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# Interception and Retention of Radioactive Fallout by Desert Shrubs in the Sedan Fallout Field

William E. Martin

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PROJECT SEDAN

PROJECT 62.83

# INTERCEPTION AND RETENTION OF RADIOACTIVE FALLOUT BY DESERT SHRUBS IN THE SEDAN FALLOUT FIELD

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## ABSTRACT

(1) Concentrations of $I^{131}$ and $Sr^{89}$ on plants contaminated by fallout ~~from Project Sedan~~ tended to decrease with increasing distance from ground zero and increasing time after the detonation. (2) Microscopic and radiometric examinations of foliage indicated that most of the activity deposited on leaves was probably due to particles $< 5 \mu$ in diameter, and virtually none of it was due to particles $> 44 \mu$ in diameter. (3) A comparison between the theoretical and observed interrelations of gamma dose rates, ~~$I^{131}$ and $Sr^{89}$~~ deposition rates, and $I^{131}$ and $Sr^{89}$ interception by desert shrubs indicated a deficiency of $I^{131}$ relative to $Sr^{89}$ in areas more than 40 mi. from ground zero and an excess of both $I^{131}$ and $Sr^{89}$ relative to dose rates in areas about 100 mi. from ground zero. (4) The effective half-lives of $I^{131}$ and $Sr^{89}$ on plants were shorter than their radioactive half-lives, and a comparison of environmental half-lives suggested that $I^{131}$ may have been lost from plants by some process, such as vaporization, which had no effect on the retention of $Sr^{89}$. (5) Statistical analyses indicated that the frequency distributions of variates representing maximum concentrations of ~~$I^{131}$ and $Sr^{89}$~~ on plants, and in the tissues of rabbits collected at the same times and locations ~~in the fallout field~~, were not normal but lognormal. Similar analyses indicated that the frequency distributions of effective half-life estimates could be treated as either normal or lognormal. 16 references. /end/.

# CONTENTS

# INTERCEPTION AND RETENTION OF RADIOACTIVE FALLOUT
# BY DESERT SHRUBS IN THE SEDAN FALLOUT FIELD

## 1.0 INTRODUCTION

### 1.1 Background.

The interception and retention of fallout particles by plants is rapidly followed by the appearance of radionuclides in terrestrial food chains involving a variety of plants and animals including man. The amounts of radionuclides available for ingestion and assimilation by herbivores depend, to a large extent, upon the amounts intercepted and retained by plants. The rates at which different radionuclides may be ingested by herbivores and subsequently transferred to higher trophic levels depend, to some extent, upon the rates of loss from fallout-contaminated plants. A better understanding of these interrelations should lead to a better evaluation of the biological hazards involved in the applications of nuclear energy which routinely or accidentally result in the release of radionuclides to the environment.

The initial distribution of radionuclides in a close-in fallout field is theoretically related to the gross gamma dose rate pattern at some reference time after the detonation. One might expect to find a similar relationship between dose rates and the initial distribution of radionuclides on fallout-contaminated plants;but this relationship could be confounded by fractionation, by variations in the particle-size composition of fallout, and/or by variations in the morphological characteristics of different plant species. The time-specific relationship between radionuclide concentrations on plants and in the tissues of herbivores may be further complicated by variations in the rates of loss from plants and in the rates of ingestion,

4

assimilation, and elimination by the herbivores.

The interpretation and evaluation of data related to gamma dose rates and to radionuclide concentrations in fallout, on plants, and in animal tissues are made difficult by their extreme range and variability. Many of the variates encountered do not have normal frequency distributions; and the use of ordinary statistical methods, which are based on the normal frequency distribution, may lead to erroneous conclusions. In this paper, I hope to provide evidence that some (perhaps most) of these variates have lognormal frequency distributions; and this obviates a real need for the development or adaptation of statistical methods to be used in the analysis of lognormal distributions.

### 1.2  Objectives.

In relation to some of the problems mentioned above, the objectives of this paper are to provide data concerning:  (a)  the concentrations of $I^{131}$ and $Sr^{89}$ in plants and rabbits collected between 5 and 60 days after the detonation from different parts of the Sedan fallout field, (b) the particle-size composition and gamma activity of fallout intercepted by the foliage of desert shrubs,  (c) the variability of fallout retention as shown by esti-mates of the effective and environmental half-lives of $I^{131}$ and $Sr^{89}$ on fallout-contaminated plants, (d) the theoretical and observed interrelations of H + 24 gamma dose rates, fallout deposition, interception, and the initial concentrations of $I^{131}$ and $Sr^{89}$ on plants, and (e) the probability that the frequency distributions of variates representing the effective half-lives of $I^{131}$ and $Sr^{89}$ on plants, the maximum concentrations of $I^{131}$ and $Sr^{89}$ on plants, and the maximum concentrations of $I^{131}$ and $Sr^{89}$ in the thyroids and bone ash of rabbits collected at the same times and places are lognormal rather than normal.

## 1.3 Literature.

It is not within the scope of this paper to review the literature concerning the interception and retention of fallout by plants. A brief review and list of references on this subject were given by Martin [1], and additional references have been cited by Romney et al. [2] and the National Academy of Science [3]. The uses and potential uses of radiometric and radiochemical data in formulating deterministic and stochastic models to represent the time-specific relationship between radionuclide concentrations on plants and in animal tissues have been discussed by Turner [4], Turner and Martin [5,6], Martin [7], and Martin and Turner [8]. (N. B. The papers just cited include additional lists of references.)

## 2.0 METHODS

### 2.1 Collection and Radiochemical Analyses of Samples.

Project Sedan involved the explosion of a $100 \pm 15$ kiloton thermonuclear bomb at a depth of 635 ft. in alluvium at the north end of the Nevada Test Site [9]. The local fallout pattern resulting from this detonation and the approximate locations at which plant samples and rabbits were collected before and after the detonation are shown in Fig. 1.

Bulk plant samples and rabbit tissue samples were analyzed to determine their $I^{131}$ and $Sr^{89}$ contents at times of collection ranging from 5 to 60 days after the detonation on July 6, 1962. The methods used in collecting, processing, and analyzing these samples have been described in previous reports [5,8].

Analyses were also made to determine the time of collection concentrations of $Sr^{90}$ and $Cs^{137}$ in plant samples, but these data (Appendix A) have not been used in the present study because postshot concentrations at more
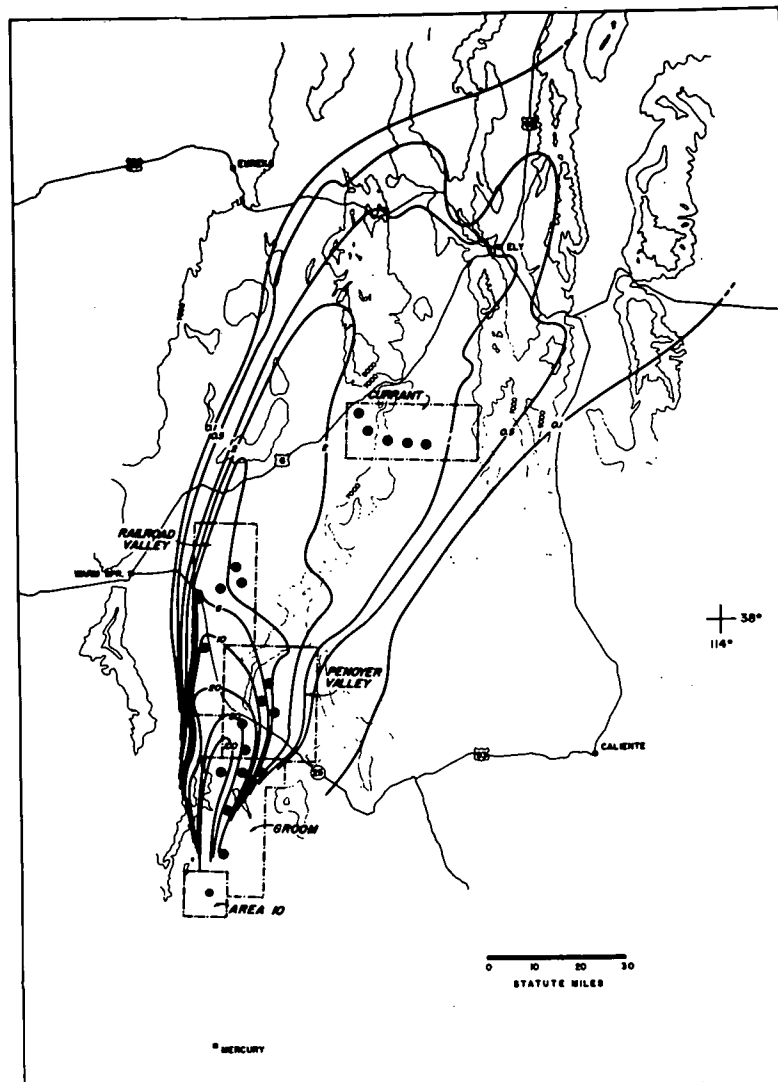
Figure 1. The Sedan fallout pattern: The black dot in Area 10 shows the approximate location of ground zero. The other black dots show the approximate locations at which plants and animals were collected after the detonation. The dose rate contours (mr/hr, 3 ft. above ground, 24 hr. after the detonation) were based on aerial survey data[10].

7

than half of the 20 stations shown in Fig. 1 were not significantly higher than preshot background concentrations.

## 2.2 Analyses of Foliage Samples.

Foliage samples were collected to determine the number and size of radioactive particles per unit area of leaf surface. The leaves used for this purpose were first fixed on transparent sheets of gummed paper and then covered with blotting paper to hold them firmly in place. Within a day or two after collection, gross gamma counts (c/m) were obtained for each sheet. These counts were used to determine exposure times for X-ray films which were placed in contact with the gummed paper to make autoradiographs. The autoradiographs were used as maps to locate radioactive particles which were then examined microscopically and measured with an ocular micrometer. After measuring leaf surface areas (one side only) with a planimeter, the results were expressed as numbers of particles $< 20$ $\mu$, $20$-$44$ $\mu$, and $> 44$ $\mu$ diameter per square centimeter (p/cm$^2$). (N. B. Since the optical resolution of the lens system used in making most of these measurements is between 5 and 7 $\mu$, particles $< 5$ $\mu$ in diameter were not observed.) Gross gamma counts were corrected for geometry (based on a Cs$^{137}$ standard) and for radioactive decay ($t^{-1.2}$). The results were expressed as counts per minute per square centimeter (c/m/cm$^2$) at the times of collection.

