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DECONTAMINATION SCHEDULING PROCEDURES FOR RADEF SYSTEMS

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ABSTRACT

This report presents a decontamination scheduling procedure that permits the user to correlate target analysis results, shelter protection factors, and decontamination data and systematically obtain feasible decontamination assignments and decontamination schedules. Because the procedure delineates individual exposure doses for all contemplated exposure periods, clear choices of personnel assignments and scheduling options are presented. Scheduling examples are given to demonstrate the procedure, and procedural aids are included to minimize decontamination scheduling calculations.

This report also demonstrates how the decontamination scheduling procedure may be used to evaluate the effectiveness of RADEF systems. The examples for decontamination scheduling and for RADEF system evaluation indicate that target area decontamination is a task requiring a relatively large decontamination organization.

CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

Over some fallout areas that could be produced in a nuclear war, the radiation intensity may be sufficiently high that resident facilities could not be occupied within a reasonable or acceptable period of time without decontamination. The purpose of decontamination is to permit reentry into fallout areas at earlier times than would otherwise be possible, and to reduce radiation dosages for target area reutilization. For a decontamination operation to be effective, it must be scheduled within the restrictions imposed by: (1) the fallout intensity; (2) the available manpower, decontamination equipment, and supplies; (3) the radiation dosage that may be allocated to decontamination; and (4) the time set for re-use of the target complex or target facility. The decision to conduct decontamination operations in any area will be based on knowledge of (a) the need for recovering the area, and (b) the gain in time resulting from the decontamination operations.

In many previous radiological recovery studies, the tacit assumption has been made that target decontamination could be accomplished by those who have survived in adequate shelters, and that the major portion of the recovery operation could be completed within the first two-week period without much consideration to the fallout intensity. Under such an assumption, many operational planners apparently have been led to believe that the task of decontamination can be relegated to a small corps of decontamition specialists. The demonstration of operational requirements, as derived from studies of sample scheduling problems, can be used to test such assumptions.

Because it is not possible to predict the level of fallout that will occur at a specific location as the result of a nuclear attack, and because the establishment of a specific decontamination schedule requires information on the fallout level, an appropriate schedule cannot be selected prior to attack. However, if all other input data are collated before the attack and provisions are made for integration of this data for a range of post-attack conditions, then postattack assessment of the fallout situation would permit the selection of suitable schedules. The preattack data that could be made available in useful form are those that could be supplied by radiological target analysis together with available decontamination data.

The stated objectives of this research task are:

1. To develop methods for making rapid analyses of radiation fields for selected locations from discontinuous radiation source

1

geometries--i.e., the dose rate in or about building structures and areas contaminated to varying degrees of radiation intensity.

2. To make radiological analyses of selected fallout areas, and develop methods for evaluating decontamination crew residual numbers and for organizing other input data needed for scheduling decontamination operations.

The report, "Radiological Target Analysis Procedures"[1] presented and illustrated the use of methods for calculating target complex radiation fields, relative contributions to the dose rate at various locations from various sources, and the relative exposure for conducting various decontamination tasks. Reference 1 also included, as an appendix, data on decontamination rates and effectiveness. The present study continues and expands on Reference 1, by presenting a procedure for formulating recovery schedules and assessing alternative postattack recovery operations, using the findings derived from radiological target analyses and the decontamination data.

SUMMARY

A procedure for scheduling personnel to carry out decontamination operations is presented, and the application of the procedure is demonstrated. Procedural aids for decontamination scheduling are also included to minimize arithmetical calculations. By requiring exposure dose accountability for the various postattack periods, the procedure presents a clear appraisal of the situation at all times. Thus not only can the effectiveness of a RADEF system be defined in terms of a limiting dose and a limiting environment, but also the degree of effectiveness of a RADEF system is indicated by the exposure dose for any fallout environment.

Before the decontamination scheduling procedure can be applied to a specific RADEF system, it is necessary that a radiological analysis of the involved target complexes be coupled with decontamination data in order to determine the magnitude of the decontamination effort and personnel exposure that must be expended to acquire a satisfactory target area residual number. Reference 1 provides a procedure for radiological target analysis.

The effects of fallout redistribution upon the results have not been evaluated but the analytical procedure provides for its evaluation when the characteristics of fallout redistribution within target complexes can be adequately described. Reference 1 also provides basic decontamination effort and effectiveness data (Appendix B), although the effort-effectiveness data require projection to the physical environments of target complexes. By applying this information to the proposed scheduling procedure, the recovery planner can estimate the size of the organization required to obtain various degrees of RADEF system effectiveness for existing or proposed shelter systems in any community, and can also establish a decontamination schedule.

The proposed decontamination scheduling procedure could also be used to provide a complete analysis of existing or proposed RADEF systems. It provides for investigating the relative merits of such options as increasing shelter shielding, increasing shelter stay times, increasing decontamination personnel, increasing decontamination equipment and supplies, or improving the target complexes for decontamination. This feature is particularly important in the course of planning a RADEF system for a community, because the RADEF system for a given potential effectiveness within the needs of the community could be planned and its costs could be estimated.

3

The required sizes of decontamination organizations for specific shelter and target complexes and for specific postattack conditions are estimated through use of decontamination scheduling examples. These examples generally illustrate the rather large amount of effort that is required to decontaminate unpaved ground areas.

An effective decontamination organization should have the capability to recover not only the vital facilities at earlier times to meet emergency needs but also virtually all facilities and areas within the community at later times. This study has dealt only with decontamination scheduling for the recovery of vital and emergency housing facilities, and although consideration of the task of decontaminating all fallout areas is included, decontamination scheduling is not complete until the entire postattack operation is scheduled and assessed. Further research will determine the extent of additional restrictions imposed upon RADEF systems by these later decontamination efforts.

RADIOLOGICAL DEFENSE SYSTEM

The basic radiological defense (RADEF) system considered in this
study consists of two components: shelter and decontamination. An
effective fallout shelter is here defined as one which must provide
(1) sufficient shielding protection so that the occupants will not be
overexposed during the early period of relatively high dose rates, and
(2) facilities and supplies in amounts permitting a long enough shelter
stay for radioactive decay to reduce the dose rates sufficiently that at
least short exposure outside of shelters are feasible.

There is little point in having shelters that provide a very high
degree of protection if only a short shelter stay time is possible and
its occupants are forced to emerge into a radiological environment that is
still lethal or debilitating. Likewise, it is pointless to have a shelter
with the capacity for a long period of occupancy if the protection afforded
is insufficient during the early period of high radiation dose rates. A
compatible shelter system incorporates these two features--shelter pro-
tection and shelter stay--in a complementary manner.

Similarly, a compatible radiological defense system incorporates the
shelter system with decontamination in a complementary manner. Until the
operations in the time periods after shelter occupancy are carefully ex-
amined, the effectiveness of the radiological defense system cannot be
assessed. The shelter protection provided may be sufficient to prevent
overexposures during the shelter period, but if the dose accumulated
during this period is high, the additional exposure after shelter emer-
gence may lead to overexposures. In such a case, the shelter protection
would be inadequate even though overexposures were prevented during the
shelter period.

The present shelter program specifies shelter systems with a minimum
protection factor (PF) of 40 and a nominal shelter occupancy period of
two weeks.* Such a system would be grossly inadequate in heavy fallout
areas. Although 40 PF is the minimum specification, much higher PF shelters

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*
  The protection factor (PF) is a dimensionless number used as an index
  of protection provided against fallout radiation in any location of
  interest and is defined in Sec. V of Reference 1.

5

are generally available, although to a lesser degree, in certain segments of communities, and thus a mixed PF shelter system generally exists. In a mixed shelter system, the burden of radiological recovery through decontamination will be on those sheltered in the higher PF shelters. In heavy fallout areas, only they will have the capability of performing decontamination operations. This facet is demonstrated in the section on decontamination scheduling.

In order for people to emerge from shelters after the two-week shelter stay period, shelters at other locations must be available for occupancy. In areas of light fallout, direct emergence into the various units of the community may be safely accomplished. In heavier fallout areas where the radiological environment outside the shelters would still be injurious for prolonged exposure after two weeks, decontamination would have to be initiated and completed before the two weeks were up, in order to provide low-exposure occupancy. An alternative operation is for the shelterees to evacuate shelters and move out of the region to less contaminated areas. The latter operation is part of a radiological defense system but is not a radiological recovery operation. Other alternatives include: (1) replenish shelter supplies and continue with part-time occupancy while conducting recovery operations, and (2) conduct recovery operations from staging areas.

TARGET COMPLEXES

The necessity to decontaminate derives from the urgency of the need or the various complexes within the area. The types of complexes are categorized as follows:

1. Survival complexes

    a. water supply facilities
    b. food supply facilities
    c. power supply facilities
    d. sanitation facilities
    e. medical facilities

2. Housing complexes

    a. staging complexes
    b. emergency housing
    c. residential areas

3. Socio-economic complexes

    a. industrial
    b. business
    c. transportation
    d. agricultural

4. Nonessential complexes

The greatest urgency following the shelter stay period is to satisfy the vital and basic needs for continued survival. However, target recovery considerations must extend beyond the vital complexes because support facilities and implementation may be necessary to deliver vital products to the location of use. These support facilities in turn may require support from other facilities in order to function. Specifically, the time when various vital complexes must be recovered to sustain survivors (undetermined) will depend in part upon the damage incurred. On the other hand, the time that various complexes can be recovered may be determined by pre-attack planning for various postattack conditions and deployment of recovery personnel.

DECONTAMINATION SCHEDULING

With a mixed PF shelter system (whether within the same or a differ-
ent radiological environment) and where the standard intensity is high,
some of the people (those in lower PF shelters) will not be able to en-
gage in radiological decontamination operations. People in better shelters
will accumulate lower radiation doses, depending on the shelter protection
that is available and the standard intensity at their shelter locations.
If the number of people in the better shelters is sufficiently large and
if these people receive radiation doses that are less than a given amount,
they will be able to carry out the recovery of the vital and housing com-
plexes and also to care for the surviving casualties rescued from inade-
quate shelters. In situations where the dosage available for decontami-
nation operations and other postattack operations is so restrictive that
these tasks cannot be performed within a given time period, the RADEF
system fails.

The characteristic parameters used in developing decontamination
schedules for a community RADEF system are: the target complex sizes
and configurations; the target complex utilization schedules; the exist-
ing or planned shelter systems; and the decontamination equipment and
supplies. The variables of decontamination scheduling for any community
are manpower, standard intensity, and fallout arrival time. As the stan-
dard intensity increases in the area of a given mixed PF RADEF system and
as the fallout arrival time decreases, the pool of healthy men (and women)
available for work decreases, and the working time of those available for
decontamination will be shortened.

The two basic decontamination scheduling parameters are (1) the
available decontamination dose, and (2) the required decontamination dose.
The available decontamination dose for any individual is equal to the
difference between the limiting exposure dose (e.g., 200 r ERD) and the
sum of the shelter and postshelter doses. The required decontamination
dose is the dose that must be expended doing decontamination operations
to provide an acceptable radiological environment. For the decontamina-
tion schedule to be feasible, the required decontamination dose must not
exceed the available decontamination dose. With the aid of target analysis
data and decontamination data, these values can be determined, and wherever
it is feasible, decontamination may be scheduled.

To this end, decontamination scheduling aids are presented for the
limiting dose criteria of 190 r/week, 270 r/month, and 700 r/year.[2]

In addition, so that the 200 r ERD would not be exceeded at any time, the additional limits of 220 r for two weeks and 240 r for three weeks were included. Proper use of the scheduling aids will provide the available decontamination dose and the required decontamination dose for any standard intensity and effective fallout arrival time, for shelter stays of one to three weeks, and for the start of decontamination that is scheduled from less than one week to three weeks. The decontamination scheduling aids constructed from the dose rate multiplier curve in Reference 1 are as follows:

1. Figures 1 through 3 provide the shelter dose for shelter periods of one, two, and three weeks, respectively, for an effective fallout arrival time of one hour for various shelter PF(s), and for various standard intensities.*

2. Figure 4 provides correction factors for Figures 1 through 3 to obtain the shelter dose for various fallout arrival times.

3. Figures 5 and 6 provide the target reutilization dose to one month and to one year, respectively, for various shelter exit times and for various target reutilization residual numbers (RN_3).

4. Figures 7 through 15 provide the available decontamination doses for an effective fallout arrival time of one hour, for shelter stays of one week, two weeks, and three weeks, and for RN_3 values of 0.10, 0.05, and 0.03.

5. Figure 16 provides the decontamination dose for decontamination on various days for I_1 = 1,000 r/hour, RN_2 = 1.0, and Δt (decontamination time per day) = 4 hours.

For any fallout environment defined by the effective fallout arrival time and standard intensity, the decontamination scheduling instructions which illustrate the use of Figures 1 to 16 are given step by step as follows:

Step 1. List the times that the complexes must be made available.

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* Included in these curves is a degradation factor of 0.75, which adjusts exposure doses from the theoretical reference geometry specified for the PF notation to an actual land area reference geometry specified for the standard intensity and residual numbers of this report (see Sec. V, Reference 1).

Figure 1

ONE WEEK SHELTER DOSES FOR VARIOUS SHELTER PF,
FOA = 1 HOUR

10^3

SHELTER PF

40 50 60 70 80 100 120 140 160 180 200 250 300 400 500

10^2

DOSE - (r)

