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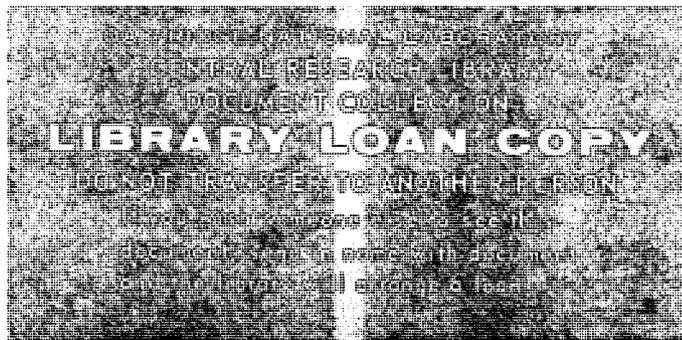


for the

**U.S. ATOMIC ENERGY COMMISSION**

ORNL - TM - 2466

PROGRESS REPORT IN POSTATTACK ECOLOGY



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PROGRESS REPORT IN POSTATTACK ECOLOGY

Interim Progress Report

Project Order No.: OCD-PS-66-83

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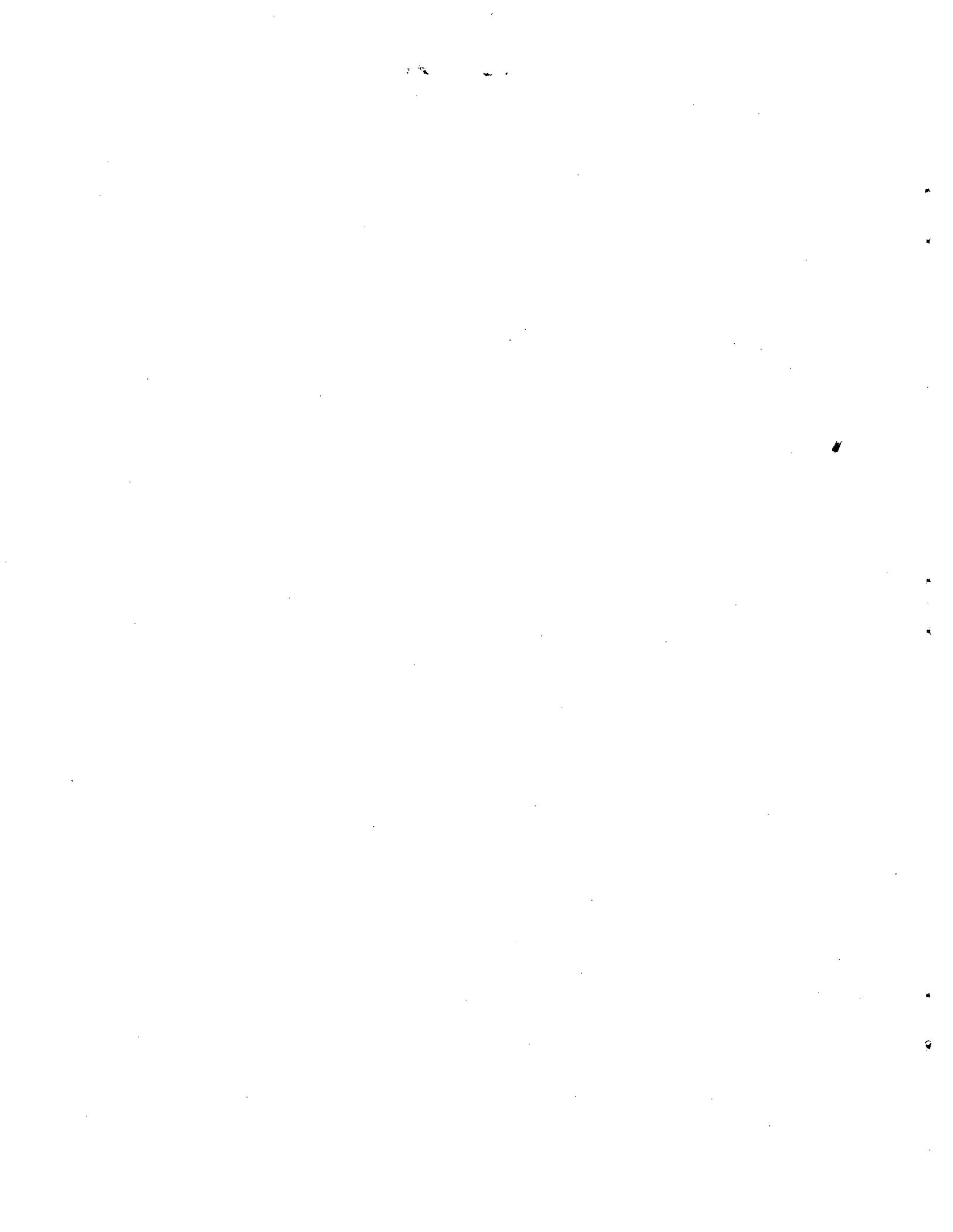
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PROGRESS REPORT IN POSTATTACK ECOLOGY

Interim Progress Report

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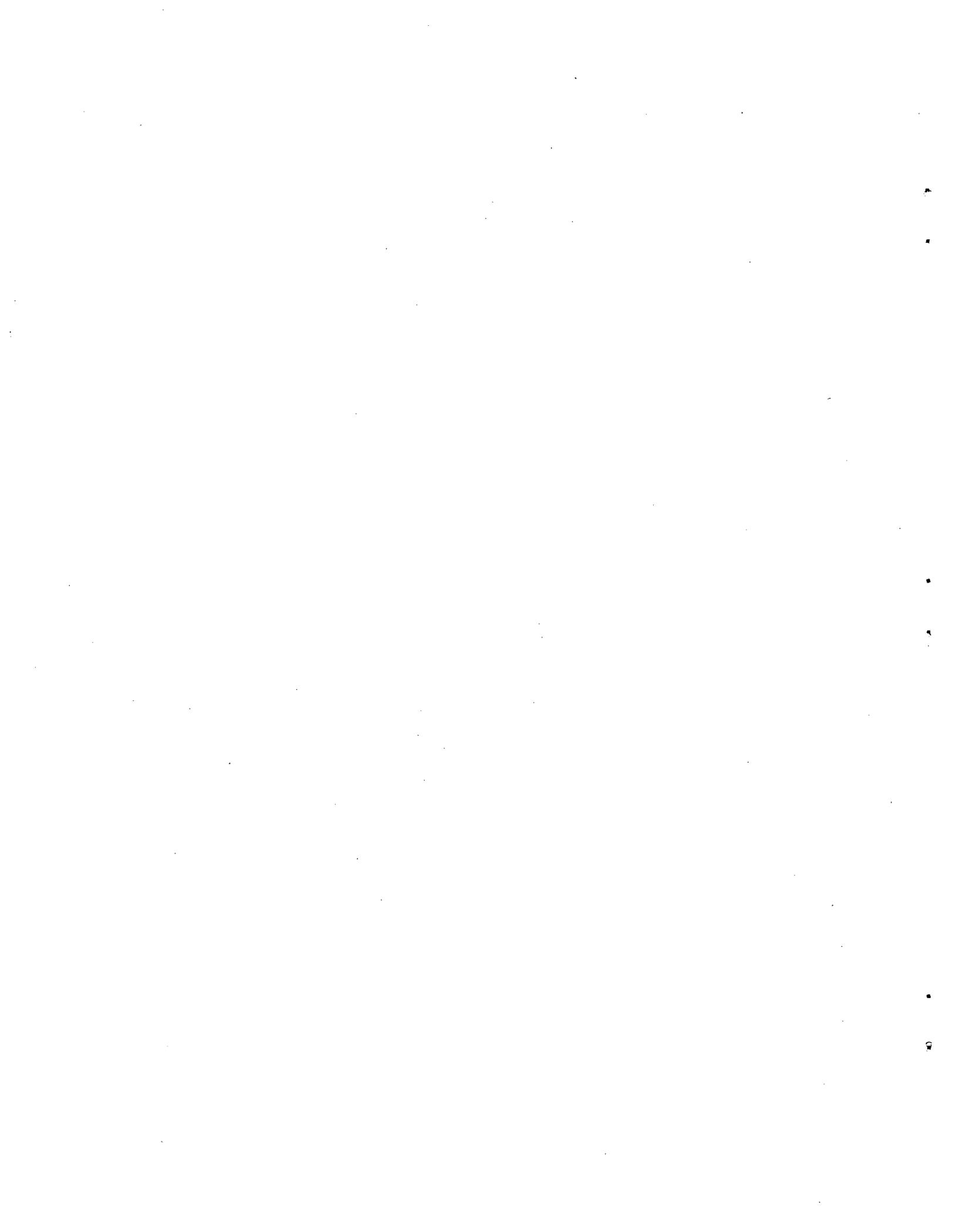
S. I. Auerbach

for

Office of Civil Defense  
Office of the Secretary of the Army  
Washington, D. C. 20310

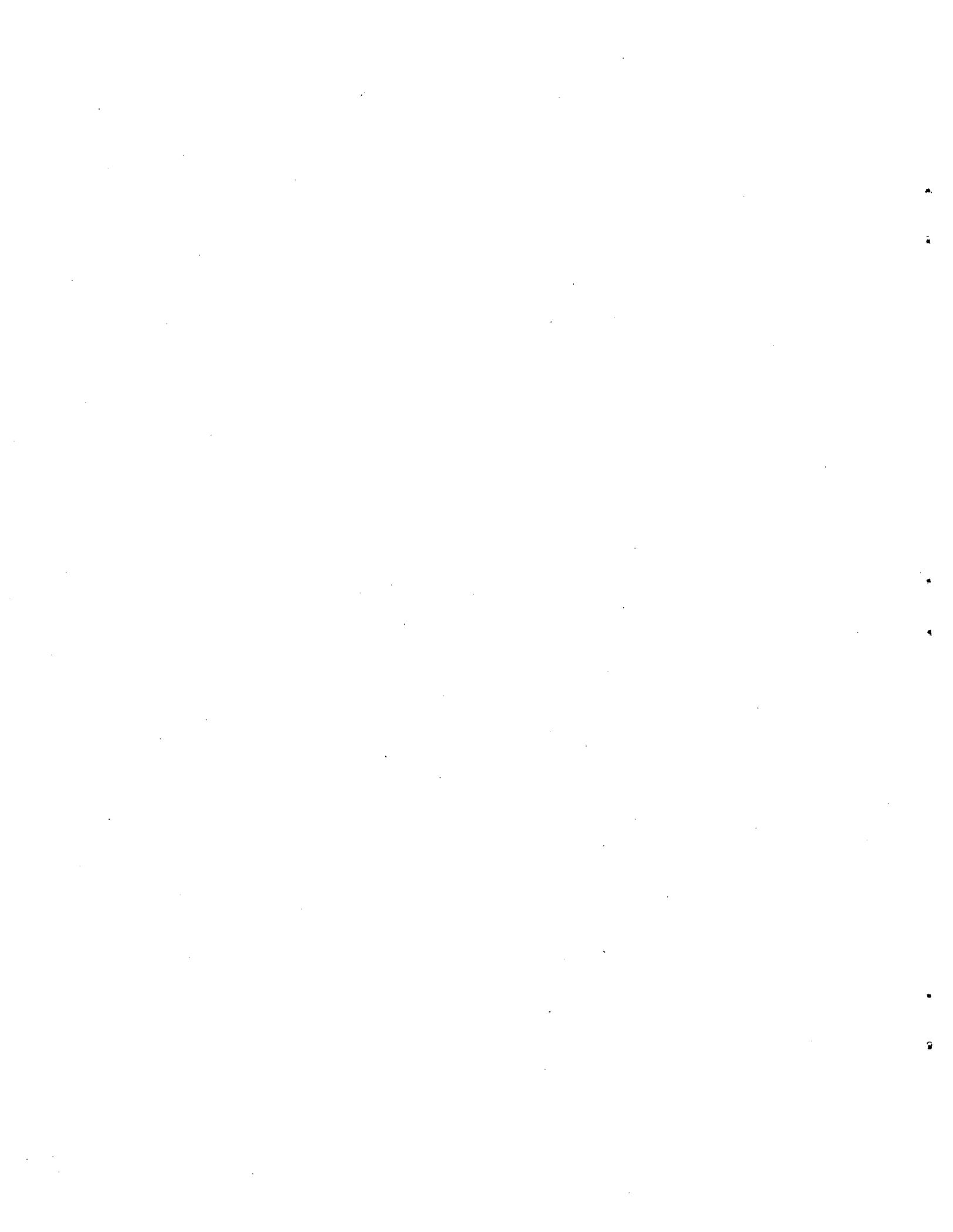
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CONTENTS

	Page
Progress Report in Postattack Ecology . . . . .	1
Introduction . . . . .	1
Effects of External Beta Radiation on Higher Plants . . . . .	2
Contact Dose Experiments . . . . .	3
Beta-Bath Experiments . . . . .	9
Uptake and Excretion of <sup>134</sup> Cs from Fallout Simulant and Vegetation by Cotton Rats . . . . .	18
Abstract . . . . .	18
Introduction . . . . .	20
General Methods . . . . .	21
Absorption of <sup>134</sup> Cs from Fallout Simulants and Transit Time of the Simulant Particles Through the Gastrointestinal Tract of <u>Sigmodon hispidus</u> . . . . .	22
Methods . . . . .	22
Results . . . . .	24
Discussion . . . . .	27
Absorption and Retention of Chronically Ingested <sup>134</sup> Cs in <u>Sigmodon hispidus</u> . . . . .	27
Methods . . . . .	28
Results . . . . .	29
Discussion . . . . .	34
Conclusions . . . . .	38
Effects of Beta and Gamma Radiation on <u>Sinella curviseta</u> (Collembola). . . . .	40
Materials and Methods . . . . .	40
Results . . . . .	42
Discussion . . . . .	45
Honey Bee Irradiation Studies . . . . .	47



PROGRESS REPORT IN POSTATTACK ECOLOGY

S. I. Auerbach

## INTRODUCTION

This report summarizes progress in research on postattack ecology being carried out by Oak Ridge National Laboratory for the Office of Civil Defense in cooperation with the Atomic Energy Commission. Post-attack ecology is concerned with the interim and long-term environmental consequences of a nuclear attack. The program at ORNL is particularly concerned with the effects of fallout and residual radiation on insects, rodents and native and crop plants.

Artificial fallout particles containing beta ray or beta-gamma ray emitting isotopes are being used extensively in the ORNL program. These particles are produced at a special facility at Camp Parks, California which is operated by Stanford Research Institute for the Office of Civil Defense. At ORNL emphasis is being placed on the use of  $^{90}\text{Sr}$  tagged particles for the study of beta radiation effects on plants and animals under laboratory-controlled or field-simulated conditions. Cesium-137 tagged particles are being utilized in a field facility in which 4 plots each 1000 ft<sup>2</sup> are being contaminated with approximately 2.2 Ci of  $^{137}\text{Cs}$  on silica sand particles (88-177  $\mu$ ) which in turn will be spread over the plots at a load of 25 grams per square foot.

In this report research progress in four projects is reported: (1) the effects of external beta radiation on higher plants, (2) uptake and excretion of  $^{134}\text{Cs}$  from fallout simulant by rodents (cotton rats), (3) effects of beta and gamma radiation on Sinella curviseta (insects), and (4) honey bee irradiation studies.

## EFFECTS OF EXTERNAL BETA RADIATION ON HIGHER PLANTS

John P. Witherspoon and Fred G. Taylor, Jr.

The major radiological hazards from fallout deposited on natural or agricultural ecosystems are external gamma and beta radiation and internal beta radiation from assimilation of radionuclides. In the case of plants, the hazard of surface contact with beta emitting fallout particles and the hazard of beta-field radiation where plant habitats are covered with fallout particles, has not been determined. Our knowledge of the biological effects of external gamma radiation on plants is much more complete. However, the formulation of realistic damage assessment predictions requires information on responses of both native and agricultural plant species to beta radiation. In fallout geometries where beta to gamma ratios (rad to roentgen ratios) are between 30 and 100, the biological hazards of beta radiation probably exceed those of gamma radiation.