## 2.3 Calculation of Retention Factors.

Retention factors were estimated in terms of the effective half-lives if I$^{131}$ and Sr$^{89}$ on fallout-contaminated plants. The calculations were based on equations 1-3.

8

$$T_p = 0.693 (t_2 - t_1) / \log_e (P_{t_1} / P_{t_2}) \tag{1}$$

where, $T_p$ = effective half-life in days

$t_1$ = five days after the detonation

$t_2$ = more than five days after the detonation

$P_{t_1}$ = pc/g (dry wt) at $t_1$

$P_{t_2}$ = pc/g (dry wt) at $t_2$

Estimates of environmental half-lives (i. e., the rates of loss due to factors other than radioactive decay) were based on

$$T_E = T_r \times T_p / T_r - T_p \tag{2}$$

where, $T_E$ = environmental half-life in days (variable)

$T_r$ = radioactive half-life in days (8.04 d $I^{131}$, 50.5 d $Sr^{89}$)

$T_p$ = effective half-life in days (variable)

Values obtained for $T_E(Sr^{89})$ were usually larger than those obtained for $T_E(I^{131})$. To estimate the difference ($T_d$) in half-life terms, calculations were based on

$$T_{dsi} = T_{Es} \times T_{Ei} / T_{Es} - T_{Ei} \tag{3}$$

where, $T_{dsi}$ = a half-life term representing the difference between $T_E(I^{131})$ and $T_E(Sr^{89})$

$T_{Es}$ = environmental half-life of $Sr^{89}$ = $T_E(Sr^{89})$

$T_{Ei}$ = environmental half-life of $I^{131}$ = $T_E(I^{131})$

## 2.4 Calculation of Interception Factors.

Comparisons between the hypothetical and observed interrelations of gamma dose rates, fallout deposition, and the interception of $I^{131}$ and $Sr^{89}$ by plants were based on equations 4-7.

$$a_s = F Y \lambda_r / D C R \qquad (4)$$

$$a_p = P_o / R_o \qquad (5)$$

$$P_o = P_t e^{\lambda_p t} \qquad (6)$$

$$f_p = a_p G / a_s \qquad (7)$$

Where, $a_s$ = theoretical deposition rate on bare soil ($pc/ft^2/mr/hr$)

$F$ = $1.43 \times 10^{23}$ fissions of $U^{235}$ / kiloton yield [11]

$Y_1$ = $3.10 \times 10^{-2}$ atoms of $I^{131}$ / fission of $U^{235}$ [12]

$Y_2$ = $4.79 \times 10^{-2}$ atoms of $Sr^{89}$ / fission of $U^{235}$ [12]

$\lambda_{r_1}$ = $8.64 \times 10^{-2}$ dis/atom of $I^{131}$/day = 0.693/8.04

$\lambda_{r_2}$ = $1.37 \times 10^{-2}$ dis/atom of $Sr^{89}$/day = 0.693/50.5

$D$ = $3.20 \times 10^3$ dis/pc/day

$C$ = $2.79 \times 10^7$ $ft^2/mi^2$

$R$ = $4.50 \times 10^4$ $mr/hr/kt/mi^2$, 24 hr. after the

detonation [13]

$a_p$ = observed deposition rate on plants ($pc/g/mr/hr$)

$P_o$ = initial concentration (pc/g) on plants (N. B. This is a

hypothetical value based on extrapolation to the time of

detonation.)

$R_o$ = mr/hr, 3 ft. above ground, 24 hr. after the detonation

$P_t$ = pc/g (dry wt.) at the time of collection

$\lambda_p$ = effective decay constant on plants = $0.693 / T_p$

$f_p$ = fraction of $I^{131}$ or $Sr^{89}$ interecepted by plants (N. B.

Percentage interception = $100 f_p$.)

$G$ = dry wt. density of plants in $g/ft^2$

10

Percentage interception estimates ($100 \, f_p$) were based on an assumed value of $G = 20 \, g/ft^2$. Estimates of $a_p$ were based on estimates of $P_o$ and $R_o$ at 5 stations in each of the study areas shown in Fig. 1. The $P_o$ estimates used for this purpose were all based on samples collected 5 days after the detonation.

### 2.5 Statistical Analyses of Frequency Distributions.

A preliminary study of the $I^{131}$ data [6] indicated that the frequency distributions of variates representing $I^{131}$ concentrations in plant samples and in the thyroids of rabbits were not normal but lognormal. Simulated samples of $P_o$ (maximum possible concentrations of $I^{131}$ and $Sr^{89}$ on plants) and of $A_m$ (maximum observed concentrations of $I^{131}$ in the thyroids and of $Sr^{89}$ in the bone ash of rabbits) were obtained by extrapolating the concentrations observed at different times of collection to a common reference time. The reference time for $P_o$ ($I^{131}$ and $Sr^{89}$) was D+0 (the time of the detonation). The reference times for $A_m$($I^{131}$) and $A_m$($Sr^{89}$) were D+5 and D+30 (5 and 30 days after the detonation) respectively.

The method of extrapolation for $A_m$ was based on the averages of samles collected at a given time. For example, the average (time of collection) concentration of $Sr^{89}$ in 20 bone ash samples collected on D+5 was 863 pc/g; and the average (time of collection) concentration in 20 samples collected at the same locations on D+ 30 was 2097 pc/g. In this case, extrapolation involved the multiplication of each D + 5 variate by $2097/863 = 2.433$.

The method of extrapolation for $P_o$ was the same except that the correction factors for D + 5 variates were based on the average effective half-lives of $I^{131}$ and $Sr^{89}$ on plants from D + 5 to D + 15.

Some estimates of $T_p(I^{131})$ and $T_p(Sr^{89})$ were based on the arithmetic means $(\bar{x}P_t)$ and the geometric means $(\bar{x}_g P_t)$ of $P_t$ as determined for 20 samples representing each time of collection. To study the frequency distributions of these variates, each estimate of $(T_p)_i$ was based on the individual values of $(P_t)_i$ representing two times of collection at each of the 20 stations.

The frequency distributions of $(T_p)_i$, $P_o$, and $A_m$ for $I^{131}$ and $Sr^{89}$ and the frequency distributions of $\log_{10}$ transforms representing the same variates were tested for normality (skewness and kurtosis) according to the procedure described by Snedecor[14]. (N. B. For the reader's convenience, the calculations involved in this procedure are illustrated in Appendix B.)

## 3.0 RESULTS

### 3.1 Radionuclide Concentrations in Plant Samples and Rabbit Tissues.

As shown in Table 1, the average concentrations of $I^{131}$ and $Sr^{89}$ in plant samples and of $I^{131}$ in rabbit thyroids tended to decrease with increasing distance from ground zero and increasing time after the detonation. Average concentrations of $Sr^{89}$ in rabbit bone ash were relatively low at $D + 5$ but reached maximum levels about $D + 30$ and then decreased to lower levels by $D + 60$.

The geometric means $(\bar{x}_g)$ are consistently lower than the arithmetic means $(\bar{x})$; but usually, the matching groups of means are more or less proportional. In all but three cases (See the thyroid data for Penoyer on $D + 25$ and $D + 30$, the thyroid data for Currant on $D + 15$ and $D + 20$, and the bone ash data for Penoyer on $D + 15$ and $D + 30$.), the rank correlations between arithmetic and geometric means are perfect.

Table 1. Concentrations of $I^{131}$ and $Sr^{89}$ in plant samples ($P_t$) and in the thyroids or bone ash of rabbits ($A_t$) collected at different times (TOC=D+5, D+10, etc.) after the detonation from different areas in the Sedan fallout field.[1]

| Radio-nuclides | Type of Sample | AREA: TOC | GROOM | | PENOYER | | RAILROAD | | CURRANT | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $\bar{x}$ | $\bar{x}_g$ | $\bar{x}$ | $\bar{x}_g$ | $\bar{x}$ | $\bar{x}_g$ | $\bar{x}$ | $\bar{x}_g$ |
| $I^{131}$ | $P_t$ (pc/g) | D+ 5 | 11964 | 7741 | 1244 | 1021 | 713 | 698 | 501 | 477 |
| | | D+10 | 6671 | 4145 | 659 | 567 | 377 | 367 | 200 | 182 |
| | | D+15 | 3192 | 2243 | 412 | 341 | 211 | 204 | 121 | 73 |
| | | D+20 | 1224 | 664 | 226 | 159 | 119 | 113 | 56 | 47 |
| | | D+25 | 526 | 389 | 192 | 98 | 96 | 92 | 35 | 30 |
| | | D+30 | 273 | 191 | 103 | 80 | 48 | 42 | 26 | 24 |
| | $A_t$ (nc/ thyroid) | D+ 5 | 466.6 | 331.0 | 257.2 | 200.9 | 105.9 | 75.4 | 26.2 | 23.2 |
| | | D+10 | 334.0 | 202.2 | 123.9 | 113.3 | 85.0 | 61.3 | 7.1 | 6.26 |
| | | D+15 | 138.9 | 86.6 | 74.6 | 55.7 | 60.9 | 47.6 | 5.9 | 3.52 |
| | | D+20 | 82.6 | 54.8 | 40.0 | 28.4 | 22.1 | 11.7 | 5.8 | 4.78 |
| | | D+25 | 61.2 | 41.4 | 28.7 | 18.4 | 28.8 | 15.3 | 1.6 | 1.56 |
| | | D+30 | 15.8 | 13.4 | 21.2 | 20.9 | 10.7 | 6.98 | 1.1 | 0.28 |
| $Sr^{89}$ | $P_t$ (pc/g) | D+ 5 | 4079 | 2772 | 948 | 720 | 397 | 385 | 318 | 290 |
| | | D+15 | 2716 | 1685 | 470 | 394 | 269 | 262 | 183 | 168 |
| | | D+30 | 1584 | 1029 | 332 | 244 | 164 | 154 | 136 | 126 |
| | | D+60 | 788 | 502 | 283 | 204 | 127 | 90 | 55 | 53 |
| | $A_t$ (pc/g) | D+ 5 | 1459 | 814 | 1363 | 651 | 334 | 289 | 295 | 121 |
| | | D+15 | 3648 | 1009 | 2024 | 1461 | 620 | 313 | 323 | 273 |
| | | D+30 | 4999 | 2639 | 2283 | 935 | 783 | 598 | 427 | 286 |
| | | D+60 | 3581 | 2084 | 552 | 421 | 483 | 390 | 280 | 207 |

[1]/Each value is the average of 5 samples: $\bar{x}$ indicates the arithmetic means and $\bar{x}_g$ indicates the geometric means of 5 samples from each area at each time of collection.