10

10^3 10^4

I_1 - r/hour @ 1 hour

11
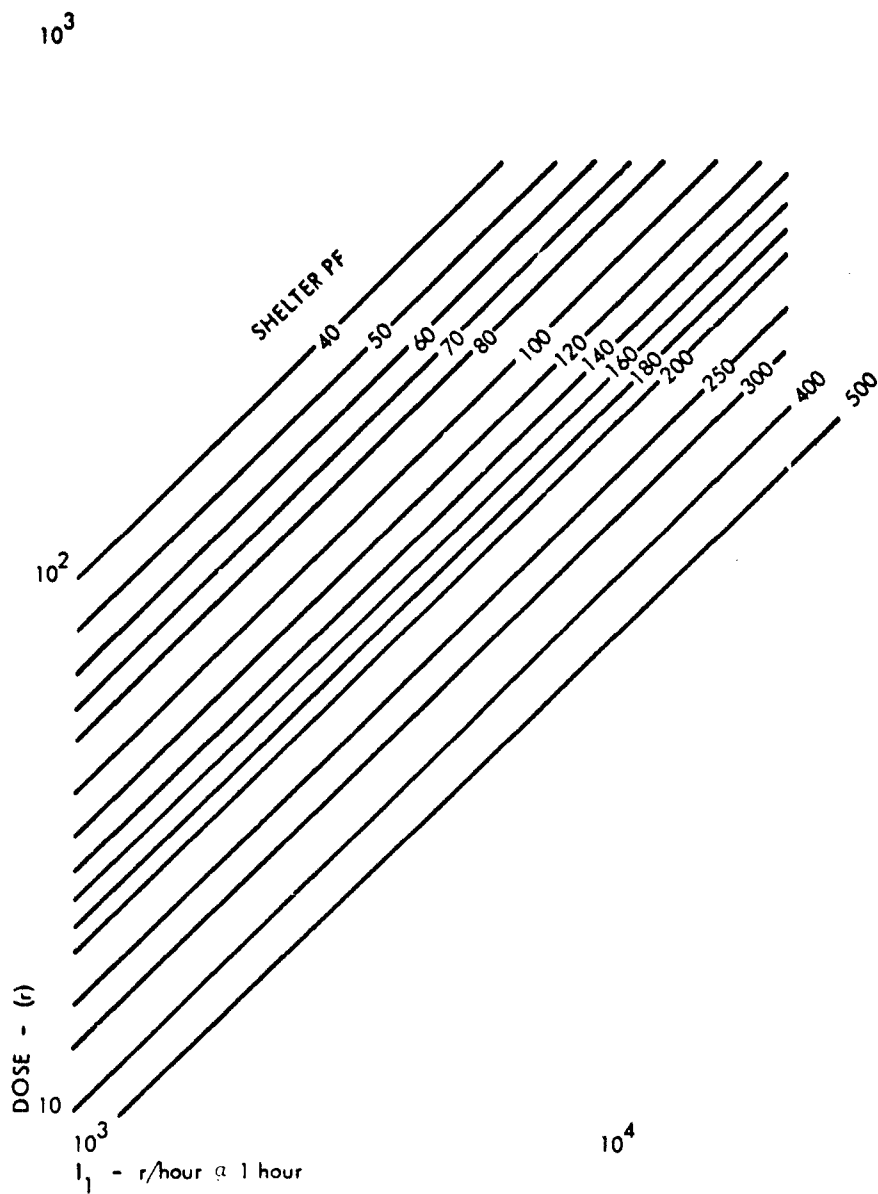
Figure 2

TWO WEEKS SHELTER DOSES FOR VARIOUS SHELTER PF, FOA = 1 HOUR
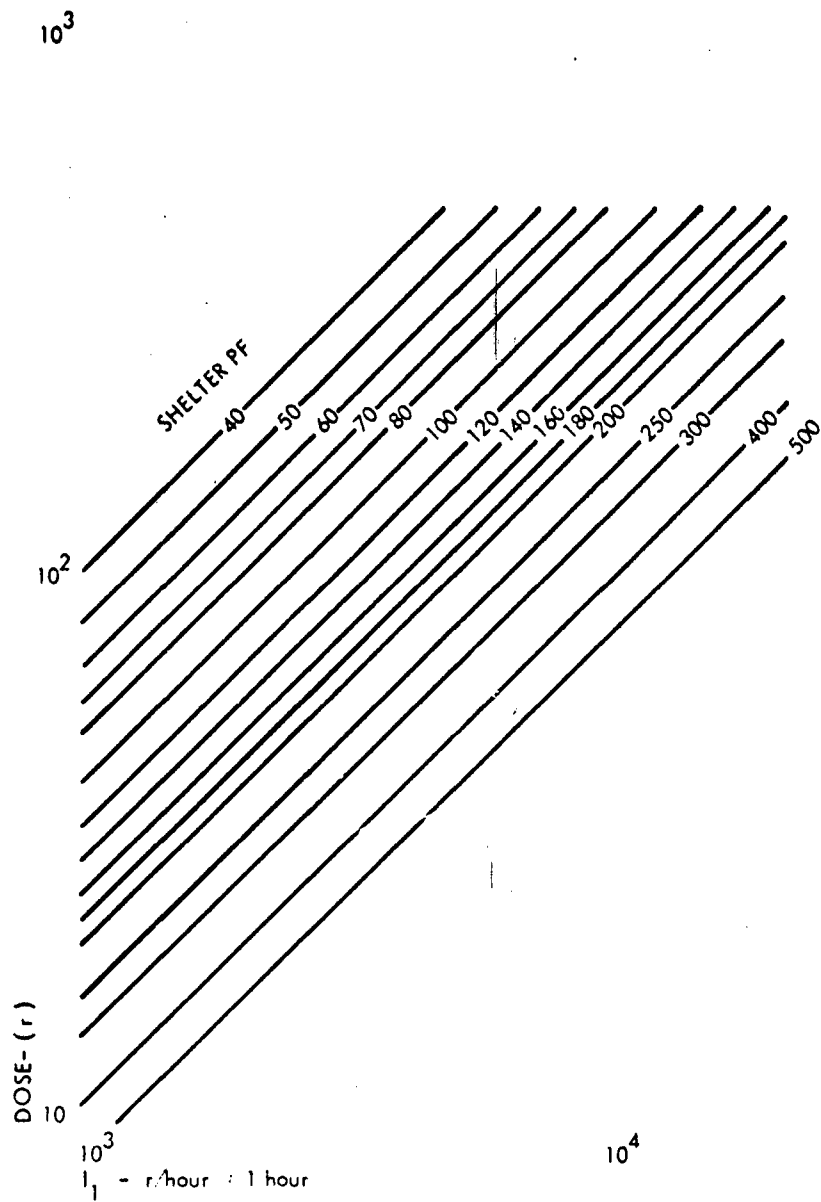
Figure 3

**THREE WEEKS SHELTER DOSES FOR VARIOUS SHELTER PF,
FOA = 1 HOUR**
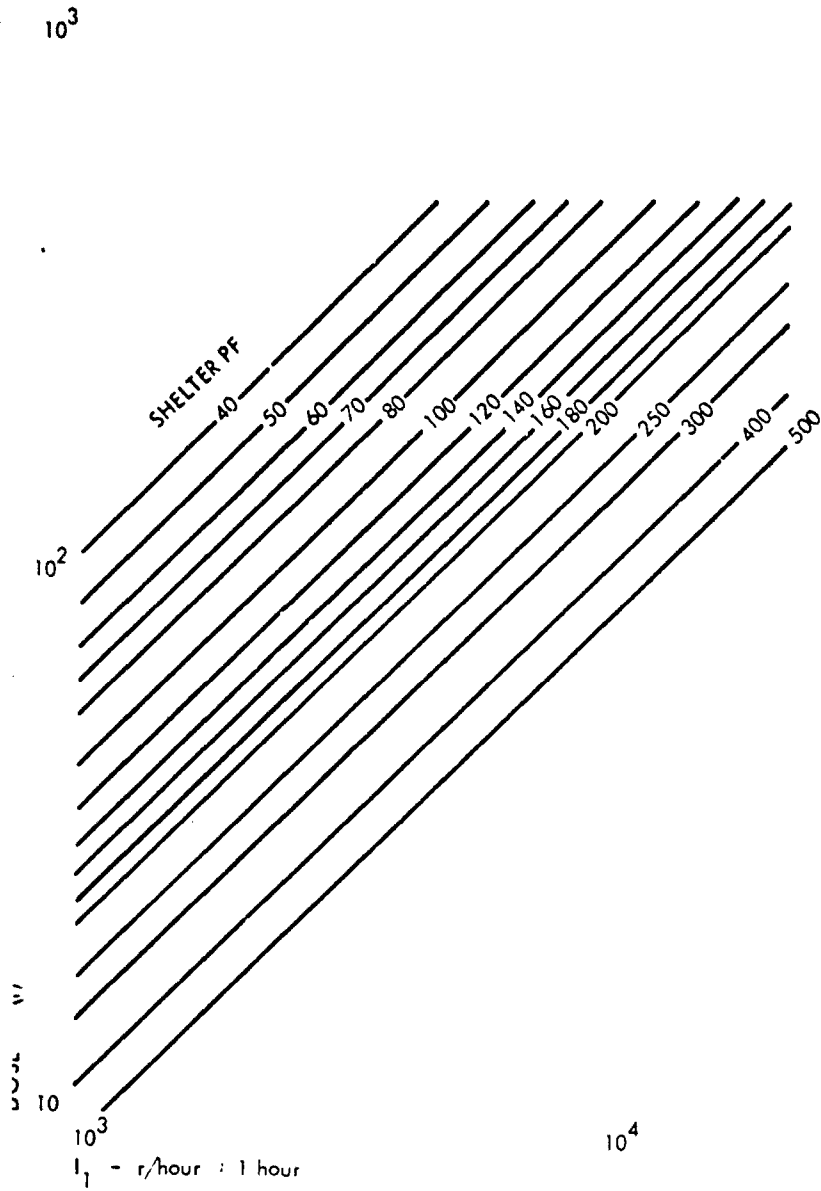
Figure 4

SHELTER DOSE REDUCTION FACTORS
FOR FALLOUT ARRIVAL TIME
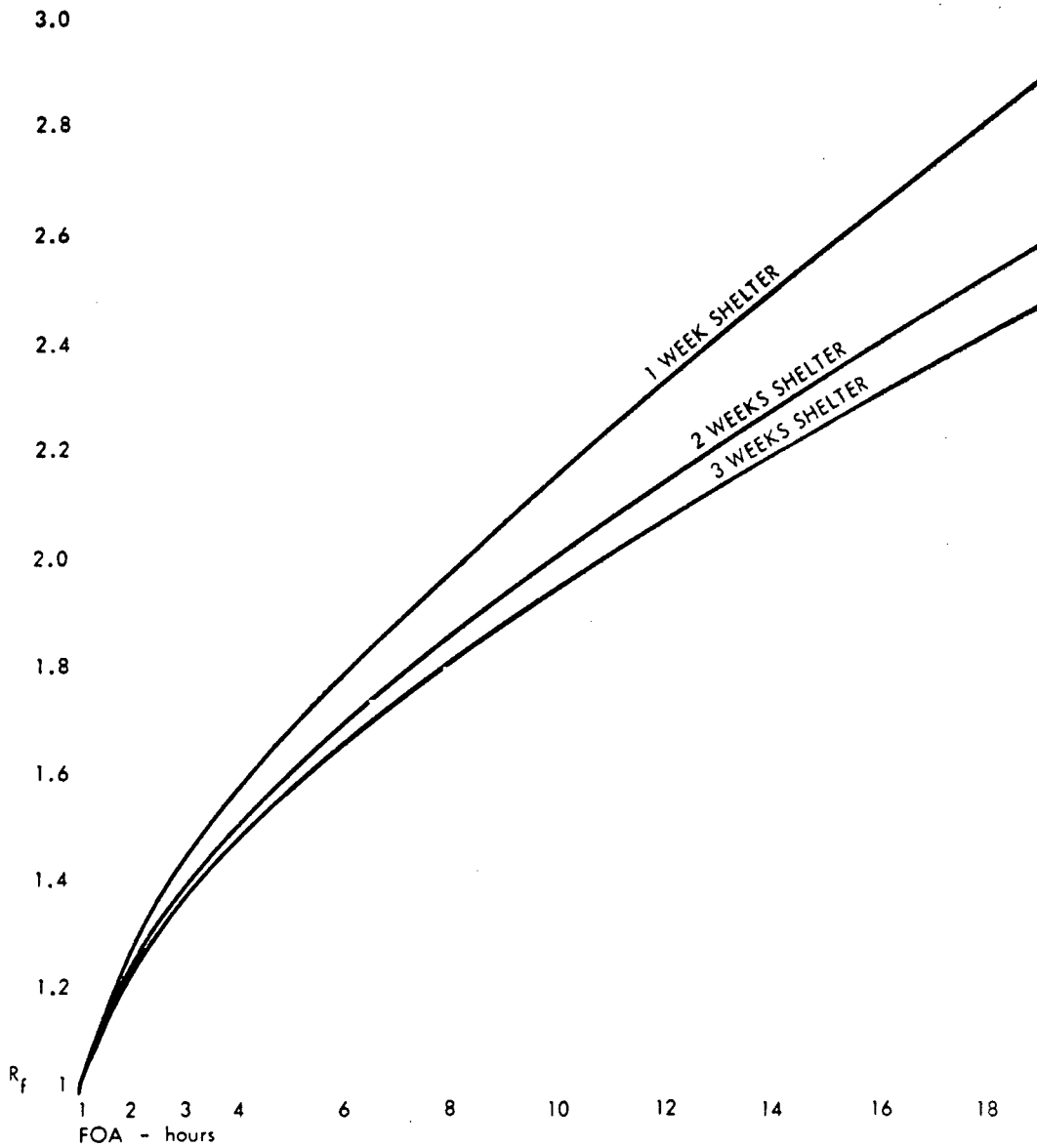
Figure 5

DOSE TO ONE MONTH FOR SHELTER EXIT TIMES
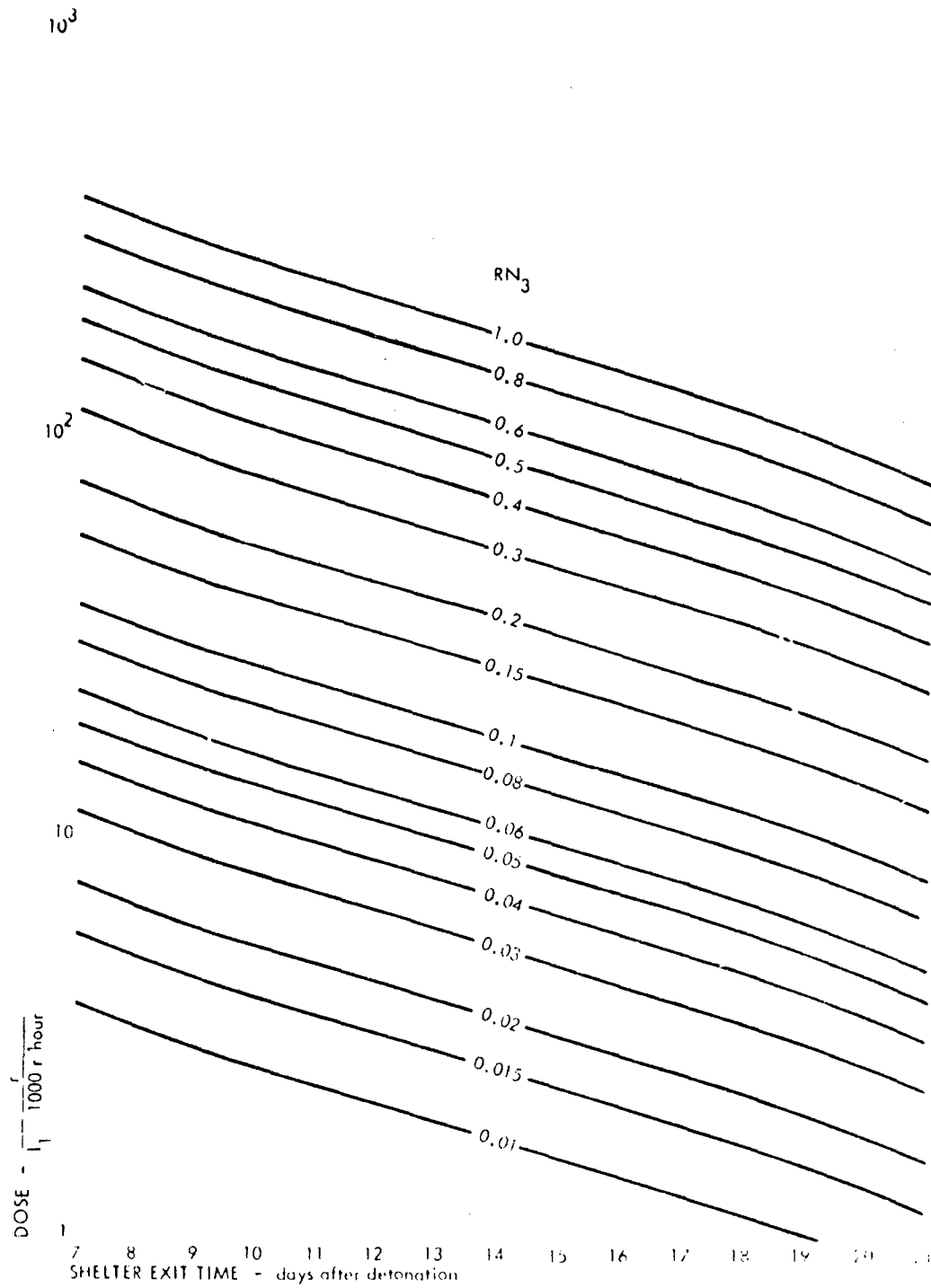
Figure 6

