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RESEARCH ON REMOVING RADIOACTIVE FALLOUT FROM FARMLAND

JAMES, P.E., MENZEL, R.G.   1 OF 1

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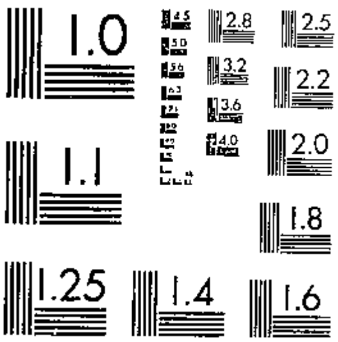

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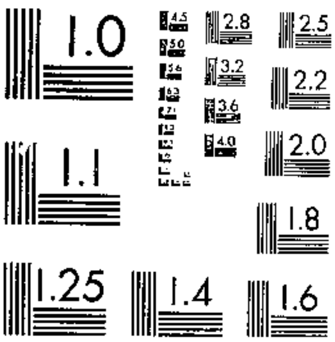

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Research On Removing Radioactive Fallout From Farmland

Technical Bulletin No. 1464

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ABSTRACT

A research project on the removal of radioactive fallout from farmland was conducted under AEC contract AT(49–7)–1527 cooperatively with the U.S. Department of Agriculture.

Methods were devised to simulate both wet and dry fallout. Distribution methods of removal were also devised. The radioactivity eliminated from farmland by removal of various contaminated crops was measured. Following this, the effectiveness of removing contaminated top soil was determined.

In a related study, the contaminated soil was treated with a concrete or asphalt coating before removal. Road graders, bulldozers, rotary and elevating scrapers as well as mechanized streetsweepers were used to remove the contamination.

Further studies involved burying contaminated soil 3 feet deep with a large plow and measuring the uptake of radioactivity in various crops planted over it. Factors controlling uptake of radioactivity were compared.

Key words: Decontamination farmland, Radioactivity, Uptake of radioactivity, Fallout preparation, Fallout distribution.

CONTENTS

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Research on Removing Radioactive Fallout From Farmland

By P. E. JAMES, *agricultural engineer, Physical Control Laboratory, Northeastern Region,* and R. G. MENZEL, *soil scientist, Water Quality Laboratory, Southern Region, Agricultural Research Service*

INTRODUCTION

Farmland could become contaminated as a result of accidents in transporting radioactive materials, mishaps in using reactors, or radioactive fallout from the atmosphere. Such incidents are expected to be rare. Nevertheless, it might be necessary to remove the contaminants from the land in order to reduce the radiation hazard in the area or to prevent the radioactive material from entering food or water.

Because effective decontamination requires considerable effort, it is important to choose suitable equipment and to use it properly. Each contamination incident would present different problems. No single decontamination method would be best for all occasions. Consequently, various means of decontamination should be considered.

This publication presents research on the decontamination methods of farmlands. The primary objective of this research was to determine the effectiveness of farm machinery, earth-moving machinery, and mechanical streetsweepers under various operating conditions in removing radioactive contamination from farmland. In addition, some research was done with tillage operations to determine whether crops would take up less radioactive material if they were left on the surface or plowed very deeply before planting.

The place of decontamination in treating contaminated soils is discussed in U.S. Department of Agriculture Handbook 395, "Treatments For Farmland Contaminated With Radioactive Material."[1] Various alternatives, including soil management practices that reduce uptake of radioactive materials by crops, are considered in the handbook. Their effectiveness and feasibility with different soil and crop conditions are compared.

[1] Available for 20 cents from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

EXPERIMENTAL PROCEDURES

The effectivenesss of each decontamination method was determined by measuring the amount of a tracer on the ground before and again after decontamination. Usually, the tracer was prepared and distributed to simulate radioactive fallout particles. Sometimes it was sprayed as a solution onto the soil or crop surface. In some tests flourescent glass spheres were used as a tracer[2] and examined in the dark with ultraviolet light; however, it was found that radioactive tracers were easier to measure accurately.

The series of experiments is summarized in table 1. Each experiment is coded with an alphabetical letter which identifies it in the sections on description of machinery and results of tests. The soil types, individual plot size, and radioactive tracer material for each experiment are given.

DESCRIPTION OF DECONTAMINATED LAND

Most of the decontamination methods were tested on two soil types, a Sassafras sandy loam at the Agricultural Research Center, Beltsville, Md., and an Elkton silt loam at the Plant Industry Station in Beltsville. Both soils were used because the effectiveness of some methods, particularly those involving earthmoving or sweeping, were expected to depend upon soil texture. Studies of plant uptake of radioactivity after deep plowing were made on Pullman silty clay loam at Bushland, Tex.

The experimental areas were enclosed with a dike which prevented runoff of the radioactive material during tests. The enclosed areas were 200 feet by 250 feet at Beltsville and 200 feet by 2,000 feet at Bushland.

The sizes of the plots varied from year to year depending on the nature of the test. The smallest plots were 6 feet by 16 feet, while the largest plots were 20 feet by 200 feet. Large guard strips or drive areas were left between plots to minimize drift of radioactivity from one plot to another during contamination or decontamination and to allow an adequate approach to each area for the decontamination machinery to attain normal operating conditions. The length of the approach at the ends of the plots was determined by the size of the machinery to be tested. The guard strips beside the plots were at least 10 feet wide. In all research, replicate plots were tested.

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[2] James, P. E., and Wilkins, D. E. AN EVALUATION OR RADIOSOTOPE AND FLUORESCENT TRACER TECHNIQUES. Amer. Soc. Agr. Engin. Trans. 8(2): 199–201, 207, 1965.

TABLE 1.—*Summary of decontamination and land management experiments*

Experiment	Removal method	Soil type	Plot size	Radioactive tracer material
A	Removal of sod, mulch, and green crops	Elkton silt loam	6′ x 30′	Ba-140 spray.
B	Road grader scraping of asphalt-coated rough or smooth soil.	Elkton silt loam and Sassafras sandy loam.	6′ x 24′	P-32 spray.
C	Various scrapers with and without irrigation	----do	6′ x 16′	Ba-140 glass spheres.
D	Farm machinery removal of full-grown rye, rainfall simulation.	----do	12′ x 16′	Do.
E	Baler removal of bermudagrass and various scrapers with and without irrigation.	----do	12′ x 16′	I-131 glass spheres.
F	Vacuuming of pastureland, followed by scraper, direct-cut harvester, or flail.	----do	12′ x 16′	Do.
G	Direct-cut harvester, flail chopper and combine—soybeans.	----do	12′ x 80′	Do.
H	Combine, vacuum with pulverized soil surface—wheat.	----do	12′ x 80′	Rb-86 glass spheres.
I	Corn chopper, picker and sheller, and concrete slurry.	Sassafras sandy loam	36′ x 80′	Ba-140 glass spheres.
			12′ x 30′	Do.
			12′ x 80′	Do.
J	Logistics of decontamination	----do	20′ x 200′	None.
K	Placement and uptake of surface	Pullman silty clay loam	30′ x 20′	Au-198 spray.
			30′ x 60′	Sr-85 spray.
L	Mechanical sweeping of sparse meadow	Elkton silt loam and Sassafras sandy loam.	30′ x 20′	Au-198 spray.
M	Uptake of surface contamination	----do	29′ x 40′	Sr-85 spray.

PREPARATION OF RADIOACTIVE TRACERS

The radioactive tracer nuclides were chosen on the basis of their life, type of radiation emitted, and chemical properties. A suitable tracer must last long enough to give a significant count when decontamination is complete, but not so long that it interferes with future experiments in the field. Usually, nuclides emitting gamma radiation were used, because they could be counted in the field without significant losses due to absorption in vegetation or soil.

Nuclides with low-energy gamma rays were preferred in order to decrease the radiation hazard and to improve collimation in the field detector. Finally, it was necessary to choose a nuclide which would go into solution when a spray was used. A soluble nuclide could not be used on particles because it washes off. Occasionally, preferred radionuclides were not available at the time they were needed.

The following radionuclides were used: barium-140, phosphorus-32, iodine-131, rubidium-86, gold-198, and strontium-85.

Barium-140, a gamma radiation emitter, was applied during early tests; as a solution or baked on small glass spheres. Phosphorus-32, a beta-energy emitter, was used for one season. Iodine-131, a gamma emitter, was precipitated as silver iodide and baked on small glass spheres which were then used as a tracer. The use of iodine was discontinued because it leached into the soil. Rubidium-86 was used during one test; however, this proved unsatisfactory because the accompanying beta energy created an unnecessary hazard. Gold-198, a gamma radiation emitter, was used as a tracer and found to be satisfactory. During the plant uptake studies, either phosphorus-32 or strontium-85 was used as a tracer, because they are long-lived enough to persist throughout the growing season.

When the physical form was not important, the radionuclide was applied as a tracer in a water solution through the use of a shielded sprayer. Solution tracers were used to determine plant uptake of radioactivity, because a solution would be more available to the plants.

A dust tracer was used to simulate the movement of particulate fallout. This dust was prepared by fixing a radionuclide on glass spheres 18 to 40 microns in diameter. The glass spheres were washed with distilled water to remove most of the soluble cations. Then a solution containing either barium-140 or iodine-131 was added to the moist glass spheres. The spheres were stirred while the solution was being added in order to produce a uniform distribution of the radionuclide.