## 3.2 Fallout Particles and Radioactivity on Plant Foliage.

As shown in Fig. 2, autoradiographs of foliage indicated rather diffuse patterns of contamination. In most cases, the areas on X-ray films corresponding to individual leaves showed several to many dark spots imposed on a more or less uniformly gray, diffuse background. The areas on leaves corresponding to the dark spots on X-ray films were explored microscopically, but discoveries of measureable particles (i. e., particles > 5 $\mu$ in diameter) were infrequent in relation to the numbers of dark spots observed on the films. These observations suggest that most of the radioactivity on leaves was associated with particles (or aerosols) < 5 $\mu$ in diameter.

The results given in Table 2 show no consistent relationship between the observed number of radioactive particles per square centimeter of leaf surface ($p/cm^2$) and gamma activity ($c/m/cm^2$), concentrations of $I^{131}$ or $Sr^{89}$ in plant samples (Table 1), distance from ground zero, or time after the detonation. In fact, a comparison of data for Groom and Currant indicates entirely opposite trends. On D + 5, $p/cm^2$ was about 4 times higher in the Currant area while $c/m/cm^2$ was about 10 times higher in the Groom area. With increasing time after the detonation, $c/m/cm^2$ decreased in both areas; but $p/cm^2$ increased in the Groom area and decreased at Currant.

There are some indications of a nonlinear relationship between $c/m/cm^2$ (Table 2) and concentrations of $I^{131}$ and $Sr^{89}$ (Table 1) in the plant samples collected on D + 5; but there is no apparent correlation between $p/cm^2$ and either $c/m/cm^2$ and $I^{131}$ or $Sr^{89}$ concentrations (pc/g). The erratic changes in $p/cm^2$ and $c/m/cm^2$ in relation to time after the detonation could be
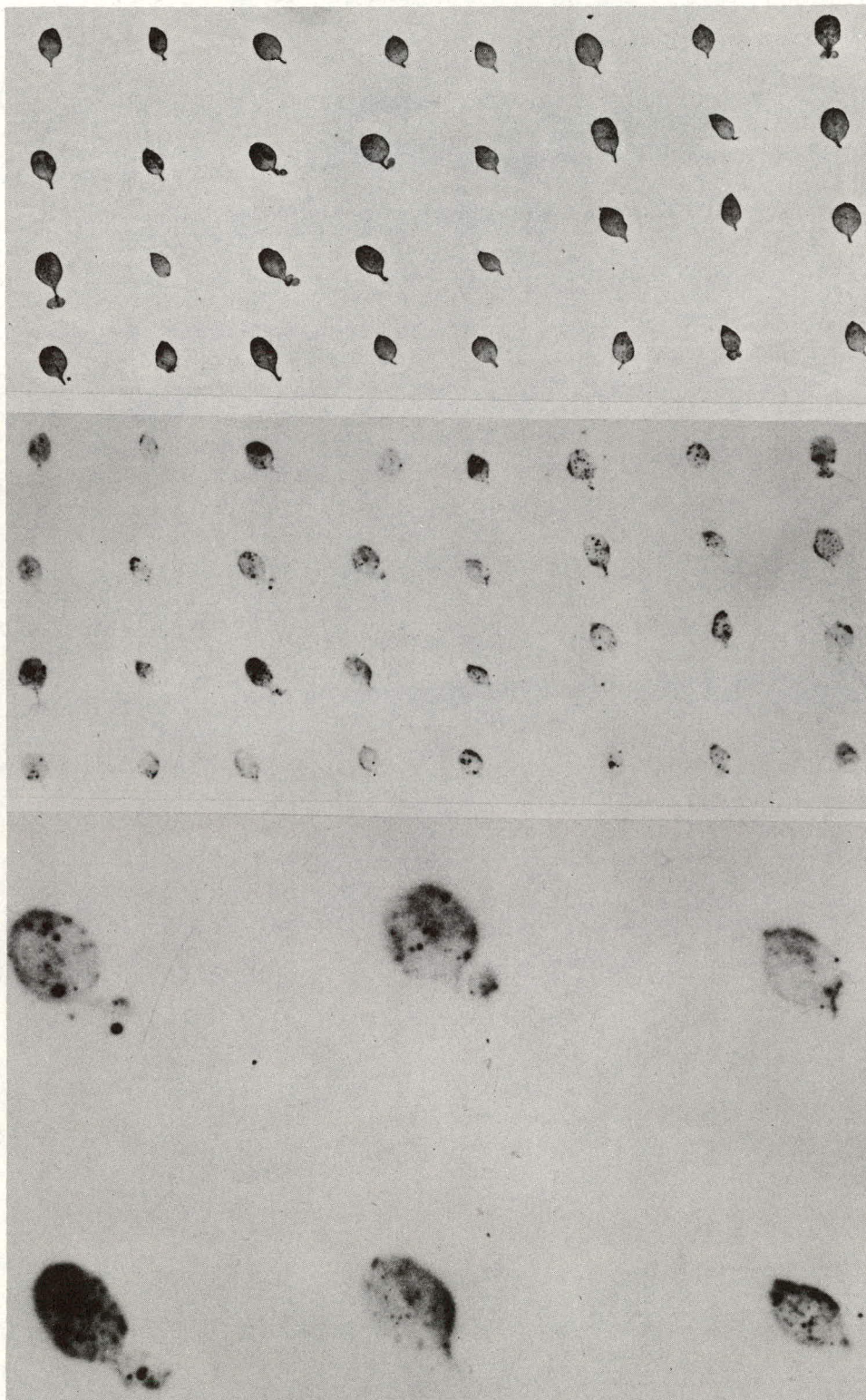
Figure 2. The autoradiographs of leaves mounted on transparent gummed
paper showed a diffuse pattern of contamination with dark spots
imposed on a more or less uniformly gray background.

15

Table 2. Number and size of radioactive particles ($p/cm^2$) and gross gamma activities ($c/m/cm^2$) on leaf samples from different parts of the Sedan fall-out field. Each value is the average of five samples.

| Study Area | Measurement | D + 5 | D+10 | D+15 | D+20 | D+25 | D+30 |
|---|---|---|---|---|---|---|---|
| Groom | $p/cm^2$, <20μ | 0.93 | 1.46 | 1.79 | 2.86 | 1.74 | 2.73 |
| | $p/cm^2$, 20-44μ | 0.68 | 0.81 | 0.73 | 1.03 | 2.06 | 1.95 |
| | $p/cm^2$, total[1] | 1.61 | 2.28 | 2.52 | 3.95 | 3.80 | 4.68 |
| | $c/m/cm^2$ x $10^3$ | 517.6 | 88.4 | 54.5 | 69.2 | 35.5 | 25.8 |
| Penoyer | $p/cm^2$, <20μ | 0.58 | 0.55 | 0.45 | 0.74 | 0.87 | 1.08 |
| | $p/cm^2$, 20-44μ | 0.55 | 0.49 | 0.63 | 1.23 | 0.92 | 0.69 |
| | $p/cm^2$, total | 1.13 | 1.07 | 1.08 | 1.97 | 1.81 | 1.92 |
| | $c/m/cm^2$ x $10^3$ | 28.8 | 3.78 | 2.40 | 1.90 | 0.76 | 2.11 |
| Railroad | $p/cm^2$, <20μ | 2.60 | 1.21 | 0.28 | 1.39 | 0.52 | 1.39 |
| | $p/cm^2$, 20-44μ | 1.24 | 0.83 | 0.64 | 1.07 | 0.70 | 0.84 |
| | $p/cm^2$, total | 3.86 | 2.04 | 0.94 | 2.47 | 1.22 | 2.26 |
| | $c/m/cm^2$ x $10^3$ | 6.14 | 1.80 | 1.09 | 1.02 | 0.99 | 1.22 |
| Currant | $p/cm^2$, <20μ | 1.40 | 0.66 | 0.50 | 0.31 | 0.28 | 0.79 |
| | $p/cm^2$, 20-44μ | 3.25 | 1.03 | 1.23 | 2.01 | 0.82 | 0.71 |
| | $p/cm^2$, total | 4.76 | 1.69 | 1.77 | 2.34 | 1.25 | 1.51 |
| | $c/m/cm^2$ x $10^3$ | 5.77 | 0.72 | 0.39 | 0.23 | 0.29 | 0.19 |

[1] Total includes particles > 44μ in diameter.

interpreted as indications of fallout redistribution by wind action. The virtual absence of particles $> 44\ \mu$ in diameter -- less than 2 per cent of all those measured -- seems to confirm the notion that virtually none of the radioactivity on leaves was associated with particles $> 44\ \mu$ in diameter.

### 3.3 Retention Factors:  Effective and Environmental Half-lives.

Estimates of the effective half-lives $(T_p)$ and the environmental half-lives $(T_E)$ of $I^{131}$ and $Sr^{89}$ on fallout-contaminated plants are given in Table 3. The estimates indicated by $T_p(\bar{x}P_t)$ and $T_p(\bar{x}_gP_t)$ are based on the means and geometric means of $I^{131}$ and $Sr^{89}$ concentrations (pc/g) in 20 samples representing each time of collection (D + 5, etc.)  The estimates indicated by $(\bar{x}T_p)$ and $(\bar{x}_gT_p)$ are the means and geometric means of 20 different estimates of $T_p$ each of which was based on the $P_t$ values representing two times of collection at a given station.

The environmental half-life estimates $(T_E)$ for $I^{131}$ are mostly smaller than those for $Sr^{89}$, and this suggests that part of the $I^{131}$ intercepted by plants may have been lost by some process such as vaporization which had no effect on the retention of $Sr^{89}$. The rate of this "other process" can be estimated by equation 3. For example, the $T_E$ values indicated in Table 3 by $T_p(\bar{x}P_t)$ for $I^{131}$ and $Sr^{89}$ during the period from D + 5 to D + 30 are 13.1 and 27.4 days respectively. The effective rate of the other process $(T_d)$ is given by $T_{dsi} = 27.4 \times 13.1\ /\ 27.4 - 13.1 = 24.2$ days; and this suggests a significant difference in regard to the relative efficiency of $I^{131}$ and $Sr^{89}$ retention. Similar comparisons based on $T_p(\bar{x}_gP_t)$, $(\bar{x}T_p)$ and $(\bar{x}_gP_t)$ indicate $T_{dsi} = 31.3$, 105.5, and 105.0 days respectively.