DOSE TO ONE YEAR FOR SHELTER EXIT TIMES
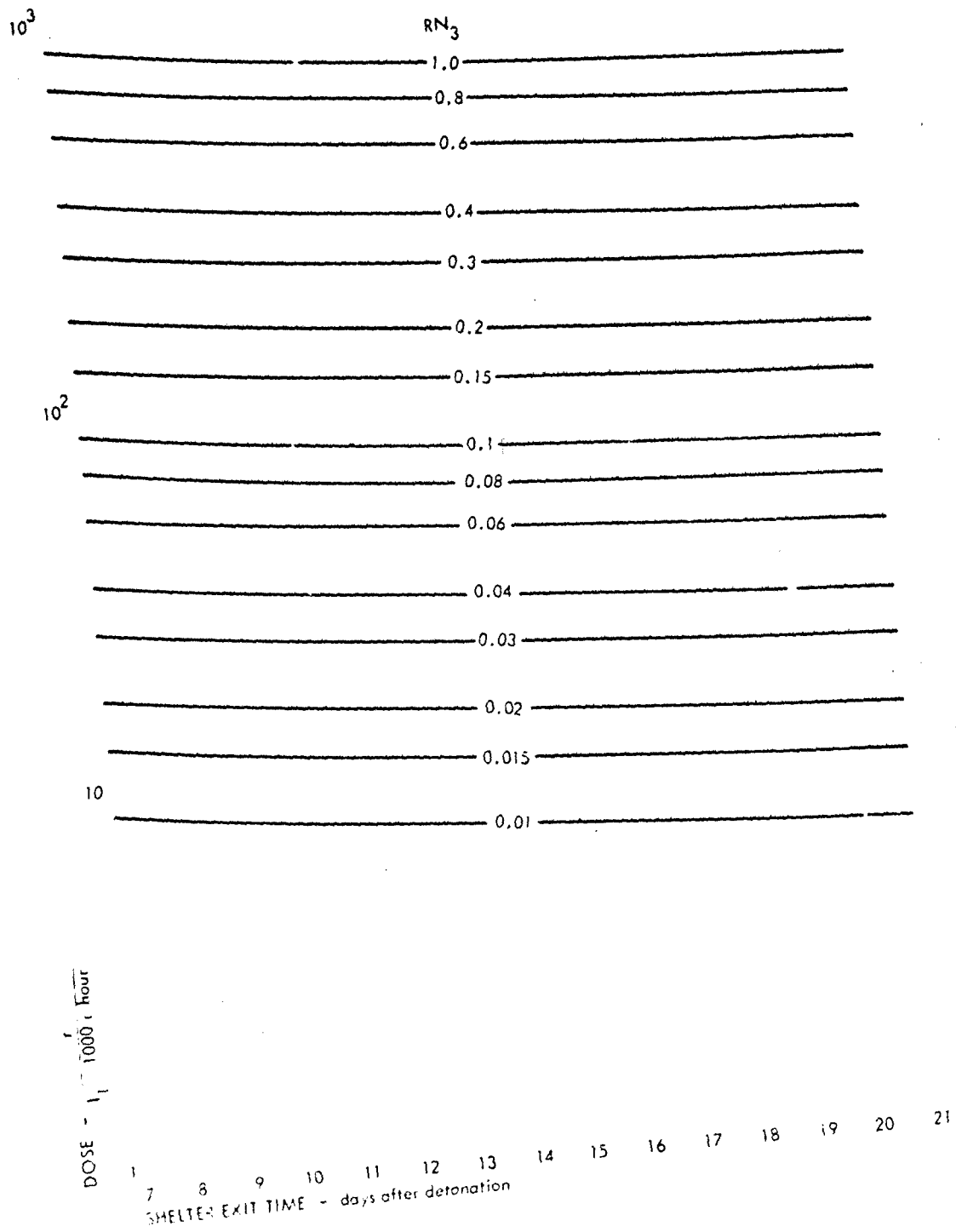
AVAILABLE DECONTAMINATION DOSE FOR ONE WEEK SHELTER STAY, $RN_3 = 0.03$
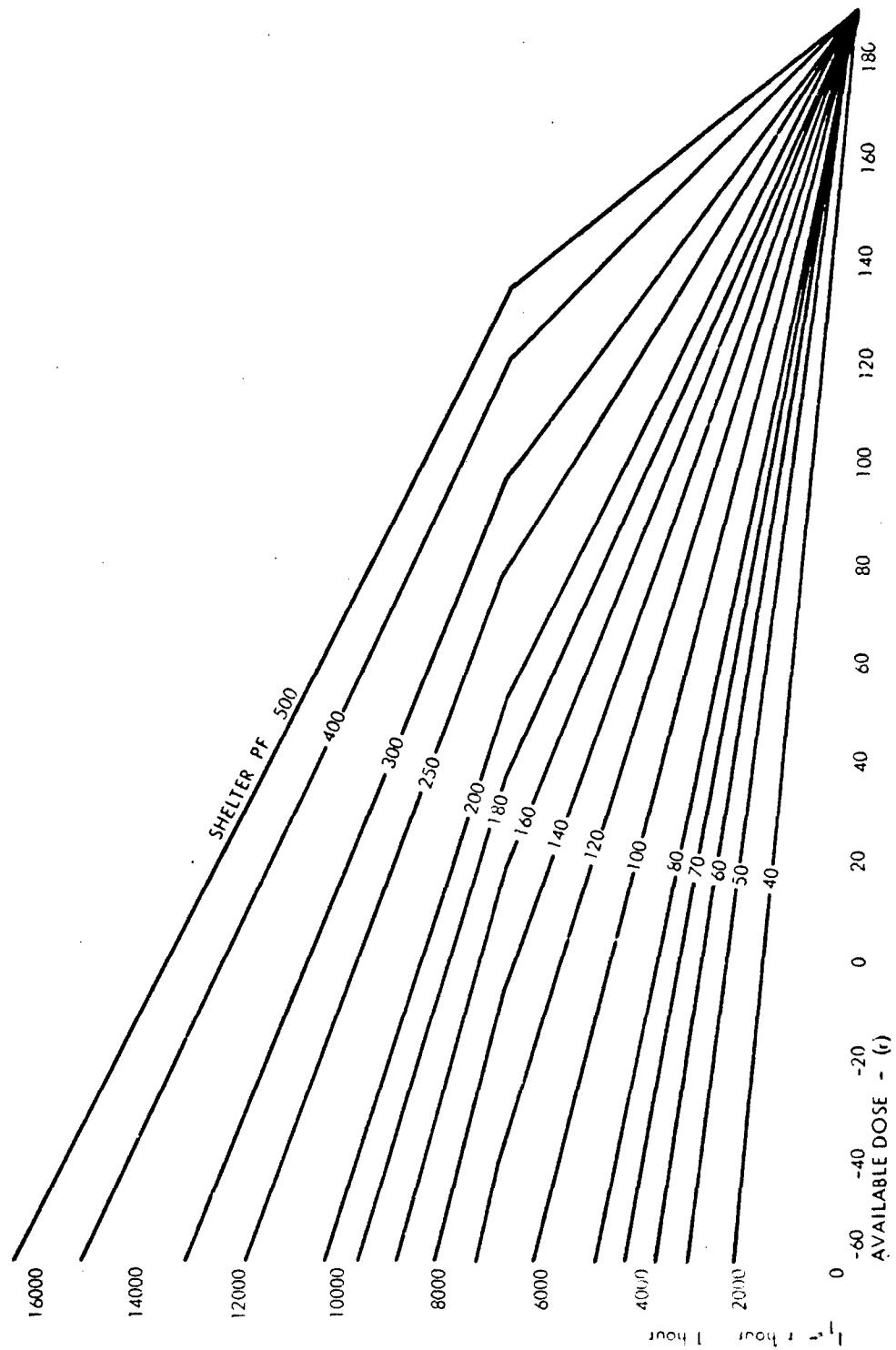
Figure 8

AVAILABLE DECONTAMINATION DOSE FOR ONE WEEK SHELTER STAY,
$RN_3 = 0.05$

AVAILABLE DECONTAMINATION DOSE FOR ONE WEEK SHELTER STAY, $RN_3 = 0.10$

19
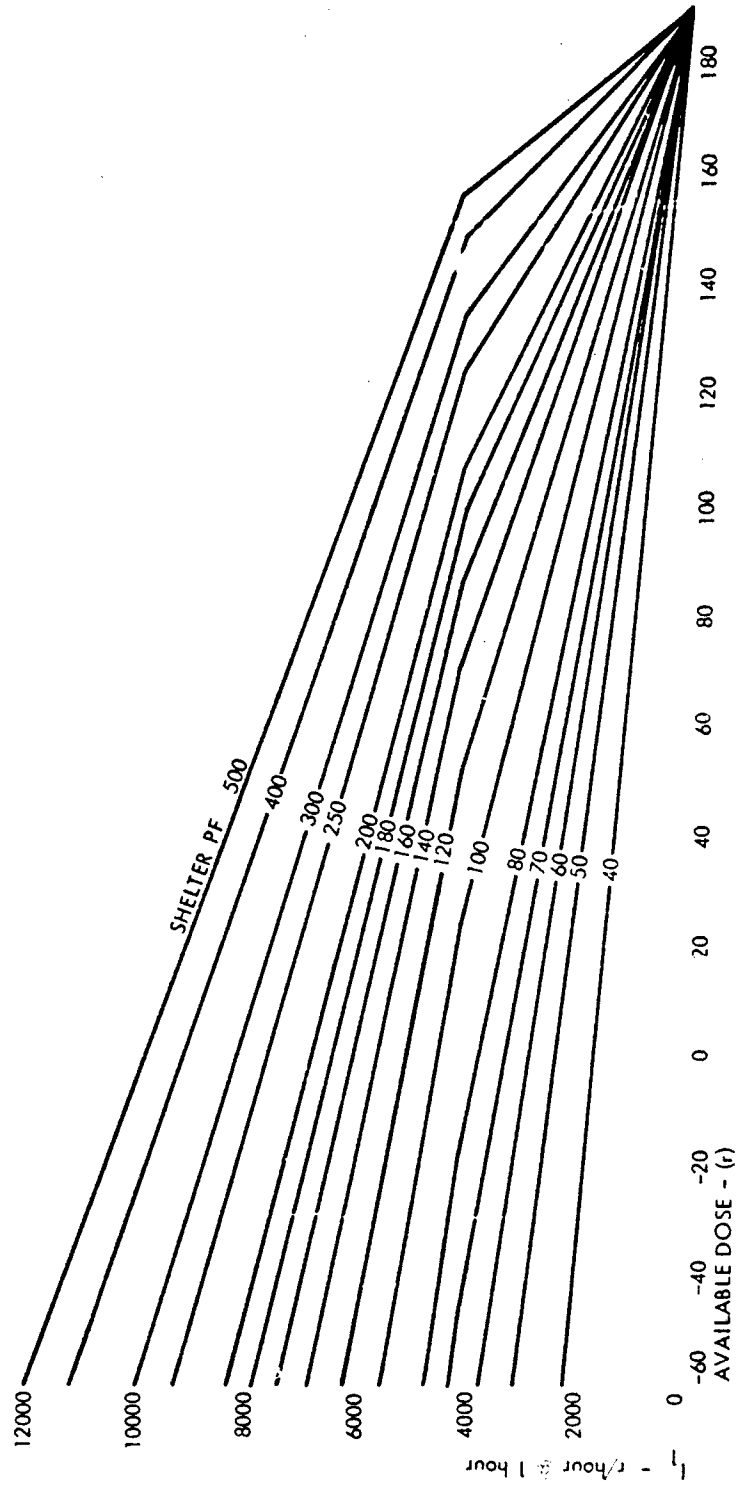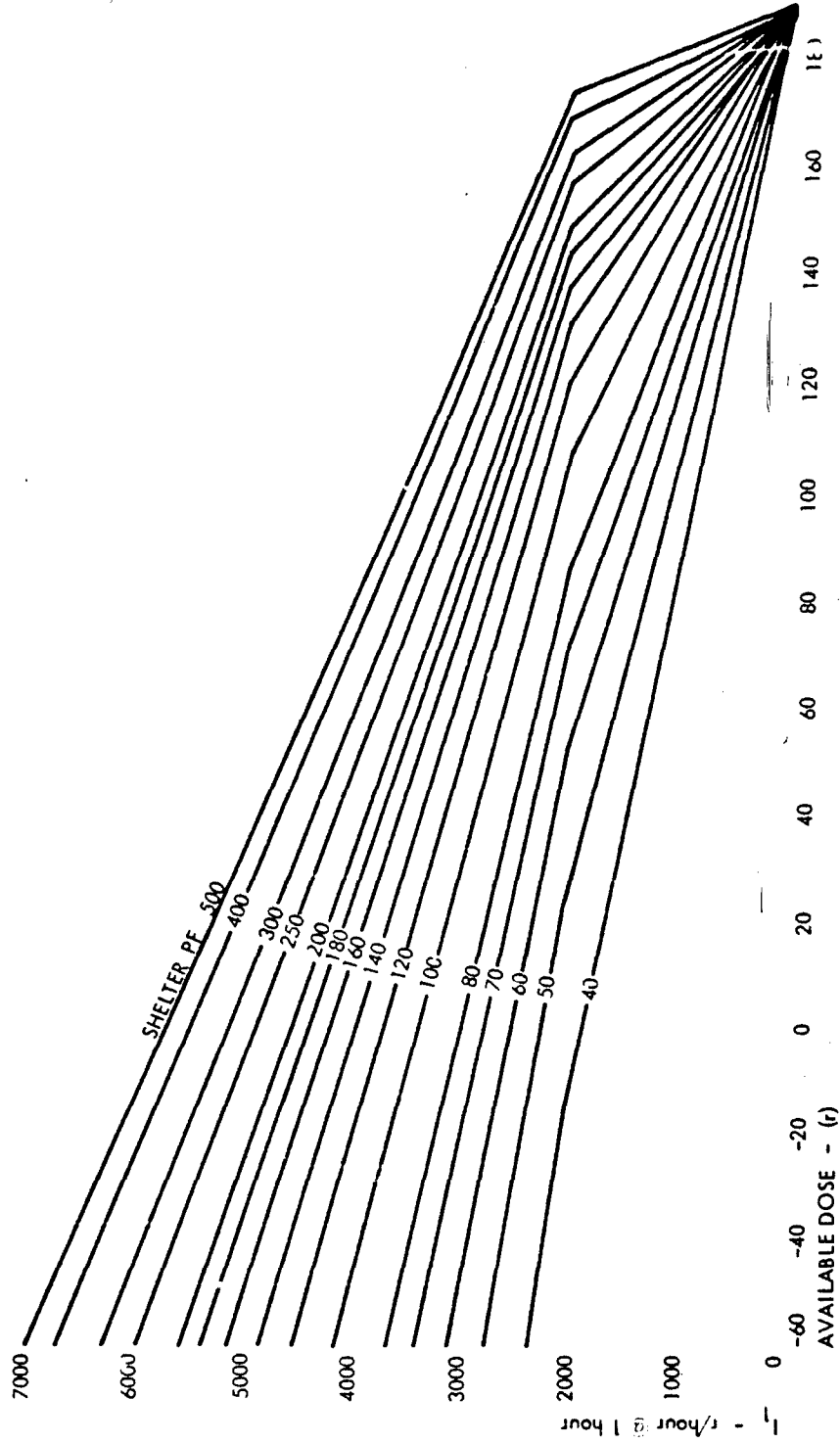
Figure 10

