RADIOLOGICAL TARGET ANALYSIS PROCEDURES

Code 1

CONTRACT NO. N228-(62479)65421
OCD WORK UNIT NO. 3231C

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March 1966

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SRI Project No. MU-5069

CONTRACT NO. N228-(62479)65421
OCD WORK UNIT NO. 3231C

Prepared for:

OFFICE OF CIVIL DEFENSE
DEPARTMENT OF THE ARMY
WASHINGTON, D.C. 20310

Through:

TECHNICAL MANAGEMENT OFFICE
U.S.N.R.D.L.
SAN FRANCISCO, CALIFORNIA 94135

ABSTRACT

The radiological target analyses in this report consist of a series of analytical procedures for evaluating the residual numbers for shelters and other locations before, during, and after decontamination so that exposure doses may be calculated. These residual numbers are used to provide estimates of (1) shelter stay times, (2) manpower requirements for proposed decontaminati (3) exposure to recovery personnel, (4) decontamination effectiveness requirements, (5) equipment and supplies requirements, and (6) feasibility of plans and schedules for the recovery of vital facilities and living areas. Tables, charts, figures, and sample calculations provide working tools which may be used for civil defense planning and training, and similar practical levels of radiological defense preparation.

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I. INTRODUCTION

Radiological target analyses are required for assessing hazards from fallout contamination and for formulating recovery operations. Specifically, the analysis provides an estimate of the relative contribution to the intensity of the gamma radiation field at a given location from fallout that is deposited at a variety of nearby locations. The analytical procedure includes consideration of the influence of (1) source geometry factors, (2) shielding attenuation, (3) the alteration of source strengths by decontamination, and (4) the alteration of source strengths by deposition characteristics and weathering. The results obtained from such an analysis, combined with the performance characteristics of radiological defense systems, provide estimates of (1) shelter stay times, (2) manpower requirements for proposed decontamination operations, (3) the exposure dose to recovery personnel, (4) decontamination effectiveness requirements, (5) equipment and supply requirements, and (6) plans and schedules for the recovery of vital facilities and living areas. Item 6 may be used to establish training requirements and information for decontamination crews.

Miller et al[1] have discussed the interrelationships of various planning parameters including shelter-stay time, exposure-dose limiting criteria, shelter shielding effectiveness, standard intensity fallout arrival time, decontamination crew residual numbers, and target reutilization residual numbers. This report carries forward the work on radiological defense planning by adding evaluations of the effects of target characteristics on the planning parameters. Such evaluations are made by the use of radiological target analysis procedures.

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 geometries.

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

II. SUMMARY AND CONCLUSIONS

A radiological target analysis procedure is presented which provides calculations of the relative exposure intensities within target complexes during the shelter period, the decontamination period, and the target reutilization period. These calculations are made by systematically determining the intensity at typical target locations as modified by fallout geometries, structural shielding geometries, and the movement of fallout by nature or by decontamination operations. The results are residual numbers for the three postattack periods that are specified in the general equation for exposure dose.

Examples and sample calculations are included in each analytical step to provide not only illustrations of the procedures but also training aids for operational and planning personnel in RADEF systems. The latest information was included on several decontamination methods, with examples and sample calculations showing how decontamination operations may be scheduled, crew doses may be controlled, and recovery objectives may be achieved. A final step was the evaluation of several representative RADEF systems in terms of target analysis results, decontamination performance, and logistic limitations.

The primary conclusion of the procedural effort reported here is that each RADEF system should be analyzed with its target area. The accuracy of the target complex analysis procedure is limited by the accuracy to which target complexes and fallout sources could be delineated. Nevertheless, the data obtained by the procedure can be coordinated with decontamination methods, manpower and other operational factors to provide effective RADEF planning and evaluation.

Radiological target analysis also shows that RADEF systems need decontamination capability as well as good shelter protection if they are to cope with fallout intensities of more than 2,000 r/hr at 1 hour. Shelter stay times can be considerably reduced by decontamination efforts that employ not only decontamination specialists but also the general population, because large numbers of decontamination personnel will mean shorter decontamination exposure per worker.

A final conclusion is that further study and experimental verification are required for several important fallout phenomena:

1. The variations of the target attenuation factor, $\bar{A}$, and the residual numbers, RN_2 and RN_3 due to:
    a. Nonuniform distribution of fallout deposition within target complexes
    b. Fallout deposition on and hold-up by target and structural components other than roofs
    c. Fallout entry into structures
2. Barrier shielding effects for various fission-product compositions
3. The effects of obliquely incident radiation upon barriers for various locations
4. Air-scattered radiation effects
5. Back-scattered radiation effects.

III. RADIOLOGICAL DEFENSE SYSTEMS

Standard Operations

A radiological defense (RADEF) system is a planned organizational and operational setup providing measures to reduce the exposure dose from nuclear radiations caused by radiological attack. The three major measures for RADEF use against fallout are: (1) shelter, (2) decontamination, and (3) evacuation. The standard operations to carry out these measures are:

1. To take shelter upon warning (or before fallout arrives), and to remain in the shelter until some designated time when short-period operations outside the shelter are feasible

2. To conduct decontamination or evacuation operations at this designated time

3. To reoccupy areas and to recover the use of facilities at some later time according to some criterion of feasibility.

Feasibility

The use of any RADEF operation requires a precise definition of what is considered to be feasible. A major part of this definition involves an upper limit in the exposure dose to humans,[1] but another part of the definition depends on the effectiveness of the RADEF protective counter-measures; the effectiveness, in turn, depends on the geometrical and structural characteristics of the target area and on the techniques used in applying the measures. This latter group of factors is considered in the radiological target analysis procedures, as needed for evaluating the operational feasibility of a proposed RADEF system.

The effectiveness of a radiological defense system is determined by the reduction of accumulated dose to the people protected by the system. A technically feasible radiological defense system is therefore an effective system in which the exposure dose of a person in a given situation does not exceed a specific exposure dose limit. If the facilities, equipment, manpower, and organization are available to carry out the designated operations, such a system would also become an operationally feasible system. In this report, only the technically feasible aspects are considered, and a RADEF system is considered nonfeasible if the specific exposure dose limit is exceeded. Because of biological repair processes, a net or effective residual dose, ERD, rather than the total exposure dose is used as an estimate of radiation injury for maximum ERD values less than about 200 r.[2] In Reference 1, it is shown that limiting exposure doses of 190 r per week, 270 r per month, and/or 700 r per year collectively approximate 200 r ERD (max). This definition of feasibility implies the belief that essentially all people receiving a dose of 200 r ERD (max) or less would not require medical assistance, and barring other complications, would be capable of performing useful work.

The use of this set of exposure doses as a criterion for establishing RADEF system feasibility should provide limiting design requirements for the system by limiting the exposure doses to the borderline at which casualties would result. This limit is of major interest because the post-attack recovery process will require a healthy work force with a minimum casualty burden, and the overall RADEF system must be evaluated with this requirement in mind. In other words, it is not sufficient to consider a RADEF system whose objective is only to save lives.

Exposure Dose Equation

The exposure dose for any set of standard operations of the radiological defense system is represented, in general, by the following equation:

$$D^{*} = I_1 RN_1 \Delta DRM_1 + I_2 RN_2 \Delta DRM_2 + I_3 RN_3 \Delta DRM_3 \quad (1)$$

where the subscripts pertain to three consecutive periods of time, each period being one of the standard operations, and where

- D^{*} is the limiting exposure dose for selected periods of time
- I_1 is the standard intensity at the shelter location
- RN_1 is the shelter residual number
- ΔDRM_1 is the dose rate multiplier for the shelter period
- I_2 is the standard intensity at the site being decontaminated
- RN_2 is the decontamination crew residual number (or evacuation movement residual number)
- ΔDRM_2 is the dose rate multiplier for the decontamination period
- I_3 is the (average) standard intensity for the reoccupied area or the evacuation area
- RN_3 is the target reutilization residual number
- ΔDRM_3 is the dose rate multiplier for the target reutilization period

The standard intensity is the dose rate, referenced at 1 hour after weapon detonation, of the fallout uniformly deposited upon an extended area, as measured at 3 feet above the surface of the area. The shelter residual number (RN_1) is the ratio of the intensity (dose rate) at a location inside a shelter to the intensity 3 feet above an extended plane area at the same location. The absolute value of RN_1 would be the ratio of the exposure dose in the shelter to the potential exposure dose outside the shelter. The decontamination crew residual number is the ratio of the exposure dose of a person actively engaged in a decontamination operation to the potential exposure dose of an individual standing on an extended plane area at the same locations and at the same time as the decontamination operations. The target reutilization residual number is the ratio of the exposure dose of a person reusing the target area and facilities (usually after decontamination) to the potential exposure dose of an individual standing on an extended plane area at the same locations and at the same times.

The assignment of residual numbers for target complexes through rapid analysis methods was the prime objective of the work described in this report, and the evaluation of the residual numbers is discussed in detail in Chapter V.

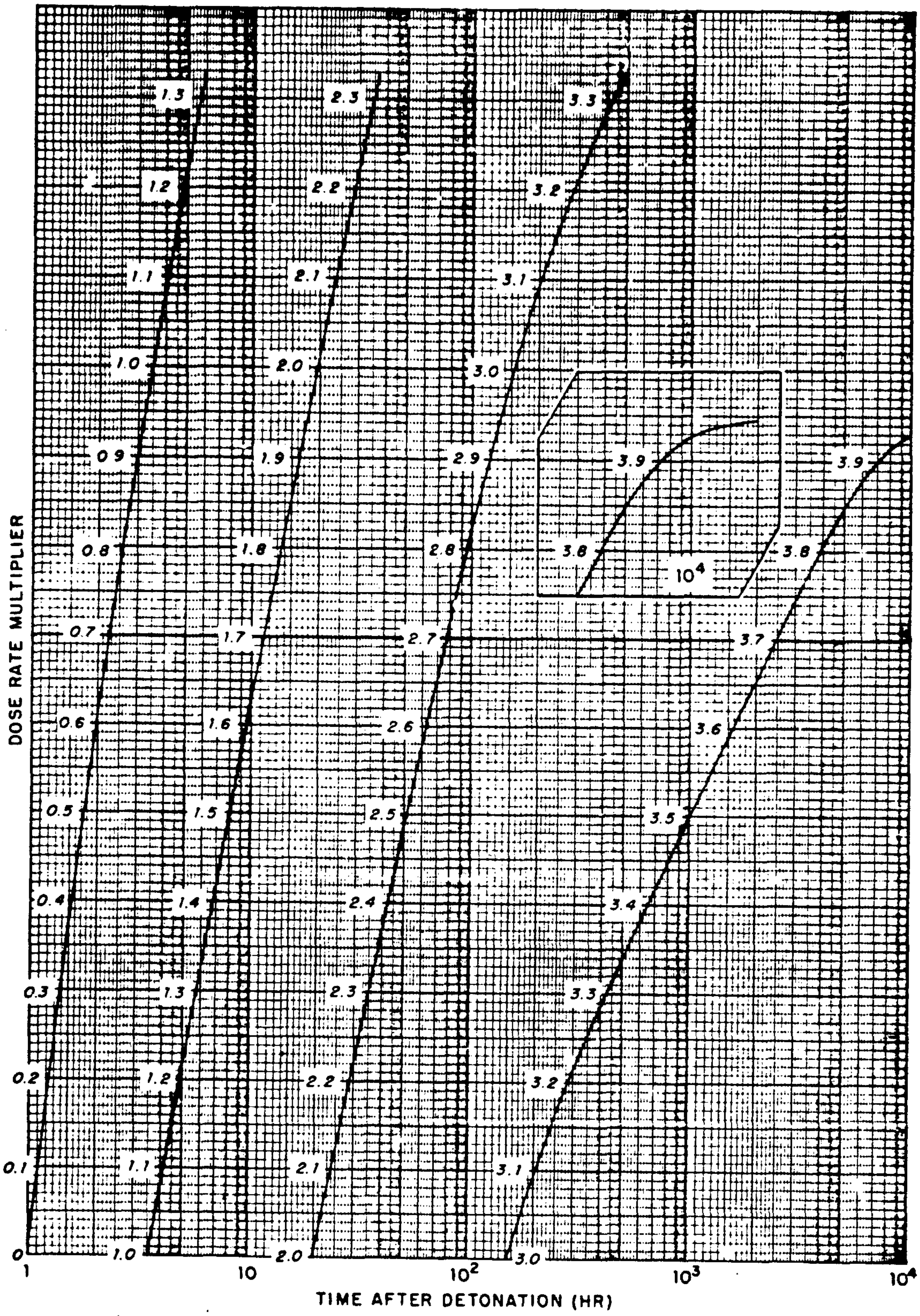
The dose rate multipliers for each exposure period are determined from the resultant ionization or dose rate decay function for all the radioactive elements contained in fallout.[3] In Figure 1 the dose rate multiplier standardized to 1 hour and to various times thereafter, is plotted as a function of time after detonation. The ΔDRM for specific time periods may be obtained by differences in the DRM curve. As an example, the DRM for 100 hours is 2.821, and the DRM for 10 hours is 1.626; thus ΔDRM for the period from 10 hours to 100 hours is 1.195.

Variation of Exposure Dose

Equation (1) may be shortened or expanded to suit specific (assumed or planned) radiological defense operations. An example of shortening would be a situation where no decontamination is contemplated or where people do not participate in the decontamination operations. In this case, $\Delta DRM_2 = 0$, and only one location is considered, $I_1 = I_2 = I_3$; the exposure dose equation is then shortened to

Figure 1

DOSE RATE MULTIPLIER CURVE



$$D^* = I_1 (RN_1 \Delta DRM_1 + RN_3 \Delta DRM_3) \qquad (2$$

An example of expanding Eq. (1) would be a situation where individuals must leave shelters to work a decontamination shift and then return to shelters. After the target complex is recovered by the participation of other decontamination crews, the first group of individuals emerges from shelters again and reutilizes the target complex. The limiting dose equation is expanded to

$$D^* = I_1 \left[RN_1 (\Delta DRM_{1a} + \Delta DRM_{1b}) + RN_2 \Delta DRM_2 + RN_3 \Delta DRM_3 \right] \qquad (3$$

where 1a designates the first period of shelter stay, and 1b designates the shelter stay period after the completion of an assigned unit of decontamination or a decontamination work shift.

The numerical value of ΔDRM_{1a} depends upon the effective fallout arrival time and the first shelter exit time. The numerical value of ΔDRM_1 depends upon the first shelter exit time plus the length of the decontamination assignment (the shelter reentry time) and the total time required to complete decontamination of the target complex (the shelter reexit or the start of the target reutilization time). For a given or assumed RADEF system operation as a function of standard intensity, effective fallout arrival time, and RN_1 values when combined with the exposure dose criteria, the evaluation of Eq. (1) requires decontamination operational and effectiveness data for the determination of RN_2 and RN_3.

Time Periods

It may be noted that Eq. (1) cannot be evaluated without consideration of the time periods associated with each ΔDRM. The time period of ΔDRM_1, as stated previously, is the shelter stay time (considering the fallout from a single detonation only), and the end of this time period is the shelter exit time. It may also be the starting time for decontamination or evacuation.

Similarly, the time period associated with ΔDRM_2 is the decontamination time or evacuation time, and the end of this time period may be variously designated as required: the decontamination completion time; the shelter exit time for the general population who have not participated in the decontamination operation; the area or site reentry time; or the evacuation completion time. The time period associated with ΔDRM_3 is often called the final post-attack recovery period, and when only the external gamma exposure doses are considered, its end is about 2.3 years after the radiological attack.

The various times after detonation when each period may start and end are determined from the DRM curve of Figure 1, used in conjunction with Eq. (1). When the parameters of Eq. (1) are evaluated with the exposure dose constraint imposed by D^*, the various time periods also become limiting values. Thus the shelter stay time becomes the minimum shelter stay time, and the decontamination time (or the evacuation time) becomes the maximum decontamination time, given set values of other parameters.

One characteristic of the relationships among the RADEF system variables is that the length of the different time periods is often very sensitive to small changes in the other variables. For example, if a very simple RADEF system is assumed in which the standard routine is to take shelter and stay there until the appropriate time to reoccupy the immediate area (with no decontamination and no evacuation operations) and if a good shelter (RN_1 = 0.001) is available, then for the conditions where D^*/I_1 is 0.3 for one year and RN_3 (average shielding attenuation factor for the reutilized area) is 0.5, the minimum shelter stay time is 20 days. However, if RN_3 is 0.7 instead of 0.5, the minimum shelter stay time is 41 days, or about twice as long.

This example could be stated in reverse to indicate that, if decontamination could be carried out to reduce the value of RN_3 from 0.7 to 0.5, the shelter stay time would be reduced from 41 to 20 days.

Decontamination reduces the dose rate through removal of the radiation sources carried by the fallout particles, and as indicated above, decontamination is a means of shortening the shelter stay time. If decontamination personnel were well sheltered during the shelter period, their effective residual dose (ERD) accumulated during the shelter period would be small, and a large portion of the D^* could be allocated for the decontamination period. In general, the values of RN_2 are much larger than RN_3 and very much larger than RN_1; consequently, the term $I_1 RN_2 \Delta DRM_2$ could be a major contributing term in Eq. (1). The value of ΔDRM_2 in this term may be reduced by delaying the start of decontamination (i.e. longer shelter stay) or by shortening the decontamination time per worker. However, decontamination time depends also on the area to be cleaned, the working rates, size of work force, and other operational factors. In most cases, these factors are the ones that control the decontamination time and the value of ΔDRM_2.