A reexamination of the $\log_{10}T_p$ data showed that the average environ-

Table 3. Estimates of effective half-lives $(T_p)$ and environmental half-lives $(T_E)$ based on the means $(\bar{x})$ and geometric means $(\bar{x}_g)$ of $I^{131}$ and $Sr^{89}$ concentrations on plants $(P_t)$ and on the individual variates $(P_t)_i$ at different times of collection (D+5 to D+10, etc.)

| Basis of Estimates[1/] | $I^{131}$ | | | | | $Sr^{89}$ | | |
|---|---|---|---|---|---|---|---|---|
| | 5-10 | 5-15 | 5-20 | 5-25 | 5-30 | 5-15 | 5-30 | 5-60 |
| $T_p(\bar{x}P_t)$ | 5.76 | 5.35 | 4.76 | 4.89 | 4.98 | 15.2 | 17.8 | 25.2 |
| $T_E$ | 20.3 | 15.0 | 11.7 | 12.5 | 13.1 | 22.5 | 27.4 | 52.4 |
| $T_p(\bar{x}_gP_t)$ | 5.42 | 5.56 | 4.50 | 4.96 | 5.11 | 13.6 | 18.1 | 25.0 |
| $T_E$ | 17.3 | 18.0 | 10.5 | 13.0 | 14.5 | 18.8 | 27.0 | 49.0 |
| $(\bar{x}T_p)$ | 5.24 | 5.92 | 5.21 | 5.93 | 6.00 | 15.8 | 19.0 | 26.8 |
| $T_E$ | 15.6 | 23.6 | 15.3 | 23.6 | 23.6 | 23.0 | 30.4 | 57.0 |
| $(\bar{x}_gT_p)$ | 4.87 | 5.56 | 5.07 | 5.70 | 5.86 | 13.5 | 17.7 | 25.7 |
| $T_E$ | 12.4 | 18.0 | 13.7 | 19.6 | 21.6 | 18.4 | 27.2 | 52.3 |

1/ For n = 20 and i = 1

$(\bar{x}P_t) = \Sigma (P_t)_i / n$

$T_p(\bar{x}P_t) = 0.693 (t_2 - t_1) / \log_e \left[ (\bar{x}P_{t_1}) / (\bar{x}P_{t_2}) \right]$

$(\bar{x}_gP_t) = \text{antilog} \Sigma \log_{10} (P_t)_i / n$

$T_p(\bar{x}_gP_t) = 0.693 (t_2 - t_1) / \log_e \left[ (\bar{x}_gP_{t_1}) / (\bar{x}_gP_{t_2}) \right]$

$(T_p)_i = 0.693 (t_2 - t_1) / \log_e (P_{t_1} / P_{t_2})_i$

$(\bar{x}T_p) = \Sigma (T_p)_i / n$

$(\bar{x}_gT_p) = \text{antilog} \Sigma \log_{10} (T_p)_i / n$

$T_E = T_r \times T_p / T_r - T_p$

$T_r = 8.04$ day I-131, 50.5 day Sr-89

mental half-lives of $I^{131}$ and $Sr^{89}$ from 5 to 30 days after the detonation

at stations (n = 7) where the H + 24 gamma dose rates were $\geq$ 10 mr/hr were

14.5 and 29.0 days respectively ($T_{dsi}$ = 29 days). Comparable estimates

based on stations where the H + 24 dose rates were < 10 mr/hr (n = 13)

indicated environmental half-lives of 25.6 and 29.6 days respectively for

$I^{131}$ and $Sr^{89}$ ($T_{dsi}$ = 189.2 days).

### 3.4 Interception Factors: Deposition on Soil vs. Interception by Plants.

Estimates of $a_s$ (equation 4) were 95,870 and 23,400 pc/ft$^2$/mr/hr for $I^{131}$

and $Sr^{89}$, indicating a theoretical ratio of 4.097 for deposition on bare

soil. As shown in Table 4, the average $I^{131}/Sr^{89}$ ratio (independent of $R_o$)

on plants in the Groom area was 4.374 while the comparable ratios for

Penoyer, Railroad, and Currant were 2.210, 2.682, and 2.415 respectively.

Estimates of $a_p$ (equations 5 and 6) ranged from 129 to 784 pc/g/mr/hr

for $I^{131}$ and from 47 to 327 pc/g/mr/hr for $Sr^{89}$. The average values of

$a_p$ for $I^{131}$ and $Sr^{89}$ interception by plants in the Groom area indicated a

ratio of (406.9 / 102.4 =) 3.97, which is fairly close to the theoretical

ratio indicated by $a_s$. Comparable ratios for Penoyer, Railroad, and Currant

were 2.14, 2.63, and 2.17 respectively.

Since the averages of $a_p$ estimates for $Sr^{89}$ in Penoyer and Railroad

were about the same as the average for Groom, the lower $a_p$ values for $I^{131}$

in Penoyer and Railroad suggest a deficiency of $I^{131}$ relative to $Sr^{89}$. The

higher $a_p$ values in the Currant area may indicate an excess of both $I^{131}$

and $Sr^{89}$ relative to $R_o$, or they may be due to gross underestimates of $R_o$.

Since G and $a_s$ were assumed to be constant, the 100 $f_p$ (percentage

interception as defined by equation 7) values in Table 4 vary only in

relation to $a_p$. In the Groom area, where the species collected was

Table 4. Estimates of $R_o$ (mr/hr) were based on aerial survey data (Fig. 1). Estimates of $P_o$, $a_p$, and $f_p$ were based on Eqs. 4-7.[1/]

| Study Areas | $R_o$ (mr/hr) | $P_o$ $I^{131}$ | $Sr^{89}$ | Ratio $P_o$'s | $a_p$ $I^{131}$ | $Sr^{89}$ | $100\ f_p$ $I^{131}$ | $Sr^{89}$ |
|---|---|---|---|---|---|---|---|---|
| Groom | 120.0 | 42193 | 8685 | 4.858 | 351.6 | 72.4 | 7.33 | 6.19 |
| | 80.0 | 36414 | 6487 | 5.613 | 455.2 | 81.1 | 9.50 | 6.93 |
| | 70.0 | 15158 | 3266 | 4.641 | 216.6 | 46.7 | 4.52 | 3.99 |
| | 25.0 | 17074 | 5575 | 3.063 | 683.0 | 223.0 | 14.2 | 19.0 |
| | 5.0 | 1641 | 444 | 3.696 | 323.2 | 88.8 | 6.85 | 7.59 |
| $\bar{x}$: | 60.0 | 22496 | 4891 | 4.374 | 406.9 | 102.4 | 8.49 | 8.75 |
| Penoyer | 40.0 | 5164 | 2878 | 1.795 | 129.1 | 71.9 | 2.69 | 6.14 |
| | 20.0 | 2865 | 1129 | 2.540 | 143.2 | 56.4 | 2.99 | 4.82 |
| | 8.0 | 1284 | 1279 | 1.004 | 160.5 | 159.9 | 3.35 | 13.7 |
| | 3.5 | 978 | 337 | 2.899 | 279.3 | 96.3 | 5.83 | 8.23 |
| | 3.0 | 1402 | 499 | 2.810 | 467.3 | 166.3 | 9.75 | 14.2 |
| $\bar{x}$: | 14.9 | 2339 | 1224 | 2.210 | 253.9 | 110.2 | 4.92 | 9.41 |
| Railroad | 10.0 | 1852 | 778 | 2.380 | 185.2 | 77.8 | 3.86 | 6.65 |
| | 7.0 | 1026 | 455 | 2.255 | 146.6 | 65.0 | 3.06 | 5.56 |
| | 6.0 | 1414 | 385 | 3.671 | 235.6 | 64.2 | 4.92 | 5.49 |
| | 3.5 | 1269 | 513 | 2.474 | 362.6 | 146.6 | 7.57 | 12.5 |
| | 3.0 | 1143 | 435 | 2.628 | 381.0 | 145.0 | 7.95 | 12.4 |
| $\bar{x}$: | 5.9 | 1341 | 513 | 2.682 | 262.2 | 99.7 | 5.47 | 8.52 |
| Currant | 2.0 | 1397 | 654 | 2.136 | 698.5 | 327.0 | 14.6 | 28.0 |
| | 1.8 | 912 | 385 | 2.369 | 506.7 | 213.9 | 10.6 | 18.3 |
| | 1.5 | 1083 | 535 | 2.024 | 722.0 | 356.7 | 15.0 | 30.5 |
| | 1.5 | 538 | 186 | 2.890 | 358.4 | 124.0 | 7.48 | 10.6 |
| | 1.0 | 748 | 295 | 2.658 | 748.0 | 295.0 | 16.4 | 25.2 |
| $\bar{x}$: | 1.56 | 943 | 411 | 2.415 | 613.9 | 283.3 | 12.8 | 22.5 |

[1/] Estimates of $P_o$ were based on concentrations of $I^{131}$ and $Sr^{89}$ in plant samples collected on D+5, $T_p(I^{131}) = 5.56$ days and $T_p(Sr^{89}) = 13.5$ days.

sagebrush (_Artemisia tridentata_), the average value of 100 $f_p$ for $Sr^{89}$

was 8.75 per cent. The comparable value for Penoyer and Railroad, where

the species collected was shadscale (_Atriplex confertifolia_), was

9.41 + 8.52 / 2 = 8.96 per cent. This comparison suggests only a slight

difference between sagebrush and shadscale in regard to the interception

of $Sr^{89}$. (One might assume that sagebrush is more efficient than shadscale

in regard to $I^{131}$ interception, but the $a_p$ ratios for shadscale in Penoyer

and Railroad was (2.14 + 2.63 / 2 = 2.38) about the same as the ratio

(2.17) for sagebrush in the Currant area.)