With iodine-131, a few milliliters of $AgNo_3$ were added to precipitate silver iodide on the surface of the spheres. Stirring continued during drying, so that after drying the spheres would not be baked together. They were kept dry in an oven until used in the field. The glass spheres containing rubidium-86 were prepared by the Minnesota Mining and Manufacturing Co.

DISTRIBUTION OF RADIOACTIVE TRACERS

Radionuclides in solution were applied with a sprayer built for this purpose (fig. 1). The isotope sprayer consisted of a compressed air cylinder which supplied air through a pressure regulator into the top of a lead-shielded reservoir containing the isotope.

From the reservoir, the isotope went through a solenoid-controlled valve to a spray boom having flat spray-pattern agricultural nozzles, 20 inches apart. To minimize the exposure of personnel when handling the solution, small volumes of solution were used. The boom was operated 18 inches above the ground. The solenoid valve was opened and closed by the operator of the tractor on which the sprayer was mounted. Spray drift was minimized

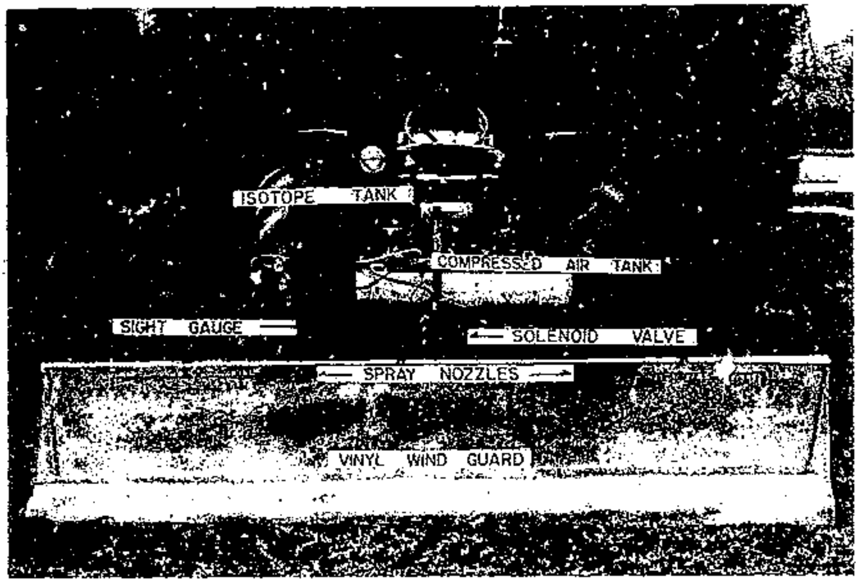

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Figure 1.—Shielded sprayer for distributing simulated fallout.

by attaching a plastic skirt to the sprayer boom and spraying when there was little wind.

The particle-fallout distributor consisted of a bottomless aluminum box 6 feet wide and 8 feet long. It was 4 feet high with a vinyl skirt extending down 15 inches. The hem of this wind-diverting skirt was weighted with ¼-inch-diameter steel balls. In early work, the box was pulled on wheels; later, it was mounted in a frame attached to a tractor (fig. 2).

The glass spheres simulating fallout were placed in a 6-inch-diameter, 10-inch-long canister. One-sixteenth-inch-diameter holes were located every one-half inch around the canister, 1 inch below the lid. Compressed air introduced into the canister ejected the spheres. The distribution pattern below the box was measured by letting the 18- to 40-micron glass spheres float down on 2- by 2-inch-paper swatches placed in a grid pattern below the box.

The average variation in weight of spheres deposited at different locations was less than $\pm$ 3 percent. However, the flow of beads diminished as the ejection proceeded. This was eliminated by placing a smaller cylinder inside the large one and injecting compressed air at its base (fig. 3).

MEASUREMENT OF RADIOACTIVE TRACERS

Two methods of measuring radioactivity were used: (1) The land surface of soil profile was scanned on the plots by passing a

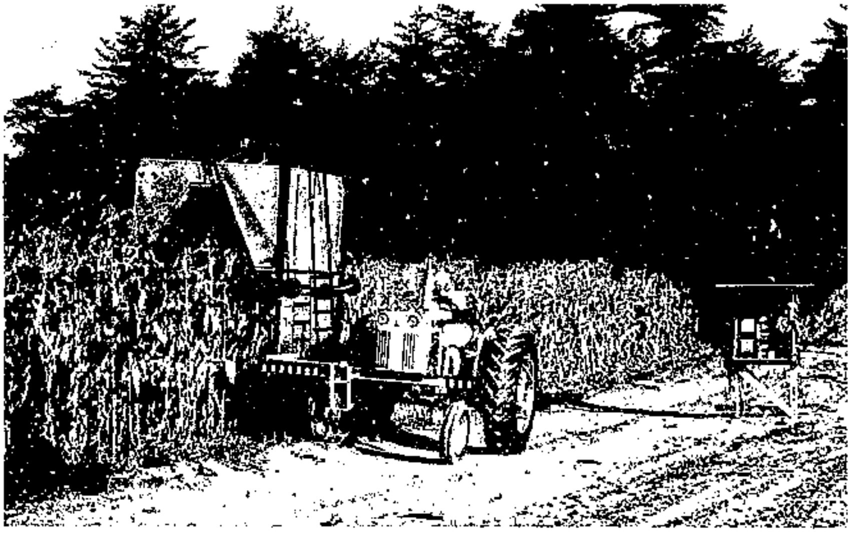

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Figure 2.—Radioactive particle distributor.

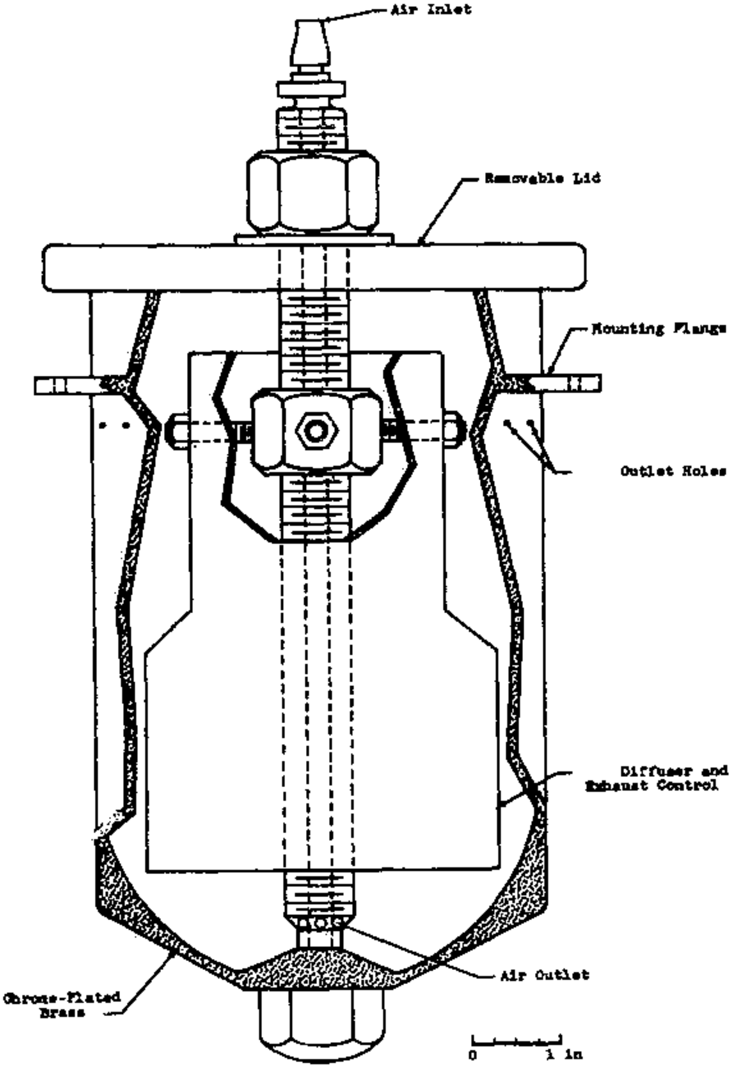

Figure 3.—Canister used to distribute radioactive particles uniformly.

field monitor over it; or (2) vegetation or soil samples were removed and taken to the laboratory for measurement.

The field monitor consisted of a transistorized, integrating, count-rate meter with a detecting probe consisting of a sodium iodide crystal, matching photomultiplier tube, and preamplifier.[3]

[3] James, P. E., and Menzel, R. G. TRANSPORTABLE FALLOUT DETECTOR MEASURES RADIOACTIVITY ON FARMLAND. Agr. Engin. 42(6): 306–307, 1961.

The probe was mounted 6 feet above ground. It was shielded with 2 inches of lead to minimize radiation from all directions, except beneath the detector. The shield admitted radiation primarily from a circle 6 feet in diameter at ground level.

A radioassay was made by first measuring the background radiation level with no radioactive materials under the detector. The material upon which a radioassay was to be made was then placed under the shielded detector and the radiation measured for several minutes.

In addition to making measurements while the detector was stationary, scans were made by moving the carriage bearing the detector over the area to be tested. The boom upon which the carriage rolled was mounted on a tractor (fig. 4). The levels of radioactivity were measured at 12 or 16 locations before and again after decontaminating a plot. This method was used mainly on plots that were decontaminated by removing a crop.