Operational Choices

Many of the variables of Eq. (1) can be altered operationally within limits to conform to the feasibility times. For example, if the decontamination period is short, the decontamination effectiveness need not be as good; also, if the decontamination crew exposure dose is large (longer exposure), a higher decontamination effectiveness (lower value of RN_3) will be necessary for the same shelter exit time. The different variables under control can be balanced one against the other in the planning of a decontamination operation for a contaminated area.

The decontamination data available today include some data for decontamination effectiveness and performance rates of various decontamination methods on various surface types. Very little information is available on the decontamination of vital facilities and large urban target areas. Experiments on target complex recovery have been carried out by the U.S. Naval Radiological Defense Laboratory at Camp Parks.[4,5] More data on decontamination operations and effectiveness, and more data on exposure dose from such target complex experiments are needed for the planning of post-attack recovery operations for various types of facilities and areas. Until such experimental data are available, estimates of the various parameters must be made from presently available decontamination data. Finally, the scheduling of decontamination operations is required so that the decontamination time allotted to individual contamination crew members may be estimated.

Summary of RADEF Requirements

The rate of recovering a contaminated area depends upon the available manpower, supplies, and equipment and upon the complexity of interaction of the decontamination methods needed in the operation. The practicality of decontamination (using available surviving resources) will depend upon whether or not decontamination can be completed in time to permit earlier entry into an area. If the time required to decontaminate a large area is too long without additional supplies and equipment, thus failing to shorten the shelter stay time appreciably, then no advantage will result from decontamination. Also, if the standard intensity is less than a given value (depending on the value of RN_1 and other parameters), decontamination will not be considered necessary even though such an effort would provide reduced dosages (below the maximum limit) for a large proportion of the population.

Analyses of these and other problems related to the recovery of specific target complexes are required before preattack estimates can be made for decontamination operations.

IV. THE RADIATION CONTRIBUTION FACTOR

Source Geometry

The intensity (dose rate) at any point location within a contaminated target complex consists of the contributions from a large number of contributing radiation sources. The relative amount that each source contributes is a function of the source size (which, for uniformly contaminated plane surfaces, is proportional to the area), distance of the source from the point, and the shielding material between each source and the point location.

Although, in general, the exposed projected horizontal surfaces in a contaminated complex may not be uniformly contaminated, first approximation equations describing the radiation intensity assume uniform contamination (in lieu of more definitive descriptions). The basic simplified equations describing the intensity of direct radiation at a point location lying within a contaminated area are given in terms of three types of geometry:

Relatively Close Radiation Sources

A. Radiation from a Circular Area

$$I_j = I_o A_j \int_{\theta_1}^{\theta_2} \int_{r_1}^{r_2} \frac{d\theta \, r dr}{h^2 + r^2} \tag{4}$$

B. Radiation from a Rectangular Area

$$I_j = I_o A_j \int_{y_1}^{y_2} \int_{x_1}^{x_2} \frac{dy \, dx}{x^2 + y^2 + h^2} \tag{5}$$

Relatively Distant Radiation Sources

$$I_j = I_o A_j A/d^2 \tag{6}$$

In the above equations, I_o is the source strength intensity in r/hr for the contributing surface, and A_j is the effective attenuation factor for shielding materials (other than air) between the contaminated area source and the point of radiation detection.

Equation 4 describes the source contribution from a contaminated plane radial sector where r_1 and r_2 are respectively the nearest and farthest distances (feet) between the sources on the point location; θ is the angle subtended; and h is the height (feet) of the location of interest above the plane circular sector. Equation 5 describes the source contribution from a contaminated rectangular area of width $y_2 - y_1$ and distances x_1 to x_2 in the x direction. If its center is offset a distance y_c in the y direction, the approximation of Equation 5 is

$$I_j = I_o A_j \int_{y_1}^{y_2} dy \int_{x_1}^{x_2} \frac{dx}{x^2 + y_c^2 + h^2} \tag{7}$$

and is valid where $y_2 - y_1 < x_1$ and $x_1^2 > y_c^2 + h^2$. Equation 6 describes the contribution from a contaminated surface of area A at distance d from the point of interest where A is small compared to d^2.

It has been shown that, if the limits to equation 4 are 0 and 2π for θ and 0 and 300 feet for r, and $A_j = 1$, and h = 3 feet, the equation will approximate measured test data over an extended contaminated plane (desert) surface (Operation Plumbbob).[6,7] Thus, the value I, for a uniformly contaminated surface, reduces to 28.9 I_o. The contribution factor for each contributing source is expressed as

$$C_j = I_j/28.9\ I_o \tag{8}$$

The sum of all contribution factors for all contributing sources is equivalent to the attenuation factor for a target complex prior to decontamination, relative to the open-field radiation source geometry. The target complex attenuation factor is defined as

$$\bar{A} = \Sigma_j C_j = \Sigma_j I_j / 28.9\ I_o \tag{9}$$

Within a target area, Eq. 4 is applied to the central area of noncircular contaminated surfaces that are above or below the location of interest. An equivalent circular area may be substituted for near-equal-sided rectangular areas. The intensity contributed from a contaminated oblong rectangular area is approximated by substituting an equivalent circular area for the central part of the rectangular area, and by using either Equation 6 or 7 for the end areas.

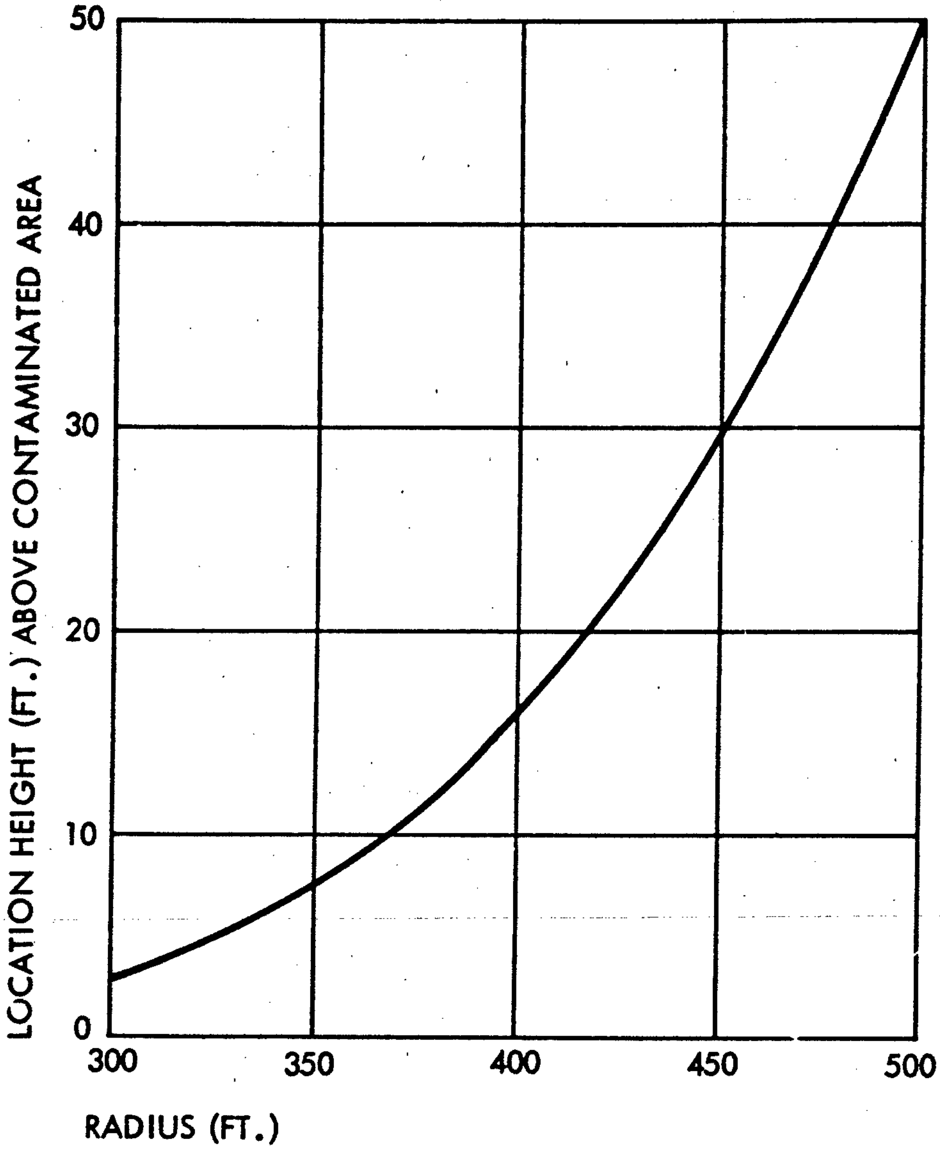
Finally, an adjustment in the geometric calculations is necessary to compensate for a point location height greater than 3 feet above a contaminated plane. With an increase in point location height, a greater expanse of area (area beyond 300 feet) contributes significantly to the dose rate at the point location. The adjusted maximum radii values for various point location heights are given in Figure 2.

Barrier Attenuation

In Reference 7, the author used values of A_j (the attenuation factor for a shielding mass thickness), directly with Eq. 4 for a barrier or several barriers shielding the location of I_j from a limited finite area source or sources on the surface designated by j without regard to the geometry of the barrier. Yet, such a value of A_j is in error when only the mass-thickness of the shielding material is considered. The geometric shape and size of the shielding, and its orientation to the geometrias of radiation sources and the point location, will often significantly influence the value A_j, and therefore these factors must be taken into account in estimating the values of A_j.

Figure 2

MAXIMUM RADIUS ADJUSTMENTS VS. LOCATION HEIGHTS



The calculation of A_j from a quasiexact method would be complicated and impossible to use if one were to consider in detail the myriad shielding thicknesses between the point locations and the many contaminated sources which emit radiation through various pathways within a target area. In addition, the variations of I_o from surface to surface and from moment to moment for a given surface do not justify using more than simplified computational methods for evaluating Equation 4. A simplified method of calculation for evaluating I_j is therefore necessary, but the method must consider the scattered radiation (barrier-scattered and air-scattered) as well as direct radiation contributing to the intensity at the point of interest.

The radiation received at any point of interest includes one or more of the following components: (1) radiation transmitted through a medium with insignificant attenuating qualities, (2) radiation directly transmitted through a barrier, (3) radiation scattered by a barrier, and (4) radiation scattered by air (see Figure 3).

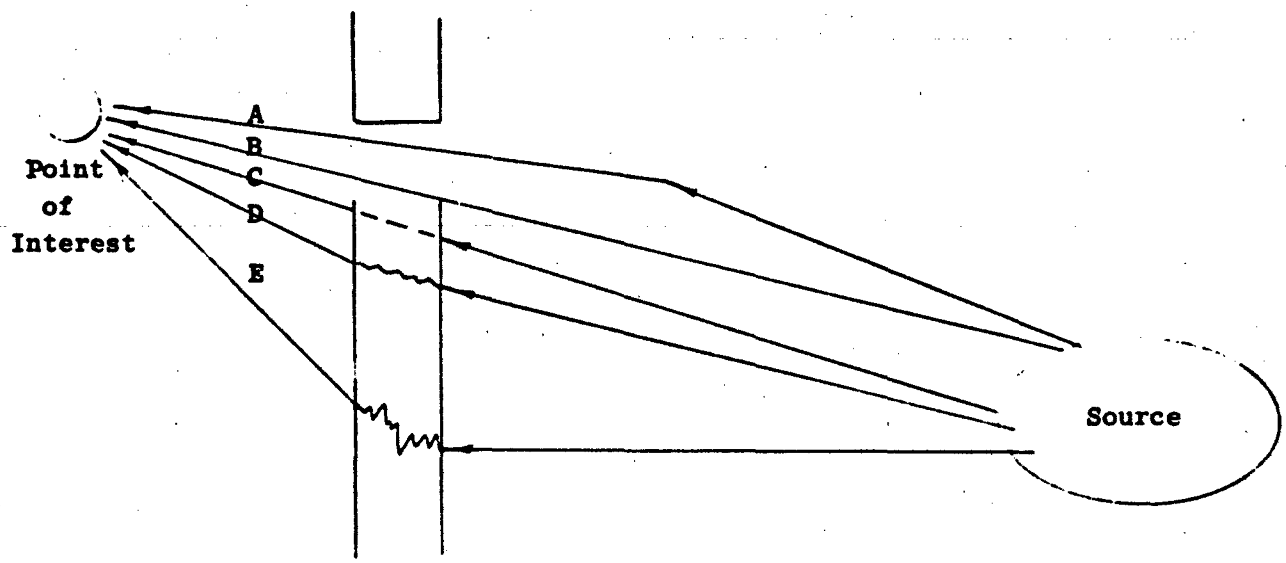
The solution of Equation 4 is approximated by the convenient separation of I_j into three parts as follows:

$$I_j = I_{jd} + I_{ja} + I_{jw} \tag{10}$$

where I_{jd} is the contribution of radiation that penetrates a shielding barrier or medium and emerges or remains within a narrow angle; I_{ja} is the air scattered contribution; and I_{jw} is the contribution of radiation that penetrates a shielding barrier and is scattered to emerge through a wide angle only, i.e., not included in I_{jd}. Barrier-scattered radiation or unscattered barrier-attenuated radiation not directed toward the point of interest may subsequently be air-scattered toward the point of interest. Air-scattered radiation may also be subsequently barrier-scattered or barrier-attenuated.

Figure 3

Components of Radiation



A	Air-scattered component (through opening in barrier or around it)
B	Direct unattenuated radiation
C and D	Unscattered barrier-attenuated and narrow-angle barrier-scattered components
E	Wide-angle barrier-scattered component

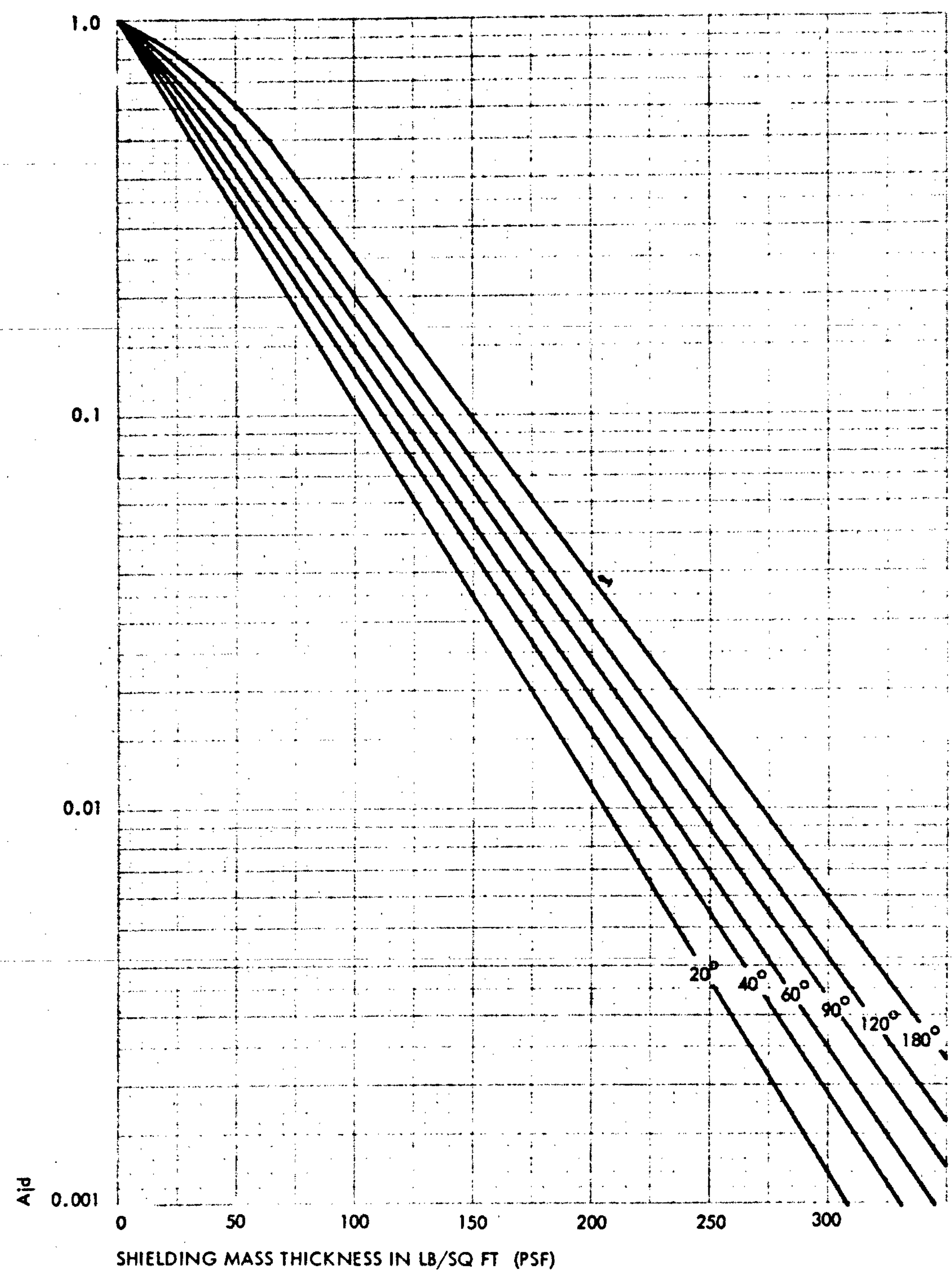
Normally, I_{jd} constitutes the major component of I_j. and is evaluated from the equation

$$I_{jd} = I_o A_{jd} A_{jr} \int_{\theta_1}^{\theta_2} \int_{r_1}^{r_2} \frac{d\theta rdr}{h^2 + r^2} \qquad (11)$$

where A_{jd} is the wall attenuation factor for vertical barrier shielding of direct and scattered radiation, from a horizontal contaminated plane through an angle α, and A_{jr} is the horizontal barrier (e.g., roofs and floors) attenuation factor that includes the effects of unscattered as well as scattered radiation from a horizontal contaminated plane. The angle α for a wall is approximated by taking the average of (1) the angle subtended at the point of interest by its top and bottom,and (2) the angle subtended by the ends of the wall. The error incurred by simple averaging is not large because a radiation detector at a point location responds mainly to radiation scattered within narrow angles. Figure 4, constructed from available data,[8,9] gives the A_{jd} values for various α angles and barrier mass thicknesses. Mass thickness, expressed in 16/sq. ft. is used to describe structure barriers because the attenuation of most building materials may be collectively treated as a function of thickness and density.[8] Figure 5 gives the A_{jr} values of various roof mass thicknesses for several L/h ratios, where L is the length of the source plane and h is the height difference between a point location and the roof. The barrier attenuation of gamma rays depends not only on the characteristics of the barrier but also on the energy of the gamma rays. For fission products, the net energy effect varies with time after detonation. As experimental data becomes available, the A_{jd} and A_{jr} curves will require alteration to reflect these variations. The A_{jr} factors obtained from Figure 5 are for area sources centrally located over a point location. For area sources not directly overhead (e.g., adjacent contaminated roof), A_{jr} can be obtained from Figure 5 with the application of simple algebra.