This line of reasoning indicates no large difference between sagebrush

and shadscale in regard to the interception of $I^{131}$ and $Sr^{89}$. It further

suggests that the quantity $(f_p / G) = 0.0044$ $ft^2/g$ could be treated as

a constant for sagebrush and shadscale. According to this hypothesis,

an alternative to the one defined by equations 4-7, variations in $a_p$ would

be attributed primarily to disparities between apparent and theoretical

values of $a_s$, i. e., to the nonuniform distribution of $I^{131}$ and $Sr^{89}$

relative to estimates of $R_o$ based on aerial survey data.

### 3.5 Frequency Distribution of Variates.

Figure 3 illustrates the frequency distributions of extrapolated

values representing $P_o(Sr^{89})$. Histogram A shows the frequency distribution

of the whole array (n = 80) based on estimates of the arithmetic mean

and standard deviation. Histogram B shows the frequency distribution

of the same array based on estimates of the mean and standard deviation

of $\log_{10} P_o (Sr^{89})$. The shaded part of the histogram shows the frequency

distribution of variates representing 7 stations where $R_o \geq 10$ mr/hr

$(S \geq 10)$ while the unshaded part shows the frequency distribution of variates

21
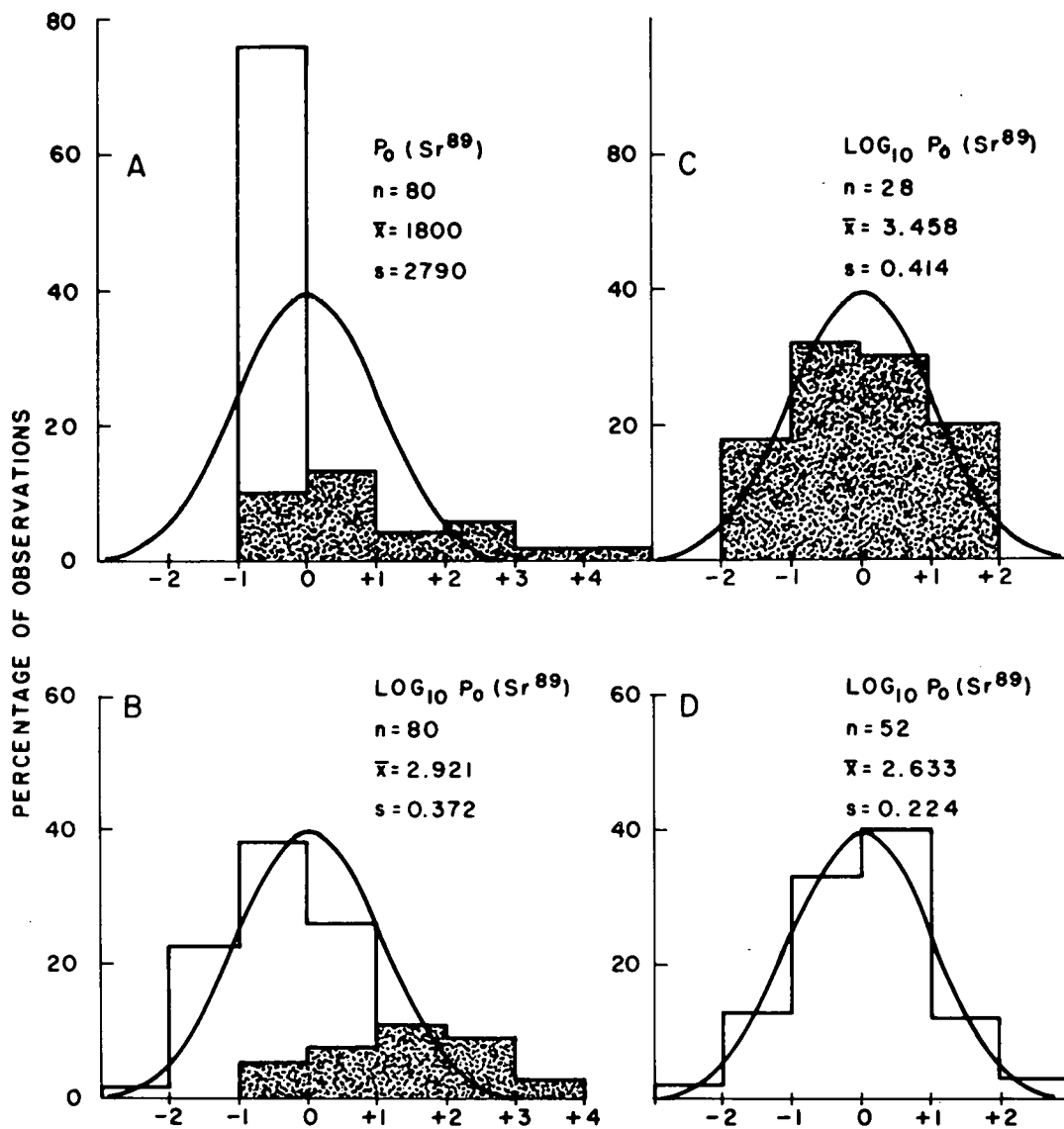
Fig. 3. Frequency distributions of $P_o(Sr^{89})$ = pc/g of $Sr^{89}$ on plants extrapolated to the time of the detonation where n = number of samples, $\bar{x}$ = sample mean, and s = sample standard deviation. Shaded areas indicate samples from S $\geq$ 10; unshaded areas indicate samples from S $<$ 10. The abcissa measurement is = $(X - \bar{x})$ / s. The areas under the normal curves are approximately equal to the areas of the histograms.

representing 13 stations where $R_o < 10$ mr/hr ($S < 10$). Histograms C

and D show the frequency distributions for $S \geq 10$ and $S < 10$ treated

as different populations. Similar patterns were observed for extrapo-

lated values representing $P_o$ ($I^{131}$), $A_m$ ($I^{131}$), and $A_m$($Sr^{89}$).

Statistics based on the frequency distributions of $T_p$ estimates and

extrapolated values of $P_o$ and $A_m$ for $I^{131}$ and $Sr^{89}$ are given in Table 5.

The statistics $g_1$ and $g_2$ are measures of skewness and kurtosis. Values

of 0 for both $g_1$ and $g_2$ indicate perfect agreement between the observed

and the expected (normal) frequency distribution. Positive values of

$g_1$ indicate an excess of items below the mean while negative values

indicate an excess of items above the mean. Positive values of $g_2$

indicate an excess of items near the mean and far from it while negative

values indicate a flat-topped distribution curve due to a deficiency

of items near the mean and far from it.

The frequency distributions of both $T_p$ and $\log_{10}T_p$ were analyzed

and compared. The results (Table 5) indicate normal frequency distributions

for both $T_p$ and $\log_{10}T_p$ variates representing $S \geq 10$ and $S < 10$; but

when the variates representing these two groups are combined ($\Sigma S$), the

results indicate significant or highly significant deviations from the

normal frequency distributions. The large positive value of $g_1$ for $T_p$

($I^{131}$)$\Sigma S$ indicates a highly significant excess of items below the

arithmetic mean (5.67 days). Using $\log_{10}T_p$($I^{131}$)$\Sigma S$ corrected the asymmetry

and indicated a geometric mean of 5.40 days. (An earlier estimate [5]

based on ($\bar{x}P_t$) was 5.5 days.) The frequency distribution of $T_p$ ($Sr^{89}$)$\Sigma S$

showed negative skewness and positive kurtosis. Using $\log_{10}T_p$($Sr^{89}$)$\Sigma S$

Table 5. Statistics based on the frequency distributions of variates representing the effective half-lives ($T_p$), initial concentrations on plants ($P_o$), and maximum concentrations in rabbit tissues ($A_m$) of $I^{131}$ and $Sr^{89}$ in the Sedan fallout field.[1]

| Variates | Stas. | n | $\bar{x}$ | s | $g_1$ | $t(g_1)$ | $g_2$ | $t(g_2)$ |
|---|---|---|---|---|---|---|---|---|
| $I^{131}$   $T_p$ | S≥10 | 34 | 5.54 | 1.27 | -0.776 | -0.978 | 1.979 | 1.246 |
| | S<10 | 64 | 5.74 | 1.91 | -0.633 | -0.921 | -1.311 | -0.983 |
| | ΣS | 98 | 5.67 | 1.79 | 7.823 | 14.275** | 0.023 | 0.042 |
| $\log_{10} T_p$ | S≥10 | 34 | 0.728 | 0.120 | -0.528 | -0.768 | -0.110 | -0.082 |
| | S<10 | 64 | 0.735 | 0.112 | 0.174 | 0.291 | 1.005 | 0.871 |
| | ΣS | 98 | 0.732 | 0.135 | 0.509 | 0.877 | 0.131 | 0.116 |
| $\log_{10} P_o$ | S≥10 | 42 | 4.009 | 0.522 | 0.623 | 0.869 | -0.283 | -0.202 |
| | S<10 | 78 | 3.124 | 0.334 | 0.504 | 0.703 | 1.408 | 1.006 |
| $\log_{10} A_m$ | S≥10 | 42 | 2.464 | 0.500 | -0.791 | -1.286 | 0.908 | 0.762 |
| | S<10 | 78 | 1.671 | 0.548 | 0.027 | 0.043 | 1.255 | 1.049 |
| $Sr^{89}$   $T_p$ | S≥10 | 21 | 21.9 | 2.85 | 1.051 | 1.466 | 0.820 | 0.587 |
| | S<10 | 37 | 19.6 | 1.28 | -0.194 | -0.244 | -1.405 | -0.885 |
| | ΣS | 58 | 18.8 | 7.9 | -1.390 | -2.390* | 3.150 | 2.811** |
| $\log_{10} T_p$ | S≥10 | 21 | 1.268 | 0.252 | -0.511 | -0.713 | 0.605 | 0.433 |
| | S<10 | 37 | 1.256 | 0.189 | -0.024 | -0.032 | -1.699 | -1.147 |
| | ΣS | 58 | 1.259 | 0.216 | -0.980 | -1.538 | 4.535 | 3.681** |
| $\log_{10} P_o$ | S≥10 | 28 | 3.458 | 0.414 | 0.437 | 0.581 | -0.592 | -0.400 |
| | S<10 | 52 | 2.633 | 0.224 | 0.194 | 0.282 | -1.933 | -1.449 |
| $\log_{10} A_m$ | S≥10 | 28 | 3.521 | 0.455 | -0.168 | -0.212 | -0.479 | -0.301 |
| | S<10 | 52 | 2.575 | 0.433 | 0.141 | 0.213 | -0.222 | -0.174 |

[1]/ S≥10 and S<10 indicate variates representing stations where $R_o ≥ 10$ mr/hr (n = 7) and stations where $R_o < 10$ mr/hr (n = 13). ΣS indicates variates for all stations (n = 20) combined.

n = number of sample variates, $\bar{x}$ = sample mean, s = sample standard deviation, $g_1$ = measure of skewness, $g_2$ = measure of kurtosis, $t(g_1)$ and $t(g_2)$ are estimates of significance

* Deviations from normal are significant at the 5% level of probability.