In some later work, the radiation signal was sent through a single channel analyzer and ratemeter into one axis of an X-Y recorder. The probe location signal was sent to the other axis. This gave a graphic record of radionuclide distribution on the ground surface. The spectrometer and X-Y recorder were carried in a vehicle (fig. 5), to permit movement in the field with the tractor-mounted detector.

The scanning technique gave a good comparison between the radioactivity before and after decontamination; however, it failed

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Figure 4.—Radioactivity detector mounted on boom attached to tractor.

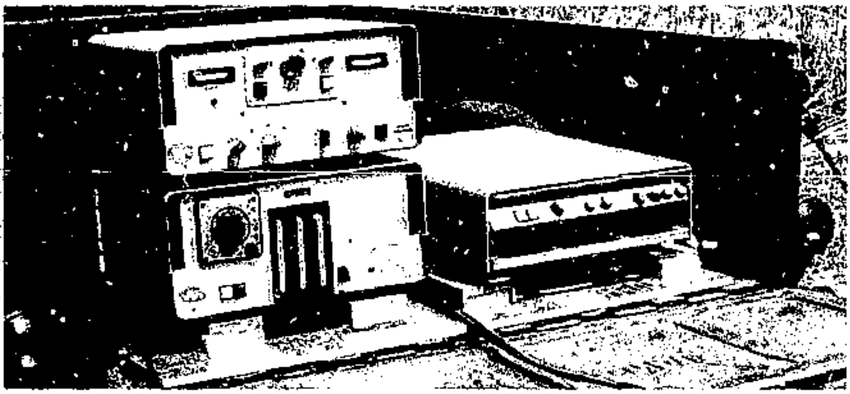

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Figure 5.—Monitoring equipment for radioactivity detector.

to define a boundary of radioactivity. This was because a circular area was being scanned. As the circle of radiation detected by the probe advanced over a boundary of contamination, the chart would show a gradual increase in activity rather than the boundary line which existed. It was also difficult to shield the scanning detector from scattered radiation.

In an experiment with plant uptake of radioactivity after various tillage treatments, the distribution of the radionuclide in the soil profile was measured. In addition, the radioactivity in plant samples was determined at various times during the growing season.

The distribution of the radionuclide in the soil profile was observed from core samples 2 inches in diameter and 2 inches deep which were taken on one side of a trench. A backhoe was used to dig the trench perpendicular to the direction traveled by the plow or other tillage machinery. The samples were taken across several furrows on a 6-inch-square grid pattern to a depth of 48 inches on deep-plowed plots, and on a 4-inch-square grid pattern to a depth of 16 inches on other plots (fig. 6). The soil samples were pressed into 3-inch-diameter cans, which were placed on a shielded probe connected to a gamma ray spectrometer.

In some experiments, soil core samples were used to determine how much radioactivity was removed by decontaminating. Ten cores were collected from randomly located points on the plots before and after decontamination. The cores were mixed thoroughly in a paper sack, and the amount of radioactivity in a representative sample was measured with a gamma ray spectrometer or an end-window Geiger-Mueller tube. After measuring the

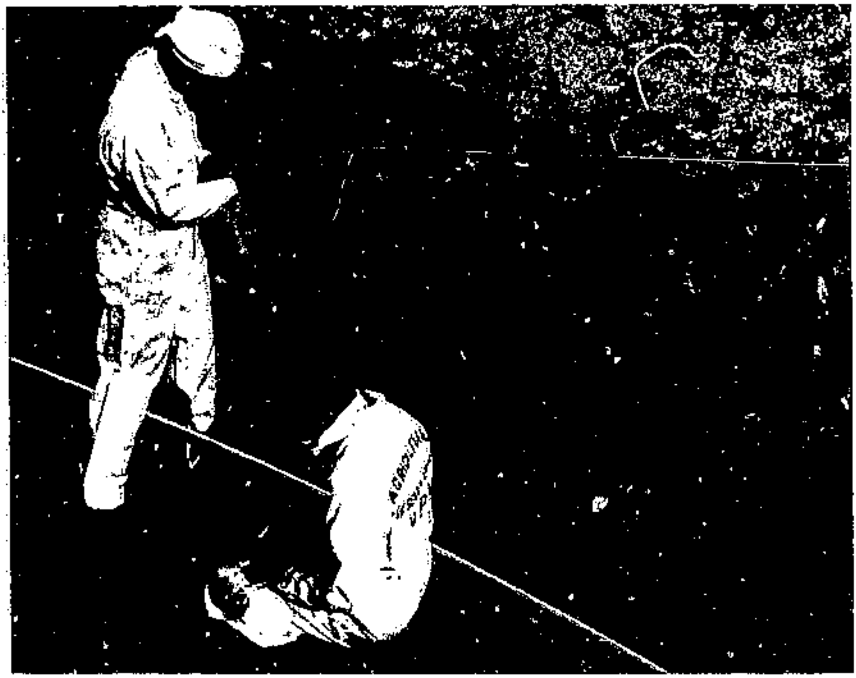

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Figure 6.—Removing samples on a grid pattern from the soil profile.

radioactivity in each sample, background radiation was subtracted and a decay factor applied to normalize the measurement.

After drying and grinding the plants, samples were measured for concentrations of radionuclides so that representative subsamples could be taken. The subsamples were dryashed. The ash was pressed into a vial which was then inserted into the well of a scintillation crystal for detecting gamma rays. When greater amounts of radionuclides were present in the samples, it was unnecessary to ash them. The gamma-ray energy was recorded with a 400-channel pulse-height analyzer. Count rates were corrected for background, for the presence of varying amounts of potassium-40 in the samples, and for counting efficiency, which varied with the height of the sample in the vial.

DESCRIPTION OF MACHINERY

With few exceptions, machinery that would be readily available for treatment of farmland was used. To determine how effectively a farm could be decontaminated by using machinery already present, tests were conducted using common types of farm machinery. In most circumstances, disposal of crops was so ineffective in removing fallout that further decontamination by removal of soil would have been necessary. Accordingly, the applicability of various types of earth-scraping equipment was determined.

The effectiveness of applying coatings of asphalt or cement on contaminated surface soil and then removing the coating with the radioactivity imbedded in it was tested. This was followed by research to determine how much radioactivity was taken into plants when the contaminated surface soil was buried at various depths. Identification of the models and a brief description of the machinery used in the various phases of the research follows.

Crop-Harvesting Machines

Conventional crop-harvesting machines were used in several experiments in removing a contaminated crop. All machines were powered by a power take-off from either a 35- or 50-horsepower general-purpose tractor. They included the following:

Mower with 6-foot sickle (Experiments A and D)
Side-delivery hayrake (Experiments A, D, E, H, and I)
Flail-type forage harvester (Experiments A, F, and G)
Hay Baler, P.T.O.-operated (Experiments D and E)
Cylinder-type, grass-forage harvester (Experiments D, F, G, and I)
Pull-type,general-crop combine (Experiments D, G, H, and I)
Flail-type forage harvester (Experiment H)
Cornpicker head on forage harvester (Experiment I)

These machines were operated normally, except that the flail-type forage chopper in Experiment A was set at a low height to pick up some surface soil. The side-delivery rake in Experiment I was used to rake off pieces of concrete that were coating the soil surface. Neither of these attempts at unconventional use was successful.

Surface Soil and Sod-Removal Machines

In several experiments, a sod cutter and various kinds of scrapers removed contaminated surface soil. The machines were:

Sidewalk roller (Experiment B).
Corrugated roller-seeder pulled by tractor (Experiment B).
Asphalt sprayer mounted on tractor, designed, and built by researchers (fig. 7) (Experiment B).
Sod cutter, 12 inches wide (Experiment A).
Motor grader, 7-foot blade (Experiments B, D, G, I, and J).

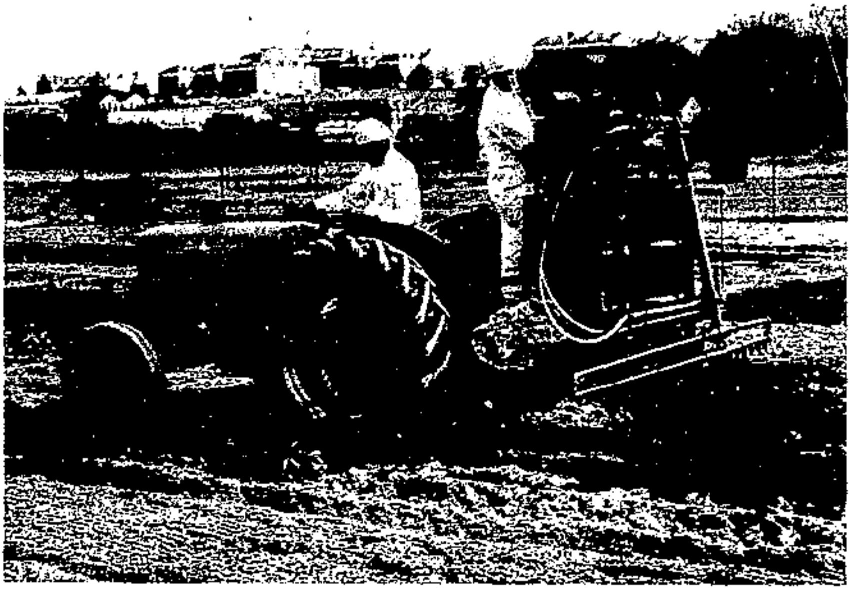

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Figure 7.—Asphalt sprayer.