Figure 4

WALL ATTENUATION FACTORS FOR VARIOUS α AND WALL THICKNESS



Although A_{jw} is normally included in I_{jd} by the selection of the appropriate α angle, and although I_{jd} normally is the overriding contributor to I_j, there are occasions within target complexes where the effects of I_{ja} and I_{jw} are not included in I_{jd} and are sufficiently significant to warrant separate evaluation. Wherever the air-scattered component penetrates a barrier or aperture by a radically different path than I_{jd}, usually through wide deflection angles, this component is approximated as follows:

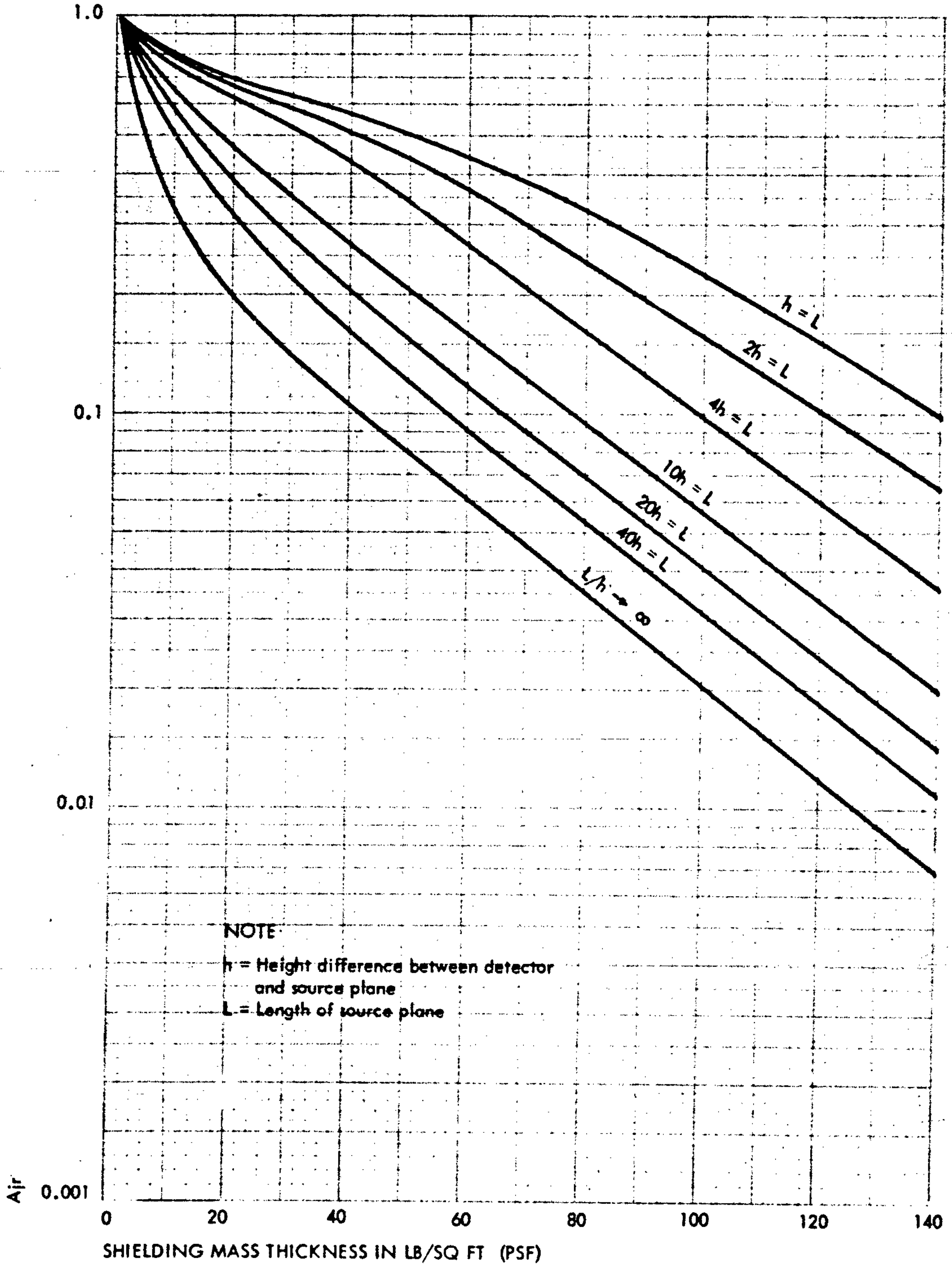
$$I_{ja} = 0.1 \frac{\gamma}{180} I_o A_{jd} A_{jr} \int_{\theta_1}^{\theta_2} \int_{r_1}^{r_2} \frac{d\theta\, r dr}{h^2 + r^2} \qquad (12)$$

where γ is the angle of air-scattered radiation seen from a point location through the roof or walls. This equation and the I_{ja} should not be included in the calculations unless the equation describes a path different from that used when assessing I_{jd}. The air-scattered fraction of 0.1 is used as an approximation for all geometries, although its value varies with the angle of scatter. Also, by using the A_{jd} and A_{jr} values of Figures 4 and 5, the air-scattered fraction is overestimated for heavy-barrier shielding because of the degradation of energy by the scattering process. However, the air-scattered component through heavy shielding is generally negligible, and consequently the error derived from using the same A_{jd} and A_{jw} values is also negligible. Refinements to calculations of the air-scattered component not only would require more experimental evaluation but also would lead to more detailed and complex mathematical treatments.

Because the I_{jd} component includes radiation scattered through the angle α, which need not be large to account for a very large percentage of the total radiation transmitted through a barrier having a large plane area, the wide-angle scattered component I_{jw} is small, and for simple geometries,

Figure 5

ROOF ATTENUATION FACTORS



I_{jw} is included in I_{jd} by the appropriate selection of α, and does not require additional calculation. As the incident angle formed at a wall by a line between the source area and the detector increases, geometric asymmetry is incre sed but the effect of small asymmetries is not significant. For area sources opposite a corner of a structure, the effective barrier thickness is also increased, hence the contribution to the dose rate from this source is decreased. This decrease may be compensated by using the attenuation factor for the slant thickness. At maximum asymmetry, the detector is affected by the radiation scattered through the two adjacent walls, and decreases in the dose rate because of asymmetry are made up to some extent by this means and are implicit in Eq. (11). This cancelling effect of small error provides only a small net error if I_{jw} is assigned a zero value.

Nevertheless, there are occasions when the I_{jw} component may be significant. For example, the walls of the upper stories of a multi-story structure may receive scattered radiation from a street, and the radiation entering the structure at a small angle is greatly reduced by the heavy shielding of intervening floors. In this case (and similar special cases), the radiation entering at wide angles is the significant contribution, and may be estimated by subtraction as follows:

$$I_{jw} = (A_{jd\alpha_1} - A_{jd\alpha_2})\, A_{jr} \int_{\theta_1}^{\theta_2} \int_{r_1}^{r_2} \frac{d\theta\, r dr}{h^2 + r^2} \qquad (13)$$

where α_1 is the average angle formed by the point location and the entire wall, and α_2 is the angle formed by the point location and the lower floors only. The equation is not rigorously accurate, but is used because of its simplicity for handling an otherwise difficult calculation. Within a target complex, the net dose rate from I_{jw} for a given I_o will always be small and consequently Eq. (13) is considered sufficiently accurate fcr target analysis.

The effective wall mass thickness increases with height from contaminated ground sources, and although the height of intercept at the wall with respect to a point location and source is the relevant reference height, the point location heights are used in the mass thickness adjustment factors given in Table 1.

Table 1

HEIGHT-MASS THICKNESS ADJUSTMENTS

Height (ft)	Mass Thickness Adjustment Factors
0 - 10	1.0
10 - 20	1.1
20 - 30	1.2
30 - 40	1.3
40 - 50	1.4

The mass thickness adjustment factors in Table 1 are for area sources of large expanse beyond the building walls. The shielding effect of small areal sources may be estimated by the wall-penetration slant-thicknesses.

Barrier Apertures

Shielding barriers within urban complexes are usually roofs, floors, and walls. Roofs and floors can normally be estimated as barriers of uniform mass thickness, but the openings (e.g., windows) in walls provide additional complications to the calculation procedure. The detector response within windowed structures is sensitive to the detector location within the structure. Where an aperture is aligned between a point location and a radiating source, the contribution from this source is maximized and the calculations are straightforward because the radiation incident upon and scattered by the wall is negligible. Where the areal radiation sources are not aligned with an aperture and a point location, the aperture effect need not be considered. The scattering omitted for the aperture area is compensated to a degree by the backscatter of the gamma rays that have traversed the aperture. The errors incurred are generally not significant for the overall problem because the contributions of these effects, even when taken singly, are minimal. The apertures, however, are ports of ready access for previously scattered and redirected radiation. In many cases, the air-scattered component entering through apertures could constitute a large portion of the total dose rate, so that calculation of this component by Eq. (11) could lead to significant errors. A closer approximation is obtained by conveniently separating the air-scattered component into two components: (1) wide angle scattered (through skylights in the roof), and (2) narrow angle scattered (through windows in the wall). Thus for air-scattered radiation through wall apertures, the decimal multiplier of 0.15 is used instead of 0.10, and the decimal multiplier of 0.05 is used for air-scattered radiation through roof apertures.

Sample Calculations

In this section, the calculation of $\bar{A}$ and the dose-rate contribution factor for each contributing source component is demonstrated for five point locations:

Example 1

Point location is 3 feet above the center of a downtown street. The street width is 80 feet, and the buildings are multistory structures with an average height of 40 feet. The roof and floor mass thicknesses are estimated at 50 PSF and the walls are estimated at 75 PSF.

$\bar{A}$ **and C for Example 1**

Street contribution:

Central section: Use Eq. (11). Let $A_{jd} = 1$, $A_{jr} = 1$, $\theta_1 = 0$, $\theta_2 = 2\pi$, $r_1 = 0$, $r_2 = (80^2/\pi)^{.5}$

Solution: $I_1 = 17.05\ I_o$.

End sections: Use Eq. (7). Let $x_2 = 300$, $x_1 = 40$, $y =$ [illegible]

Solution: $I_2 = 3.47\ I_o$.

Roof contribution: Assume negligible

Skyshine contribution: Use Eq. (11), subtracting the street contribution as follows:

$$I_3 = 0.1 \frac{\gamma}{180} I_o \left[2\pi \int_0^{300} \frac{rdr}{h^2 + r^2} - 2\pi \int_0^{45.14} \frac{rdr}{h^2 + r^2} - 160 \int_{40}^{300} \frac{dx}{x^2 + y^2} \right.$$

Let $h = 37$ and $\gamma = 2 \tan^{-1} \frac{40}{37}$

Solution: $I_3 = 0.386\ I_o$

Summary:

I, street	=	$20.52\ I_o$
I, roofs	=	$0.39\ I_o$
ΣI_j	=	$20.91\ I_o$
C, street	=	0.71
C, roof	=	0.01
$\bar{A}$	=	0.72

Example 2

Point location is 3 feet above the center of an intersection of Example 1 above.

$\bar{A}$ and C for Example 2

Street contribution:

Central section: $I_1 = 17.05\ I_o$, see example 1 above

End sections: 4 end sections instead of 2 as shown in example 1 above

Solution: $I_2 = 6.94\ I_o$

Roof contribution: Negligible

Skyshine: $I_3 = 0.23\ I_o$

Summary:

I, street $= 23.99\ I_o$

I, roof $= 0.23\ I_o$

$\Sigma I_j = 24.22\ I_o$

C, street $= 0.83$

C, roof $= 0.01$

$\bar{A} = 0.84$

Example 3

Point location is 3 feet above the center of a residential street. The street (+ sidewalk) width is 60 feet. The distance from the sidewalk to the house is 40 feet (lawn and planting beds). The lot sizes of this complex are 50 feet wide and 100 feet deep, and the houses are 35 feet wide, 40 feet long, and 9 feet tall.

$\bar{A}$ and C for Example 3

Street contribution: Use Eqs. (7) and (11). Let $\theta_1 = 0$, $\theta_2 = 2\pi$
$r_1 = 0$, $r_2 = (60^2/\pi)^{.5}$; $y_1 = {}^{-}30$, $y_2 = 30$,
$x_1 = 30$, $x_2 = 300$

Solution: $I_1 = 18.9\ I_o$

Lawn and planting bed contribution: Use Eqs. (7) and (11). Let $\theta_1 = 0$, $\theta_2 = 2\pi$, $r_1 = 0$, $r_2 = (140^2/\pi)^{.5}$; $y_1 = 0$, y_2 $x_1 = 70$, $x_2 = 300$, and subtract street contribution.

Solution: $I_2 = 4.78\ I_o$

Roof contribution: Assume 1/2 from roofs and 1/2 from remaining areas to 300 ft. Use Eq. (12) as follows:

$$I_3 = 0.1 \frac{\gamma}{180} I_o A_{jd} A_{jr} \left[28.9 - (I_1 + I_2)\right]$$ and let

$\gamma = 180^\circ$, $A_{jd} = 1$, $A_{jr} = 1$.

Solution: $I_3 = 0.52\ I_o$

Summary:

I, street	=	18.9 I_o
I, lawn	=	5.04 I_o
I, roofs	=	0.26 I_o
ΣI_j	=	24.2 I_o
C, street	=	0.66
C, lawn	=	0.17
C, roof	=	0.01
$\bar{A}$	=	0.84

Example 4

Point location is 3 feet above the center of the floor in a house on the residential street of Example 3 above. Assume that the mass thickness of roofs and walls is 10 PSF, and that the effects of the apertures are negligible.

$\bar{A}$ and C for Example 4

Roof contribution (subject roof): Use Eq. (11). Let $A_{jd} = 1$, A_{jr} (see fig. 4, 10 PSF, $7h \sim L$) $\theta_1 = 0$, $\theta_2 = 2\pi$, $r_1 = 0$, $r_2 = (40 \times 35/\pi)^{.5}$, $h = 6$.

Solution: $I_1 = 5.47\ I_o$

Roof contribution (neighboring roofs): The estimated roof shielding is determined algebraically by using values from Figure 5 as follows:

$$A_{jr} = \frac{A_{jr_1}\int_{\theta_1}^{\theta_2}\int_{r_1}^{r_2} \frac{d\theta rdr}{h^2 + r^2} - A_{jr_2}\int_{\theta_1}^{\theta_2}\int_{r_1}^{r_3} \frac{d\theta rdr}{h^2 + r^2}}{\int_{\theta_1}^{\theta_2}\int_{r_3}^{r_2} \frac{d\theta rdr}{h^2 + r^2}}$$

where $\theta_1 = 0$, $\theta_2 = 2\pi$, $r_1 = 0$, $h = 6$, $r_2 = 67.5$, $r_3 = 32.5$

Use 23 $h \sim L$ for A_{jr_1}, and 11 $h \sim L$ for A_{jr_2} in Figure 5

Solution: $A_{jr} = 0.33$

$A_{jd} = 0.66$ ($\alpha = 38°$)

Use Eq. (7) to solve for I_2. Let $y_1 = -20$

$y_2 = 20$, $x_1 = 32.5$, $x_2 = 67.5$

Solution: $I_2 = 0.28\ I_o$

Lawn and planting bed contribution (adjacent): Use Eqs. (7) and (11).

Let $A_{jd} = 0.87$ (Figure 4, $\alpha = 90°$)

and $A_{jr} = 1$. For Eq. (11)

$\theta_1 = 0$, $\theta_2 = 2\pi$, $r_1 = 21.1$, $r_2 = 34$; for Eq. (12),

$\theta_1 = 0$, $\theta_2 = \frac{2\pi\ 234}{360}$, $r_1 = 34$, $r_2 = 65$

Solution: $I_3 = 5.1\ I_o$

Lawn and planting bed contribution (across the street): Use Eq. (6) in parts and sum. $A_{jd} = 0.87$

Solution: $I_4 = 0.047\ I_o$.

Other areas: All other lawn and planting beds are at least doubly shielded by other structures and their contribution to the dose rate is assumed to be negligible.

Street contribution: Assume shallow curbs and ignore curb shieldi

Use Eq. (12), and let $A_{jd} = 0.87$,

$A_{jr} = 1$, $\theta_1 = 0$, $\theta_2 = \frac{2\pi\ 107}{360}$, $r_1 = 65$, $r_2 =$

Solution: $I_5 = 1.36\ I_o$

Skyshine contribution: Assume contribution is roughly proportional to area contaminated (and distance) as follows:

a.	Lawn and planting areas	60%
b.	Roofs	20%
c.	Streets	20%

Use Eq. (12); let $\gamma = 160°$, $A_{jd} = 1$, $A_{jr} = 0.68$, $\theta_1 = 0$, $\theta_2 = 2\pi$, $r_1 = 21.1$, $r_2 = 300$.

