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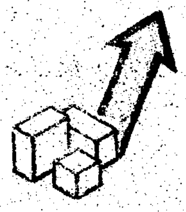
Research Memorandum 2

Denial Times for Facilities Denied by Radioactive Fallout

J. T. Ryan and R. H. Thornton



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Research Memorandum

RM-OU-241-2

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DENIAL TIMES FOR FACILITIES DENIED BY RADIOACTIVE FALLOUT

BY

JOSEPH T. RYAN and ROBERT H. THORNTON

20 MAY 1966

Headquarters, USAF
Directorate of Studies and Analysis
DCS/Plans and Operations (AFXSA)
under
Contract No. AF 49(638)-1628

ABSTRACT

This report contains four studies performed under Air Force Contract 49(638)-1628, "A Recovery and Reconstitution Model for the Strategic Strike Forces." The first three of these studies are related to analyzing radioactive fallout and its effects on the ability of personnel at an installation to carry out their assigned missions or other operations. The fourth study is a procedure proposed by RTI to compute fallout denial times (with or without decontamination) for specified installations or facilities.

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I. INTRODUCTION

This report contains four studies performed under Air Force Contract 49 (638)-1628, "A Recovery and Reconstitution Model for the Strategic Strike Forces". The first three of these studies are related to analyzing radioactive fallout and its effects on the ability of personnel at an installation to carry out their assigned missions or other operations. The fourth study is a procedure proposed by RTI to compute fallout denial times (with or without decontamination) for specified installations or facilities. It is planned that this procedure be incorporated in the Recovery and Reconstitution Model (R & R Model) under development for the Directorate of Studies and Analysis (DSA).

The purpose of this report is to furnish DSA as early as possible with technical information related to fallout denial times at facilities. This information is derived from some analytical studies conducted in support of the R & R Model development.

Design details of the R & R Model are elaborated upon in a companion document, Design Phase Report on a Recovery and Reconstitution Model for the Strategic Strike Forces.[1/]

The four appendices describing these studies are:

Appendix A: General Concepts and Definitions Related to the Effects of Radioactive Fallout on the Recovery and Reconstitution Process.

The purpose of Appendix A is to examine in a relatively broad fashion the effects of fallout radiation on the ability of personnel on a facility

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1/ Ryan, J. T. and R. H. Thornton. Design Phase Report on a Recovery and Reconstitution Model for the Strategic Strike Forces. RM-OU-241-1. Research Triangle Institute, Durham, North Carolina. 16 May, 1966.

to perform their assigned activities. The essential elements of the recovery and reconstitution process as they relate to fallout radiation and decontamination are discussed and defined. The basic mathematics relating fallout radiation intensity and activity patterns associated with essential base activities to the fallout denial time of a facility are presented.

Appendix B: Alternative Simplified Procedures for Determining Composite Dose Rates for Fallout Denial Time Calculations.

Appendix B presents alternative simplified procedures for determining composite dose rates for fallout denial time calculations. Error bounds on the composite intensities obtained are furnished. Error bounds on the denial times themselves are also discussed.

Appendix C: Analytical Relationships Among Radiation Dose, Decontamination and Facility Denial Time.

The purpose of Appendix C is to present clearly the analytical relationships among a number of the parameters associated with computing fallout denial times. As such, this appendix does not purport to present quick or approximate techniques for creating "reasonable" inputs to the R & R Model. It only attempts in a pocket-size format to relate the parameters in a manner so as to allow the input planner to get some idea how different choices of input values might alter the denial times. The analysis presented is for one weapon only so that errors introduced by approximating the several weapon case with a single intensity curve and detonation time should be taken into account. Appendix B can be used in this regard.

Appendix D: A Computational Procedure for Estimating the Denial Time for Facilities Denied by Radioactive Fallout.

Appendix D presents a procedure for computing fallout denial times for facilities. The routine described is to be a part of the Initial Edit Phase of the R & R Model. (See Reference 1 for a description of the overall R & R Model logic as well as a discussion of the functions to be performed in the Initial Edit Phase.) This routine does not employ (as yet) any of the simplified procedures discussed in Appendix B. Additional logic to account for the dose accumulated prior to the resumption of essential facility activities will be incorporated at a later date.

II. ULTIMATE OBJECTIVES OF THESE STUDIES

Ultimately, it is hoped that these studies will lead to:

1. Simple methods for approximating the composite intensity curves and corresponding denial times at a facility with or without decontamination.
2. Operational guides for choosing either dose or dose rate constraints for strike force operating personnel and for decontamination personnel.
3. Using the above, methods for computing in as realistic a manner as possible the earliest time at which decontamination can take place.
4. Using the above, methods for computing in as realistic a manner as possible the denial time after decontamination.

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1. Ryan, J. T. and R. H. Thornton. Design Phase Report on a Recovery and Reconstitution Model for the Strategic Strike Forces. Contract AF 49 (638)-1628, RTI No. RM-OU-241-1. Durham, North Carolina: Research Triangle Institute, Operations Research and Economics Division, 16 May 1966.

Appendix A

General Concepts and Definitions Related to the Effects of Radioactive Fallout on the Recovery and Reconstitution Process

I. INTRODUCTION

The purpose of this appendix is to examine in a relatively broad fashion the effects of fallout radiation on the ability of personnel on a facility to perform their assigned activities. The essential elements of the recovery and reconstitution process as they relate to fallout radiation and decontamination are discussed and defined. The basic mathematics relating fallout radiation intensity and activity patterns associated with essential base activities to the fallout denial time of a facility are presented. Guidelines are also provided which can be used in the mathematical sections attached at the end of this appendix.

II. DEFINITIONS

The nature of the recovery and reconstitution process depends on the overall objectives of the recovery operation considered. For the strategic forces, postattack recovery operations will attempt to manage the surviving resources in such a way as to restore the surviving strike forces to a condition of readiness, as rapidly as possible.

In this section, definitions are introduced which are used to relate the effects of radioactive fallout on the recovery and reconstitution process.

The purpose of the recovery and reconstitution process is to organize and ready "forces". Recovery is the process of bringing damaged forces to a ready status. Reconstitution is the process of assemblying recovered forces at specified facilities. If the strategic strike force is being recovered, then the forces will generally refer to the weapon carriers. Hence, the word "force", is usually reserved for the weapon carrier (aircraft, Polaris submarine, etc.). The force may be located anywhere geographically and in a wide variety of readiness states. In this usage, a "ready" force could consist of an A/C armed, fueled and essentially ready to launch. In recovering or reconstituting forces, three mutually exclusive classes of items are required, consumable resources, reusable resources, and carriers. Manpower is usually treated as a reusable resource. Reusable resources are items used repeatedly in the recovery, such as tools, maintenance equipment, construction equipment, and manpower. Consumable resources can be used only once in recovering a particular force; examples are POL, weapons, etc. Carriers are items used to transport resources or forces from one facility to another.

Each force, resource, or carrier is at a particular facility. Fallout and transportation data must be provided for each facility. The effect of the environment on forces, resources, or carriers while in transit is not explicitly defined or accounted for by the model in its present stage of development.

Recovery of a force involves applying all of the resources required by the force in its given readiness state and repairing damage that the force may have received. The time of recovery is the time at which the force attains a ready status. The recovery facility is the facility where a given force is recovered. Recovery is affected very much by other events which can occur during the recovery period. Decontamination reduces the fallout intensity at a facility by a specified fraction of its pre-decontamination intensity. Evacuation is the movement of specified forces from specified facilities. Evacuation facilities are facilities from which forces are evacuated. Such evacuations may or may not be constrained by prescribing zones into which and out of which forces will be moved. Zones are specified by naming some or all of the facilities contained therein. Relocation is the preplanned movement of certain forces from one specified facility to another specified facility. Relocation facilities are facilities to which forces are relocated.

This appendix concentrates on only one of these recovery events, decontamination. The purpose of decontamination, in the context of the R & R process, is to reduce the duration of time that a facility and its inventory are unavailable for recovery operations due to the high radiation intensity. This time (duration) is called the fallout denial time. Often, in this, as well as the other appendices, fallout denial time will also refer to the point in time when a facility becomes free of fallout. The expressions "becomes free after the third hour" and "is denied for three hours" are used synonymously with "fallout denial time equals three hours".

See Reference A-1 for a more elaborate treatment of all the above terms.

III. THE EFFECT OF DOSE RATE REDUCTION ON DENIAL TIME

A. Introduction

In a postattack environment, the initiation of recovery activities at a given facility must be scheduled so that radiation dose received by personnel engaged in the activities remains below an acceptable level. When the radiation dose rate at the facility where an activity must take place is sufficiently high, the activity cannot take place. In these situations it is necessary to wait until the dose rate decreases to an acceptable level through natural radioactive decay, weathering, or active decontamination. The length of time that must elapse before the activity can be resumed is ordinarily called the denial time, T_f. Because decontamination can effectively decrease the dose rate in a region, decontamination can effectively decrease the denial time for resumption of an activity. This reduction in denial time through decontamination is called the "time saved" in resuming an activity. "Time saved" will be examined in this appendix as a function of the personnel exposure pattern required in conducting the activity, the local radiation environment, and the dose rate reduction achieved by decontaminating the activity area.

B. Resumption of Activities

The time of resumption of activities depends on the specified service or activity, the dose histories and allowable doses of personnel who provide the service, and the radiation environment that limits the capability. To isolate the effectiveness of decontamination in postattack recovery, it is important to distinguish each of the three factors - activity, personnel, environment - by its scope and important characteristics.

The specification of an activity is independent of whether the activity is to be performed in a preattack or a postattack environment. The specification of an activity includes the complete temporal and spatial behavior patterns of all personnel engaged in the activity. A repetition of daily behavior patterns normally will comprise the complete behavior pattern. An activity whose duration is ten days is likely to be a repetition of ten daily activities sufficiently alike to be considered identical. Thus, the activity description includes both working and sleeping patterns. Short duration activities - less than one day in length - can either include or exclude the non-working portion of the day at the discretion of the input planner.

The personnel engaged in an activity are specified in terms of their individual radiation doses. A dose includes the pre-activity dose, activity dose, and post-activity dose. The total of these three is constrained to remain below an acceptable safety level. When the pre-activity dose and the post-activity dose are analyzed, together with the acceptable safety level, it is possible to determine the maximum allowable dose to be received while performing the activity. This dose is called the allowable activity dose, D_A. It may be specified either as a total dose constraint or as an (Equivalent Residual Dose)

ERD [A-1] constraint, depending on the duration of the activity. In either case, when coupled with the activity and the environment, it determines the earliest time at which the activity can commence. The earliest time is a point in time equal to the time of arrival of the fallout plus the denial time.

When, in addition to the activity, the radiation environment is specified, a dose rate profile for each individual engaged in the activity can be determined as a function of the time when the activity commences. This dose rate profile will reflect the various intensity fields through which the individual proceeds while engaging in the activity. From the dose profile, an individual's accumulated dose at any time during the performance of the activity can be determined. The dose received while performing a specified activity is conventionally defined as the dose received by a detector at a point three feet above an infinite, smooth, uniformly contaminated plane.[A-2] The unshielded standarized dose rate at this point is:

$$I_s(t) = I(1)t^{-1.2} \text{ roentgens/hr.,} \tag{A-1}$$

where t is the time after detonation in hours and I(1) is the unit time reference dose rate applicable to the region where the activity is located. The corresponding dose received during the performance of the activity in the standard environment is, therefore,

$$D_s = I(1) \int_{t_e}^{t} W(t-x)x^{-1.2}\, dx \text{ roentgens} \tag{A-2}$$

where t_e is the time in hours when the activity commences, t is the time of

---

A-1/ Equivalent Residual Dose reflects biological repair. See Reference A-5 for a definition of ERD. A more elaborate discussion of this concept is contained in Appendix C.

A-2/ See Reference A-4.

interest in hours, and $W(t-x)$ is the appropriate weighting function, normally equal to $.1 + .9e^{-.001(t-x)}$ for ERD and equal to 1.0 for total dose. The dose used to represent the activity dose is the standard dose multiplied by an appropriate fraction. This fraction, called the activity residual number, R_{NA}, is a constant, independent of the time when the activity commences. The activity residual number is the true total dose received during the performance of the activity divided by the total dose that would be received during the same time period in the standard environment. The function used to represent the activity dose, D, is, therefore,

$$
\begin{aligned}
D &= R_{NA} D_s \\
&= R_{NA}\, I(1) \int_{t_e}^{t} W(t-x)x^{-1.2}\, dx \qquad \text{(A-3)} \\
&= H \int_{t_e}^{t} W(t-x)x^{-1.2}\, dx
\end{aligned}
$$

where H is equal to $I(1)\, R_{NA}$, and is called the activity intensity.

This maximum value is the allowable activity dose, D_A. When it is specified, along with the environment, and the activity pattern, H, and Δt, then the earliest time at which the activity can commence, t_e, (and therefore, the denial time) can be determined.

C. <u>Denial Time</u>

The denial time is the point in time that a facility and its items of inventory are available for recovery operations. This denial time is shown in Figure A-1 as a function of the maximum allowable activity dose (total dose and ERD) normalized with respect to H for various activity durations. The ERD curve for a continuously repeated activity (duration 800 days) was determined graphically. The ERD curves

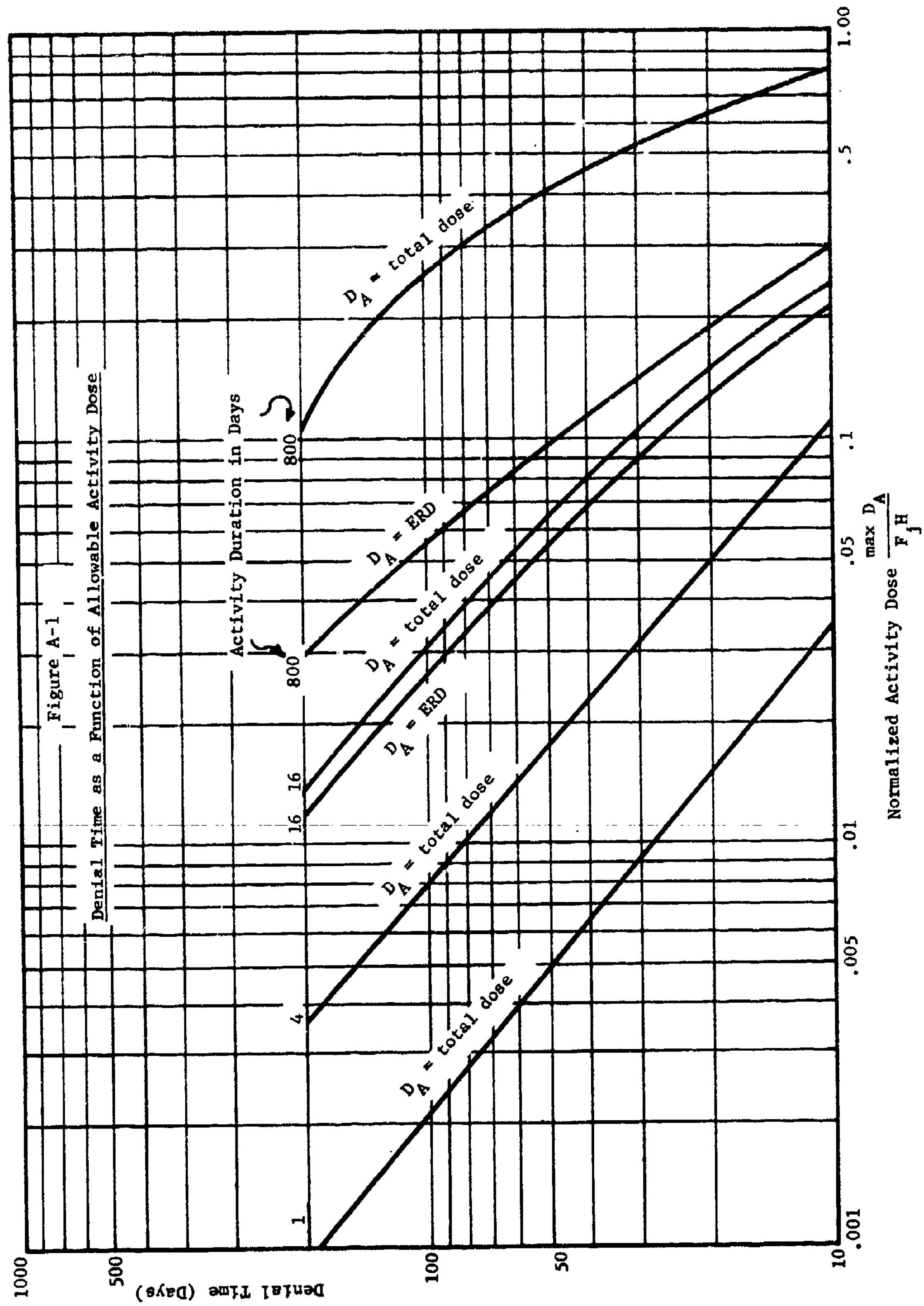

Figure A-1

Denial Time as a Function of Allowable Activity Dose for activity durations, Δt, less than 32 days were determined from the equation,[A-3/]

$$t_f = \left(\frac{H\Delta t}{D_A} \right)^{.833} (1 - .008\Delta t)^{.833} - \frac{\Delta t}{2} \qquad \text{(A-4)}$$

and the total dose curves for activity durations less than 32 days were determined from the equation,[A-4/]

$$t_f = \left(\frac{H\Delta t}{D_A} \right)^{.833} - \frac{\Delta t}{2} . \qquad \text{(A-5)}$$

D. Dose Rate Reduction Effectiveness

If the radiation activity level is reduced, then the denial time is also reduced. The time by which the denial time is reduced is called the time saved. This time saved, or denial time reduction, is a measure of the effectiveness of decontamination in assisting recovery and reconstitution in a postattack environment.

When contaminated surfaces at a facility are decontaminated, the activity dose

$$H \int_{t_e}^{t} W(t-x)x^{-1.2}\, dx \qquad \text{(A-6)}$$

is reduced to

$$F_j H \int_{t_e}^{t} W(t-x)x^{-1.2}\, dx \qquad \text{(A-7)}$$

where F_j is the fractional dose rate remaining after the decontamination operation. F_j is expected to range between .05 and .2. In the above equations, the effect of

A-3/ See Appendix C, Equation C-16

A-4/ See Appendix C, Equation C-17

F_j can be interpreted as decreasing the activity dose rate by a factor F_j. In Figure A-2, a decrease in H increases the normalized allowable activity dose, $\frac{D_A}{H}$. When the normalized allowable activity dose increases, the denial time decreases.

IV. TIME SAVED

From equations and/or curves that relate the denial time, the maximum allowable activity dose, D_A, and the radiation environment activity constant, H (as are illustrated in the previous section), the time saved can be calculated for any set of conditions. This is done in detail in Appendix C. For general planning purposes, where extreme detail is neither necessary nor desirable, very simple estimates of the potential time savings attributable to decontamination can be formed by a quick examination of Figure A-1. This will be done by determining for various activity durations the fractional reduction in denial time that results when H is decreased by a factor of 10 (that is, when the dose rate reduction achieved by decontamination is F_j = .1). The results of such an examination of Figure A-1 are presented in Table A-1 reprinted from Reference A-4. There it can be seen that by reducing the dose rate by a factor of 10, the denial time is reduced by a factor ranging from 7 to 20. For example, if the activity duration is 16 days, the allowable dose (maximum ERD) is 100 roentgens, and $H = I(1)\ R_{NA}$ = 5000 roentgens per hour, then the denial time is 130 days. With a dose rate reduction factor of .1, H becomes 500 roentgens per hour and the denial time is reduced by a factor of 12 to $\frac{130}{12}$ = 11 days. This example is presented as a portion of Table A-1.

For rough planning purposes it is often desirable to have available methods of estimating the range of decontamination effectiveness. As a general rule, if the dose rate reduction factor is F_j, then the denial time will be reduced by dividing it by a number greater than $\left(\frac{1}{F_j}\right)^{.833}$ and less than $\left(\frac{1}{F_j}\right)^{1.3}$.

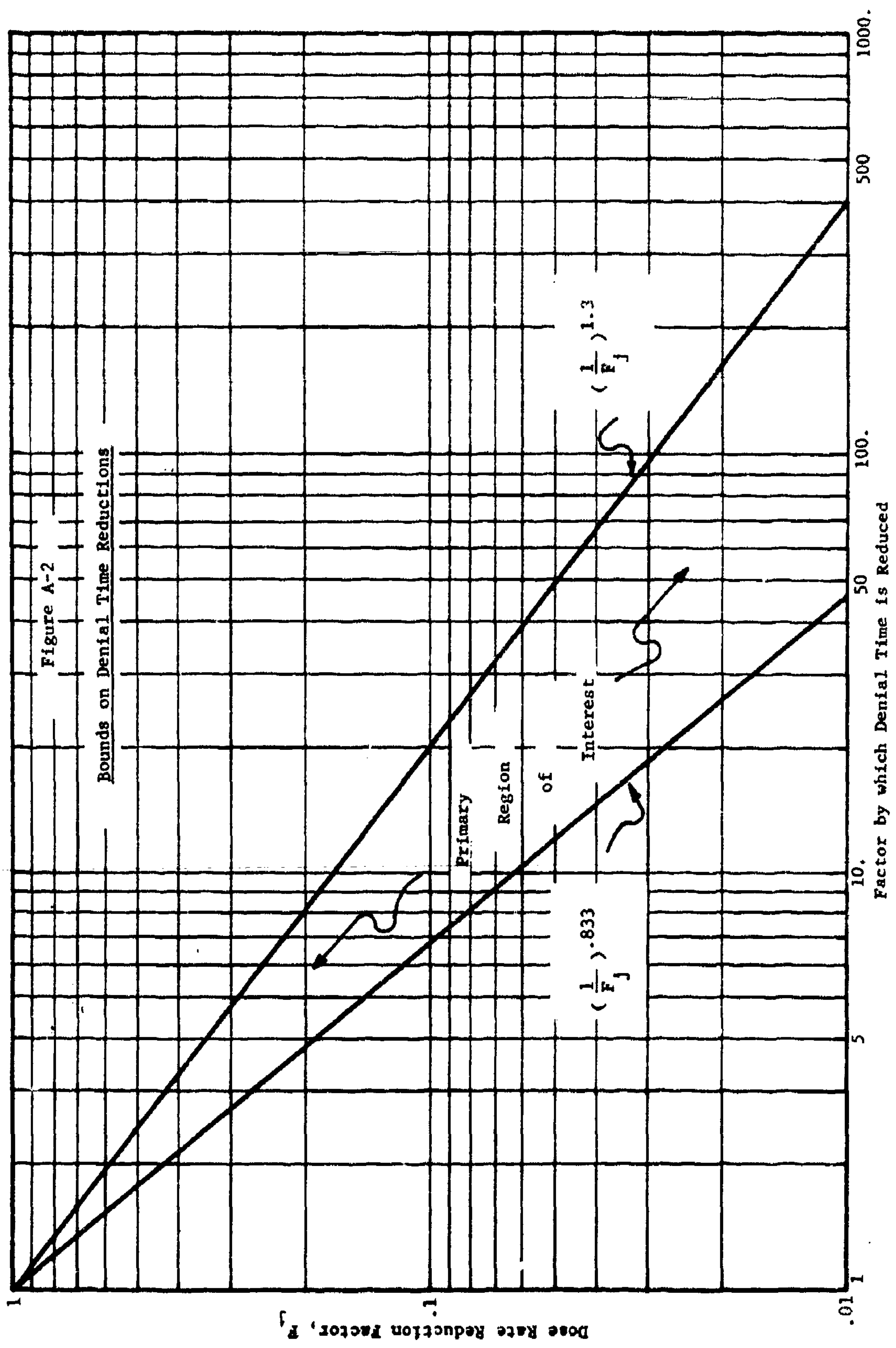

Figure A-2
Bounds on Denial Time Reductions

Referring to the previous example, $(10)^{.833} = 6.8 \approx 7$ and $(10)^{1.3} = 20$. These two bounds indicating the range of the denial time divisor reflecting decontamination are shown in Figure A-2. The exact value for the divisor is a function of D_A, H, F and can be determined using the performance curves presented in Appendix C to this report.

V. GUIDELINES FOR PRESCRIBING MAXIMUM ALLOWABLE DOSES OR INTENSITY FOR PERSONNEL CONDUCTING ESSENTIAL ACTIVITIES ON A FACILITY

A. Introduction

The time at which activities can be resumed at a facility earlier denied by fallout depends upon the local radiation environment and the radiation dose that personnel are permitted to accumulate in conducting the specified activities. The purpose of this section is to provide some guidance as to how a maximum allowable dose or maximum allowable outside intensity might be prescribed. Of course, similar guidelines are available from a number of sources including the Air Force handbook, Nuclear Weapons Employment Handbook, AFM200-8 (Reference A-2).

B. Radiation Effects

The following paragraphs and table were extracted from Radiological Recovery Of Fixed Military Installations (Reference A-3). They can be used to estimate probable effects on personnel of specified radiation doses.

"2.2.3 Operational Significance of Radiation Exposure

"For practical purposes, the effects of gamma radiation can be divided into two categories - early effects and late effects. Early effects are those noticeable during exposure or within a few hours or days after exposure while late effects appear much later, probably years after exposure.

"The early effects usually occur as radiation sickness (nausea, vomiting and general indisposition). The onset of radiation sickness depends mainly upon the whole-body radiation dose received. Even at the lowest doses that will cause a sickness, there may be several hours before nausea occurs.

Following the initial period of sickness, there is likely to be a long latent period during which the individual shows no outward symptoms other than a lack of feeling of well-being. After a week or so, the second and most serious phase of sickness occurs. The second phase lasts several weeks before death or recovery occurs. The first phase of radiation sickness is generally associated with injury to the intestines while the second phase is linked to injury to the blood forming tissues. As the dose increases, the pace of the illness quickens, the onset being more rapid and the latent period shorter. The probability of ultimate death also increases.

"The human body has a limited ability to repair the damage caused by gamma radiation. This ability is limited to the early effects of radiation exposure and means that more radiation exposure is required to produce sickness and death when delivered over a long period of time than when delivered over a short period of time.

"The guidance relating measured dose to early effects of gamma radiation is shown in Table 2.1 as a casualty risk table. The effect of various measured doses is presented as a probability that the personnel so exposed in a particular time period will become sick or subsequently die. It is not possible to indicate the operational significance of radiation exposure more precisely at this time, not only because of the small amount of information on humans but because of other important variables that are known to exist in the actual situation. In addition to the known variation in susceptibility of individuals to radiation, there are important variations in the conditions of exposure, accuracy of instrumentation, etc. The table is intended to apply to a wide range of military situations. In any particular situation, a group is likely to respond to radiation exposure in a more uniform manner than indicated in the casualty risk table. For example, it is stated that, if a group were exposed to a measured dose of 150 roentgens within any one day, there is one chance in four of sickness, and no deaths are anticipated. It is undesirable to interpret this statement as meaning that 25 percent of the group will be sick and that 75 percent of the group can be counted upon to be available for duty following exposure. A more useful interpretation for planning purposes is that the chance that the group will be sick is one in four. It is to be emphasized that the guidance in Table 2.1 is the best available information for planning purposes and for estimating radiological defense requirements. In actual operations where radiation exposure occurs, it is not a substitute for accurate measurement of doses to which personnel are exposed and continual observation of the effects.

"The last column of Table 2.1 concerns late effects - those that will affect an individual's post war potential but not his wartime potential. Late effects depend upon the total dose received, independent of the time period over which the dose is delivered. That is, biological recovery does not apply to late effects. Late effects will include an increased incidence of leukemia, cancer, and general shortening of the life span. Table 2.1 indicates that the threshold of significant late effects is considered to be in the neighborhood of 150-200 roentgens. It should be noted that there is no real threshold for late effects, but that with small doses these late effects are very unlikely to appear. Admittedly, the status of an individual's postwar potential is a secondary consideration to that of his wartime potential; however, late effects still merit attention, especially to the degree that awareness of postwar jeopardy effects the morale of the personnel involved. For example, a man who receives 450 roentgens spread over six months will probably never exhibit sickness but later effects may be quite significant.

"2.2.4 Use of Casualty Risk Table

"The information in Table 2.1 is used to determine the wartime maximum permissible exposure for personnel to be used in radiological defense planning. The determination of permissible dose is a command decision. Normally, it will be desired to expose personnel to as little radiation as possible. If significant military advantage is expected to accrue by allowing them to be deliberately exposed, such exposure should be planned but it will be desirable to avoid the possibility of sickness and significant late effects. As conditions become more stringent and demand greater exposure, the command may be willing to accept significant late effects but will always desire to hold early effects to a minimum.

"If it is desirable to plan without risking casualties, acceptable doses must be chosen above the heavy line in Table 2.1. The three months column is to be used for all periods of exposure greater than 3 months. If significant late effects are to be averted, a total dose greater than 150 roentgens cannot be accepted. This limitation is shown by a heavy dashed line in the 3 months column.