For the past several years radiation botany studies at ORNL have been oriented toward determining the radiosensitivities of important native plant species to fast neutron and gamma radiation. Moreover, some of the ecological factors that modify radiosensitivity of higher plants have been investigated. This experience is now being brought to studies on the biological effects of external beta radiation on both native tree species and agricultural plants.

This work was initiated last winter and the objectives of these studies are (1) to determine radiosensitivities of important native and agricultural plant species to beta radiation, and (2) to provide improved estimates of the ecological effects of postattack radioactive fallout by assessing the radiological hazards of contact and beta bath exposures to plants.

Our work to date has utilized a fallout simulant, prepared by Stanford Research Institute (Lane 1968a), consisting of 44 to 88  $\mu$  diameter albite particles (Fig. 1) which contain approximately 5 nCi  $^{90}\text{Sr}$  per particle (9.1 mCi/g). The simulant has been used both for direct application to plants and in the preparation of plane and cylindrical sources for exposure of selected plant parts.

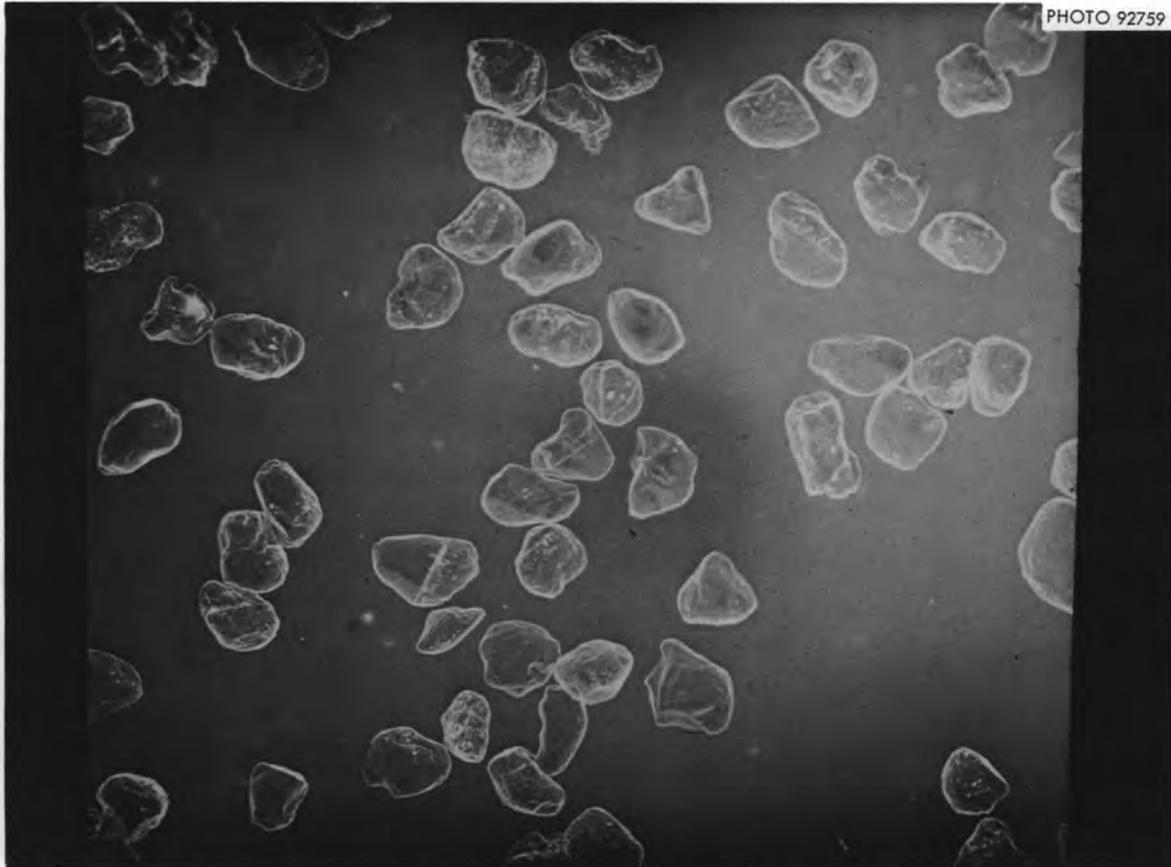


Fig. 1. Photomicrograph of albite particles used as a fallout simulant. These particles range from 44 to 88  $\mu$  in diameter. This size range would be found commonly between 100 and 200 miles downwind from nuclear weapon detonations of the magnitudes of those fired in the 1955 Teapot Series.

Dosimetric analyses have involved both consideration of models using disintegration rate multipliers (Brown 1965) and measurement of absorbed dose to tissue-equivalent volumes by scintillation extrapolation dosimetry of particles (Fish et al. 1966).

#### Contact Dose Experiments

Direct application of albite particles to plant structures was achieved by painting plant surfaces with particles which were coated with glycerol. Figure 2 illustrates the technique used to apply the simulant to buds of white pine trees. The glycerol insured retention of particles to the tissues of interest and prevented contamination of other plant parts or work areas. Control plants received a glycerol treatment without



Fig. 2. Application of fallout simulant to terminal bud cluster of a white pine tree. Particles are painted on in a glycerol medium. Metal cup serves both to hold needles away from buds during application and furnish shielding for hands.

the fallout simulant. These experiments were conducted in environmental growth chambers to minimize loss of particles by wind and rain, thereby insuring a constant dose rate to the tissues of interest. In a field situation dose rate to plants would vary due to fission product decay and variable retention rates of particles by plants. Since the objectives of these experiments were to determine relative radiosensitivities and to establish the types of biological effects produced by external beta radiation, it was desirable to control dosimetric variables that would be introduced in field studies.

Table 1 summarizes the results of particle application to three species of plants. In all cases plant parts which received contact exposures were killed while other plant organs survived with varying degrees of biological damage depending upon distance from the contaminated

Table 1. Effects of beta radiation from albite particles containing  $^{90}\text{Sr}$ - $^{90}\text{Y}$ .

Plant species and age	Treatment		Affected Portion of Plant	Dose rate range (rads/hr)	Biological effect	Time (days)
	$\mu\text{Ci}$	application site				
White pine ( <u>Pinus strobus</u> ) 2 years old	4-23	apical bud	apical bud	54-310 <sup>a</sup>	100% lethality-brittle	10
	"	"	apical needles	92-300 <sup>b</sup>	brown, dry "beta burn	5
	"	"	non-contaminated vegetative buds	0.07-0.20 <sup>b</sup>	12-47% reduction in height growth	30
Cocklebur ( <u>Xanthium pennsylvanicum</u> ) 4 days old	2.5-5.6	apical meristem	whole plant	34-76 <sup>a</sup>	100% lethality of plants	27-
	1.2-1.8	"	stem and foliage	16-25 <sup>a</sup>	20-73% reduction in height growth, reduction in number and size of leaves	15
Bean ( <u>Phaseolus vulgaris</u> ) 3 weeks old	2.5-2.9	flower buds	flowers	34-40 <sup>a</sup>	wilted, dry, sterile	7
	"	"	fruit from non- contaminated flowers	0.3-0.4 <sup>b</sup>	50% reduction in size and 30% reduction in number of seed per pod	10

<sup>a</sup>Contact dose at 100  $\mu$  tissue depth.

<sup>b</sup>Beta bath dose at 100  $\mu$  tissue depth.

area of the plant. The results obtained with two-year-old white pines illustrate a gradient of biological effects ranging from mortality of buds receiving a contact dose to growth reduction of shoots growing in relatively low-level beta bath exposures. The appearance of a ring of dead needles around these buds at five days (Fig. 3) was unexpected. This browning of foliage appeared much earlier in the case of these "beta burns" than comparable foliar damage resulting from exposure to gamma radiation. Had these particles covered the entire plant, the effect would have been a very rapid mortality of the entire plant. Complete browning and dehydration of foliage would greatly increase tree susceptibility to fire.



Fig. 3. White pine five days following application of fallout simulant to terminal buds. Note ring of "burned" needle bases around contaminated bud. Contact dose to buds is about 200 rads/hr in this plant.

Figure 4 shows a pine 15 days following application of particles to terminal bud clusters. Here the needle "burn" has progressed. In addition to mortality of contaminated buds (topmost and upper left bud clusters) new shoot growth from other buds increased from top to bottom of plant or with increasing distance from contaminated buds. Beta bath exposures of these noncontaminated portions ranged from 0.07 to 0.20 rads/hr and growth was reduced from 12 to 47% of that of controls in 30 days. These growth inhibitions illustrate the relatively high radio-sensitivity of white pine. Similar height growth inhibitions in cocklebur (Table 1) were observed in plants receiving 16 to 25 rads/hr for 15 days.

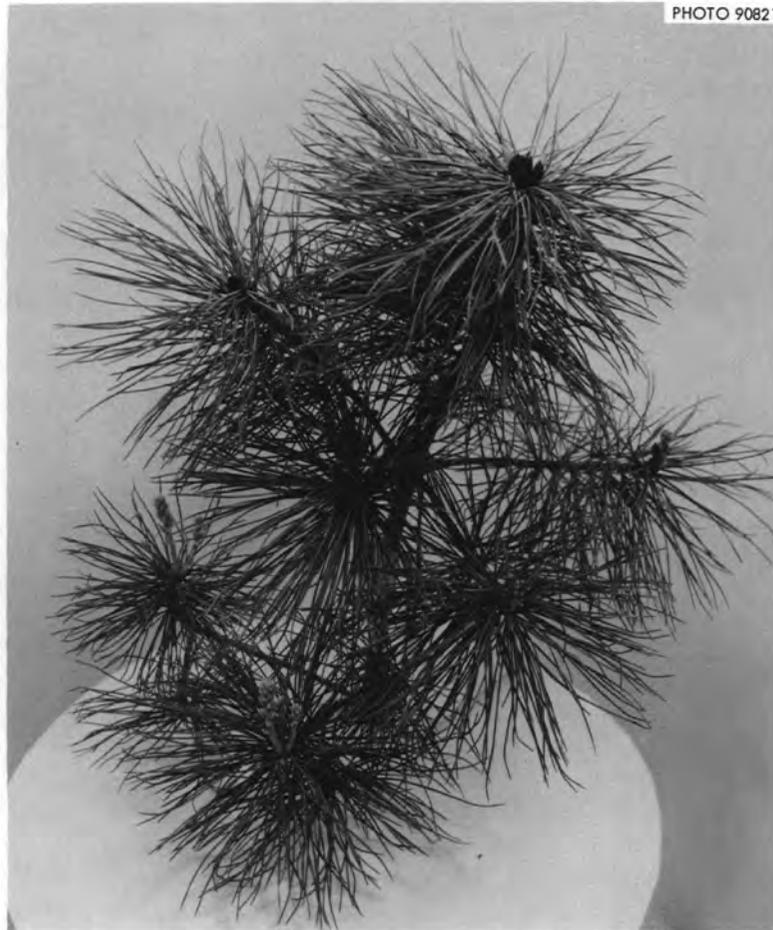


Fig. 4. White pine 15 days following application of fallout simulant to topmost buds and bud cluster on branch at upper left.

Figure 5 depicts cocklebur plants at 27 days following application of the fallout simulant to apical meristems of 4-day-old plants. The plant on the left is a control and the others, from left to right, received 16, 25 and 34 rads/hr to the apical meristem region. There has been no growth exhibited by the plant on the right and the terminal shoot portion is dead. Still attached are the two cotyledons (seed leaves) which are burned at the base and will subsequently fall off.

Fallout simulant applied directly to bean flower buds (Table 1) prevented development of fruit and affected growth of fruit from nearby uncontaminated flowers. Contact doses of the order of 30 to 40 rads/hr

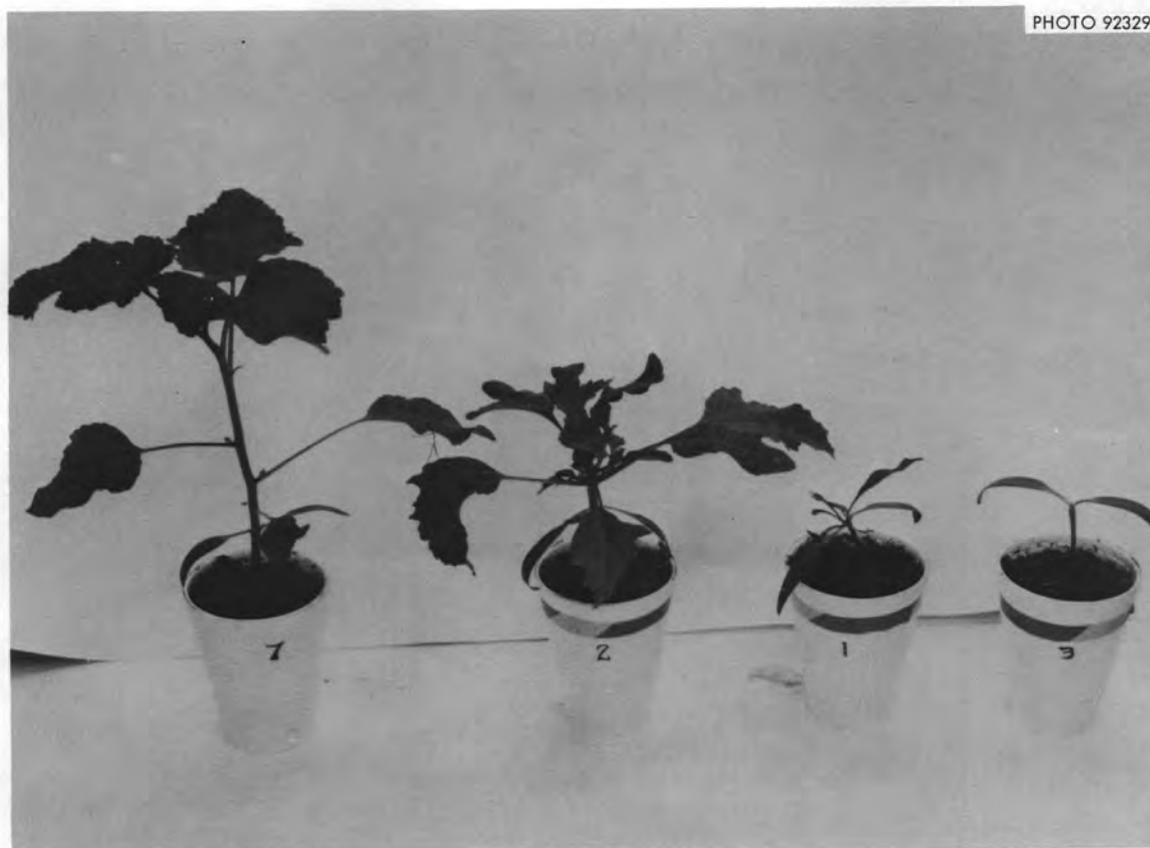


Fig. 5. Cocklebur plants 27 days following application of fallout simulant to apical meristems of plants in the cotyledon stage. Plant on right failed to grow and basal portion of the two cotyledons were severely burned (dose rate about 34 rads/hr). Plant second from right did not increase in height and produced dwarf, aberrant leaves (dose rate about 25 rads/hr). Plant third from right increased in height and produced aberrant foliage and fasciation of shoots (dose rate about 16 rads/hr). Plant on left is a control.

for one week sterilized plants while fruit which developed in a beta bath of approximately 100 times less dose were reduced in size and number of seed per pod. An additional hazard of fallout was suggested by the presence of translocated  $^{90}\text{Sr}$ - $^{90}\text{Y}$  in the bean which developed from flowers that were not directly contaminated. Even though radiostrontium is a relatively nonmobile element in plants and the albite particle activity had a solubility of only 4% in pH 1.0 water, the glycerol leached particles to the extent that from 0.06 to 0.1% of the tag translocated to other plant parts. Bean fruit in this experiment contained from 0.4 to 5.0 nCi  $^{90}\text{Sr}/\text{g}$ . Translocation of even a small fraction of a percent of fallout activity may represent a hazard in the case of edible fruits or vegetables.