** Deviations from normal are significant at the 1% level of probability.

corrected the asymmetry but accentuated the kurtosis which is probably due to the nonuniform distribution of $T_p(Sr^{89})$ with respect to time after the detonation. The arithmetic mean of $T_p(Sr^{89})$, based on n = 58, was 18.8 days while the geometric mean was only 18.2 days. (An earlier estimate [8] based on $(\bar{x}P_t)$ was 18.0 days.)

The frequency distributions of $\log_{10}P_o$ and $\log_{10}A_m$ for $I^{131}$ and $Sr^{89}$ show no significant deviations from normal when the variates are grouped as representative of two populations, $S \geq 10$ and $S < 10$, as indicated in Fig. 3 and in Table 5. However, the $\log_{10}$ means and standard deviations given in Table 5 are not necessarily the same as those of the real populations they represent because the method of extrapolation introduced an extraneous variable which increased the variance. For example, the data for $\log_{10}P_o(I^{131})$ $S < 10$ (Table 5) indicates a mean and standard deviation of 3.124 ± 0.334, and the individual variates ranged from 2.083 to 3.815. When the same group of original variates, $(P_t)_i$, were extrapolated to $(P_o)_i$ on the basis of individual half-life estimates $(T_p)_i$, the frequency distribution of variates $(\log_{10}P_o)_i$ was normal; but the simulated sample mean and standard deviation were 3.061 ± 0.147, and the range of individual variates was from 2.743 to 3.443. This suggests that the method of extrapolation based on sample means produced simulated samples of $P_o$ and $A_m$ whose means and standard deviations are somewhat higher than the real populations they represent. However, there is no evidence that the method of extrapolation caused any significant change in the general form of the frequency distribution curves.

The means ($\bar{x}$) and geometric means ($\bar{x}_g$) of $P_t$ and $A_t$ for $I^{131}$ and $Sr^{89}$ representing $S \geq 10$ (n = 7) and $S < 10$ (n = 13) and $\Sigma S$ (n = 20) are compared in Fig. 4. Both $\bar{x}$ and $\bar{x}_g$ are indicative of the large difference (approximately an order of magnitude) between $S \geq 10$ and $S < 10$. In most cases $\bar{x}$ is larger than $\bar{x}_g$. For $S \geq 10$ and $S < 10$, the values of $\bar{x}$ and $\bar{x}_g$ are fairly close; but for $\Sigma S$, the differences between $\bar{x}$ and $\bar{x}_g$ are large. For $A_t(I^{131})$ and $A_t(Sr^{89})$ representing $S < 10$, the $\bar{x}$-values indicate time-specific variations which are considerably more erratic than those indicated by $\bar{x}_g$-values. This difference is probably attributable to a few exceptionally high (or low) variates which have a greater influence on $\bar{x}$ than on $\bar{x}_g$.

It should be obvious, if the variates are lognormally distributed, that $\bar{x}_g$ is a more useful parameter than $\bar{x}$. Table 6 was prepared to illustrate the kinds of errors resulting from the assumption of a normal distribution. The columns headed "S. M." are standard measures of the normal curve. Tau is given by $\mathcal{T} = (X - \bar{x})/s$ where X is the magnitude of a given variate, $\bar{x}$ is the sample mean, and s is the standard deviation of the sample mean. The values of X given in the body of Table 6 are based on $X = x \pm \mathcal{T}s$. Those indicated by N (normal) are based on the arithmetic means and standard deviations of $P_o$ and $A_m$. Those indicated by L (lognormal) are the antilogarithms obtained from the means and standard deviations of $\log_{10}P_o$ and $\log_{10}A_m$. The column headed "C. P." indicates the cumulative percentage of variates expected to be less than or equal to the magnitudes of X indicated in columns N or L. Comparing columns N and L for the several groups of variates shows that
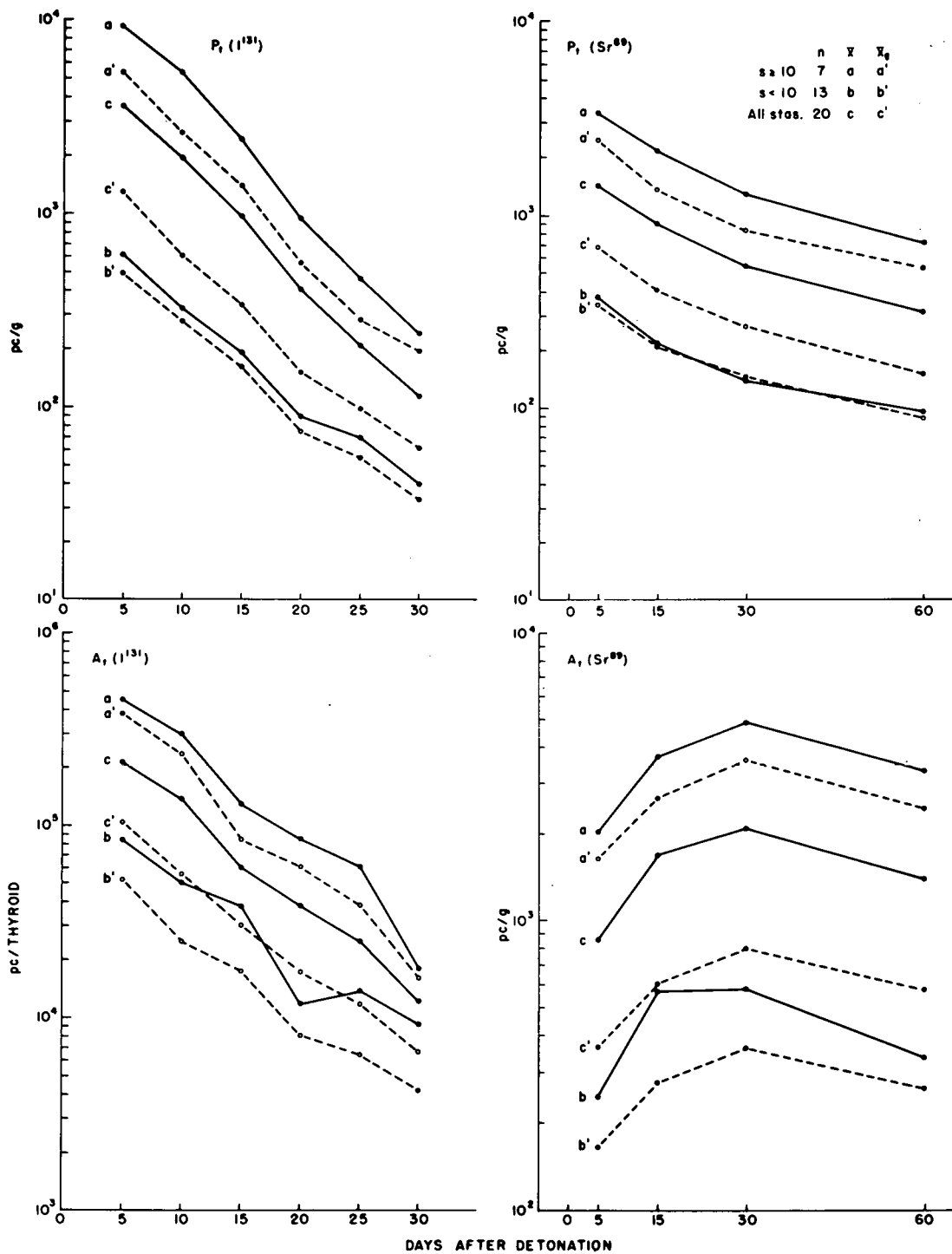
Fig. 4. Comparison of means ($\bar{x}$) and geometric means ($\bar{x}_g$) of $P_t(I^{131})$, $A_t(I^{131})$, $P_t(Sr^{89})$, and $A_t(Sr^{89})$ for $S \geq 10$ (n = 7), $S < 10$ (n = 13) and $\sum S$ (n = 20).

Table 6. Estimated frequency distributions of variates representing the initial concentrations on plants ($P_o$) and the maximum concentrations in rabbit tissues ($A_m$) of $I^{131}$ and $Sr^{89}$ in the Sedan fallout field.[1]