"The estimating procedure described in Section III requires that the appropriate level of command prescribe an acceptable dose for personnel over the entire mission duration following a contaminating nuclear attack. The acceptable dose will equal the maximum permissible exposure only if it is decided to plan a capability for operational recovery following a single contaminating event. If an estimate of the situation is desired for the operational capability following two or more nuclear weapon detonations, the acceptable dose for a single attack will be an appropriate fraction of the maximum permissible exposure. This matter is discussed in paragraph 4.3.2.

"The acceptable dose is stated for the maximum period of the exposure. The casualty risk implicit in this statement will hold only if the dose is delivered over the time period in such a way as to avoid exceeding the casualty risk at some earlier time. For example, suppose 150 roentgens is chosen as the acceptable dose for a three months mission, based on a desire to avoid both early effects and significant late effects. In order that this no-casualty condition exist, the dose in any week may not exceed 125 roentgens; the dose in any three day period may not exceed 100 roentgens and the dose in any single day may not exceed 75 roentgens. In other words, whenever an acceptable dose is selected to cover the time period of a mission, care must be exercised that unacceptable casualties do not occur because of doses taken during a short interval of the total period. The estimating procedure in Section III provides an automatic check on the acceptability of intermediate doses."

Table 2.1

CASUALTY RISK TABLE

Estimated Medical Effects of Radiation Doses Expressed as
Probability of Sickness or Death

Measured Dose (r)	Early Effects for Periods of Time Over Which Total Dose is Received										Significant Late Effect
	1 Day		3 Days		1 Week		1 Month		3 Mo. or More		
	Sickness	Death	Sickness	Death	Sickness	Death	Sickness	Death	Sickness	Death	
0-75	2%	0%	0	0	0	0	0	0	0	0	None
100	2%	0%	0	0	0	0	0	0	0	0	None
125	15%	0%	2%	0%	0	0	0	0	0	0	None
150	25%	0%	10%	0%	2%	0%	0	0	0	0	None
200	50%	0%	25%	0%	15%	0%	2%	0%	0%	0%	Some
300	100%	20%	60%	5%	40%	0%	15%	0%	0%	0%	Some
450	100%	50%	100%	25%	90%	15%	50%	0%	5%	0%	Some
650	100%	95%	100%	90%	100%	40%	80%	10%	10%	0%	Some

This table applies to healthy, young adults under usual working conditions. The probability of fatalities will be decreased with adequate medical treatment. The casualty estimates are based on an interpretation of the best current available evidence and may be changed as more information is accumulated.

Source: Radiological Recovery of Fixed Military Installations (Reference A-3)

GLOSSARY OF TERMS FOR APPENDIX A

D	The dose used to represent the activity dose at a facility ($D = R_{NA} D_s$).
D_A	The maximum allowable dose (the maximum specified dose while performing essential activities at a facility).
D_s	Dose received during the performance of activities where the facility is not decontaminated prior to the performance of activities on the facility.
d_i	The fraction of fallout uniformly removed from a contaminated plane i.
E_i	The fraction of fallout remaining on contaminated plane i after decontaminating the plane. ($E_i = 1 - d_i$).
F_j	The combined intensity reduction factor - the fraction of the pre-decontamination dose-rate remaining at detector location j after decontaminating several surfaces simultaneously.
H	The activity reference dose rate ($H = I(1)\ R_{NA}$) without decontamination.
$I(1)$	The unit time reference dose rate applicable at the facility.
$I_s(t)$	The dose rate at time t; ($I_s(t) = I(1)\ t^{-1.2}$ roentgens/hr.)
R_{NA}	Activity Residual Number - the total radiation dose received during the performance of an activity divided by the total dose that would be received during the same time period in the standard unshielded environment.
T_f	Denial Time - The point in time after which an activity can be safely resumed in a fallout contaminated area subject to the specified radiation exposure constraint.
t_e	The time in hours when the activity commences.
Δt	The duration of an activity.
$W(t-x)$	The appropriate weighting function, normally equal to $.1 + .9e^{-.001(t-x)}$ for Equivalent Residual Dose[A-5] and equal to 1.0 for exposure dose.

[A-5] See Reference A-5.

REFERENCES FOR APPENDIX A

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Appendix B

Alternative Simplified Procedures for Determining Composite Dose Rates for Fallout Denial Time Calculations

I. INTRODUCTION

To reduce computer running time when fallout denial time calculations are made, simple approximation techniques can be employed to determine composite H+1 reference intensities. Of course, these techniques are needed only when multiple weapons with different detonation times are contributing fallout to a facility. Since a composite dose rate-time curve is an approximation based on the dose rate contributions from the individual weapons, some error is introduced into the denial times that are subsequently determined. Error bounds on composite intensitites as well as on denial times are discussed later in this appendix.

When the more nearly exact method described in Appendix D of this memorandum is used for computations, the fallout contribution of each weapon affecting a facility must be computed separately (unless the detonation times are the same) and the contributions summed. The resultant is then used to compute denial time. The approximation discussed here can serve in most instances, however.

One of the simplest approaches to representing a composite fallout decay curve resulting from n contributing weapons with a single analytic function is to assume that the approximating function has the same $t^{-1.2}$ decay law. That is, we wish to approximate Equation (1) with a function of the form of Equation (2)

$$I = \sum_{i=1}^{n} I_{oi} \, (t-t_i)^{-1.2} \qquad (t > t_i \text{ max}) \tag{1}$$

where I is the total intensity due to all contributing weapons, and I_{oi} and t_i are the reference intensity and the detonation time of the ith weapon, respectively,

$$I' = I_c\,(t-t_c) \qquad t > t_i \max \tag{2}$$

where I' is the approximation to the intensity, I_c is the composite reference intensity and t_c is the composite detonation time. Note that for I' to approach I as t becomes large (which is desirable in the context of this simulation model where we are computing denial times), then we must have

$$I_c = \sum_{i=1}^{n} I_{oi} \tag{3}$$

This characteristic of the approximating function seems so desirable that we have used it throughout the analysis presented below. Thus, there remains only one parameter at our disposal to fit the approximation to the composite decay curve. This is t_c, the composite detonation time. There are a myriad of ways in which this parameter might be chosen. A number of specific ways of evaluating t_c were tried and analyzed for the two-weapon case in terms of relative error in intensity and denial time (based both on an intensity constraint and on a dose constraint). These include t_c = detonation time of the second weapon (t_2); t_c chosen so that approximate and exact intensities at t_{2+1} are equal; and t_c chosen so that the slopes of I and I' curves match at t_{2+1}, and t_c = mean detonation time.

It soon became apparent, however, that the errors in the approximating function were small no matter how t_c was chosen, provided the denial times are long. The quantitative requirement is reasonable and is discussed subsequently. Of course, for a good fit it is clear that it must lie in the interval t_1 to t_n. Thus, the choice of t_c may be made on the basis of computational convenience. The computationally simplest choice is probably t_c = the mean detonation time of all the contributing weapons. The proof of these assertions follows:

II. DERIVATION OF RELATIVE ERROR OF APPROXIMATING FUNCTIONS

A. Dose Rate or Intensity

Define the error E(I) to be

$$E(I) = \frac{I' - I}{I} \qquad (4)$$

it may be shown that

$$E(I) = \left[\sum f_i \left(\frac{t-t_i}{t-t_c} \right)^{-1.2} \right]^{-1} - 1 \qquad (5)$$

where f_i is the fractional contribution to total reference intensity of the ith weapon and t_i is its time of detonation. To reduce the dimensionality of the problem, we choose t_1, the time of detonation of the first weapon to be zero, and we make the unit of time t_n, the time of detonation of the last weapon. Making these transformations, we rewrite Equation (5) as Equation (6)

$$E(I) = \left(\frac{X}{X-a} \right)^{1.2} \left[f_1 + f_2 \left(\frac{X}{X-t_{c/t_n}} \right)^{1.2} + \ldots + f_n \left(\frac{X}{X-1} \right)^{1.2} \right]^{-1} - 1 \qquad (6)$$

where $X = t/t_n$ and $a = t_c/t_n$ and now all the ratios of t_i/t_n fall in the interval 0 to 1. Note that as t/t_n becomes very large, E(I) approaches zero. Just how large t/t_n must be for E(I) to be acceptably small depends on the particular combination of the remaining variables. Since we are interested in this study in denial time accuracy rather than dose rate accuracy, we shall reserve the discussion of the range of parameter values yielding acceptably small errors to Paragraph D.

B. Relative Error in Denial Time Based on Intensity Constraint

When the denial time criterion is a maximum intensity or dose rate, IC, then t_f, the denial time is defined by:

$$(AVGP)\ (IC') = (I_c)\ (t_f - t_c)^{-1.2} \qquad (7)$$

where AVGP is the average protection factor available at the facility while carrying out the required operations. A similar expression holds for IC, the constraint based on the exact expression (3). Defining the relative error in denial time, $E(t_f)_{IC}$ by

$$E(t_f)_{IC} = (t_f' - t_f)/t_f \qquad (8)$$

and letting $t_1 = 0$ and t_n be our unit of time, we obtain Equation (9)

$$E(t_f)_{IC} = \left[f_1 + f_2 \left(\frac{X}{X - t_2/t_n} \right)^{1.2} + \ldots + f_n \left(\frac{X}{X-1} \right)^{1.2} \right]^{-5/6} - \left(1 - \frac{a}{X} \right) \qquad (9)$$

where $X = t_f/t_n$, $a = t_c/t_n$ and all t_i/t_n lie in the interval zero to one. Note also that as t_f/t_n (=X) becomes large, $E(t_f)_{IC}$ approaches zero no matter what the value of a or the f_i's. It however remains to be shown just how large t_f/t_n must be for acceptable accuracy. This will be done in Paragraph D.

C. Relative Error in Denial Time Based on Accumulated Dose

The Dose Constraint, D_{max} is defined by:

$$(AVGP)\ D'_{max} = \int_{t_f}^{\infty} I'dt \qquad (10)$$

and similarly, D_{max} for the exact intensity expression (3). Equating D'_{max} and D_{max}, we obtain the relative error in denial time based on a dose constraint, $E(t_f)_D$

$$E(t_f)_D = \left[f_1 + f_2\left(\frac{X}{X-(t_c/t_n)}\right)^{0.2} + \dots + f_n\left(\frac{X}{X-1}\right)^{0.2}\right]^{-5} - (1-\frac{a}{X}) \quad (11)$$

having let $t_1 = 0$ and t_n be our time unit, $X = t_f/t_n$ and $a = t_c/t_n$. Note that again $E(t_f)_D$ approaches zero as X becomes large. The parameter values, particularly the t_f/t_n, required to make these approximations acceptable will be discussed next.

D. The Value of t_f/t_n Required for an Acceptable Approximation

For any particular combination of parameters it is a simple matter to evaluate equations (6), (9), or (11) to obtain the value of t_f/t_n which makes the error less than 5 per cent say. For the two-weapon case one can even prepare plots showing the range of acceptable parameter values. For the purposes of this study, however, we must explore the more general case of n weapons. This we do by the following argument.

We have n weapons, detonating over time in the interval zero to one (detonation times are measured in units of t_i/t_n) and we approximate this with $a(t-t_c)^{-1.2}$ decay law. This approximation to the composite intensity curve will be better than the approximation to the most extreme n-weapon case in which all the weapons are detonated either at time zero or at time t_n provided this latter composite curve is approximated using the <u>same</u> t_c. Thus, if we find how large t_f must be to yield an acceptable error in the latter two cases, the same t_f will yield an even smaller error when the weapons are distributed in time over the interval t_1 to t_n (or zero to one if t_n is the time unit).

The n-weapon case now becomes a special case of the two-weapon case:

<u>Case 1</u>

$t_n = 0$ (all weapons detonated at time zero)

and t_c is equal to t_n, so $f_1 = 1$, $f_2 = 0$

or, <u>Case 2</u>

$t_n = t_n$ (all weapons detonated at t_n)

and $t_c = 0$, so $f_1 = 0$, $f_2 = 1$

We can now best show the results by arranging Equations (6), (9) and (11) in tabular form as follows:

TABLE B-I

<u>Analysis of Error as a Function of Denial Time</u>

	$E(I)$	$E(t_f)_{IC}$	$E(t_f)_D$
2-Weapon Equation	$\left(\frac{X}{X-a}\right)^{1.2}\left[f_1+f_2\left(\frac{X}{X-1}\right)^{1.2}\right]^{-1}$	$\left[f_1+f_2\left(\frac{X}{X-1}\right)^{1.2}\right]^{-5/6} - (1-\frac{a}{X})$	$\left[f_1+f_2\left(\frac{X}{X-1}\right)^{0.2}\right]^{-5} - (1-\frac{a}{X})$
<u>Case 1</u>: All w[illegible] deton[illegible] time [illegible] 1, $f_2 = 0$ and $a = t_c/t_n = 0$	$\left(\frac{X}{X-1}\right)^{1.2} - 1$	$1 - \left(1-\frac{1}{X}\right) = \frac{1}{X}$	$[1] - 1 + \frac{1}{X} = \frac{1}{X}$
<u>Case 2:</u> All weapons detonated at t_n, so $f_1 = 0$, $f_2 = 1$ and $t_c = 0$, so $t_c/t_n = a = 0$	$\left(\frac{X}{X-1}\right)^{-1.2} - 1$	$\frac{1}{X-1}$	$\frac{1}{X-1}$
<u>Case 1:</u> Values for X for a 5% error	$\left(\frac{X}{X-1}\right)^{1.2} - 1 \leq .05$ $X \geq 23\ 3$	$\frac{1}{X} \leq .05$ $X \geq 20$	$\frac{1}{X} \leq .05$ $X \geq 20$
<u>Case 2:</u> Values for X for a 5% error	$\left(\frac{X-1}{X}\right)^{1.2} - 1 \geq -.05$ $X \geq 23.8$	$\frac{X}{X-1} - 1 \leq .05$ $X \geq 21$	$\frac{X}{X-1} - 1 \leq .05$ $X \geq 21$

It is interesting to note that the restriction on t_f is slightly less stringent to achieve a 5 per cent error in denial time than it is on t to achieve a 5 per cent error in intensity, or dose rate, i.e., the denial times are less affected by the use of the approximation than are the intensities. The difference is, of course, not operationally significant.

Operationally then, if denial times are of the order of twenty times t_n, where t_n is the time interval between the first and last weapon affecting the facility, the error incurred by approximating the composite intensity with a single $t^{-1.2}$ decay law will be less than 5 per cent. Note that this is a conservative estimate. Some limited computations using the mean detonation time for the two-weapon case indicate that this requirement on denial time is more nearly ten times the interval between weapons to yield a 5 per cent error. If a 10 per cent error is tolerable, the requirements on t_f calculated as in Table B-1 would become $t_f \geq 10$ times the interval between the first and last contributing weapon.

We mention again that the above estimate is conservative; the requirement in t_f is more nearly five times the interval between weapons to yield a 10 per cent or less error on denial time. In cases of interest in this study, the interval between contributing weapons is presumably on the order of a day; hence this approximation is reasonable for denial times of the order of five to ten days.

Note in addition, a large percentage error on short denial times is not necessarily unacceptable; a large percentage error of a small number may still be an error acceptably small in absolute value not to affect our calculations. It is instructive therefore to find, for short denial times, the absolute value of the error. Using the first line of Table B-1 for the denial time based upon dose in the two-weapon case, one can deduce that for a time between first and last contributing detonations of 12 hours, an exact denial time (t_f) of one day, and equal contributions to the reference intensity ($f_1 = f_2 = 0.5$) the error in the denial time introduced by the approximation will be 4.8 hours. Further analyses can be undertaken using these equations of Table B-1 as required.

Appendix C

Analytical Relationship Among Radiation Dose, Decontamination, and Facility Denial Time

I. INTRODUCTION

The material in this Appendix was developed to determine the analytical relationship between decontamination and the recovery of facilities in the postattack period. In the development, the recovery of a facility is specified in terms of the total duration of an activity, Δt, required at the facility and the time when the facility can be considered open, T_f. This work is based largely on the results presented in Reference C-1, Radiological Recovery Concepts, Requirements and Structures. A glossary of the terms and symbols used is at the end of this appendix.

Other activity characteristics which affect the dose received by the personnel are absorbed into an activity intensity constant, H, which also accounts for the fallout radiation field characteristics. H may be considered to be the common H+1 reference intensity, I_o, at the place where the personnel are located. The allowable radiation dose, DMAX, which may be received in performing the activity is specified for personnel. This dose specification is made in terms of either total dose or equivalent residual dose (ERD), or both, depending upon the length of the activity duration. Decontamination is specified by its effectiveness, f_d, in causing a reduction in dose received by an individual in performing an operation.

The above parameters are not independent. Of the five (Δt, T_f, H, DMAX, f_d), any four may be regarded as independent and the fifth can be expressed in terms of them. The relationships between them are developed in the analysis section of this appendix. Although each parameter is treated as the dependent variable at some time in the analysis, the emphasis is placed on expressing T_f

as a function of H, DMAX, Δt, and f_d. The intent is to determine how the time when the facility is no longer denied by fallout, T_f, varies as a function of decontamination effectiveness, f_d, and the constraints, Δt, H, and DMAX. By holding these operating constraints constant, it is then possible to determine the difference between the time when the facility is no longer denied by fallout if decontamination <u>is</u> <u>not</u> applied, T_f^*, and the denial time if the countermeasure <u>is</u> employed, T_f. Decontamination must, of course, be completed before T_f.

This difference, $T_f^* - T_f$, is the time, T, that is saved in recovering an activity as a direct result of decontamination. This time saved is expressed in this report as a function of the operating constraints, Δt, DMAX, and H, and the countermeasure effectiveness, f_d. Sets of performance curves that describe the behavior of T as the four parameters vary singly are presented at the end of the analysis section as Figures C-15 through C-27.

In the final section of this appendix, these figures are examined in a broad, general manner to determine a rough impression of the range of situations where decontamination appears to be most valuable. The measure of value is the time saved. The situations obtained are based on the assumption that T should be at least one week, and that T should be at least 30 percent of T_f^*. Under these two assumptions it is shown that the range of potentially valuable application is specified by two inequalities, $f_d \leq .7$ and $H\Delta t \geq k(f_d)DMAX$. Here, $k(f_d)$ is a function of f_d whose value is determined from one of the curves in Figures C-24 through C-29. When $f_d = .7$, $k(f_d) - 100$ and range of application is defined by the inequality $H\Delta t \geq 100DMAX$. In addition, the more $H\Delta t$ exceeds 100DMAX, the more time is saved.

II. ANALYSIS

A. Introduction

By applying decontamination, it is possible to reduce the fallout denial time associated with a specified facility. The amount by which the denial time is reduced depends on the effectiveness of decontamination, the amount and distribution of radioactive fallout present in the area where the recoverable activity and/or facility is located, and on the personnel--their dose history and the additional allowable dose that they may receive in performing their activity.

In the following analysis, the radioactive fallout hazard is measured, at the facility where the activity is to be recovered, by the dose in roentgens that will be received by the individuals performing the activity. If this dose is called the performance dose, the effectiveness of decontamination is measured by the fractional reduction in the performance dose brought about by activating decontamination before resuming the activity. The allowable dose to be received in performing the activity is defined in three ways, depending on the duration of the activity: if the duration is less than four days, then the total dose is used; if the duration is more than four days but less than thirty days, then the equivalent residual dose (ERD) at the end of the activity is used; if the duration is sufficiently long that the ERD reaches a maximum in this period then the maximum ERD that is reached is used. Obviously, these three veiwpoints are not mutually exclusive.

The following analysis combines the above concepts and arrives at a measure of the reduction in denial time, $T_f^* - T_f$ achieved by decontamination applied to a particular situation when the allowable dose constraints are specified. The amount of reduction is measured by the "time saved" in resuming or initiating recovery activities on a facility. As will become apparent, interest is centered on facilities to be recovered during the first few days following detonation.

B. Dose Rate

The expression for dose rate which will be used in the subsequent development is

$$I(t) = Ht^{-1.2} \text{ roentgens/hour,} \tag{C-1}$$

where t is the time after detonation in hours and H is independent of time. This expression for dose rate will be used to determine the dose that will be received by an individual while he is performing the activity of interest.

In this expression, Equation C-1, the constant H depends on the particular situation and on the intent of the analyst. This constant relates the activity characteristics (location in the fallout field, facility AVGP,...) to the dose received in performing the activity. The scope and flexibility of the results produced by the subsequent analysis are critically dependent on the imagination utilized in interpreting H in a broad and flexible manner. In the simplest case of preattack planning the constant H may be set equal to $\frac{I_o}{AVGP}$ where I_o is the unit time reference intensity in the activity area and AVGP is the average fallout protection afforded the limiting activity on a given facility (e.g., the equivalent protection factor might be used; see Reference C-2, page 56). In the simplest case of postattack planning, H might be set equal to $Iy^{1.2}$ where I is the measured dose rate where the activity will be performed and y is the time after detonation when the measurement is made. These examples are presented to illustrate simple interpretations of H. More complicated or flexible interpretations will arise as the individual's (or individuals') behavior pattern varies in a complicated fashion over time. Irrespective of the particular interpretation, two rules must be followed. First, H must be independent of time; and second, if the activity is performed from time t_e to time $t_e + \Delta t$, where Δt is the activity duration, then H must be chosen so that the total dose[C-1] received by the individual in performing the activity is:

$$D_T = H\int_{t_e}^{t_e + \Delta t} x^{-1.2}\, dx \text{ roentgens.} \qquad \text{(C-2)}$$

C. Countermeasure Effectiveness

In the preceding section the constant H in the dose rate equation was chosen to relate the effect of the activity characteristics (radiation intensity, AVGP, ...) to the total dose received in performing the activity, Equation C-2. A similar constant, f_d, is chosen to show the effect of decontamination on the dose received in performing the activity. The constant, f_d, is chosen so that if the activity, which is the object of decontamination, is performed from time T_f to time $T_f + \Delta t$, then the total dose received by the individual in performing the activity when decontamination is not activated will be

$$D_T = H\int_{T_f}^{T_f+\Delta t} x^{-1.2}\, dx \text{ roentgens,} \qquad \text{(C-3)}$$

and when decontamination is completed before time T_f, will be

$$D_T = f_d H\int_{T_f}^{T_f+\Delta t} x^{-1.2}\, dx \text{ roentgens.} \qquad \text{(C-4)}$$

Values of f_d that lie between zero and one ($0 \leq f_d \leq 1$) are the only ones of operational significance. Notice that when f_d is set equal to 1, the countermeasure is, in effect, not activated.

[C-1] Throughout this paper, D_T will refer to total dose, D_R will refer to equivalent residual dose (ERD), and DMAX will refer to a dose that is either total dose or ERD. In both cases, D_T and D_R are calculated assuming zero prior dose. This assumption dose not restrict the usefulness of the analysis. Prior dose enters into the application of the analysis when a determination is made of the allowable subsequent dose.

D. Activity Performance Dose

While performing a given activity, the individual will receive a certain dose of radiation. Because it is not clear how hazardous a certain dose of radiation is to an individual, two approaches to the dose received will be taken in the subsequent development. The first approach will be to determine the total dose received,

$$D_T = f_d H \int_{T_f}^{T_f+\Delta t} x^{-1.2}\, dx \text{ roentgens,} \qquad \text{(C-4)}$$

when the activity is performed from time T_f to time $T_f+\Delta t$,

$$D_R = \underset{t}{\text{maximum}} \left\{ f_d H \int_{T_f}^{t} W(t-x)\, x^{-1.2}\, dx \right\} \text{ roentgens,} \qquad \text{(C-5)}$$

$$T_f \leq t \leq T_f + \Delta t$$

where W(t-x) is a function used to weight the dose rate in order to account for the effect of biological repair and recovery.

For the first approach, the total dose received, from Equation C-4, is,

$$D_T = f_d H\ (5(T_f^{-.2} - (T_f + \Delta t)^{-.2}) \text{ roentgens.} \qquad \text{(C-6)}$$

It has been shown in Reference C-1 that this expression can be approximated as follows:

$$D_T = f_d H \Delta t\ (T_f + \frac{\Delta t}{2})^{-1.2} \text{ roentgens.} \qquad \text{(C-7)}$$

The concomitant error is less than 1 percent when $\frac{T_f}{\Delta t} \geq 2.85$ and is less than 5.2 percent when $\frac{T_f}{\Delta t} \geq 1.0$. Because this error is small and its bound is known, Equation C-7 will be used to determine the total dose received in the performance of the activity. This equation is graphed in Figure C-1 where $\frac{D_T/\Delta t}{f_d H}$ is displayed as a function of earliest activity entry time (which is, of course, the fallout denial time), T_f, for selected activity durations, Δt, = 1 day, 4 days, 16 days, and 32 days. Therefore, in Figure C-1 the normalized effective intensity, $\frac{D_R}{f_d H\ t}$, is displayed as a function of T_f.

For the second approach, the maximum ERD received is determined from Equation C-5 for two separate cases: Case I, where the maximum occurs at the end of the activity (when $t = T_f + \Delta t$) and Case II, where the maximum occurs before the end of the activity (when $t \leq T_f + \Delta t$.) In both cases it is necessary to begin by selecting the appropriate weighting function W(t). A weighting function commonly used to approximate the effect of biological repair and recovery is (See Reference C-3),

$$W(t) = .1 + .9e^{-.024t}. \qquad \text{(C-8)}$$

This approximation is shown in Figure 2 along with the function

$$W(t) = .1 - .016t, \qquad \text{(C-9)}$$

which will be used in this discussion to approximate the biological effect for Case I when $t \leq 35$ days. Substituting Equation C-9 in Equation C-5, the maximum ERD for Case I becomes:

$$D_R = f_d H \int_{T_f}^{T_f+\Delta t} (1-.016(T_f+\Delta t-x))\ x^{-1.2} dx \qquad \text{(C-10)}$$

or

$$D_R = f_d H(1-.016T_f-.016\Delta t) \int_{T_f}^{T_f+\Delta t} x^{-1.2}\ dx$$

$$+ f_d H\ .016 \int_{T_f}^{T_f+\Delta t} x^{-0.2}\ dx \text{ roentgens}, \qquad \text{(C-11)}$$