The results of a study on the effects of application of the simulant to apical meristems of cottonwood trees are given in Table 2. The early response of wilting of leaves near the point of application, followed by a loss of these leaves, suggests that foliage loss from plants covered by fallout may be prompt—within one to two weeks—if dose rates are high enough to produce this rapid wilting and drying. The results of such a foliage loss would be rapid transfer of the fallout to the soil. A rapid, extensive foliage loss may be more detrimental to the plant, depending upon when it occurred, than the beta radiation effects on growth.

Rates and quantities of  $^{90}\text{Sr}$  translocating from tagged meristematic regions to other plant parts were determined in cottonwood trees at intervals up to 42 days. Maximum quantities represented about 0.5% of the tag with the leaves receiving 0.35; stem 0.1 and roots 0.05%. Figure 6 is a cottonwood leaf autoradiogram that shows  $^{90}\text{Sr}$ - $^{90}\text{Y}$  which has translocated into veins and secretory glands at the leaf margin. The five large dark spots represent particles on the surface of the leaf.

#### Beta-Bath Experiments

Additional experiments designed to assess the hazard of beta-field radiation geometries have been conducted. Cylindrical sources have been used to determine thresholds of beta dose necessary to produce certain

Table 2. Effects of Beta Radiation on Populus Deltoides (Eastern Cottonwood)

Application $\mu$ Ci	Affected portion of plant	Dose rate <sup>a</sup> range rads/hr	Biological Effect	Time Days
2.18-21.36	uppermost pair of leaves	29.4-287	Wilting	3
2.04-21.36	region of original apex	27.5-287	Stem burn preceding observable death	10
1.39-21.36	apical meristem	18.8-287	Visible lethality-burned (No elongation after six days)	21
.147	shoot height	1.98	50% growth reduction	42
2.01-21.36	foliage	?	Aberrant leaves	13
.147-2.18	apical meristem	1.98-29.4	Complete or partial survival until harvested (Growth inhibition not measured but >50%)	14-42

<sup>a</sup> Contact dose at 100  $\mu$  tissue depth.

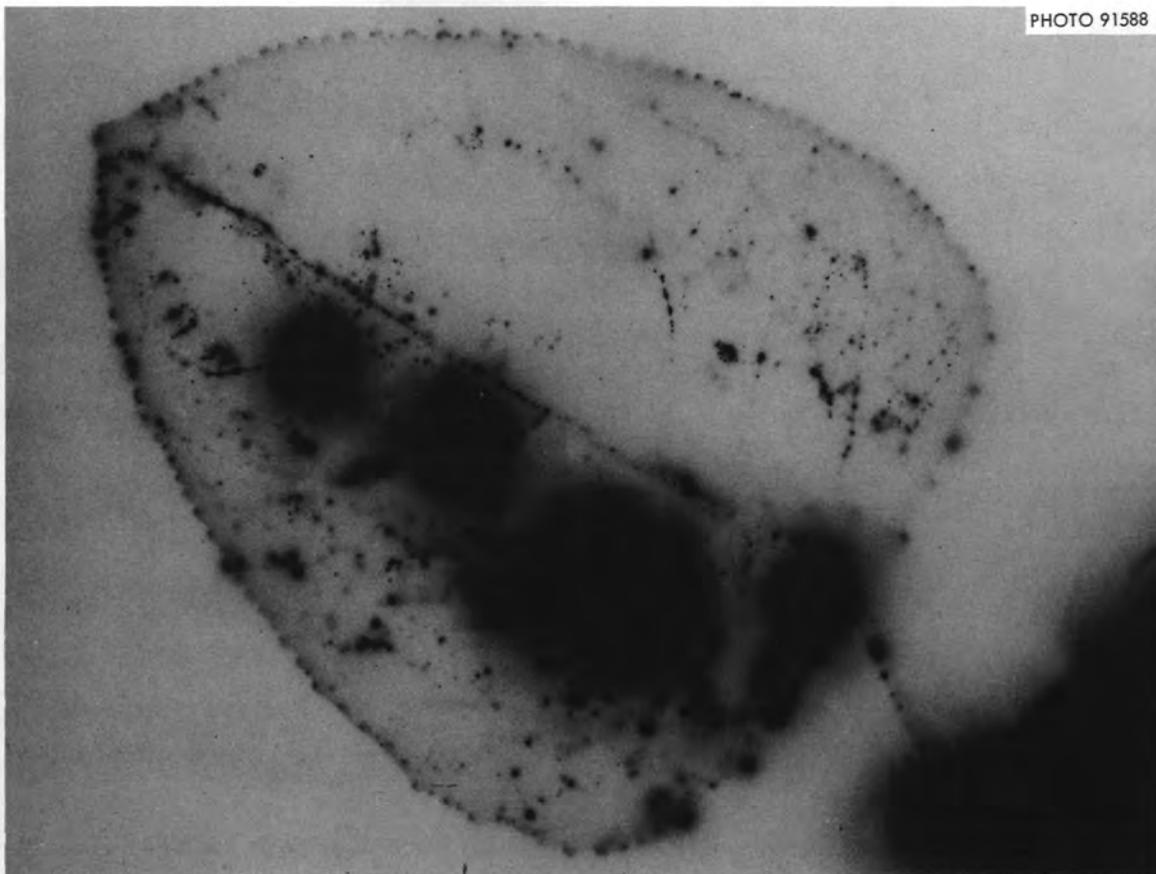


Fig. 6. Autoradiogram (24 hr exposure) of cottonwood leaf showing external particle contamination (large dark spots) and translocated <sup>90</sup>Sr in veins and leaf margin.

biological endpoints. These sources are placed over selected plant parts then removed at intervals, thus total dose to plant parts can be controlled. These sources were constructed by painting glycerol coated particles on filter paper which is then rolled into a cylinder and taped shut. These cylinders are 1.5 cm diameter by 4 cm long and activity ranges from 6.9 to 12.7  $\mu\text{Ci}/\text{cm}^2$  of internal surface area.

Estimates of beta dose to tissues within cylinders were calculated from models furnished by Lane (1968b) where the beta energy flux density,  $\phi_1$  in  $\text{MeV}/\text{sec per cm}^2$ , within a cylinder is estimated by

$$\phi_1 = \frac{\beta_0 \bar{E}_\beta}{r}$$

where  $\beta_0$  is the activity in  $\text{dps}/\text{cm}^2$  of surface area,  $\bar{E}_\beta$  is the average beta energy and  $r$  is the inside radius of the cylinder.

If this energy flux density inside the cylinder is assumed to be absorbed by plant tissue of volume  $v$  and mass  $m$ , then the initial dose rate to the tissue inside the cylinder is estimated by

$$D_0 = 5.77 \times 10^{-5} \frac{O_1 v}{m} \text{ rads/hr}$$

Estimates of dose delivered to plant parts outside of the cylinder, but in the same plane as plant parts inside the cylinder is estimated by

$$\frac{r \tan^{-1}(\ell/r')}{r' \tan^{-1}(\ell/r)}$$

where  $\ell$  is the cylinder height;  $r$ , the inside radius of the cylinder and  $r'$ , the distance from the center of the cylinder to the plant part outside the cylinder. Solution of this equation gives a ratio which is applied to the computed inside dose for estimates of dose at desired distances outside the cylinder.

Beta bath exposure experiments have been conducted with white pine, a radiosensitive species, and red oak, a relatively radioresistant species. Currently, experiments on tomato plants and cottonwood trees are in progress.

Figure 7 shows one of these cylindrical sources on a terminal bud of a two-year-old white pine. Beta bath doses above 338 rads (12 hr exposure) were found to prevent growth of shoot buds exposed inside the cylinders. Buds outside the source received about 30 to 40% of the inside dose. Figure 8 illustrates a typical gradient of biological effects ranging from mortality of a bud (338 rads) to rather severe growth effects on buds outside the source where the dose was estimated to be 122 rads. Twenty-four hour exposures in which buds inside sources received 600 rads or more stopped growth and killed apical meristems (Fig. 9).

In red oak trees total doses exceeding 1500 rads (delivered in 1 to 3 days) were sufficient to kill apical buds (Fig. 10). Growth of shoots was severely impaired at doses in the range of 500 to 750 rads.

Estimated beta-bath doses to both pines and oaks have produced three biological effects at about one-fourth the dose required in the



Fig. 7a. Application of cylindrical  $^{90}\text{Sr}$  beta source to terminal bud of white pine.

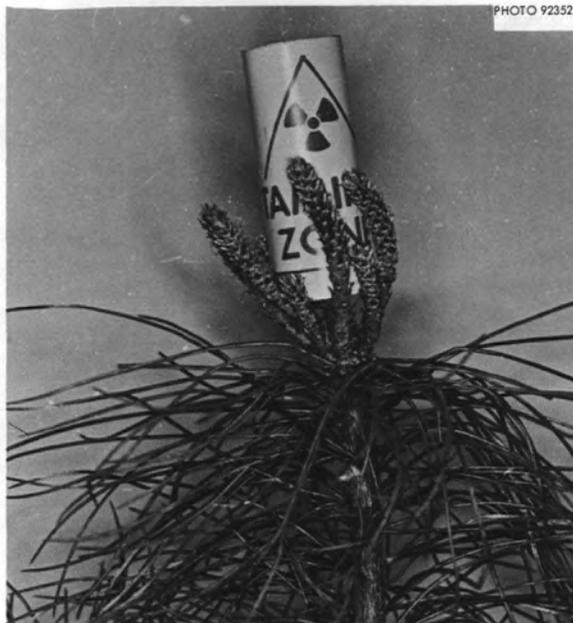


Fig. 7b. Cylindrical beta source on terminal shoot bud of a white pine tree. Lateral buds outside of cylinder receive a beta radiation dose which is 30 to 40% of that received by the bud in the cylinder.



Fig. 8. Buds of white pine 1 week following a 12 hr exposure of  $^{90}\text{Sr}$  beta radiation. Cylindrical source was on center bud which after 338 rads has failed to grow. Surrounding lateral shoot buds show growth curvature and inhibition of needle elongation on the side which faced the source (122 rads).



Fig. 9. White pines 14 days following 24 hr exposure of buds on plant at right with cylindrical  $^{90}\text{Sr}$  beta source. The center bud at top of plant received 622 rads and surrounding buds on top received from 210 to 280 rads. All failed to develop. Control on left has produced good terminal growth.



Fig. 10. Red oaks 18 days following a 64 hr cylindrical source exposure of terminal bud on plant at right. Terminal shoot is dead (total dose 1680 rads) and lateral shoots were produced following removal of source. Plant on left is a control showing a well-developed terminal growth with no lateral shoots.

case of gamma radiation. However, before any final analyses are made regarding the relative biological effectiveness of this beta radiation, we hope to have a TLD dosimetry system calibrated for use with these sources. Many of the models used to estimate beta dose need to be tested against physical measurements of both contact and beta-bath geometries.

Additional experiments are planned such that plants having a wide range of chromosome volumes will be tested for beta radiosensitivity. If the correlation between chromosome size and radiosensitivity exists in the case of beta radiation (as it does for fast neutron and gamma radiation), then we will be in a position to predict radiosensitivities for other species. New estimates of beta radiation dose from fallout, such as those by Wong (1967), can be used with these beta radiosensitivities predictions to establish a more realistic assessment of the radiological hazard of fallout to plants of natural and agricultural landscapes.

UPTAKE AND EXCRETION OF  $^{134}\text{Cs}$  FROM FALLOUT SIMULANT  
AND VEGETATION BY COTTON RATS

J. T. Kitchings III, P. B. Dunaway, J. D. Story, and L. E. Tucker

ABSTRACT

Cesium- $^{134}\text{Cs}$  tagged simulants with varying in vitro nuclide solubilities were analyzed with respect to absorbabilities of the  $^{134}\text{Cs}$  by the gastrointestinal tracts of cotton rats (Sigmodon hispidus). Whole-body retentions and excretory patterns were used to discern variations in  $^{134}\text{Cs}$  metabolism caused by solubility differences. Transit times of the simulant particles through the GI tract were determined, because the particles constitute internal point sources as long as they are present.

A mass-loading gavaging technique was developed to insert the simulant into the stomachs of the rats. Three different simulants were used, with injected dose and in vitro solubilities as follows: (1) 0.197  $\mu\text{Ci}$ , 60.6%; (2) 0.201  $\mu\text{Ci}$ , 17.6%; (3) 0.209  $\mu\text{Ci}$ , 4.3%. Whole body, fecal, and urine samples were counted every 18 and 24 hr for 66 hr and then every 24 hr until 158 hr postinjection. Analysis of fecal material showed a rapid increase in radioactivity until the 42nd hr postadministration. Complete passage of the particulate matter was assumed to have occurred by the 66th hr. Regression analysis, using the percent activity remaining after 66 hrs gave  $\underline{Y}$ -intercepts of 68.7%, 16.8%, and 8.2%. The elimination coefficients ( $\lambda_b$ ) and biological half-lives ( $T_b$ ) for the respective three groups of experimental animals were: (1) 0.76%/hr, 3.79 days; (2) 1.16%/hr, 2.50 days; (3) 1.46%/hr, 1.98 days.

The second experimental phase was to establish uptake rates and equilibrium levels for  $^{134}\text{Cs}$  in lab-born and wild trapped cotton rats under chronic ingestion conditions and to determine retention curves for  $^{134}\text{Cs}$  following termination of the chronic ingestion.

Lettuce tagged with  $^{134}\text{Cs}$  was given daily in doses of 0.06  $\mu\text{Ci}$  to groups of laboratory-born and wild-trapped cotton rats for approximately 30 days. Whole body and excreta counts were made at various intervals over a 712-hr time span. After 712 hr, administration of the isotope was stopped and measurements of excretion of cesium were begun. Serial sacrifices were made during both the accumulation phase and

excretion phase of the equipment, and eight tissues were analyzed for  $^{134}\text{Cs}$ . Accumulation and loss of  $^{134}\text{Cs}$  was slowest in muscle.

The  $^{134}\text{Cs}$  uptake curve for both groups appeared to be a multicomponent curve. The first component occurred from about hour 16 to hour 208. Uptake equations for each group were as follows:

$$\begin{aligned} \text{wild trapped: } \underline{Y} &= 0.7727 \cdot 10^{-2} \underline{X}^{0.5614} \\ \text{lab born: } \underline{Y} &= 0.7746 \cdot 10^{-2} \underline{X}^{0.5354} \end{aligned}$$

The second compartment began at about the 208th hr and ran to the 544th hr:

$$\begin{aligned} \text{wild trapped: } \underline{Y} &= 0.4039 \cdot 10^{-2} \underline{X}^{0.3448} \\ \text{lab born: } \underline{Y} &= 0.4327 \cdot 10^{-2} \underline{X}^{0.3278} \end{aligned}$$

After the 544th hr the rate increase was so slight that it was considered to be zero. Students' "T" test analysis of the wild-trapped vs lab-born group means showed a significant difference by the 64th hr, and a gradual increase in the divergence of the two curves was apparent throughout the uptake phase.