Solutions:
$$I_{6a} = 0.363\ I_o$$
$$I_{6b} = 0.121\ I_o$$
$$I_{6c} = 0.121\ I_o$$

Summary:
$$I,\ \text{roofs} = 5.91\ I_o$$
$$I,\ \text{lawns} = 5.51\ I_o$$
$$I,\ \text{streets} = 1.48\ I_o$$
$$\Sigma I_j = 12.9\ I_o$$
$$C,\ \text{roof} = 0.21$$
$$C,\ \text{lawn} = 0.19$$
$$C,\ \text{street} = 0.05$$
$$\bar{A} = 0.45$$

Example 5

Point location is 3 feet above the center of the second floor of a large department store within a shopping center. The building is a 2-story structure, 250 ft × 200 ft × 40 ft tall, with a wall mass thickness of 75 PSF and roof and floor mass thicknesses of 50 PSF. There are no wall apertures on the second floor, and 1/4 of the wall area of the first floor is glass with a mass thickness of 5 PSF.

$\bar{A}$ and C for Example 5

Roof contribution (subject roof): Use Eq. (11). Let $A_{jd} = 1$,

$A_{jr} = 0.15$, $\theta_1 = 0$, $\theta_2 = 2\pi$, $r_1 = 0$, $r_2 = (200 \times 250/\pi)^{.5}$,

$h = 12$

Solution: $I_1 = 2.02\ I_o$

Other roofs: Negligible

Paved area contribution: The contribution from the paved areas is divided into two parts: (1) that which penetrates through the walls of the first floor and the floor of the second story; and (2) that which is wide-angle scattered through the wall of the second floor.

Part (1): Use Equation (11) and subtract areas shielded by other structures within the complex by use of Eq. (6). The calculated $A_{jr} \simeq 0.005$ by use of Figure 4, and the process is demonstrated in Example 4. Also $A_{jw} = 0.21$ for the walls and $A_{jw} = 0.92$ for the windows in the wall. The effective $A_j = 0.00194$.

Solution: $I_2 = 0.013\ I_o$

Part (2): Use Eq. (13). Let $\alpha_1 = 53.8°$, $\alpha_2 = 50.6°$, and by interpolation of Figure 3, $A_{jd\alpha_1} - A_{jd\alpha_2} = 0.0064$

Solution: $I_3 = 0.044\ I_o$

Skyshine contribution: Use Eq. (12). Let $\gamma = 169°$, $A_{jr} = 0.15$

Solution: I_{4a}, roofs $= 0.014\ I_o$

I_{4b}, paved areas $= 0.096\ I_o$

Summary:	I, roofs	= $2.034\ I_o$
	I, paved areas	= $0.153\ I_o$
	ΣI_j	= $2.19\ I_o$
	C, roofs	= 0.0704
	C, paved areas	= 0.0053
	$\bar{A}$	= 0.076

Discussion

The results obtained from the calculation of C and $\bar{A}$ provides relative exposure values which may be used for planning postattack operations. Thus, if a fallout model gives a standard intensity of I_1 or a radiological monitoring system indicates a standard intensity of I_1 (for a reference geometry) at the location of example 1, the standard intensity or dose rate associated with the street location is $\bar{A}\ I_1$ or for the target geometry specified, 0.72 I_1. The results also indicate that 0.71/0.72, or about 99% of the dose rate, originates from fallout on the street. If it is assumed that the street is to be used as a thoroughfare and the street intensity of 0.72 I_1 is unacceptably high, it follows that the only surface requiring decontamination is the street surface.

In example 3, the lawn contribution to the dose rate (C = 0.17) is significant and if a large reduction in dose rate is desired, lawn decontamination in addition to street decontamination would be required. Example 4 shows that the relative exposure for the internal location specified is 0.45 of the reference geometry and that the major contributors to this exposure are fallout on the subject roof and fallout on the surrounding grounds. Example 5 shows that the same structures within their target surroundings provide greater protection from fallout sources and consequently the resulting dose rate (0.076 I_a) may be so low that the structure may be occupied after a shelter period without decontamination.

V. RESIDUAL NUMBER EVALUATIONS

The residual number is the ratio of the exposure dose or dose rate received at a given location after countermeasures are applied to the dose or dose rate that would be received without the countermeasures. The numerical value of the residual number depends upon the reference location and exposure conditions. In this report, the reference condition is the exposure dose or dose rate 3 feet above a uniformly contaminated flat open field.

The Shelter Residual Number, RN_1

The definition of the residual number emphasizes applications to the evaluation of operational RADEF systems, and therefore the RN_1 value for a shelter period is not, except for isolated situations, equal to the inverse value of the commonly used protection factor (P or PF). The protection factor reference condition is the "Standard Unprotected Location" and in short, is defined as a detector location 3 feet in air above a contaminated hypothetical smooth infinite plane interface of ground density.[8] Because of this reference condition, a dilemma is encountered when an attempt is made to verify the PF of structures or locations by dose rate measurements either experimentally or in a real fallout situation. The inverse of the measured dose-rate ratios for location in an unshielded area to a shielded location is the residual number of the location.

In effect RN_1 is a function of fallout source distributions in the target area where the shelter is located, the fallout composition gamma energies, and any changes in the exposure ratio during the shelter period. Thus the RN_1 for a shelter would be equal to the ratio of the dose rate, measured or calculated, in the shelter to that at 3 feet above the surface at a nearby open field that is contaminated with the same amount of fallout per unit area as at the shelter location.

The current minimum DOD requirements for public shelter designation are (a) a minimum fallout protection factor* of 40; (2) space for at least 50 people at 10 square feet per person; (3) adequate ventilation. Most of the candidate shelters are above ground in the core area of multistory buildings, whereas in general the more highly protected candidate shelters are located below grade; e.g., in basements. The qualified candidate shelters, as determined by a nationwide survey and with the agreement of owners, are being marked and also stocked for a shelter stay time of two weeks. Although a minimum protection factor of 40 is required and shelters with near-minimum PF values constitute the bulk of presently available shelters, higher PF shelters do exist.[10] Shelter categories according to the current PF rating system are listed as follows:

OCD Shelter Categories	1	20 to 40 PF (currently not acceptable to OCD)
	2	40 to 70 PF
	3	70 to 100 PF
	4	100 to 150 PF
	5	150 to 250 PF
	6	250 to 500 PF
	7	500 to 1000 PF
	8	> 1000 PF

* A designation that is not used in this study, because we prefer the shelter residual number, RN_1

The Target Reutilization Residual Number, RN_3

The target reutilization residual number is the ratio of the exposure dose rate of a person utilizing the target complex after target reclamation to the exposure dose of an individual standing upon an open land area uniformly contaminated by source fallout deposit. The value of RN_3 would vary among different target areas as well as among the inhabitants within a given target area. The person spending most of his time outdoors in a reclaimed target area would generally have a higher RN_3 than a person spending most of his time indoors. The assignment of an effective or average value of RN_3 requires a knowledge of (1) the RN_3 values for locations frequented and (2) the times spent at each location within an individual's daily schedule. The general expression for the target reutilization residual number is

$$RN_3 = RN_3^\circ \bar{A} \tag{14}$$

where RN_3° is the average ratio of the source intensities after decontamination to the same intensities prior to decontamination, and $\bar{A}$ is the net attenuation factor for the same location. If an individual spends a significant portion of his day at several locations, his RN_3 may be obtained by averaging the RN_3's of each location according to the time spent at each location.

The residual number for any location due to decontamination, RN_3°, of several of the j surfaces, is determined by

$$RN_3^\circ = \frac{\Sigma_j I_j F_j}{\Sigma_j I_j} \tag{15}$$

where F_j is the decontamination ratio for each j surface decontaminated.

The target reutilization residual number may therefore be readily determined from the following equation:

$$RN_3 = \frac{\Sigma_j I_j F_j}{28.9\ I_o} \tag{16}$$

Appendix B includes data on decontamination methods, effectiveness, rate of performance, and manpower and equipment requirements, related to the types and amounts of surfaces decontaminated. In most instances, the present data require some adjustment before they can be applied to an evaluation of the decontamination factors for target areas with intermixed surface types.

Sample Calculations of RN_3

In this section, the examples listed in Chapter IV are used. Decontamination factors are applied to the surface sources given in these examples, and RN_3 values are obtained for the various locations. The decontamination factors for these examples are:

Streets	F_j	= 0.05
Roofs	F_j	= 0.08
Unpaved areas	F_j	= 0.12

RN_3 for Example 1

I, street = $20.52\ I_o$, I, roof = $0.39\ I_o$ (page 28)

$RN_3 = \Sigma_j I_j F_j / 28.9\ I_o$

$RN_3 = 0.037$

RN_3 for Example 2

I, street = $23.99\ I_o$, I, roof = $0.23\ I_o$ (page 29)

$RN_3 = 0.054$

RN_3 for Example 3

I, street = 18.9 I_o, I, lawn = 5.04 I_o, I, roofs = 0.26 I_o (page 30)

RN_3 = 0.054

RN_3 for Example 4

I, roofs = 5.91 I_o, I, lawns = 5.51 I_o, I, streets = 1.48 I_o (page 32)

RN_3 = 0.042

RN_3 for Example 5

I, roofs = 2.034 I_o, I, paved = 0.153 I_o (page 34)

RN_3 = 0.0059

Table 2 lists the target reutilization residual numbers after decontamination, RN_3, as calculated in the examples. In addition, the table gives residual numbers for other locations in various urban-type target areas for various surface decontamination factors.

Table 2

RN_3 FOR STANDARD TARGET LOCATIONS

	F_j - Decontamination Factor *				
F_1	0.08	0.05	0.05	0.03	0.03
F_2	0.05	0.03	0.01	0.01	0.01
F_3	0.12	0.10	0.10	0.10	0.05
Location	**RN_3**				
Residential house +	0.04	0.03	0.03	0.02	0.015
Small downtown building ≠					
First floor	0.009	0.005	0.002	0.002	0.002
Second floor	0.003	0.002	0.002	0.001	0.001
Third floor	0.02	0.01	0.01	0.006	0.006
Large department store #					
First floor	0.008	0.005	0.002	0.002	0.002
Second floor	0.006	0.004	0.004	0.002	0.002
Residential street	0.05	0.04	0.03	0.008	0.008
Downtown street	0.04	0.02	0.008	0.008	0.008
Highway, 60 foot width **	0.13	0.13	0.12	0.12	0.12

* F_1 = Roof decontamination factor, all roofs
F_2 = Pavement decontamination factors
F_3 = Planting area decontamination factor

\+ Single story light frame structure (see Example 4).
≠ Three stories, 5000 sq.ft. plan, concrete.
\# Two stories, 50,000 sq.ft. plan, concrete (see Example 5).
** Inside truck: use F_3 for 100 feet to each side of highway, and F_2 for highway; disregard F_1.

The Decontamination Crew Residual Number, RN_2

The decontamination crew residual number, RN_2, is of particular importance in decontamination scheduling because it establishes, for any RADEF system, fallout condition, and exposure dose criteria, the length of time that anyone may engage in decontamination activities for any decontamination start time. Also, given the dimensions of the target complex to be recovered and the decontamination rates, RN_2 can be used to determine the number of people that would be needed to carry out the operation in the allocated time.

Definition

The decontamination crew residual number is defined as the ratio of the integrated exposure dose of a decontamination worker in the target area for a decontamination period to the potential exposure dose for the same period (without decontamination) over an open area uniformly contaminated by the same fallout deposit. The decontamination crew residual number is not only a function of source shielding within the area; it is also a function of the decontamination procedures and schedules used.

Intensity Variations During Decontamination

Decontamination is essentially a process in which fallout particles are moved from one location (deposition areas) to another (disposal areas). During this process, the relative intensity to which the crew members are exposed can change significantly: (1) In some cases, the intensity will increase as decontamination progresses; (2) in other cases, it will continuously decrease (in all cases, the intensity will decrease toward the end of the operation). An example of Case 1 is the RN_2 for the operator of a mechanical sweeper, where an increase in RN_2 results from the accumulation of fallout swept into the hopper of the sweeper. An example of Case 2 is the decontamination of a small roof by firehosing, where the decrease in RN_2 results from the removal of the particles from the roof; in this case the fallout removed from the roof is deposited on the ground below. Because of the larger distance and shielding by the structure, the intensity on the roof contributed by these particles is reduced.

Number of Decontamination Passes

The intensity for a given location at the start of a decontamination procedure (first pass over the area) is represented by

$$I_1 = 28.9\ I_o \sum_{j=1}^{j=n} A_j^s\ C_j \tag{17}$$

where A_j^s is the attenuation factor for the decontamination equipment regarding the radiation from the sources on the contributing surface, j.

After an area has been decontaminated, the intensity at the location (end of the first pass or beginning of the second pass) is represented by

$$I_2 = 28.9\ I_o \left[F_1 A_1 C_1 + \sum_{j=2}^{j=n} A_j^s C_j\right] + I_n \tag{18}$$

where F_1 is the average fraction of I_o remaining after the first pass, A_1 is the attenuation factor for the sources on the decontaminated surface, C_1 is the contribution factor for these sources, and I_n is the intensity from the new source that is created by redeposition and relocation of the sources by the decontamination procedure. Because the new source is usually localized when compared with the area contaminated by fallout, the effects of self-shielding are normally present and must be included in the calculatio

Because of the increased number of terms involved in deriving an equation for RN_2, it is desirable to treat the effects of the term separately. Thus, the first calculation excludes I_n temporarily (to be dealt with later) and considers other sources only--i.e., Eqs. (17) and (18) without I_n are combined and solved for I_2:

$$I_2 = I_1 - 28.9\ I_o(1-F_1)A_1^s C_1 \qquad (19)$$

If a linear decrease in I from I_1 to I_2 with decontamination is assumed, as would be the case where the sources are removed at a constant rate during the pass over the area and the time period for the pass is sufficiently short so that radioactive decay can be neglected, then the variation of the intensity at a selected location in the area being decontaminated can be represented by

$$I(t) = I_1 - b(t-t_1) \qquad (20)$$

where t_1 is the time (after detonation) at which the first pass is started. In this case, $I(t)$ is equal to I_1 when $t = t_1$ and $I(t)$ is equal to I_2 when $t = t_2$. The constant b is then given by

$$b = \frac{(I_1 - I_2)}{(t_2 - t_1)} \qquad (21)$$

or with Eq. (19)

$$b = \frac{28.9\ I_o\ (1 - F_1)A_1^s C_1}{(t_2 - t_1)} \qquad (22)$$

The exposure dose at the location of the first pass, from integration of I(t)dt between t_1 and t_2, is given by

$$D(1) = I_1(t_2 - t_1) - \frac{28.9\ I_0(1-F_1)A_1^s C_1 (t_2-t_1)}{2} \quad (23)$$

where D(1) designates the dose for the first pass. Since the reference exposure dose is 28.9 $I_o(t_2-t_1)$, the residual number, after substituting Eq. (17) for I_1, is given by

$$RN_2(1) = \sum_{j=1}^{j=n} A_j^s C_j - \frac{(1-F_1)A_1^s C_1}{2} \quad (24)$$

If the area is decontaminated again, the intensity after the second pass is represented by

$$I_3 = I_1 - 28.9\ I_o\ (1 - F_2)\ A_1^s C_1 \quad (25)$$

Repeating the above procedure, the residual number for the second pass is found to be given by

$$RN_2\ (2) = \sum_{j=1}^{j=n} A_j^s C_j - \frac{(2-F_1-F_2)A_1^s C_1}{2} \quad (26)$$

For pass number i over the area, the residual number is given by

$$RN_2(i) = \sum_{j=1}^{j=n} A_j^s C_j - \frac{(2-F_{i-1} - F_i)A_1^s C_1}{2} \quad (27)$$

where $F_o = 1$.

Effects of Self-Shielding

As previously stated, the term I_n normally should include the effects of self-shielding, especially if large quantities of fallout particles (and other dirt) are concentrated by a procedure before disposal. The effects of self-shielding for a source with a thickness x is generally given as

$$A_s = B(x)e^{-ux} \tag{28}$$

where u is the linear absorption factor, its value depending upon the shielding material (fallout particles) and the energy of the radioactive source (fallout radionuclides); and B(x) is the "build-up factor" due to multiple scattering through the material. The value of B(x) depends upon the shielding thickness. To facilitate calculations, B(x) is approximated by

$$B(x) = 1 + ux \tag{29}$$

If the decontamination rate is constant, I_n for a point source at time τ after the start of decontamination (first pass) is represented by

$$I_n(\tau) = \frac{(1-F_1)WL\ I_o\ A_n^s A_s}{d^2} \tag{30}$$

where WL (W for width and L for length) is the area of the surface that is being decontaminated ,

A_n^s is the attenuation factor for the equipment parts between the source and detector,

d is the distance between the new source and a detector (or a decontamination crew member).