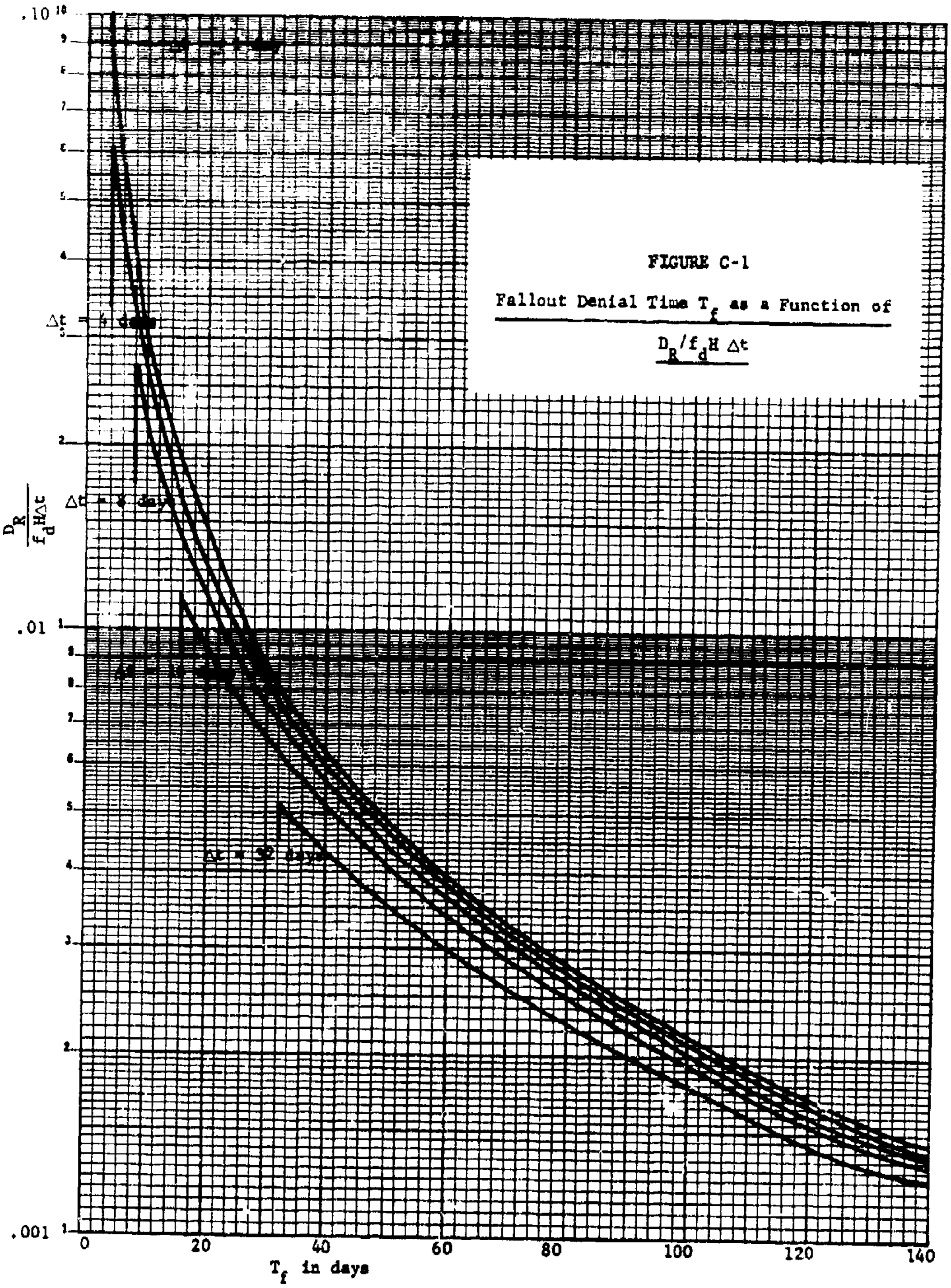


FIGURE C-1

Fallout Denial Time T_f as a Function of $D_R/f_d H\ \Delta t$

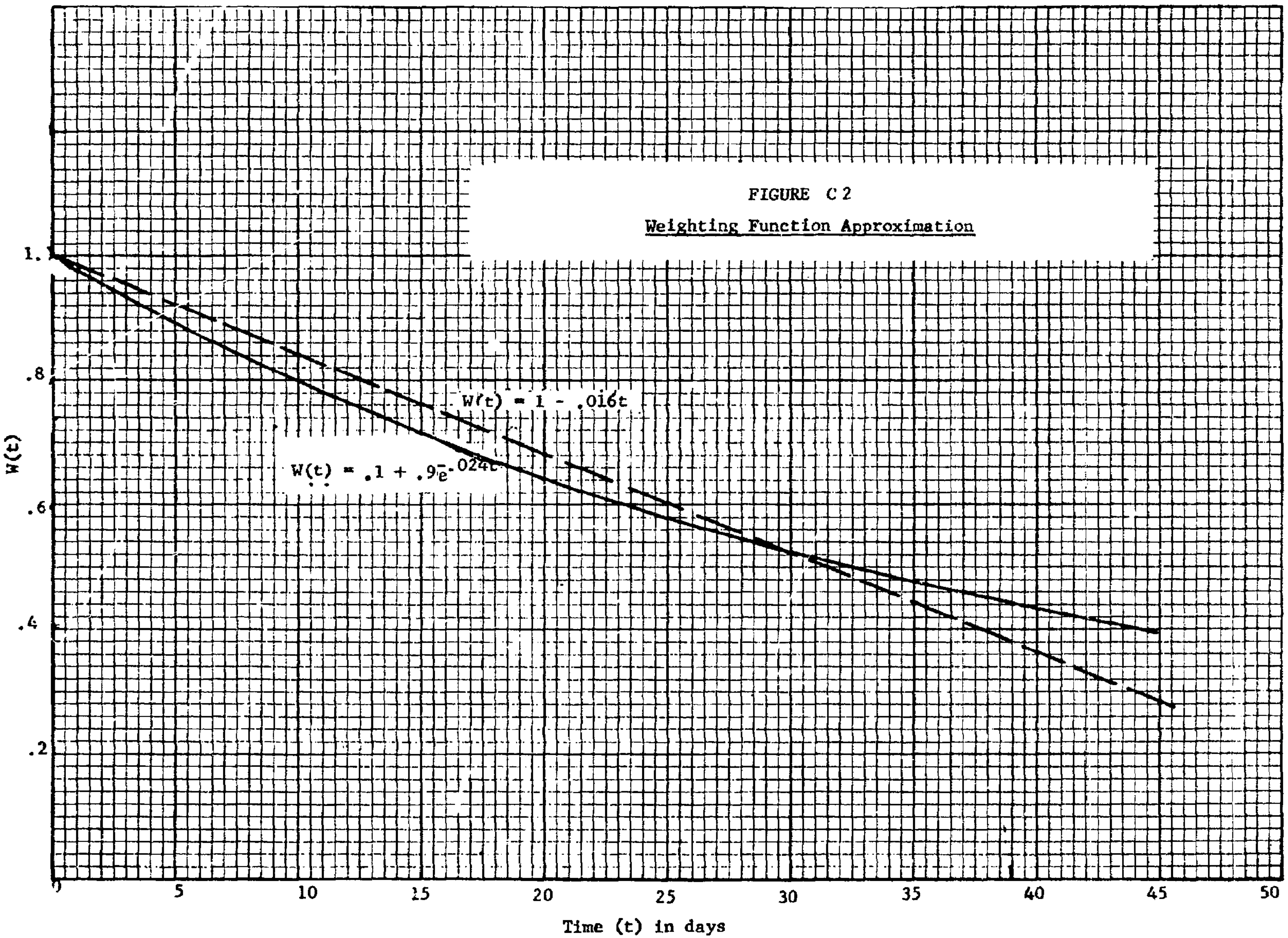


FIGURE C 2

Weighting Function Approximation

which can be approximated to the same accuracy as D_T (in Equation C-7) as follows:

$$D_R = f_d H \; (1-.016(T_f + \Delta t(T_f + \frac{\Delta t}{2})^{-1.2}$$

$$+ f_d H \; .016 \; (T_f + \frac{\Delta t}{2}) \; \Delta t(T_f + \frac{\Delta t}{2})^{-1.2} \qquad \text{(C-12)}$$

$$= f_d H \Delta t \; (1-.008\Delta t) \; (T_f + \frac{\Delta t}{2})^{-1.2} \text{ roentgens.} \qquad \text{(C-13)}$$

Combining Equation C-7 with Equation C-13, this becomes:

$$D_R = (1-.008\Delta t) \; D_T \text{ roentgens.} \qquad \text{(C-14)}$$

This equation will be used to determine the ERD in Case I where it reaches a maximum at the conclusion of the activity performance. This equation is graphed in Figure C-3 where $\frac{D_R/\Delta t}{f_d H}$ is displayed as a function of activity entry time or fallout denial time T_f, for selected activity durations, $\Delta t = 1, 4, 8, 16, 32$ days.

In Case II, where the maximum (Equation 5) occurs for $t < T_f + \Delta t$, a slightly different approach will be used. First, it is necessary to use an approximation for W(t) that is applicable over a wider range of t's. The function which will be used is

$$W(t) = \begin{cases} .96 - .0135t & 0 \leq \frac{t}{24} \leq 40 \\ .6 - .0045t & 40 < \frac{t}{24} \leq 92 \; , \\ .27 - .000914t & 92 < \frac{t}{24} \; . \end{cases} \qquad \text{(C-15)}$$

where t is in hours. This function is shown in Figure C-4 along with the common approximation given as Equation C-8. If this expression, with t-x substituted for t, is used to replace W(t-x) in Equation C-5, then the integration can be performed and the derivative of D_R with respect to t can be taken. Setting this derivative equal to zero produces the t's that maximize the dose D_R.

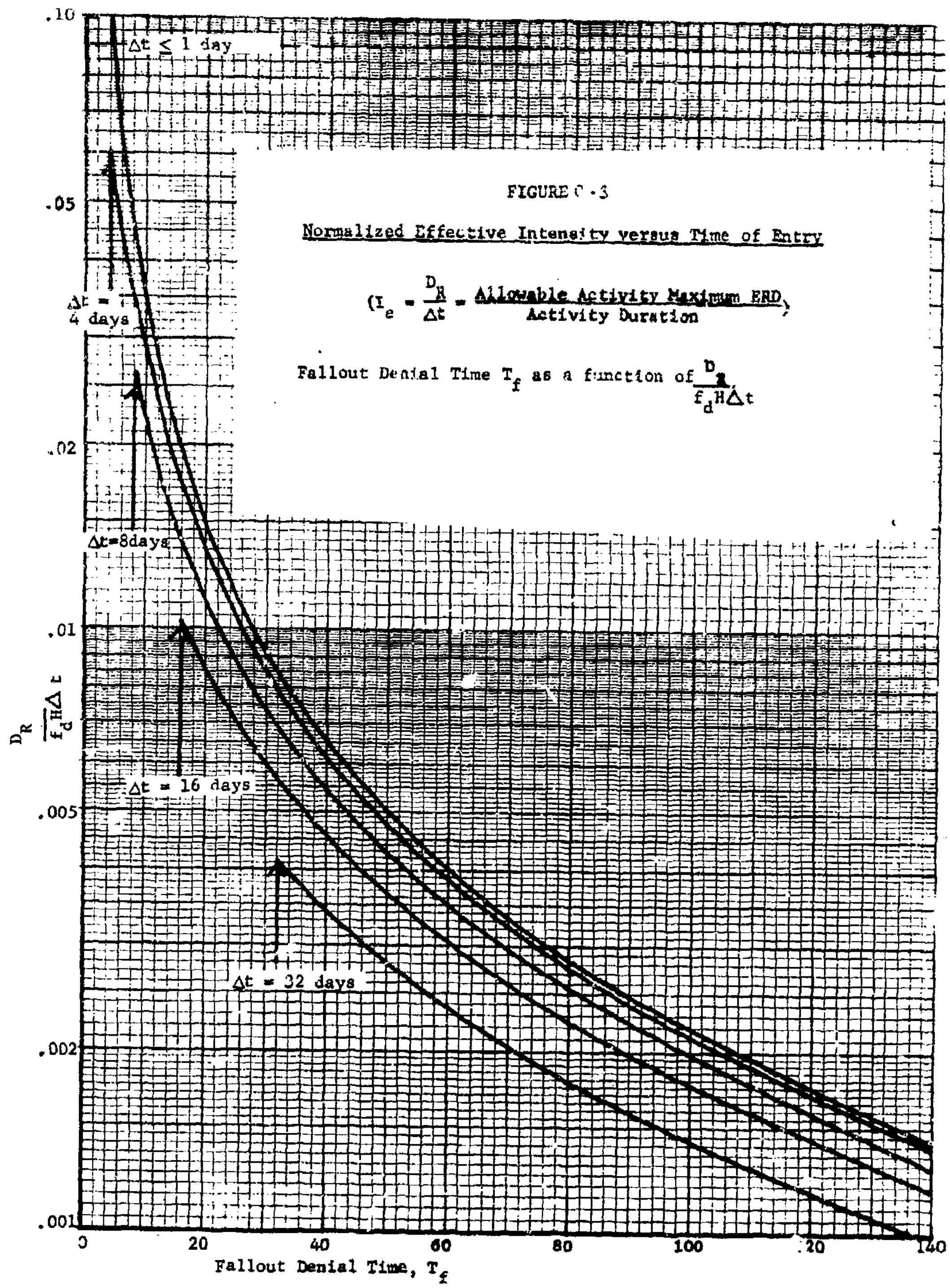


FIGURE C-3

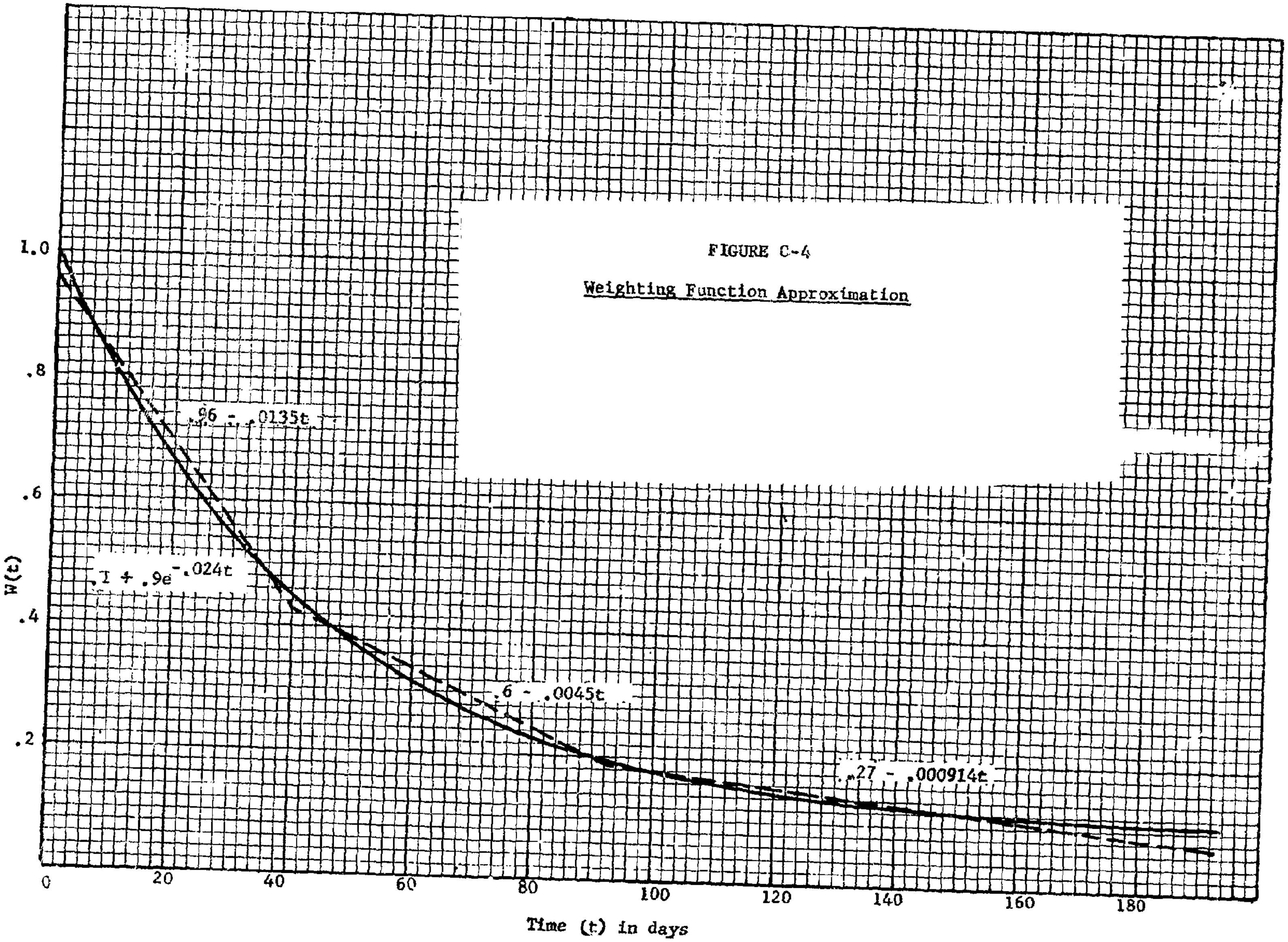
Normalized Effective Intensity versus Time of Entry

$$\left(I_e = \frac{D_R}{\Delta t} = \frac{\text{Allowable Activity Maximum ERD}}{\text{Activity Duration}}\right)$$

Fallout Denial Time T_f as a function of $\frac{D_R}{f_d H \Delta t}$

FIGURE C-4

Weighting Function Approximation



These t's (denoted by t_m) are graphed in Figure C-5 as a function of T_f. The discontinuity in the first derivative of this function that appears when T_f is 21 days in Figure C-5 is the result of the discontinuity in the first derivative of W(t) as given in Equation C-15. It is useful to smooth the function in the region surrounding $T_f = 21$ days and replot the function. This has been done to arrive at Figure C-6, which presents $t_m - T_f = \Delta t_m$ (that is, the time interval between T_f and the time when the ERD becomes a maximum) as a function of T_f. The value of the corresponding maximum ERD is presented in Figure C-7 as a function of T_f. This illustration, Figure C-7, presents the normalized maximum ERD, $\frac{D_R}{f_d H}$, as a function of the fallout denial time, T_f, for the Case II situations where the maximum occurs before the activity is completed. Therefore, Figure C-7 applies to situations where the activity durations, Δt, are greater than the $t_m - T_f = \Delta t_m$ values given in Figure C-6 as a function of T_f.

To compare the Case II approach to ERD that produced Figure C-7 with the Case I approach to ERD that produced Figure C-3, it is necessary to introduce a fictitious Δt into Figure C-7. If this is done, then the Case II result can be redrawn as $\frac{D_R/\Delta t}{f_d H}$ versus T_f and then compared with the Case I graph in Figure C-3. To do this, the most logical Δt to use in the Case II approach is $\Delta t_m = t_m - T_f$ as presented in Figure C-6 as a function of T_f. Figure C-8 was obtained for such a comparison by dividing the $\frac{D_R}{f_d H}$ values in Figure 7 by the $t_m - T_f$ values in Figure C-6. The dashed line included in Figure C-8 is the curve for $\Delta t = 32$ from Figure 3 extended to intersect the solid line (Case II approach) at the proper position.

This completes the second approach to the dose received in the performance of a certain activity. The results of the two approaches (Figures 1, 3, and 7) are summarized in Figure C-9 where the normalized total dose $\frac{D_T}{f_d H}$,

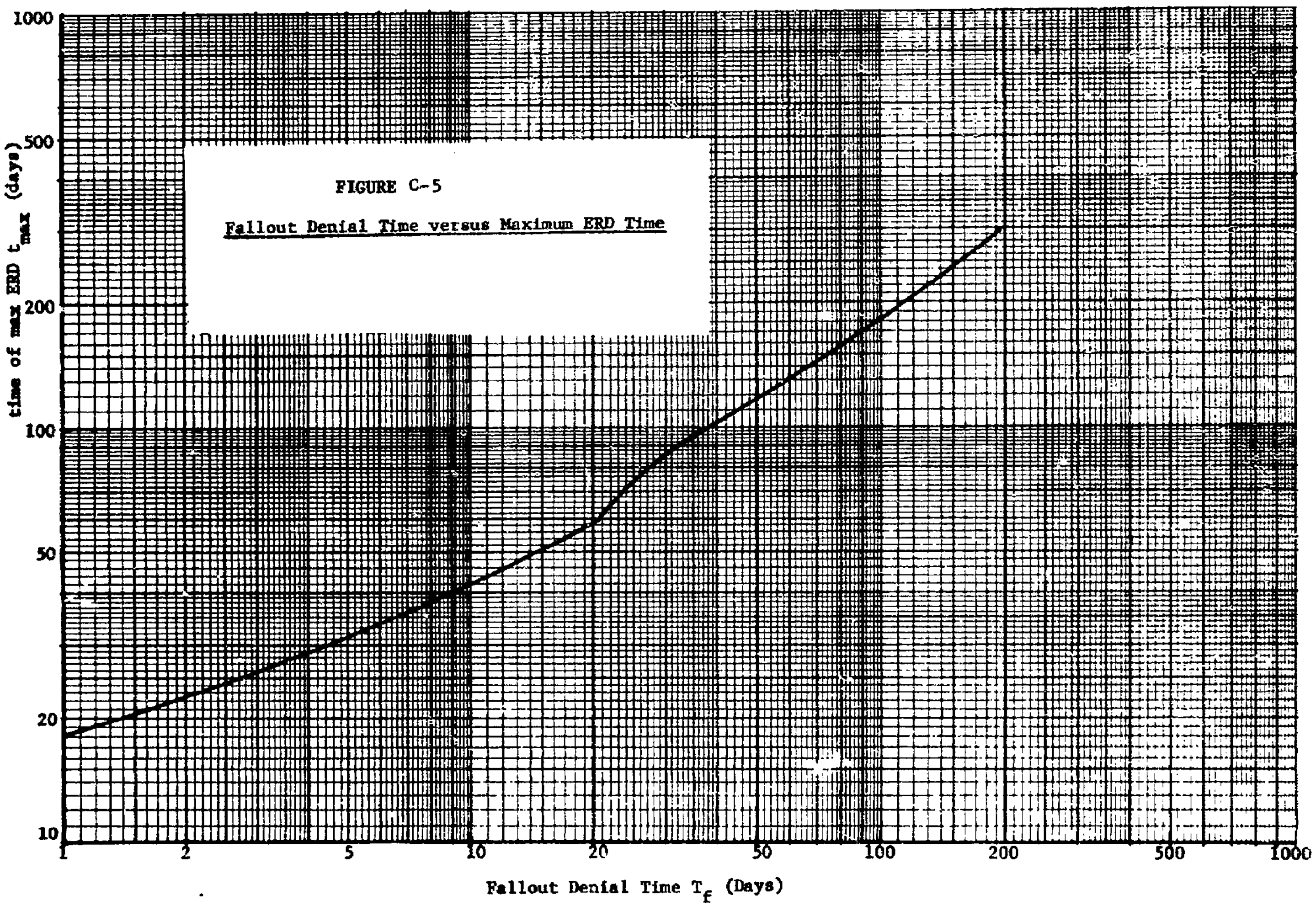


FIGURE C-5

Fallout Denial Time versus Maximum ERD Time

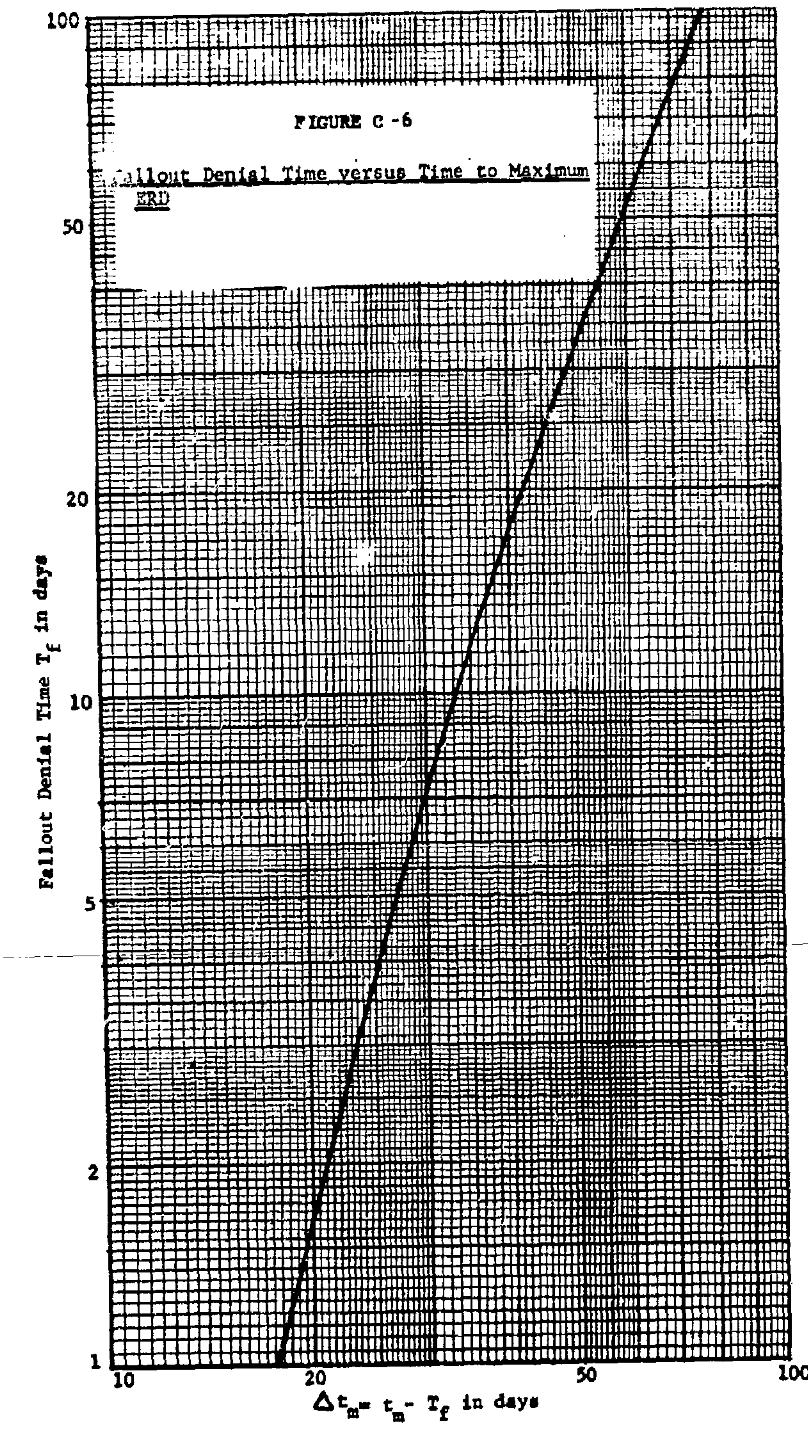


FIGURE C-6
Fallout Denial Time versus Time to Maximum ERD
100
50
20
10
5
2
1
Fallout Denial Time T_f in days
10
20
50
100
$\Delta t_m = t_m - T_f$ in days

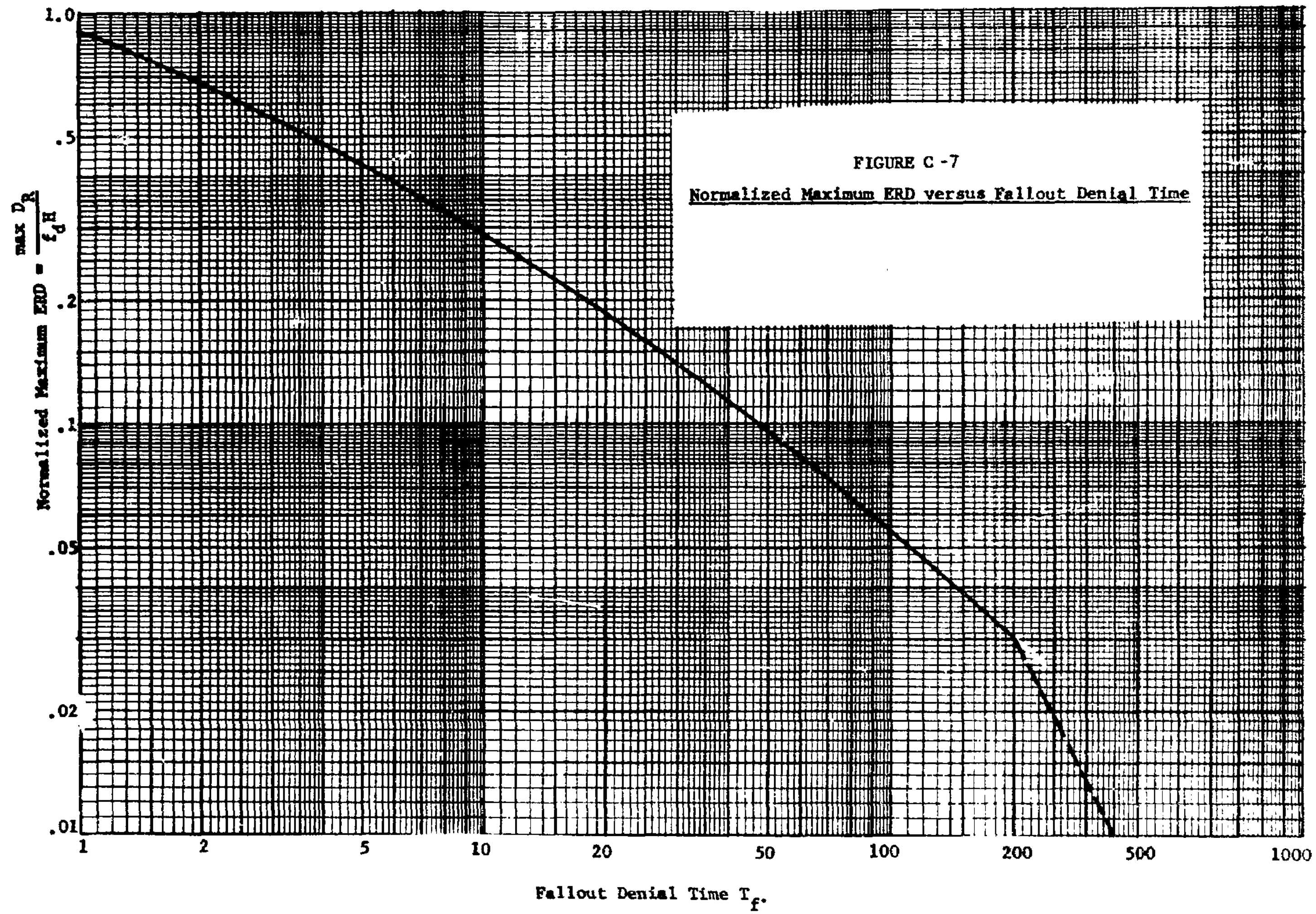


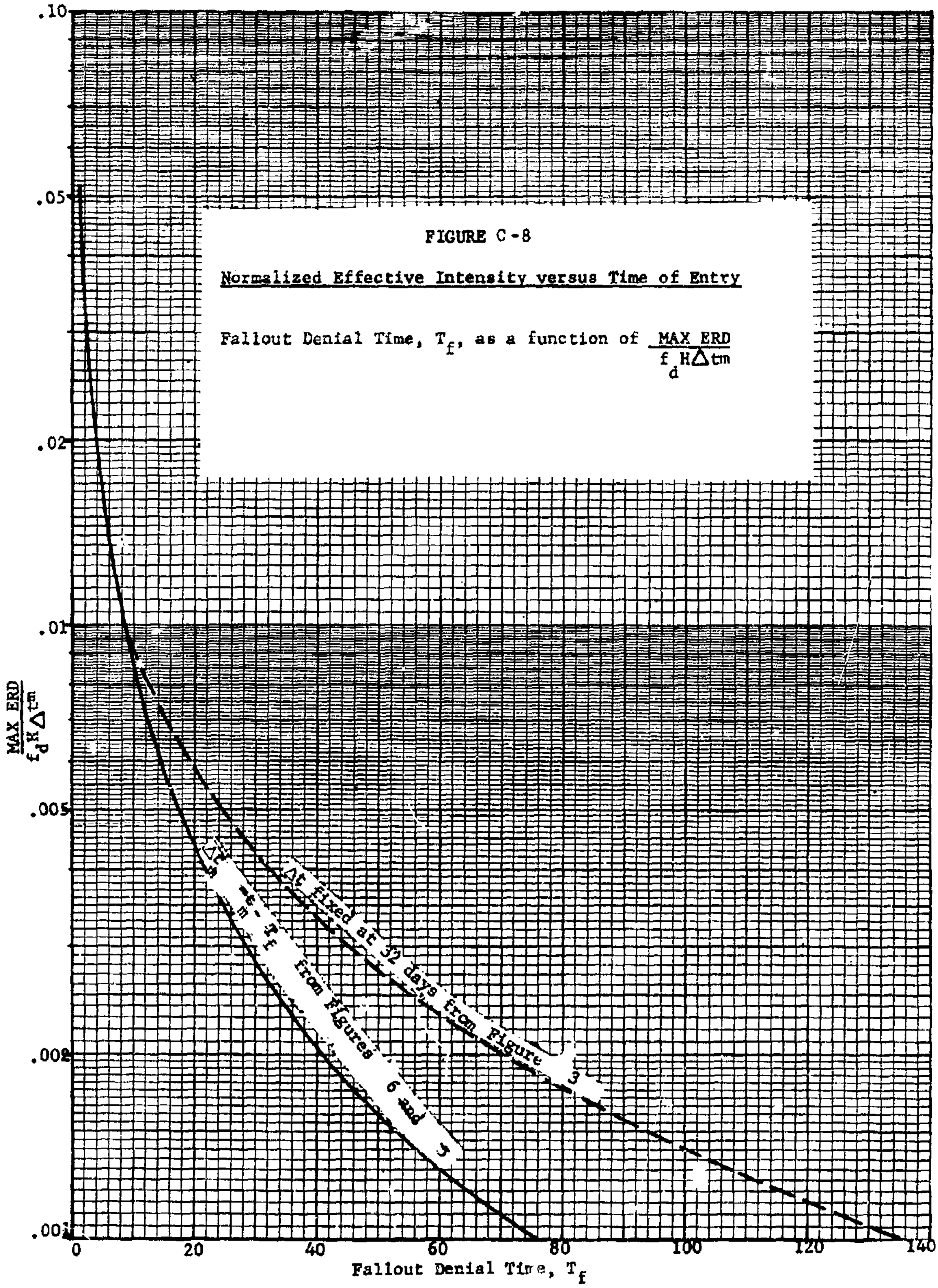
FIGURE C-7

Normalized Maximum ERD versus Fallout Denial Time

FIGURE C-8

Normalized Effective Intensity versus Time of Entry

Fallout Denial Time, T_f, as a function of $\frac{\text{MAX ERD}}{f_d H \Delta t_m}$



and normalized maximum ERD, $\frac{D_R}{f_d H}$, are displayed as a function of fallout denial time, T_f, and activity duration, Δt. In the following section, these functions will be inverted to display the fallout denial time when the duration, Δt, and the dose to be received, D_R or D_T, are specified.