Retention curves, using the equilibrium level as 100% absorbed dose, broke down into two components. The first component (day 1 through 7) considered to be representative of systems such as the liver and intestinal tract, gave retention equations and biological half-lives

$$\begin{aligned} (T_b) \text{ of: } \quad \text{lab born: } \underline{Y} &= 92.8 e^{-0.1332 \underline{X}}, T_b = 5.20 \text{ days} \\ \text{wild trapped: } \underline{Y} &= 100.8 e^{-0.1116 \underline{X}}, T_b = 6.21 \text{ days} \end{aligned}$$

The second component (days 8 through 35) is believed to be indicative of the longer compartments, such as muscle, and is represented by:

$$\begin{aligned} \text{lab born: } \underline{Y} &= 61.7 e^{-0.0853 \underline{X}}, T_b = 8.12 \text{ days} \\ \text{wild trapped: } \underline{Y} &= 79.0 e^{-0.0827 \underline{X}}, T_b = 8.38 \text{ days} \end{aligned}$$

It appears that the type of ingestion, acute (simulant) vs chronic (vegetation), influenced the metabolic kinetics of  $^{134}\text{Cs}$  in cotton rats under laboratory conditions. Presumably, the cesium  $T_b$  was shorter in animals receiving a single dose of simulant because less cesium is incorporated in compartments with slow uptake and long retention times.

## INTRODUCTION

The problem of predicting consequences to free-ranging mammal populations exposed to environmental contamination by fallout involves a variety of factors. Initial consideration must be given to the external level of radiation, both gamma and beta, caused by the fallout. However, the ingestion and metabolism of fission products carried by fallout particles and incorporated in food should also be investigated in order to evaluate the total dose to which the animal is exposed.

Radionuclides in fallout debris enter vertebrates primarily by ingestion and inhalation of the particles and by ingestion of foods contaminated with nuclides leached or weathered from the particles. Incorporation and accumulation of these radionuclides by mammals will depend on ingestion rate of the nuclides, solubility of the nuclides within the GI tract, and physiological importance of the nuclides. Internal radiation doses to vertebrates from fallout thus results from two pathways of exposure. First, ingested radioactive particles essentially are point sources of irradiation while in the gastrointestinal tract. Second, radionuclides leached from fallout particles or from contaminated vegetation may be incorporated into tissues.

Considerable attention has been given to the metabolism of  $^{137}\text{Cs}$  in several animal species primarily because it is a major radionuclide in fallout debris. The half life of  $^{134}\text{Cs}$ , 2.3 years, is much shorter than that of  $^{137}\text{Cs}$ , 26.6 years, thus affording less hazard for experimentation. Since no biological discrimination between these two isotopes has been demonstrated,  $^{134}\text{Cs}$  was chosen for these experiments.

Knowledge of the metabolic patterns of fission products under laboratory conditions will enhance ability to interpret and predict consequences of fallout contamination in natural ecological systems. Therefore, the objective of this research was concerned with establishing baseline values for  $^{134}\text{Cs}$  metabolism in a wild species, the cotton rat (*Sigmodon hispidus*). We measured (1) absorbability of  $^{134}\text{Cs}$  from a single dose of simulated fallout and transit time of the simulant particles through the GI tract, and (2) accumulation and retention of  $^{134}\text{Cs}$  during chronic administration of the

isotope. Values obtained from these studies will be useful for design of future field studies with cotton rats in  $^{137}\text{Cs}$ -contaminated field enclosures and in the interpretation of results from these studies.

### I. General Methods

The colony room where all experimental animals were housed was maintained at a temperature of 21-22°C and a relative humidity of 40-45%. A photoperiod of 12 hr light and 12 hr dark was maintained throughout both experiments.

Experimental animals were housed in suspension cages, with houses and nesting material removed in order to prevent self-contamination by the animals and to allow collection of fecal material and urine. Water and Purina lab chow were available ad libitum throughout the duration of the experiment. Collection of excreta was made possible by the construction of a double layer of screen mesh with a piece of blotter paper between the layers. The mesh size of the layer closest to the floor of the cage was small enough to retain fecal material dropped between counting times, and the blotter paper was used to collect most of the urine.

A Packard Armac liquid scintillation detector was used for whole-body, feces, and urine assays. The phantom for the chronic ingestion experiment consisted of a polyethylene bottle containing distilled water to approximate the average weight of the experimental animals. A single 0.060- $\mu\text{c}$  dose was placed in the phantom and used to calculate the counter efficiency on each counting day. The counting interval was 1 min, and all animals were counted from 8 a.m. to 11 a.m. to insure as much physiological uniformity as possible.

The percent  $^{134}\text{Cs}$  remaining at any time ( $T_n$ ) during the simulant study was derived by the following formula:

$$\% \text{ remaining at } T_n = \frac{\text{cpm animal } T_n}{\text{cpm standard } T_n} \div \frac{\text{cpm animal at } T_0}{\text{cpm standard at } T_0} .$$

The calculation for microcuries absorbed at  $T_n$  for the absorption phase of the chronic ingestion experiment was:

$$\mu\text{c absorbed at } T_n = \frac{\text{dpm animal } T_n}{2.22 \times 10^6},$$

where  $2.22 \times 10^6$  is equal to dpm for 1  $\mu\text{c}$  of radioactive material.

Percent of original microcuries remaining at  $T_n$  for the excretion phase was calculated by

$$\% \mu\text{Ci remaining} = \frac{\mu\text{Ci present at } T_n}{\mu\text{Ci present at } T_0}.$$

Probability values for uptake and excretion were computed using the standard t-test analysis for sample means.

Elimination coefficients ( $\lambda_b$ ) were calculated by linear regression analysis with all Y values transformed to natural logarithmic equivalents. The b value (slope) obtained is therefore identical to  $\lambda$  (physical decay constant) in the equation  $A = A_0 e^{-\lambda t}$ .

Biological half lives ( $T_b$ ) were calculated using  $T_b = \frac{0.693}{\lambda_b}$ .

## II. Absorption of $^{134}\text{Cs}$ from Fallout Simulants and Transit Time of the Simulant Particles Through the Gastrointestinal Tract of Sigmodon hispidus

The availability of radionuclides from ingested fallout particles to vertebrates is determined mainly by (1) solubility rates of the nuclides from the particulate matter in the GI tracts, (2) transit time of the fallout particles through the GI tract, and (3) absorbabilities of the nuclides by the GI tracts.

Cesium- $^{134}\text{Cs}$  tagged simulants with varying in vitro nuclide solubilities were analyzed with respect to  $^{134}\text{Cs}$  solubilities in GI tracts and absorbabilities by GI tracts of cotton rats (Sigmodon hispidus). Determinations of whole body retention and excretory patterns were used to discern variations in  $^{134}\text{Cs}$  metabolism caused by solubility differences. Transit times of the particles through GI tracts were determined because the particles constitute internal point sources as long as they are present.

### Methods

Three batches of  $^{134}\text{Cs}$ -tagged sand were prepared by the Stanford Research Institute in cooperation with the United States Naval Defense Laboratory, San Francisco, California, to be used as simulants for

localized or regional fallout debris. A wide variation in solubilities among the batches was requested to permit us to evaluate the absorption of the radionuclide from the simulant and the transit time of the particles. At the same time, we could choose the simulant which offered effectiveness in field work and afforded a minimum exposure to personnel working in contaminated areas. The solubility of the isotope was determined by the manufacturer, by measuring the amount of isotope leached overnight from 1 g of simulant in 10 ml of a solution of pH 1. Properties of the simulants were as follows:

Batch 1: No reheating after absorption of the isotope  
Specific activity: 1.31  $\mu\text{Ci/g}$   
Solubility: 60.6%

Batch 2: Reheated to 900 $^{\circ}\text{C}$  after absorption of the isotope  
Specific activity: 1.34  $\mu\text{Ci/g}$   
Solubility: 17.6%

Batch 3: Reheated to 1200 $^{\circ}\text{C}$  after absorption of the isotope  
Specific activity: 2.09  $\mu\text{Ci/g}$   
Solubility: 4.3%

All animals used in the study were laboratory-born cotton rats (Sigmodon hispidus) whose ages ranged from three to four months.

Placement of the simulant into the stomachs presented a unique problem since conventional gavaging methods would not allow administration of the large amount of sand necessary to achieve the desired dosage without entering the stomach several times. A method utilizing polyethylene catheter tubing was devised. This type of tubing is very flexible and permits easy passage through the esophagus and into the stomach. A 16-cm length of tubing (inside diameter .086 cm, outside diameter .127 cm) was filled with the desired amount of sand and plugged with a thin layer of chemical-grade gelatin at the bottom. Following loading of the tube, the sand was saturated with tap water. A hydrodermic syringe and 16-gauge needle were filled with 2 ml of tap water and the tube containing the sand was attached. Immediately before

insertion of the tube into the animal's mouth the gelatin plug was broken to allow the sand to flow freely when pressure was applied. The tube was then worked into the animal's stomach, and the water contained in the syringe was used to force the sand into the stomach in a single mass. Prior to gavage, all animals were anesthetized with an injection of pentobarbital sodium (4.5 mg/100 g body weight) to facilitate handling.

Eleven cotton rats were divided into three groups, each group corresponding to the three batches of prepared simulant. The three animals (2 ♂♂ 1 ♀) in group I each received 0.197  $\mu\text{Ci}$ ; the four animals (2 ♂♂ 2 ♀♀) in group II each received 0.201  $\mu\text{Ci}$ ; and the four (3 ♂♂ 1 ♀) animals in group III each received 0.209  $\mu\text{Ci}$ . Whole body, fecal, and urine samples were counted every 18 and 24 hr for 66 hr and then every 24 hr until 138 hr had passed from time of the initial injection.

Laboratory and caging conditions were the same as described in the general methods section of this paper. This arrangement proved highly satisfactory for at the termination of the experiment 94% of the initial dose was accounted for.

### Results

There were no apparent differences between males and females in each group so they were lumped together and treated as a single unit. Whole body retention and cumulative feces and urine excretion of  $^{134}\text{Cs}$  absorbed from the simulant material are shown in Table 3. Analysis of fecal material showed a rapid increase in radioactivity until 42 hr postadministration. After 66 hrs the radioactivity level reached a plateau, after which no increase in  $^{134}\text{Cs}$  was detectable. It was at this point (66 hr) that complete passage of the particulate matter was assumed to have occurred. Regression analysis, using the percent activity remaining after 66 hr gave Y intercepts of 68.7, 16.8, and 8.2% for groups I, II, and III, respectively. These figures closely approximate the in vitro solubility values supplied by the manufacturer for each batch of simulant.

The  $\lambda_b$ 's and  $T_b$ 's for the absorbed  $^{134}\text{Cs}$  are shown in Table 4. Retention and excretion patterns for the varying solubilities are shown in Fig. 11.

Table 3. Whole Body Retention and Loss by Feces and Urine Expressed as Percentages of the Initial Activity

	Hours Post-injection	% Retention Whole Body	% Activity Lost by Urine (Cumulative Total)	% Activity Lost by Feces (Cumulative Total)
Group I	0	100	0	0
(60.6% in vitro leached, injected dose 0.15 g, 0.197 $\mu$ c)	18	85.4	7.2	6.9
	24	82.8	8.3	7.3
	42	54.8	16.0	26.3
	48	51.9	17.5	26.4
	66	41.8	25.1	30.7
	72	39.7	26.0	30.7
	90	34.7	31.1	31.7
	114	28.4	35.9	32.1
	138	24.3	39.2	32.3
Group II	0	100	0	0
(17.6% in vitro leached, injected dose, 0.15 g, 0.201 $\mu$ c)	18	43.7	6.1	46.9
	24	38.6	7.3	50.0
	42	12.5	10.3	70.5
	48	10.9	10.9	70.9
	66	7.6	12.7	72.7
	72	7.2	12.9	72.7
	90	6.1	14.2	72.7
	114	4.9	15.2	--
	138	3.2	15.9	72.7
Group III	0	100	0	0
(4.34% in vitro leached, injected dose, 0.10 g, 0.209 $\mu$ c)	18	65.6	1.8	36.4
	24	55.4	2.1	40.5
	42	14.3	2.8	78.9
	48	11.8	3.0	80.7
	66	3.3	3.5	89.0
	72	3.0	3.6	89.0
	90	2.0	3.8	89.8
	114	1.4	--	--
	138	1.2	3.9	89.8

Table 4. Biological Elimination Rates and Half-lives of  $^{134}\text{Cs}$  and Transit Time of the Particles

	$\lambda_b$ (%/hr)	$T_b$		Transit Time of Simulant (hr)
		(hr)	(days)	
Group I	0.76	91.3	3.79	66
Group II	1.16	60.0	2.50	66
Group III	1.46	47.5	1.98	66

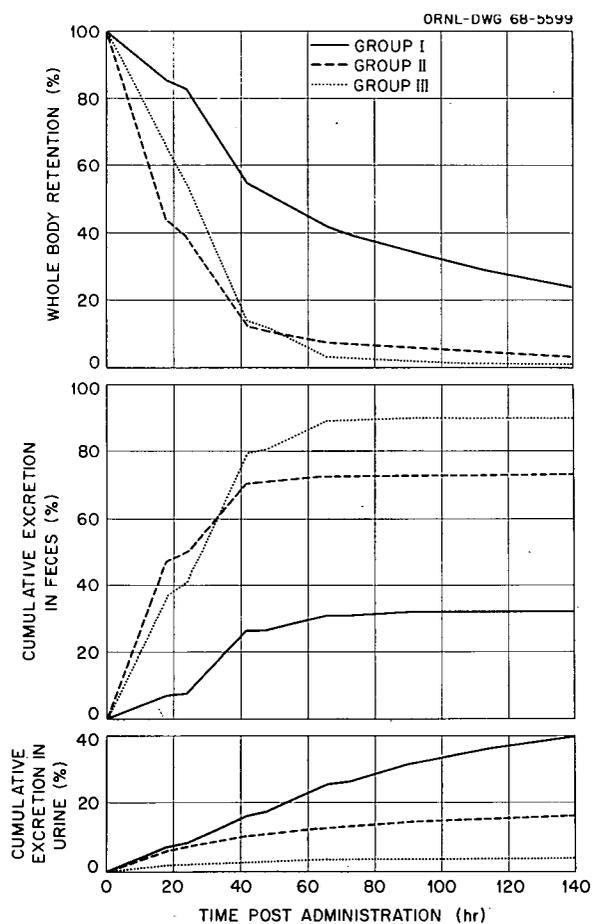


Fig. 11. Whole body and excretion patterns following acute administration of simulated fallout particles. % represents percentage of initial dose administered. Groups I, II, and III denote experimental animals receiving fallout simulant with manufacturer's in vitro  $^{134}\text{Cs}$  solubilities of 60.6%, 17.6%, and 4.34%, respectively.

## Discussion

Our findings indicate that measurements for absorbed  $^{134}\text{Cs}$  and serial sacrifices to evaluate tissue distribution patterns could begin three days after introduction of the simulant. Our data suggest that the in vivo leaching was greater than the in vitro leaching except in Group II where it was about the same. LeRoy et al. (1963) also reported that more leaching occurred in the intestinal tract of man than in vitro. Hayes et al. (1963) used  $^{140}\text{La}$  citrate as an insoluble tracer on humans and measured the activity in the feces. It is interesting to note that his curves for cumulative excretion are quite similar to the ones presented in this study.

There is a hint of an increasing elimination of the absorbed  $^{134}\text{Cs}$  with a decrease in solubility, but the evidence is highly inconclusive and a wider range of solubility gradient is needed to resolve this question.

The amount of radioactivity (Fig. 11) measured during the time intervals from hour 18 (8 a.m.) to hour 24 (2 p.m.) and hour 42 to hour 48 seem to indicate that the animals might be in a postabsorptive state. Very small amounts of fecal material were passed during this time and the amount of  $^{134}\text{Cs}$  contributed to the cumulative fecal excretion was less than 5% for all groups.

### III. Absorption and Retention of Chronically Ingested $^{134}\text{Cs}$ in Sigmodon hispidus

Evaluation of accumulation and retention of  $^{134}\text{Cs}$  in cotton rats under field conditions requires establishment of some basic parameters which can be used in subsequent analysis of the effects of environmental variables (temperature, moisture, population stress, etc.) on normal metabolic patterns of this isotope.

