows:
6	26C	
2	39A	
2	39B	
9	39D	
6	39E	
5	39F	
		Other Selected Activities with CEC Officers Assigned, as follows:
3	21	
3	23A	
1	24A	
2	24F	
1	C5	
1	J48	
1	J95	
2	L7	
2	M26	
5	W2A	
1	W3A	
1	W3B	
1	W3E	
1	W3F	
1	W11F	

Distribution List (Cont'd)

No. of copies	Code
Other Activities	
3	A2A (2 copies), A2A (Code 320)
2	A3, A3 (OP07)
1	C5B
1	F16
1	F17
1	F21
2	J12
1	J14
1	J73
1	J93
1	L7
1	L24
8	W2A
1	W4A
1	W7C
1	W7Q
2	Director of Defense Research and Engineering
2	Defense Research Member (Via ONI-OP-321)
2	Chief of Engineers, U. S. Army
2	Commanding Officer, Engineer Research and Development Laboratories
2	Commander, Wright Air Development Center
3	Headquarters, USAF, Directorate of Civil Engineering, Attn: AFOCE-ES
2	Commander, Hdq., Air Research & Development Command, Andrews Air Force Base
2	President, Marine Corps Equipment Board
2	Director, Division of Plans and Policies, Hdq., U. S. Marine Corps
2	Director, Bureau of Reclamation
2	Office of the Director, U. S. Coast and Geodetic Survey
2	Director, National Bureau of Standards
2	Technical Division, Code 141, CBC, Port Hueneme
2	Materiel Department, Code 142, CBC, Port Hueneme
10	Commandant, Armed Services Technical Information Agency
10	Director, Office of Technical Services
2	Library of Congress, Washington: 25, D. C.

Distribution List (Cont'd)

No of copies	
1	Commandant, Industrial College of the Armed Forces
1	Commandant, U. S. Armed Forces Staff College, Norfolk
1	Chief, Bureau of Ships, Attn: Chief of Research and Development Division
1	Officer in Charge, U. S. Naval Biological Laboratory, Oakland
1	Officer in Charge, U. S. Navy Unit, Rensselaer Polytechnic Institute, Troy
1	Chief, Bureau of Medicine and Surgery, Attn: Research Division
1	Officer in Charge, U. S. Naval Supply Research and Development Facility, Attn: Library, Bayonne
1	Director, Marine Physical Laboratory, U. S. Navy Electronics Laboratory, San Diego
1	Chief Bureau of Naval Weapons, Attn: Research Division
1	Commander, Pacific Missile Range, Attn: Technical Director, Point Mugu
1	Commanding Officer, Amphibious Construction Battalion One, Coronado
1	Commander, Amphibious Force, U. S. Pacific Fleet, Norfolk
1	Officer in Charge, U. S. Naval Supply Research and Development Facility, Bayonne
1	Commander, Norfolk Naval Shipyard, Attn: Metallurgical Laboratory, Portsmouth
1	Commander, Norfolk Naval Shipyard, Attn: Chemical Laboratory
1	Commanding Officer, Fleet Training Center, San Francisco
1	Commander, U. S. Naval Shipyard, Attn: Rubber Laboratory, Vallejo
1	Commander, U. S. Naval Shipyard, Attn: Materials and Chemical Lab., Boston
1	Commander, U. S. Naval Shipyard, Attn: Material Laboratory, Brooklyn
1	The Hydrographer, U. S. Hydrographic Office
1	Navy Liaison Officer, Detroit Arsenal, Centerline
1	Office of Naval Research, Branch Office, New York
1	Commanding Officer, Naval Electronics Laboratory, Attn: Technical Director, San Diego
1	Commanding Officer, Yards and Docks Supply Office, U. S. Naval Construction Battalion Center, Port Hueneme
1	Commanding Officer, U. S. Naval Unit, U. S. Army Chemical Corps School, Fort McClellan, Alabama
1	U. S. Naval Research Laboratory, Chemistry Division
1	Commanding Officer, Field Research Laboratory, Bureau of Medicine and Surgery, Camp Lejeune
1	Commandant, 1st Naval District, Boston
1	Commandant, 3rd Naval District, New York
1	Commandant, 4th Naval District, Philadelphia
1	Commandant, 5th Naval District, Norfolk
1	Commandant, 6th Naval District, Charleston
1	Commandant, 8th Naval District, New Orleans
1	Commandant, 9th Naval District, Great Lakes