By combining Eqs. (28), (29), and (30), the average value of I_n for a source of thickness x is given by

$$I_n\ (av.) = \frac{\sum I(x)}{\sum x} = \frac{(1-F_1)WL\ I_o A_n^s}{d^2 x}\int_0^x (1 + ux)e^{-ux}dx \tag{31}$$

The value of x in Eq. (31) increases with time because the fallout particles accumulate in the hopper of a sweeper or on the surface in front of a firehosing crew as the decontamination progresses. If v is designated as the rate that the thickness of the source increases, and if τ is designed as the time after starting the decontamination, then for a given location in a flat pile of particles, x is equal to $v\tau$. For some operations v will decrease with time and for such operations v may be expressed as a function τ. However, if cyclic disposal of the build-up material is planned for these operations to eliminate inefficient execution, v is relatively constant. Substituting $v\tau$ for x in Eq. (31) and integrating over τ for a constant v gives

$$D = \frac{\Sigma\Sigma I(x)\ \tau(x)}{\Sigma x^2} = \frac{(1-F_1)WL\ I_o\ A_n^s \tau}{d^2 (v\tau)^2} \int_0^T \left[\int_0^T (1 + uv\tau)e^{-uv\tau} v d\tau \right] v d\tau \quad (32)$$

or

$$D = \frac{(1-F_1)WV\ I_o A_n^s}{d^2\ v^2} \left[\frac{2v\tau}{u} + \frac{v\tau}{ue^{uv\tau}} + \frac{3}{u^2 e^{uv\tau}} - \frac{3}{u^2} \right] \quad (33)$$

where u is normally given in cm^{-1} units, x is in cm, and V is the rate of decontamination in ft/sec along a path of W width.

The decontamination crew residual number for these displaced sources is given by

$$RN_2(n) = \frac{(1-F_1)WV\ A_n^s}{d^2 v^2 \tau 28.9} \left[\frac{2v\tau}{u} + \frac{v\tau}{ue^{uv\tau}} + \frac{3}{u^2 e^{uv\tau}} - \frac{3}{u^2} \right] \quad (34)$$

or

$$RN_2(n) = \frac{(1-F_1)WV\tau A_n^s}{d^2 x^2\ 28.9} \left[\frac{2x}{u} + \frac{x}{ue^{ux}} + \frac{3}{u^2 e^{ux}} - \frac{3}{u^2} \right] \quad (35)$$

When the newly created source remains relatively thin and the self-shielding effect is negligible, i.e., $e^{-ux} = 1/(1+ ux)$ in Eq. (32), the double integration reduces to $v^2\pi^2/2$ and

$$RN_2(n) = \frac{(1-F_1)WL\ A_n^s}{2d^2\ 28.9} \quad (36)$$

where d must be treated as a variable rather than a constant if the area expanse or length of the new source is large relative to d.

Net Residual Numbers

The RN_2 for the surface decontamination (Eq.27) can be combined with the RN_2 (n) for the new source created during the surface decontamination process. This combination gives the net RN_2 for three general cases.

Case 1. No significant new source intensity is created by the decontamination process.

$$RN_2(i) = \sum_{j=1}^{j=n} A_j^s C_j - \frac{(2-F_{i-1} - F_i)\, A_i^s C_i}{2} \tag{37}$$

Case 2. A new thin source is created by the decontamination process.

$$RN_2(i) = \sum_{j=1}^{j=n} A_j^s C_j - \frac{(2-F_{i-1} - F_i)\, A_i^s C_i}{2} + \frac{(F_{i-1} - F_i)\, WL\, A_n^s}{2\, d^2\, 28.9} \tag{38}$$

Case 3. A new thick source is created by the decontamination process.

$$= \sum_{j=1}^{j=n} A_j^s C_j - \frac{(2-F_{i-1} - F_i)\, A_i^s C_i}{2} + \frac{(F_{i-i} - F_i)\, WV_T\, A_n^s}{d^2 x^2\, 28.9} \left[\frac{2x}{u} + \frac{x}{ue^{ux}} + \frac{3}{u^2 e^{ux}} - \frac{3}{u^2}\right] \tag{39}$$

where $F_o = 1$, and

$$x = \frac{30.5\, (F_{i-1} - F_i)\, WL\, m_o}{w\ell\, \rho} \tag{40}$$

where $w\ell$ is the area dimensions of the new source in sq. ft,

m_o is the fallout deposit in g/sq.ft, and

ρ is the bulk density of the fallout particles in g/sq. ft.

With respect to decontamination procedures, Case 1 does not exist in the strictest sense but may be applied as an approximation for slow decontamination procedures where only a small area is decontaminated. Examples are roof decontamination by firehosing and the decontamination of planted areas by manual procedures. Where the decontamination procedure is relatively rapid, decontamination personnel continuously move away from decontaminated areas and are constantly confronting new contaminated areas that, along with any newly created source, constitute the major contribution to the total intensity. The RN_2 equation for Case 2 applies to decontamination procedures such as street decontamination by firehosing or motorized flushing. In both cases, the dose rate is rapidly reduced initially, but as decontamination progresses, the term $\sum_{j=1}^{j=n} A_j^s C_j - \frac{(2-F_{i-1} - F_2)A_i^s C_i}{2}$ remains rather constant. Meanwhile, the new source increases linearly with the size of the area decontaminated until the new source is removed (flushed into the storm drain).

Sample Calculations of RN_2

In this section, the calculations necessary for obtaining residual numbers for decontamination processes are demonstrated. The value of RN_2 for any decontamination process depends upon its sequence in the decontamination schedule. The RN_2 for firehosing roofs will have one value if it is not preceded by street decontamination in the general area, and will have another smaller value if it is preceded by street decontamination (e.g., see Eq. 18).

Example 6. Calculate the RN_2 for the decontamination of a downtown street by firehosing. Assume no previous decontamination effort in the area

Also assume that the source built up by firehosing the street surface stretches across the width of the street and is 20 feet in front of the advancing decontamination personnel. The distance between drains is 300 ft, $F = 0.05$, and A_1^s and $A_n^s = 1.0$

Use Eq. (36), $F_i = F_1$

$$\sum_{j=1}^{j=n} A_j^s C_j = 0.72 \qquad \text{(See Example 1, page 28)}$$

$$\frac{(2-F_{i-1} - F_i)\, A_1^s C_1}{2} = 0.25 \qquad \text{(Use Eqs. 4 and 7)}$$

$$\frac{(F_{i-1} - F_i)\, WL\, A_n^s}{2\, d^2\, 28.9} = 0.658 \qquad \text{(Use Eq. 7 to obtain effective d for the source configuration)}$$

$RN_2 = 1.1$

<u>Example 7.</u> Calculate the RN_2 for the decontamination of a downtown street by motorized sweeping. Assume no previous decontamination and a sweeping speed of 5 ft. per second. The motorized sweeper on its first pass cleans a path 7 feet wide and 1000 feet long prior to dumping the hopper. Let $F = 0.10$, the fallout mass loading = 100 g/sq.ft., ρ = 100 lb/cu.ft,

$$A_1^s \text{ and } A_n^s = 0.8,\ A_j^s = 0.5,\ d = 7.5 \text{ ft. and } u = 0.10$$

Use Eqs. (37) and (38).

$\sum_{j=1}^{j=n} A_j^s C_j = 0.36$, (the estimate of $A_j = 0.5$ includes the change in height.

$$\frac{(2-F_{i-1}-F_i)\ A_1^s C_1}{2} = 0.16 \qquad (C_1 = \frac{20.52}{28.9}\text{, see Example 1, page}$$

$$x = 21.16 \text{ cm} \qquad (\text{Use } w = 5 \text{ ft.; } \ell = 4 \text{ ft})$$

$$\frac{(F_{i-1}-F_i)\ WV_T\ A_n^s}{d^2 x^2\ 28.9} = 5.945 \times 10^{-3}$$

$$\left[\frac{2x}{u} + \frac{x}{ue^{ux}} + \frac{3}{u^2 e^{ux}} - \frac{3}{u^2} \right] = 185.1$$

$$RN_2 = 1.5$$

Example 8. A second decontamination for the situation in Example 7. Calculate the RN_2 for motorized sweeping a second pass, with $F_2 = 0.05$, and the same conditions as in Example 7.

$$\sum_{j=1}^{j=n} A_j^s C_j = 0.36$$

$$\frac{(2-F_{i-1}-F_i)\ A_1^s C_1}{2} = 0.328$$

$$x = 1.17 \text{ cm (because x is thin, use Eq. 36).}$$

$$\frac{(F_{i-1}-F_i)\ WL\ A_n^s}{2\ d^2\ 28.9} = 0.086$$

$$RN_2 = 0.12$$

Example 9. Calculate the RN_2 for the same conditions of Example 8 except that the dumping frequency is 30 minutes.

$$x = 10.53$$

$$\frac{(F_{i-1} - F_i)\, WV_T\, A_n^s}{d^2 x^2\; 28.9} = 0.014$$

$$\left[\frac{2x}{u} + \frac{x}{ue^{ux}} + \frac{3}{u^2 e^{ux}} - \frac{3}{u^2}\right] = 52$$

$$RN_2 = 0.76$$

The effective or average RN_2 values for the first pass of decontaminating various lengths of streets (and distances to storm drains) by firehosing are shown in Figure 6. The values obtained are very sensitive to the value of d that is assumed for Eq. (36). The calculated values of Figure 6 are based on the assumption that the new source created by firehosing is a line source with its length equal to the width of the street, and that this line source is located 20 feet in front of the decontamination crew(s).

The effective RN_2 values for decontaminating a street by motorized sweeping for various fallout deposits are shown in Figure 7.* The values are for the complete operation (one pass over all street areas). As can be seen from the curves, the longer the time between dumps, the higher the value of RN_2; the curves also show that because of the self-shielding effects, the RN_2 values are lower for sweeping the heavier deposits.

First-pass RN_2 values for other decontamination operations and locations are listed in Table 3.

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* This figure pertains to first-pass efforts. For second, third, and other successive passes, use Eq. (39).

Figure 6

RN_2 FOR STREET DECONTAMINATION BY FIRE HOSING

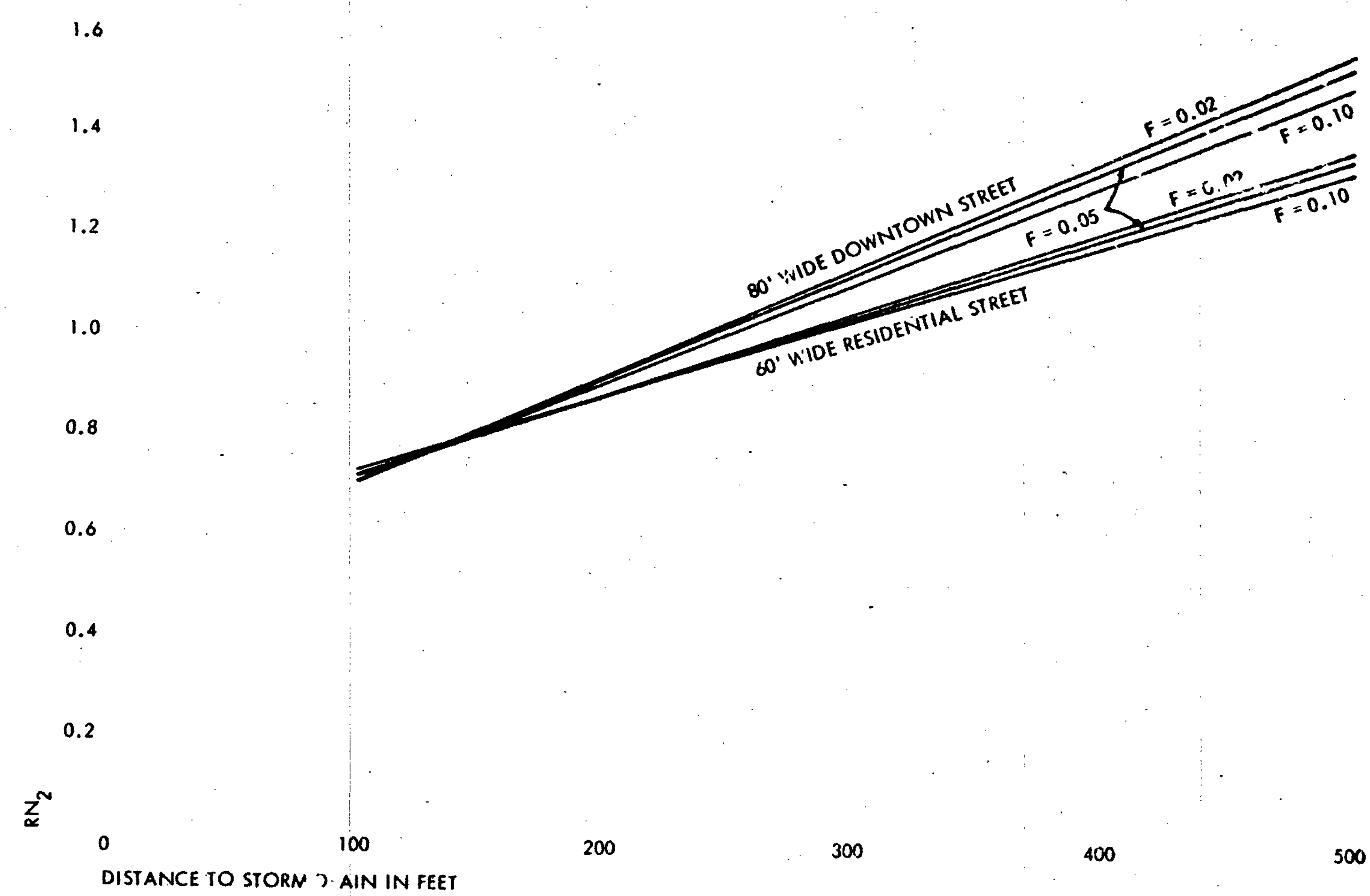

Figure 1

RN_2 FOR STREET DECONTAMINATION BY MOTORIZED SWEEPING

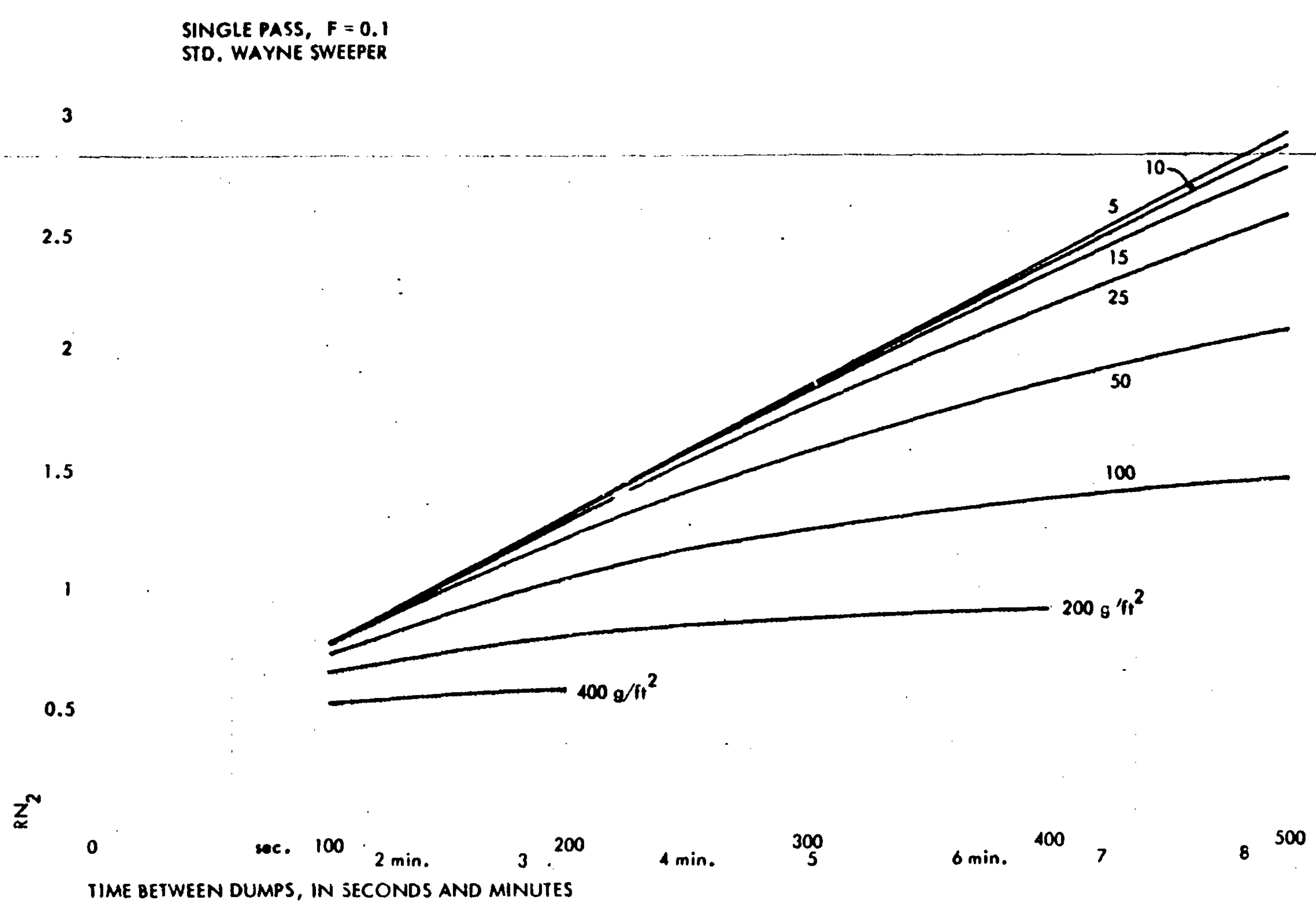

Table 3

RN_2 FOR DECONTAMINATION OF TARGET UNITS

Set-up Operations not Included

Decontamination Method	RN_2
FIREHOSING	
Roofs	
Residential (small and large)	0.5
Downtown, common	0.3 - 0.4
Downtown, large	0.4 - 0.5
Streets	(See Figure 5)
Parking lot, large (contaminated surroundings)	1.5
MOTORIZED FLUSHING (street, 300 ft. between drains)	0.6 - 0.7
MOTORIZED SWEEPING	(See Figure 6)
MANUAL SPADING (residential planting areas, streets and roofs decontaminated)	0.3
MOTORIZED SCRAPING (residential planting areas, streets and roofs decontaminated)	0.2
BULLDOZING (open areas)	0.3
MOTORIZED GRADING (open areas)	0.4
MOTORIZED SCRAPING (open areas, large scraper)	0.4
PLOWING (open areas)	0.5 - 0.7
SUPPORT OPERATIONS	
FRONTEND LOADER OPERATOR (on decontaminated residential street)	0.2
DUMP TRUCK OPERATOR (contaminated environs, to and from dump average)	1.6

Nonuniform Contamination

Except for unusual circumstances, the fallout deposited upon a target complex will be nonuniformly distributed. Although no analyses have been made of this effect, observations of "contaminated complexes" have indicated that fallout particles will generally tend to collect at locations protected from the scavenging effects of the surface winds (generally present in varying velocities). Under these conditions, open paved areas, especially those with smooth surfaces, will not retain a dense loading of particles even when the initial deposit occurs under calm surface wind conditions. In general, however, the deposited fallout particles are not expected to travel far before they are trapped in a depression, upon a rough surface, or against a vertical barrier. Particles deposited on land areas (lawns, plowed fields, grain fields. etc.) generally are not displaced to any significant degree by the wind. Erosion of the land surface itself is required to bring about significant displacement.