AVAILABLE DECONTAMINATION DOSE FOR TWO WEEKS SHELTER STAY,
$RN_3 = 0.03$

20
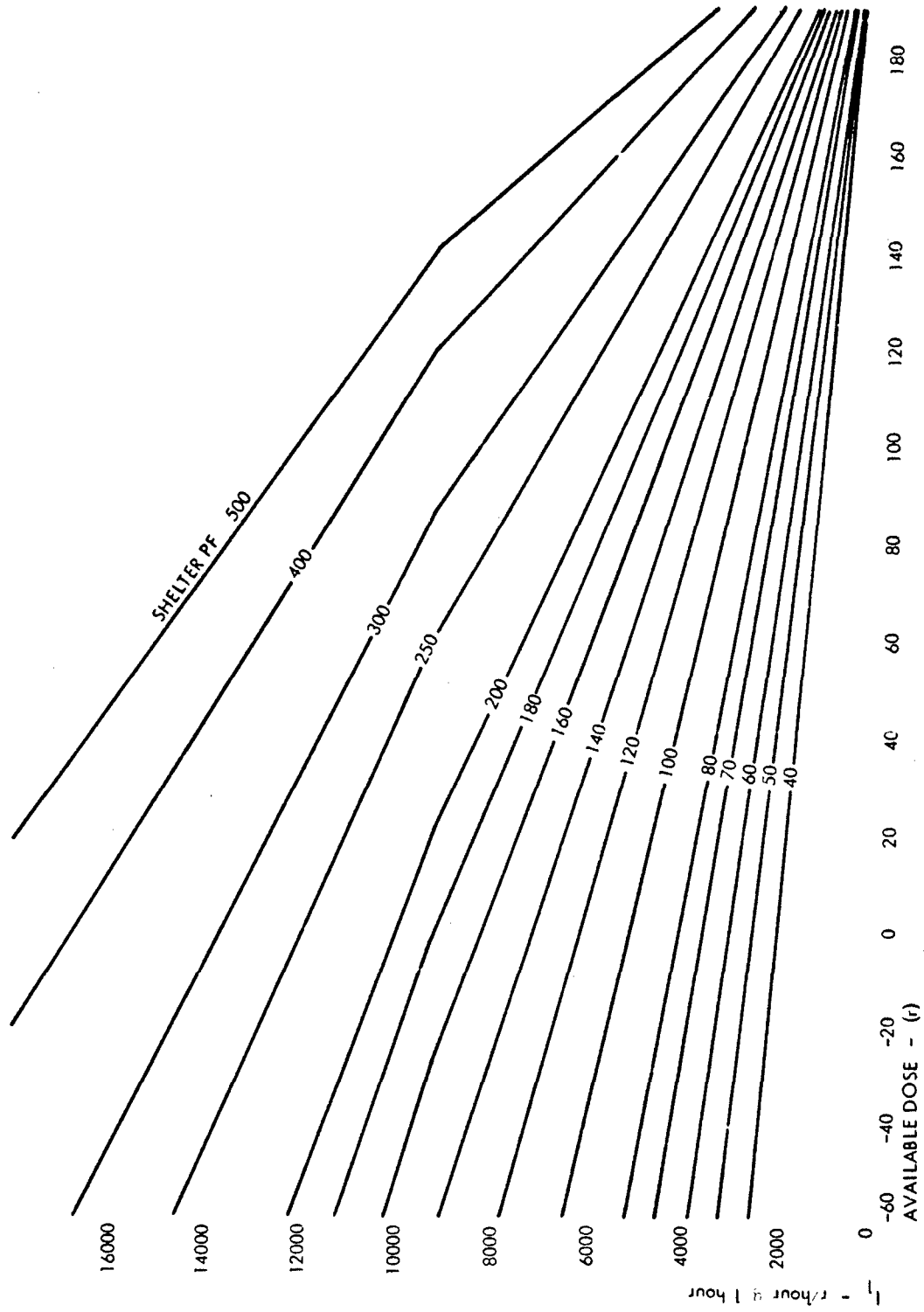
AVAILABLE DECONTAMINATION DOSE FOR TWO WEEKS SHELTER STAY,
$RN_3 = 0.05$
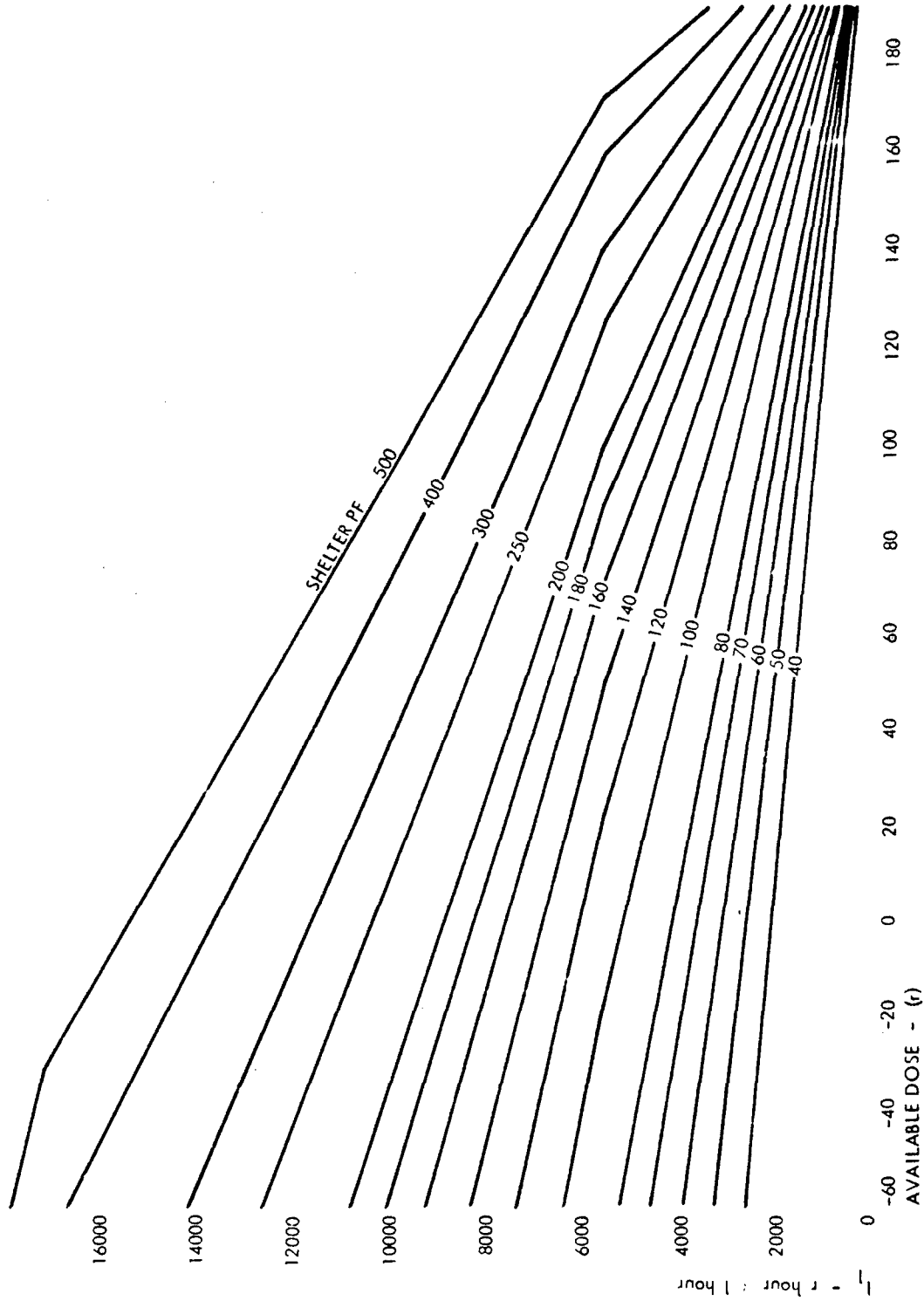
Figure 12