E. <u>Fallout Denial Time when Δt and DMAX are Specified</u>

The fallout denial time can be thought of as the time before which a specified activity cannot begin if the duration, Δt, and the dose, D_R or D_T, are specified. In the previous discussion the dose was determined in terms of the fallout denial time, T_f, and the activity duration, Δt. These same expressions can be inverted to give the fallout denial time, T_f, in terms of the dose and the duration. Expressed in this manner, T_f is the activity entry lead time.

The lead time will depend on the normalized dose, the type of dose (ERD or total dose), and the duration. If the interest is in a specified total dose, then from Equation C-7, the lead time is:

$$T_f = \left(\frac{f_d H \Delta t}{D_T}\right)^{.833} - \frac{\Delta t}{2} \text{ hours.} \qquad \text{(C-16)}$$

If the interest is in a specified maximum ERD occurring at time $T_f + \Delta t$, Case I, then from Equation 13 the lead time is:

$$T_f = \left(\frac{f_d H \Delta t}{D_R}\right)^{.833} (1-.008\Delta t)^{.833} - \frac{\Delta t}{2} \text{ hours.} \qquad \text{(C-17)}$$

If the interest is in a specified maximum ERD occurring before time $T_f + \Delta t$, Case II, then the lead time is graphically determined from Figure 7.

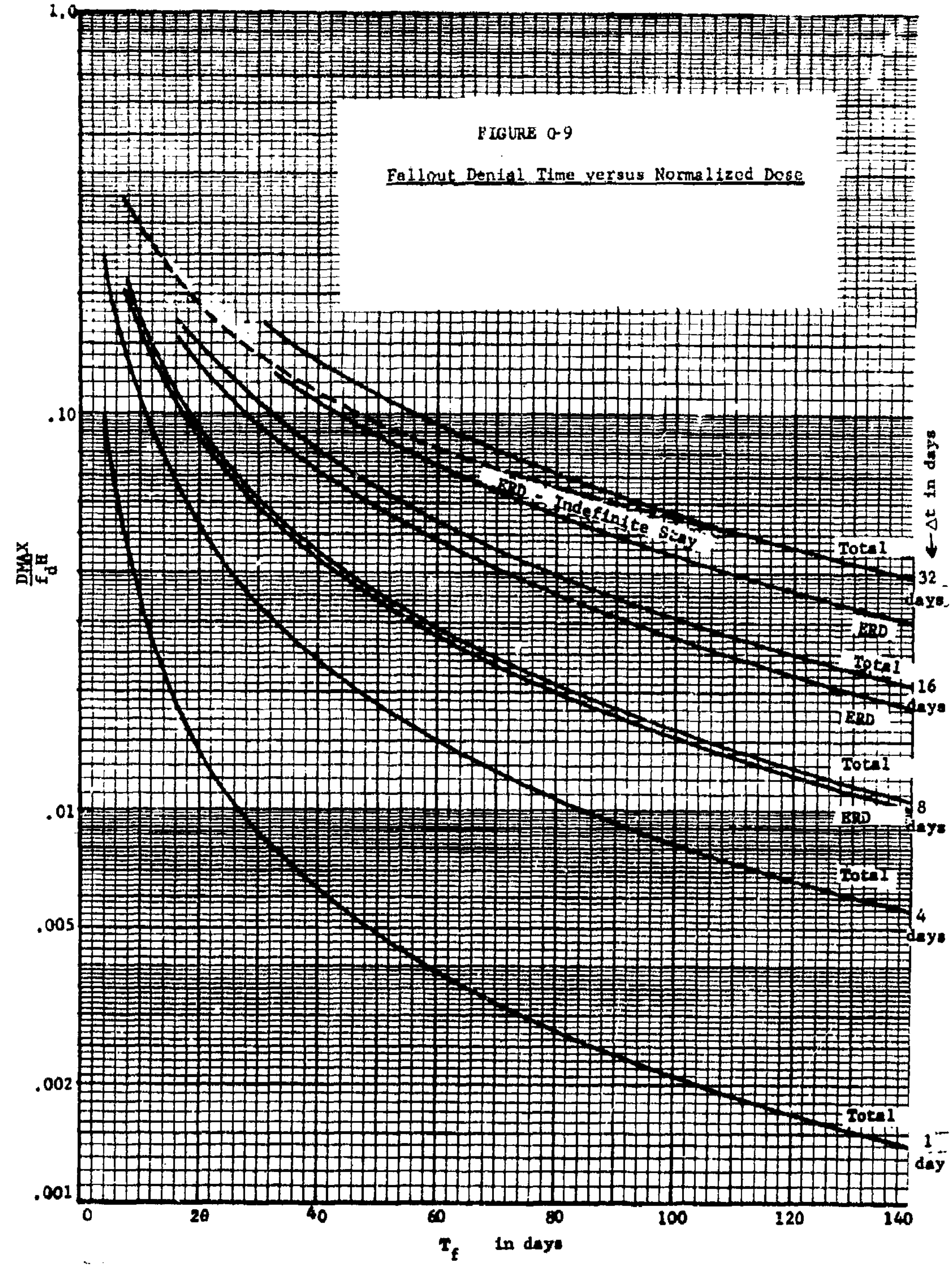


FIGURE C-9
Fallout Denial Time versus Normalized Dose
1.0
.10
.01
.005
.002
.001
$\frac{DMAX}{f_d H}$
0
20
40
60
80
100
120
140
T_f in days
ERD - Indefinite Stay
Total
32 days
ERD
Total
16 days
ERD
Total
8 days
ERD
Total
4 days
Total
1 day
← Δt in days

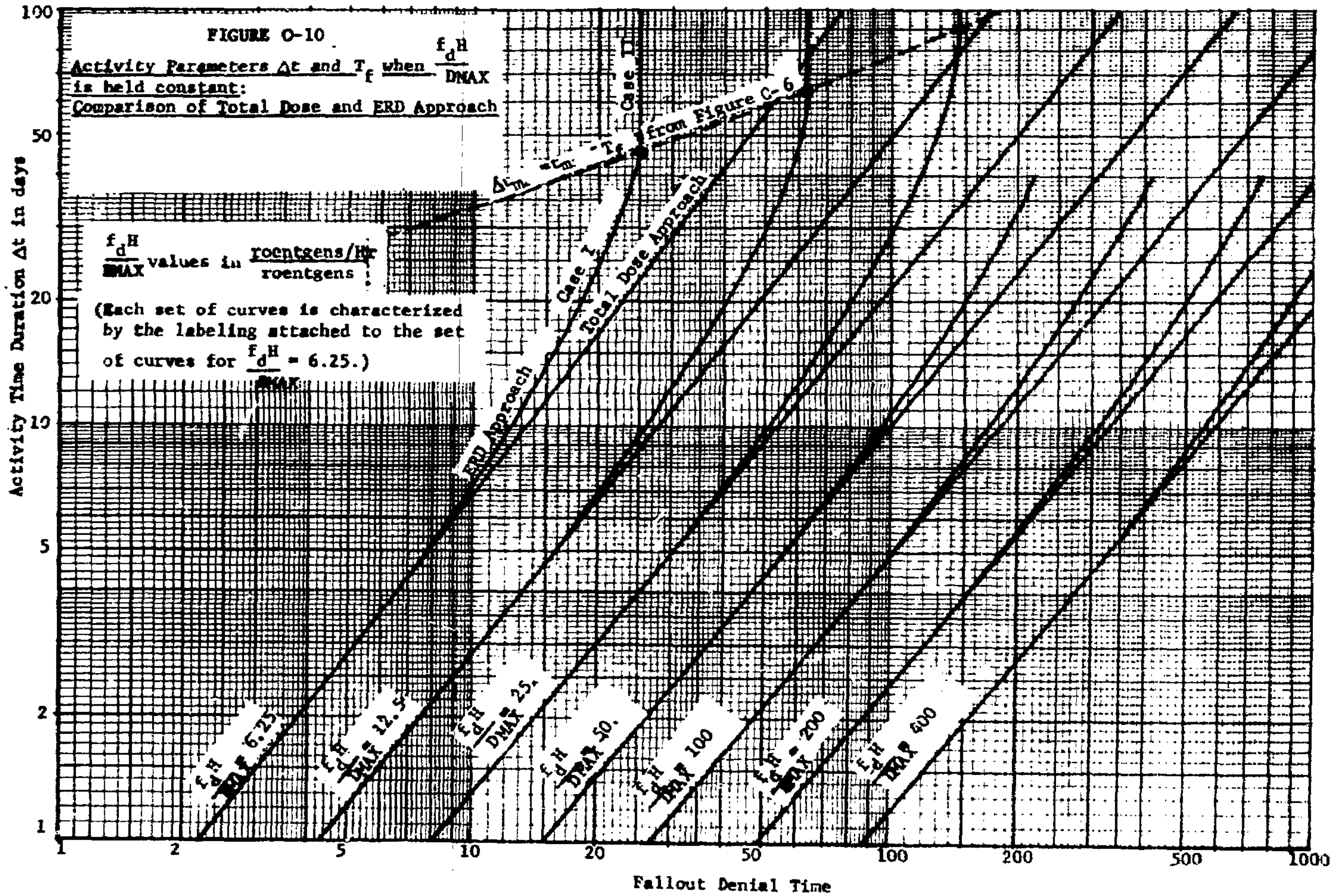


FIGURE C-10

Activity Parameters Δt and T_f when $\frac{f_d H}{DMAX}$ is held constant: Comparison of Total Dose and ERD Approach

These three approaches to the activity entry lead time are shown in Figure 9 (T_f versus normalized dose) and in Figure 10 (T_f versus activity duration Δt). These two figures and Equations 16 and 17 will be used in the following discussion to determine the effect of the countermeasure, F_d, on reducing the lead time.

F. Countermeasure Effect on Lead Time

From the lead time equations (Equations 16 and 17) it can be seen that as the decontamination effectiveness increases (that is, as f_d decreases) the lead time, T_f, decreases. This effect can be viewed as the lead time saved, T, as follows:

$$T = T_f^* - T_f \text{ hours} \tag{C-19}$$

where T_f^* is the lead time without decontamination (a result of setting f_d equal to 1) and T_f is the lead time with decontamination. Therefore, the time saved when the total dose is specified is, from Equation 16,

$$T = \left(\frac{H}{DMAX/\Delta t}\right)^{.833} (1-f_d{}^{.833}) \text{ hours.} \tag{C-20}$$

From Equation C-17, the time saved when maximum ERD, occurring at time $T_f + \Delta t$, is specified, Case I, is

$$T = (1-.008\Delta t)^{.833} \left(\frac{H}{DMAX/\Delta t}\right)^{.833} (1-f_d{}^{.833}) \text{ hours.} \tag{C-21}$$

In these two equations (Equation C-20 and Equation C-21) care must be exercised in estimating the error. The error arises out of the error that is contained in T_f^* and in T_f in Equation C-19. Because these two terms in

Equation 19 are of opposite sign, the errors are also of opposite sign. Therefore, the error in T is less than either the error in T_f^* or the error in T_f. Because both T_f^* and T_f involve the same time interval, Δt, and because T_f is less than T_f^*, the dominant error arises out of the T_f term. This error increases as T_f decreases and hence, increases as f_d decreases (see Equations C-16 and C-17). Therefore, Equations C-20 and C-21 cannot be used as f_d approaches zero. (The actual error in T is less than the error in T_f, which is less than the error in D_T as given in the paragraph following Equation C-7.) If one is careful not to apply Equation C-20 when f_d approaches zero (and, normally, when f_d is less than .2), then Equation 20 can be interpreted as the product of potential maximum time saved,

$$T_m = \left(\frac{H\Delta t}{DMAX}\right)^{.833}, \qquad \text{(C-22)}$$

and the fraction realized due to imperfect countermeasure effectiveness,

$$F = (1-f_d^{\,.833}) , \qquad \text{(C-23)}$$

as follows:

$$T = T_m F . \qquad \text{(C-24)}$$

Similarly, Equation 21 can be interpreted as the product of T_m, F, and the result of biological recovery,

$$B = (1-.008\Delta t)^{.833} \qquad \text{(C-25)}$$

as follows:

$$T = T_m FB. \qquad \text{(C-26)}$$

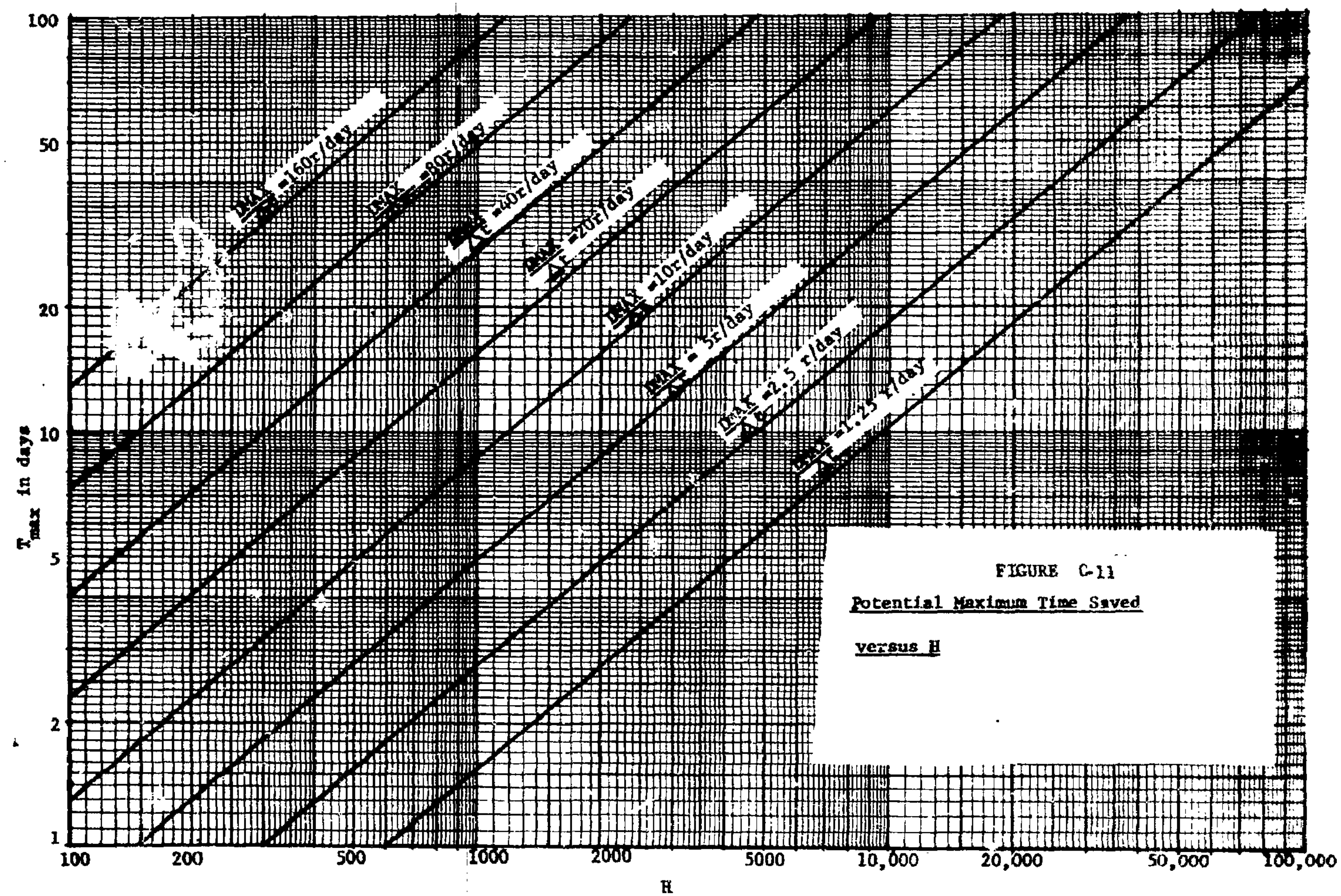


FIGURE C-11

Potential Maximum Time Saved

versus H

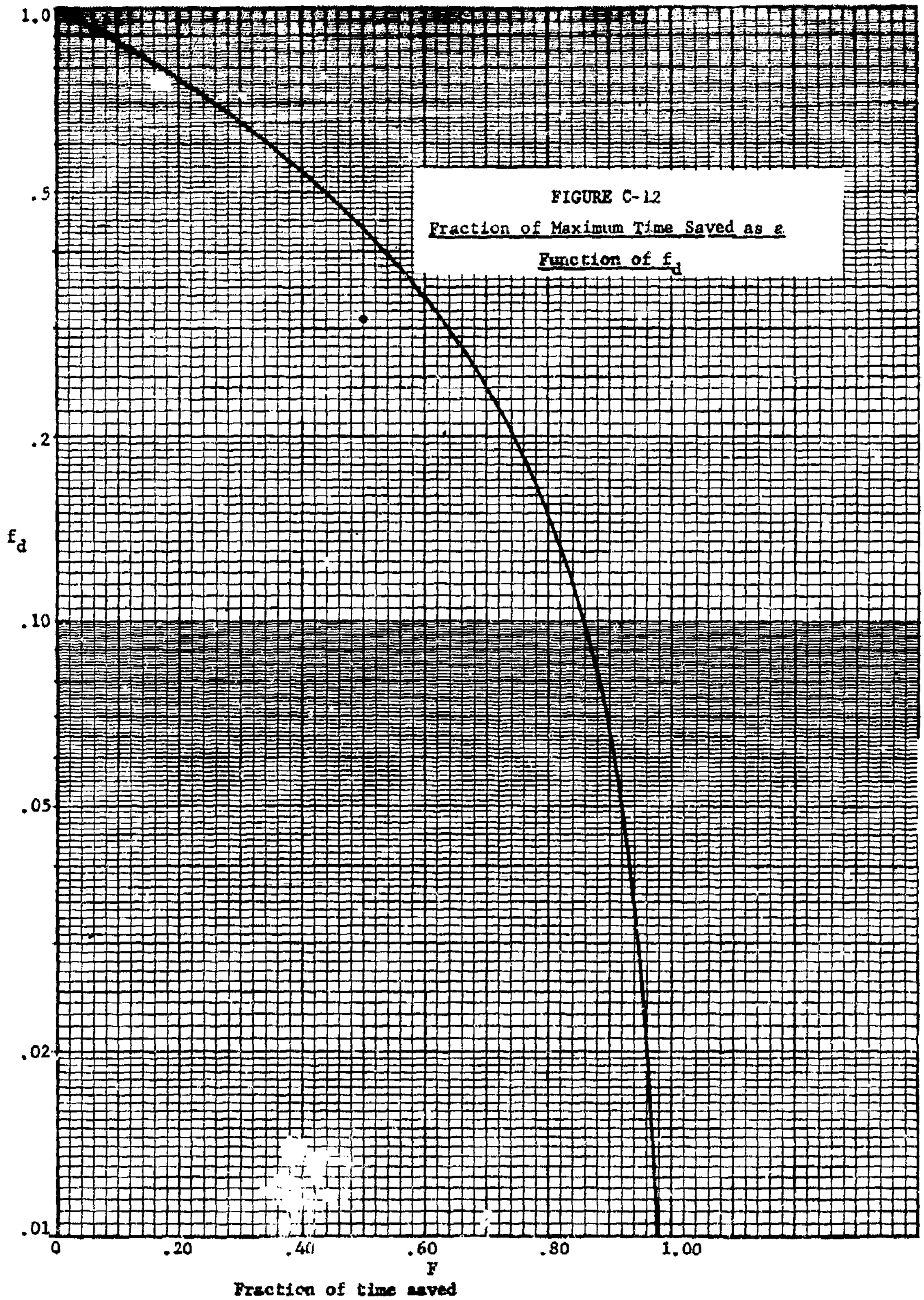


FIGURE C-12
Fraction of Maximum Time Saved as a Function of f_d
1.0
.5
.2
f_d
.10
.05
.02
.01
0
.20
.40
.60
.80
1.00
F
Fraction of time saved

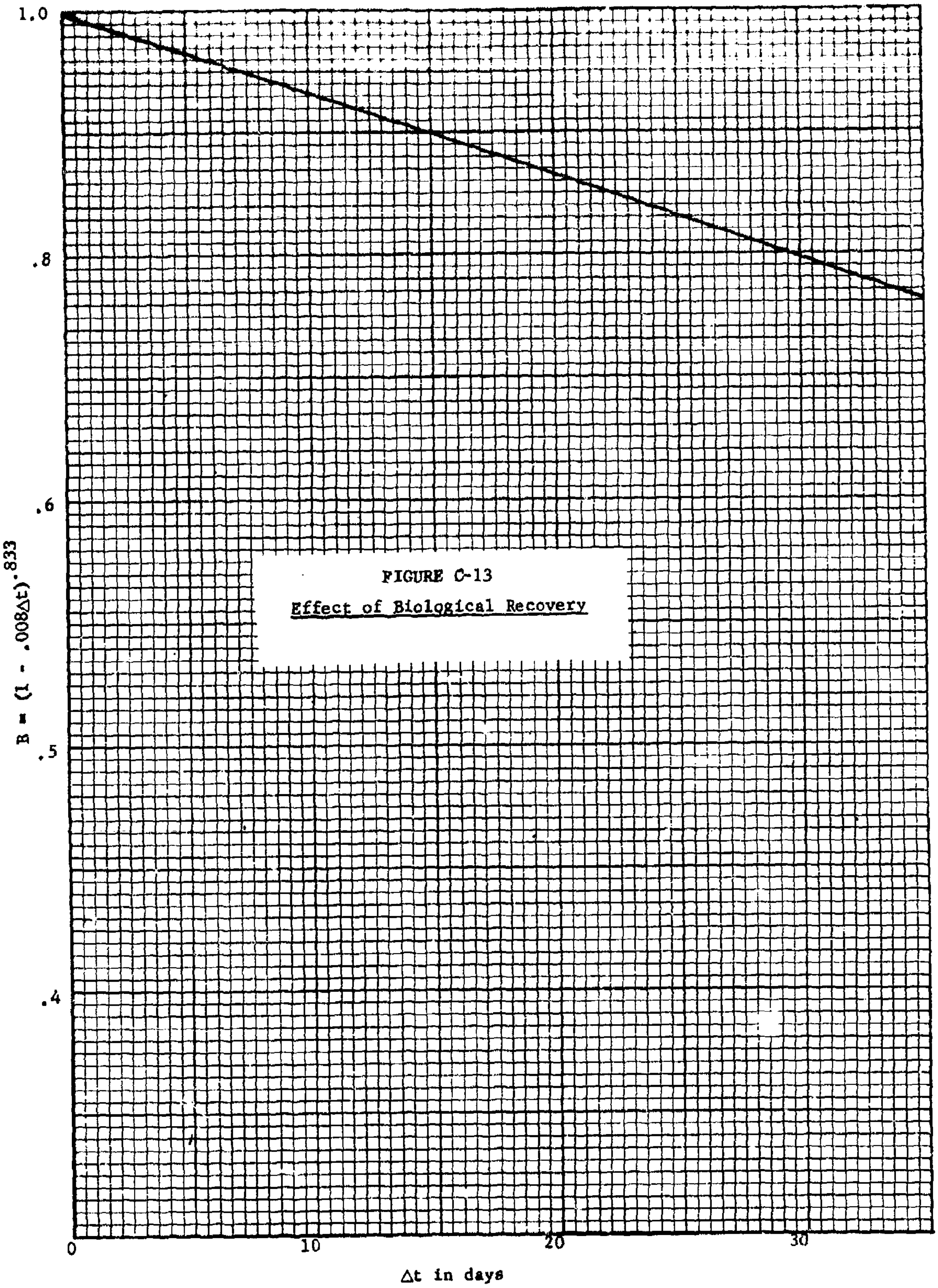


FIGURE C-13

Effect of Biological Recovery

By interpreting Equations 20 and 21 in this manner it is easy to quickly determine the effectiveness of f_d, of allowable ERD or total dose constraints, and of $\frac{H\Delta t}{DMAX}$ in reducing the lead time to activity resumption with countermeasure effectiveness, f_d, when the other variables are constrained in a particular manner. Two different methods of constraining the variables are used to produce two sets of surves. In the first set of curves (solid lines), the normalized intensity, $\frac{DMAX}{H\Delta t}$ is fixed. If this is viewed as $\frac{DMAX}{f_d H\Delta t}$ with f_d set equal to unity, then the corresponding solid curves relate the time saved to f_d when the time to the center of the performance interval, $T_f + \frac{\Delta t}{2}$, is held constant. This interpretation follows directly from Equation u, which has $T_f = \frac{\Delta t}{2}$ equal to $\frac{f_d H\Delta t}{DMAX}^{.833}$ times a constant. Because $f_d = 1$, the above fallout denial time T_f is the time the activity may commence when the countermeasure is not activated. In summary, when the activity-intensity characteristics, H, the allowable dose, D_T, and the activity duration, Δt, are specified, the solid curve for $\frac{D_T}{H\Delta t}$ defines that situation and shows how the time saved in commencing the activity depends on the countermeasure effectiveness, f_d. For the same situation, the actual fallout denial time can be determined from Figure C-1.

The second set of curves (dashed lines) in Figure C-14 is developed by holding constant the fallout denial time with decontamination activated. This is accomplished by altering the form of Equation C-20 as follows:

$$T = \left(\frac{H\Delta t}{DMAX}\right)^{.833} (1-f_d^{.833}) , \qquad \text{(C-20)}$$

$$\left(\frac{f_d H\Delta t}{DMAX}\right)^{.833} f_d^{-.833} -1). \qquad \text{(C-27)}$$

In the dashed curves, the first factor, $\left(\frac{f_d H\Delta t}{DMAX}\right)^{.833}$, has been held constant.