The fallout particles that are blown off the roofs (pitched smooth roofs will retain the least amount of fallout particles) will deposit in the roof gutters or in the surrounding grounds, and will be retained upon lawns or will be piled up close to the structure. The fallout particles that are blown off the center of the streets will collect against the curbs. The fallout particles that are blown off walks will come to rest on the ground next to the structure or on the adjacent lawns or graveled areas.

The effects of nonuniform contamination are important not only for the calculation of exposure dose, but also for the planning of contamination procedures. For example, if only the curbs of streets require decontamination, the manpower or equipment requirements would be less than those for decontaminating entire streets. Also, if certain roofs were sufficiently decontaminated by the weathering effect, the roof decontamination effort could be diverted to other areas.

The nonuniform contamination and redistribution effects have not yet been quantitatively documented or otherwise studied in detail, and therefore have not been considered in this report. But from the above general description, the actual initial and redistributed sources would tend to be a mixture of line sources and fairly uniform area sources. The line sources would be found at the periphery of smooth surfaces, and the uniform area sourc would be found on the rougher surfaces such as lawns, fields, and flat tar-and gravel roofs.

Accuracy

The procedures for target analysis are relatively accurate for calculating exposures outdoors and in lightly shielded structures, but decrease in accuracy and reliability with increased structural shielding because:

1. The exposure within well-shielded structures is more sensitive to the direction of incident radiation.

2. The exposure within well-shielded structures is more sensitive to differences in gamma energies.

3. The exposure within well-shielded structures is more sensitive to the fallout deposition geometry within the surrounding areas.

4. In all structures (well-shielded or otherwise), any possible effect of interior furnishings and equipment on the shielding residual has not been considered.

In the sample calculations and in the listed residual numbers in Tables 1, 2, and 3, uniform contamination of all roof areas and ground areas, both paved and unpaved was assumed. Nonuniform contamination of these surfaces, and the contribution of uniform or nonuniform contamination from other target components could be a cause of error in the values. However, the magnitude of the error from these causes is as yet unknown.

Because only estimated values for actual detailed structural features could be used, the accuracy of the results obtained from the computational procedures is generally limited by the ability to describe the structural shielding components of each target area, and by the ability to describe the fallout distribution before and after decontamination. However, in combination with some flexibility in operational procedures, the results are considered to be sufficiently accurate for application in planning post-attack radiological defense countermeasures.

VI. RADIOLOGICAL DEFENSE SYSTEMS EVALUATIONS

Existing or planned radiological defense systems which include a system of shelters and an organization with decontamination capabilities may be evaluated by the use of Eq. (1). After the time that various target complex components must be recovered to assure continued survival has been determined, decontamination personnel may be scheduled to meet the required rate of target complex recovery. If the required rate of recovery cannot be met by the organization, the system will fail for the lack of an adequate decontamination capability. If the rate of recovery can be met but the individual effort required will overexpose recovery personnel, then the number of people in the organization is too small. For a given decontamination schedule, the required minimum capability of the RADEF system may be determined for a given limiting exposure dose.

The radiological defense system determines the other input parameters and Eq. (1) is solved to give the required capability of the system in terms of the maximum standard fallout intensity and the fallout arrival time. The major parameters for the radiological defense system described by Eq. (1) include a shelter stay period; a decontamination period; and after decontamination, a target reutilization period. Because the postattack operation followed or scheduled for each individual will differ, just as the shelter protection available to each individual or group of individuals will differ, the evaluation of a system on an individual basis simplifies the analysis.

The postattack operation followed by an individual, however, is not solely dictated by his personal circumstances, dose history, and postattack requirements. It will also depend upon the circumstances, dose history, and the requirements of other inhabitants of his community. For example, it is improbable that everyone in the community will be uniformly protected by the shelter system. For a mixed PF shelter RADEF system, the onus of decontamination rests with those sheltered in the higher PF shelters, and they would be required to recover sufficient facilities for all survivors. Under these conditions, where the people in low PF shelters would be exposed to high radiation doses or overexposed while in shelter, the available manpo for decontamination could be reduced to the extent that the system's RADEF effectiveness would also be critically reduced even with respect to those sheltered in the higher PF shelters. Thus the evaluation of a RADEF system for a community requires the analysis of postattack operations that may be safely scheduled for each individual and that would collectively promote the ultimate recovery of the community. A simplified decontamination scheduling and RADEF system evaluation procedure for mixed shelter systems will be introduced in a forthcoming report.*

For the present, if it is assumed that sufficient manpower and equipmen and supplies are available to decontaminate the target complex, then the maximum potential effectiveness of a RADEF system may be determined by Eq. by assigning a minimum decontamination schedule and a postattack routine to an individual. Such a cursory analysis will show general relationships amon shelter protection, shelter stay time, decontamination effectiveness, decontamination scheduling, and the maximum potential effectiveness of plann or adopted RADEF systems. The planning and final adoption of a RADEF system or a component of a RADEF system by a community can thus be based upon its maximum potential effectiveness. Used in conjunction with local radiologica recovery requirements and decontamination rates, the analysis based on Eq. 1 can infer the general size of the organization necessary to make the system operational for various fallout conditions. The subject of decontamination

* Tentative title: "Decontamination Scheduling Procedures for RADEF Systems."

organizations and decontamination schedules is omitted from the present analysis, but will be treated in detail in a subsequent report, in order to promote a more definitive analysis of RADEF systems.*

The evaluation of a RADEF system, with respect to an individual or group of individuals for the limiting dose criteria of 190 r/week, 270 r/month, and 700 r/year ($\sim$ 200 ERD), requires examination of all 1 week, and 1 month exposure periods as well as the 1 year exposure period. A simplified example is that of a sheltered individual who must participate in decontamination prior to his return to normal living routines. In this example, assume that he is required to engage in decontamination operations lasting 8 hours each on the 10th, 11th, and 12th day respectively, and that final shelter exit is after the 14th day. For this individual, a 2-week shelter stay includes three decontamination sorties prior to the final shelter exit time.

Then, the critical 1 week periods requiring examination for maximum constraint are:

1. The first week after the effective fallout arrival time
2. The week ending at the completion of his decontamination sortie on the 12th day
3. The week starting at the start of his decontamination sortie on the 10th day
4. The first week after final shelter exit

The critical 1-month periods requiring examination are:

1. The first month after the effective fallout arrival time
2. The month starting at the start of his decontamination sortie on the 10th day
3. The first month after final shelter exit.

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* Tentative title: "Decontamination Scheduling Procedures for RADEF Systems."

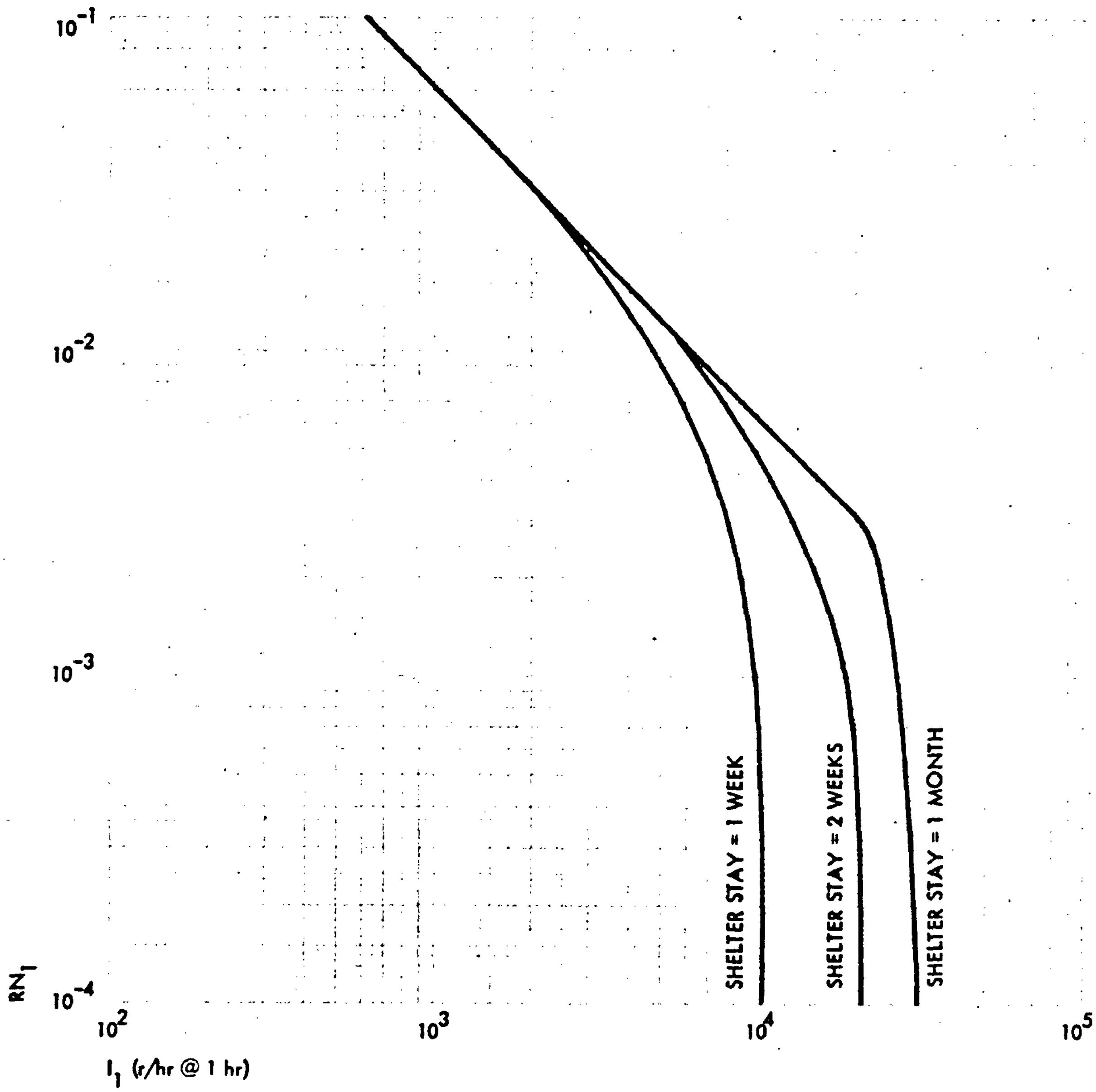
The critical 1-year period starts with the effective fallout arrival time. To illustrate the simple example above without going into details, assume a fallout arrival time of 3 hours and let $RN_1 = 0.02$, $RN_2 = 0.4$, and $RN_3 = 0.03$. To shorten the calculations, the RN_2 for the 3 days of decontamination, which also includes 16 hours of shelter stay each day, may be given an effective value of 0.14. In this instance, the first month after fallout arrival is the critical period, and the radiological defense system as related to this particular individual is adequate for a fallout standard intensity of 4300 r/hr. This radiological defense system may be compared with one where decontamination is not included. For 2 weeks stay in the same shelter, the same fallout arrival time, and $RN_3 = 0.5$, the critical exposure period is 1 year, and the radiological defense system is adequate for a fallout standard intensity of 1800 r/hr. As a final example, the first radiological defense system is compared with a similar system except that $RN_1 = 0.01$. In this case, the critical period is also the first month and the system is adequate for a fallout standard intensity of 6,800 r/hr.

Figure 8 shows the limiting standard intensity for a radiological defense system for various RN_1 and shelter stay times of 1 week, 2 weeks, and 1 month This radiological defense system requires critical-dose individuals to make two decontamination sorties of 8 hours each on successive days in areas where their average $RN_2 = 0.4$ while they are actually participating in decontamination. After two days of decontamination, the target complex is occupied and the effective RN_3 for the users of the target complex is 0.04. The assumed effective fallout arrival time for the values given is 1 hour.

A better radiological defense system, able to cope with a higher limiting standard intensity and to permit earlier shelter exit time, is obtained by the preparation and use of suitable staging areas as an intermediate step between shelter exit and target recovery-reutilization. Selected vital facilities and temporary holding areas are decontaminated first, and then used to relieve

Figure 8

FEASIBLE STANDARD INTENSITY LIMITS FOR SHELTER-DECONTAMINATION RADEF SYSTEMS



crowded shelter conditions, thus promoting an additional period of radioactive decay and biological recovery prior to tackling the problem of decontaminating the entire target complex. The limiting standard intensities of this system are shown in Figure 9. The operations and numerical values used in the calculations are: 1 week, 2 weeks, and 1 month shelter-stay times followed by 2 weeks stay time within the staging area when $RN_3 = 0.004$ (see Table 2); after 2 weeks stay time in the staging area, three decontamination sorties of 8 hours each on successive days; and finally occupation of the target complex, where RN_2 and RN_3 are the same as for the previous system. Table 4 gives the capability of some RADEF systems in terms of various values for standard intensities, residual numbers, decontamination schedules, and fallout arrival times. The assumed shelter stay period is 2 weeks, and it is also assumed that decontamination is conducted prior to 2 weeks so that the complex is ready for occupancy at the end of the 2-week period.

By examination of Figures 8 and 9, and Table 4, the following conclusions emerge regarding RADEF systems:

1. Without decontamination the capability of a radiological defense system is limited to standard intensities of about 2,000 r/hr regardless of the shelter protection afforded if the shelter stay is limited to two weeks.

2. Decontamination extends the capability of systems with high PF shelters to higher standard intensities.

3. A system that requires individuals to make shorter or fewer decontamination sorties has a higher capability than one that requires individuals to participate in longer or more decontamination sorties.