Bulldozer, 8-foot blade (Experiment C).
Panscraper, 8-cubic-yard capacity (Experiment C).
Panscraper, 1-cubic-yard capacity, pulled by tractor (Experiment C).
Motor grader, 12-foot blade (Experiments E, F, and J).
Rotary scraper, 6.5-cubic-yard-capacity, pulled by tractor (fig. 8) (Experiment E).
Elevating scraper, 4.5-cubic-yard capacity, pulled by 50-hp. tractor (fig. 9) (Experiment E).
Constant draft scraper mounted on 3-point hitch of tractor (Experiment G).
Front-end loader on tractor (Experiments I and J).

Mechanized Streetsweepers

Vacuum cleaning or brush sweeping of the contaminated surface soil was tried in several experiments with the following self-propelled streetsweepers:

Motorized vacuum sweeper with centrifugal fan, no brooms (fig. 10) (Experiments F and H).
Streetsweeper with steel wire brush, sweeping debris onto

conveyor belt which delivers to hopper (fig. 11) (Experiment L).

Tillage Machinery

The primary tillage machines listed below were used to obtain deep or thoroughly mixed shallow placement in Experiment K, or normal plowing placement in Experiment M.

In Experiment M, we also used a special planter for planting with minimum disturbance of the contaminated surface soil.

Rotary tiller.

Moldboard plow, capable of 36-inch-deep furrow (fig. 12) pulled by two track-type tractors in tandem.

Pasture drill, especially constructed (fig. 13).

The 36-inch-deep moldboard plow was modified to improve the efficiency of burying surface contamination. A scraper blade, supplied with the plow was used to push contaminated surface soil from the unplowed land into the open furrow behind the moldboard. A retainer panel was attached to the moldboard to keep the turned soil from falling into it. Hydraulic cylinders were installed to control the depth of both wheels independently.[4]

[4] James, P. E., and Wilkins, D. E. DEEP PLOWING—AN ENGINEERING APPRAISAL. Paper No. 69-152, presented at the meetings of the American Society of Agricultural Engineers, Purdue Univ., Lafayette, Ind., June 22-25, 1969.

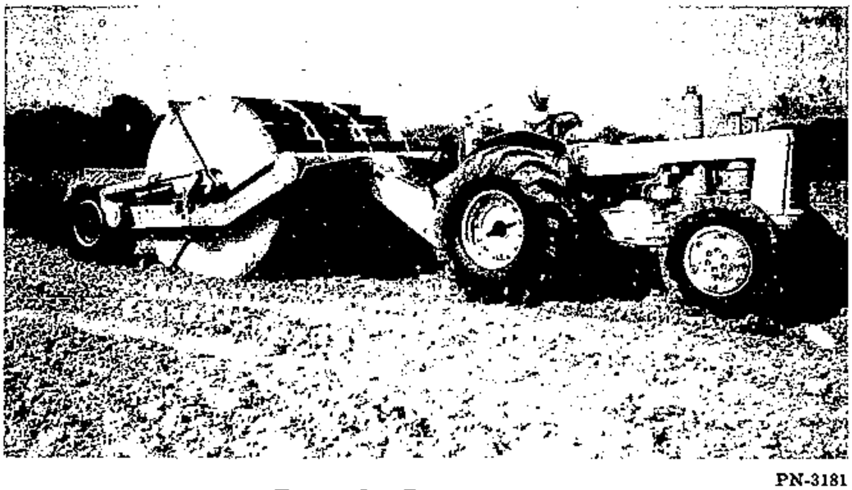

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Figure 8.—Rotary scraper.

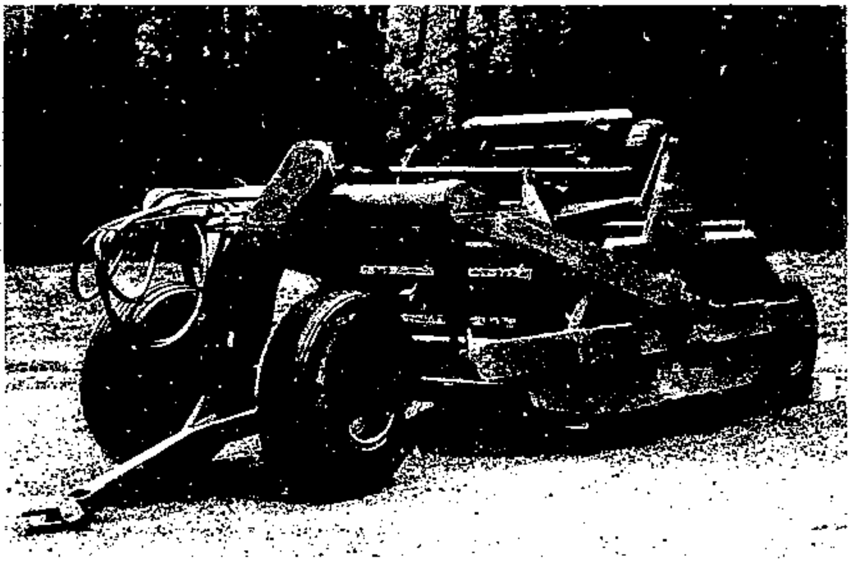

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Figure 9.—Elevating scraper.

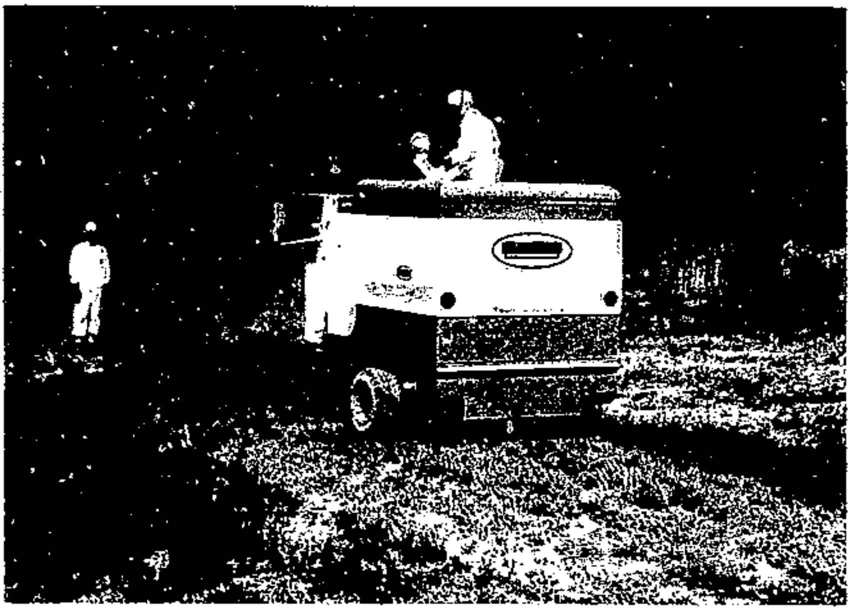

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Figure 10.—Motorized vacuum sweeper.

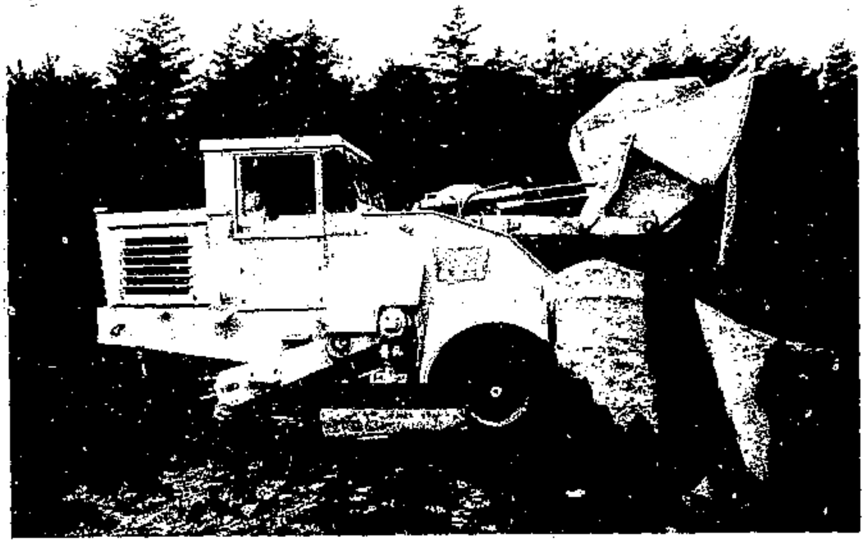

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Figure 11.—Rotating-brush, mechanical streetsweeper in unloading position.

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Figure 12.—Plow used for deep plowing.