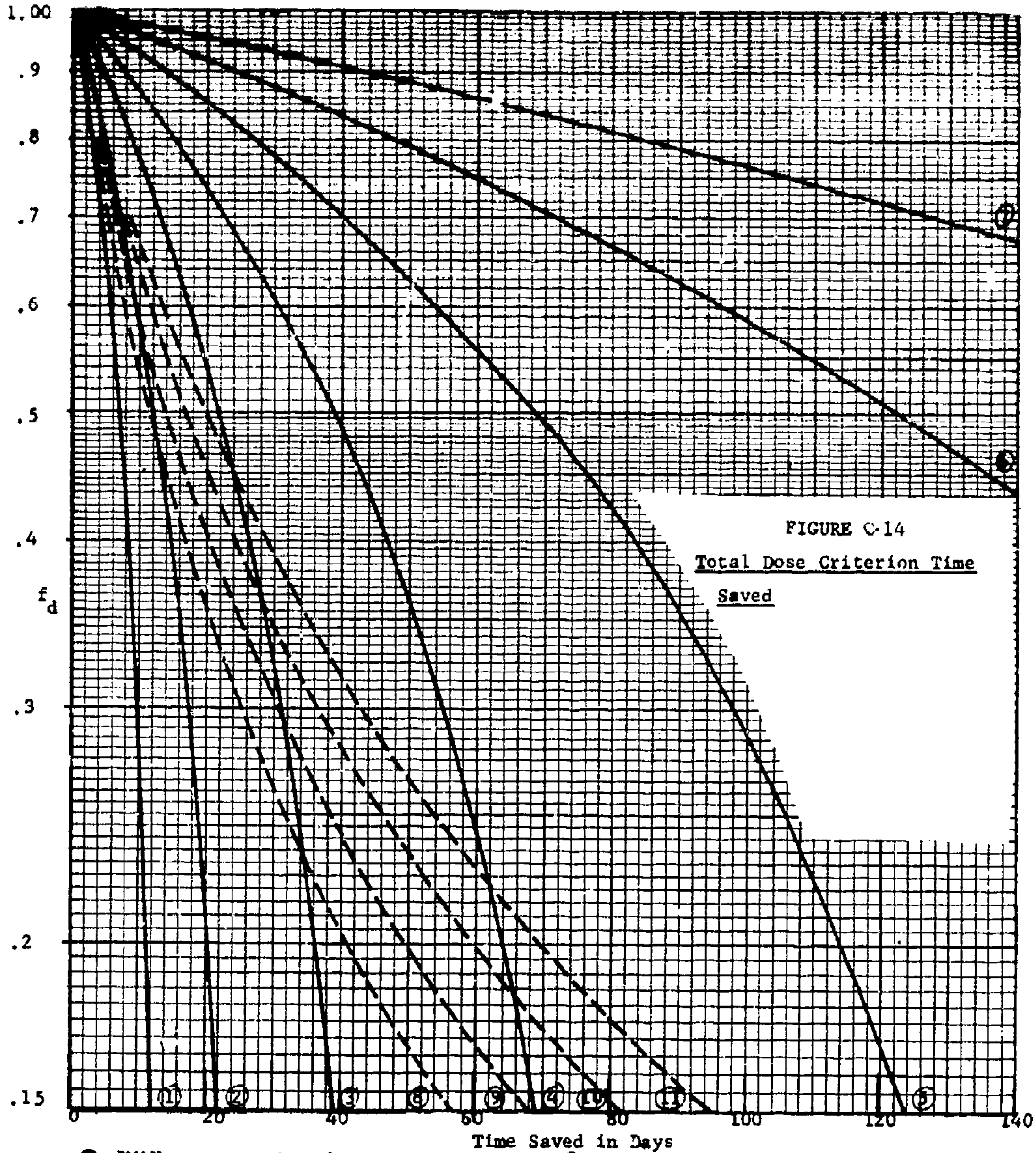


FIGURE C-14

Total Dose Criterion Time Saved

① $\frac{DMAX}{H\Delta t} = .02,\ T_f^* + \frac{\Delta t}{2} = 15.3$ days

② $\frac{DMAX}{H\Delta t} = .01,\ T_f^* + \frac{\Delta t}{2} = 27.4$ days

③ $\frac{DMAX}{H\Delta t} = .005,\ T_f^* + \frac{\Delta t}{2} = 48.8$ days

④ $\frac{DMAX}{H\Delta t} = .0025,\ T_f^* + \frac{\Delta t}{2} = 86.7$ days

⑤ $\frac{DMAX}{H\Delta t} = .00125,\ T_f^* + \frac{\Delta t}{2} = 155.$ days

⑥ $\frac{DMAX}{H\Delta t} = .00625,\ T_f^* + \frac{\Delta t}{2} = 276.$ days

⑦ $\frac{DMAX}{H\Delta t} = .003125,\ T_f^* + \frac{\Delta t}{2} = 494.$ days

⑧ $T_f = 14$ days, $\Delta t = 1$ day

⑨ $T_f = 14$ days, $\Delta t = 7$ days

⑩ $T_f = 14$ days, $\Delta t = 14$ days

⑪ $T_f = 14$ days, $\Delta t = 21$ days

From Equation C-7, this factor is equal to $T_f + \frac{\Delta t}{2}$, which is the time to the center of the performance interval when decontamination is activated. In Figure C-14, these dashed lines were developed for the case where no activity would be recovered before the end of a two week shelter period, independent of any decontamination. This was accomplished by setting T_f equal to 14 days. The four curves were then selected by varying the performance interval, Δt. The four curves represent intervals of 1 day, 1 week, 2 weeks, and 3 weeks. These curves, therefore, represent the bound of useable f_d, or T, when the time of entry with the countermeasure activated is fixed

To determine the time saved when maximum ERD occurs during the performance of the activity (rather than at the conclusion of the activity), Case II, Equation C-19 is solved graphically by using Figure C-7. That is, for a given normalized dose, $\frac{D_R}{H}$, the fallout denial time without the countermeasure, T_f^* is determined from Figure C-7. Then the effect of decontamination is determined by obtaining from Figure C-7 the fallout denial time, t_e, when the normalized dose, $\frac{D_R}{f_d H}$, is used. The difference, $T_f^* - T_f$ is the time saved for the situation defined by the given value of $\frac{D_R}{H}$.

The three approaches to time saved are combined and presented in a set of performance curves, Figures C-15 through C-22. Each figure shows how the time saved varies as a function of f_d, the activity duration, Δt, and the manner in which the dose (total dose or ERD) is defined when the normalized dose, $\frac{D}{H}$, is specified. The figures cover normalized doses from .16 to .00125 in seven steps. The activity durations considered are 1, 2, 4, 8, 16, and 32 days (total dose and maximum ERD occurring before the end of the activity, Case I) and an infinite duration (maximum ERD occurring before the end of the activity, Case II). In addition, any curve not explicitly presented can be quickly obtained in the manner discussed in the preceding paragraphs of this section.

An additional set of performance curves, Figures C-23 through C-29, are included to illustrate the H, $\frac{DMAX}{\Delta t}$, f_d trade-offs available when the time to be saved is specified and total dose is the constraint. Figure 23 shows the effect of f_d and $\frac{DMAX}{\Delta t}$ on the relationship between H and T. Each of Figures C-24 through C-29 show, for a fixed f_d, the H, $\frac{DMAX}{\Delta t}$ trade-offs when the time to be saved is specified as 1, 2, 4, 7, 14, 21, 28, 35, or 42 days. This set of curves is presented to help delimit the range of situations where decontamination is potentially useful in reducing the fallout denial time.

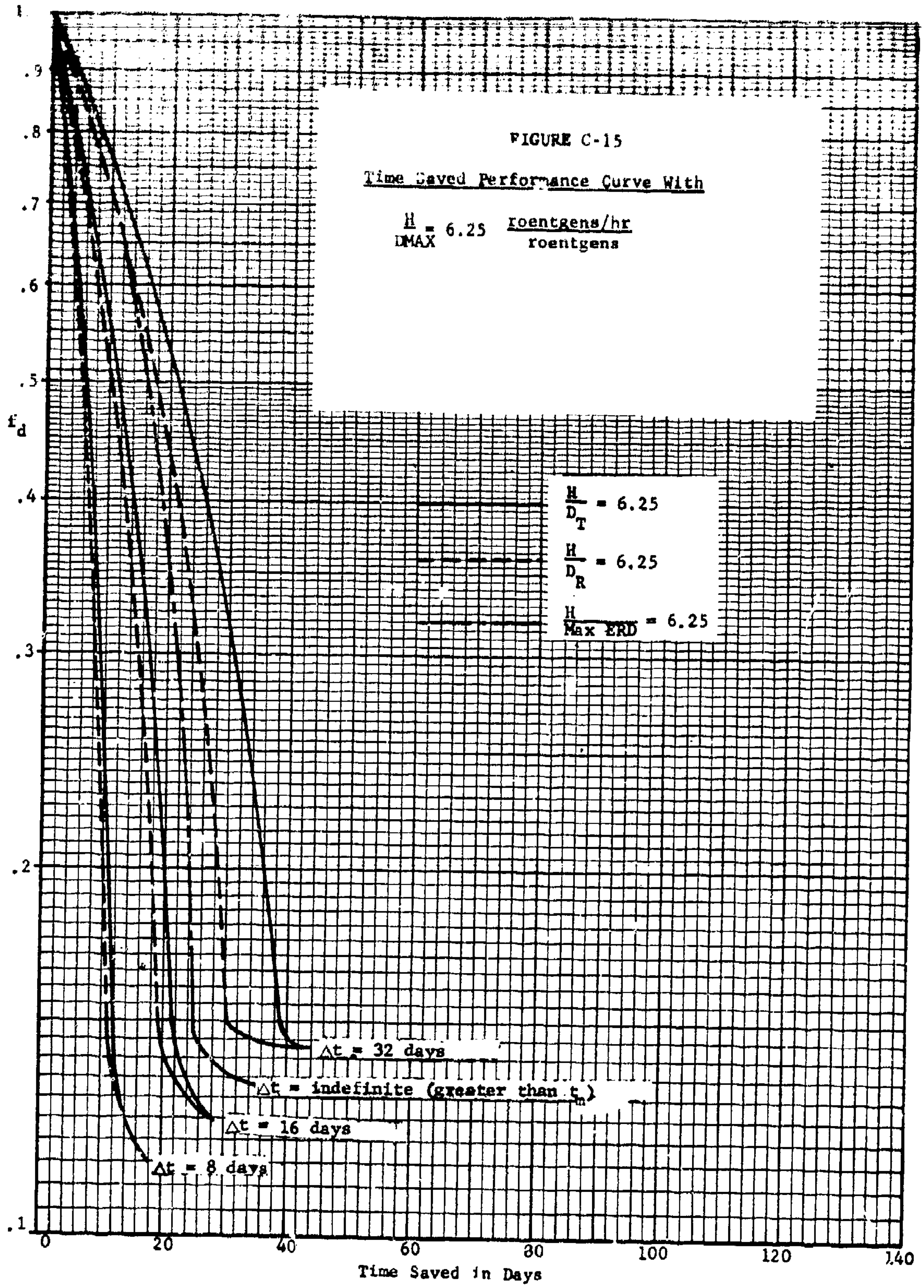


FIGURE C-15
Time Saved Performance Curve With
$\frac{H}{DMAX} = 6.25 \frac{\text{roentgens/hr}}{\text{roentgens}}$
$\frac{H}{D_T} = 6.25$
$\frac{H}{D_R} = 6.25$
$\frac{H}{Max\ ERD} = 6.25$
Δt = 32 days
Δt = indefinite (greater than t_m)
Δt = 16 days
Δt = 8 days
f_d
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
20
40
60
80
100
120
140
Time Saved in Days

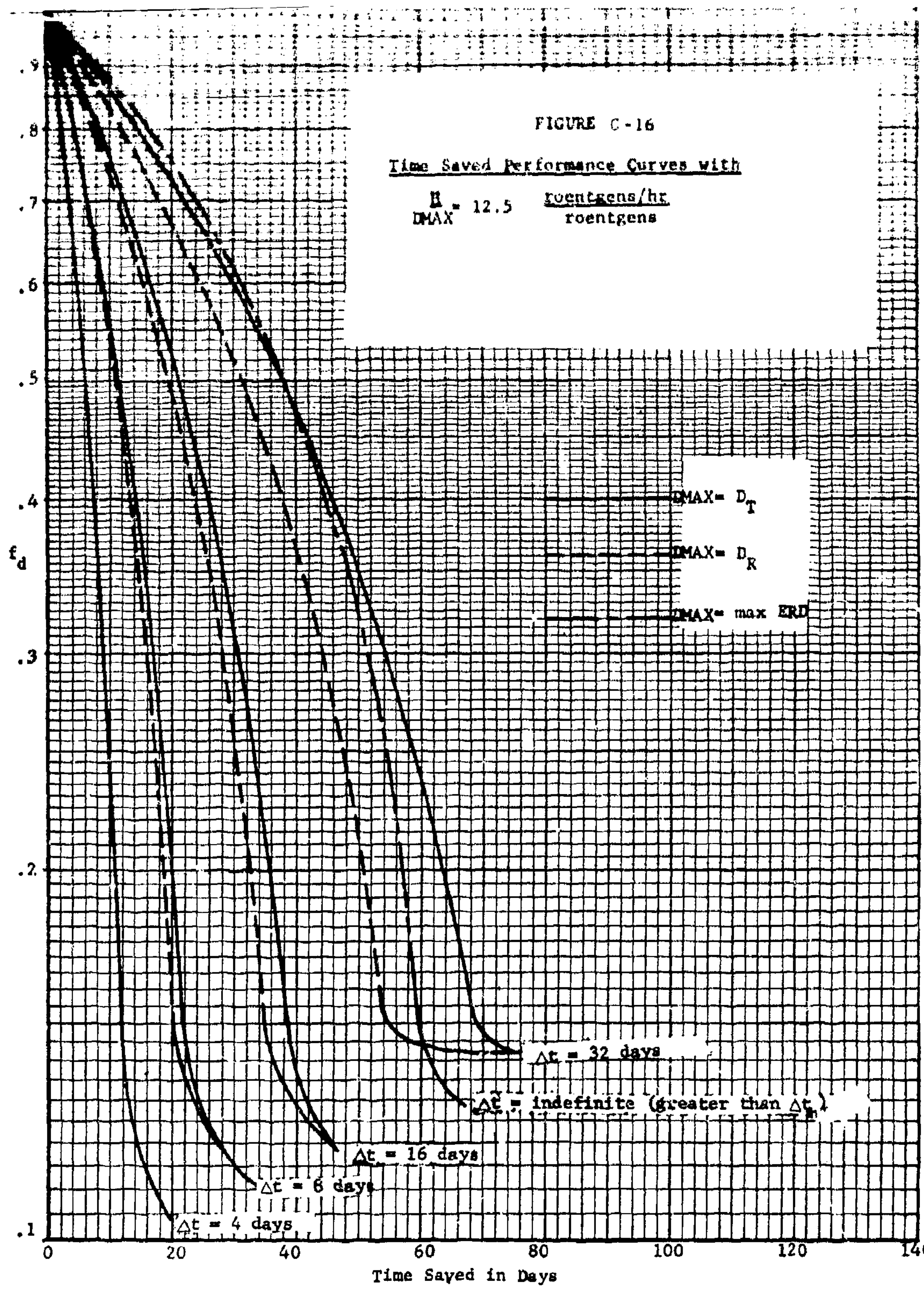
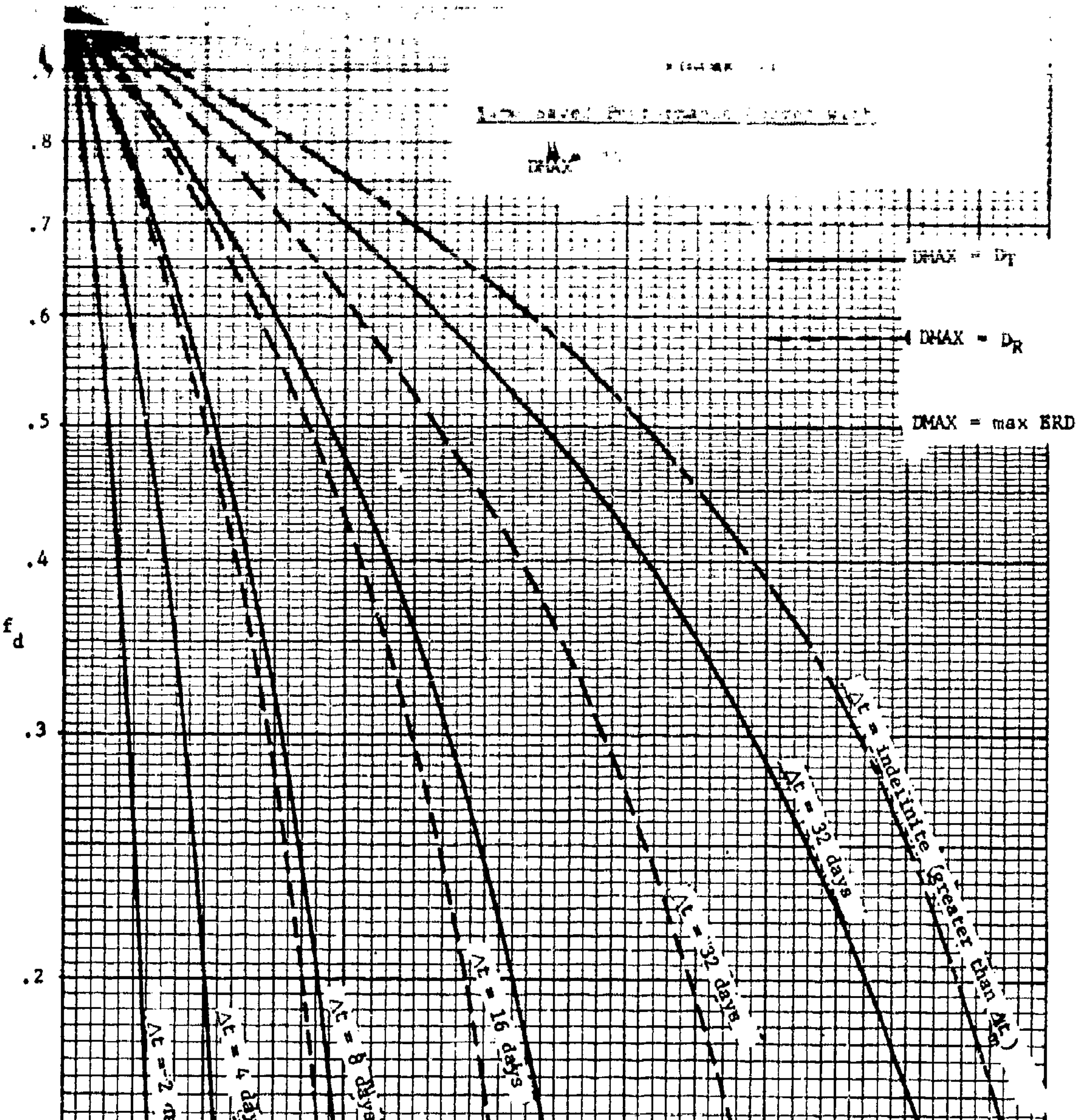
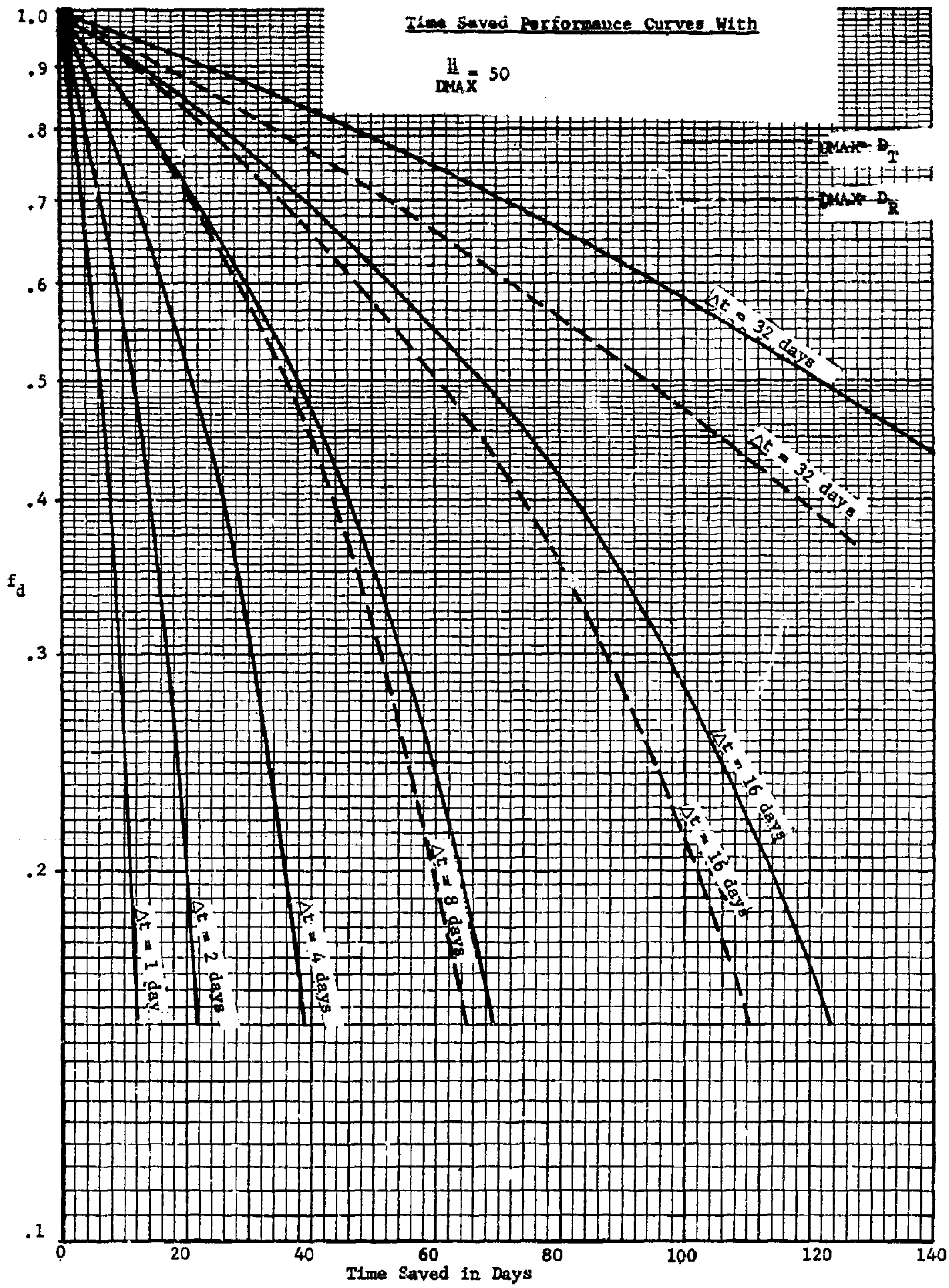


FIGURE C-16
Time Saved Performance Curves with
$\frac{\dot{R}}{DMAX}$ = 12.5 roentgens/hr / roentgens
DMAX= D_T
DMAX= D_R
DMAX= max ERD
Δt = 32 days
Δt = indefinite (greater than Δt_p)
Δt = 16 days
Δt = 6 days
Δt = 4 days
f_d
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
20
40
60
80
100
120
140
Time Saved in Days



DMAX = D_T
DMAX = D_R
DMAX = max ERD
.8
.7
.6
.5
.4
f_d
.3
.2
.1
0
20
40
60
80
100
120
140
Time Saved in Days
Δt = 2 days
Δt = 4 days
Δt = 8 days
Δt = 16 days
Δt = 32 days
Δt = 32 days
Δt = indefinite (greater than Δt_m)

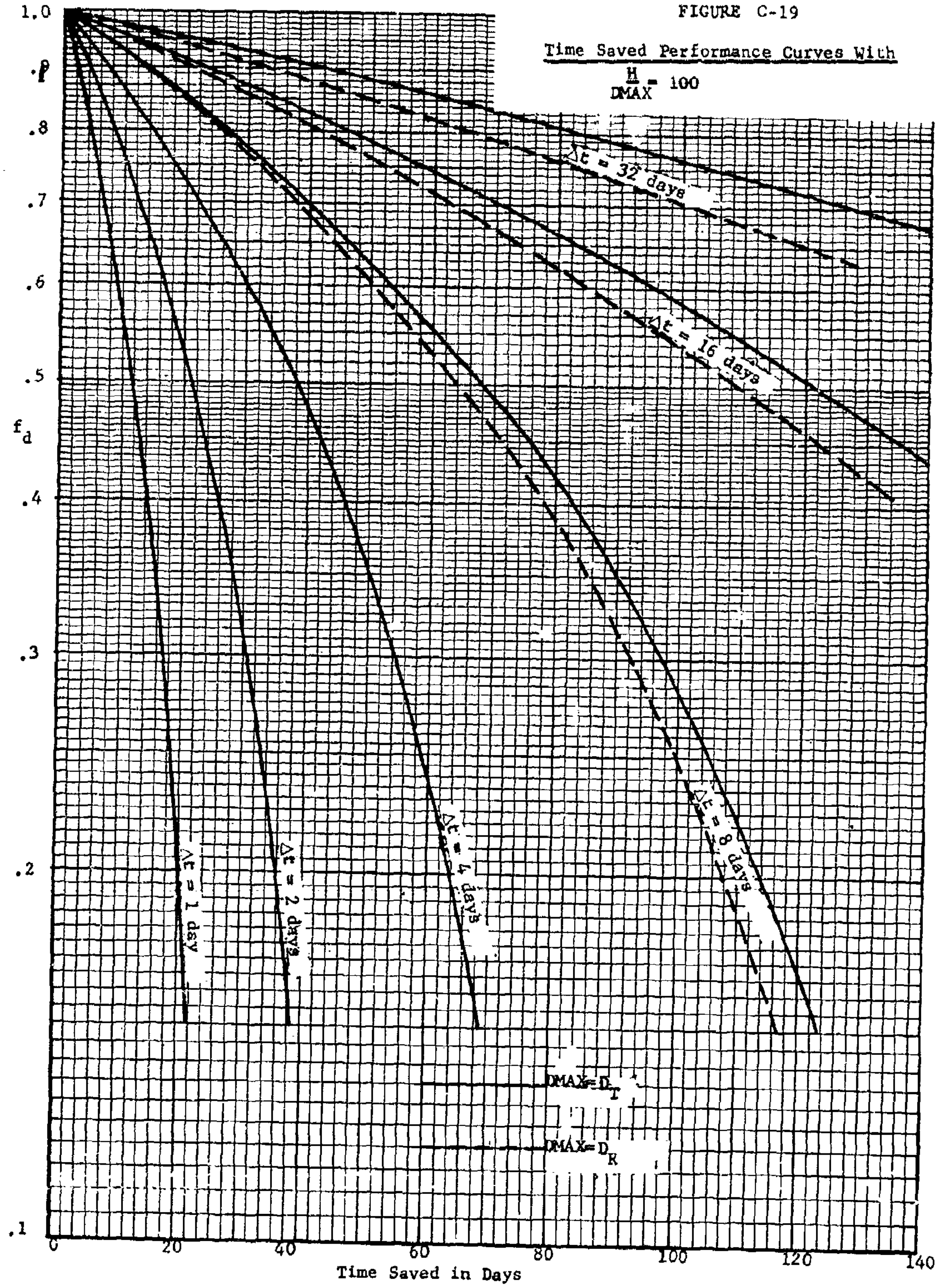
FIGURE C -18



Time Saved Performance Curves With
$\frac{H}{DMAX} = 50$
DMAX = D_T
DMAX = D_R
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
f_d
Δt = 32 days
Δt = 32 days
Δt = 16 days
Δt = 16 days
Δt = 8 days
Δt = 4 days
Δt = 2 days
Δt = 1 day
0
20
40
60
80
100
120
140
Time Saved in Days