Distribution List (Cont'd)

No of
copies

1	Commandant, 11th Naval District, San Diego
1	Commandant, 12th Naval District, San Francisco
1	Commandant, 13th, Naval District, Seattle
1	Deputy Chief of Staff, Research & Development Headquarters, U. S. Marine Corps, Washington
1	Director Marine Corps Landing Force Development Center, Marine Corps Schools, Quantico
1	Paint Laboratory, U. S. Engineers Office, Clock Tower Building, Rock Island
1	Deputy CCMLO for Scientific Activities, Washington
1	Office of the Quartermaster General, Department of the Army, Attn: Research and Development Branch, Washington
1	Chief of Ordnance, U. S. Army, Attn: Research & Development Laboratory, Washington
1	U. S. Army, Attn: Director of Research and Development Group, Washington
1	Director, Waterways Experiment Station, Corps of Engineers, U. S. Army, Vicksburg
1	Frost Effects Laboratory, Corps of Engineers, Waltham
1	President, Beach Erosion Board, Washington
1	President, Signal Corps Board, U. S. Army, Fort Monmouth
1	Commanding Officer, Signal Corps Engineering Labs, Fort Monmouth
1	President, Chemical Warfare Board, Army Chemical Center
1	Directorate of Medical Research, Chemical Warfare Laboratory, Army Chemical Center
1	Commanding Officer, Chemical Warfare Laboratories, Army Chemical Center
1	Commanding Officer, U. S. Army Transportation Research and Development Command, Fort Eustis
1	Commanding Officer, Biological Warfare Laboratories, Fort Detrick
1	U. S. Army Corps of Engineers, Office of the District Engineer, St. Paul District
1	Snow, Ice, and Permafrost Research Establishment, Corps of Engineers, U. S. Army, Wilmette
1	Commanding General, U. S. Army Engineer Research and Development Labs (Petroleum Branch), Fort Belvoir
1	Chief, Concrete Division, Waterways Experiment Station, Jackson
1	Coles Signal Laboratory, Red Bank, N. J.
1	Taft Sanitary Engineering Center USPHS, Cincinnati
1	Arctic Health Research Center, Anchorage, Alaska
1	Hdqs., Air Research & Development Command, Laurence A. Hanscom Field, Bedford, Mass.
1	Commander, Air Research & Development Command, Attn: Library, Andrews Air Force Base
1	Directorate of Research, Air Force Special Weapons Center, Kirtland Air Force Base
1	Arctic Aeromedical Laboratory, United States Air Force, Seattle
1	Director, Forest Products Laboratory, U. S. Department of Agriculture, Forest Service, Madison, Wis.
1	Commissioner, Public Roads Administration, Federal Works Agency, Washington

Distribution List (Cont'd)