Figure 9

FEASIBLE STANDARD INTENSITY LIMITS FOR SHELTER-STAGING AREA-DECONTAMINATION RADEF SYSTEMS

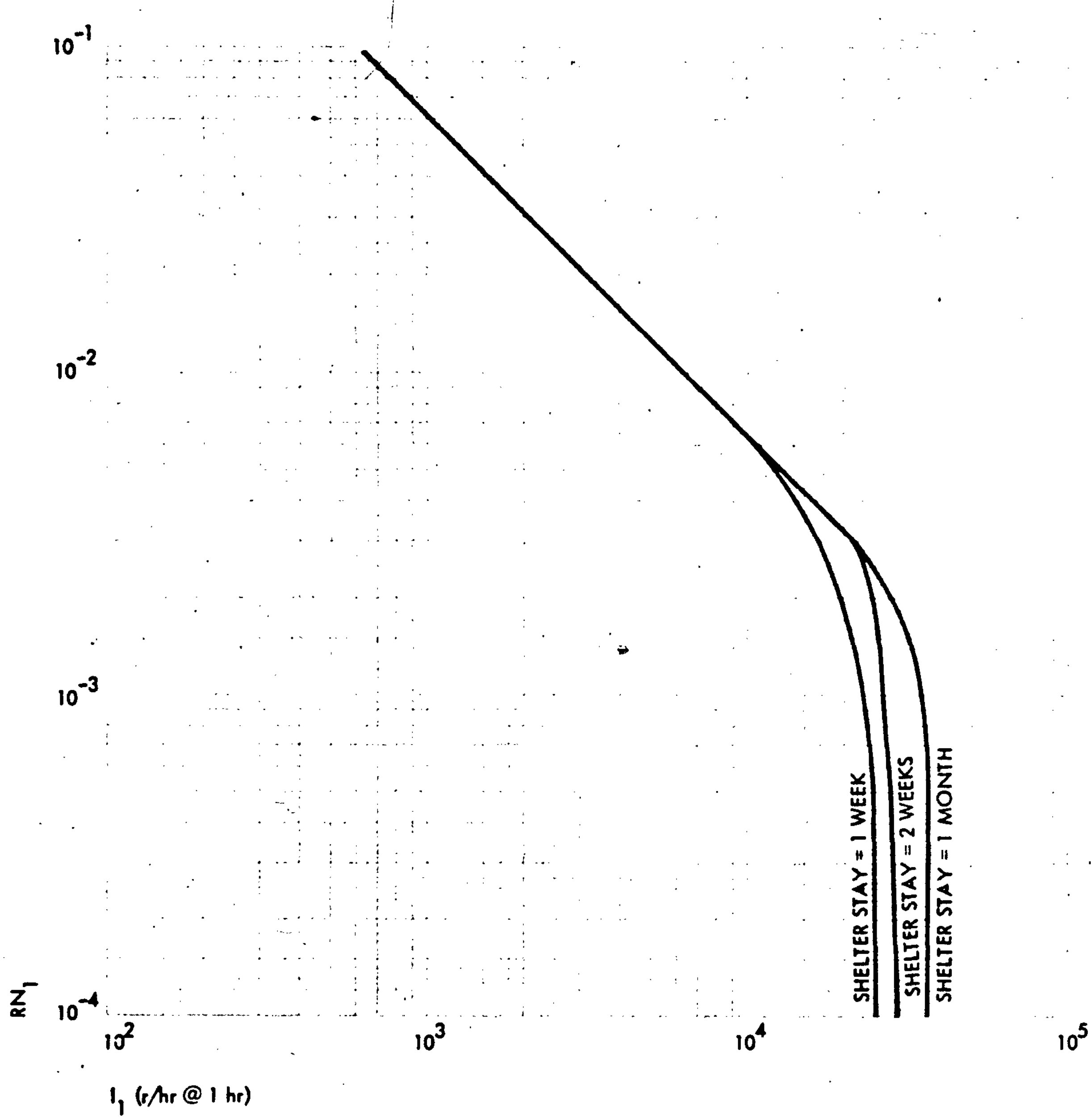


Table 4

RADEF SYSTEM CAPABILITIES

RN_1	RN_2	RN_3	Decontamination Days (8 hours each)	I_1 (max)* in r/hr for Fallout Arrival			
				t_a = 1 hr	t_a = 3 hr	t_a = 6 hr	t_a = 10
0.02		0.5	(No decontamination)	1700	1800	1900	1900
0.01		0.5	(No decontamination)	1900	1900	2000	2000
0.001		0.5	(No decontamination)	2000	2000	2000	2000
0.02	0.6	0.03	8th thru 14th	2400	2900	3200	3500
0.02	1.0	0.03	10th thru 14th	2800	3400	3900	4200
0.02	0.4	0.03	8th thru 14th	2800	3500	3900	4300
0.01	0.6	0.03	8th thru 14th	3400	3800	4000	4200
0.02	0.6	0.03	10th thru 12th	3100	3900	4500	5000
0.02	0.4	0.03	10th thru 14th	3100	4000	4600	5100
0.02	0.4	0.03	10th thru 13th	3100	4100	4700	5200
0.02	0.4	0.03	10th thru 12th	3100	4300	5000	5600
0.01	0.4	0.03	8th thru 14th	4100	4800	5200	5500
0.01	1.0	0.03	10th thru 14th	4300	5000	5400	5700
0.01	0.6	0.03	10th thru 12th	4900	5900	6500	7000
0.01	0.4	0.03	10th thru 14th	5000	6000	6600	7100
0.01	0.4	0.03	10th thru 13th	5200	6300	7000	7500
0.01	0.4	0.03	10th thru 12th	5500	6800	7600	8200
0.02	0.4	0.04	13th and 14th	3100			
0.01	0.4	0.04	13th and 14th	6200			
0.001	1.0	0.03	10th thru 13th	8000	8200	8300	8400
0.005	0.4	0.04	13th and 14th	10000			
0.002	0.4	0.04	13th and 14th	15000			
0.001	0.4	0.04	13th and 14th	19000			20000
0.0001	0.4	0.04	13th and 14th	21000			21000

* I_1 (max) is relatively unchanged if RN_2 is doubled and the duration of each decontamination sortie is halved--i.e., 4 hours each.

4. The capability of RADEF systems that include decontamination is limited by low shelter protection; where the shelter protection is high, the RADEF system capability is limited at a higher radiation range by the dosage received during the decontamination period; and for a RADEF system with moderate protection shelters, system capability is limited at moderate radiation ranges by the combination of shelter and decontamination doses.

Because the capability of a RADEF system with adequate shelter protection is maximized with decontamination and is a markedly improved system over a system without decontamination, a decontamination capability is mandatory for a successful defense. A decontamination capability is also required in less than maximum fallout conditions for shortening the shelter confinement time, or for reducing exposure doses, or both. Decontamination capability is restricted by manpower and decontamination equipment and supplies. Usable manpower is restricted by radiation dosage, and conversely, restriction in manpower can be somewhat alleviated by having shelters with a greater amount of shielding. On the other hand, usable manpower may generally be increased by increasing the size of the manpower pool from which decontamination personnel may be drawn. The size should be commensurate with a planned decontamination schedule that accounts for manpower attrition due to radiation dosage. Finally, effective manpower utilization may also be restricted by the available decontamination equipment and supplies either because of poor preparations or because of attack destruction.

For any community, radiological defense planning starts with the determination of the required reutilization time of all target area components. This is followed by planning a decontamination schedule so that the decontamination completion time (where decontamination is required) would coincide with, or would be prior to, the required target utilization time.

Finally, the radiological system is checked by applying decontamination personnel to the decontamination schedule and calculating the exposure doses. These doses are then compared with some selected value of maximum allowable dose (e.g., 200 r ERD or other limit), thus determining the number of decontamination personnel required by the radiological defense system for a specific fallout intensity. In decontamination schedules, the term $RN_2\Delta DRM_2$ requires particular attention. Its value depends on the number of decontamination sorties, the length of each sortie that must be made by each individual, the time each sortie is scheduled, the target complex configuration, and the decontamination procedure applied.

Normally the population density in large cities is high, and given shelters with adequate protection, densely populated areas would not require excessive demands upon individual effort if the general population could be organized to conduct recovery operations. In suburban areas where the population density is low--e.g., less than 500 people per square mile--the demand upon individual effort will be high, and the decontamination exposure time will be longer. The limiting standard intensity for the same radiologic defense system in the less populated target complexes will consequently be lower.

REFERENCES

1. Miller, C.F., et al, Introduction to Radiological Defense Planning, Stanford Research Institute, Menlo Park, Calif., May 1965
2. Exposure to Radiation in an Emergency, National Committee on Radiation Protection and Measurement, Report No. 29, University of Chicago, Chicago, Ill., January 1962.
3. Miller, C.F. and P. Loeb, Ionization Rate and Photon Pulse Decay of Fission Products From Slow Neutron Fission of U-235, USNRDL-TR-247, U.S. Naval Radiological Defense Laboratory (USNRDL), San Francisco, Calif., August 1958.
4. Owen, W.L. and J.D. Sartor, Radiological Recovery of Land Target Components--Complex I and II, USNRDL-TR-570, USNRDL, San Francisco, Calif., May 1962.
5. Owen, W.L. and J.D. Sartor, Radiological Recovery of Land Target Components--Complex III, USNRDL-TR-700, USNRDL, San Francisco, Calif., November 1963.
6. Strope, W.E., Evaluation of Countermeasure System Components and Operational Procedures, Operation Plumbbob, Project 323, WT-1464, USNRDL, San Francisco, Calif., September 1959.
7. Lee, H., Estimating Cost and Effectiveness of Decontaminating Land Targets, Vol. I, Estimating Procedure and Computational Technique, USNRDL-TR-435, USNRDL, San Francisco, Calif., June 1960.
8. Spencer, L.V., Structure Shielding Against Fallout Radiation From Nuclear Weapons, National Bureau of Standards (NBS), Monograph 42, June 1962.
9. Barrett, M.J., et al, Transmission of Gamma Radiation Through Thin, Finite Slabs, TO-B 64-44, Technical Operations Research, Burlington, Mass., May 1964.

10. National Fallout Shelter Survey, Phase 2, Computer Printouts, OCD, 1963.

11. Owen, W. L., Radiological Protective Construction, USNRDL-467, USNRDL, San Francisco, Calif., January 1962.

12. Owen, W. L., et al., Performance Characteristics of Wet Decontamination Procedures, Operation Stoneman II, Vol. II, USNRDL-TR-335, USNRDL, San Francisco, Calif., July 1960.

13. Lee, H., et al., Performance Characteristics of Dry Decontamination Procedures, Operation Stoneman II, Vol. III, USNRDL-TR-336, USNRDL, San Francisco, Calif., June 1959.

14. Lee, H., et al., Performance Characteristics of Land Reclamation Procedures, Operation Stoneman II, Vol. IV, USNRDL-TR-337, USNRDL, San Francisco, Calif., January 1959.

15. Taylor, D., et al., Development of Radiological Decontamination Methods and Equipment for Cold Weather Regions, USNCEL, Port Hueneme, Calif., July 1960.

MAJOR SYMBOLS

Symbol	Definition
A	Area (contaminated) in sq ft
A_j	Attenuation factor for surface j
A_{jd}	Attenuation factor, vertical barrier, surface j
A_{jr}	Attenuation factor, horizontal barrier, surface j
A_{jw}	Attenuation factor, wide angle scattered components
$A_{jd\alpha}$	Attenuation factor, components within angle α
A_j^s	Attenuation factor, decontamination equipment
A_s	Attenuation factor, source self-shielding
$\bar{A}$	Attenuation factor, net, target complex
α_j	Angle of radiation penetration, walls, in degrees
C	Dose rate contribution factor, surface type
C_j	Dose rate contribution factor, surface unit
D^*	Limiting dose in roentgens per period of time
$D(i)$	Exposure dose for decontamination pass i
d	Distance in ft
ΔDRM_1	Dose rate multiplier, shelter period
ΔDRM_2	Dose rate multiplier, decontamination period
ΔDRM_3	Dose rate multiplier, post-decontamination period
F_j	Decontamination factor for surface j
γ	Included angle of air-scattered radiation in degrees
h	Height or height difference in ft
I_o	Source strength intensity in r/hr
I_1	Standard intensity in r/hr (except where j = 1 in I_j, see below)
I_j	Radiation intensity from surface j in r/hr
I_{ja}	Radiation intensity, airborne, surface j in r/hr

MAJOR SYMBOLS (Continued)

Symbol	Definition
I_{jd}	Radiation intensity, thru vertical barrier, surface j, r/hr
I_{jw}	Radiation intensity, wide angle scattered component, r/hr
I_n	Radiation intensity, new source, r/hr
$I(t)$	Radiation intensity at time t, r/hr
I_1 max	Limiting standard intensity in r/hr
L	Length of contaminated or decontaminated area in ft
RN_1	Residual number for the shelter period
RN_2	Residual number for decontamination
$RN_2(i)$	Residual number for decontamination, i th pass
RN_3	Residual number after decontamination
r	Radius of contaminated area in ft
t	Time after detonation in hours
τ	Time for one decontamination cycle in seconds
θ	Horizontal sector angle in degrees
u	Linear absorption factor in cm^{-1}
V	Linear velocity of decontamination in ft per second
W	Width of contaminated or decontaminated area in ft
x	Horizontal distance in the x direction in ft, or fallout build-up thickness in cm
y	Horizontal distance in the y direction in ft

Appendix

MASS THICKNESS OF BUILDING MATERIALS

The use of Figures 4 and 5 and the subsequent solution of Eqs. (14), (15), and (16) require mass thickness values for various building components. Table A-1 presents the equivalent mass thicknesses for various thicknesses of some common building materials.[11] Short of examining individual building plans or actual measurements, only architects and people in the building trade, because of their specialized training, could reliably estimate the thicknesses of building components by mere observation of the structures.

Table A-1

SHIELDING POTENTIAL (MASS THICKNESS) OF BUILDING MATERIALS

Material	Component	Nominal Thickness (inches)	Mass Thickness (lb/sq.ft)
Adobe	wall	12	116
Asbestos board	wall	3/16	1.7
Asbestos, corrugated	roof, wall	--	4.
Asbestos, shingles	roof, wall	5/32	1.8
Asphalt, 3 ply, ready	roof	--	1
Asphalt, 4 ply and gravel	roof	--	5.5
Asphalt, 5 ply and gravel	roof	--	6.2
Asphalt shingles	roof	--	2.3
Book tile	roof	2	12
	roof	3	20
Clay brick	wall	4	38-40
	wall	8	69-89
	wall	12-1/2	100-130
	wall	17	134-174
Clay tile shingles, flat	roof	--	10-20
Clay tile shingles, Spanish	roof	--	8.5-10
Clay tile, structural	wall	4	18
	wall	8	42
	wall	12	58
Clay tile, interior	wall	4	18
	wall	6	28
	wall	8	34
	wall	10	40

Table A-1 (continued)

Material	Component	Nominal Thickness (inches)	Mass Thickness (lb/sq ft)
Clay tile facing	wall	2	15
	wall	4	25
	wall	6	38
Concrete, poured:			
Low density			
vermiculite	wall, roof, floor	per inch	2-4
perlite	↓	↓	3.5-5.5
diatomite	↓	↓	4.5-6
pumice	↓	↓	5-7.5
foam slag	↓	↓	7.5-8.5
haydite	↓	↓	8.5-10
cinders	↓	↓	9-9.5
crushed slag	↓	↓	10-11
Conventional			
crushed stone	↓	↓	12
gravel-sand	↓	↓	12-12.5
reinforced	↓	↓	12.5
High density			
limonite	↓	↓	15-18
hydrous iron ore	↓	↓	18
barite	↓	↓	18-19
magnetite	↓	↓	19-20
barite-iron shot	↓	↓	22
ferrophosphorus-barite	↓	↓	22
iron-limonite	↓	↓	22
ferrophosphorus	↓	↓	25
iron-magnetite	↓	↓	25-29
iron slugs - iron shot	↓	↓	31-34

Table A-1 (continued)

Material	Component	Nominal Thickness (inches)	Mass Thickness (lb/sq ft)
Concrete block, hollow:			
light aggregate (cinder or slag)	wall, partition	4	20
		6	28
		8	38
		12	55
heavy, aggregate (stone)		4	26-34
		6	38-46
		8	50-60
		12	75-95
Concrete brick:			
light aggregate (cinder or slag)	wall	4	33
	wall	8	68
	wall	12-1/2	98
heavy aggregate (stone)	wall	4	46
	wall	8	89
	wall	12-1/2	130
Concrete shingles	roof	--	16
Fiber board	wall	1/2	0.8
Fiber sheeting	wall	1/2	0.9
Glass block masonry	wall	4	18
Gypsum block	wall	2	8-11
	wall	3	10.5
	wall	4	10-15
	wall	6	18.5
Gypsum board	wall, ceiling	1/2	2.1
Gypsum plank	roof	2	12

Table A-1 (continued)

Material	Component	Nominal Thickness (inches)	Mass Thickness (lb/sq.ft)
Marble facing	wall	2	26
Plaster, directly applied	wall, ceiling	3/4	5
Plaster on fiber lath	wall, ceiling	1/2	5
Plaster on gypsum lath	wall, ceiling	1/2	6
Plaster on metal lath	wall, ceiling	3/4	6
Plaster on wood lath	wall, ceiling	3/4	5
Plaster, solid	wall	2	20
	wall	4	30
Plaster, hollow	wall	4	22
Plywood, finish	wall	5/16	1
	ceiling	1/2	1.5
Plywood, sheathing	wall, roof	3/8	1.1
Slate	roof	3/16	7.3
	roof	1/4	10
Split furring tile	wall	1-1/2	8
	wall	2	12
Steel, corrugated	roof, wall	20 gauge	2
Steel panel	wall, roof	18 gauge	3.3
Steel partitions, insulated	wall	--	8
Stone	wall	12	130
Stone, cast facing	wall	2	24

Table A-1 (concluded)

Material	Component	Nominal Thickness (inches)	Mass Thickn (lb/sq
Stucco, metal lath	wall	3/4	9
Stucco, wood lath	wall	3/4	8
Terra cotta facing	wall	1	5.
Terrazzo	floor	1	12
Wood block	floor	3	10
Wood finish	floor	25/32	2.
Wood sheathing	floor, roof	3/4	2.
Wood shingles	roof	--	2.
Wood shingles, 6-1/2" to weather	wall	--	1.
Wood siding, 8" bevel	wall	--	1.
Wood siding, 6" drop	wall	--	2.
Wood studs, exposed	wall	2 x 4	1.

Appendix B

DECONTAMINATION DATA

The available decontamination data are those for roof surfaces, paved surfaces, and unimproved surfaces such as turfed ground, planting areas, and bare ground. The decontamination methods are conveniently separated into the following categories: wet methods, dry methods, and surface-removal methods. Limited data are also available for decontamination in a frigid environment. The wet methods are firehosing and motorized flushing; firehosing is the more versatile. Motorized flushing has three limitations: it can be used only on paved ground areas such as streets and large parking lots; maneuverability is restricted; and motorized flushers are not very available. The only suitably developed large area dry decontamination method to date is motorized sweeping. For special conditions, pavement decontamination may be accomplished by an "air broom," whereby the surface is scoured by air jets but the lifted fallout is permitted to drift downwind. Surface-removal methods are generally applicable for unpaved ground areas. The large area decontamination methods available are motorized scraping, and the combination of motorized grading with motorized scraping. In restricted spaces, large equipment cannot be used effectively and surface removal is limited to drag-type scrapers and hand shoveling. Other methods of reducing radiation effects of contaminated ground areas are plowing and contaminated surface burial. For locations away from plowed or buried areas, the effectiveness of these methods is greater than that indicated.