FIGURE C-19

Time Saved Performance Curves With $\frac{H}{DMAX} = 100$



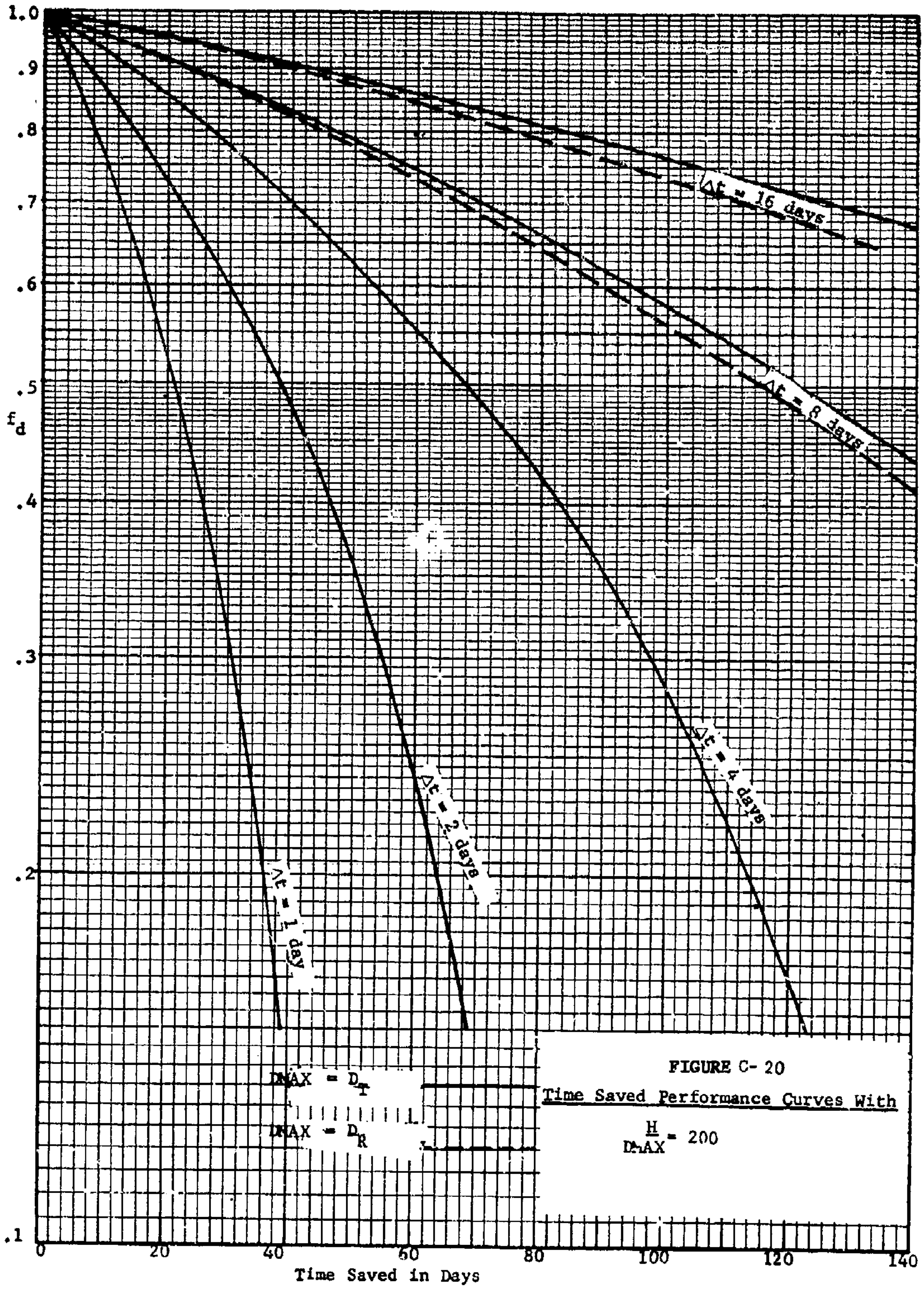


FIGURE C- 20

Time Saved Performance Curves With

$\frac{H}{DMAX} = 200$

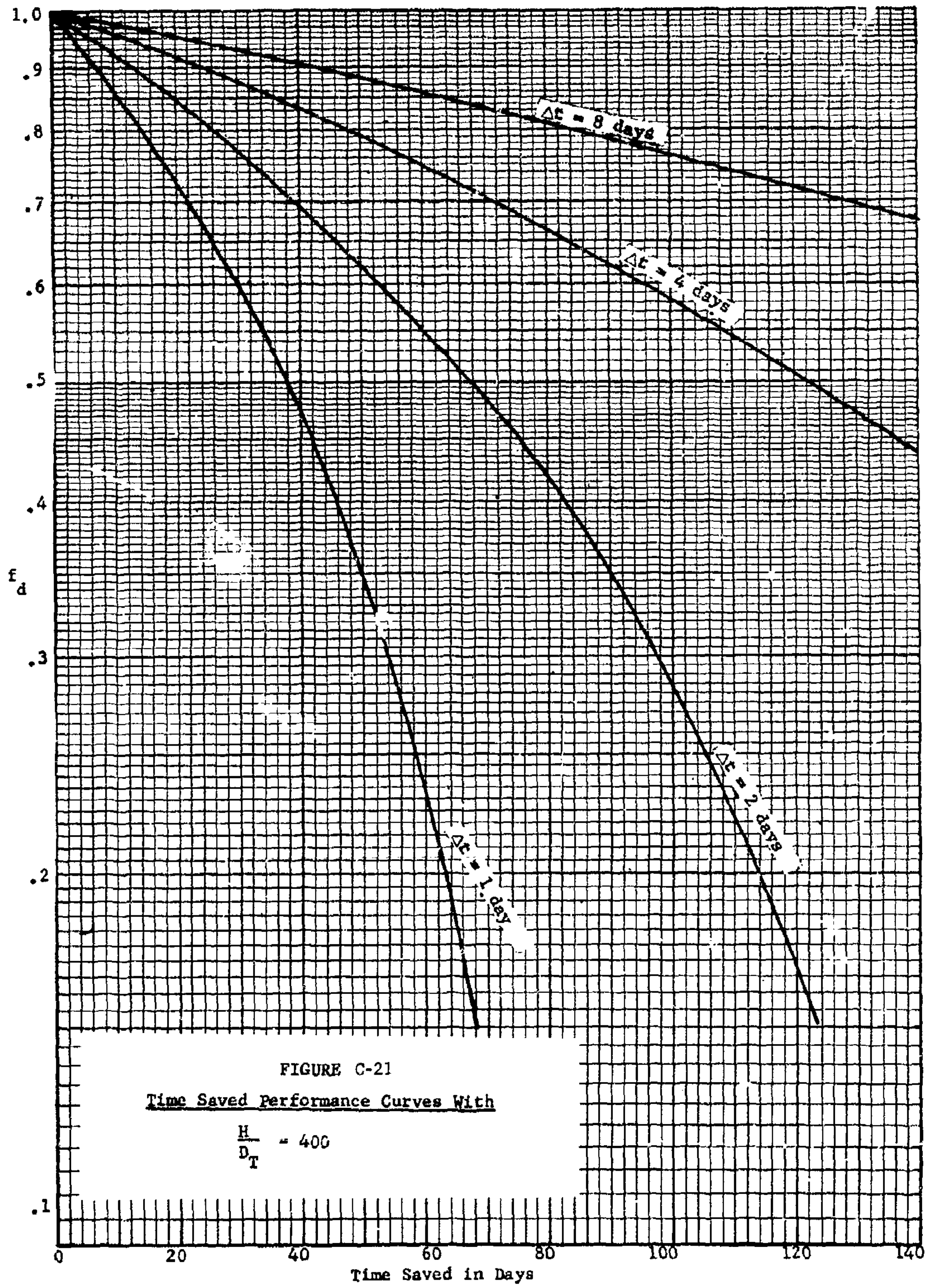


FIGURE C-21

Time Saved Performance Curves With

$\frac{H}{D_T} = 400$

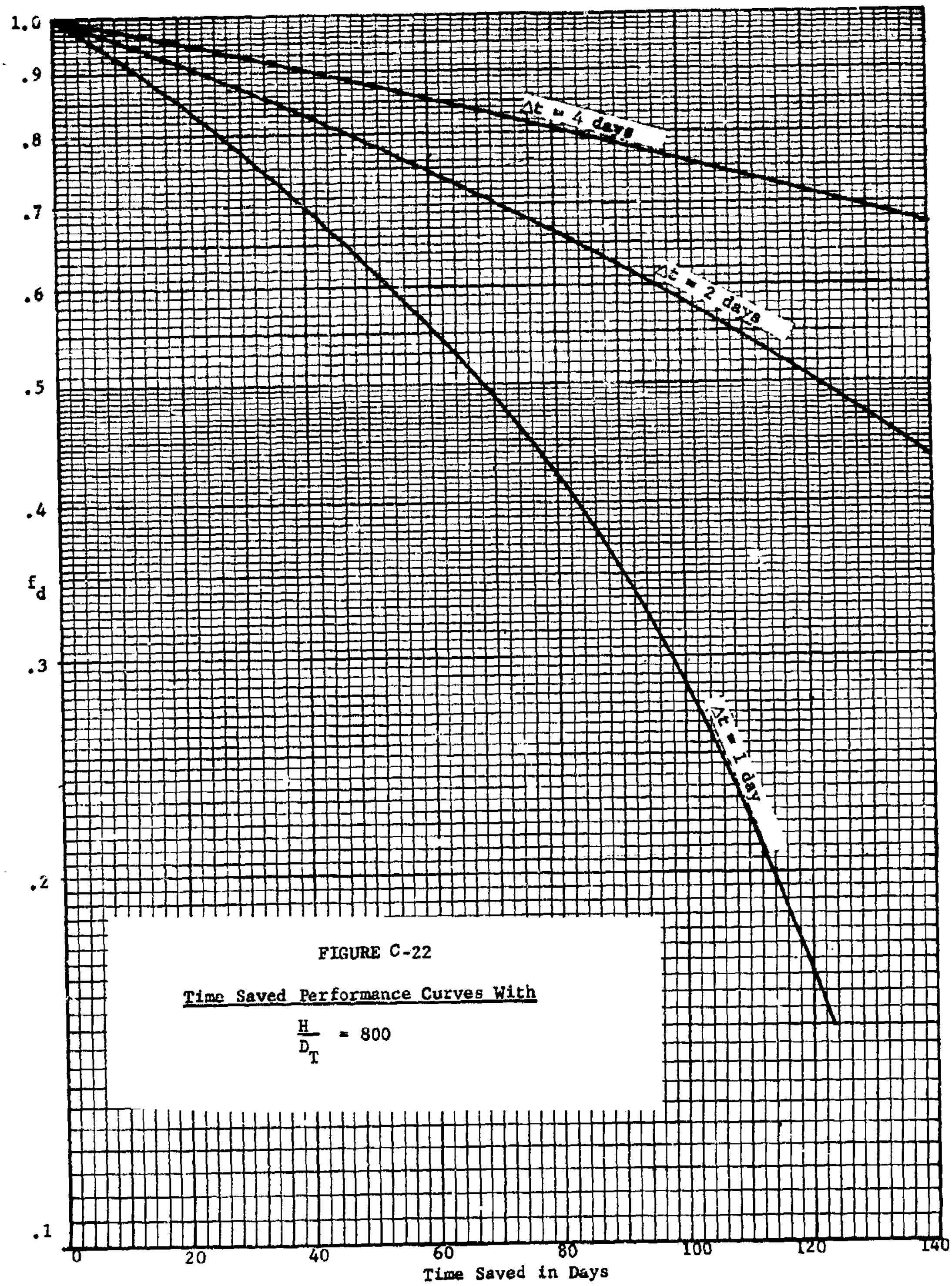


FIGURE C-22

Time Saved Performance Curves With

$\frac{H}{D_T} = 800$

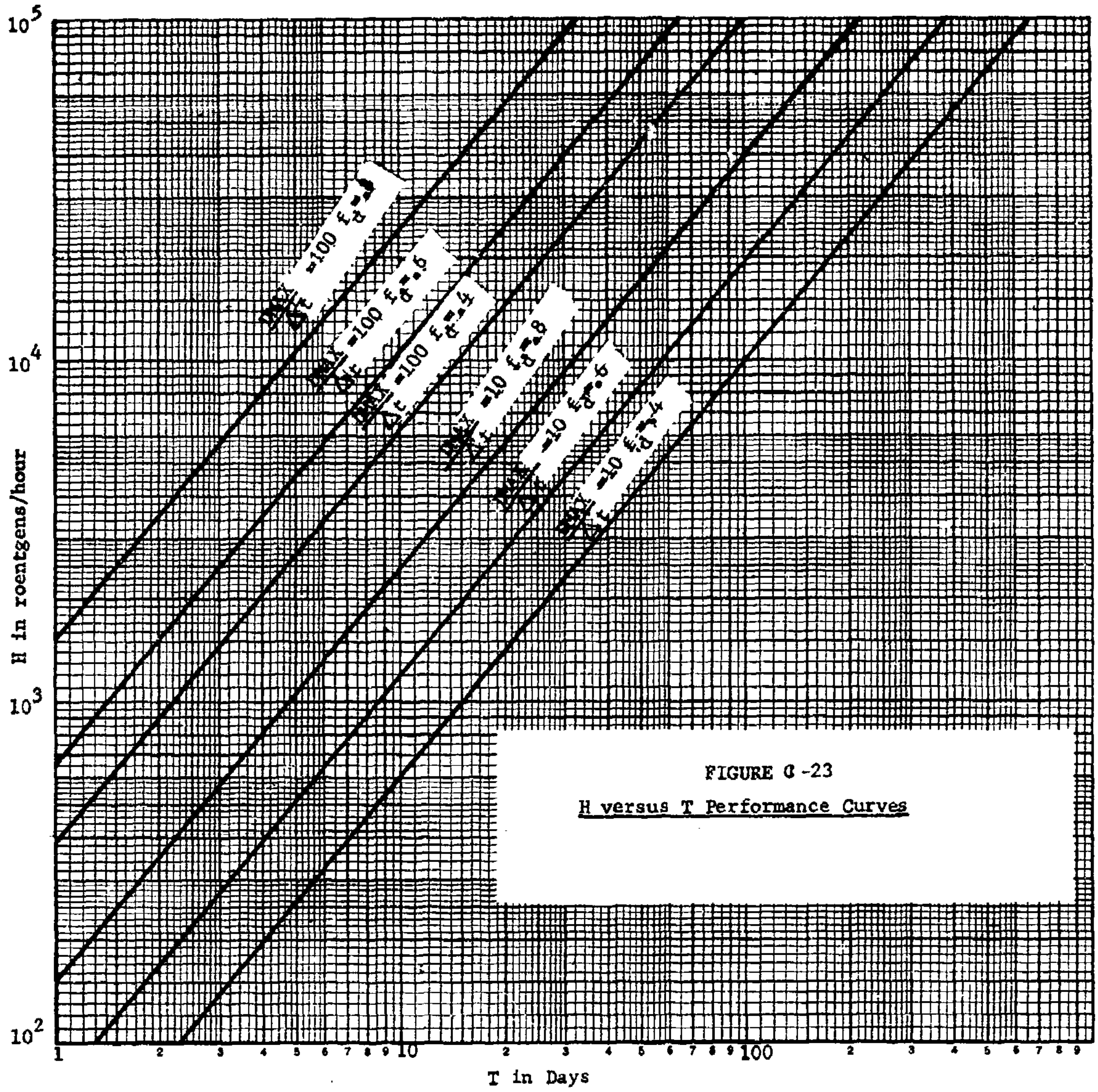


FIGURE C-23

H versus T Performance Curves

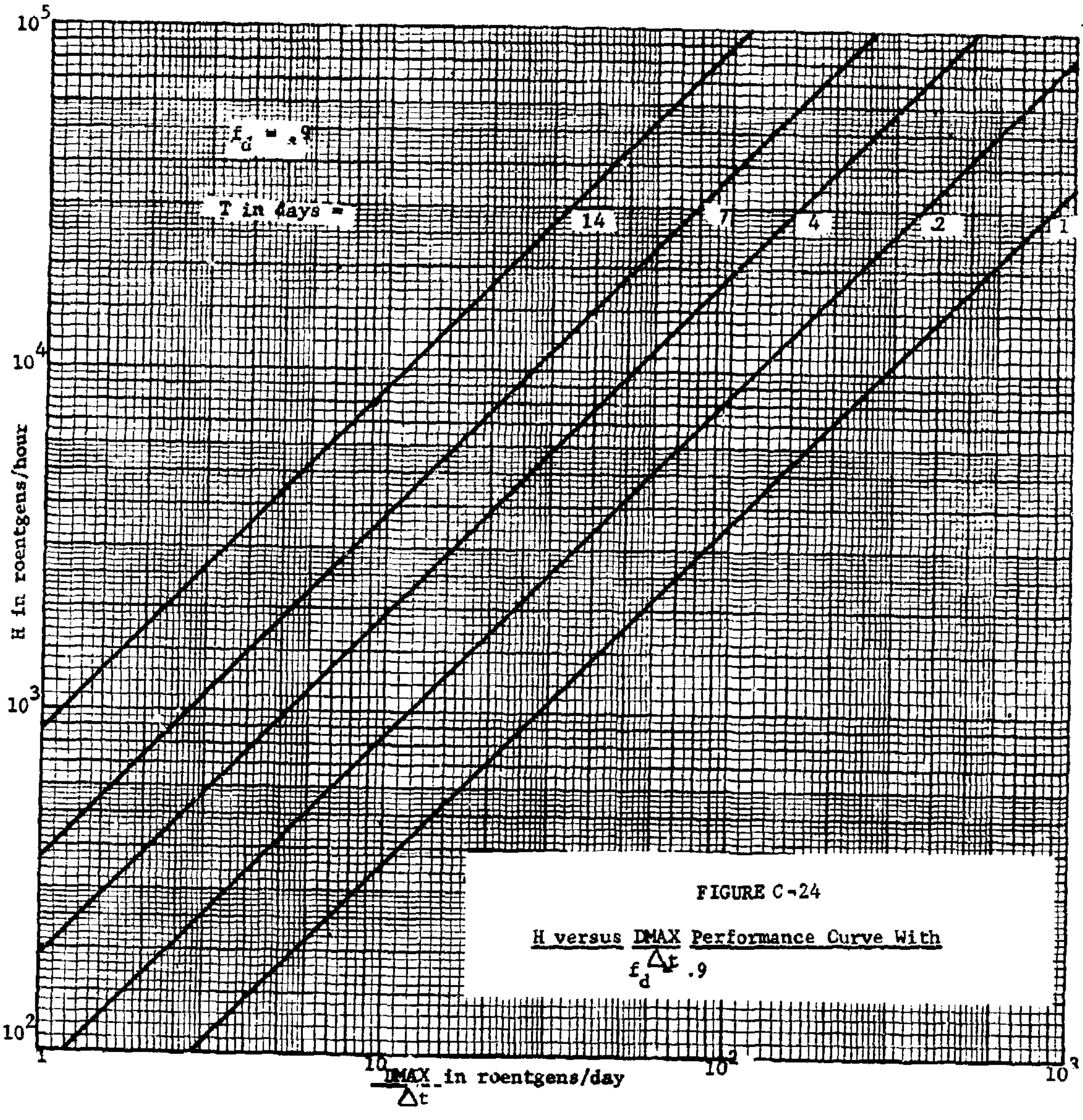


FIGURE C-24

H versus $\frac{DMAX}{\Delta t}$ Performance Curve With $f_d = .9$

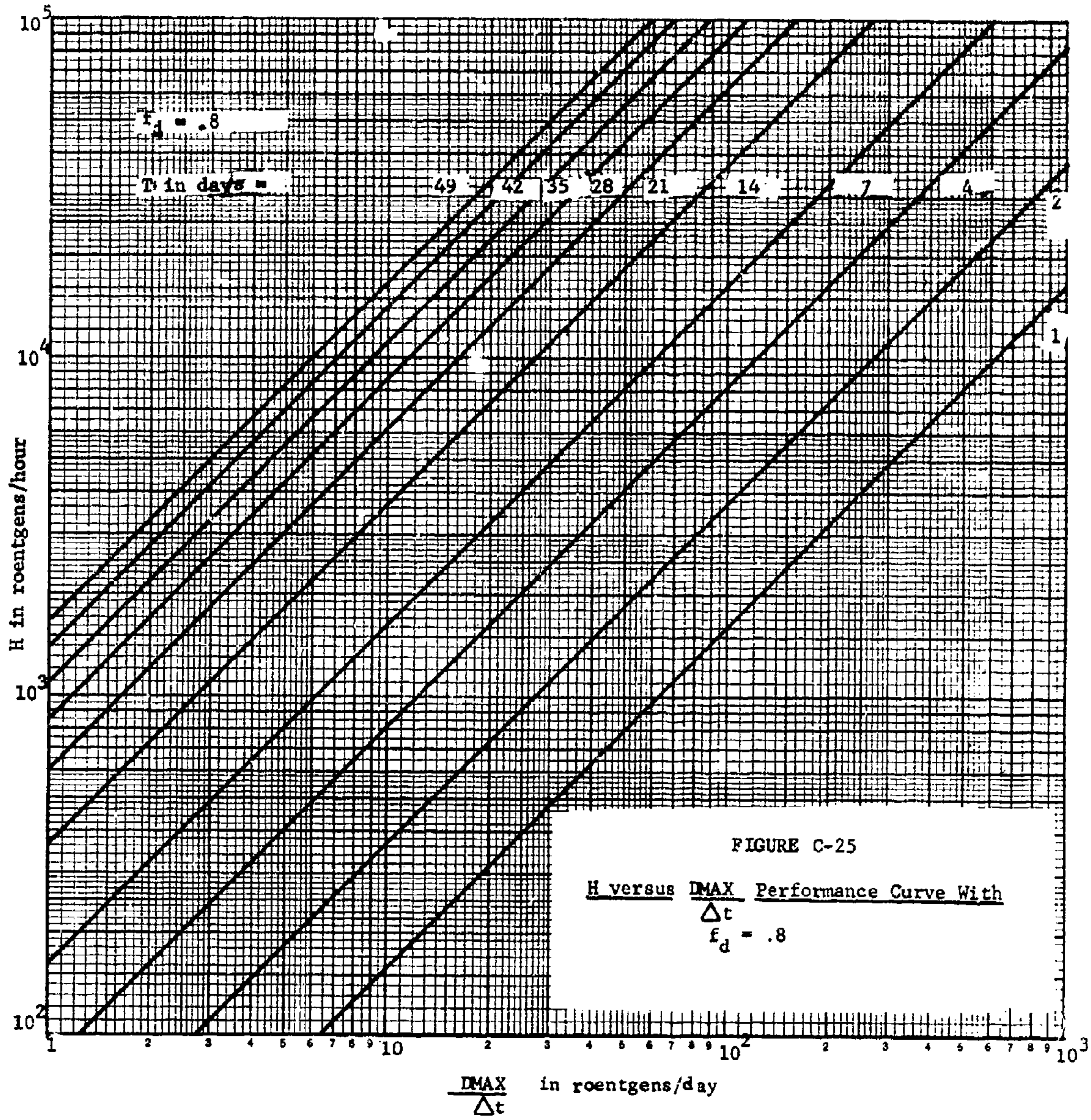


FIGURE C-25

H versus $\frac{DMAX}{\Delta t}$ Performance Curve With $f_d = .8$

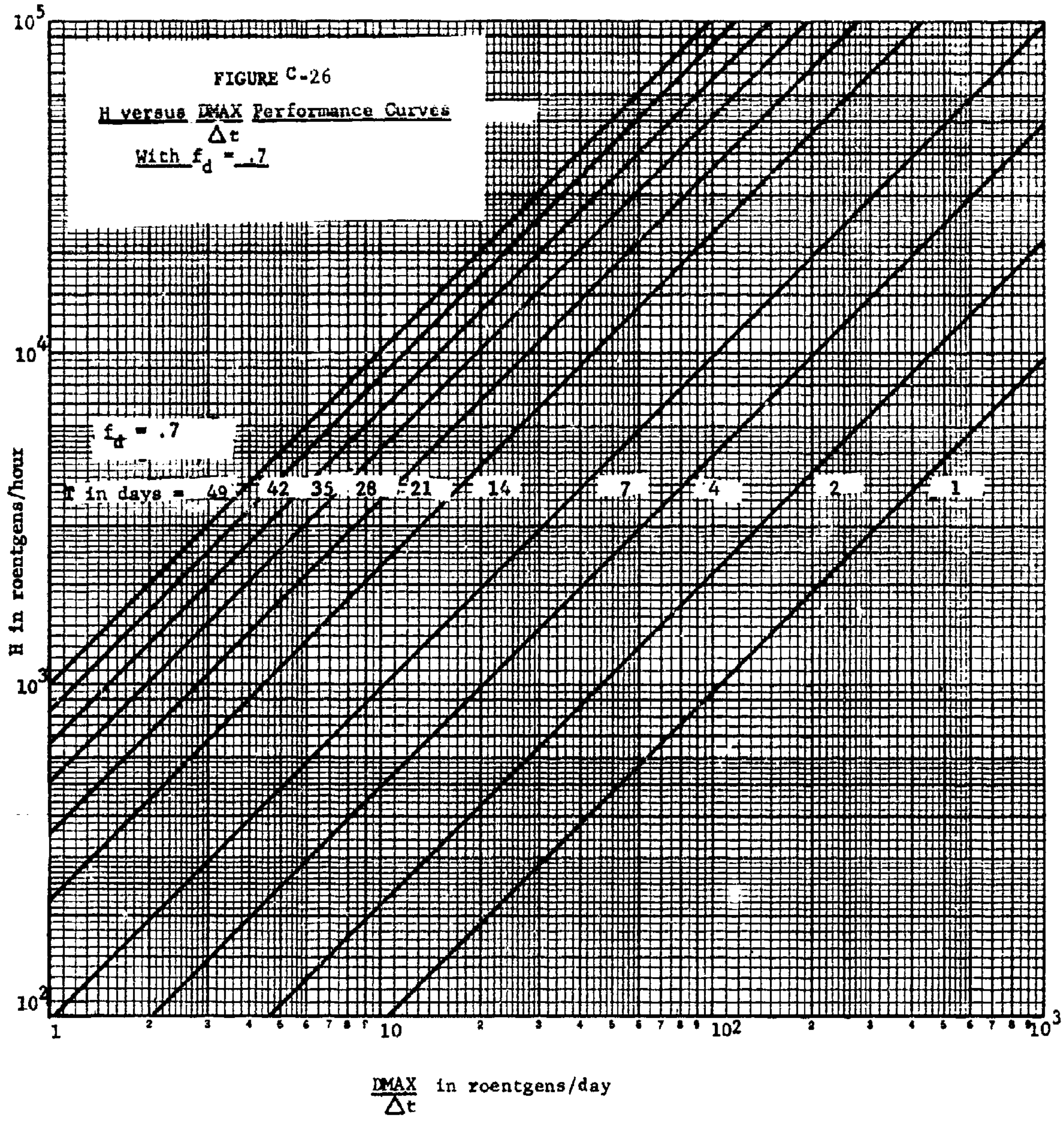


FIGURE C-26
H versus DMAX/Δt Performance Curves
With f_d = .7
f_d = .7
T in days = 49 42 35 28 21 14 7 4 2 1
H in roentgens/hour
DMAX/Δt in roentgens/day

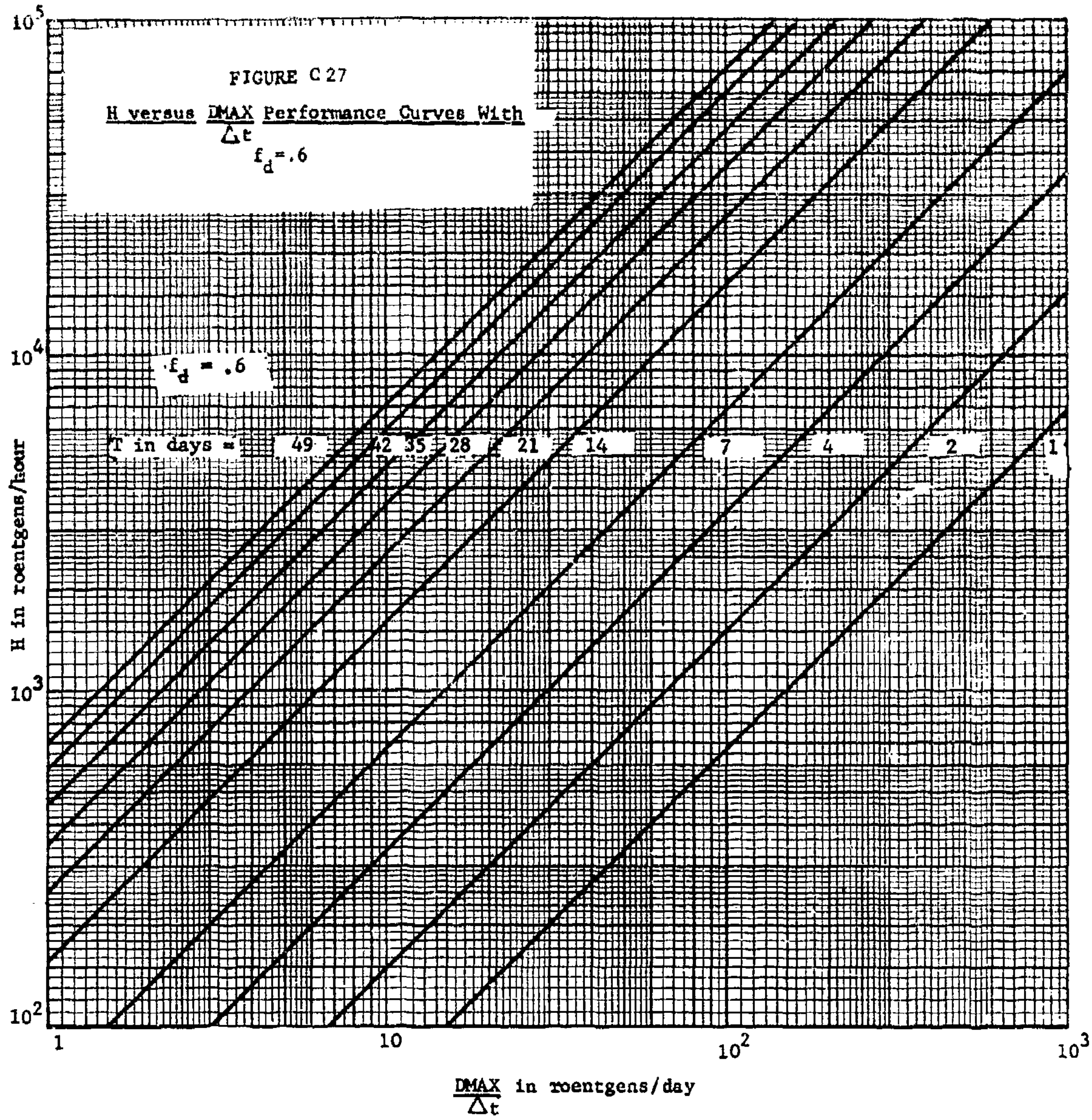


FIGURE C 27
H versus DMAX/Δt Performance Curves With f_d=.6
f_d = .6
T in days = 49 42 35 28 21 14 7 4 2 1
H in roentgens/hour
10^5
10^4
10^3
10^2
1
10
10^2
10^3
DMAX/Δt in roentgens/day