After fallout particles reach the soil or litter layer, the quantity of radioactive materials in small mammals normally is the culmination of long-term uptake of the nuclide from contaminated foods. Thus, chronic administration of an isotope is more likely to simulate uptake under field conditions a few weeks after fallout cessation. The following experiment was designed to (1) establish uptake rates and

equilibrium levels of  $^{134}\text{Cs}$  in the cotton rat under chronic ingestion conditions, and (2) determine retention curves for  $^{134}\text{Cs}$  following termination of chronic ingestion. Cesium- $^{134}\text{Cs}$ -tagged lettuce was used to simulate vegetative material contaminated by leachate containing the radioisotope.

Groups of laboratory-born and wild-trapped cotton rats were used in the experiment to determine if significant variations in absorption or retention between the groups was discernible. If no large variations occurred, it should be possible to use lab-born animals to control such variables as age, parasitism, disease, and intraspecific stresses in field studies.

### Methods

Six male and six female cotton rats, wild-trapped on the Oak Ridge National Laboratory reservation, were used for whole-body counts during uptake and excretion phases, while the same number of male and female laboratory-born cotton rats comprised another study group.

Cesium- $^{134}\text{Cs}$ , in doses of  $0.06 \mu\text{Ci}$  was given daily to each experimental animal for 30 days. The  $^{134}\text{Cs}$  solution was pipetted onto a 4-g piece of lettuce and was then evaporated using a heat lamp. After evaporation of the solution, the lettuce was fed to the animals at 4 p.m. each day. This method of administration of the isotope provided a highly satisfactory means of inducing chronic ingestion because the animals readily accepted the contaminated lettuce. Analysis of possible contamination areas of the animals (mouth-nasal region, urogenital region, and front paws) revealed no significant amounts of external radioactivity.

Whole body and excreta counts were made initially 16 hr after the first feeding, then every 24 hr for the first 256 hr and subsequently 1 or 2 times a week until an equilibrium level was attained. After 712 hr, feeding of the tagged lettuce was ceased, and measurements of the excretion of the absorbed cesium were begun. Periodic counts were made until the level of radioactivity reached low proportions.

A group of 24 animals was used for tissue analysis. These animals were treated in the same manner as the other experimental groups, and

the whole body and excreta counts at the time of sacrifice were included in the respective experimental groups. Serial sacrifices were made during both the accumulation phase and the excretion phases of the experiment, and eight tissues were analyzed for  $^{134}\text{Cs}$ . All tissues were stripped of excess connective tissue, washed, blotted to remove excess water, and weighed. All intestinal contents were cleaned out and discarded.

### Results

The whole-body accumulation of  $^{134}\text{Cs}$  in the wild-caught and lab-born groups is shown in Fig. 12. No significant difference was noted between the males and females of each group so they were treated as a single group. The initial absorption was very similar in both groups, but as equilibrium levels were approached the divergence became highly significant. The uptake curve for both groups was a multicomponent curve when plotted on log/log paper. The first (fast) component occurred from

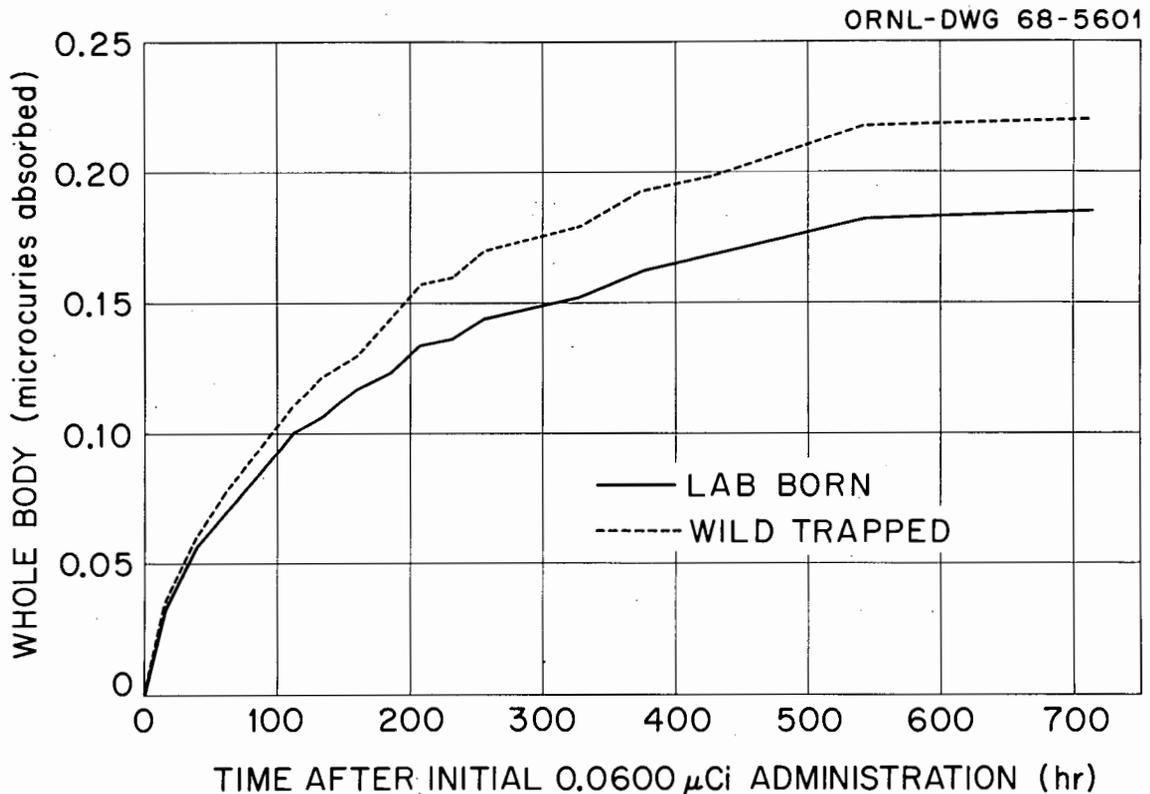


Fig. 12. Whole body uptake of  $^{134}\text{Cs}$  during chronic ingestion of tagged lettuce.

the 16th to about the 208th hr. Regression equations for each group are as follows:

$$\begin{aligned} \text{wild trapped: } \underline{Y} &= 0.7727 \cdot 10^{-2} \underline{X}^{0.5614} \\ \text{lab born: } \underline{Y} &= 0.7746 \cdot 10^{-2} \underline{X}^{0.5354} \end{aligned}$$

where  $\underline{Y}$  equals microcuries absorbed and  $\underline{X}$  equals time in hours after the initial administration. The second major component began at the 208th hr and continued to the 544th hr:

$$\begin{aligned} \text{wild trapped: } \underline{Y} &= 0.4039 \cdot 10^{-2} \underline{X}^{0.3448} \\ \text{lab born: } \underline{Y} &= 0.4327 \cdot 10^{-2} \underline{X}^{0.3278} \end{aligned}$$

After the 544th hr the rate increase was so slight that it was considered to be zero. The designation of the uptake curve as multicomponent may be misleading. It is highly unlikely that each component is discretely separate from the other. It is more probable that a smoother transition between components would be made if smaller counting intervals were utilized.

Table 5 gives means and standard errors for whole-body accumulation and excreta. T-tests were run on the whole body sample means of the two experimental groups, and a significant difference was noted on the 64th hr at the 99.0% level and a gradual increase in the divergence of the two curves occurred throughout the remaining hours. Significance at the 99.5% level was noted by 712 hr.

After the 712th hr count, feeding of  $^{134}\text{Cs}$ -tagged lettuce was discontinued. Using the equilibrium level as 100% absorbed dose, retention curves (Fig. 13) for both groups was plotted. The resulting retention levels, Table 6, are expressed as percentages of initial activity remaining at any time  $T_n$ . The retention curves seem to be composed of two components. Component one, from day 1 to day 7, is probably a reflection of  $^{134}\text{Cs}$  clearance from systems such as the liver and intestinal tract. The retention equation and  $T_b$  for both groups are as follows:

$$\begin{aligned} \text{lab born: } \underline{Y} &= 92.8 e^{-0.1332 \underline{X}}, T_b = 5.20 \text{ days} \\ \text{wild trapped: } \underline{Y} &= 100.8 e^{-0.1116 \underline{X}}, T_b = 6.21 \text{ days} \end{aligned}$$

where  $\underline{Y}$  equals % remaining and  $\underline{X}$  equals time in days after last feeding.

Table 5. Uptake of  $^{134}\text{Cs}$  by Lab-Born and Wild-Caught Sigmodon hispidus under a Chronic Feeding Regimen.

Hours After Initial Feeding	Group (Lab-Born or Wild-Caught)	Weight (g)	Whole Body Accumulation ( $\mu\text{Ci}$ )	Probability of $\bar{X}$ Lab and $\bar{X}$ Wild Being Different	Urine Excreted ( $\mu\text{Ci}$ )	Feces Excreted ( $\mu\text{Ci}$ )	Ratio of Urinary: Fecal $^{134}\text{Cs}$
16	Lab	114.73 $\pm$ 6.23 (13) <sup>a</sup>	.0334 $\pm$ .0008 (13)	0.1 < P	.0241 $\pm$ .0009 (13)	.0030 $\pm$ .0004 (13)	8.0:1
	Wild	110.38 $\pm$ 8.21 (13)	.0368 $\pm$ .0015 (13)		.0210 $\pm$ .0011 (13)	.0024 $\pm$ .0003 (13)	8.8:1
40	Lab	119.58 $\pm$ 7.05 (13)	.0568 $\pm$ .0016 (13)	0.1 < P	.0332 $\pm$ .0014 (12)	.0047 $\pm$ .0007 (12)	7.1:1
	Wild	111.81 $\pm$ 8.24 (13)	.0609 $\pm$ .0016 (13)		.0316 $\pm$ .0009 (12)	.0048 $\pm$ .0006 (12)	6.6:1
64	Lab	104.15 $\pm$ 11.01 (13)	.0728 $\pm$ .0004 (13)	0.01 < P	.0404 $\pm$ .0010 (12)	.0050 $\pm$ .0007 (12)	8.1:1
	Wild	111.58 $\pm$ 8.60 (13)	.0796 $\pm$ .0023 (13)		.0384 $\pm$ .0016 (12)	.0055 $\pm$ .0006 (12)	7.0:1
88	Lab	117.96 $\pm$ 6.23 (13)	.0856 $\pm$ .0019 (13)	0.005 < P	.0444 $\pm$ .0014 (12)	.0047 $\pm$ .0006 (12)	9.4:1
	Wild	108.62 $\pm$ 8.06 (13)	.0950 $\pm$ .0020 (13)		.0413 $\pm$ .0018 (12)	.0056 $\pm$ .0006 (12)	7.4:1
112	Lab	118.31 $\pm$ 3.61 (13)	.0996 $\pm$ .0027 (13)	0.01 < P	.0461 $\pm$ .0015 (12)	.0068 $\pm$ .0007 (12)	6.8:1
	Wild	107.04 $\pm$ 6.59 (13)	.1109 $\pm$ .0027 (13)		.0431 $\pm$ .0013 (12)	.0069 $\pm$ .0007 (12)	6.2:1
136	Lab	113.69 $\pm$ 6.13 (13)	.1071 $\pm$ .0039 (13)	.005 < P	.0495 $\pm$ .0013 (11)	.0050 $\pm$ .0008 (11)	9.9:1
	Wild	106.77 $\pm$ 8.41 (13)	.1230 $\pm$ .0027 (13)		.0464 $\pm$ .0012 (11)	.0070 $\pm$ .0007 (11)	6.6:1
160	Lab	116.21 $\pm$ 6.26 (12)	.1172 $\pm$ .0040 (12)	.005 < P	.0509 $\pm$ .0008 (11)	.0065 $\pm$ .0010 (11)	7.8:1
	Wild	105.79 $\pm$ 7.95 (14)	.1296 $\pm$ .0037 (14)		.0475 $\pm$ .0011 (11)	.0073 $\pm$ .0008 (11)	6.5:1
184	Lab	116.00 $\pm$ 6.46 (12)	.1234 $\pm$ .0028 (12)	.001 < P	.0524 $\pm$ .0009 (11)	.0063 $\pm$ .0007 (11)	8.3:1
	Wild	107.86 $\pm$ 7.60 (14)	.1442 $\pm$ .0037 (14)		.0470 $\pm$ .0015 (11)	.0069 $\pm$ .0009 (11)	6.8:1
208	Lab	116.75 $\pm$ 7.97 (12)	.1337 $\pm$ .0049 (12)	.005 < P	.0524 $\pm$ .0017 (11)	.0064 $\pm$ .0008 (11)	8.2:1
	Wild	112.68 $\pm$ 6.28 (14)	.1568 $\pm$ .0046 (14)		.0495 $\pm$ .0014 (11)	.0073 $\pm$ .0007 (11)	6.8:1
232	Lab	116.50 $\pm$ 6.40 (12)	.1360 $\pm$ .0040 (12)	0.001 < P	.0525 $\pm$ .0005 (11)	.0064 $\pm$ .0009 (11)	8.2:1
	Wild	111.57 $\pm$ 8.06 (14)	.1602 $\pm$ .0037 (14)		.0546 $\pm$ .0013 (11)	.0081 $\pm$ .0008 (11)	6.7:1
256	Lab	116.50 $\pm$ 6.24 (12)	.1442 $\pm$ .0049 (12)	0.001 < P	.0546 $\pm$ .0022 (11)	.0062 $\pm$ .0009 (11)	8.8:1
	Wild	116.21 $\pm$ 9.22 (14)	.1700 $\pm$ .0037 (14)		.0562 $\pm$ .0013 (11)	.0080 $\pm$ .0011 (11)	7.0:1
328	Lab	115.46 $\pm$ 6.74 (12)	.1518 $\pm$ .0064 (12)	0.005 < P	.0501 $\pm$ .0013 (11)	.0073 $\pm$ .0008 (11)	6.7:1
	Wild	112.0 $\pm$ 8.87 (12)	.1792 $\pm$ .0057 (12)		.0468 $\pm$ .0018 (11)	.0090 $\pm$ .0011 (11)	5.2:1
376	Lab	118.83 $\pm$ 6.11 (12)	.1624 $\pm$ .0068 (12)	0.005 < P	.1115 $\pm$ .0019 (11)	.0151 $\pm$ .0014 (11)	7.4:1
	Wild	110.75 $\pm$ 8.49 (12)	.1933 $\pm$ .0068 (12)		.1085 $\pm$ .0021 (11)	.0176 $\pm$ .0016 (11)	6.2:1
424	Lab	119.54 $\pm$ 6.69 (12)	.1679 $\pm$ .0065 (12)	0.005 < P	.1150 $\pm$ .0023 (10)	.0154 $\pm$ .0018 (10)	7.5:1
	Wild	113.46 $\pm$ 8.74 (12)	.1980 $\pm$ .0062 (12)		.1122 $\pm$ .0025 (11)	.0170 $\pm$ .0018 (11)	6.6:1
544	Lab	122.58 $\pm$ 8.59 (12)	.1824 $\pm$ .0092 (12)	0.005 < P	.2684 $\pm$ .0056 (10)	.0476 $\pm$ .0042 (10)	5.6:1
	Wild	116.17 $\pm$ 6.79 (12)	.2184 $\pm$ .0085 (12)		.2580 $\pm$ .0063 (11)	.0467 $\pm$ .0037 (11)	5.5:1
712	Lab	122.50 $\pm$ 7.08 (11)	.1853 $\pm$ .0090 (12)	0.005 < P	.3572 $\pm$ .0069 (10)	.0728 $\pm$ .0070 (10)	4.9:1
	Wild	116.46 $\pm$ 7.45 (14)	.2208 $\pm$ .0108 (14)		.3542 $\pm$ .0079 (11)	.0739 $\pm$ .0069 (11)	4.8:1

<sup>a</sup> Values are  $\bar{X} \pm 1 \text{ S.E.}$ ;  
numbers in parentheses are sample numbers.