AVAILABLE DECONTAMINATION DOSE FOR TWO WEEKS SHELTER STAY,
$RN_3 = 0.10$

AVAILABLE DECONTAMINATION DOSE FOR THREE WEEKS SHELTER STAY,
$RN_3 = 0.03$

SHELTER PF

23
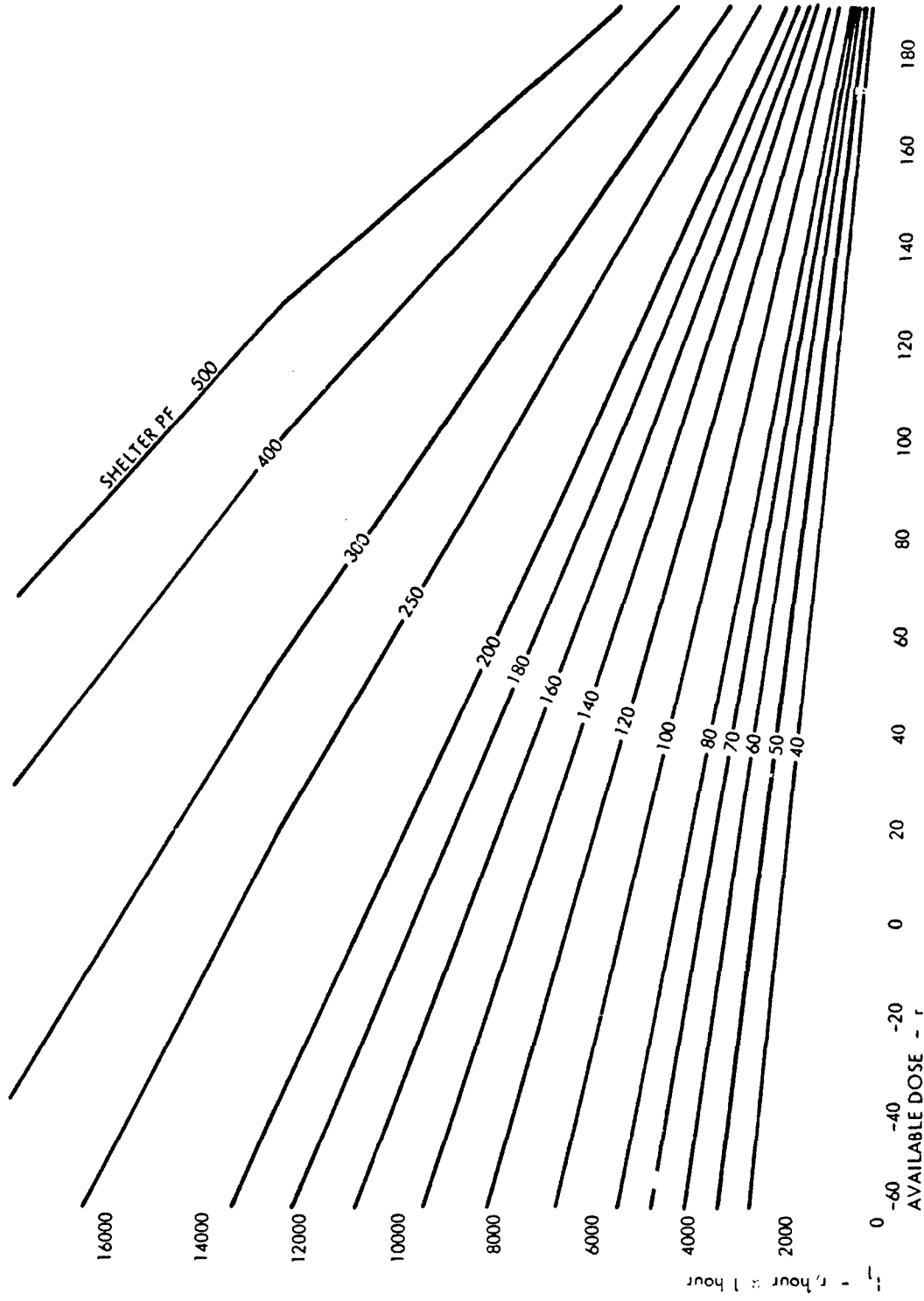
Figure 14

AVAILABLE DECONTAMINATION DOSE FOR THREE WEEKS SHELTER STAY,
$RN_3 = 0.05$

24

AVAILABLE DECONTAMINATION DOSE FOR THREE WEEKS SHELTER STAY, $RN_3 = 0.10$

SHELTER PF 500
400
300
250
200
180
160
140
120
100
80
70
60
50
40

12000
10000
8000
6000
4000
2000

$I_1 - r$ hour : 1 hour

-60 -40 -20 0 20 40 60 80 100 120 140 160 180

AVAILABLE DOSE – r

25
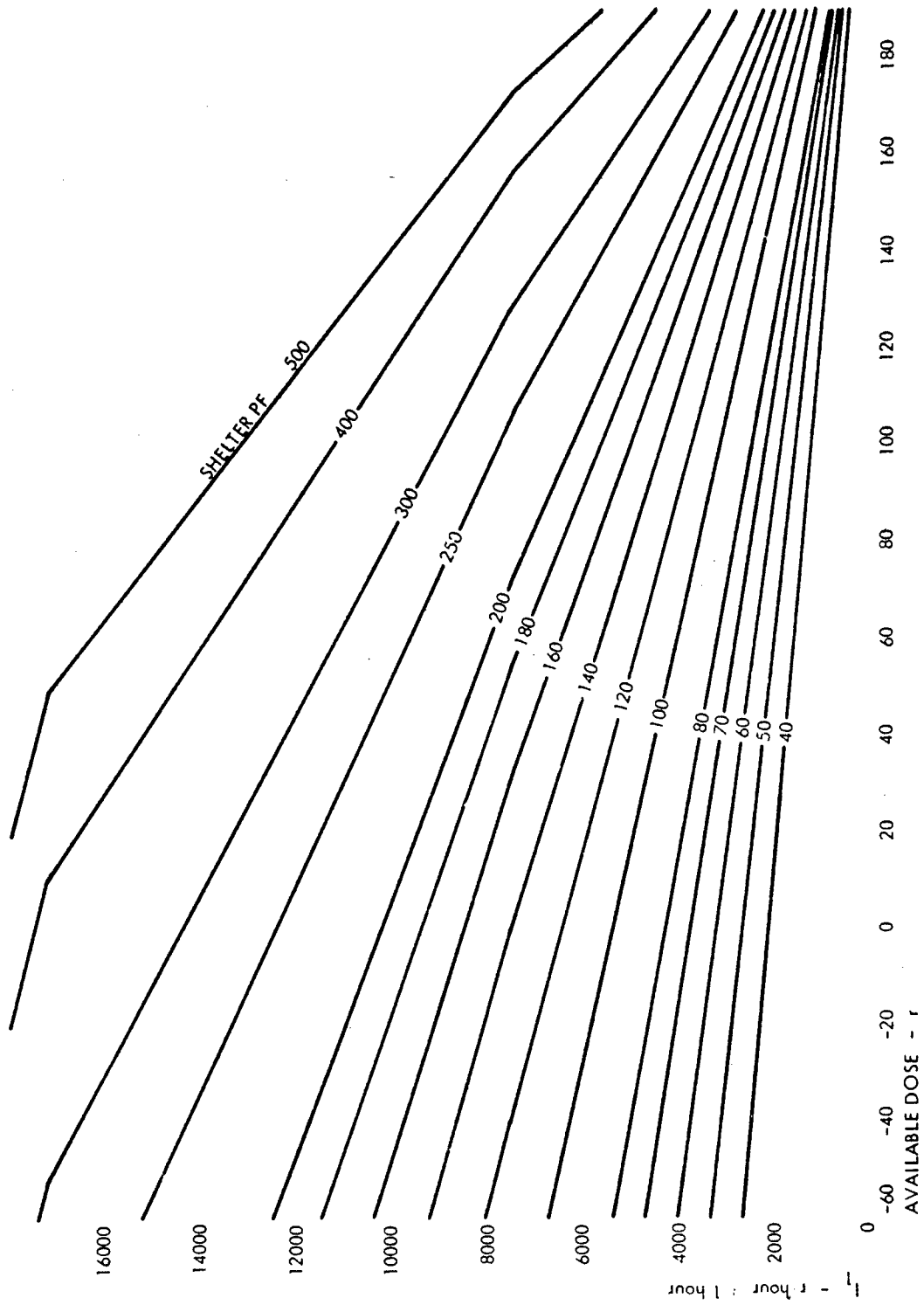
Figure 16

DECONTAMINATION DOSE PER 4 HOUR PERIODS ON VARIOUS DAYS

10^2

$RN_2 = 1.0$

10

D+5
D+6
D+7
D+8
D+9
D+10
D+11
D+12
D+13
D+14
D+15
D+16

D+18
D+19
D+20
D+21
D+22
D+23
D+24
D+25
D+26
D+27
D+28
D+29
D+30

D+32
D+33
D+34
D+35
D+36
D+37
D+38
D+39
D+40
D+41
D+42
D+43
D+44

1

DOSE — $\frac{r}{1000 \text{ r hour}}$

0.1

ELAPSED TIME – days
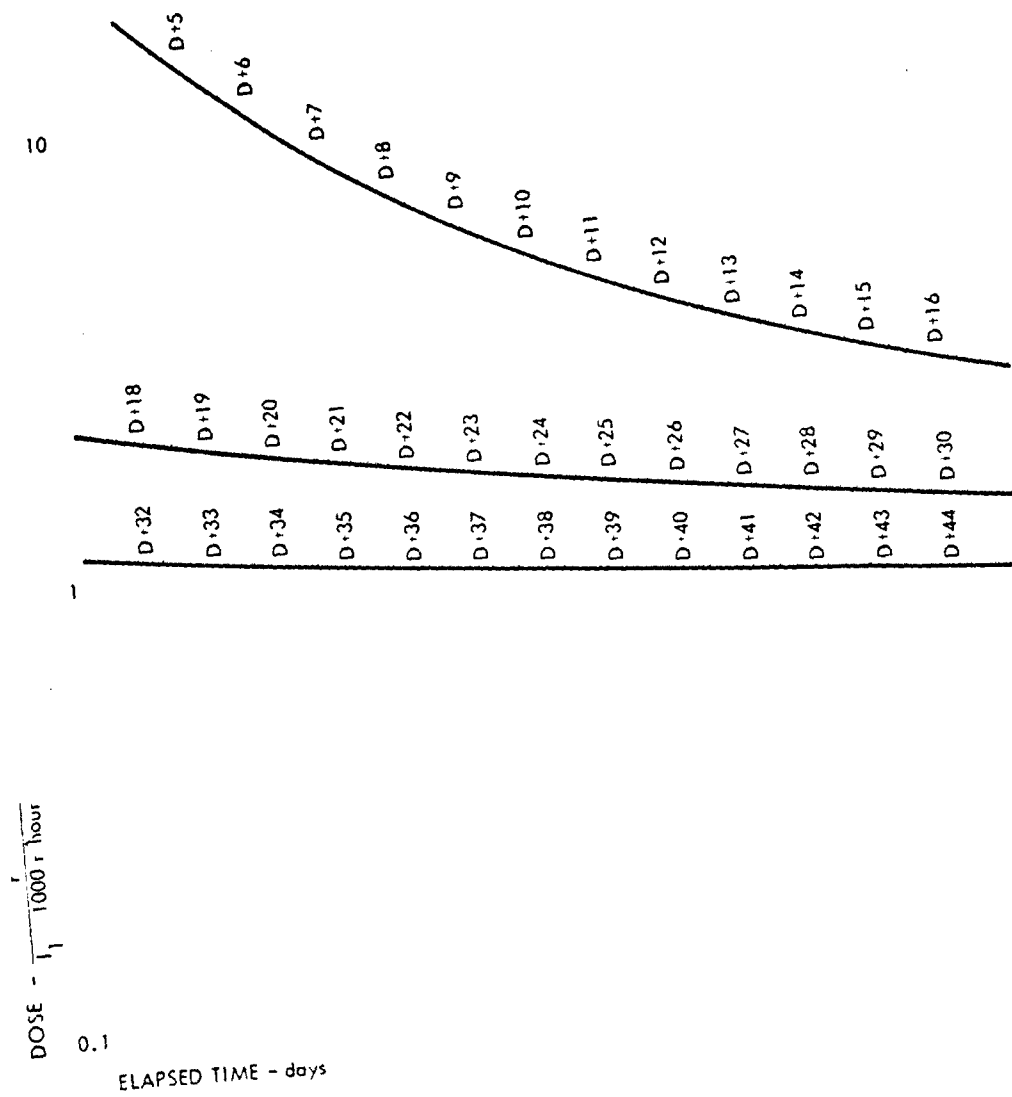
Step 2.   Determine target reutilization residual numbers, RN_3, assuming no decontamination.*

Step 3.   List the number of people in each shelter category-- a list by PF is necessary for accurate appraisal and scheduling.

Step 4.   Check the one-week shelter dose for shelter adequacy.

   a.   Use Figure 1 to obtain one-week shelter doses for FOA = 1 hour.**

   b.   Use Figure 4 to obtain the correction factor for the appropriate actual fallout arrival (FOA) time.

   c.   If the quotient from dividing the dose obtained in Step 4a by the correction factor obtained in Step 4b is larger than 190 r, i.e., 4a/4b > 190 r, the shelter is inadequate.

   d.   If 4a/4b < 190 r, go to Step 5.

Step 5.   Determine the one-month dose and the one-year dose.

   a.   Use Figure 1, 2, or 3 to determine the shelter dose for the appropriate shelter stay time for FOA = 1 hour.

      (1)   Use one-week shelter dose for shelter exit within one week.

      (2)   Use two-week shelter dose for shelter exit between one week and two weeks.

      (3)   Use three-week shelter dose for shelter exit between two weeks and three weeks.

   b.   Use Figure 4 to obtain the FOA time correction factor.

   c.   Determine shelter dose (5a/5b).

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*
Reference 1 provides the target analysis procedures for calculating residual numbers.

**
The exposure dose during the first week is the controlling factor for the limiting dose criteria.

27

d. Use Figure 5 to determine the postshelter dose to one month. Use an RN_3 that is applicable to the location and the appropriate multiplication factor to adjust for the Figure 5 standard intensity base of 1,000 r/hour, e.g., multiply the dose by 6 for a standard intensity of 6000 r/hr.

e. Use Figure 6 to determine the postshelter dose to one year.

f. If (5c + 5d) < 270 r and (5c + 5e) < 700 r, decontamination is not necessary.

g. If (5c + 5d) > 270 r or (5c + 5e) > 700 r, go to Step 6.

Step 6. Using radiological target analysis and decontamination data, determine the equipment hours required per complex to obtain the RN_3 (as determined from Figures 5 and 6) that would permit entry and utilization at the required times, i.e., (5c + 5d) ≤ 270 r and (5c + 5e) ≤ 700 r.

Step 7. Determine the man-hours required.

Step 8. Determine the available decontamination dose for all shelterees according to the PF afforded ($D_2 = D^*-D_1-D_3$).

a. Use Figures 7 through 15 corresponding to the shelter stay time, shelter PF, and selected RN_3 to obtain the available decontamination dose for FOA = 1 hour.

b. To this value add (5a - 5a/5b) to obtain the available decontamination dose for the actual FOA time. The maximum exposure limits for this study are: 190 r/week, 220 r/two weeks, 240 r/three weeks, and 270r/month.

Step 9. Determine the decontamination dose expenditure rates for the days of decontamination operations.

a. From radiological target analysis, determine the RN_2 values for the planned decontamination procedures and target units.*

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* The RN_2 for a particular decontamination procedure in a decontamination operation involving many procedures will be affected by preceding operations as well as by simultaneous operations being conducted in the same general area.

28

b. Use Figure 16 to obtain the decontamination dose for I_1 = 1000 r/hour, RN_2 = 1.0, and Δt = 4 hours for the days that decontamination is scheduled.

c. Multiply by the appropriate correction factors for actual I_1, RN_2, for each decontamination procedure, and Δt at the duration time for each decontamination sortie.

Step 10. Plan the decontamination schedule and personnel assignments by adjusting the available resources (manpower, dose, equipment, and supplies) with decontarination dose expenditure rates to obtain the required target utilization dates.

Examples I through IV that follow were specifically designed to demonstrate the proper use of the decontamination scheduling aids. Because scheduling Steps 3, 6, and 7 were omitted in the examples, only partial scheduling solutions for a specific shelter PF system were obtained. Example V, on the other hand, is a more complete example, and includes sufficient information for decontamination personnel assignments. Thus by following the steps of Example V, one can determine the size of the required decontamination organization and the effectiveness of a RADEF system.

Example I

Given: Shelter PF = 100; FOA = 3 hours; I_1 = 5,000 r/hour;
RN_3 = FA = 0.4 (F = 1, no decontamination);
RN_3 = FA = 0.03 (F = 0.075, decontamination);
RN_2 = 0.4 (for a particular method-surface combination);
and shelter stay = two weeks

Determine: 1. Shelter adequacy
2. Necessity of decontamination
3. Available decontamination dose
4. Earliest decontamination start time for a single 8-hour sortie
5. Maximum number of 8-hour decontamination sortie days prior to final shelter evacuation per individual

1. The adequacy of the shelter is determined by finding the 1-week shelter dose.

a. From Figure 1, the 1-week shelter dose for FOA = 1 hour is 201 r.

b. From Figure 4, the FOA correction factor for FOA = 3 hours is 1.43.

c. The 1-week shelter dose is 141 r. The shelter would provide adequate protection since the exposure experienced (while in shelter only) would not be incapacitating. Whether the shelter would provide adequate protection to assure survival during the postshelter period cannot be determined without additional information.

2. The necessity of decontamination is determined by finding the 1-month or 1-year dose or both as follows:

a. From Figure 2, the 2-week shelter dose for FOA = 1 hour is 216 r.

b. From Figure 4, the FOA correction factor for FOA = 3 hours is 1.38.

c. The 2-week shelter dose is 156 r.

d. From Figure 5, the target utilization dose (no decontamination) from 2 weeks to 1 month = (72 x 5) or 360 r.

e. The total 1-month radiation dose (no decontamination) is 516 r. The 1-month limit of 270 r is exceeded, and therefore, decontamination is required.

3. The available decontamination dose that may be expended within the 2-week shelter period is determined as follows:

a. From Figure 10, the available decontamination dose for FOA = 1 hour is 4 r.

b. The difference in shelter dose for FOA = 1 hour and FOA = 3 hours is 60 r (2a - 2c above).

c. By addition of 3a + 3b, the available decontamination dose is 64 r.

4. The earliest decontamination start time for a single 8-hour decontamination sortie is determined as follows:

a. Multiply the available decontamination dose by $\frac{1}{RN_2}$, by $\frac{1000}{I_1}$ and by $\frac{4}{\Delta t}$. The product is 16 r.

b. From Figure 16, the earliest decontamination start time is D + 4 days and 14 hours.

5. The number of 8-hour days of feasible decontamination participation is determined as follows:

a. From Figure 16, the doses for various days for I_1 = 1,000, RN_2 = 1.0, and Δt = 4 are multiplied by the actual RN_2, (0.4), by $\frac{I_1}{1,000}$ and by $\frac{8 \text{ hours}}{4 \text{ hours}}$ and listed from D + 13 as follows:

Day	Dose (Fig. 16) (r)	Dose (r)	Accumulated Dose* (r)
D + 13	3.2	12.8	12.8
D + 12	3.6	14.4	27.2
D + 11	4.0	16.0	43.2
D + 10	4.6	18.4	61.6

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* Actual decontamination dose accumulation starts at D + 10 and totals 61.6 r at D + 13.

b. Since the available decontmaination dose is 64 r, the maximum number of 8-hour day sorties per individual is four for decontamination completion by 2 weeks.

Example II

Determine the available decontamination dose, using all the conditions of Example I except that RN_3 = 0.05 instead of RN_3 = 0.03.

a. From Figure 11, the available decontamination dose for FOA = 1 hour is 4 r.

b. The difference in shelter dose for FOA = 1 hour and 3 hours is 60 r.

Answer: 64 r (same as for RN_3 = 0.03).

31

Example III

Determine the available decontamination dose using example I conditions except that $RN_3 = 0.10$ instead of $RN_3 = 0.03$, and also determine the number of 8-hour days that the shelterees may feasibly participate in decontamination operations.

From Figure 12, $D_2 = -36$ r.

Answer: $\Sigma D_2 = 24$ r.

Answer: > one 8-hour day and < two 8-hour days.

Example IV

Determine and list the radiation doses for all shelterees when there has been no decontamination, and also when decontamination has achieved $RN_3 = 0.03$, 0.05, and 0.10, for the periods of 1 month and 1 year.

a. The 2-week shelter dose is 156 r.

b. The target utilization doses determined from Figures 5 and 6 are added to the shelter dose and the maximum decontamination dose, and are tabulated below for appraisal.

	RN_3			
	(Doses)			
Period	0.4	0.10	0.05	0.03
One month				
Decontamination personnel	--	270 r	265 r	246 r
Other personnel	516 r	246 r	201 r	182 r
One year				
Decontamination personnel	--	520 r	390 r	320 r
Other personnel	1,520 r	496 r	326 r	256 r

Example V

Given:

1. A shelter complex for a target area with a population of 10,000 as follows:

a. 1,000 spaces, PF = 200
b. 2,000 spaces, PF = 100
c. 5,000 spaces, PF = 70
d. 2,000 spaces, PF = 40

2. The RADEF routine is 2 weeks shelter stay with decontamination as necessary.

3. The size of the emergency housing and vital facility areas (including buffer zones) is 0.5 square miles, consisting of:

   Roofs: 30 percent
   Paved areas: 50 percent
   Unpaved areas: 20 percent

4. Use I_1 = 5,000 r/hour and FOA = 3 hours.

5. The decontamination procedures and rates to obtain a desired effective RN_3 (0.03) are:*

   Roofs: Firehosing, 800 square feet per man-hour; 2,400 square feet per nozzle hour.

   Paved areas: 60 percent motorized sweeping, 25,000 square feet per man-machine hour; 40 percent firehosing, 800 square feet per man-hour.**

   Unpaved areas: 50 percent tractor scraping, 2,000 square feet per man-machine hour; 50 percent manual methods, 200 square feet per man-hour.

   Required: Determine the decontamination organization required, and prepare a complete decontamination schedule. Provide a comparison of radiation doses for system appraisal.

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* The procedure and rates given are assumed to reflect inductive alterations of decontamination data to suit details delineating the target complex.

** This rate is only a fraction of the rates given in decontamination data because many of these paved areas are assumed to be difficult to decontaminate, discontinuous, and often require the flushing of fallout over areas previously decontaminated by motorized sweeping.

Decontamination Scheduling Steps

1. The required complex availability time is assumed to be two weeks.

2. The target complex residual number RN_3 without decontamination is assumed to be 0.4 (see Example I).

3. For people in shelter, the PF is as given.

4. The people overexposed while in shelters are as follows:

People	Shelter PF	One-Week Dose	Two-Week Dose
2,000	40	350	384
5,000	70	201	219

5. Target complex decontamination is required for people in 40 PF and 70 PF shelters (already overexposed) to promote greater probability for recovery. Decontamination is required for people in 100 PF and 200 PF shelters to avoid overexposures, i.e., > 270 r/month (see Example I).