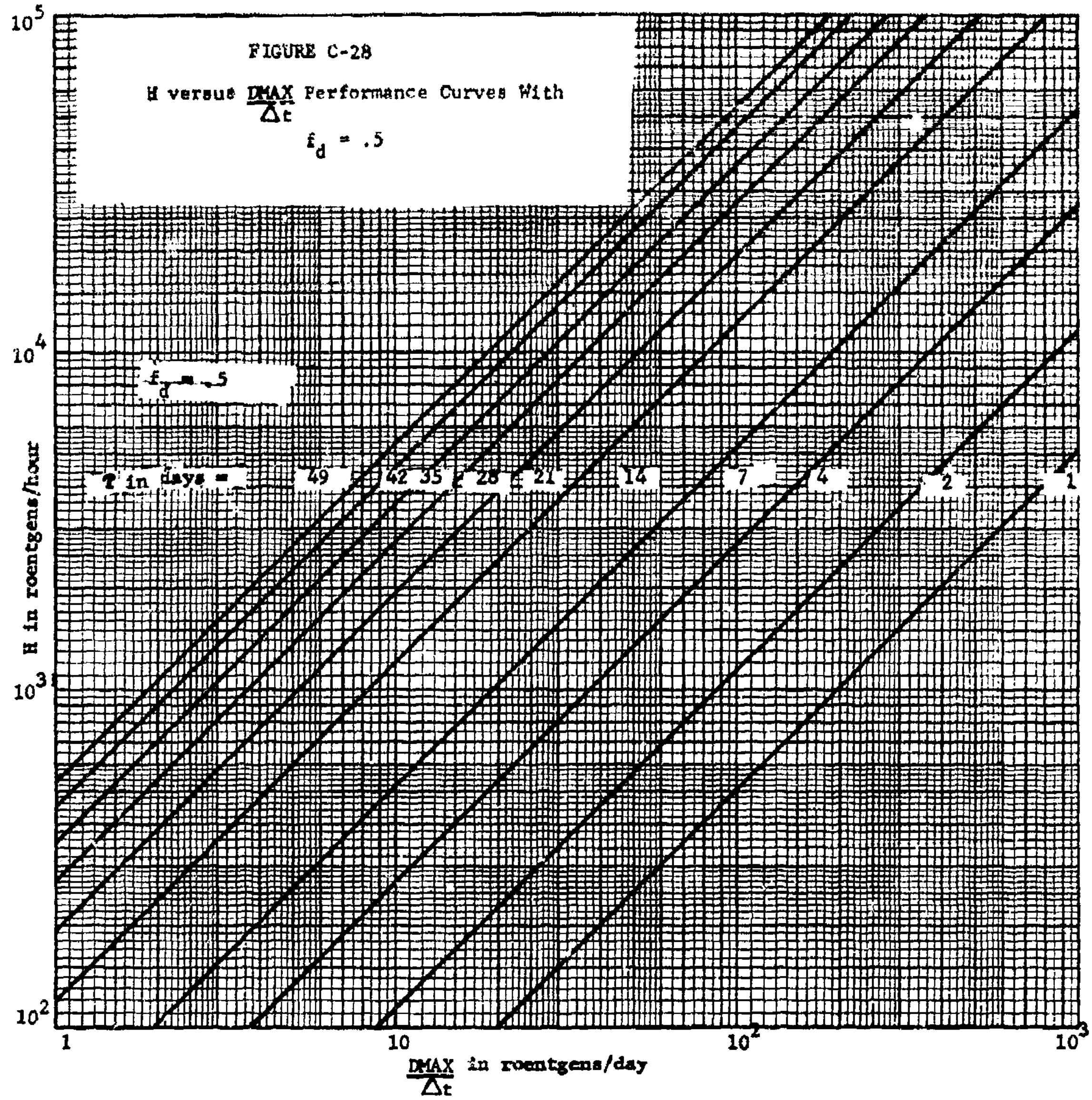


FIGURE C-28
H versus DMAX/Δt Performance Curves With
f_d = .5
f_d = .5
τ in days =
49
42
35
28
21
14
7
4
2
1
10^5
10^4
10^3
10^2
H in roentgens/hour
1
10
10^2
10^3
DMAX/Δt in roentgens/day

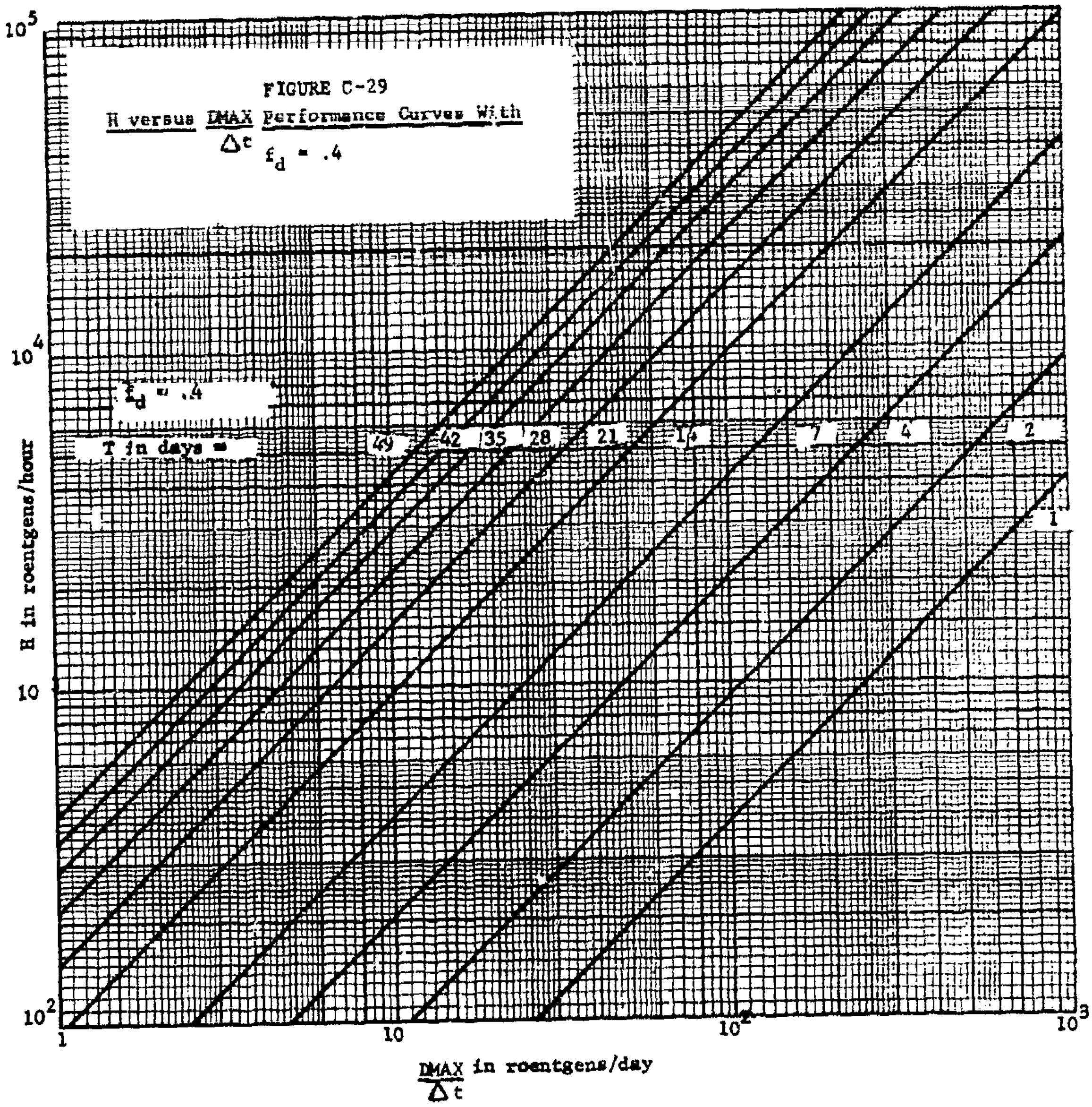


FIGURE C-29
H versus $\frac{DMAX}{\Delta t}$ Performance Curves With $f_d = .4$
$f_d = .4$
T in days =
49
42
35
28
21
14
7
4
2
1
10^5
10^4
10
10^2
1
10
10^2
10^3
H in roentgens/hour
$\frac{DMAX}{\Delta t}$ in roentgens/day

GLOSSARY OF TERMS OR SYMBOLS FOR APPENDIX C

Term or Symbol	Definition
AVGP	Average Fallout Protection at the facility
B	Result of biological recovery
DMAX	Maximum Allowable Dose (total dose or ERD)
D_R	Equivalent residual dose (ERD)
D_T	Total dose
F	Fraction realized due to $f_d \neq 0$
f_d	Decontamination effectiveness
H	Activity-intensity characteristic constant
I_e	Activity effective intensity
t	Time
T	Time saved
Δt	Activity duration
T_f	Fallout denial time for a facility with decontamination
T_f^*	Fallout denial time without decontamination
t_m	Time when $D_R(t)$ is maximum
T_m	Potential maximum time saved
Δt_m	$t_m - T_f^*$ = time interval to maximum $D_R(t)$
W(t)	Recovery weighting function

REFERENCES FOR APPENDIX C

C-1. J. T. Ryan, J. D. Douglass, Jr., and H. E. Campbell. Radiological Recovery Concepts, Requirements, and Structures. Final Report, OU-156, Office of Civil Defense Contract No. OCD-PS-64-56. Durham, North Carolina: Research Triangle Institute, 16 October 1964.

C-2. J. F. Devaney. Operations in Fallout. OCDM-SA-61-13. Washington: Office of Civil Defense Mobilization, June 1961.

Appendix D

A Computational Procedure for Estimating the Denial Times for Facilities Denied by Radioactive Fallout

I. INTRODUCTION

This appendix presents a procedure for computing fallout denial times for facilities. This routine is to be a part of the Initial Edit Phase of the R & R Model. (See Reference D-1 for a description of the overall R & R Model logic as well as a discussion of the functions to be performed in the Initial Edit Phase.)[D-1/]

One of the major computational tasks of the Initial Edit Phase of the Recovery and Reconstitution (R & R) Model is to calculate the fallout denial time for each facility of interest. "Fallout denial time" is defined as that time during which a facility and all items of its inventory are unavailable for recovery operations because of high fallout radiation intensity.

A facility may be a complex installation, such as an airfield containing many different force and resource types, or a small site, such as a surface-to-air missile site, or a small part of an installation. A facility can also be a non-military installation where one or more forces happen to exist (e.g., a dry lake bed). Forces are defined to be items for which recovery is specfically defined. Resources are items which must be applied to forces in order to recover them. Carriers are the items which are required to move forces or resources from a facility at one location to a facility at another location. All forces, resources and carriers are listed in the facility inventory tables and the fallout denial time may be calculated separately for each item on a

[D-1/] Ryan, J. T. and R. H. Thornton. Design Phase Report on a Recovery and Reconstitution Model for the Strategic Strike Forces. RM-OU-241-1. Research Triangle Institute, Durham, North Carolina. 20 May 1966.

facility or for an entire facility. This flexibility in designating denial times is required because different R & R operations may well have different personnel exposure patterns, and hence different denial times at the identical geographic location.

Suppose several defensive missile sites were located on the perimeter of an airfield which has received heavy fallout. If the SAM sites are listed in the inventory facility tables under the airfield designation, they will not become available until the entire field becomes available. However, if the SAM site is considered as a separate facility, even though it is included in the airfield complex, it will be handled separately in the facility tables. A denial time will be calculated for it independently of the constraints which apply in calculating the denial time for the airfield.

Since the R & R Model is a time-sequenced model, the fallout denial times provide a logical method for ordering facilities, forces, and resources in the model; they are entered in the active inventory tables for the time period in which they become available. This method is logical in that the fallout denial time constraints are independent of the recovery process, provided the decisions to decontaminate or not are made in advance for each facility by the input planners.

The planner has three options available concerning decontamination: (1) decontaminate none of the facilities; (2) decontaminate selected facilities; or (3) decontaminate all facilities listed in the facility tables.

This appendix describes the methods for calculating fallout denial times for facilities denied by radioactive fallout with and without decontamination. In either case, all of the fallout is assumed to be down prior to the beginning of the game. It is also assumed that the required decontamination resources are available at the time specified.

The next three sections describe both the overall procedure proposed and a detailed description of the logic employed. Both English-language flow charts and detailed flow charts are presented.

II. OVER-ALL LOGIC OF COMPUTATIONAL PROCEDURE

An English-language flow chart of the routine which computes the fallout denial time for a given facility is given by Figure D-1, Logic of Denial Time Computation. Briefly stated, this routine computes the earliest time at which personnel at the facility can begin or resume essential activities and either (i) received total dose less than or equal to a specified maximum total dose, or (ii) be exposed to no more than a specified radiation intensity. The routine takes into account whether or not the facility is to be decontaminated. The inputs required to perform this computation are as follows:

1. The fallout profile: The detonation times and H + 1 hour reference intensities for each detonation which contributes fallout to the facility.
2. The essential activity profile: The activities of required personnel are characterized by an "average radiation shielding protection" (24 hours per day) afforded these people performing the activities at the facility.
3. The time over which dose is to be computed.
4. The dose or intensity constraints for personnel required to perform essential activities at the facility.
5. Decontamination parameters: The dose constraints on the decontamination crew and the effectiveness of decontamination measured as a fraction of the intensity remaining after decontamination. The former determines the earliest time at which decontamination can occur.
6. Decontamination time required for the specified effectiveness.

The routine begins by determining whether or not decontamination is to be performed. If it is, then the time when decontamination can be completed is determined taking into account the fallout profile, the decontamination time

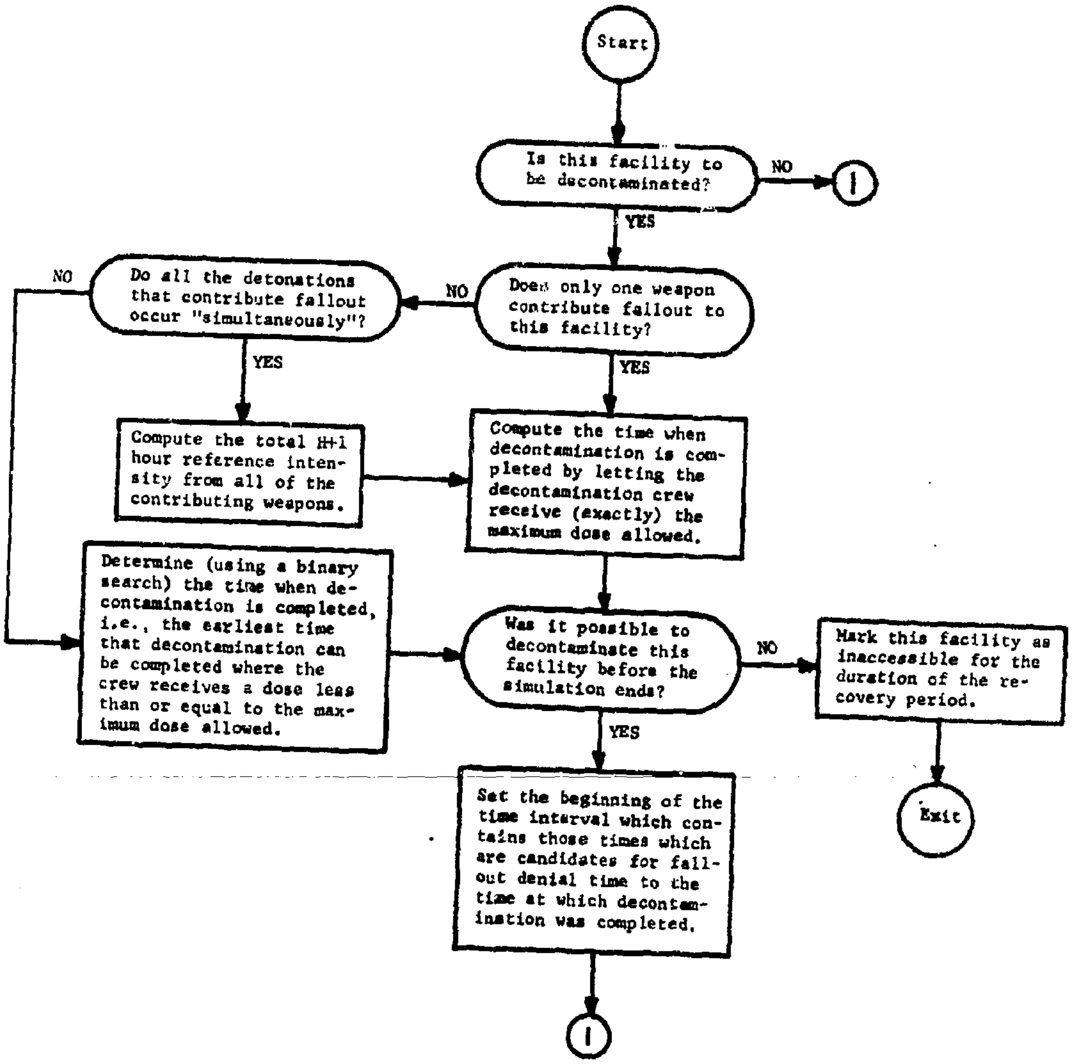


Fig. D-1. Logic of Denial Time Computation

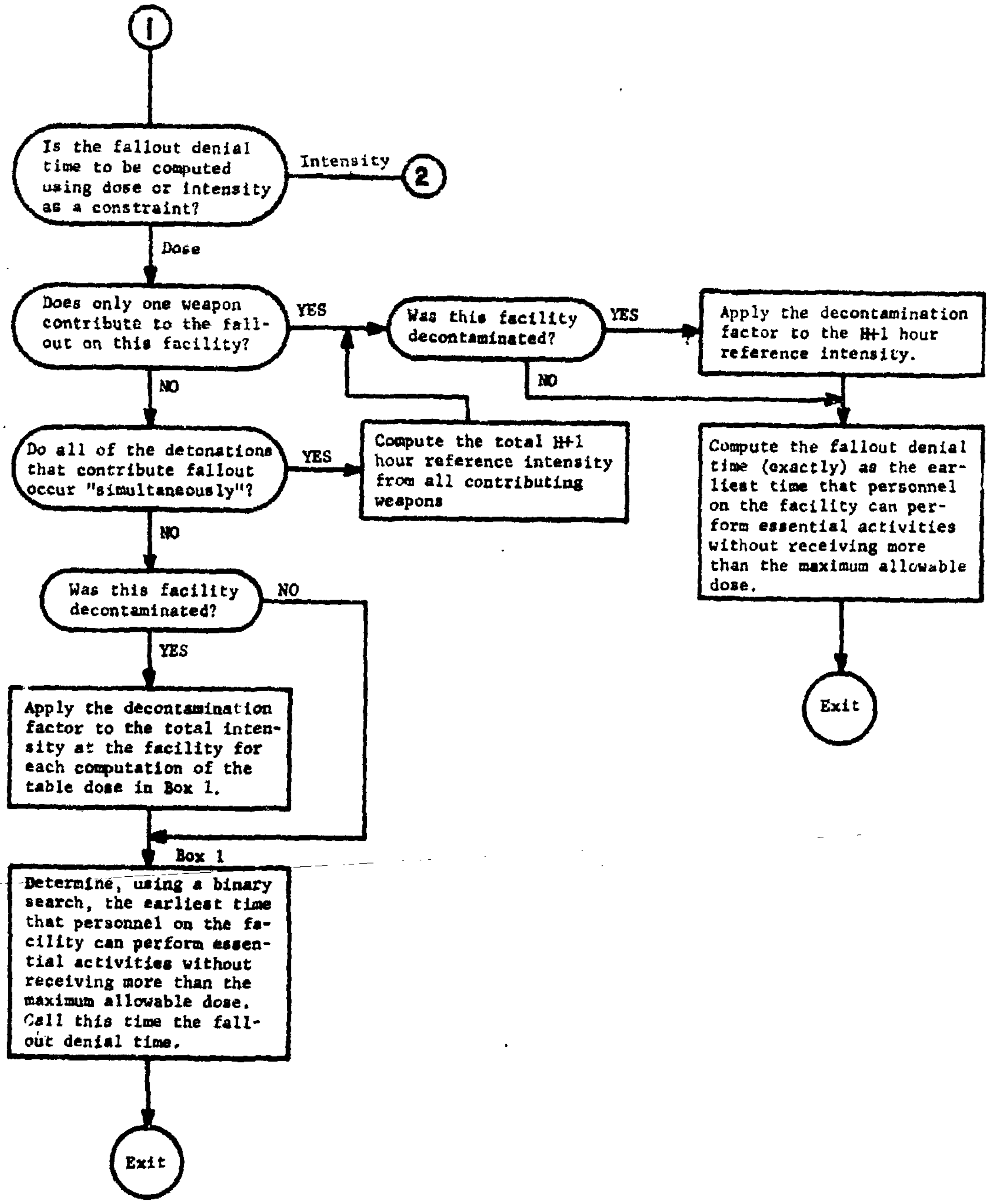


Fig. D-1. Logic of Denial Time Computation (Cont.)

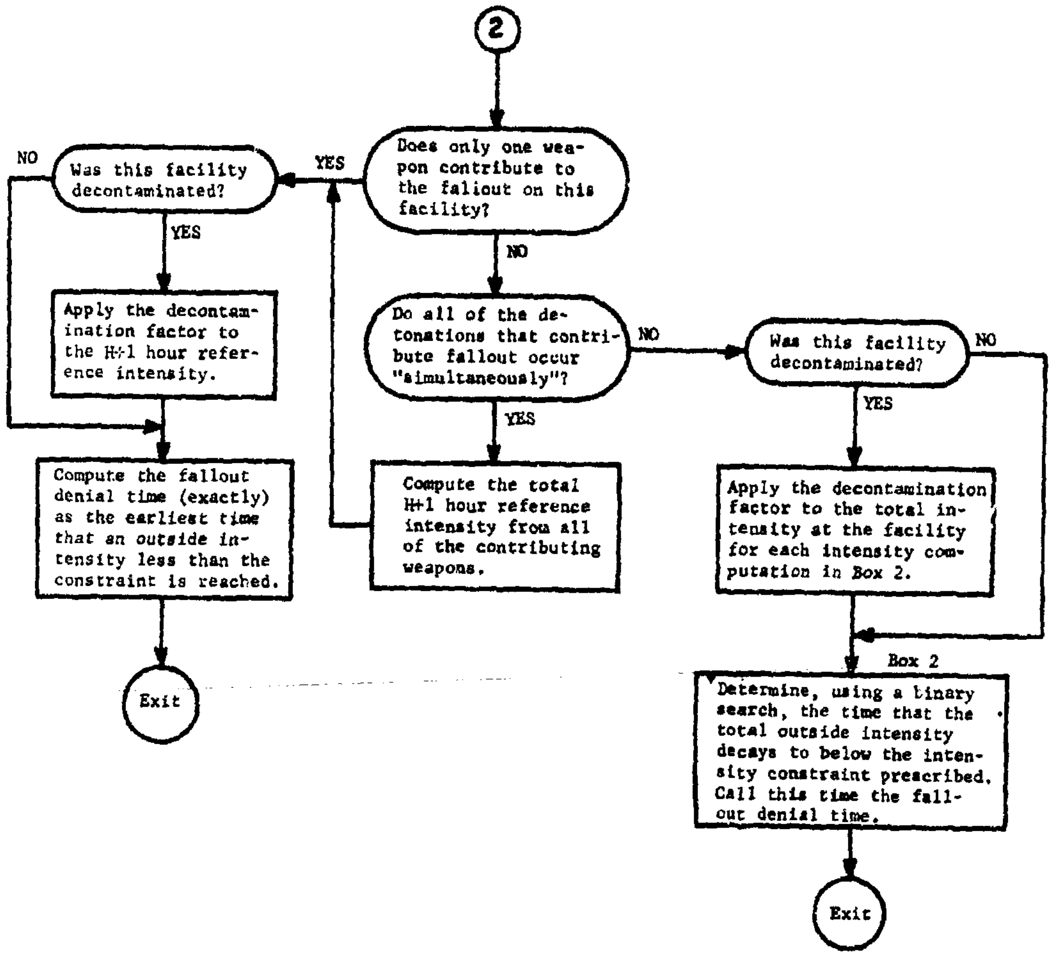


Fig. D-1. Logic of Denial Time Computation (Cont.)

required, and the maximum allowable dose for the decontamination crew. If the facility cannot be decontaminated before the simulation is to end, the facility is marked as "inaccessible" during this run and its inventories are not written onto the ordered facility tape.

Because of this formulation it should be noted that in the event R & R activities required at a particular facility are of short duration, then (since decontamination is a long operation), the recovery (fueling a single aircraft, say) could in fact be carried out long before decontamination could take place (if reasonable dose constraints are put on the decontamination crew.) Hence, care should be utilized in spacifying the decontamination option in the program to avoid two sources of unrealism:

1. If the decontamination option in input for a particular facility when fallout may be moderate to heavy, yet recovery operations are short, the facility may be dropped from the list of facilities becoming available during the game (because the time at which it can be decontaminated is beyond game end);
2. Even if the decontamination is possible before game end, and the game is relatively long, specifying decontamination might result in the facility's becoming available later than if decontamination were not specified.

   Hence, if time required to carry out R & R operations are expected to be short on a particular facility, and fallout is expected to be moderate to heavy, decontamination should probably not be specified for it.[D-2/]

D-2/ Writing a routine in the program to determine whether fallout denial time is greater or less than the time at which the facility could be decontaminated (equivalent, in effect, to a dynamic decontamination decision rule) would significantly increase the program complexity. It is not recommended at this time.

If it can be decontaminated, then the fallout denial time is computed using the decontamination factor (fraction of intensity remaining after decontamination) as a multiplying factor to be applied in all dose or intensity computations. If no decontamination is requested to be performed, the denial time is computed using no multiplying factor.

Either dose or intensity can be computed directly when one of the following two conditions hold: (i) there is only one contributing detonation, (ii) all contributing detonations occur within a small interval of time.[D-3/] If neither of these conditions hold, the denial time is computed by employing a binary search.

The computed denial time is the earliest time that an individual's dose (computed over a prescribed time) is less than or equal to the maximum allowable dose or that the unshielded intensity at the facility is less than or equal to a prescribed maximum allowable intensity. The inputs discussed above are described in more detail in the description of the Facility Inventory and Characteristics Input List in Reference D-1.

The following two sections describe in detail the method for finding the values of the fallout denial times (T_f), for facilities denied by radioactive fallout. Section III describes the method without decontamination, while Section IV shows how decontamination is taken into account.

III. DETAILED CALCULATION OF FALLOUT DENIAL TIMES WITHOUT DECONTAMINATION

A. Introduction

This section describes a method for estimating the fallout denial times for facilities which are denied by fallout and no decontamination is performed.

D-3/ One hour is the smallest unit of time which the R & R Model can handle. Detonations separated by greater intervals may be considered "simultaneous"; this is discussed in Appendix B.

The analytical relationships among dose, decontamination, and fallout denial time have been analyzed extensively in Reference 1, Radiological Recovery Concepts, Requirements and Structures. A summary of this work as it relates to the computation of facility denial times is included as an earlier appendix, Appendix C, to this report.

B. Data Requirements and Definitions

A list of the data requirements including definitions for all of the symbols and terms used in this section is now presented. These data are required for each facility for which the fallout denial time is to be computed. They are:

T_o	Pre-game reference time.
H_i	The detonation time (hr.) measured from a pre-game reference time, T_o, of the ith weapon whose fallout affects the facility.
I_i	The H_i + 1 hour (measured from pre-game reference time, T_o) reference intensity (r/hr.) of the fallout field at the facility from the ith weapon.
n	The total number of weapons which contribute fallout affecting the facility.
AVGP	"Average fallout protection" at the facility. The factor by which unshielded exposure dose is divided to calculate the dose received by persons performing activities on the facility with protection varying during the course of the day.
IC	Intensity constraint (r/hr.); a parameter which enables the input planner to make a facility available when the radiation intensity has decreased to the value of IC (i.e., $ISUM(T_f) = IC$).
GEND	The time (hr.) to which recovery is simulated measured from pre-game reference time, T_o.

TSTOP	The time (hr.) to which total dose is computed in determining denial time, (also measured from time T_o).
DTIME	If TSTOP is not specified, DTIME is a finite time interval over which total dose will be computed.
TRB	Time (hr.) that recovery begins to be simulated, measured from pre-game reference time, T_o.
DMAX	Maximum allowable dose (r).
T_f	Fallout denial time (hr.).