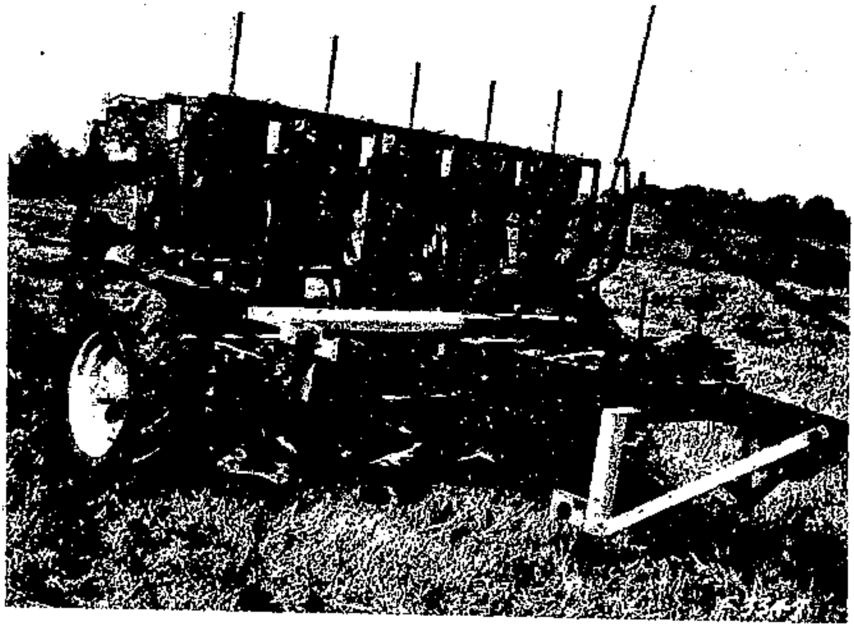

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Figure 13.—Pasture drill.

Results of Decontamination

To determine how much fallout decontamination might be accomplished by removing fallout-covered vegetation, Experiment A was conducted (table 2). The mulch was good-quality wheat straw, which had been spread and anchored 2 weeks before the plots were contaminated. The bluegrass sod used for sod-removal studies had been transplanted onto the plot areas previously. Soybeans and sudangrass were approximately 12 inches high.

Since the contaminant was sprayed in a small amount of solution, it was expected that most of the material that fell on the vegetation would be retained. Later research showed that the form of fallout greatly affected its retention on mulch. For comparison, some results with dry fallout on mulch from Experiment A are shown in table 2. The fallout deposited on the mulch in the form of a spray adhered more tightly than that deposited in the form of small particles. The droplets evaporated on the mulch, leaving a deposit of radioactivity adhering to the mulch. The dry particles sifted through the mulch and fell to the ground below as the mulch was picked up. This sifting was much more pronounced with a light mulch.

The amount of fallout removed with mulch depended on the thickness of the mulch as well as on the nature of the fallout when it was deposited on the mulch. More contamination was removed with thick mulch than with thin.

Removing sod was effective but time consuming. The radiation hazard was also greater because it was necessary to carry the contaminated sod by hand. While the flail seemed fairly effective in removing fallout from soybean-covered land, it clogged quickly and raised a cloud of dust that was redistributed over the surrounding terrain (fig. 14). Mowing and collecting soybeans or sudangrass removed less than 40 percent of the radioactivity.

To determine how much fallout contamination could be removed from farmland by scraping off surface soil, Experiment B was conducted (table 3). A light road grader with a blade 7 feet wide was used for scraping. Before contamination, the soil surface was given different roughness by plowing, disking, or preparing a seedbed. After contamination, some of the plots were smoothed by rolling with a sidewalk roller on the sandy loam and with a corrugated roller on the silt loam. The asphalt was then sprayed at the rate of 1 gallon of water emulsion per square yard and allowed to dry before scraping.

Scraping was quite effective in decontaminating the plots with a prepared seedbed. Each pass with the grader removed about 2 inches of the Sassafras sandy loam with rolling and five-eighths of

TABLE 2.—*Experiment A: Reduction of radioactivity by removing vegetation*

Vegetation	Sassafras sandy loam	Elkton silt loam	
	Dry fallout	Wet fallout	Dry fallout
	Percent	*Percent*	*Percent*
Raking mulch, 10 tons per acre		100	----------
Raking mulch, 5 tons per acre	81	97	51
Raking mulch, 2 tons per acre	41	94	28
Removing sod		94	----------
Flail soybeans and soil		89	----------
Flail sudangrass and soil		60	----------
Mowing-collecting soybeans		37	----------
Mowing-collecting sudangrass		29	----------

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Figure 14.—Radioactive dust around flail chopper.

an inch with no rolling. On Elkton silt loam, each pass removed about 1⅜ inches when not rolled and 1⅛ inches when rolled.

Rolling the land seemed to inbed or bury the contaminated surface soil in the low areas. This was true, especially with the sidewalk roller, because it tended to tilt. Contrasted to this, light rolling was of some help in heavy soil, although with less certainty. The rolling operation added to the equipment needed and time required to decontaminate, with no significant increase in fallout removal in sandy soil.

The asphalt spray had very little effect on decontamination. One asphalt application penetrated to a depth of about one-sixteenth of an inch. It would not penetrate the rolled surface or the unrolled surface. Heavier applications caused the asphalt to run off and pool in the low spots.

The black coating was of some value as a visual aid in telling whether the road grader had removed the entire top surface. When the blade was too high, a black streak could be seen on the plot. This was sometimes covered with turned-up soil, so it was not a reliable indicator. The cost of the asphalt for large-scale operations would be a significant item. In bulk quantities, the asphalt costs $12 per drum. At this price, the asphalt would cost a minimum of $250 an acre.

To determine the amount of fallout material on the effectiveness of decontamination by scraping, Experiment C was conducted

TABLE 3.—*Experiment B: Percentage of radioactivity scraped off with surface soil following various treatments*

Soil type and treatment	Plowing followed by—		Disking followed by—		Preparing seedbed followed by—		Average
	Rolling	No rolling	Rolling	No rolling	Rolling	No rolling	
Sassafras sandy loam:							
One pass, asphalt-coated	75	96	66	70	82	99	81
First pass, no asphalt	85	68	60	80	62	100	76
Second pass, no asphalt	89	100	95	100	93	100	96
Elkton silt loam:							
One pass, asphalt-coated	91	69	88	89	99	92	88
First pass, no asphalt	98	84	91	91	94	96	92
Second pass, no asphalt	87	91	100	86	100	100	94

(table 4). The rates of fallout application were chosen to represent areas of low and high radiation intensity. In addition to the road grader, a bulldozer and two self-loading scrapers were used.

All of the scrapers produced good decontamination, averaging 95 percent. There were no differences caused by the amount of fallout or soil-surface preparation. The large scraper (8-cubic-yard capacity) was so heavy that it sank into the silt loam, which was quite moist and soft. This continually increased the depth of cut. At times it cut as deep as 7 inches, pushing soil in front of the cutting edge. It was not possible to maintain a constant cutting depth with this scraper under these conditions. The small scraper (1-cubic-yard capacity) had the disadvantage of requiring frequent emptying. Nevertheless, it made a clean cut and maintained about the same depth of cut throughout the operation. About 2 inches of soil were removed with the road grader, bulldozer, and small scraper.

To determine the effectiveness of decontaminating by removing a crop of rye when the crop is contaminated after it is fully grown, Experiment D was conducted (table 5). Sprinkler irrigation was applied to simulate the effects of rainfall which might occur before a contaminated crop could be removed. The treatments on Elkton silt loam were made while the crop was still

TABLE 4.—*Experiment C: Percentage of radioactivity scraped off with different soil preparation and amounts of fallout per 48 square feet*

Soil type and treatment	Plowed Surface amount of fallout		Seedbed Surface amount of fallout	
	0.03 lb.	3 lb.	0.03 lb.	3 lb.
Sassafras sandy loam:				
Small, self-loading scraper	88	98	87	93
Road grader	90	88	100	81
Bulldozer	97	99	89	94
Elkton silt loam:				
Large, motorized self-loading scraper	100	100	100	100
Road grader	94	86	100	99
Bulldozer	93	96	98	99

TABLE 5.—*Experiment D: Percentage of radioactivity removed from a rye crop with farm machinery*

Treatment	Sassafras sandy loam		Elkton silt loam	
	Non-irrigated	Irrigated	Non-irrigated	Irrigated
Direct-cut forage harvestor	37	14	28	19
Mow, windrow, bale	26	19	23	17
Threshing	22	13		

green. Treatments on Sassafras sandy loam were made on the mature crop.

More radioactivity is removed by harvesting the rye before sprinkling than by harvesting it afterward. The water washed the radioactivity off the plants to the ground so that all types of subsequent plant harvesting removed less radioactivity. Not more than 40 percent of the radioactivity was removed when harvesting the contaminated crops. Therefore, this is not a satisfactory method of decontamination. All methods of crop removal took off about the same amount of radioactivity.

To determine the effectiveness of mulch removal with dry fallout and the effectiveness of scrapers that are designed for making shallow cuts into soil, Experiment E was conducted (table 6). Bermudagrass hay was spread as a mulch 1 month before contamination. Several rains had pressed it into close contact with the soil surface. After contamination, some plots were sprinkler-irrigated to simulate rainfall. The soil surface was disked for the scraping treatments.

The pickup and baling of mulch was an ineffective way to remove radioactivity from either sandy soil or silt loam soil. The mulch did not rake cleanly from the soil surface. When the mulch was irrigated before baling, much of the radioactivity from the mulch washed to the ground. As a result, less radioactivity was removed from the mulch that had been exposed to irrigation before removal.

Removing the contaminated soil with a road grader is a relatively effective way to decontaminate. The operator can see its effectiveness for himself. Scarcely any radioactive material is raised to become airborne. Progress, however, is slow.