6. Equipment hours required:

   Motorized sweeper (MS): $(0.5 \text{ mi}^2 \times 28 \times 10^6 \times 0.5 \times 0.6)/$
   $25,000 = 168$ hours

   Tractor scraper (TS): 700

   Firehosing, roofs (FH): 1,740 hours

   Firehosing, paved areas (FH): 1,160 hours

   Spades, brooms, etc. (S): 7,000 hours

7. Man-hours required:

   MS operator: 168 hours
   TS operator: 700 hours
   FH operator: 6,090 + 4,060 hours
   S laborer: 7,000 hours

8. Available decontamination dose:

   2,000 people in 100 PF shelters: 64 r each (see Example 1)
   1,000 people in 200 PF shelters: 142 r each

34

Note: Not all the sheltered population is able to perform decontamination operations. These include small children, the elderly, the physically unfit, and people with more demanding duties.

9. The dose expenditures for various days to perform the various decontamination methods per 8-hour shift (and also for a 4-hour motorized sweeping shift) determined from Figure 16 are given in Table 1.

10. Schedule decontamination operations within the limits of available equipment, supplies, manpower, and dosage. The procedure is as follows:

   a. List available decontamination equipment and supplies.

   b. For each decontamination procedure, list the number of people per shift needed for full utilization of available equipment and supplies.

   c. Divide the equipment hours required, as determined by Step 6, by the number of equipment units available.

   d. Subtract the quotient of the above from the required decontamination completion time. The difference is the latest decontamination start time for the particular procedure. This instruction assumes that the decontamination equipment will be used 24 hours each day. Appropriate adjustments must be made if full time usage is not contemplated.

   e. By inspecting the dose expenditures listed in Step 9 for various procedures on various days, set up a decontamination schedule for each decontamination crew so that the available decontamination dose, Step 8, is not exceeded. If the dosage for a single sortie exceeds the available decontamination dose for the decontamination start time determined in Step 10d above, a shorter sortie (less than 8 hours) may be considered: otherwise, the available equipment is insufficient.

Example calculations for Step 10:

Consider the roof decontamination by firehosing operation, and assume 14 nozzle units are available and can be operated simultaneously. In this example, 7 men are required to handle two nozzle units, and the number of men required per shift is 49.

35

Table 1

DECONTAMINATION COSTS IN RADIATION DOSES PER 8-HR SHIFT (EXAMPLE V)

Day	FH Paving $(RN_2=1.0)$	Roofs $(RN_2=0.4)$	MS $(RN_2=1.7)$ $\Delta t=8$ hrs	$\Delta t=4$ hrs	TS $(RN_2=0.2)$	S $(RN_2=0.3)$
	(r)	(r)	(r)	(r)	(r)	(r)
D + 13	32	13	53	27	6	10
D + 12	35	14	60	30	7	11
D + 11	40	16	68	34	8	12
D + 10	46	18	78	39	9	14
D + 9	53	21	90	45	11	16
D + 8	64	26	108	54	13	19
D + 7	77	31	130	65	15	23
D + 6	95	38	162	81	19	29

Dividing 1,740 hours by 14 gives 124.3 hours. Subtracting 124.3 from 336 leaves 211.7; decontamination must be started no later than 211.7 hours--the 19th hour of D + 8. If the decontamination personnel are from 100 PF shelters, their available decontamination dose is 64 r. On the other hand, if an individual participates in operations 8 hours each day and 4.3 hours on D + 8, his decontamination dose will be 96r. The scheduling of four groups of 49 people each, on 8-hour work schedules on rotation would provide the following schedule, where the first number identifies the group, and the second number indicates the accumulated dose per person within the group. The underlined numbers are the final decontamination doses for each group.

Period of Day	D + 8	D + 9	D + 10	D + 11	D + 12	D + 13
1	--	2-21	1-32	4-37	3-53	2-68
2	--	3-21	2-39	1-48	4-51	3-66
3	1-14*	4-21	3-39	2-55	1-62	4-64

The available decontamination dose of 64 r would be exceeded with this schedule. Scheduling five groups of 49 people each on rotation would provide the following schedule:

Period of Day	D + 8	D + 9	D + 10	D + 11	D + 12	D + 13
1	--	2-21	5-18	3-47	1-46	4-60
2	--	3-21	1-32	4-47	2-53	5-47
3	1-14*	4-21	2-39	5-34	3-61	1-59

The number of roof decontamination (firehosing) personnel required is 5 x 49 - 245 men.

As an aid to decontamination scheduling for the example problem, manpower schedules for decontamination personnel either from 100 PF shelters or 200 PF shelters are presented in Table 2 for various equipment availabilities.

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*

4.3 hours only.

From Table 2, the choice of decontamination schedules listed, based either upon minimum personnel or upon minimum equipment and supplies, would require the efforts of about 550 to 1,150 people (including support personnel, and depending upon the manpower ratio drawn from the two adequate shelter categories). This range corresponds to approximately 18 to 38 percent of the people in adequate shelters. The choice of a listed decontamination schedule based upon minimum total dosage and minimum dose per man would require 55 percent of the people in adequate shelters (1,650) at an average cost of 27 r/man. This latter operation, scheduled to be completed in two 24-hour days (D + 12 and D + 13), also requires the availability of a large number of equipment, a large water pumping capability, and superlative coordination. On the basis of indiscriminate shelter assignments, just about one out of every two persons (including men, women, and children) must be capable of effective participation.

A final dose computation is required for system appraisal not only regarding the emergency operations planned but also regarding the dose available for the recovery of the entire contaminated complex of which the emergency area is only a fraction. The target utilization doses, determined from Figures 5 and 6, are added to previously accumulated doses to provide the total exposure dose. The doses listed in Table 3 for the example are for an equal number of people from both adequate shelter categories and for the minimum equip' ᵤ schedule but assigned according to the 100 PF shelter decontamination schedule listed in Table 2.

For the conditions specified--i.e., I_1 = 5000 r/hr, etc.-- and for no decontamination or where manpower or equipment to conduct decontamination is lacking, all the people in the complex would be overexposed within one month. If it is assumed that the capability for decontamination exists and decontamination of an emergency complex large enough to house everyone is conducted, 30 percent of the population can avoid overexposures and another 50 percent, barely overexposed while in shelter, will be provided an environment more conducive to recovery; virtually everyone from this latter group may be expected to recover. The remaining 20 percent of the population that have been grossly overexposed while in shelter will be provided a better chance for recovery with decontamination than without decontamination.

For the conditions specified, ultimate recovery remains tenuous because only a small fraction of the complex has been recovered, and even this effort has assumed that 40 percent of the people in the 100 PF and 200 PF shelters are capable and free to conduct decontamination tasks effectively and efficiently. Continuing decontamination will be required in the fringe areas to prevent recontamination from the undecontaminated surroundings so that the size of the decontaminated area can be kept approximately constant. Also, the recovery of the entire target complex will

38

require additional decontamination, and additional radiation doses to
decontamination personnel. Thus the 1-year dose listed for decontamina-
tion personnel in Table 3 will be increased. For the radiological con-
dition specified, the acceptance of the above RADEF system is the tacit
acceptance of some deaths from overexposure, and of large radiation doses
for all survivors.

Table 2

DECONTAMINATION SCHEDULES (EXAMPLE V)

Motorized Sweeper Operations, $RN_2 = 1.7$[a]

Sweepers	Max Decon Start Time	100 PF Shelters		200 PF Shelters		Total Decon Dose (r)
		Men	Dose/Man	Men	Dose/Man	
1	D + 7	32	55	15	117	1750
2	D + 10	24	55	12	110	1310
3	D + 11	24	50	9	133	1200
4	D + 12	24	48	12	96	1150

Tractor Scraper Operations, $RN_2 = 0.2$

(After roofs and streets in area decontaminated)

Scrapers	Max Decon Start Time	100 PF Shelters		200 PF Shelters		Total Decon Dose (r)
		Men	Dose/Man	Men	Dose/Man	
5	D + 8	15	52	15	52	778
6	D + 9	18	40	18	40	711
8	D + 10	24	27	24	27	644
11	D + 11	33	18	33	18	600
15	D + 12	45	13	45	13	570

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[a] The RN_2 for motorized sweeping is a function of (a) the fallout mass deposition per unit area, (b) the physical and operational characteristics of the sweeper and operation procedure employed, and (c) the target complex configuration (see Equation 37 and Figure 7 of Reference 1). The value of 1.7 was chosen because it is generally, although not always, within the realm of attainment by lengthening or shortening the time between dumps. All RN_2 values in this table are considered typical and were obtained from techniques given in Reference 1.

Table 2 (continued)

Firehosing Operations, Pavings, $RN_2 = 1.0$

Nozzles	Max Decon Start Time	100 PF Shelters		200 PF Shelters		Total Decon Dose (r)
		Men	Dose/Man	Men	Dose/Man	
8	D + 8	504	45	168	135	22680
10	D + 9	424	41	175	124	21630
12	D + 10	504	36	168	107	17980
16	D + 11	504	36	168	107	17980
24	D + 12	504	33	252	67	16880

Firehosing Operations, Roofs, $RN_2 = 0.4$

Nozzles	Max Decon Start Time	100 PF Shelters		200 PF Shelters		Total Decon Dose (r)
		Men	Dose/Man	Men	Dose/Man	
12	D + 8	252	54	126	108	13600
15	D + 9	265	49	159	81	12860
19	D + 10	201	58	201	58	11570
25	D + 11	264	42	264	42	11000
37	D + 12	390	27	390	27	10490

Manual Spading Operations, $RN_2 = 0.3$

Spades	Max Decon Start Time	100 PF Shelters		200 PF Shelters		Total Decon Dose (r)
		Men	Dose/Man	Man	Dose/Man	
50	D + 8	200	59	150	79	11850
60	D + 9	180	61	180	61	10980
75	D + 10	225	45	225	45	10230
100	D + 11	300	32	300	32	9600
150	D + 12	450	21	450	21	9250

Table 2 (concluded)

Minimum Support Equipment and Manpower

Equipment	Number	RN_2	Men
Front-end loaders (FL)	2	0.2	6
Dump trucks (DT)	6	1.6	160
Fuel trucks (FT)	1	0.2	3
Bulldozers (BD)[a]	1	1.0	15
Pumpers	as required		
Vehicles[b]	as required		

[a] Waste dump management
[b] Transportation

Table 3

RADIATION DOSE COMPARISON FOR SYSTEM APPRAISAL (EXAMPLE V)

(No Decontamination: 2 Weeks Shelter, $RN_3 = 0.4$)

Shelter PF	People	1 Week (r)	2 Weeks (r)	1 Month (r)	1 Year (r)
200	1000	70	78	438	1438
100	2000	140	156	516	1516
70	5000	201	220	580	1580
40	2000	350	384	744	1744

(Decontamination $RN_3 = 0.03$, Average Decontamination Dose = 51 r)

Shelter PF	People	1 Week (r)	2 Weeks (r)	1 Month (r)	1 Year (r)
200	406	70	78	105	180
200	594[a]	70	129	156	231
100	1406	140	156	182	256
100	594[a]	140	207	233	307
70	5000	201	220	247	322
40	2000	350	384	411	486

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[a] Decontamination personnel

RADEF SYSTEM EVALUATION

The use of fallout shelters during the early postattack period can easily be proved an effective defense against fallout radiation. It is similarly easy to demonstrate the usefulness of decontamination as an additional measure to reduce the radiation dosage for target complex reutilization after shelter emergence. From the examples in the preceding chapter, we can acquire an overall view of postattack problems of survival and recovery, particularly in terms of applying various countermeasures. It is easily proved that a combination countermeasure of shelter plus decontamination will be the most effective measure: fallout shelters for use during actual attack and continuing into the early postattack period; and decontamination to reduce the radiation dosage for target complex reutilization after shelter emergence.

Yet there is still a need to integrate decontamination operations with a shelter program. RADEF systems that presently provide for post-attack decontamination do not always provide the logistical and radio-logical analysis that is necessary for successful and effective reduction of the radiation hazard. It is not enough to specify a given number of decontamination personnel who will be available for assignment in the postattack recovery phase. The RADEF system must also test the provision by first acquiring radiological data about its particular target complex. Such data are acquired by assuming a certain type of attack or series of attacks, by calculating the radiation intensities over the target complex from these attacks, and by making a radiological target analysis, as presented in Reference 1. Finally, the scheduling of decontamination personnel is made along the lines presented in the preceding chapter, step by step, by type of target-complex area (paved, unpaved, etc.). Only after such calculations are made can the RADEF system know whether its fallout shelter plus decontamination capability will be adequate. The actual effectiveness of RADEF systems as well as the limits of their effectiveness may be determined by applying the decontamination scheduling procedure to specific target complexes and fallout conditions. The effectiveness of a RADEF system for any fallout environmental condition is measured by the potential radiation dose to people protected by the RADEF system. The limiting effectiveness of the RADEF system, on the other hand, is determined by the maximum fallout environmental condition (I_1) that the system could withstand without subjecting protected personnel to overexposures. The step by step approach, therefore, is different from that listed in Section V and demonstrated in Example V.

45

The limiting features of RADEF systems are the degree of shelter protection, the amount of decontamination manpower, and the amount of decontamination equipment and supplies. The limiting feature of a specific RADEF system is isolated by the scheduling procedure, and consequently the remedial response for system improvement is thus indicated. The alternatives for RADEF system improvement are to (1) increase shelter shielding, (2) increase shelter stay, (3) increase decontamination personnel, (4) increase decontamination equipment and supplies, and (5) improve target complex decontaminability.

The decontamination scheduling aids used to schedule personnel to decontamination operations for a fallout environment (postattack) are also used for the evaluation of RADEF systems that consist of a shelter system (mixed PF) and a decontamination organization.

The evaluation procedure is as follows:

<u>Step 1</u>

Determine the limiting I_1 for the minimum shelter in the RADEF system for a selected FOA time. Use Figure 4 to obtain the FOA factor, and multiply this by 190 r--the 1 week dose limit--to obtain the 1 week dose for a FOA time of 1 hour. This 1 week dose and the minimum shelter PF are used in Figure 1 to determine I_1 (max).

<u>Step 2</u>

Determine the shelter doses and the available decontamination doses for all decontamination personnel. The shelter doses for various shelter PFs and shelter stay times are determined by reversing the procedure of Step 1. Within the two-week shelter period the available decontamination dose is equal to $220 - D_1$ per man (D_1 = shelter dose).

<u>Step 3</u>

Determine the maximum feasible RN_3 for decontamination personnel and non-decontamination personnel sheltered in minimum shelters. For non-decontamination personnel, the maximum feasible dose per 1000 r/hr standard intensity from shelter exit to one month is given as

$$D_3{}^* = \frac{1000}{I_1 \text{ (max)}} (270 - D_1) \tag{1}$$

46

where 270 r is the maximum feasible dose for one month. For the special case of shelter exit at 2 weeks, the D_1 for those in minimum shelters is equal to 210 r. For decontamination personnel, the maximum feasible dose per 1,000 r/hr standard intensity from shelter exit to one month is given as

$$D_3^* = \frac{1000}{I_1 \text{ (max)}} (270 - D_1 - D_2) \tag{2}$$

where D_2 is the decontamination dose. For the special case of decontamination completion and shelter exit at 2 weeks, with the required D_2 = the available D_2,

$$D_3^* = \frac{1000}{I_1 \text{ (max)}} (270-220). \tag{3}$$

Using the appropriate shelter exit time and the appropriately calculated D_3^* (max), the RN_3(max) is determined from Figure 5.

Step 4

From radiological target analysis, decontamination data, and the available decontamination equipment and supplies, attempt scheduling decontamination personnel to provide decontamination completion of the various target complexes at the required times and for the required RN_3 (see Chapter IV, Steps 6, 7, 9, and 10).