| S. M. | | S≥10 | | S<10 | | S≥10 | | S<10 | |
|---|---|---|---|---|---|---|---|---|---|
| $\gamma$ | C. P. | N | L | N | L | N | L | N | L |
| | | $P_o$ ($I^{131}$) | | | | $A_m$ ($I^{131}$) | | | |
| -1.96 | 2.5 | -12886 | 969 | -577 | 294 | -169 | 30 | -144 | 3.95 |
| -1.65 | 5.0 | -8062 | 1383 | -211 | 373 | -75 | 44 | -105 | 5.84 |
| -1.29 | 10.0 | -2460 | 2166 | 213 | 493 | 34 | 60 | -60 | 9.20 |
| -0.85 | 20.0 | 4386 | 3677 | 732 | 691 | 149 | 109 | 5 | 16.0 |
| -0.53 | 30.0 | 9365 | 5525 | 1109 | 884 | 264 | 158 | 35 | 24.0 |
| 0.00 | 50.0 | 17612 | 10205 | 1734 | 1330 | 425 | 291 | 101 | 46.8 |
| 0.53 | 70.0 | 25859 | 19290 | 2359 | 1999 | 586 | 536 | 157 | 91.4 |
| 0.85 | 80.0 | 30838 | 28330 | 2736 | 2557 | 682 | 775 | 207 | 135.9 |
| 1.29 | 90.0 | 37684 | 48060 | 3255 | 3588 | 816 | 1286 | 262 | 238.5 |
| 1.65 | 95.0 | 43286 | 74070 | 3679 | 4735 | 925 | 1946 | 307 | 375.7 |
| 1.96 | 97.5 | 48110 | 107730 | 4045 | 6011 | 1019 | 2781 | 346 | 555.5 |
| | | $P_o$ ($Sr^{89}$) | | | | $A_m$ ($Sr^{89}$) | | | |
| -1.96 | 2.5 | -2904 | 443 | 22 | 156 | -2356 | 425 | -750 | 48.7 |
| -1.65 | 5.0 | -1774 | 595 | 59 | 183 | -1213 | 588 | -536 | 67.2 |
| -1.29 | 10.0 | 462 | 839 | 153 | 221 | 115 | 858 | -287 | 97.9 |
| -0.85 | 20.0 | 1142 | 1276 | 267 | 277 | 1738 | 1362 | 17 | 155 |
| -0.53 | 30.0 | 2308 | 1732 | 350 | 327 | 2919 | 1903 | 238 | 216 |
| 0.00 | 50.0 | 4240 | 2870 | 488 | 429 | 4874 | 3317 | 604 | 376 |
| 0.53 | 70.0 | 6172 | 4756 | 626 | 564 | 6829 | 5780 | 970 | 653 |
| 0.85 | 80.0 | 7338 | 6455 | 709 | 666 | 8009 | 8082 | 1191 | 911 |
| 1.29 | 90.0 | 8942 | 9820 | 823 | 835 | 9633 | 12815 | 1495 | 1441 |
| 1.65 | 95.0 | 10254 | 13840 | 917 | 1005 | 10961 | 18690 | 1744 | 2098 |
| 1.96 | 97.5 | 11384 | 18605 | 998 | 1180 | 12104 | 25864 | 1958 | 2899 |

[1] S. M. : standard measures of the normal curve, $\gamma = (X - x) / s$ ; C.P. = cumulative percentage of variates $\geq X$ as given in the body of the table. Columns headed by N are based on the assumption of normal distributions and $X = \bar{x} \pm \gamma s$. Columns headed by L are based on the assumption of lognormal distributions and $X =$ antilog $\bar{x}(\log_{10}) \pm \gamma s(\log_{10})$. $S \geq 10$ and $S < 10$ indicate variates representing stations where $R_o \geq 10$ or $R_o < 10$ mr/hr. Additional explanations are given in the text.

the erroneous assumption of normal distributions may result in (1) over-estimates of the mean and values near the mean, (2) underestimates of values far from the mean, and (3) negative values, which are untenable, far below the mean.

4.0 DISCUSSION

4.1 Radionuclide Concentrations in Plant Samples and Rabbit Tissues.

The results given in Table 1 showed that the maximum concentrations of $I^{131}$ and $Sr^{89}$ in plant samples and rabbit tissues decreased with increasing distance from ground zero and decreasing gamma dose rates at H + 24. In this respect, the four study areas -- Groom, Penoyer, Railroad, and Currant -- could be ranked as follows: G>>> P>> R > C. Similar results were indicated (Appendix A) for $Sr^{90}$ and $Cs^{137}$, but the postshot concentrations of these radionuclides were not significantly higher than the preshot concentrations at more than half of the 20 sampling stations.

The time-specific relationships between $I^{131}$ and $Sr^{89}$ concentrations on plants and in rabbit thyroids and bone ash were illustrated in Fig. 4. The formulation of deterministic and stochastic models to represent these relationships and the potential uses of such models in predicting radio-nuclide levels and tissue doses resulting from a single fallout event were discussed in earlier papers[4-9].

4.2 Fallout Particles and Radioactivity on Plant Foliage.

While the results given in Table 2 showed no consistent relation-ship between the number of particles 5 to 44 μ in diameter ($p/cm^2$) and gross gamma activity ($c/m/cm^2$) per unit area of leaf surface, the ranking of study areas on the basis of $c/m/cm^2$ was the same as the ranking based

on radionuclide concentrations, i. e., G>> P >> R> C.  In all study areas, the gamma activities ($c/m/cm^2$) and the radionclide concentrations ($pc/g$) decreased with increasing time after the detonation, but the number of particles per unit area ($p/cm^2$) decreased in some areas and increased in others.

These results and the general appearance of autoradiographs suggested that most of the radioactivity deposited on plants in all four study areas was due to particles smaller than the optical resolution of the microscope used to measure them, i. e., < 5 $\mu$ in diameter.  Since particles > 44 $\mu$ in diameter accounted for < 2 per cent of all those measured, we may assume that virtually all the activity deposited on plants was associated with particles < 44 $\mu$ in diameter. These results are similar to those reported earlier by Romney et al.[2]

The apparently erratic changes in $p/cm^2$ and $c/m/cm^2$ (Table 2) with increasing time after the detonation may be the results of fallout redistribution by wind.  For example, the increasing number of particles per unit area of leaf surface in the Groom study area, which is northeast of ground zero, may have been due to the continuing postshot deflation by southwesterly winds of materials initially deposited close to ground zero. While the effects of redistribution on fallout retention by plants are not precisely known, it has generally been assumed [1] that mechanical disturbances by wind (or rain) cause radionuclide losses in excess of radioactive decay.

4.3 Retention Factors:  Effective & Environmental Half-lives.

The results given in Table 3 showed that the effective half-lives of $I^{131}$ and $Sr^{89}$ on fallout-contaminated plants (approximately 5.5 and 18 days

respectively) were significantly shorter than their radioactive half-lives (8.04 and 50.5 days respectively). The effective half-life of $I^{131}$ on plants was more or less uniform with respect to time (5 to 30 days) after the detonation, but the effective half-life of $Sr^{89}$ apparently increased with increasing time (5 to 60 days) after the detonation. (N. B. Since the rate of loss was not strictly exponential, the use of "half-life" in reference to $Sr^{89}$ retention by plants is technically inaccurate; but in this case, the estimated rate in half-life terms is a useful approximation of the true rate.)

Estimates of the environmental half-life ($T_E$) of $I^{131}$ were mostly smaller than estimates of the environmental half-life of $Sr^{89}$. This may have been due to the loss of $I^{131}$ by some process, probably vaporization, which had no effect on the retention of $Sr^{89}$. Comparisons of effective ($T_p$) and environmental ($T_E$) half-life estimates for $I^{131}$ and $Sr^{89}$ representing $S \geq 10$ and $S < 10$ suggested that the probability of $I^{131}$ loss by vaporization was greatest in areas relatively close to ground zero.

The differences between effective and radioactive half-lives of radio-nuclides on plants lower the availability of radionuclides for ingestion by herbivores and hence for transfer to higher trophic levels. In the case of long-lived radionuclides, such as $Sr^{90}$ and $Cs^{137}$, there may be several orders of magnitude difference between the radioactive and effective half-lives. In studies of food chain kinetics and in comparison of plant vs. soil contributions to tissue burdens failure to consider this factor could lead to serious errors.

### 4.4 Interception Factors: Deposition on Soil vs. Interception by Plants.

No attempt was made in this study to consider all the factors which

which could influence the interception and retention of fallout radionuclides by plants. Instead, we proposed a fairly simple hypothesis (equations 4-7) to explain the basic interrelations of H + 24 gamma dose rates, hypothetical concentrations ($pc/ft^2/mr/hr$) of $I^{131}$ and $Sr^{89}$ on soil, and observed concentrations ($pc/g/mr/hr$) on plants. (N. B. An earlier report by Miller [15] and a recent review paper by Russell [16] present more detailed analyses of the problem.)

The results given in Table 4 suggested (1) an apparent deficiency of $I^{131}$ deposition relative to $Sr^{89}$ deposition in all study areas except Groom, the area closest to ground zero, and (2) an apparent excess of both $I^{131}$ and $Sr^{89}$ deposition relative to gamma dose rates ($R_o$) in the Currant study area, the one farthest from ground zero. Since the data provided no firm evidence of a significant difference between sagebrush (collected in the Groom and Currant study areas) and shadscale (collected in Penoyer and Railroad Valleys) in respect to their interception of $I^{131}$ and $Sr^{89}$, I believe that most of the variation observed in relation to initial concentrations on plants could probably be attributed to the nonuniform distribution of these radionuclides in relation to $R_o$, i. e., to fractionation and/or to errors in estimating $R_o$ from aerial survey data.

The assumption of $I^{131}$ loss by vaporization before fallout deposition could explain the apparent deficiency of $I^{131}$ deposition in study areas more distant from ground zero than Groom. The assumption of $I^{131}$ loss by vaporization after fallout deposition could explain the shorter environmental half-life of $I^{131}$ in areas relatively close to ground zero. The apparent excess of both $I^{131}$ and $Sr^{89}$ may have been due to a combination of meteorological and orographic conditions similar to those involved in

32

the development of "hot-spots" at even greater distances from ground zeros.

The data collected from the Currant study area may also indicate a marked tendency for the percentage interception of fallout by plants to increase as total fallout deposition, indicated by $R_o$, decreases. If this tendency is real and if it extends beyond the limits of the present study, one could expect to find significant concentrations of $I^{131}$ and $Sr^{89}$ on plants in areas where increased gamma dose rates due to fallout are barely distinguishable from background.

### 4.5 Lognormal vs. Normal Frequency Distributions.

The results given in Fig. 3 and Table 5 provided evidence that variates representing the initial concentrations ($P_o$) of $I^{131}$ and $Sr^{89}$ on fallout-contaminated plants and subsequent maximum concentrations ($A_m$) of $I^{131}$ in rabbit thyroids and of $Sr^{89}$ in rabbit bone ash are lognormally distributed. Figure 3, and similar comparisons not illustrated in this paper, showed that $P_o$ and $A_m$ variates representing $S \geq 10$ and $S < 10$ were apparently drawn from different populations. The results given in Table 5 suggested that the same assumption should be made in regard to effective half-life estimates, but both $T_p$ and $\log_{10} T_p$ could then be treated as normally distributed variates.

The lognormal frequency distributions of variates representing radio-nuclide concentrations in plant samples and rabbit tissues are probably related to the manner in which fallout is initially distributed in the fallout field.