The selection of decontamination methods for a target complex requires consideration of more than the base data presented but the data will provide a measure of obtainable decontamination effectiveness and the effort required. The following tables give the expected decontamination performance of various techniques and personnel on surfaces having three fallout mass loadings: Table B-1, 3-men firehose team for tar-and-gravel roofs and composition shingle roofs;[12] Table B-2, firehosing of large paved areas;[12] Table B-3, motorized flushing of pavements;[12] and Table B-4, three dry decontamination methods on pavements.[13] Table B-5 gives the expected performance of various unpaved area reclamation methods; the effort and effectiveness of these methods are independent of mass loading.[4, 14] Table B-6 gives the expected performance of various decontamination methods in a frigid environment.[15]

Table B-1

FIREHOSING OF ROOFS

Standard Intensity (r/hr)	Mass Loading (g/sq.ft)	Unit Effort (man-minutes per 1,000 sq.ft)	Rate per Nozzle (sq.ft/min)	Water Consumption (gal/sq.ft)	Fraction Remaining (F)
		* Tar and Gravel - Practically No Slope			
300	10	20	150	0.3	0.6
		30	100	0.45	0.3
		40	75	0.6	0.2
		60	50	0.9	0.1
1000	30	20	150	0.3	0.2
		30	100	0.45	0.1
		40	75	0.6	0.08
		60	50	0.9	0.05
3000	100	20	150	0.3	0.06
		30	100	0.45	0.03
		40	75	0.6	0.02
		60	50	0.9	0.01
		+ Composition Shingles - Slope of 1/2.5			
300	10	5	600	0.06	0.09
		10	300	0.12	0.06
		20	150	0.3	0.045
1000	30	5	600	0.06	0.09
		10	300	0.12	0.06
		20	150	0.3	0.04
3000	100	5	600	0.06	0.09
		10	300	0.12	0.05
		20	150	0.3	0.03

* Nozzle pressures 60 to 70 psi.

\+ Nozzle pressures 60 psi when hosing at roof level and 40 to 45 psi when lobbing fire streams from ground level.

Table B-2

FIREHOSING OF PAVEMENTS

Standard Intensity (r/hr)	Mass Loading (g/sq.ft)	Unit Effort (man-minutes per 1,000 sq.ft)	Rate per Nozzle (sq.ft/min)	Water Consumption (gal/sq.ft)	Fractio Remaining (concrete asphal
300	10	15	2000	0.05	0.06
		25	1200	0.08	0.04
		50	600	0.17	0.02
		100	300	0.33	0.015
1000	30	15	2000	0.05	0.06
		25	1200	0.08	0.04
		50	600	0.17	0.02
		100	300	0.33	0.015
3000	100	15	2000	0.05	0.055
		25	1200	0.08	0.035
		50	600	0.17	0.02
		100	300	0.33	0.01

Table B-3

MOTORIZED FLUSHING OF PAVEMENTS
(Conventional Street Flusher) *

Standard Intensity (r/hr)	Mass Loading (g/sq.ft)	Unit Effort equip.-minutes per 10,000 sq.ft	Average Rate (sq.ft/min)	Forward Speed (mph)	Water Consumption (gal/sq.ft)	Fraction Remaining, F	
						Concrete	Asphalt
300	10	1	10,000	15	0.045	0.05	0.06
		2	5,000	7.5	0.09	0.025	0.035
		5	2,000	3	0.22	0.01	0.02
1000	30	1	10,000	15	0.045	0.05	0.055
		2	5,000	7.5	0.09	0.025	0.035
		5	2,000	3	0.22	0.01	0.02
3000	100	1	10,000	15	0.045	0.045	0.05
		2	5,000	7.5	0.09	0.025	0.03
		5	2,000	3	0.22	0.01	0.015

* This machine uses two forward nozzles and one side nozzle under a pressure of 55 psi. One man can operate a flusher, but two are better on older models having manually controlled valves.

Table B-4

SWEEPING OF PAVEMENTS

Method	Standard Intensity (r/hr)	Mass Loading (g/sq.ft)	1st Pass E*	1st Pass F	2nd Pass E*	2nd Pass F	3rd Pass E*	3rd Pass F
Wayne 450+	300	10	11	.09	17	.07	23	.07
	1000	30	9	.07	16	.05	20	.03
	3000	100	14	.03	22	.02	--	--
Tennant 100 ±	300	10	20	.07	30	.02	40	.015
	1000	30	20	.03	30	.015	40	.011
	3000	100	20	.025	30	.012	40	.010
Air Broom #	300	10	16	.03	24	.015	32	.008
	1000	30	16	.03	24	.01	32	.007
	3000	100	16	.03	24	.009	32	.006

* Effort expended in man/min per 10,000 sq. ft

\+ Conventional motorized sweeper

± Vacuumized motorized sweeper

\# An experimental device consisting of a manifold of air nozzles attached below the rear bumper of a compressor truck.

Table B-5

RECLAMATION OF UNPAVED LAND AREAS

Method	Effort (man-min. per 1000 sq.ft)	Fraction Remaining, F
Motorized Scraping (1 man)		
1st cycle	5-8	0.0016-0.036
2nd cycle	4	0.0002-0.007
Motorized Grading plus Motorized Scraping (2 men)		
1st cycle	10-17	0.015-0.124
2nd cycle	9-17	0.00024-0.0041
Plowing (4-share gang-plow, 1 man)		
continuous	2.5	0.2*
one direction only	4.8	0.2
Earth Filling (3 scrapers, 3 men)		
6" of fill	10-20	0.15
12" of fill	20-40	0.02
18" of fill	40-80	0.002
Scraping - Small drag type	20-50	0.15
Shovel Removal, hand	100-200	0.1-0.15

* Within the plowed area. Away from the plowed area, the effective dose rate fraction is reduced.

Table B-6

PREDICTED PERFORMANCE OF COLD WEATHER RECOVERY MEASURES

Method	Conditions for Application	Average Rate	Fraction Remaining
Skip loading	3 in. and more of snow	12 ton/hr	0.1
Motorized sweeping	Less than 3 in. of snow	10,000 sq.ft/hr per 1 in. of snow depth	
Snow plowing	More than 3 in. of snow mixed with contam.;or less than 3 in. with contam.on top	53 ton/hr, blade type, 625 ton/hr rotary type	0.15
Firehosing	Above 10° F	7500 sq.ft/hr., ground level	0.01
		2000 sq.ft/hr, buildings	0.05
Thawing + Firehosing	Above 10° F	2000 sq.ft/hr, buildings	0.05
Thawing + Scraping	Cohesive soil	9000 sq.ft	0.01

BIBLIOGRAPHY

Adams, C.E. et al, The Nature of Individual Radioactive Particles, I. Surface and Underground ABD Particles from Operation Jangle, USNRDL-374, U.S. Naval Radiological Defense Laboratory (USNRDL), San Francisco, Calif., 1952.

Anxier, J.A. et al, Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, CETO-CEX 58.1, U.S. Atomic Energy Commission (USAEC) Wash., D.C., 1959.

Baran, J.A., Blockhouse Dosage Contributions Resulting From Window-Collimated Ceiling Scattered Fallout Radiation, Dept. of Nuclear Engineering, Kansas State University, Manhattan, Kansas, 1963.

Barrett, M.J. et al, Transmission of Gamma Radiation Through Thin Finite Slabs, TI-B 64-44, Technical Operations Research, Burlington, Mass., May 1964.

Barrett, M.W. and R.L. MacNeil, Dose Rate Distribution in a Compartmental Structure. TO-B 64-1, Technical Operations Research, Burlington, Mass., June 1964.

Barrett, M.J. et al, Experimental Evaluation of Fallout Protection Using Modeling Techniques, TO-B 64-62, Technical Operations Research, Burlington, Mass., July 1964.

Barrett, M.J. and J. Waldman, Experimental Gamma Ray Backscattering by Various Materials, RI-B 63-68, Technical Operations Research, Burlington, Mass., July 1964.

Battle, Joseph, Calculating ERD During a Prolonged Exposure in a Fallout Environment, RM-OU-156-6, Research Triangle Institute, Durham, N.C., June 1964.

Brusse, J.C., A Study of the Infiltration of Radioactive Fallout Particles Into Shelter Spaces through Large Openings, Texas Engineering Experiment Station, College Station, Texas, June 1964.

Cammarano, M.V. et al, A Prototype Civil Defense Manual for Radiological Decontamination of Municipalities, Curtiss-Wright Corp., Caldwell, N.J., May 1964.

Cannell, R.S., LIVE: Plan to Survive a Nuclear Attack, Prentice Hall, New York, N.Y., 1961.

Cannon, E.W., Building Materials as Commonly Used in Existing Urban Buildings in the United States, UCIER, University of California, Berkeley, Cal., January 1958.

Clifford, C.E., Effects of Ground Roughness on the γ Dose from Cs^{137} Contamination, Defense Research Chemical Laboratories, Ottawa, Canada, March 1963.

Cochran, R.W., Scattered Radiation From a Cobalt-60 Source in a Brick Structure, USAF School of Aerospace Medicine, Brooks Air Force Base, Texas, June 1964.

Degelman, L. et al, Evaluation of the Shielding Characteristics of Structures for Simulated Residual Radiation, Dept. of Nuclear Engineering, Pennsylvania State University, University Park, Penna., November 1963.

Donovan, L.K. and A.B. Chilton, Dose Attenuation Factors for Concrete Slab Shields Covered With Fallout As A Function of Time After Fission, USNCEL-TR-137, USNCEL, Port Hueneme, California, June 1961.

Earl, J.R., Land Reclamation, USNRDL-AD-332, USNRDL, San Francisco, Calif., March 1952.

Eisenhauer, C., An Engineering Method for Calculating Protection Afforded by Structures Against Fallout Radiation, NBS-7810, National Bureau of Standards, Washington, D.C., 1963.

Facci, H.A. and M.K. Wood, PARM-Fallout and Decontamination, NREC-36, National Resource Evaluation Center, Washington, D.C., March 1964.

Huddleston, C.M. et al, Ground Roughness Effects On the Energy and Angular Distribution of Gamma Radiation From Fallout, CEX-62.81 Edgerton, Germeshausen and Grier, Inc., Las Vegas, Nevada, July 1964.

Jones, J.L. and J.F. Batter, Experimental Determination of Well-Scattered Radiation Function $G_s(\omega)$, TO-B 63-88 Technical Operations Research, Burlington, Mass., December 1963.

Ksanda, C.F., Gamma Radiations From Contaminated Planes and Slabs, USNRDL-TM-27, USNRDL, San Francisco, Calif., January 1955.

Laurino, R.K., Effectiveness Specifications for Radiological Defense Countermeasures, USNRDL-TR-47, USNRDL, San Francisco, Calif., 1955.

LeDoux, J.C. and L.K. Donovan, Shielding Factors for Underground Shelters of Various Geometric Shapes, USNCEL-TR-080, USNCEL, Port Hueneme, Calif., April 1961.

Lee, H. et al, Performance Characteristics of Land Reclamation Procedures, Operation Stoneman II, Vol. IV, USNRDL-TR-337, USNRDL, San Francisco, Calif., January 1959.

Lee, H. et al, Performance Characteristics of Dry Decontamination Procedures, Operation Stoneman II, Vol. III, USNRDL-TR-336, USNRDL, San Francisco, Calif., June 1959.

Lee, H., Estimating Cost and Effectiveness of Decontaminating Land Targets, Vol. I, Estimating Procedure and Computational Technique, USNRDL-TR-435, USNRDL, San Francisco, Calif., June 1960.

Lee, H., A Method For Determining Mission Reentry Times for Fallout-Contaminated Industrial Complexes, USNRDL-TR-585, USNRDL, San Francisco, Calif., March 1962.

Maloney, J.C. and J.L. Meredith, Cold Weather Decontamination Study, McCoy I, USANDL-TR-24, USANDL, Edgewood Arsenal, Maryland, 1962.

Maloney, J.C. et al, Cold Weather Decontamination Study, McCoy II, USANDL-TR-32, USANDL, Edgewood Arsenal, Maryland, July 1962.

Maloney, J.C. and J.L. Meredith, Simple Decontamination of Residential Areas, McCoy III, USANDL-TR-33, USANDL, Edgewood Arsenal, Maryland, September 1962.

eredith, J.L. et al, Cold Weather Decontamination Study, McCoy IV, USANDL-TR-58, USANDL, Edgewood Arsenal, Maryland, April 1964.

iller, C.F., Estimated Effectiveness of Common Decontamination Methods For Paved Areas and Building Surfaces, USNRDL-TR-140, USNRDL, San Francisco, Calif., 1957.

Miller, C.F., Gamma Decay of Fission Products From Slow Neutron Fission of U^{235}, USNRDL-TR-187, USNRDL, San Francisco, Calif., July 1957.

Miller, C.F. and P. Loeb, Ionization Rate and Photon Pulse Decay of Fission Products From Slow Neutron Fission of U-235, USNRDL-TR-247, USNRDL, San Francisco, Calif., August 1958.

Miller, C.F., Theory of Decontamination, USNRDL-TR-460, USNRDL, San Francisco, Calif., July 1958.

Miller, C.F., Analysis of Radiological Decontamination Data Obtained From Field Tests, USNRDL-TR-321, USNRDL, San Francisco, Calif., April 1959.

Miller, C.F., A Theory of Formation of Fallout, USNRDL-TR-425, USNRDL, San Francisco, Calif., 1960.

Miller, C.F., Nuclear War: A Post Attack Picture, Office of Civil Defense, Washington, D.C. (UNPUBLISHED)

Miller, C.F., Fallout and Radiological Countermeasures, Stanford Research Institute, Menlo Park, Calif., January 1963.

Miller, C.F. et al, Introduction to Radiological Defense Planning, Stanford Research Institute, Menlo Park, Calif., May 1965.

Owen, W.L. et al, Performance Characteristics of Wet Decontamination Procedures, Operation Stoneman II, Vol. II, USNRDL-TR-335, USNRDL, San Francisco, Calif., July 1960.

Owen, W.L., Radiological Protective Construction, USNRDL-467, USNRDL, San Francisco, Calif., January 1962.

Owen, W.L. and J.D. Sartor, Radiological Recovery of Land Target Components--Complex I and II, USNRDL-TR-570, USNRDL, San Francisco, Calif., May 1962.

Owen, W.L. and J.D. Sartor, Radiological Recovery of Land Target Components--Complex III, USNRDL-TR-700, USNRDL, San Francisco, Calif., November 1963.

Putz, R.R. and A. Broido, A Computation Method for Gamma Radiation Intensity in the Presence of General Shielding and Source Configurations, UCIER University of California, Berkeley, Calif., December 1957.

Raso, D.J. and S. Woolf, The Dose Resulting From A 1.25 Mev Plane Source Behind Various Arrangements of Iron Barriers, To-B-64-49, Technical Operations Research, Burlington, Mass., June 1964.

Rexroad, R.E. and M.A. Schmoke, Scattered Radiation and Far-Field Dose Rates From Distributed Cobalt-60 and Cs-137 Sources, USANDL-TR-2, USANDL, Edgewood Arsenal, Maryland, September 1960.

Ryan, J.T., An Error Analysis for Total Dose Calculations, RM-156-7, Research Triangle Institute, Durham, N.C., June 1964.

Ryan, J.T. et al, Radiological Recovery Concepts, Requirements and Structures, R-OU-156, Research Triangle Institute, Durham, N.C., October 1964.

Sartor, J.D. et al, Cost and Effectiveness of Decontamination Procedures For Land Targets, Operation Stoneman I, USNRDL-TR-196, USNRDL, San Francisco, Calif., December 1957.

Spencer, L.V., Structure Shielding Against Fallout Radiation From Nuclear Weapons, NBS, Monograph 42, June 1962.

Starbird, A.W. et al, The Effect of Interior Partitions on the Dose Rate in a Multistory Windowless Building, TO-B-63-6, Technical Operations Research, Burlington, Mass., January 1963.

Starbird, A.W. and J.F. Batter, Angular Distribution of Skyshine Radiation At the Surface of A Plane of Fallout Contamination, TO-B 63-40, Technical Operations Research, Burlington, Mass., March 1964.

Strope, W.E. et al, Protection and Decontamination of Land Target and Vehicles, Operation Jangle, Project 6.2, WT-400, DASA, June 1952.

Strope, W.E., Radiological Defense Measures as a Countermeasure System, USNRDL-TR-74, USNRDL, San Francisco, Calif., February 1956.

Strope, W.E., Evaluation of Countermeasure System Components and Operational Procedures, Operation PLUMBBOB, Project 32.3, WT-1464, DASA, August 1958.

Taylor, D. et al, Development of Radiological Decontamination Methods and Equipment for Cold Weather Regions, USNCEL, Port Hueneme, Calif., July 1960.

The Effects of Nuclear Weapons, U.S. Government Printing Office, Washington, D.C., 1957.

Radiological Recovery of Fixed Military Installations, NAVDOCKS-TP-PL-13, April 1958.

Fallout Shelters Survey: Guide for Architects and Engineers, OCD Document NP-10-2, National Plan Appendix Series, May 1960.

Design and Review of Structures For Protection From Fallout Gamma Radiation, DOD-OCD-EN-61-1, October 1961.

Exposure to Radiation in an Emergency, National Committee on Radiation Protection and Measurement, Report No. 29, University of Chicago, Chicago, Ill., January 1962.

National Fallout Shelter Survey, Phase 2, Computer Printouts, OCD, Washington, D.C., 1963.

UNCLASSIFIED
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DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) STANFORD RESEARCH INSTITUTE Menlo Park, California 94025	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE

RADIOLOGICAL TARGET ANALYSIS PROCEDURES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (Last name, first name, initial)

LEE, Hong

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1966	94	15

8a. CONTRACT OR GRANT NO. N228-(62479)65421	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. OCD Work Unit No. 3231C	
c. SRI Project No. MU-5069	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d. USNRDL TRC-6	

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Office of Civil Defense Department of the Army Washington, D.C. 20310

13. ABSTRACT

The radiological target analyses in this report consist of a series of analytical procedures for evaluating the residual numbers for shelters and other locations before, during, and after decontamination so that exposure doses may be calculated. These residual numbers are used to provide estimates of (1) shelter stay times, (2) manpower requirements for proposed decontamination, (3) exposure to recovery personnel, (4) decontamination effectiveness requirements, (5) equipment and supplies requirements, and (6) feasibility of plans and schedules for the recovery of vital facilities and living areas. Tables, charts, figures, and sample calculations provide working tools which may be used for civil defense planning and training and similar practical levels of radiological defense preparation.

DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Civil defense						
Radiological						
Fallout						
Contamination						
Target Analysis						
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