No. of copies	
1	Sandia Corporation, Attn: Classified Document, Division, Albuquerque
1	Chief, Physical Research Branch, Research Division, U. S. Department of Commerce, Bureau of Public Roads, Washington
1	Department of Interior, Office of Saline Water, Washington
1	Operation Civil, University of California, Richmond Field Station, Berkeley 4, California
1	Texas Instruments, Inc., 6000 Lemmon Avenue, Dallas 9, Texas
1	Library, University of Alaska, Fairbanks, Alaska
1	Department of Zoology, Duke University, Durham, N. C.
1	Narragansett Marine Laboratory, University of Rhode Island, Kingston, R. I.
1	Department of Physiology and Pharmacology, University of Nebraska, Omaha 5, Neb.
1	Columbia University, Lamont Geological Observatory, Attn: Biology Program, Borer Project, Palisades, N. Y.
1	Columbia University, Lamont Geological Observatory, Attn: Library, Palisades, N. Y.
1	Department of Zoology, University of Washington, Seattle 5, Washington
1	Library, Engineering Department, Stanford University, Stanford, California
1	Library, Harvard University, Graduate School of Engineering, Cambridge, Mass.
1	Director, Engineering Research Institute, University of Michigan, Ann Arbor, Mich.
1	Library, Engineering Department, University of California, Berkeley 4, California
1	Library, Battelle Institute, Columbus, Ohio
1	Library, Southwest Research Institute, San Antonio, Texas
1	Library, University of Southern California, University Park, Los Angeles 7, California
1	Director, Marine Laboratory, University of Miami, Coral Gables, Florida
1	Director, Scripps Institution of Oceanography, La Jolla, California
1	Director, Soil Physics Laboratory, Department of Engineering, Princeton University, Princeton, N. J.
1	Director, Soil Physics Laboratory, Department of Engineering, Attn: Library, Princeton University, Princeton, N. J.
1	Director, William F. Clapp Laboratories, Duxbury, Massachusetts
1	Director, Woods Hole Oceanographic Institute, Woods Hole, Massachusetts
1	Head, Department of Oceanography and Meteorology, Agricultural and Mechanical College of Texas, College Station, Texas
1	Director, Oceanographic Laboratories, University of Washington, Seattle 5, Washington
1	Director, The Technological Institution, Northwestern University, Evanston, Illinois
1	Library, Institute of Technology, University of Minnesota, Minneapolis, Minnesota
1	Library, California Institute of Technology, Pasadena, California
1	Office of the Chief of Engineers, Gravelly Point, Washington, Attn: ENGB
1	Commanding Officer, U. S. Army Chemical Corps, Research and Development Command, Washington
4	Officer in Charge, CECOS (Attn: ADCE Course), Port Hueneme

Distribution List (Cont'd)

26

No. of
copies

- 1 Headquarters U. S. Air Force, Director of Research and Development, DCS/D, Washington, (Attn: Combat Components Division)
- 1 Commander, Air Force Special Weapons Center, Kirtland Air Force Base, Albuquerque
- 1 Chief, Defense Atomic Support Agency, Washington
- 1 Commander, Field Command, Defense Atomic Support Agency, Albuquerque
- 1 Director, Civil Effects Test Group, Atomic Energy Commission, (Attn: Mr. R. L. Corsbie), Washington
- 1 Office of Civil and Defense Mobilization, Attn: Mr. Ben Taylor, Battle Creek, Mich.
- 1 Chief, Bureau of Yards and Docks, Code D-230
- 1 Holmes and Narver, Inc., Atomic Energy Commission, Facilities Division, 849 S. Broadway, Los Angeles 14, California (Attn: Mr. Sherwood B. Smith)
- 1 U. S. Atomic Energy Commission, Technical Information Service, Oak Ridge, Tennessee
- 1 Commander, Naval Construction Battalions, U.S. Atlantic Fleet, Administrative Hdq., U. S. Naval Construction Battalion Center, Davisville
- 1 Mr. W. R. Perret 5112, Sandia Corporation, Sandia Base, Albuquerque
- 1 Mr. Fred Sauer, Physics Department, Stanford Research Institute, Menlo Park, California
- 1 Dr. Harold Brode, RAND Corporation 1700 Main Street, Santa Monica, California
- 1 Dr. Robert V. Whitman, Massachusetts Institute of Technology, Cambridge, Massachusetts
- 1 Mr. Kenneth Kaplan, Broadview Research Corporation, 1811 Trousdale Drive, Burlingame, Calif.
- 1 Prof. J. Neils Thompson, Civil Engineering Department, University of Texas, Austin 12, Texas
- 1 Mr. G. L. Arbuthnot, Waterways Experiment Station, Post Office Box 631, Vicksburg, Miss.
- 1 Mr. William J. Taylor, Terminal Ballistics Laboratory, Aberdeen Proving Ground, Md.
- 1 Dr. T. H. Schiffman, Armour Research Foundation of Illinois Institute of Technology, Technology Center, Chicago 16, Illinois
- 1 Chief of Engineers, Department of the Army, Washington
- 1 Mr. Eric Wang, Air Force Special Weapons Center, Kirtland AFB, Albuquerque
- 1 Commander, Air Force Ballistic Missile Division, Air Research and Development Command, Attn: Dr. George Young, Post Office Box 262, Inglewood 49, California
- 1 Dr. Lewis V. Spencer, Chairman, Ottawa University, Ottawa, Kansas
- 1 Mr. John Auxier, Oak Ridge National Laboratory, Oak Ridge, Tennessee
- 1 Dr. James O. Buchanan, Office of Civil and Defense Mobilization, Battle Creek, Michigan
- 1 Dr. Eric T. Clarke, Technical Operations, Inc., Burlington, Massachusetts
- 1 Mr. Charles M. Eisenhauer, Radiation Physics Laboratory, High Voltage Laboratory, National Bureau of Standards, Washington 25, D. C.
- 1 Mr. L. Neal FitzSimons, Office of Civil and Defense Mobilization, Winder Bldg, Washington 25, D. C.
- 1 Mr. Jack C. Greene, Office of Civil and Defense Mobilization, Battle Creek, Michigan
- 1 Dr. William Kreger, Naval Radiological Defense Laboratory, San Francisco 24, California
- 1 Mrs. Shea L. Kruegel, CRTZS, Cambridge Research Center, Bedford, Massachusetts
- 1 Mr. Richard Park, National Academy of Sciences, 2101 Constitution Ave., Washington 25, D. C.
- 1 CAPTAIN William D. Sheehan, U. S. Army Defense Atomic Support Agency, Washington 25, D. C.
- 1 COL G. D. Rich, Department Assistant and Director, Chemistry, Biology, Radiation Defense, Battle Creek, Michigan
- 1 Dr. Ronald Shephard, University of California, Engineering Field Station 1301 South 46th St., Richmond 4, California