The percentage decontamination by scraping was generally lower than in preceding experiments, averaging only 81 percent. This probably results, in part, from a shallower depth of cut with

TABLE 6.—*Experiment E: Percentage of radioactivity removed from mulch or soil with various equipment*

Removal method	Sassafras sandy loam		Elkton silt loam	
	Non-irrigated	Irrigated	Non-irrigated	Irrigated
Mulch, 2 tons per acre, pickup baling	41	14	28	30
Mulch, 5 tons per acre, pickup baling	82	56	51	43
Road-grading soil	84	89	62	60
Scraping and pickup of soil with rotary scraper	98	84	80	91
Scraping and pickup of soil with elevating scraper	88	69	74	94

these scrapers and, in part, from a tendency for the iodine-131 tracer to move downward into the moist soil.

Although the rotary scraper could be handled easily, the cutting depth could not be judged accurately by the operator. Stones about the size of baseballs would become wedged between the scraper blade and the vanes sweeping across it. This would stop the sweeping vanes from revolving.

The rotary scraper was not suitable for rocky soil. It also had the disadvantage of not being capable of unloading in any one location. It was necessary to distribute the soil as it was unloaded. The elevating scraper was difficult to maintain at a fixed cutting depth because the scraper was behind the operator. In addition, this machine was complicated and had many crevices and corners where contaminated soil might accumulate.

To study decontamination methods on hay or pasture field, Experiment F was conducted during June and July (table 7). The hay was a light crop of mixed Kentucky 31 fescue and ladino clover which had been seeded just after Experiment E. It was about 12 inches tall when it was contaminated. The pasture was simulated by clipping the hay crop regularly for several months before the experiment.

The decontamination methods included removal of the hay crop with conventional farm machinery and cleaning the pasture with a street vacuum cleaner. Owing to the failure of the crops on most of the sandy loam field, only the vacuum sweeper could be tested on this field. A grader was used to scrape the plots after hay removal or vacuum cleaning. A light rain occurred between the times these plots were contaminated and decontaminated. Even so,

TABLE 7.—*Experiment F: Percentage of radioactivity removed from pasture or hayfield with and without sprinkler irrigation*

Method of decontamination	Sassafras sandy loam		Elkton silt loam	
	Rain	Rain and irrigation	Rain	Rain and irrigation
Pasture vacuumed once	30	28	30	24
Pasture vacuumed twice	54	46	42	36
Pasture vacuumed, followed by grader with 1 inch cut	91	94	90	82
Hay cut 2 inches high using direct-cut harvester			17	12
Hay cut one-half-inch high with flail [1]			34	24
Pasture cut through with flail			42	62
Hay removed by direct cut followed by road grader 1-inch cut			88	90
Hay left removed with grader 1-inch cut			94	94

[1] Measurements made only with field monitor after decontamination; that is, no soil samples taken.

the Elkton silt loam was dry and hard when it was scraped, and a heavy grader was needed to make a 1-inch cut.

More radioactivity was washed off the plants when rain was followed by irrigation. If it is desirable to decontaminate as much as possible by removing the vegetation, the vegetation should be removed before it gets wet.

Vacuuming without any removal of the vegetation was ineffective. A second pass of the vacuum removed about 10-percent more activity; however, enough remained to make this method unacceptable. When the vacuum was followed by a road grader, the decontamination was much more complete. When vegetation was removed with a direct-cut harvester or flail, generally less than 30 percent of the contamination was removed. This is unsatisfactory. When the harvesters were followed by a road grader, the decontamination was much more complete.

To study decontamination methods for land covered with soybeans, Experiment G was conducted in September and October (table 8). Crop removal with conventional machinery was followed by scraping the stubble. The soybeans were fully grown, but still green at the time of the experiment on Elkton silt loam. Those on Sassafras sandy loam were mature.

These results showed that irrigation had washed radioactivity

TABLE 8.—*Experiment G: Percentage of radioactivity removed from land in soybeans with a combine, direct-cut harvester, or flail chopper, with and without sprinkler irrigation*

Soil and method of decontamination	Non-irrigation	Irrigation
Sassafras sandy loam:		
Combine, straw left on	0	2
Combine, large scraper	86	69
Combine, small scraper	83	81
Combine, straw removed	9	6
Combine, large scraper	84	80
Combine, small scraper	86	67
Elkton silt loam:		
Direct-cut harvester	58	35
Direct-cut harvester, followed by large scraper	90	79
Direct-cut harvester, followed by small scraper	96	88
Flail chopper	42	31
Flail chopper, followed by large scraper	92	86
Flail chopper, followed by small scraper	94	87

from the plants. Subsequent removal of vegetation resulted in poor irrigation and made decontamination more difficult, regardless of whether the decontamination was attempted by crop removal or soil removal. These results could have been influenced by the movement or iodine-131 into the soil. The results with the flail chopper were highly variable.

The combine harvester was not suitable as a machine for decontaminating. The straw is ejected from the rear of the machine after the grain is shaken off. When this straw was collected, there was a slight decontamination. In testing the combine followed by scrapers, the scrapers were again less effective on irrigated plots.

To study decontamination methods for land with a mature wheat crop, Experiment H was conducted (table 9). Crop removal was followed by vacuuming or flail cleaning of the soil surface. The soil surface was pulverized after removal of the crop by shallow disking on the silt loam and operating a weeder over the sandy soil.

Vacuuming with farm machinery proved ineffective, regardless of the condition of the soil or the crops tested. The combine had been unsuccessful in removing fallout from soybeans in Experiment G. It now failed to decontaminate full-grown wheat as well. It made little difference if the surface soil of the wheat stubble field had been pulverized. Although irrigation was detrimental, the difference was not important. The flail chopper proved equally

TABLE 9.—*Experiment H: Percentage of radioactivity reduction by combining wheat and pulverizing soil before soil removal*

Method of decontamination	Sassafras sandy loam		Elkton silt loam	
	Irrigated	Non-irrigated	Irrigated	Non-irrigated
Combine with straw removed	[1] −6	0	0	1
Combine, straw removed, vacuum (soil not pulverized)	50	28	1	18
Combine, straw removed, vacuum (soil pulverized)	39	42	33	26
Combine, straw removed, flail (soil not pulverized)	14	20	[1] −19	12
Combine, straw removed, flail (soil pulverized)	[1] −1	21	[1] −10	6

[1] Radioactivity carried on these plots from other plots by combine. Blower of combine became plugged and ejected on these plots.

ineffective when operated over both the pulverized and the unpulverized surface soil of the wheat stubble field.

To study decontamination methods for mature corn and to see whether a concrete slurry would improve decontamination of a soil surface, Experiment I was conducted in September (table 10). Removal of the corn crop was followed by scraping, although land in corn stubble was difficult to scrape. The concrete slurry was spread through a lime spreader to coat a contaminated bare soil surface in the same way that asphalt was used in Experiment B.

These results show that very little fallout removal can be achieved with any of the common corn-crop removal methods. The rough terrain and large roots along with moist soil reduced the effectiveness of the scraper to the lowest level obtained in all tests. No effective means of decontaminating a cornfield was determined.

The concrete slurry was difficult to apply and remove. It clogged the spreader at low flow rates. As a result, the coating on the soil surface was thicker than intended, nearly 1 inch thick in places. The coating had to be broken by running over it with tractor wheels. Even then the rake would remove little of it. A front-end loader would pick it up, but this was a slow job.

To compare the time required to decontaminate bare soil and to bury the waste using a small scraper with the time required for the same procedure using a large scraper, Experiment J was conducted during the spring (table 11). Slow removal is objectionable because it increases the possibility or recontaminating a cleaned area by gusts of wind blowing from the field during decontamination. Slow decontamination also results in more radiation exposure to the machinery operator. Adjacent cleaning passes were

TABLE 10.—*Experiment I: Radiation reduction by removing mature corn with chopper, picker, or sheller, and by removing concrete coating*

Method of decontamination	Percent
Corn chopper	12
Corn chopper, followed by scraper	48
Cornpicker	3
Cornpicker, followed by scraper	57
Corn sheller	0
Corn sheller, followed by scraper	63
Concrete coating removed by:	
Side-delivery rake	23
Front-end loader	89

TABLE 11.—*Experiment J: Logistics of decontaminating 100,000 square feet and burying the waste with road scrapers*

Equipment and method	Cleaned area	Disposal area	Cleaned area	Productive time	Support time	Hours [1]
			Percent	*Percent*	*Percent*	*Number*
Small road grader (9′ blade):						
1 pass to make 1 windrow, 3 ditch-digging passes beside windrow in cleaned soil, 1 ditch-filling pass with contaminated soil, 2 clean-soil covering passes.	12′8″ x 209′	2′ x 209′	86.3	18.8	81.2	20.4
3 passes to make 1 windrow, 1 pass-moving windrow back on clean soil.	22′6″ x 209′	2′6″ x 209′	90.0	53.4	46.6	5.62
Large road scraper (12′ blade):						
3 passes to make 1 windrow, 2 ditch-digging passes beside windrow in cleaned soil, 1 ditch-filling pass with contaminated soil, 1 clean-soil covering pass.	19′2″ x 209′	3′ x 209′	87.0	18.5	81.5	9.14
3 passes to make 1 windrow, 1 pass to move windrow back on clean soil.	30′ x 209′	3′6″ x 209′	90.0	40.8	59.2	3.32
3 passes to make 1 windrow, which was moved to center of field in 3 sections by grader.	7,392 sq. ft.	14′ x 22′	96.0	----------	----------	8.73
3 passes to make 1 windrow, which was moved to center of field by front-end loader.	1,900 sq. ft.	10′ x 10′	95.0	18.2	81.8	9.48

[1] Decontaminating time—Hours/100,000 sq. ft.

made to move the windrow of contaminated soil into one large row. No more than three adjacent cleaning passes could be made with either grader before there was objectionable spillage of contaminated soil over the top of the blade.