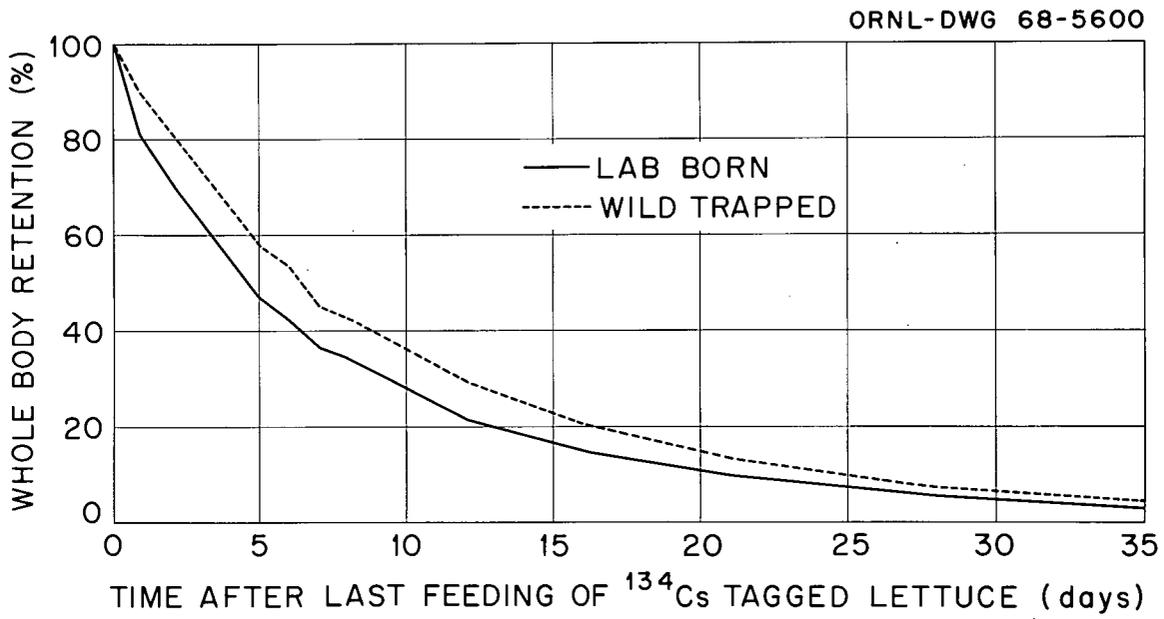


Fig. 13. Whole body retention of <sup>134</sup>Cs following termination of a thirty-day chronic ingestion of tagged lettuce.

Table 6. Excretion of  $^{134}\text{Cs}$  in Lab-Born and Wild-Caught *Sigmodon hispidus* Following a Chronic Feeding Regimen.

Days After Last Feeding	Group (Lab-Born or Wild-Caught)	Weight (g)	Whole Body Activity ( $\mu\text{Ci}$ )	Initial Activity Remaining (%)	Probability of X Lab and X Wild Being Different	Urine Excreted ( $\mu\text{Ci}$ )	Feces Excreted ( $\mu\text{Ci}$ )	Ratio of Urinary: Fecal $^{134}\text{Cs}$
1	Lab	122.50 $\pm$ 7.08 (11) <sup>a</sup>	.1511 $\pm$ .0091 (11)	81.5	P > .001	.0282 $\pm$ .0006 (11)	.0044 $\pm$ .0005 (11)	6.4:1
	Wild	116.46 $\pm$ 7.45 (14)	.1998 $\pm$ .0073 (14)	90.4		.0302 $\pm$ .0008 (14)	.0050 $\pm$ .0005 (14)	6.0:1
2	Lab	122.73 $\pm$ 7.09 (11)	.1318 $\pm$ .0088 (11)	71.1	P > .001	.0208 $\pm$ .0007 (11)	.0026 $\pm$ .0004 (11)	8.0:1
	Wild	121.32 $\pm$ 7.34 (14)	.1772 $\pm$ .0068 (14)	80.3		.0235 $\pm$ .0006 (14)	.0035 $\pm$ .0003 (14)	6.7:1
5	Lab	126.86 $\pm$ 7.06 (11)	.087 $\pm$ .0065 (11)	47.0	P > .001	.0397 $\pm$ .0018 (11)	.0053 $\pm$ .0008 (11)	7.5:1
	Wild	118.08 $\pm$ 6.71 (12)	.1279 $\pm$ .0065 (12)	57.9		.0486 $\pm$ .0020 (12)	.0066 $\pm$ .0006 (12)	7.4:1
6	Lab	127.82 $\pm$ 7.27 (11)	.0784 $\pm$ .0062 (11)	42.3	P > .001	.0091 $\pm$ .0003 (11)	.0011 $\pm$ .0002 (11)	8.3:1
	Wild	132.54 $\pm$ 9.15 (14)	.1178 $\pm$ .0063 (14)	53.4		.0113 $\pm$ .0006 (14)	.0015 $\pm$ .0002 (14)	7.5:1
7	Lab	128.91 $\pm$ 7.12 (11)	.0677 $\pm$ .0056 (11)	36.5	P > .001	.0081 $\pm$ .0005 (11)	.0013 $\pm$ .0002 (11)	6.2:1
	Wild	125.67 $\pm$ 8.62 (12)	.0997 $\pm$ .0057 (12)	45.1		.0096 $\pm$ .0004 (12)	.0014 $\pm$ .0001 (12)	6.9:1
8	Lab	128.36 $\pm$ 6.86 (11)	.0630 $\pm$ .0053 (11)	34.0	P > .001	.0073 $\pm$ .0004 (11)	.0009 $\pm$ .0002 (11)	8.1:1
	Wild	123.63 $\pm$ 9.14 (12)	.0944 $\pm$ .0046 (12)	42.8		.0090 $\pm$ .0005 (12)	.0012 $\pm$ .0001 (12)	7.5:1
12	Lab	135.90 $\pm$ 6.77 (10)	.0401 $\pm$ .0033 (10)	21.6	P > .001	.0197 $\pm$ .0008 (10)	.0027 $\pm$ .0004 (10)	7.3:1
	Wild	124.64 $\pm$ 7.42 (11)	.0650 $\pm$ .0034 (11)	29.5		.0258 $\pm$ .0012 (11)	.0033 $\pm$ .0003 (11)	7.8:1
16	Lab	134.75 $\pm$ 6.55 (10)	.0277 $\pm$ .0025 (10)	14.9	P > .001	.0115 $\pm$ .0009 (10)	.0018 $\pm$ .0003 (10)	6.6:1
	Wild	124.68 $\pm$ 7.27 (11)	.0449 $\pm$ .0027 (11)	20.4		.0171 $\pm$ .0009 (11)	.0029 $\pm$ .0003 (11)	5.9:1
21	Lab	138.89 $\pm$ 7.55 (9)	.0183 $\pm$ .0020 (9)	9.9	P > .005	.0107 $\pm$ .0008 (9)	.0017 $\pm$ .0003 (9)	6.3:1
	Wild	127.15 $\pm$ 8.25 (10)	.0292 $\pm$ .0019 (10)	13.2		.0151 $\pm$ .0008 (10)	.0019 $\pm$ .0003 (10)	7.9:1
28	Lab	142.56 $\pm$ 7.54 (9)	.0100 $\pm$ .0012 (9)	5.4	P > .005	.0089 $\pm$ .0007 (9)	.0017 $\pm$ .0002 (9)	5.2:1
	Wild	130.00 $\pm$ 8.03 (10)	.0167 $\pm$ .0013 (10)	7.6		.0131 $\pm$ .0010 (10)	.0018 $\pm$ .0005 (10)	7.3:1
35	Lab	149.06 $\pm$ 7.74 (8)	.0063 $\pm$ .0008 (8)	3.3	P > .01	.0057 $\pm$ .0006 (8)	.0009 $\pm$ .0002 (8)	6.3:1
	Wild	137.78 $\pm$ 8.18 (9)	.0102 $\pm$ .0010 (9)	4.6		.0076 $\pm$ .0006 (9)	.0012 $\pm$ .0002 (9)	6.3:1

<sup>a</sup> Values are  $\bar{x} \pm 1 \text{ S.E.}$ ;  
numbers in parentheses are sample numbers.

53

The second component (day 8 to day 35) is believed to be indicative of the longer compartments:

$$\begin{aligned} \text{lab born:} \quad & \underline{Y} = 61.7 e^{-0.0853 \underline{X}}, T_b = 8.12 \text{ days} \\ \text{wild trapped:} \quad & \underline{Y} = 79.0 e^{-0.0827 \underline{X}}, T_b = 8.38 \text{ days} \end{aligned}$$

A significant difference (Table 6) between sample means of the two groups is evident throughout the 35-day excretion period.

During the uptake phase the quantity of radiocesium absorbed by the gastrocnemius muscle was slow and did not reach its greatest concentration until the 208th hr, in contrast to rapid accumulation of  $^{134}\text{Cs}$  by the liver and small intestine (Table 7). For the first eight days of the excretion phase (Table 8), the percent of the total body of  $^{134}\text{Cs}$  decreased in all tissues except the muscle, which remained above the equilibrium percentage (Table 7). On day 16 an increase in the percentage of  $^{134}\text{Cs}$  was apparent in all tissues except the liver and skin. The increase at this time was due to higher tissue percentages in one of the experimental animals than in the other. Following this transient increase a consistent decrease occurred until day 35 when all sample tissues contained less than .0001  $\mu\text{Ci}$ . Of all tissues sampled blood showed the lowest levels throughout both experimental phases, which substantiates the observation made by Hood and Comar (1953) that cesium was taken up against a concentration gradient.

### Discussion

The significantly different levels of  $^{134}\text{Cs}$  absorption between the wild-caught and lab-born rats cannot be attributed to either sex or weight differences. Other authors (Whicker 1968, Mraz *et al.* 1957, Hood and Comar 1953, Thomas and Thomas 1967) also report no difference in cesium metabolism between males and females. Weight of the animals did not significantly differ between the lab-born and wild-trapped groups and thus cannot be considered as the principal reason for the absorption differences.

Whicker (1968) has reported a more rapid elimination for five-month-old mule deer as compared to adult animals but found no differences in the rates of yearlings and adults. Hood and Comar (1953) also found a higher excretion rate in young rats than in older ones.

Table 7. Distribution of Absorbed <sup>134</sup>Cs in Sigmodon hispidus During Chronic Ingestion.

Sample number in all cases is two (1 laboratory born, 1 wild trapped).

Tissue		Hours After Initial Administration							
		16	40	64	88	112	136	208	712
Liver	μCi	.0019	.0035	.0023	.0039	.0047	.0034	.0045	.0034
	% total <sup>a</sup>	4.89	5.88	2.99	3.78	3.98	3.33	2.75	2.29
	weight <sup>b</sup>	3.2983	5.7779	4.1152	4.2797	5.1553	3.1570	4.7199	3.7181
Heart	μCi	.0002	.0004	.0003	.0006	.0008	.0006	.0008	.0006
	% total	0.51	0.67	0.39	0.58	0.67	0.58	0.48	0.39
	weight	0.4110	0.5268	0.4209	0.4192	0.4272	0.4219	0.4308	0.3335
Blood	μCi	.0001	.0001	.0001	.0005	.0005	.0004	.0005	.0002
	% total	0.25	0.16	0.13	0.48	0.42	0.39	0.30	0.17
	volume <sup>c</sup>	1	1	1	1	1	1	1	1
Stomach	μCi	.0007	.0009	.0011	.0022	.0019	.0013	.0019	.0016
	% total	1.80	1.51	1.43	2.13	1.61	1.27	1.16	1.09
	weight	0.8218	0.8230	0.8527	0.7619	0.7658	0.6220	0.7560	0.7091
Small intestine	μCi	.0018	.0020	.0019	.0024	.0041	.0020	.0028	.0027
	% total	4.63	3.36	2.47	2.32	3.48	1.96	1.71	1.81
	weight	1.7967	1.7474	1.4614	1.2476	1.7001	1.4839	1.2913	1.4254
Caecum	μCi	.0005	.0008	.0009	.0010	.0017	.0012	.0011	.0011
	% total	1.28	1.34	1.17	0.96	1.44	1.17	0.67	0.72
	weight	0.8007	1.3331	1.1445	0.9557	1.4639	0.8101	0.7943	0.8783
Large intestine	μCi	.0005	.0004	.0006	.0007	.0010	.0008	.0009	.0007
	% total	1.28	0.67	1.78	0.67	0.84	0.78	0.55	0.47
	weight	0.5973	0.5207	0.6143	0.5002	0.5298	0.4302	0.4697	0.5195
Gastrocnemius	μCi	.0003	.0006	.0008	.0015	.0019	.0015	.0022	.0021
	% total	0.78	1.00	1.04	1.45	1.61	1.47	1.34	1.40
	weight	0.9426	2.0757	0.7301	1.1052	1.0480	0.7392	0.8237	0.7754
Skin	μCi	.0039	.0048	.0057	.0090	.0109	.0087	.0111	.0108
	% total	10.05	8.06	7.41	8.72	9.25	8.54	6.79	7.31
Residual	μCi	.0289	.0460	.0632	.0813	.0903	.0819	.1376	.1218
Carcass	% total	74.48	77.31	82.18	78.85	76.65	80.45	84.21	82.85

<sup>a</sup> % total of whole body activity

<sup>b</sup> wet weight (in grams)

<sup>c</sup> volume, 1 c.c.

Table 8. Distribution of  $^{134}\text{Cs}$  in Sigmodon hispidus After Termination of Chronic Ingestion.

Sample number in all cases is two (1 laboratory born, 1 wild trapped).

Tissue		Days After Last Administration						
		1	2	5	8	16	28	35
Liver	$\mu\text{Ci}$	.0033	.0024	.0016	.0014	.0005	.0002	T
	% total <sup>a</sup>	1.82	1.57	1.20	1.28	1.23	0.75	-
	weight <sup>b</sup>	4.3861	5.0246	7.1335	5.6129	5.5958	4.3573	3.8594
Heart	$\mu\text{Ci}$	.0006	.0004	.0003	.0002	.0003	T <sup>d</sup>	T
	% total	0.34	0.25	0.19	0.15	0.74	-	-
	weight	0.3816	0.4261	0.5161	0.4178	0.3809	0.3073	0.3414
Blood	$\mu\text{Ci}$	.0004	.0003	.0001	.0002	.0002	T	T
	% total	0.23	0.18	0.08	0.15	0.49	-	-
	volume <sup>c</sup>	1	1	1	1	1	1	1
Stomach	$\mu\text{Ci}$	.0013	.0011	.0008	.0007	.0003	T	T
	% total	0.74	0.74	0.58	0.59	0.74	-	-
	weight	0.6871	0.7421	1.1287	1.0907	0.6640	0.6729	0.7399
Small intestine	$\mu\text{Ci}$	.0024	.0022	.0013	.0010	.0004	.0002	T
	% total	1.31	1.45	0.97	0.92	0.98	0.75	-
	weight	1.4239	1.6283	2.4565	1.7334	1.0682	1.4893	1.5184
Caecum	$\mu\text{Ci}$	.0013	.0007	.0005	.0004	.0003	T	T
	% total	0.70	0.46	0.37	0.38	0.74	-	-
	weight	0.9381	1.1368	1.2685	0.8799	0.8068	0.8996	1.2533
Large intestine	$\mu\text{Ci}$	.0008	.0007	.0003	.0002	.0004	T	T
	% total	0.45	0.44	0.20	0.21	0.98	-	-
	weight	0.5441	0.5790	0.5461	0.5455	0.5343	0.4401	0.4476
Muscle (gastrocnemius)	$\mu\text{Ci}$	.0036	.0038	.0017	.0019	.0010	.0003	T
	% total	1.98	2.49	1.25	1.75	2.45	1.63	-
	weight	0.8096	1.0364	0.8222	0.9131	0.6948	0.8409	0.8790
Skin	$\mu\text{Ci}$	.0106	.0079	.0066	.0064	.0018	.0009	.0009
	% total	5.83	5.17	4.92	5.88	4.41	7.89	8.35
Residual carcass	$\mu\text{Ci}$	.1561	.1317	.1221	.0967	.0357	.0093	.0063
	% total	86.20	86.61	90.78	88.27	87.50	81.58	80.42

a % total of whole body activity

b wet weight (in grams)

c volume, 1 c.c.

d trace amount, <.0001  $\mu\text{c}$

30

Since the age of the wild-trapped cotton rats is unknown, it is not possible to draw any definite conclusions about the correlation of age and  $^{137}\text{Cs}$  uptake from our data. However, the excretion data indicates a slightly higher elimination for the lab group, which was known to be 6 to 9 months of age. Some authors have indicated that potassium intake in the daily diet has an effect on cesium elimination (Mraz et al. 1957, Wasserman and Comar 1961), but only in cases where the diets were potassium deficient or contained very small amounts of potassium; and Whicker (1968) indicates that foliage type and amount of food intake has some bearing on elimination of cesium. The amount and type of food available to both groups of cotton rats was standardized and thus any profound effect cannot be attributed to food differences.