U. S. Naval Civil Engineering Laboratory.

Technical Report R-083.

RADIATION SLIDE RULE FOR ATOMIC FALLOUT

PROBLEMS, by J. C. LeDoux.

27 p. illus. 24 May 1960. UNCLASSIFIED

The theory, construction, and use of a circular slide rule is presented. It is designed to solve passive-defense residual-radiation problems. The rule is based on the $t^{-1.2}$ law of radioactive decay and can solve an infinite number of problems without recourse to tables, construction, or graphic plots. Several typical problems are worked with the slide rule to demonstrate it. A slide rule is enclosed with this report.

1. Radiation -- Measurement

2. Radiation slide rules

I. LeDoux, J. C.

II. Y-F011-05-401

U. S. Naval Civil Engineering Laboratory.

Technical Report R-083.

RADIATION SLIDE RULE FOR ATOMIC FALLOUT

PROBLEMS, by J. C. LeDoux.

27 p. illus. 24 May 1960. UNCLASSIFIED

The theory, construction, and use of a circular slide rule is presented. It is designed to solve passive-defense residual-radiation problems. The rule is based on the $t^{-1.2}$ law of radioactive decay and can solve an infinite number of problems without recourse to tables, construction, or graphic plots. Several typical problems are worked with the slide rule to demonstrate it. A slide rule is enclosed with this report.

1. Radiation -- Measurement

2. Radiation slide rules

I. LeDoux, J. C.

II. Y-F011-05-401

U. S. Naval Civil Engineering Laboratory.

Technical Report R-083.

RADIATION SLIDE RULE FOR ATOMIC FALLOUT

PROBLEMS, by J. C. LeDoux.

27 p. illus. 24 May 1960. UNCLASSIFIED

The theory, construction, and use of a circular slide rule is presented. It is designed to solve passive-defense residual-radiation problems. The rule is based on the $t^{-1.2}$ law of radioactive decay and can solve an infinite number of problems without recourse to tables, construction, or graphic plots. Several typical problems are worked with the slide rule to demonstrate it. A slide rule is enclosed with this report.

1. Radiation -- Measurement

2. Radiation slide rules

I. LeDoux, J. C.

II. Y-F011-05-401

U. S. Naval Civil Engineering Laboratory.

Technical Report R-083.

RADIATION SLIDE RULE FOR ATOMIC FALLOUT

PROBLEMS, by J. C. LeDoux.

27 p. illus. 24 May 1960. UNCLASSIFIED

The theory, construction, and use of a circular slide rule is presented. It is designed to solve passive-defense residual-radiation problems. The rule is based on the $t^{-1.2}$ law of radioactive decay and can solve an infinite number of problems without recourse to tables, construction, or graphic plots. Several typical problems are worked with the slide rule to demonstrate it. A slide rule is enclosed with this report.

1. Radiation -- Measurement

2. Radiation slide rules

I. LeDoux, J. C.

II. Y-F011-05-401