Step 5

If any combination of decontamination personnel, decontamination dose, and decontamination equipment and supplies is inadequate, either the decontamination organization must be upgraded, or I_1 (max), the measure of the limiting effectiveness of the RADEF system, is reduced. The required increase in decontamination personnel or decontamination equipment and supplies, or both, can be readily determined by scheduling the support to meet the needs. Within the shelter period, the reduced limiting standard intensity for the existing RADEF system may be solved by applying the following equation to decontamination personnel with inadequate available decontamination doses, and by solving for $I_1(r)$.

$$D_2' = D^* - \frac{I_1(r)}{I_1(\text{max})} D_1 = \frac{I_1(r)}{I_1(\text{max})} D_R \qquad (4)$$

where

D_2' is the new decontamination dose for $I_1(r)$

D^* is the dose limit that applies--i.e., 190 r/week, 220 r/2 weeks, or 270 r/month

$I_1(r)$ is the reduced standard intensity which is the measure of the RADEF system effectiveness

$I_1(\text{max})$ is the limiting standard intensity for the minimum shelter in the RADEF system

D_1 is the shelter dose for $I_1(\text{max})$

D_R is the required decontamination dose determined by scheduling for $I_1(\text{max})$.

Solving for the reduced limiting standard intensity,

$$I_1(r) = \frac{D^* I_1(\text{max})}{D_1 + D_R} . \qquad (5)$$

Where decontamination operations are scheduled for completion within the shelter period of 2 weeks

$$I_1(r) = 220\, I_1(\text{max})/D_1 + D_R \qquad (6)$$

and where the decontamination personnel from minimum shelters are the only ones requiring additional decontamination dosage

$$I_1(r) = 220\, I_1(\text{max})/210 + D_R. \qquad (7)$$

The RADEF system evaluation procedure is demonstrated by the examples that follow. In these examples, it is assumed that target analysis was conducted and that the given decontamination procedures and rates would provide the effectiveness specified. In reality, the effort required of some procedures to obtain various degrees of effectiveness could be

determined only after much more data on target complex decontamination (rather than isolated surface decontamination) are made available. Notably lacking in the examples are the effort and exposure doses that must be expended in removing vehicles parked over surfaces requiring decontamination by a method that could not otherwise be satisfactorily executed--i.e., motorized sweeping.

Example VI

Given: The same shelter complex, target area, and population as Example V. The effective fallout arrival time is 4 hours; shelter stay is limited to two weeks, and 10 percent of the people from each shelter category are decontamination personnel.

Find: The limiting effectiveness of the RADEF system, i.e., I_1(max).

1. Minimum standard intensity for FOA = 4 hours:

From Figure 4, the FOA reduction factor = 1.554;
1.554 x 190 = 295 r

From Figure 1, I_1(max) = 2950 r/hr

2. Two-week shelter doses and tentative available decontamination dose from Figures 2 and 4:

D_1		Tentative Available Decontamination Dose	
PF =	40, 315/1.50 = 210	10 r/man	(200 men)
	70, 180/1.50 = 120	100 r/man	(500 men)
	100, 127/1.50 = 85	135 r/man	(200 men)
	200, 63.5/1.50 = 42	178 r/man	(100 men)

3. Max RN_3 for 2 weeks to 1 month period:

PF = 40, 270-210/2.95 = 20; from Figure 5, RN_3(max) = 0.11

Decon Pers, 270-220/2.95 = 17; from Figure 5, RN_3(max)=0.095.

4. From target analysis, the following application of decontamination procedures would provide an effective RN_3(max) = 0.08:

   a. FH 0.15 mi^2 of roofs at 6000 ft^2/nozzle hour
   b. MS 0.15 mi^2 of paved areas at 40,000 ft^2/machine hour

49

c. FH remaining 0.10 mi^2 of paved areas at 6000 ft^2/nozzle hour

d. TS 0.05 mi^2 of unpaved areas at 2000 ft^2/machine hour

e. Spade 0.05 mi^2 of remaining unpaved areas at 400 ft^2/manhour

Since the $RN_3 = 0.08$ is less than the RN_3 (max) of Step 3, the available decontamination dose as indicated in Step 2 is adequate.

The dose expenditures for decontamination sorties for various procedures and for various days after the attack are as shown in Table 4 (taken from Figure 16).

The required equipment hours are as follows:

a. FH roofs: 4,200,000 ft^2 at 6000 ft^2/hr: 700 nozzle hours

b. FH paved areas: 2,800,000 ft^2 at 6000 ft^2/hr: 467 nozzle hours

    1167 nozzle hours

c. MS paved areas: 4,200,000 ft^2 at 40,000 ft^2/hr: 105 MS hours

d. TS unpaved areas: 1,400,000 ft^2 at 2000 ft^2/hr: 700 TS hours

e. Spade unpaved areas: 1,400,000 ft^2 at 400 ft^2/hr: 3500 spade hours

From the information provided, a table of schedules for equipment availability and manpower requirements is constructed in Table 5.

A schedule according to equipment availability, manpower, and dosage may now be selected. An example selection may be based upon minimum equipment, minimum organization, and a limiting decontamination dose of 60 r. This selection is summarized as follows:

Equipment	Men	Average Decontamination Dose (r/man)
1 MS	9	58
6 TS	18	26
10 FH nozzle units	147	55
30 spades	90	39
Support Equipment		
2 front-end loaders	6	26
6 dump trucks	54	55
1 fuel truck	3	26
1 bulldozer	6	51
	333	

Table 4

DECONTAMINATION COSTS (EXAMPLE VI)

Hours to Shelter Exit	D +	FH = 8 hours		MS (RN$_2$ = 1.7)		TS 8 hrs RN$_2$ = 0.2 (r)	S 8 hrs RN$_2$ = 3 (r)
		Paved Areas RN$_2$ = 1.0 (r)	Roofs RN$_2$ = 0.4 (r)	Δt = 8 hrs (r)	Δt = 4 hrs (r)		
24	13	19	8	32	16	4	6
48	12	21	9	36	18	5	7
72	11	24	10	40	20	5	8
96	10	27	11	46	23	6	9
120	9	32	13	54	27	7	10
144	8	38	15	64	32	8	12

Note: Decontamination personnel from 40 PF shelters may participate only in operations that are scheduled not to exceed a dose of 10 r.

51

Table 5

DECONTAMINATION SCHEDULES (EXAMPLE VI)

	Maximum Decontamination Start Time	Men	Average Dose/Man	Men	Average Dose/Man
Sweepers					
1	D + 9	6	87	12	44
2	D + 11	12	36	24	18
3	D + 12	18	24	36	12
Tractor Scrapers					
6	D + 9	18	26	36	13
8	D + 10	24	18	48	9
11	D + 11	33	13	66	7
Firehose Nozzles (roofs)					
6	D + 9	63	50	126	25
8	D + 10	84	35	168	18
10	D + 11	105	26	210	13
Firehose Nozzles (paved areas)					
4	D + 9	42	120	84	60
6	D + 10	63	71	126	36
8	D + 11	84	51	168	26
Spades					
30	D + 9	90	39	180	20
40	D + 10	120	27	240	14
50	D + 11	150	21	300	10

The number of decontamination personnel required is only 333, and therefore the decontamination operation could easily be manned by decontamination personnel from 70 PF, 100 PF, and 200 PF shelters. The adequacy of the decontamination organization for minimum requirements during the emergency period has been demonstrated, but the organization cannot be considered adequate unless decontamination schedules for the recovery of the entire target complex could be met. In this case, only a fraction of the available decontamination dose is expended during the emergency period; the exposure dose for decontamination sorties decreases with time; and additional decontamination personnel can be pressed into service. Consequently, later decontamination schedules do not appear to be critical. In this example, the maximum effectiveness of the RADEF system is not limited by the capability of the decontamination organization but by the low PF shelters (PF = 40). The RADEF system is effective to a standard intensity of 2950 r/hr for an effective fallout arrival time of 4 hours. An improvement of the RADEF system requires the provision of improved shelters for the 2000 people in 40 PF shelters.

Example VII

Determine the effectiveness of the RADEF system if the 2000 people in 40 PF shelters in the previous example are provided 70 PF shelters:

1. Max shelter standard intensity for FOA = 4 hours; from Figure 4 and Figure 1; I_1(max) = 5150

2. Two-week shelter doses and tentative available decontamination dose from Figures 2 and 4:

		D_1	Tentative Available Decontamination Dose
PF = 70	315/1.50	= 210	10 r/man (700 men)
100	223/1.50	= 149	71 r/man (200 men)
200	112/1.50	= 75	145 r/man (100 men)

3. Max RN_3 for 2 week to 1 month period:

PF = 70, 270-210/5.15 = 11.7; from Figure 5, RN_3(max) = 0.065
Decon Pers, 270-220/5.15 = 9.71; from Figure 5, RN_3(max)=0.055

Note: The previous decontamination effort would provide only RN_3 = 0.08, and therefore a greater effort is required.

53

Also: If the final RN_3 is 0.065 instead of 0.055, then the 1 month rather than the 2 weeks dose is limiting, and the available decontamination dose is obtained by sub-tracting the shelter dose and the target utilization dose (as determined from Figure 5 for the period 2 weeks to 1 month) from the limiting dose of 270 r as follows:

700 men in 70 PF shelters; 270-210-60 or 0/man
200 men in 100 PF shelters; 270-149-60 or 61 r/man
100 men in 200 PF shelters; 270-75-60 or 135 r/man

4. From target analysis, the decontamination procedure and rate that would provide an effective $RN_3 = 0.05$ is determined as follows:

   a. FH 0.15 mi^2 of roofs at 2000 ft^2/nozzle hour

   b. MS 0.15 mi^2 of paved areas at 30,000 ft^2/machine hour

   c. FH remaining 0.10 mi^2 of paved areas at 4000 ft^2/nozzle hour

   d. TS 0.05 mi^2 of unpaved areas at 2,000 ft^2/machine hour

   e. Spade 0.05 mi^2 of remaining unpaved areas at 200 ft^2/manhour

5. The dose expenditures for decontamination sorties for various procedures and for various days after the attack are given in Table 6.

6. List required equipment hours:

   a. FH roofs: 4,200,000 ft^2 at 4000 ft^2/hr: 1050 nozzle hours

   b. FH paved areas: 2,800,000 ft^2 at 4000 ft^2/hr: <u>700 nozzle hours</u>
                                                                       1750 nozzle hours

   c. MS paved areas: 4,200,000 ft^2 at 30,000 ft^2/hr: 140 MS hours

   d. TS unpaved areas: 1,400,000 ft^2 at 2000 ft^2/hr: 700 TS hours

   e. Spade unpaved areas: 1,400,000 ft^2 at 200 ft^2/hr: 7000 Spade
                                                                               hours

7. Construct a table of schedules (Table 7) for equipment avail-ability and manpower requirements.

8. Attempt the selection of a schedule within manpower-dosage limits and with available equipment and supplies.

Table 6

DECONTAMINATION COSTS (EXAMPLE VII)

| Shelter Exit | D + | FH - 8 hours | | MS (RN_2 = 1.7) | | TS-8 hrs RN_2 = 0.2 (r) | S-8 hours RN_2 = 0.3 (r) |
		Paved Areas RN_2 = 1.0 (r)	Roofs RN_2 = 0.4 (r)	Δt = 8 hrs (r)	Δt = 4 hrs (r)		
24	13	33	13	56	28	7	10
48	12	37	15	62	31	7	11
72	11	41	17	70	35	8	13
96	10	47	19	80	40	10	14
120	9	55	22	93	47	11	17
144	8	66	27	112	56	13	20
168	7	79	32	134	67	16	24

Table 7

DECONTAMINATION SCHEDULES (EXAMPLE VII)

	Maximum Decontamination Start Time	Men	Average Dose/Man	Men	Average Dose/Man
Sweepers					
1	D + 8	12	114*	24	57
2	D + 11	12	91*	24	46
3	D + 12	18	58	36	29
Tractor Scrapers					
6	D + 9	18	42	36	21
8	D + 10	24	29	48	14
11	D + 11	33	20	66	10
Firehose Nozzles (roof)					
8	D + 8	84	98*	168	49
12	D + 10	126	58*	252	29
16	D + 11	168	41	336	20
Firehose Nozzles (paved areas)					
6	D + 9	105	124*	210	62
8	D + 10	112	107*	224	53
10	D + 11	105	108*	210	54
Spades					
60	D + 9	180	63	360	32
80	D + 10	240	44	480	22
100	D + 11	300	33	600	17

* Personnel from 200 PF Shelters only.

If it is assumed that 4-hour sorties are effective work periods and they are scheduled, the decontamination personnel may be assigned as in Table 8.

In this example, a minimum organization of 1189 decontamination personnel is required, or 189 more than available, and the RADEF system as given is technically not feasible for a standard intensity of 5150 r/hr. The support personnel include front-end loader and dump truck operators to remove the spoil from tractor scraping and manual shoveling of unpaved areas. Also included are bulldozer operators for dump management and fuel truck operators for equipment refueling. If the available decontamination dose for decontamination personnel from the 70 PF shelters were increased so that they could participate in at least two 8 hour decontamination sorties instead of one, adequate spade decontamination personnel would be available from the 70 PF shelters.

Equation 7 is applied with D_R = 21 (see Table 6) to provide a re-evaluation of the RADEF system, and

$$I_1(r) = \frac{220 \times 5150}{210 + 21} = 4900 \text{ r/hr} .$$

In this particular example, however, the number of decontamination personnel from 100 PF and 200 PF shelters is also insufficient, and the standard intensity must be reduced and assignments adjusted to accomodate decontamination operations. This includes the shifting of some duties other than spading to decontamination personnel from 70 PF shelters. Tractor scraping operations may be readily assigned to 70 PF decontamination personnel by doubling the personnel assignment to 36 men. The reduction in manpower for firehose decontamination to 84 men from 100 PF shelters requires an available dose of 98 r (see Table 7), and to provide this, the limiting standard intensity must be reduced to

$$I_1(r) = \frac{220 \times 5150}{149 + 98} = 4590 \text{ r/hr} .$$

For a standard intensity of 4590 r/hr, the decontamination operation may be scheduled as shown in Table 9.

The exposure doses to people in the RADEF system with $I_1(max)=4590$ r/hr and FOA = 4 hours are as shown in Table 10. The available dosage for decontamination in the period between 2 weeks and 1 month is listed in Table 11.

57

Table 8

DECONTAMINATION ASSIGNMENTS AND SCHEDULE (EXAMPLE VII)

Operations	Source and Number of Personnel			Decontamination Start Time	Dose/Man (r)
	200 PF	100 PF	70 PF		
MS	12			D + 8	114
TS		18		D + 9	42
FH (paved areas)	84			D + 11	108
FH (paved areas)		42		D + 11	54
PH (roofs)		126		D + 10	58
Spade	4	14		D + 9	65
Spade			800	D + 12	10
Support	38			D + 9	115
Support		9		D + 9	42
Support		36		D + 12	55
Support		6		D + 12	14
Total:	138	251	800		

Table 9

DECONTAMINATION ASSIGNMENTS AND SCHEDULE (EXAMPLE VII)

Operation	Source and Number of Personnel			Decontamination Start Time	Dose/Man (r)
	200 PF	100 PF	70 PF		
MS	9			D + 8	136
TS			36	D + 9	19
FH (paved areas)	84			D + 10	127
FH (roofs)		84		D + 8	88
Spade			360	D + 9	29
Support	7			D + 9	145
Support		116		D + 9	60
Support			129	D + 8	24
Total:	100	200	525		

Table 10

EXPOSURE DOSES FOR RADEF SYSTEM AT I_1(MAX) (EXAMPLE VII)

Shelter	Number of People	Radiation Dose (r)			
		1 Week	2 Weeks	1 Month	1 Year*
200 PF	900	59	67	108	223
	84	59	194	235	350
	9	59	203	244	359
	7	59	212	253	36c
100 PF	1800	119	132	173	288
	116	119	220	261	376
70 PF	6475	170	187	228	343
	36	170	206	247	362
	129	170	211	252	367
	360	170	216	257	372

* Assumes RN_3 = 0.05 is maintained for 1 year.