After three decontaminating passes the scraper was turned around and run over the last cleaned pass. On this pass, a ditch was excavated beside the row of contaminated soil. The contaminated soil was scraped into the ditch (fig. 15) and the clean soil removed on the fourth pass backfilled over it. Thus, the contaminated soil was buried beneath clean soil. This lessened the hazard of contaminated soil becoming airborne.

The decontaminating time shown in the last column of table 11 indicated 5.62 hours were required for decontaminating 100,000 square feet by a small scraper, whereas, only 3.3 hours were required for decontamination over the same area using a large scraper. When the windrows were moved into mounds, the decontamination time was increased almost three times with the large scraper.

Table 12 (Experiment K) shows the distribution of topsoil after

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Figure 15.—Filling ditch with contaminated soil.

TABLE 12.—*Experiment K: Percentage of radioactivity determined at various depths after deep plowing*

Sampling depth (inches)	Radioactivity of high-clay content Pullman soil	Radioactivity of sandy loam Elkton soil
	Percent	*Percent*
3	0.5	0.5
9	.3	.5
15	1.2	.7
21	1.7	4.2
27	6.2	29.2
33	27.4	62.6
39	61.4	2.0
45 [1]	1.0	

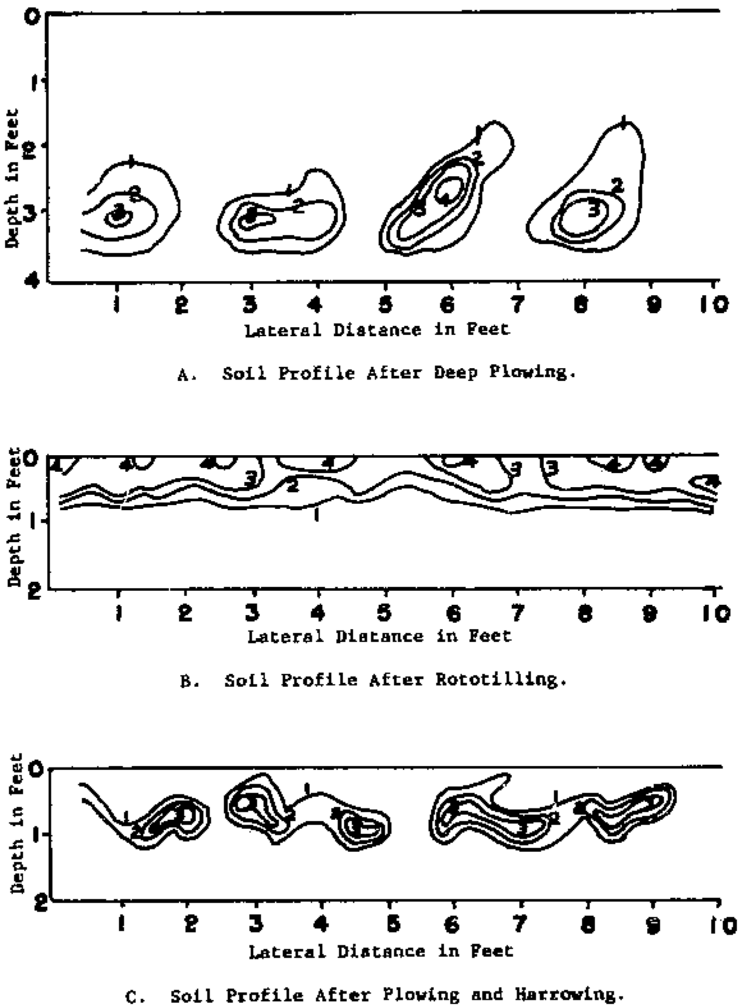
[1] Soil that has been fluffed up by the plow.

deep plowing in two types of soil. The plow broke up and increased the volume of the soil removed from the furrow. As a result, the plowed field was at a higher elevation than before plowing. While the plow was opening a 39-inch-deep furrow as measured from the former ground surface, the fluffed-up soil measured as much as 45 inches.

The specific location of this soil may be seen in figure 16. This shows the concentration of radioactive soil in furrows after deep and shallow plowing on silty loam. The distribution of radioactive soil after rototilling was quite uniform to a depth of about 8 inches. Although deep plowing buried most of the radioactive soil deeper than 30 inches, deep-rooted crops continued to take up much strontium-85 (table 13). Uptake was much less when sodium carbonate was plowed under with the radioactive soil. Despite deeper contamination burial, the uptake of radioactivity was about the same in deeper rooted plants.

At the conclusion of the experiment, by using the scraper for both decontamination and waste burial, we thought that it might be better to dispense with scraping off the contaminated soil because of the disposal problem it had created. A substitute might be to invert the contaminated topsoil to a depth where roots would not reach it. Accordingly, in the spring and again in fall, experiments were conducted to invert the soil by using a large moldboard plow. The purpose of these experiments was to determine if the radioactivity could be buried deeply enough so that it would not be available to plants.

As a further deterrent to uptake of radioactivity by the roots, a chemical root repellent, sodium carbonate, was distributed over the simulated fallout before it was plowed under. After radioactivity burial by the large plow, a 4-foot deep trench was excavated through the furrows so that the burial pattern of the radioactive soil could be examined. Every 6 inches 2-inch diameter, 2-inch deep soil samples were removed. The amount of radioactivity in



A. Soil Profile After Deep Plowing.

B. Soil Profile After Rototilling.

C. Soil Profile After Plowing and Harrowing.

Figure 16.—Radioactivity buried at various depths after cultivation.

TABLE 13.—*Experiment L: Uptake of strontium-85 by mature crops grown with different tillage operations and a growth inhibitor*

Crop	Fraction of strontium-85 application taken up with different treatments		
	Rotary-tilled	Deep-plowed	Deep-plowed with Na_2CO_3
	Percent $\times 10^4$	*Percent* $\times 10^4$	*Percent* $\times 10^4$
Sugarbeet tops	640	300	39
Sugarbeet roots	910	780	76
Sudangrass fodder	780	450	52
Soybean straw	650	540	35
Soybean seed	67	56	6
Cabbage	1,130	560	154

each sample was recorded. Table 13 summarizes the uptake of strontium-85 by mature crops grown with different tillage operations and a growth inhibitor.

To investigate the effectiveness of a conventional-type street-sweeper in removing fallout from contaminated land, Experiment M was conducted during the fall (table 14). The following variables: Type of soil, sweeping procedures, type of broom material, and use of gutter broom were considered. Several practical factors make mechanical streetsweepers attractive. Sweepers leave the topsoil relatively undisturbed; they are maneuverable in corners and around objects, and are much less destructive than scrapers to hard surfaces such as roads.

The soil type and condition were important factors in decontaminating. It was easier to decontaminate sandy soil than silty loam during the initial passes. Four passes were required on silty loam soil to achieve 90-percent decontamination, whereas, only three were required on a sandy soil. The fields were decontaminated after a rain and, consequently, were wet. Other results might occur from sweeping dry fields.

Investigations of the sweeping procedures showed that after three passes, a point of diminishing return for the effort expended occurs. Nevertheless, 10 passes removed 99 percent of the contamination. The sweeper operated as effectively at high groundspeed as it did when going slower. Higher speeds are preferable since the operator receives less exposure.

A steel wire main broom was more effective than a plastic main

TABLE 14.—*Experiment M: Cumulative percentage of radioactivity reduced by repeated passes of a rotating-brush, mechanical street sweeper with different brooms* [1]

Broom material and sweeping procedure	Cumulative percent removed from Sassafrass sandy soil by indicated number of passes					Cumulative percent removed from Elkton silt-loam soil by indicated number of passes				
	1	2	3	4	10	1	2	3	4	10 [2]
Main brooms	*Duplicative*					*Duplicative*				
Steel:										
Normal pass first	74	86	91	92	------	80	89	75	92	------
Suction pass first	73	86	92	94	100	84	95	85	94	------
Steel and gutter broom:										
Normal pass first	73	84	92	96	99	78	90	95	94	------
Suction pass first	52	75	93	90	------	50	54	77	78	------
Plastic:										
Normal pass first						38	51	70	90	------

[1] Data for results with the motorized vacuum sweeper and the rotary brush sweeper were recorded, but were not put in tabular form.

[2] The final part of this experiment was not conducted.

broom on both soil types. The gutter broom was ineffective and only stirred up dust.

For the sweeper to operate over the rough terrain of farmland, it will be necessary to modify the sweeper wheels. A pair of rear tractor wheels or dual wheels could be substituted for the rear wheels on the sweeper.

To try easier methods of soil management than deep plowing to minimize plant uptake of radioactivity, Experiment N was conducted during the summer (table 15). It was reasoned that if the radioactivity could be left undisturbed on the surface of the field and the seeds and fertilizer dropped in slots prepared for them, the roots would go on down away from the radioactivity. This should result in less uptake of radioactivity than if the roots were in soil having radioactivity mixed in it.