As shown in Fig. 1, the distance between H + 24 gamma dose rate contours tends to increase with increasing distance from ground zero. Using a planimeter to estimate the areas between contour intervals gave

the following results: 50 $mi^2$ between 1000 and 100 mr/hr, 450 $mi^2$ between

100 and 10 mr/hr, and 4500 $mi^2$ between 10 and 1 mr/hr. (N. B. These data

indicate radioactivity approximately equivalent to one kiloton of fission

products spread over an area of 5000 $mi^2$.) While these are rough estimates,

they seem to indicate that the $log_{10}$ of H + 24 gamma dose rate contours

are inversely proportional to the $log_{10}$ of areas ($mi^2$) inclosed by the

contours. In other words, 10-fold increases in the area of the fallout

field are accompanied by 10-fold decreases in the H + 24 gamma dose rates

at the perimeters of the areas.

Figure 4 showed that the arithmetic means ($\bar{x}$) of $P_t$ and $A_t$ were higher

than the geometric means ($\bar{x}_g$) of the same samples, but the correlation of

$\bar{x}$ and $\bar{x}_g$ was good enough to warrant the use of either set in estimating rates

of change or relative differences in magnitude.

The results given in Table 6 showed that the assumption of normal

frequency distributions of variates representing $P_o$ and $A_m$ resulted in over-

estimates of the means and values near the means and underestimates (even

negative numbers) of values far from the means.

These observations suggest that estimates of population exposures

based on arithmetic means (e. g., on the average concentrations of radio-

nuclides in milk or other human foods) may be somewhat pessimistic. On

the other hand, the assumption that critical variates may be lognormally

distributed implies a relatively higher frequency of individuals exposed to

radionuclide levels 2 or 3 times the average for the population. In view

of these discrepancies, it would be a desirable practice -- before drawing

inferences or basing conclusions on samples of radionuclide concentrations

in environmental media, foods, or human tissues -- to determine whether

the variates are normally or lognormally distributed. The procedure described by Snedecor [14] is relatively simple, and it could quite conceivably lead to a more realistic evaluation of biological hazards related to environmental contamination by fallout.

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Appendix A. Concentrations (pc/g) of $Sr^{90}$ and $Cs^{137}$ in plant samples collected before (Bkg) and at various times after (D + 5 etc.) the detonation from 20 representative locations in the Sedan fallout field.

| Area & Sta.* | Strontium - 90 | | | | | Cesium - 137 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bkg | D+5 | D+15 | D+30 | D+60 | Bkg | D+5 | D+15 | D+30 | D+60 |
| G- 3 | 3.0 | 73.2 | 59.9 | 48.5 | 28.9 | 4.8 | 226.0 | 130.5 | 67.8 | 45.6 |
| G- 6 | 1.4 | 50.2 | 23.5 | 15.5 | 11.2 | 3.2 | 200.0 | 77.0 | 14.0 | 9.1 |
| G- 7 | 9.8 | 48.0 | 22.8 | 22.6 | 19.4 | 19.8 | 83.1 | 59.4 | 42.3 | 22.5 |
| G- 8 | 1.0 | 28.1 | 12.9 | 8.7 | 5.8 | 1.4 | 73.8 | 30.2 | 15.2 | 9.7 |
| P-16 | NS | 7.3 | 5.0 | 12.2 | 5.8 | NS | 47.7 | 22.2 | 13.0 | 10.8 |
| P-17 | NS | 17.9 | 8.9 | 9.5 | 12.5 | NS | 59.5 | 24.8 | 14.6 | 29.8 |
| Avg. | 3.8 | 37.4 | 22.2 | 19.5 | 13.9 | 7.3 | 115.0 | 57.4 | 27.8 | 21.2 |
| R-15 | 1.5 | 4.9 | 3.3 | 3.0 | 3.0 | 1.9 | 16.6 | 7.6 | 5.2 | 5.2 |
| P-10 | NS | 3.9 | NS | 2.2 | 4.6 | NS | 18.0 | 10.4 | 5.0 | 7.2 |
| R-14 | NS | 3.6 | 3.0 | 3.0 | 3.0 | NS | 10.6 | 4.6 | 1.9 | 3.0 |
| G- 5 | 1.8 | 4.7 | 3.6 | 2.5 | 2.6 | 2.0 | 12.2 | 5.8 | 2.2 | NS |
| R-12 | 3.3 | 2.7 | 3.2 | 2.6 | 3.3 | 5.5 | 8.4 | 4.5 | 3.1 | 3.3 |
| P- 8 | 1.4 | 3.3 | 3.2 | 3.0 | 3.1 | 1.0 | 10.0 | 8.7 | 9.5 | 3.4 |
| P- 9 | NS | 3.7 | 2.8 | 3.3 | 3.1 | NS | 19.3 | 6.3 | 5.2 | 5.4 |
| R- 5 | NS | 4.1 | 4.2 | 5.0 | 3.8 | NS | 12.8 | 5.0 | 7.3 | 2.3 |
| R-10 | 1.3 | 4.0 | 3.4 | 3.4 | 4.2 | 1.5 | 8.4 | 7.2 | 4.7 | 4.9 |
| C- 1 | 1.0 | 5.6 | 7.2 | 5.3 | 3.7 | 1.0 | 21.0 | 10.5 | 8.2 | 3.8 |
| C- 2 | 4.2 | 5.4 | 5.4 | 4.9 | 4.1 | 4.9 | 11.3 | 8.7 | 4.7 | 4.1 |
| C- 3 | 8.8 | 5.0 | 4.0 | 4.0 | 2.6 | 4.7 | 12.0 | 6.5 | 4.1 | 2.6 |
| C- 4 | 6.7 | 4.3 | 4.0 | 2.8 | 2.4 | 3.9 | 7.7 | NS | 3.3 | 3.3 |
| C- 5 | 4.0 | 4.0 | 4.7 | 4.0 | 4.2 | 3.7 | 8.9 | 4.6 | 3.3 | 3.4 |
| Avg. | 3.4 | 4.2 | 4.0 | 3.5 | 3.4 | 3.0 | 12.7 | 6.9 | 4.8 | 4.0 |

* G, P, R, and C refer to the Groom, Penoyer, Railroad, and Currant study areas. (See Fig. 1). NS = no sample, or sample lost.

Appendix B. **Test of normality based on estimates of the effective half-life ($T_p$) of $I^{131}$ on plants at locations (S < 10) where the H + 24 gamma dose rate was < 10 mr/hr. (See Table 5).**

| Class Intervals | f | X | (fX) | $(fX)^2$ | $(fX)^3$ | $(fX)^4$ |
|---|---|---|---|---|---|---|
| 2.01 - 3.00 | 4 | -4 | -16 | 256 | -4,096 | 65,536 |
| 3.01 - 4.00 | 8 | -3 | -24 | 576 | -13,824 | 331,776 |
| 4.01 - 5.00 | 14 | -2 | -28 | 784 | -21,952 | 614,656 |
| 5.01 - 6.00 | 15 | -1 | -15 | 225 | -3,375 | 50,625 |
| 6.01 - 7.00 | 8 | 0 | 0 | 0 | 0 | 0 |
| 7.01 - 8.00 | 8 | 1 | 8 | 64 | 512 | 4,096 |
| 8.01 - 9.00 | 4 | 2 | 8 | 64 | 512 | 4,096 |
| 9.01 - 10.00 | 1 | 3 | 3 | 9 | 27 | 81 |
| 10.01 - 11.00 | 1 | 4 | 4 | 16 | 64 | 256 |
| 11.01 - 12.00 | 1 | 5 | 5 | 25 | 125 | 625 |
| $\Sigma$ : | 64 | 1 | -55 | 2,019 | -42,007 | 1,071,747 |

f = frequency of variates in each class

$\Sigma$f = total number of variates in sample

n = number of classes = 10

X = assigned code numbers

$$s_1 = \Sigma(fX) = -55$$

$$s_2 = \Sigma(fX)^2 = 2,019$$

$$s_3 = \Sigma(fX)^3 = -42,007$$

$$s_4 = \Sigma(fX)^4 = 1,071,747$$

$$S_2 = s_2 - (s_1^2/n) = 1,717$$

$$S_3 = s_3 - (3s_1s_2/n) + 2(s_1^3/n^2) = -12,021$$

$$S_4 = s_4 - (4s_1s_3/n) + (6s_1^2s_2/n^2) - (3s_1^4/n^3) = 486,589$$

$$K_2 = S_2/(n-1) \qquad\qquad = 190.8$$

$$K_3 = nS_3/(n-1)(n-2) \qquad\qquad = -1{,}669.6$$

$$K_4 = (nS_4(n+1) - 3(n-1)S_2^2)\ /\ (n-1)\ (n-2)\ (n-3) = -51{,}641$$

$$g_1 = K_3/\ K_2\sqrt{K_2} \quad = \underline{-0.633}$$

$$g_2 = K_4\ /K_2^2 \qquad = \underline{-1.311}$$

$$(s_{g_1})^2 = 6n(n-1)/(n-2)(n+1)(n+3) = 0.472$$

$$s_{g_1} = \underline{0.687}$$

$$(s_{g_2})^2 = 24n\ (n-1)^2/(n-3)\ (n-2)\ (n+3)\ (n+5) = 1.780$$

$$s_{g_2} = \underline{1.334}$$

$$t_{g_1} = g_1/s_{g_1} = -0.633/0.687 = \underline{-0.921}$$

$$t_{g_2} = g_2\ /s_{g_2} = -1.311/1.334 = \underline{-0.983}$$

After Snedecor[14]

40

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SC       Sandia Corporation, Sandia Base, Albuquerque, New Mexico

USC&GS   U. S. Coast and Geodetic Survey, San Francisco, California

LRL      Lawrence Radiation Laboratory, Livermore, California

LRL-N    Lawrence Radiation Laboratory, Mercury, Nevada

Boeing   The Boeing Company, Aero-Space Division, Seattle 24, Washington

USGS     Geological Survey, Denver, Colorado, Menlo Park, Calif., and
         Vicksburg, Mississippi

WES      USA Corps of Engineers, Waterways Experiment Station, Jackson,
         Mississippi

EGG      Edgerton, Germeshausen, and Grier, Inc., Las Vegas, Nevada,
         Santa Barbara, Calif., and Boston, Massachusetts

BYU      Brigham Young University, Provo, Utah

UCLA     UCLA School of Medicine, Dept. of Biophysics and Nuclear Medicine,
         Los Angeles, Calif.

NRDL     Naval Radiological Defense Laboratory, Hunters Point, Calif.

USPHS    U. S. Public Health Service, Las Vegas, Nevada

USWB     U. S. Weather Bureau, Las Vegas, Nevada

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