Table 11

AVAILABLE DECONTAMINATION DOSES, 2 WEEKS TO 1 MONTH
(EXAMPLE VII)

Men	Available Decontamination Dose/Man (r)
84	9
360	13
7	17
129	18
36	23
9	26
84	35
116	37
175	42
1000	

Although the decontamination dose per sortie for all methods is reduced by radioactive decay, so that at the end of the one month period, roughly twice the decontamination effort can be scheduled for the same cost in dose as at the end of the two-week period, the rate of urban area decontamination is slow. In this case, the recovery operations after shelter exit are not delayed by inadequate equipment and supplies but by the combination of inadequate manpower and decontamination dosage. From the calculations performed, it is clear that either an increase in shelter protection or an increase in decontamination personnel will speed the recovery of urban areas. At less than the limiting standard intensity of 4590 r/hr, the rate of urban area recovery is also increased because the shortening or elimination of the waiting time between decontamination operations is facilitated by the combination of the increased available decontamination dose and the decreased exposure in conducting the decontamination operation. Finally, the selection or provision of low residual number locations for decontamination personnel after shelter exit (the staging area concept) would increase their available decontamination dose so that they could spend more time doing decontamination. Thus, if an $RN_3 = 0.02$ were provided decontamination personnel, the available decontamination dose at one month would be increased 25 r per man. With this reserve of decontamination dose, one can freely schedule the continuation of decontamination immediately following shelter exit. The rate of decontamination, instead of being limited by manpower and dosage, is now limited by the available equipment and supplies. In this case, if the apportionment of area to method is unchanged and the decontamination rates are also unchanged for the remainder of the urban area, the procedure that limits the decontamination rate is motorized sweeping (MS at 30,000 ft^2/hr), and the total rate for all methods is 100,000 ft^2/hr or 0.6 mi^2/week.

Example VIII

Determine the effectiveness of a RADEF system for the same target area as the previous example with the following shelter occupancy:

70% in 100 PF shelters	(7000 people)
20% in 200 PF shelters	(2000 people)
10% in 500 PF shelters	(1000 people)

As in the previous example, 10 percent of the people from each shelter category are decontamination personnel.

1. I_1(max) for 100 PF shelters (FOA = 4):

$$D_{FOA} = 1 = 190 \times 1.554; \quad I_1(\text{max}) = 7300 \text{ r/hr}$$

2. Two-week shelter doses and tentative available decontamination dose:

Shelter	Two-Week Dose	Available Decontamination r/man	Men
100 PF	210	10	700
200 PF	105	115	200
500 PF	42	178	100

3. RN_3(max) for 2-week to 1-month period:

$$270-220/7.3 = 6.85 \text{ r}; \quad RN_3(\text{max}) = 0.038$$

(decontamination personnel)

4. Decontamination operation and rates to obtain $RN_3 = 0.030$

1750 hr.	FH	0.15 mi^2 of roofs at 2400 ft^2/nozzle hour
1167 hr.	FH	0.10 mi^2 of paved areas at 2400 ft^2/nozzle hour
168 hr.	MS	0.15 mi^2 of paved areas at 25,000 ft^2/machine hour
700 hr.	TS	0.05 mi^2 of unpaved areas at 2000 ft^2/machine hour
7000 hr.	S	0.05 mi^2 of unpaved areas at 200 ft^2/man hour

5. Decontamination doses per 4-hour sortie for MS operations and per 8-hour sortie for other operations (I_1 = 7,300 r/hr) are given in Table 12.

6. The required equipment hours are as listed in Step 4.

7. Construct a table of schedules for equipment availability and manpower requirements (Table 13).

8. Attempt the selection of a schedule within manpower dosage limits and available equipment and supplies. (See Table 14.)

As in the previous example (Step 8 of Example VII) the decontamination organization required is larger than the available manpower and the RADEF system is technically infeasible for a standard intensity of 7300 r/hr. If Equation 7 is applied with

$$D_R = \frac{\text{men required}}{\text{men available}} \times \text{available dose}$$

63

Table 12

DECONTAMINATION COSTS (EXAMPLE VIII)

| | FH | | | | |
| | Paved | Roof | MS | TS | S |
D +	(r)	(r)	(r)	(r)	(r)
13	46	18	39	9	14
12	52	21	44	10	15
11	58	23	50	12	18
10	67	27	57	14	20
9	78	31	66	16	23
8	92	37	79	18	28
7			95		

Table 13

DECONTAMINATION SCHEDULES (EXAMPLE VIII)

	Maximum Decontamination Start Time	Men	Average Dose/Man (r)	Men	Average Dose/Man (r)
Sweepers					
1	D + 7	15	172	24	108
2	D + 10	12	161	18	108
3	D + 11	18	100		
Tractor Scrapers					
6	D + 9	36	30	72	15
8	D + 10	48	20	96	10
11	D + 11	44	20	88	10
Firehose Nozzles (roof)					
12	D + 7	126	161	183	107
16	D + 9	168	105		
Firehose Nozzles (paved areas)					
8	D + 7	196	166	324	100
10	D + 9	140	175	210	117
Spades					
60	D + 9	540	29	1080	15
80	D + 10	480	30	960	15
100	D + 11	600	23	1500	10
Support	D + 9	166	106		

Table 14

DECONTAMINATION ASSIGNMENTS AND SCHEDULE (EXAMPLE VIII)

Operations	Source and Number of Personnel			Decontamination Start Time	Dose/Man (r)
	500 PF	200 PF	100 PF		
MS	12			D + 10	161
TS			88	D + 11	10
FH (paved areas)	140			D + 9	175
FH (roofs)		168		D + 9	105
Spade			1500	D + 11	10
Support		166		D + 9	106
	152	334	1588		

for decontamination personnel, a standard intensity of 6893 r/hr is low enough for those tasks assigned to 100 PF personnel, but standard intensities as low as 5407 r/hr and 5131 r/hr are necessary for tasks assigned to 200 PF and 500 PF personnel, respectively. Without reassignment and rescheduling of personnel, the minimum standard intensity of 5131 r/hr is the limiting standard intensity of the system. However, with reassignment and rescheduling to obtain the maximum use of decontamination personnel, the average of the three reduced standard intensities is an approximation of the limiting standard intensity. In this case, the approximation of the limiting standard intensity is 5810 r/hr.

From this point, the RADEF evaluation procedure is repeated to determine the adequacy of the RADEF system for the standard intensity of 5810 r/hr and for the same effective fallout arrival time (i.e., 4 hours):

1. Two-week shelter doses and tentative available decontamination dose:

Shelter	2-Week Dose	Available Decontamination Dose (r)	Men
100	167	53	700
200	83	137	200
500	33	187	100
			1000

2. RN_3(max): $270-220/5.81 = 8.61$ r; RN_3(max) $= 0.048$

3. Decontamination operations and rates to obtain $RN_3 = 0.04$:

1400	hrs	FH	0.15 mi^2 of roofs at 3000 ft^2/nozzle hour
933	hrs	FH	0.10 mi^2 of paved areas at 3000 ft^2/nozzle hour
140	hrs	MS	0.15 mi^2 of paved areas at 30,000 ft^2/machine hour
700	hrs	TS	0.05 mi^2 of unpaved areas at 2,000 ft^2/machine hour
7000	hrs	S	0.05 mi^2 of unpaved areas at 200 ft^2/man hour

4. Decontamination dose per 4-hour sortie for MS operations and per 8-hour sortie for other operations ($I_1 = 5810$ r/hr):   See Table 15.

5. Decontamination schedule of personnel assignments and decontamination exposure doses are given in Table 16.

Table 15

DECONTAMINATION COSTS (EXAMPLE VIII)

D +	FH		MS (r)	TS (r)	S (r)
	Paved (r)	Roofs (r)			
13	37	14	31	7	11
12	41	16	35	8	12
11	46	18	40	10	14
10	53	21	45	11	16
9	62	25	52	13	18
8	73	29	63	14	22
7			76		

Table 16

DECONTAMINATION ASSIGNMENTS AND SCHEDULE (EXAMPLE VIII)

Operation	OF Personnel			Decontamination Start Time	Dose/Man (r)
	500 PF	200 PF	100 PF		
MS		12		D + 8	128
FH (paved areas)	84			D + 9	153
FH (paved areas)			163	D + 12	39
FH (roofs)		105		D + 8	118
TS			18	D + 9	47
Spading			240	D + 10	49
Support Personnel					
DT Operators	16			D + 9	185
DT Operators		77		D + 9	100
BD Operators		6		D + 9	115
FL Operators			24	D + 9	47
FT Operators			6	D + 9	47
	100	200	456		

69

Although only 70 percent of the available dose is required, all de-contamination personnel from the 500 PF and 200 PF shelters are included in the schedule. If the standard intensity is increased by as much as 5 percent, the scheduling of personnel to decontamination tasks will be very difficult mainly because the working time of the 700 decontamination men from the 100 PF shelters will be significantly reduced.

Thus in this example, although the effectiveness of the shelter system is adequate for a standard intensity of 7300 r/hr with FOA = 4 hrs, the RADEF system as a whole is adequate only for a standard intensity of 5810 r/hr. For the RADEF system to be equal to the effectiveness of the shelter system, a much larger decontamination organization is required (see Figure 17).

The projected exposure doses for the people in the RADEF system at I_1 = 5810 r/hr and FOA = 4 hours is as follows:

Number of People	Shelter PF	2-Week Dose (r)	1-Month Dose (r)	1-Year Dose (r)
6544	100	167	209	325
1800	200	83	125	241
900	500	33	75	233
756	decontamination personnel	183-218	225-260	383-418

In the examples presented, a shelter stay period and a target complex recovery completion time of 2 weeks were given. A final example will consider a RADEF system with a longer shelter stay and an attendant delay in the recovery of an emergency living area.

Example IX

Determine the effectiveness of the RADEF system described in Example VIII, but for a shelter stay period of 3 weeks instead of 2 weeks.

1. I_1(max) = 7,300 (See Example VIII, Step 1).

2. 3-week shelter dose and tentative available decontamination dose:

Shelter	3-Week Shelter Dose (r)	Available Decontamination Dose (r)	Men
100 PF	219	21	700
200 PF	110	130	200
500 PF	44	196*	100

* Note: 190 r/week limit; since shelter dose during the third week is 2 r, the maximum decontamination dose during the third week is 188 r, but up to 10 r could be expended during the second week.

3. Required RN_3:

$270-219/7.3 = 4.11$; $RN_3(max) = 0.05$

4. Decontamination operations and rates to obtain $RN_3 = 0.045$:

FH 0.15 mi^2 of roofs at 4000 ft^2/nozzle hour (1050 hours)
FH 0.10 mi^2 of paved areas at 3000 ft^2/nozzle hour (933 hours)
MS 0.15 mi^2 of paved areas at 30,000 ft^2/machine hour(140 hours)
TS 0.05 mi^2 of unpaved areas at 2000 ft^2/machine hour(700 hours)
Spade 0.05 mi^2 of unpaved areas at 200 ft^2/man hour (7000 hours)

5. Decontamination dose per 4-hour sortie for MS operations and per 8-hour sortie for other operations are listed in Table 17.

6. Decontamination schedule of personnel assignments and decontamination exposure doses are given in Table 18.

7. The exposure doses to people in the RADEF systems with $I_1(max) = 7300$ r/hr and FOA = 4 hours are given in Table 19.

This example shows that if shelter exit is delayed 1 week (3 weeks shelter instead of 2 weeks), the 10 percent RADEF organization is more than adequate, and the effectiveness of the RADEF system is equal to the effectiveness of the minimum shelter (effective to 7,300 r/hr). Figure 17 gives the reduced RADEF system effectiveness for smaller decontamination organizations for the same shelter system and target complex.

Figure 17

THE EFFECTIVENESS OF A RADEF SYSTEM
AS A FUNCTION OF DECONTAMINATION ORGANIZATION SIZE

FOA = 4 HOURS
POPULATION = 10,000
SHELTERS
70% 100 PF
20% 200 PF
10% 500 PF
VITAL TARGET
0.5 SQ. MILE
50% PAVED
30% ROOFS
20% UNPAVED

2 WEEKS SHELTER STAY

3 WEEKS SHELTER STAY

I_1 (Max) = r/hour @ 1 hour

7300
7000
6000
5000
4000
3000
2000
1000

PERCENT OF MIN-SHELTER MAX-EFFECTIVENESS

100
80
60
40
20
0

0   5   10   15   20
PERCENT DECONTAMINATION PERSONNEL FROM EACH SHELTER

0   500   1000   1500   2000
SIZE OF DECONTAMINATION ORGANIZATION

Table 17

DECONTAMINATION COSTS (EXAMPLE IX)

Day	FH Paved (r)	FH Roof (r)	MS (r)	TS (r)	S (r)
D + 20	27	11	23	5	8
D + 19	29	12	25	6	9
D + 18	31	12	26	6	9
D + 17	33	13	28	7	10
D + 16	35	14	30	7	11
D + 15	38	15	33	8	12
D + 14	42	17	36	8	13

Table 18

DECONTAMINATION ASSIGNMENTS AND SCHEDULE (EXAMPLE IX)

Operation	Source and Number of Personnel			Decontamination Start Time	Dose/Man (r)
	500 PF	200 PF	100 PF		
MS		9		D + 15	110
FH (paved areas)	84			D + 16	151
FH (roofs)		56		D + 15	69
FH (roofs)			112	D + 18	17
TS			30	D + 16	20
Spading			450	D + 15	20
Support Personnel					
DT Operators		108		D + 15	103
FL Operators			24	D + 15	20
FT Operators			6	D + 15	20
BD Operators		6		D + 15	100
	84	179	622		

Table 19

PROJECTED DOSES FOR RADEF SYSTEM I_1 (MAX)

Number of People	Shelter	2-Week Dose (r)	1-Month Dose (r)	1-Year Dose (r)
6378	100 PF	210	245	431
622	100 PF	210	265	451
1821	200 PF	105	136	322
56	200 PF	105	201	387
123	200 PF	105	240	426
909	500 PF	42	70	256
84	500 PF	42	221	407

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13 ABSTRACT

This report presents a decontamination scheduling procedure that permits the user to correlate target analysis results, shelter protection factors, and decontamination data and systematically obtain feasible decontamination assignments and decontamination schedules. Because the procedure delineates individual exposure doses for all contemplated exposure periods, clear choices of personnel assignments and scheduling options are presented. Scheduling examples are given to demonstrate the procedure, and procedural aids are included to minimize decontamination scheduling calculations.

This report also demonstrates how the decontamination scheduling procedure may be used to evaluate the effectiveness of RADEF systems. The examples for decontamination scheduling and for RADEF system evaluation indicate that target area decontamination is a task requiring a relatively large decontamination organization.

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14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

DD FORM 1 JAN 64 1473 (BACK)

TITLE: Decontamination Scheduling Procedures for RADEF Systems

By: Hong Lee

SUMMARY:

This report presents a decontamination scheduling procedure that permits the user to correlate target analysis results, shelter protection factors, and decontamination data and systematically obtain feasible decontamination assignments and decontamination schedules. Because the procedure delineates individual exposure doses for all contemplated exposure periods, clear choices of personnel assignments and scheduling options are presented. Scheduling examples are given to demonstrate the procedure, end procedural aids are included to minimize decontamination scheduling calculations.

This report also demonstrates how the decontamination scheduling procedure may be used to evaluate the effectiveness of RADEF systems. The examples for decontamination scheduling and for RADEF system evaluation indicate that target area decontamination is a task requiring a relatively large decontamination organization.