Planting was done at both 2½- and 5-inch depths below the strontium-85 radioactivity on the surface. To prevent mixing of the contaminated soil with the roots during the growing season, the weeds were controlled with chemicals. To see if the type of crop was important, spring wheat, sweet corn, and bush beans were grown. They were grown on both sandy soil and loamy soil to determine if soil type was significant. Every 2 weeks a radioassay of the crops was made to determine the effect of growing time on the accumulation of radioactivity.

Table 15 shows that the type of crop was the most significant factor in the uptake of radioactivity. Beans removed more radioactivity from the soil than either corn or wheat. This was true in both soil types and with all planting methods. Although the difference was slight, wheat had a greater uptake of radioactivity than did corn.

Planting through the radioactive-covered sandy soil resulted in

TABLE 15.—*Experiment N: Relative importance of factors controlling the uptake of radioactivity, all values highly significant, 99- to 100-percent confidence*

Factor	Relative importance	Degree of freedom	"F" value
Type of crop	1	2	58.3
Soil type vs. planting depth	2	2	21.5
Soil type	3	1	7.0
Growing time	4	3	6.4
Crop vs. planting depth	5	4	6.2
Soil type vs. growing time	6	3	4.1

less uptake of radioactivity by corn and beans than when they were planted in soil having radioactivity mixed in the soil (figs. 17 and 18). The uptake of radioactivity by wheat was about the same regardless of the planting method (fig. 19).

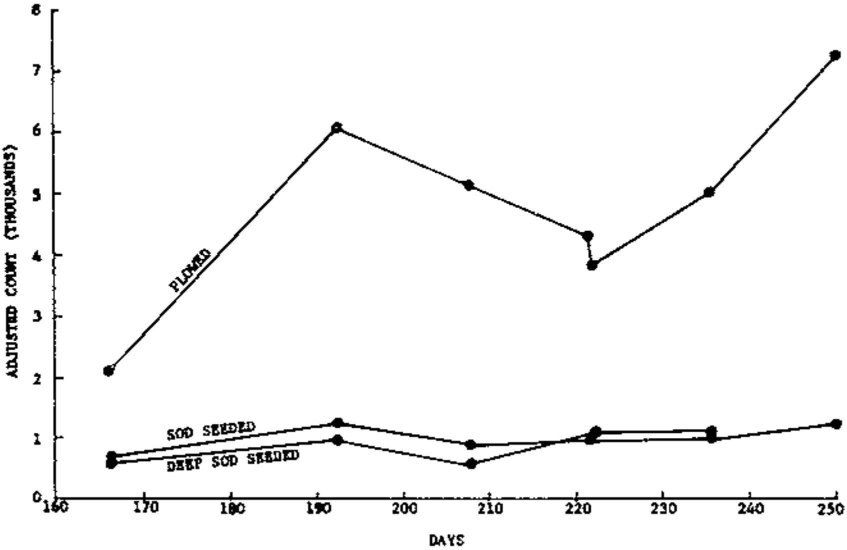


Figure 17.—Uptake of radioactivity of corn at various planting depths.

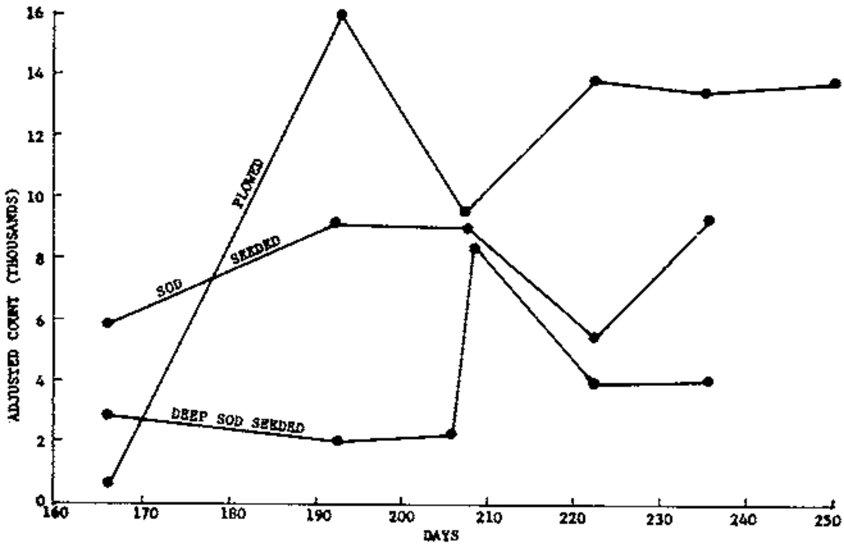


Figure 18.—Uptake of radioactivity of beans at various planting depths.

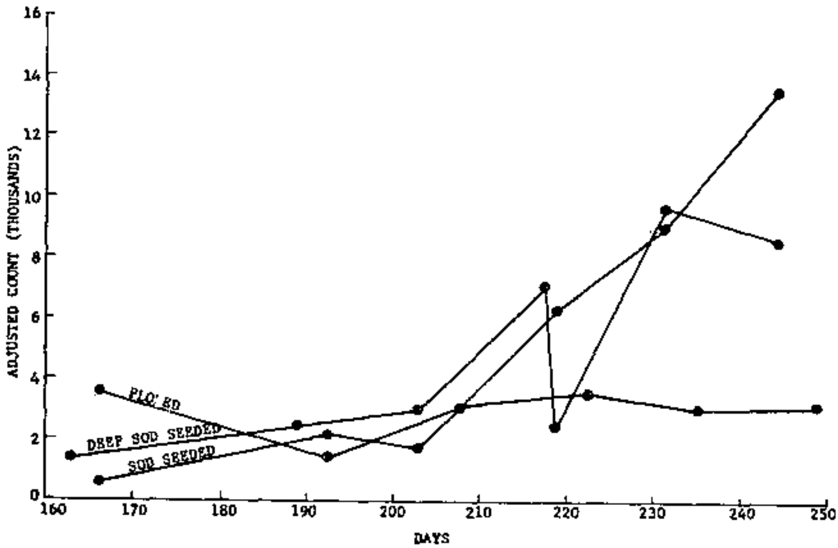


Figure 19.—Uptake of radioactivity of wheat at various planting depths.

The erratic uptake is to be expected with crops grown in the field. When the moisture and temperature were favorable, the plants grew rapidly and the uptake of radioactivity was great. During a period of drought stress, both the growth rate and the uptake of radioactivity were slow.

Planting through the radioactive-covered loamy soil did not result in any significant reduction of uptake of radioactivity by any of the crops.

SOURCES OF ERROR

Different results were sometimes obtained when the same decontamination method was repeated. This variation was greater with ineffective decontamination methods, such as vegetation removal, than with other methods. In other words, one can be more assured of attaining 90-percent decontamination with the road grader than attaining 50-percent decontamination with a mower and crop remover. Typical standard deviations were ±5 at 90-percent decontamination, and ±15 at 50-percent decontamination. All of the crop removal methods gave low decontamination percentages and typical deviations of ±10 to 15 percent.

These errors generally indicated true differences in the amount of radioactivity removed rather than error in its measurement.

With crop removal, differences could be caused by variations in crop density. With soil scraping, differences could be caused by depressions in the soil surface, variations in depths of scraping, and variations in machinery operators skill.

The skill of the machinery operator in maintaining constant scraping depth was important in obtaining uniform results. Also, some operators allowed contaminated soil to build up so high in front of the blade that it spilled over onto cleaned soil behind the blade. This recontaminated the land.

Of the simulated fallout particles that had been distributed, not all were located. Although all fallout removed from the plots was added to all that remained on the plots after decontamination, the sum was not as great as that which had been distributed. In some cases, particularly with the flail chopper, it appeared that some fallout particles had been blown away from the plots during decontamination. This decontamination by the wind was considered part of the decontamination by machinery.

There was considerable variation in uptake of strontium-85 by crops in Experiments K and M. This may be related to the size of samples taken for analysis. In Experiment K, the standard deviations for each crop and tillage treatment were about 25 percent of the strontium-85 content found. In Experiment M with smaller samples taken for analysis, the standard deviations were about 50 percent of the strontium-85 content found. This made it impossible to distinguish small differences in uptake as a result of treatment.

Other factors influenced plant growth. Plants that are grown outdoors experience irregular growth because of changes in environment. For example, a temporary cool period will accelerate the growth of plants such as peas. They will show increased growth and uptake of radioactivity at this time; whereas, growth will be slower during warm weather. Alternate cool and warm weather will result in a jagged growth curve.

CONCLUSIONS

In removing radioactive fallout from farmland, there is no method which is best in all circumstances. Some methods seem to be better under a wider variety of conditions than others. The following conclusions are made from this research:

Removal of contaminated crops is an ineffective method of decontaminating farmland.

A power-driven streetsweeper or scraper cutting 2 inches deep removes about 90 percent of the contaminant.

Decontamination should be accomplished before rainfall washes the radioactivity into low places where it is difficult to remove.

Decontamination can be accomplished by a scraper with a 12-foot blade at the rate of 100,000 square feet (2.3 acres) in 3.3 hours.

Application of a concrete or asphalt coating over the radioactivity is ineffective and only makes later pickup of radioactivity more difficult.

Burying radioactivity 3 feet deep with a large plow is costly and ineffective in reducing the uptake of radioactivity.

Planting through a contaminated surface which is then left untilled is an ineffective way to reduce the uptake of radioactivity.

The species of the crop is a highly significant factor in the uptake of radioactivity.

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