It appears that an inherent difference exists in the initial  $^{134}\text{Cs}$  uptake in the wild-trapped and laboratory-born groups. Since the muscle is the critical organ (Kereiakes et al. 1961, Hood and Comar 1953, Ballou and Thompson 1958, Mraz and Patrick 1957, Whicker 1968, Thomas and Thomas 1967), it may not be inappropriate to assume a difference in the musculature of the two groups.

Biological half-lives for the groups receiving a single administration of simulant were shorter than the second component half-lives for the groups chronically ingesting contaminated lettuce. The latter, in turn, were similar to the 8.1-day half-life reported by Baker et al. (1968) for the same species under similar laboratory circumstances using a single intraperitoneal injection and calculating excretion rates on the basis of second-day activity as 100% absorption.

It is our belief that calculations of biologically important phenomenon when the isotope is at an equilibrium level yield smoother elimination curves than curves obtained by a single oral dose or intraperitoneal injection. The almost complete disappearance of the extracellular fraction of the isotope eliminates the need for selecting some arbitrary time after administration and designating it as 100% of the absorbed dose.

Although there were statistically significant differences in uptake and excretion between the wild-caught and lab-born rats, these differences are not large enough to preclude use of lab-born rats, which can be provided as uniform groups raised in the same environment.

## CONCLUSIONS

The metabolism of cesium following contamination by widespread fallout in the environment must be considered from three aspects. First, absorption rates from the two pathways of exposure, ingestion of fallout particles per se and ingestion of contaminated foods, must be measured. The reason for the shorter  $^{134}\text{Cs}$  biological half-lives for the fallout simulant as compared with the  $T_b$  for the chronic exposure very well may be due to the low amounts of the radioisotopes available for absorption by the longer compartments, i.e., muscle. Since the short time interval (5.8 days) over which reliable measurements could be made for the simulant coincides with the time required for the fast component to clear in the chronic study, the  $\lambda_b$  and  $T_b$  reported for the simulant may be appropriate mainly for short compartment such as the liver and intestine. In an actual fallout situation or in our future studies with fallout simulant, radioactive particles will be ingested chronically and radiocesium from this source will build up to equilibrium levels along with the cesium from contaminated food.

Secondly, it is necessary to understand the effects of the interaction of the pathways. We do not know, for example, the effect of the particulate matter on the absorption and retention of  $^{134}\text{Cs}$  ingested with vegetative material and vice versa. The third and most important aspect, however, will be the influence of environmental factors on the accumulation and elimination levels of cesium. Field studies are now underway in an attempt to identify these factors.

Since many small mammals reingest part of their fecal material (a special "soft feces") as it is expelled, it is probable that reingestion of radiocesium via this route occurs. We do not know to what degree our rats practiced coprophagy or if radioactive particles, particularly the simulant, were segregated in or from the soft feces.

The differing rates of radiocesium uptake in the tissues means that food-chain transfers to predators of small prey species such as cotton rats will differ according to feeding habits of the predators. Carnivores such as foxes, bobcats, and snakes which swallow all of the prey will be exposed to the radionuclides in digestible tissues, including

the nuclides available on radioactive particles in the digestive tracts of the prey. Shrews, on the other hand, mostly ingest soft tissues such as muscle, brain, heart, liver, etc., but normally do not eat the intestines, bones, or skin. Hawks and owls ingest most of such small prey, but indigestible parts such as hair, bone, and teeth are regurgitated in pellets. Thus, it seems likely that body burdens in predators will depend greatly on feeding habits of the predators as well as on the isotope concentrations in various tissues of the prey, including the GI-tract contents.

Calculation of internal dose received by the cotton rats from the radioactive particles was not attempted. Additional requisite data for such calculation include transit times of the particles through various parts of the gut, particulate sorting, dimensions of the GI tract, shielding afforded by tract contents, coprophagic rates, etc. Similarly, sophisticated estimates of internal dose will require measurements of tissue dimensions and configurations, and radioactivity levels in differentiated zones of certain tissue and organs.

The development of values in the laboratory is important in predicting mammalian responses to radiation insult and nuclide accumulation in case of a nuclear holocaust or accidental releases of radioisotopes into an environment. While our results from this study will considerably aid in interpretation of field data, these findings should be confirmed and extended by actual field experimentation. Discrepancies between laboratory predictions and actual values in field studies were shown by Kaye and Dunaway (1962) when measuring bioaccumulation of radionuclides by small mammals in a contaminated area. Experimentation in field enclosures contaminated with simulated fallout and concomitant laboratory studies will answer some of the questions raised in this paper.

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EFFECTS OF BETA AND GAMMA RADIATION ON SINELLA CURVISETA (COLLEMBOLA)

C. E. Styron

Collembola play an important role in the breakdown of organic material in the biological cycle of soil formation, and numerically they usually take second place only to mites in the air-breathing fauna of the soil. Information on the interactions of beta and gamma radiation with the population dynamics of such small, rapidly reproducing soil arthropods is needed in planning postattack agricultural procedures. The ecological balance maintained in many agricultural situations may be altered seriously by the effects of ionizing radiation from nuclear fallout on insect populations (Wong 1967).

This report is concerned with a laboratory phase of a study on the effects of simulated radioactive fallout on natural populations of Collembola and other insects. Laboratory data were necessary to establish a basis for interpreting field observations, particularly in view of the paucity of information on the effects of ionizing radiation on soil-dwelling insects (Edwards 1969) and the difficulties involved in estimating Collembola population parameters in the field (Hale 1965). Auerbach et al. (1957) reported a preliminary study of the effects of gamma radiation on population numbers of Proistoma minuta in culture. Edwards (1969) has investigated the survivorship of adults of several species exposed to gamma radiation. The author is unaware of any reports on the effects of beta radiation on Collembola. The objective of this study is to assess the effects of acute doses of beta and gamma radiation on the survival as well as reproductive ability of a Collembola population in culture.

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## MATERIALS AND METHODS

Groups of 10 to 12 Sinella curviseta were irradiated in 2.5 x 2.5 x 1.3 cm polystyrene boxes with charcoal-plaster of Paris substrates. For beta irradiations, the top of each box was replaced with 0.1-mm-thick

polyethylene and the boxes were inverted on a  $^{90}\text{Sr} + ^{90}\text{Y}$  source (Menhinick) 1966). An exposure schedule for beta and gamma irradiations was established based on a reported contact dose rate of 4950 rads/hr for the beta radiation source (Roti Roti and Kaye 1967). After the irradiations had been carried out, a thermoluminescent dosimetry system became available. Extruded crystals of lithium fluoride (Harshaw Chemical Company TLD-100) 0.5 x 6.0 mm placed in the irradiation boxes indicated a dose rate of 3770 rads/hr. This beta dose rate was used in all calculations since the dosimeters closely approximated the geometry and size of the organisms under study and since the containers for the organisms may have reduced the dose rate slightly.

Adults were exposed to beta radiation for 0, 0.5, 1.0, 2.0, 4.0, and 6.0 hours. Other adults were exposed to  $^{60}\text{Co}$  gamma radiation at 31,950 rads/hr for doses of 0, 2475, 4950, 7425, 9900, 19,800, and 29,700 rads. Two-week-old juveniles were given the same doses of beta and gamma radiation. One day prior to irradiation of eggs, adults were placed in the plastic boxes where they laid eggs on the substrate. Adults were removed, and the eggs were irradiated in situ. Eggs were exposed to 0, 206, 413, 825, 1238, 1650, and 2475 rads of gamma radiation or to 0, 157, 315, 628, 943, 1257, and 1885 rads of beta radiation. Eggs were allowed to hatch in the plastic boxes, and after two weeks the young were transferred to culture jars. Each experiment consisted of three replicates. Cultures were kept at 20°C and fed Fleischmann's yeast. Adults were transferred to new culture jars at monthly intervals, since accumulated waste products cause a reduction in fecundity and large numbers of Collembola are difficult to count accurately. The approximate amount of food consumed and the number of adults, juveniles, and eggs were scored bidaily.  $\text{LD}_{50}$  values were obtained for beta and gamma radiation by regressing mortality in normit values on treatment in rads. Fecundity and egg mortality rates at the various treatment levels were determined by a regression analysis (Model IA) in which the regression line passes through the origin. To determine fecundity rates, the number of eggs per adult was regressed on time in days. Egg mortality is given in terms of percent of eggs laid.

## RESULTS

Survival and feeding of adult Collembola was reduced by all doses of beta or gamma radiation. LD<sub>50</sub> values for beta and gamma radiation and estimates of the relative biological effectiveness of <sup>90</sup>Sr + <sup>90</sup>Y beta radiation are given in Table 9. Day-old eggs showed the greatest sensitivity to radiation and the highest RBE. The eggs of Sinella are 20 times more sensitive to beta radiation and 10.7 times more sensitive to gamma radiation than adults.

Table 9. LD<sub>50</sub> and RBE Values ( $\pm$  S.E.) for Beta and Gamma Irradiation of Adults, Juveniles, and Eggs of Sinella curviseta

	Beta Radiation (rads)	Gamma Radiation (rads)	RBE
Adult LD <sub>50/30</sub>	30,000 ( $\pm$ 833)	14,900 ( $\pm$ 613)	0.497 ( $\pm$ 0.017)
Juvenile LD <sub>50/30</sub>	22,460 ( $\pm$ 703)	12,750 ( $\pm$ 424)	0.568 ( $\pm$ 0.020)
Egg LD <sub>50</sub>	1,493 ( $\pm$ 96)	1,390 ( $\pm$ 83)	0.931 ( $\pm$ 0.024)

An analysis of variance of fecundity and egg mortality rates among irradiated adults indicated there were significant difference between values for month 1 and months 2-4. Rates for months 2-4 were not significantly different from each other and have been grouped for this report. Fecundity rates of irradiated adults were generally reduced by beta (Fig. 14) and gamma (Fig. 15) radiation, but at the lowest dose of beta radiation (1885 rads) fecundity increased by 49% during the first month. The subsequent decline in fecundity of this group during months 2-4 suggests that the initial high rate was due to superovulation. Fertility rates were reduced to zero by the highest doses of either beta or gamma radiation. There was significant recovery during the second month from beta ( $P \leq 0.05$ ) but not from gamma ( $P \geq 0.10$ ) radiation. Mortality of eggs from irradiated adults were high during the first month, but significant recovery did occur from beta ( $P \leq 0.025$ ) and

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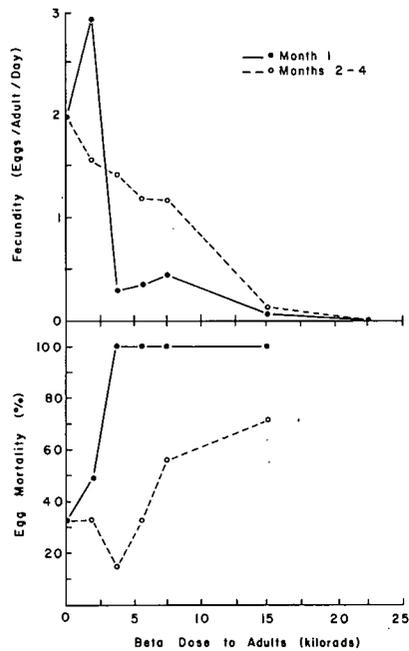


Fig. 14. Fecundity rates (eggs/adult/day) and egg mortality (%) are plotted against dose (rads) of beta radiation to adults. The rates were averaged over month 1 and again over months 2-4.

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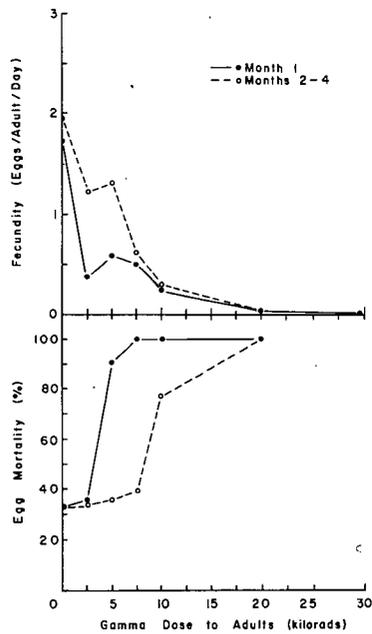


Fig. 15. Fecundity rates (eggs/adult/day) and egg mortality (%) are plotted against dose (rads) of gamma radiation to adults. The rates were averaged over month 1 and again over months 2-4.

gamma ( $P \leq 0.05$ ) radiation. Eggs hatched in six to eight days after oviposition, and juveniles reached maturity in four to five weeks. There was no significant delay in hatching ( $P \geq 0.10$ ) or maturation ( $P > 0.10$ ) with radiation treatment. Fertility of the F1 offspring did not vary significantly ( $P > 0.10$ ) between controls and all other treatments.

Juveniles reached maturity two weeks after irradiation. Initial fecundity rates of beta (Fig. 16) and gamma (Fig. 17) control animals were lower than those previously observed for nonirradiated adults, but these rates increased during the second month. Superovulation was not observed when juveniles reached maturity, and recovery of fecundity rates during months 2-4 was small for beta ( $P \leq 0.10$ ) and for gamma ( $P > 0.10$ ) radiation. Egg mortality was increased by 5655 rads of beta radiation (Fig. 16) but otherwise did not vary significantly with dose ( $P > 0.10$ ). There was no effect of higher doses on egg mortality, since it was masked by the zero fecundity rates. Fertility of F1 offspring of these irradiated juveniles also did not vary significantly ( $P > 0.10$ ) with dose.

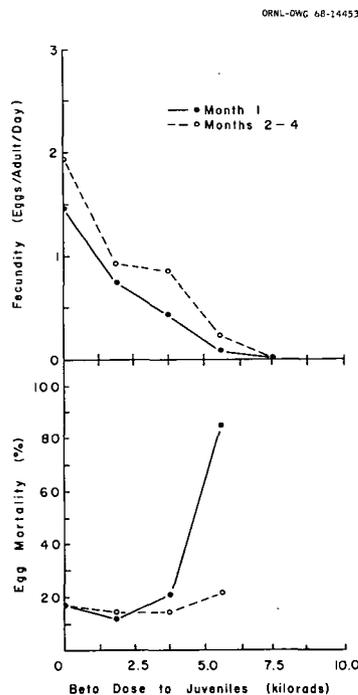


Fig. 16. Fecundity rates (eggs/adult/day) and egg mortality (%) are plotted against dose (rads) of beta radiation to juveniles. The rates were averaged over month 1 and again over months 2-4.