C. Basic Assumptions

The following assumptions are made to permit a reasonable yet simple procedure for computing facility fallout denial times.

First, all of the personnel performing essential activities on the facility have the "average fallout protection" specified by AVGP for the facility after time T_f. This must be taken into account when specifying AVGP as well as when specifying the maximum allowable radiation dose (DMAX) for persons required to perform activities on the facility.

It is recommended that AVGP be computed as the equivalent protection factor[D-4/] associated with an individual's activity pattern on the facility.

Further, certain time orderings are assumed. They are as follows:

TRB < GEND

TRB < TSTOP (when TSTOP is specified)

H_i < TRB $i = 1, 2, \ldots n$

D-4/ The basic equation defining the equivalent protection factor is:

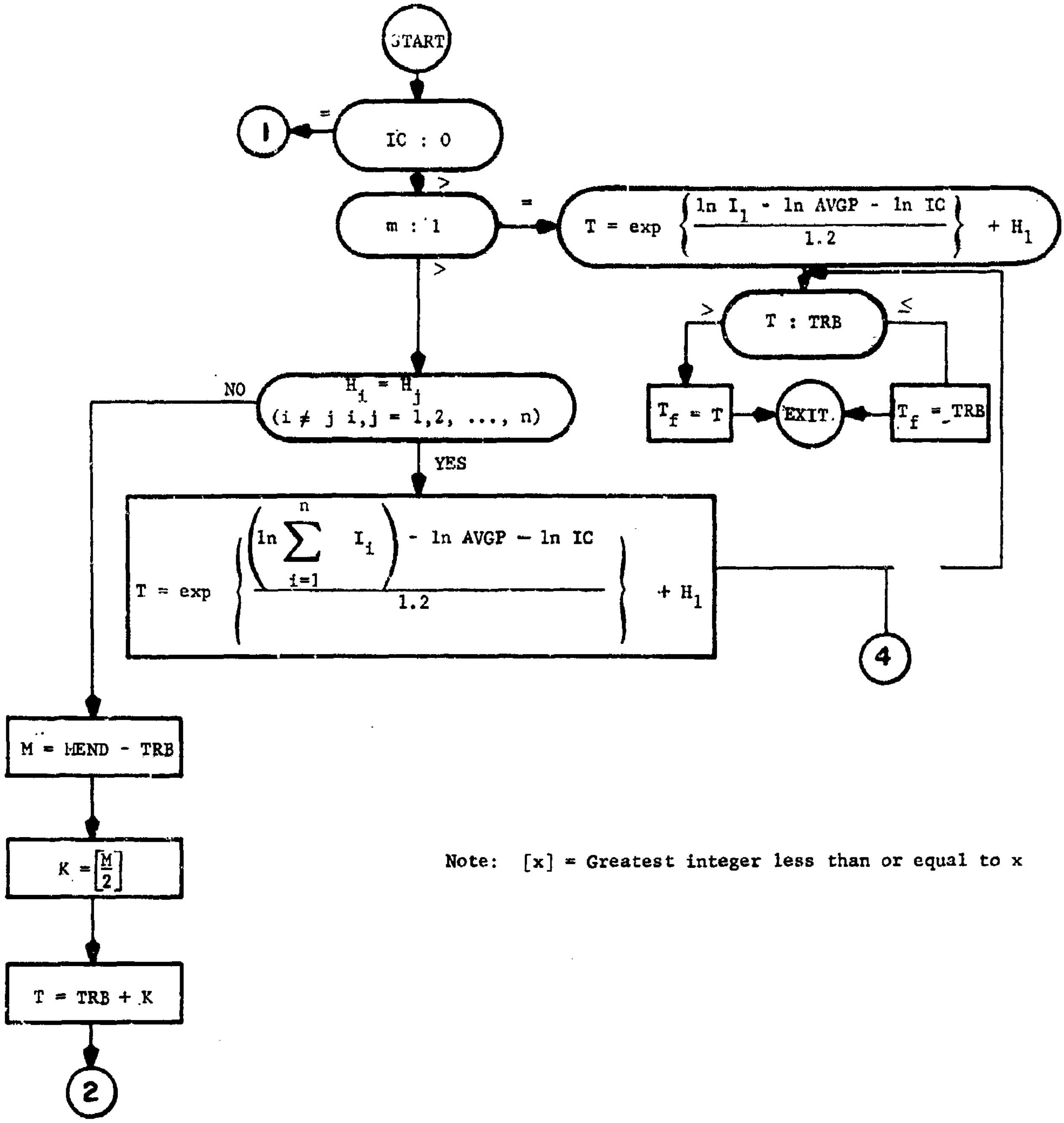
$$\text{Equivalent PF} = \frac{1}{f_1/P_1 + f_2/P_2 + \ldots f_n/P_n}$$

where f_i is the fraction of time spent with protection P_i on the facility.

TRB should be chosen so as to assure that fallout cessation precede the recovery period and thus, that all of the total doses computed are positive quantities.

D. Computational Procedure

Figure D-2 is a flow chart of a procedure for computing fallout denial times without decontamination. Briefly stated, the procedure either computes the time T_f such that the dose from time T_f to either TSTOP or T_f + DTIME (whichever is applicable) is as close to DMAX as possible, or computes the time T_f that the outside intensity has decayed below IC roentgens per hour. A binary search for this time T_f is employed when more than one detonation (not "simultaneously" occurring) contributes fallout to the facility.



Note: [x] = Greatest integer less than or equal to x

Fig. D-2. Flow Chart of Routine to Compute Fallout Denial Time without Decontamination

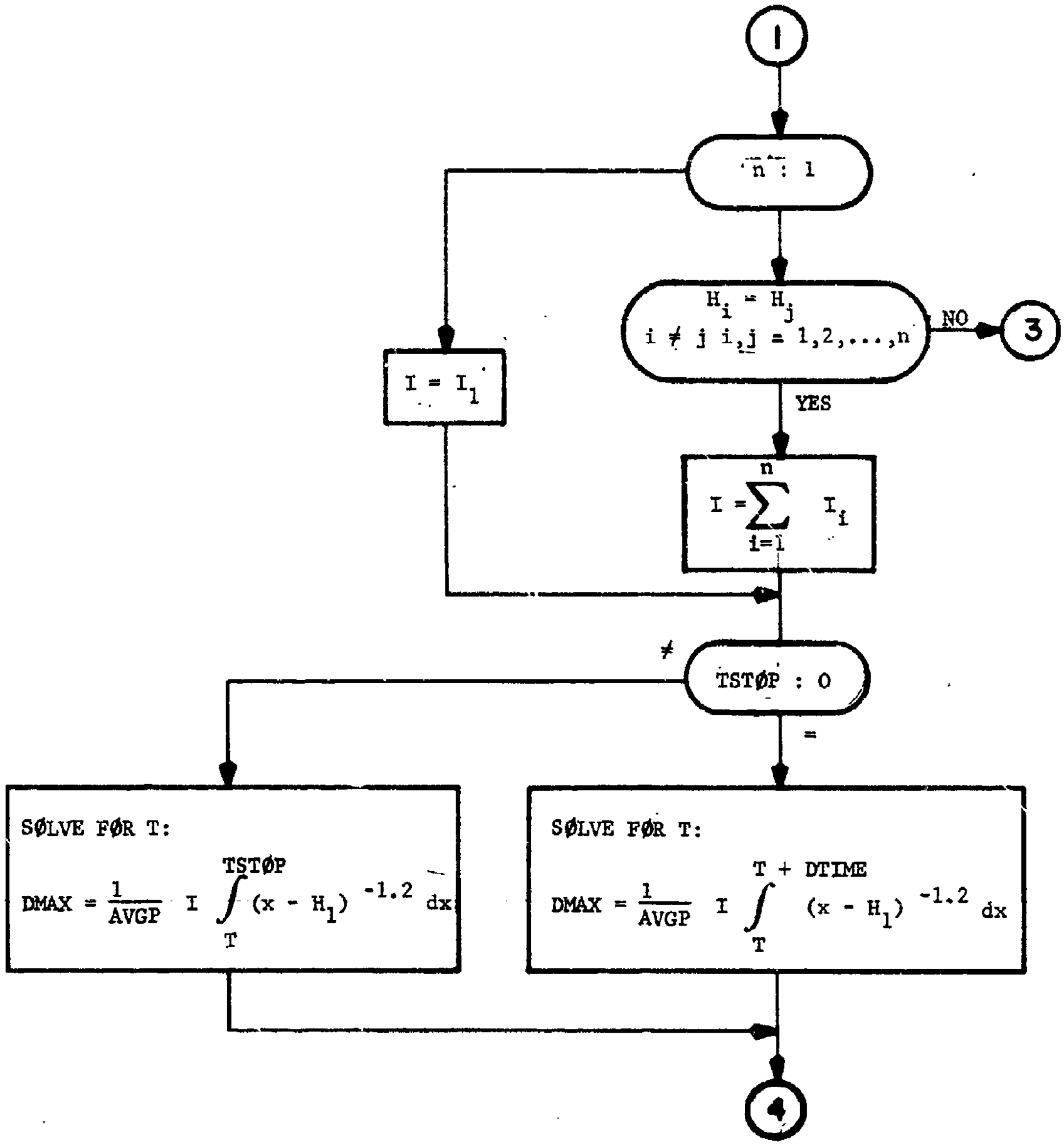
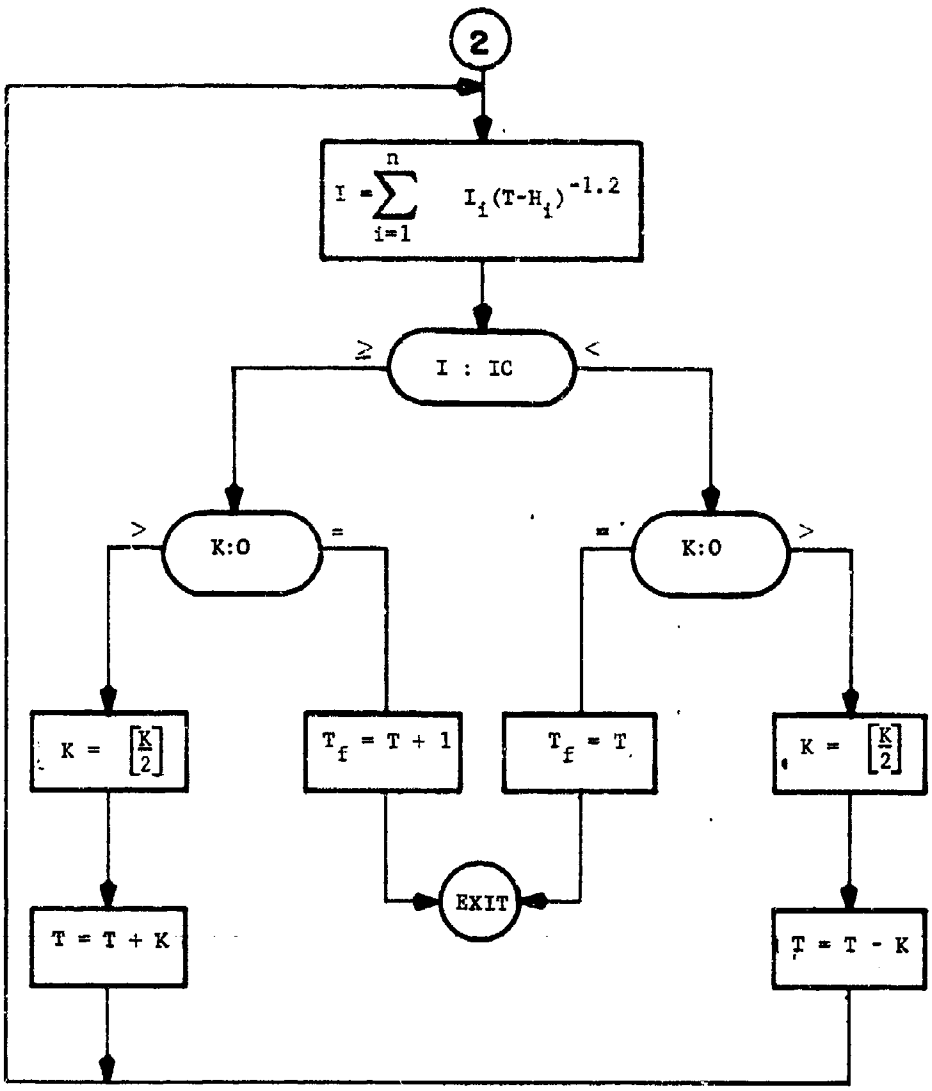
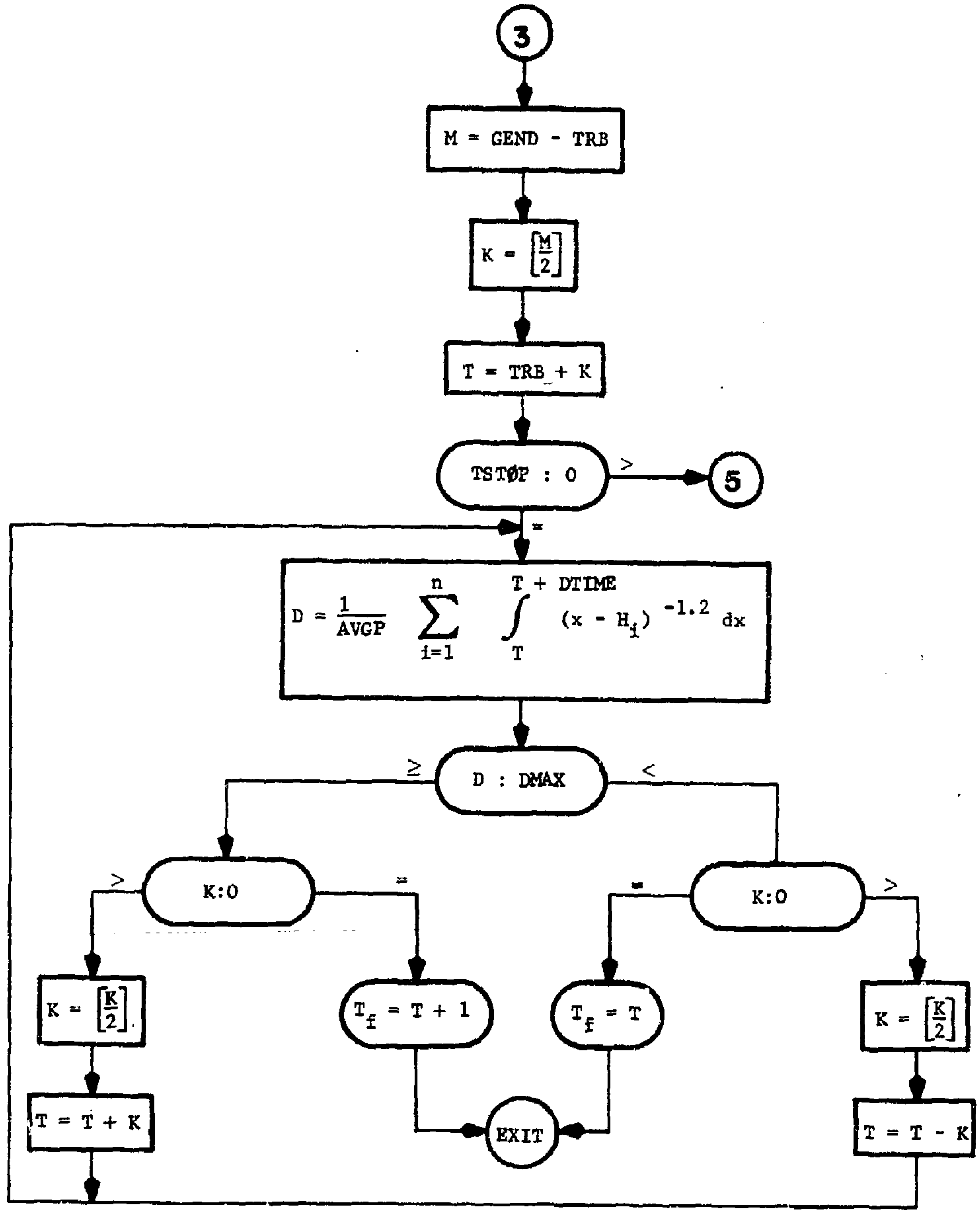


Fig. D-2. Flow Chart of Routine to Compute Fallout Denial Time without Decontamination (cont.)



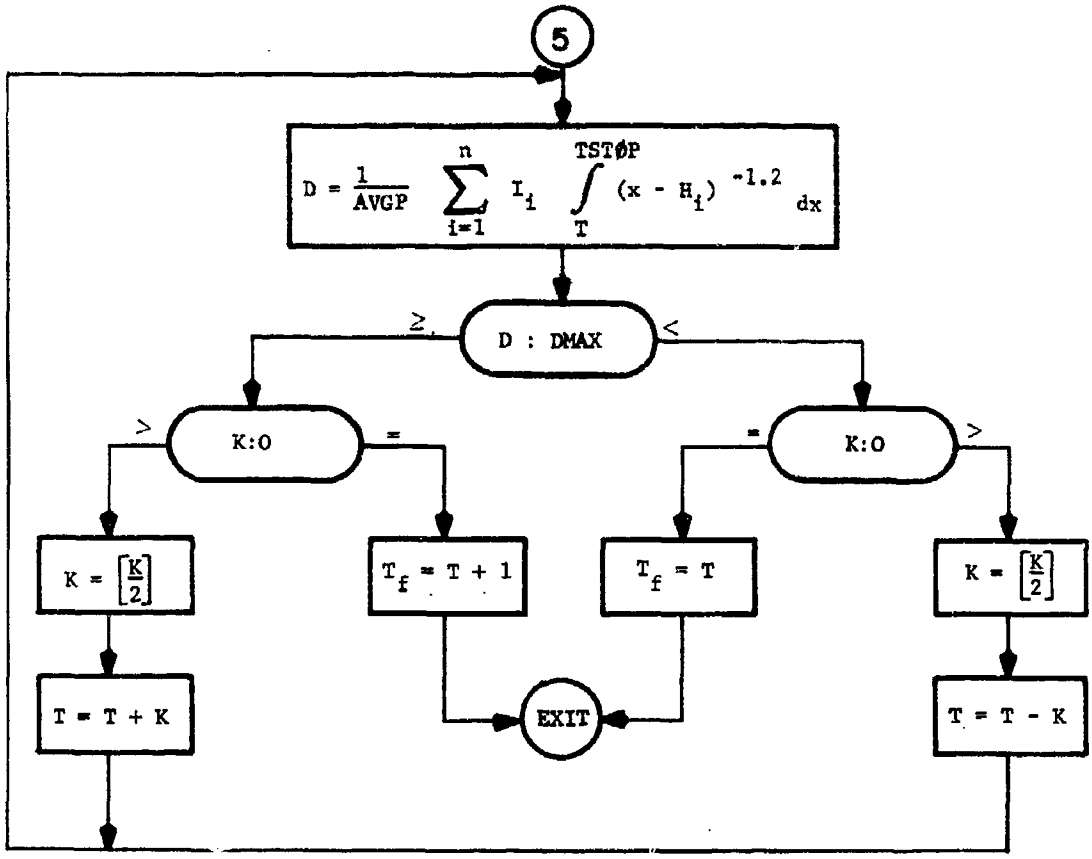
Note: [x] = Greatest integer less than or equal to x

Fig. D-2. Flow Chart of Routine to Compute Fallout Denial Time without Decontamination (cont.)



Note: [x] = Greatest integer less than or equal to x

Fig. D-2. Flow Chart of Routine to Compute Fallout Denial Time without Decontamination (cont.)



Note: [x] = Greatest integer less than or equal to x

Fig. D-2. Flow Chart of Routine to Compute Fallout Denial Time without Decontamination (cont.)

IV. CALCULATION OF FALLOUT DENIAL TIMES WITH DECONTAMINATION

A. Introduction

This section describes how fallout denial time can be computed where decontamination is considered. This subject is discussed analytically in Appendix C to this report. It is seen in Appendix C that decontamination can reduce the fallout denial time appreciably in many practical situations. The additional data requirements when decontamination is considered are specified in the following discussion.

B. Additional Data Requirements and Definitions

The additional data required to compute fallout denial times for facilities with decontamination are presented here. The data required are for each facility for which denial times are to be computed. They are:

F	Fraction of intensity remaining after decontamination.
DDMAX	Maximum allowable dose during decontamination operation.
DECONT	Time (hrs.) required to perform the decontamination operation.
DP	Fallout protection afforded the decontamination crew.

C. Computational Procedure

Figure D-3 is a flow chart of the computation of the time, t_d, at which decontamination can be completed. The time t_d is computed such that the dose received by the decontamination crew from time t_d - DECONT to t_d is the integer value that is as close as possible to DDMAX. After the time at which decontamination can be completed is computed, TRB is set to t_d and the flow chart of Figure D-2 is entered, all of the I_i's ($i = 1, 2, \ldots, n$) are first multiplied by F and the resulting I_i^*'s are used in place of the I_i's.

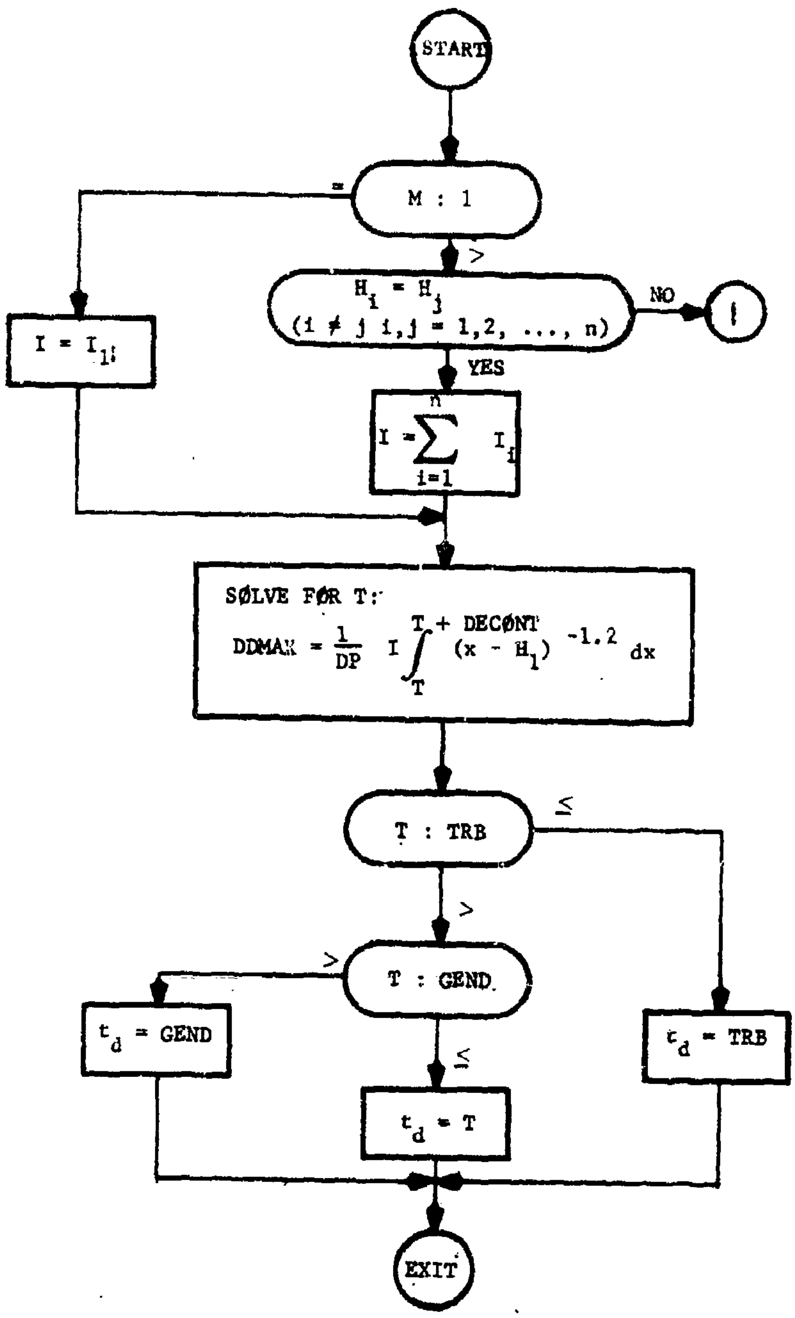
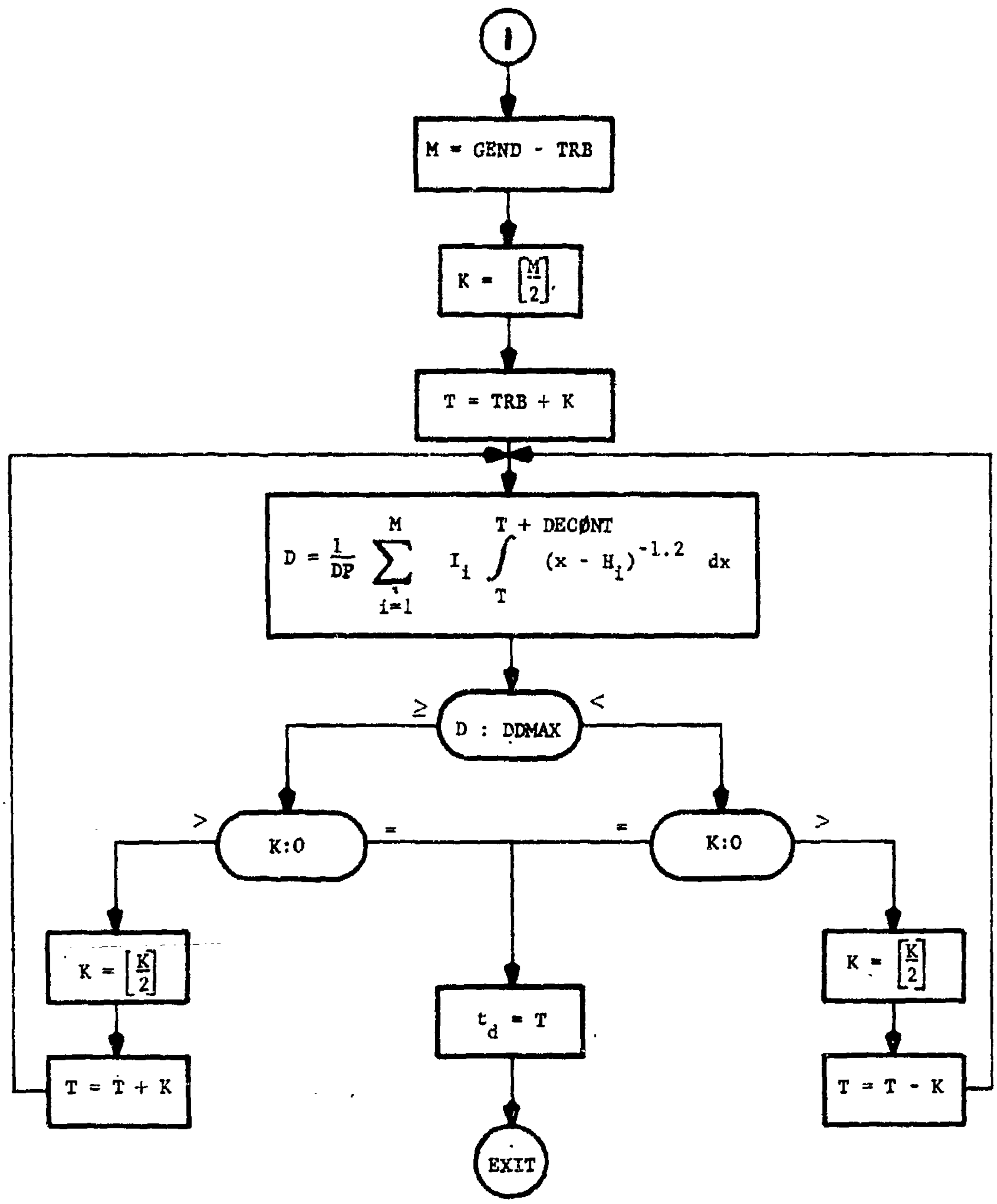


Fig. D-3. Flow Chart of Routine to Compute Time When Decontamination Can be Completed



Note: [x] = Greatest integer less than or equal to x

Fig. D-3. Flow Chart of Routine to Compute Time When Decontamination Can be Completed (cont.)

REFERENCES FOR APPENDIX D

D-1. Ryan, J. T. and R. H. Thornton. Design Phase Report on a Recovery and Reconstitution Model for the Strategic Strike Forces. RM-OU-241-1. Research Triangle Institute, Durham, North Carolina. 20 May 1966.

SUPPLEMENTARY

INFORMATION

AD-489 506L Research Triangle Inst., Durham, N. C. Operations Research and Economics Div. Research memo. Rept. no. RM-OU-241-2 20 May 66 Contract AF 49(638)-1628	Controlled: all requests to Computer Applications Group, Assistant Chief of Staff, USAF, Washington, D. C.	No Foreign without approval of Computer Applications Group, Assistant Chief of Staff, USAF, Washington, D. C.	USAF ltr, 2 May 69