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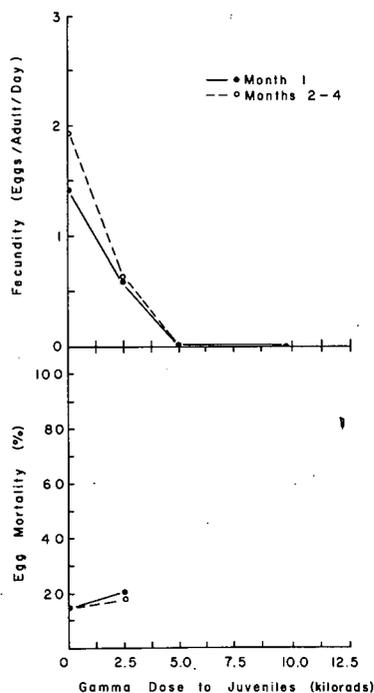


Fig. 17. Fecundity rates (eggs/adult/day) and egg mortality (%) are plotted against dose (rads) of gamma radiation to juveniles. The rates were averaged over month 1 and again over months 2-4.

Irradiated eggs reached maturity 34 days after oviposition. Increased fecundity of adults from these eggs was not detectable in this case. No eggs receiving  $\geq 1650$  rads survived to maturity. Fecundity and egg mortality among the survivors did not vary significantly ( $P > 0.10$ ) from controls.

#### DISCUSSION

Sensitivity of adult *Sinella curviseta* to gamma radiation was similar to that reported by Edwards (1969) for other species of Collembola when survival of irradiated individuals is the observed endpoint. As expected, the juveniles and eggs were more sensitive than adults to gamma as well as beta radiation. Survival values (Table 9) for irradiated adults suggests a relative biological effectiveness, or RBE, of 0.497 for  $^{90}\text{Sr} + ^{90}\text{Y}$  beta radiation. The value is not a true RBE since the beta and gamma dose rates differed, but it is considered to be a close approximation since both exposures were in an acute mode. The slightly higher

RBE for juveniles, 0.568, can be explained in terms of their smaller size and thinner cuticle. Deviation of adult and juvenile RBE values from the typical value of 1.0 probably resulted from the shielding of vital organ systems by the cuticle. The RBE value 0.931 for eggs of Sinella indicates that they have comparatively little protection from beta radiation.

The greatest fluctuations in population numbers during these experiments resulted not from death of irradiated individuals, but from changes in fecundity rates and egg mortality. Fecundity rates of irradiated adults increased by 49% during the first month following exposure to 1885 rads of beta radiation, and egg mortality increased by only 16%. In the field such an effect could cause great increases in the population density of Collembola and shift predator/prey balances. This is an area in which we have very little information. At other doses of radiation, fecundity rates were reduced and egg mortality increased. Although adults receiving  $\geq 3770$  rads of beta or  $\geq 4950$  rads of gamma radiation laid eggs, 90 to 100% of the eggs died and none of the juveniles reached maturity.

The eggs of Sinella curviseta are without question the critical stage in the response of the population to ionizing radiation. Their sensitivity is evident whether the parents or the eggs themselves are irradiated. It seems reasonable to assume that this is true for other populations of Collembola. The ecological significance of high egg sensitivity to a Collembola population may be masked, however, by seasonal cycles in reproduction. Population maxima are reached by different species in every season. Milne (1962) reports maxima for Onychiurus procampatus in the summer, Isotoma viridis in early summer, and Folsomia quadrioculata in June and December. Knight (1967) reports maxima for Tomocerus flavescens in the summer and T. lamelliferus in the spring and summer. Ford (1935, 1937, 1938) reports population maxima of Collembola in winter; Strenzke (1949), autumn; and Van der Drift (1951), summer. If adults of a species are not in or are just entering a reproductive phase when irradiated, sensitivity of eggs may not be an important factor in population survival. To another population a dose insufficient to kill adults could collapse the population by reducing fecundity rates and increasing egg mortality.

## HONEY BEE IRRADIATION STUDIES

A. F. Shinn

The ultimate goal of these studies is to assess the effect of various doses of ionizing radiation on the pollinating behavior of colonies of honeybees. Changes in such behavior could have important consequences for postattack recovery of fruit and vegetable agriculture as well as the general wild landscape.

In the first stage of this project, queen bees of known genetic composition were substituted for the original queens in ten colonies of honeybees to convert all colonies from the Carniolan-Caucasian-Italian (CCI) strain to the same genetic constitution (Dadant hybrid GF). We investigated the effects of radiation on the longevity of lab-caged bees and on the daily pollen collection by irradiated colonies of bees in the field.

Four series of irradiations were conducted using samples of 150 bees from field hives. Bees were transferred directly from the hives to cylindrical screen-wire cages, irradiated\*, and maintained in cages until death occurred. In Series I through Series III (Fig. 18), the irradiated bees and controls were kept at normal internal conditions of the hive:  $34^{\circ}\text{C}$  ( $93^{\circ}\text{F}$ ) and in darkness. The change in mean longevity from controls was statistically different for all doses except the lowest one, 50 rads of fission fast neutron radiation. The reduction in longevity produced by 4250 rads of neutron radiation was close to that given by 5000 rads of gamma radiation. This implies an RBE of 1 for this insect, which is similar to that obtained for vertebrates when using acute doses. Doses of 5000 and 15,000 rads ( $^{60}\text{Co}$  gamma), respectively, produced the same reduction in life span of bees. In Series IV, honey bees which were given 5000 rads of beta, or gamma, or neutron radiation, and were maintained at  $21^{\circ}\text{C}$  ( $70^{\circ}\text{F}$ ) showed no significant reduction in life span, although in Series I and III bees given 5000 rads of  $^{60}\text{Co}$  gamma radiation and kept at  $34^{\circ}\text{C}$  suffered a reduction of 22% in life span.

Five entire colonies of GF bees were given 5000 rads\* of  $^{60}\text{Co}$  gamma radiation in the Large Animal Irradiator of the UT-AEC Agricultural

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\* All irradiations of the study were completed in less than 80 min.

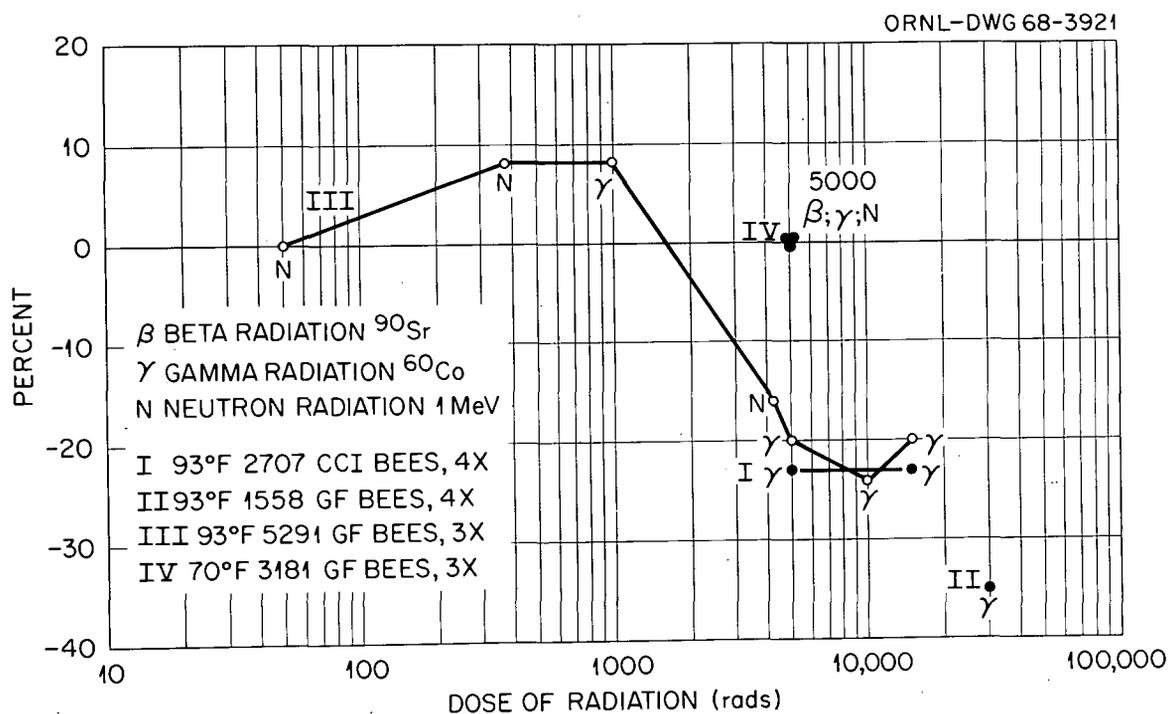


Fig. 18. Percent change from controls in mean longevity of lab-caged irradiated honey bees.

Research Laboratory. The weights of daily pollen collections of the five irradiated hives and of five control hives at the same site were recorded one week before and for two weeks following irradiation. On the basis of laboratory tests of longevity, a slight reduction of the lifetime of individual bees was the only expected result--thus presumably allowing time to obtain good estimates of any changes in pollen collections. The actual result was the elimination of all the irradiated colonies as functional social units within two weeks. At the end of three weeks postirradiation only 200 of the original 87,000 irradiated adult bees remained alive along with a few male pupae; all other individuals of all stages of development had died.

The changes in pollen collections are given in Table 9. The colonies to be irradiated averaged, in the week prior to irradiation, 61% as much pollen as the intended controls. However, within a week following irradiation they collected only 28% as much as the controls;

within two weeks postirradiation they collected only 7%; and by the beginning of the third week, collected none.

Table 9. Grams of Pollen Collected Daily by Colonies of GF Worker Honey Bees Irradiated on September 6, 1967

	Preirradiation	Postirradiation		
	8/28 - 8/31	9/9 - 9/15	9/19 - 9/20	9/21
Irradiated Colonies (5)	13.7	7.0	0.8	0
Nonirradiated Colonies (5)	22.6	24.6	11.5	5.8

In the second stage of this project, twenty acres of waste land on Burial Ground 4 were sown to three species of clovers\* to provide bee forage from May through September. Forty colonies of bees were moved to this site and all were converted to special cordovan hybrids which are visually different from any bees of this region. Inspection of the colonies at the end of May showed that they were flourishing and had gotten adequate nectar and pollen supplies for brood rearing. Trials to assess daily flight activity and daily pollen collection indicate that automated sampling is highly desirable. A greatly simplified pollen trap is under trial and a trap to collect dead bees from the hive is under construction. Colonies will be given doses of 500, 1000, and 2000 rads of <sup>60</sup>Co gamma radiation in the UT-AEC Large Animal Irradiator. The effects of irradiation will be assessed by measuring daily flight activity, pollen collection, and mortality of the colonies.

\*White Sweet Clover, Hubam variety, Melilotus alba; White Dutch Clover, Trifolium repens; Crimson Clover, Trifolium incarnatum.

## REFERENCES

- Auerbach, S. I., D. A. Crossley, Jr., and M. D. Engelmann. 1957. Effects of gamma radiation on Collembola population growth. *Science* 126:614.
- Baker, C. E., P. B. Dunaway, and S. I. Auerbach. 1968. Measurement of metabolism in cotton rats by retention of cesium-134. Oak Ridge National Laboratory Report, ORNL-TM-2069, 48 pp.
- Ballou, J. E., and R. C. Thompson. 1958. Metabolism of cesium-137 in the rat: Comparison of acute and chronic administration experiments. *Health Physics* 1:85.
- Brown, S. L. 1965. Disintegration rate multipliers in beta-emitter dose calculations. Stanford Research Institute Project Mu-5116.
- Edwards, C. A. 1969. The effects of gamma irradiation on populations of soil invertebrates. Proceedings of the Second National Symposium on Radioecology. Ann Arbor, Michigan (in press).
- Fish, B. R. et al. 1966. Aerosol Physics in Health Physics Division. Annual Progress Report, ORNL-4007.
- Ford, J. 1935. The animal population in a meadow near Oxford. *J. Animal Ecology* 4:195-207.
- \_\_\_\_\_. 1937. Fluctuations in natural populations of Collembola and Acarina. *J. Animal Ecology* 6:98-111.
- \_\_\_\_\_. 1938. Fluctuations in natural populations of Collembola and Acarina. Part 2. *J. Animal Ecology* 7:350-369.
- Hale, W. G. 1965. Observations on the breeding biology of Collembola (II). *Pedobiologia* 5:161-177.
- Hayes, R. L., J. E. Carlton and W. R. Butler, Jr. 1963. Radiation dose to the human intestinal tract from internal emitters. *Health Physics* 9:915-920.
- Hood, S. L., and C. L. Comar. 1953. Metabolism of cesium-137 in rats and farm animals. *Arch. Biochem. and Biophys.* 45:423.
- Kaye, S. V., and P. B. Dunaway. 1962. Bioaccumulation of radioactive isotopes by herbivorous small mammals. *Health Physics* 7:205-217.
- Kereiake, J. G., D. D. Ulmer, A. T. Krebs, and T. D. Sterling. 1961. Cesium-137 retention and distribution in X-irradiated rats. USAMRL Report No. 504, Fort Knox, Kentucky, 12 pp.

- Knight, C. B. 1963. The microstratification of Tomocerus (Collembola) in a Beech-Maple forest in North Carolina. *Amer. Midl. Natur.* 70:187-196.
- Lane, W. B. 1968a. Fallout simulant development: Temperature effects on the sorption reactions of strontium on feldspar, clay and quartz. Stanford Research Institute Project No. MU-6503.
- \_\_\_\_\_. 1968b. Response of bean plants to beta radiation. Stanford Research Institute Project No. MU-6358.
- LeRoy, G. V., J. H. Rust, and R. J. Hasterlik. 1963. The consequences of ingestion by man of real and simulated fallout. Argonne Cancer Research Hospital, Illinois. 34 pp.
- Menhinick, E. F. 1966. <sup>90</sup>Sr plaques for beta radiation studies. *Health Physics* 12:973-979.
- Milne, S. 1962. Phenology of a natural population of soil Collembola. *Pedobiologia* 2:41-52.
- Mraz, F. R., M. LeNoir, J. J. Pinajian, and H. Patrick. 1957. Influence of potassium and sodium on uptake and retention of cesium-134 in rats. *Arch. Biochem. and Biophys.* 66:177-182.
- \_\_\_\_\_, and H. Patrick. 1957. Factor influencing excretory patterns of cesium-134, potassium-42, and rubidium-86 in rats. *Proc. Soc. Exptl. Biol. Med.* 94:409.
- Roti Roti, J. L., and S. V. Kaye. 1967. Calibration of <sup>90</sup>Sr + <sup>90</sup>Y plaques for irradiating insects. Oak Ridge National Laboratory Report, ORNL-TM-1921.
- Strenzke, K. 1949. Ökologische Studien über die Collembolengesellschaften feuchter Böden Ost-Holsteins. *Arch. Hydrobiol.* 42:201-203.
- Thomas, R. G., and R. L. Thomas. 1967. Long-term whole-body retention after high-level cesium-137 administration to rats. Lovelace Foundation for Medical Education and Research. Albuquerque, New Mexico, AT(29-2)-1013.
- Van der Drift, J. 1951. Analysis of the animal community in a beech forest floor. *Tijdschr. Entomol.* 94:1-168.
- Wasserman, R. H., and C. L. Comar. 1961. The influence of dietary potassium on the retention of chronically ingested cesium-137 in the rat. *Radiation Res.* 15:70-77.
- Whicker, F. W. 1968. Sixth Technical Progress Report. Dept. of Radiology and Radiation Biology. Colorado State University, Fort Collins, Colorado, AT(11-1)-1156. 31 pp.

Wong, P. W. 1967. Initial study of effects of fallout radiation on simple selected ecosystems. United States Naval Radiological Defense Laboratory, TR-68-11.

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