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THE ABSORPTION AND TRANSLOCATION OF SEVERAL FISSION ELEMENTS BY RUSSIAN THISTLES

by

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ABSTRACT

An investigation was conducted to determine the absorption and translocation of fission products by Russian thistle from a localized spot of contaminated soil. The amount and identity of the radioactive elements absorbed and translocated by the Russian thistle is given along with the location of these elements in the plants. Beta radioactivity to the amounts of 10 microcuries per gram caused no visible effects on the growth habits of the plants. Illustrations of gross autoradiographs and of autoradiographs of sectioned material are included.

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INTRODUCTION

In June 1946, a break was discovered in a metal waste line at a point near the 271-B Building, 200-East Area. At this point, the liquid wastes containing radioactive fission products had come to the surface of the ground and caused a slight cave-in. The cave-in was filled and an extensive area of the soil surface around the cave-in was covered with washed gravel. A layer approximately three and one-half feet deep was used to protect personnel against the radiation hazard.

In December 1948, the Health Instrument Operational Division informed the author that Russian thistle plants (Salsola pestifer, Nels.) growing in the break area were emitting high levels of radiation. This indicated that these plants, which are prominent weeds in all Hanford Areas where the soil has been disturbed, were absorbing fission elements from the soil contaminated by the break.

An investigation was initiated to determine the amount and the identity of the beta emitting radioactive elements being absorbed and translocated by the plants. The distribution of the radioactivity in the different plant parts and the effect of this activity on the morphology of the plant were also studied. Previously, Berry (1) had made autoradiographs of Russian thistles growing in the break area. In addition Jacobson and Overstreet (2) had shown that barley and dwarf pea plants have the ability to absorb and fix the fission producta strontium, yttrium, cerium, zirconium, and tellurium from a clay suspension and from "Hanford Works" topsoil. These workers found that strontium was most readily absorbed and fixed. Activities of the order of 0.1 microcuries per gram in the soil at the region of root contact caused injury to the plant. Their experiments were conducted under laboratory and greenhouse conditions.

METHODS

Samples of thistle growing in the contaminated area were collected in December 1948, and determinations were made of the amount of radioactivity present in the above ground parts. Radiochemical analyses were also made and decay curves were started on different plant parts.

On June 6, 1949, five individual plants growing in the contaminated area were selected for sampling. Samples were collected from these plants twice each month throughout the growing season to determine when the plants would absorb the activity. Russian thistle plants growing in the immediate area and giving high radiation readings were collected for additional studies.

All vegetation samples were air-dried, weighed and then digested in nitric acid. At the completion of digestion, samples were transferred to one and one-half inch stainless steel plates and dried under infra-red lamps.

Samples were counted with a standard mica-window beta counter. Appropriate factors allowing for differences in diameters of samples and variation in the distance of samples from the mica-window were used to convert counts to microcuries. No corrections were made for the self-absorption of the ash. Counts were reliable to a 90 per cent confidence level.

Decay curves were plotted for samples collected in December of 1948. Absorption curves, using standard aluminum absorbers, were also made on these samples.

Gross autoradiographs of thistles were made by exposure of the plant to Type K x-ray film. Autoradiographs of sectioned material were made on N.T.B. stripping film by the methods described by Boyd (3).

Soil samples were collected twice during December, 1949 at the 2½-3-3½ and 4 foot depths by driving a casing containing a driver into the ground. At the sampling depths the driver was removed from the casing and samples were taken with a soil sampler. This method proved quite satisfactory and prevented exposure of personnel to the radiation. Samples were placed on stainless steel plates and counted directly for beta activity.

RESULTS

Beta activity counts on above ground thistle parts collected in December 1948, showed that the activity was not evenly distributed among the parts. Variation also occurred between like parts of the same plant. However, the seeds, including their winged appendages, and the bracts each had an average beta activity of about 3 microcuries per gram. The activity for the stem averaged about 0.9 microcuries per gram.

The results of the radiochemical analyses on the seeds, and the bracts and stem are given in Table 1. The elements strontium and yttrium constituted about 90 per cent of the total activity present in these plant parts.

It was not possible to interpret accurately the decay curves at the end of one year because of the long half-lives of the elements present. Absorption curves for all plant parts indicated that the beta activity was due to particles having two definite energy ranges. One had an energy of 0.2 to 0.3 mev and the other had an energy of 2.1 to 2.2 mev.

The results of sampling the individual plants during the growing season showed that the radioactive elements were not absorbed until about the third month of growth. Beta activity of the plants was less than 2×10^{-4} microcuries per gram through the first two months. During the third month it increased 3,000 times. During the remaining two months, absorbed activity increased only slightly.

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TABLE 1

BETA ACTIVITY ATTRIBUTABLE TO EACH

RADIOACTIVE ELEMENT IN RUSSIAN THISTLE

Radioactive Elements*	Seeds		Bracts & Stems	
	Microcuries Per Gram	Per cent of Total	Microcuries Per Gram	Per cent of Total
$Strontium^{90}$	~ 1.4	~ 45	~ 1.5	~ 45
$Yttrium^{90}$	~ 1.4	~ 45	~ 1.5	~ 45
$Cerium^{144}$ $Prasodymium^{144}$	< 0.03	< 1	< 0.03	< 1
$Cesium^{137}$	~ 0.03	~ 1	< 0.03	< 1
$Ruthenium^{106}$ $Rhodium^{106}$	< 0.03	< 1	< 0.03	< 1
$Zirconium^{95}$	~ 0.03	~ 1	< 0.03	< 1
Rare Earths (other than those listed)	~ 0.16	~ 5	~ 0.17	~ 5
Total Activity	~ 3.1	~ 99	~ 3.3	~ 99

* Strontium and zirconium were counted without their daughters, whereas cerium and ruthenium were counted with their daughters.

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On September 10, 1949, two individual thistle plants which had high beta activities were removed from the soil. Approximately two and one-half feet of primary root were removed with each of these plants. Photographs of these plants are shown in Figures 1 and 2. The activities expressed in microcuries per gram for numerous portions of the plants appear on the photographs. Letter symbols indicate plant parts counted.

Figures 1 and 2 indicate that there was not an even distribution of beta activity throughout the plants, although there was activity present in all parts. In both of the plants, the activity present in the aerial portions was more than that in the primary root. The small secondary roots contained more activity than the aerial portions or the primary root.

Gross autoradiographs and photographs of two branches are shown in Figures 3, 4, 5, and 6. The levels of beta activity in individual parts of these branches are given in Table 2. The autoradiograph in Figure 3 indicates that the amount of beta activity in bracts, flower parts, and leaves is about equal. However, the autoradiograph (Figure 5) shows the highest activity to be in the flower parts. Counting results substantiate both autoradiographs.

A photomicrograph of an autoradiograph at grain level of a 10 micron longitudinal section of the embryo of a thistle is shown in Figure 7. The highest activity is generally located in an area where crystals appear in the cells, although some crystals appear to be inactive. A photomicrograph of a representive crystal (inactive) is shown in Figure 8. The crystals are present in all microtechnique preparations of active and non-active tissue of Russian thistle. Microchemical tests showed the crystals in inactive thistle to be calcium oxalate and it is thought that the active

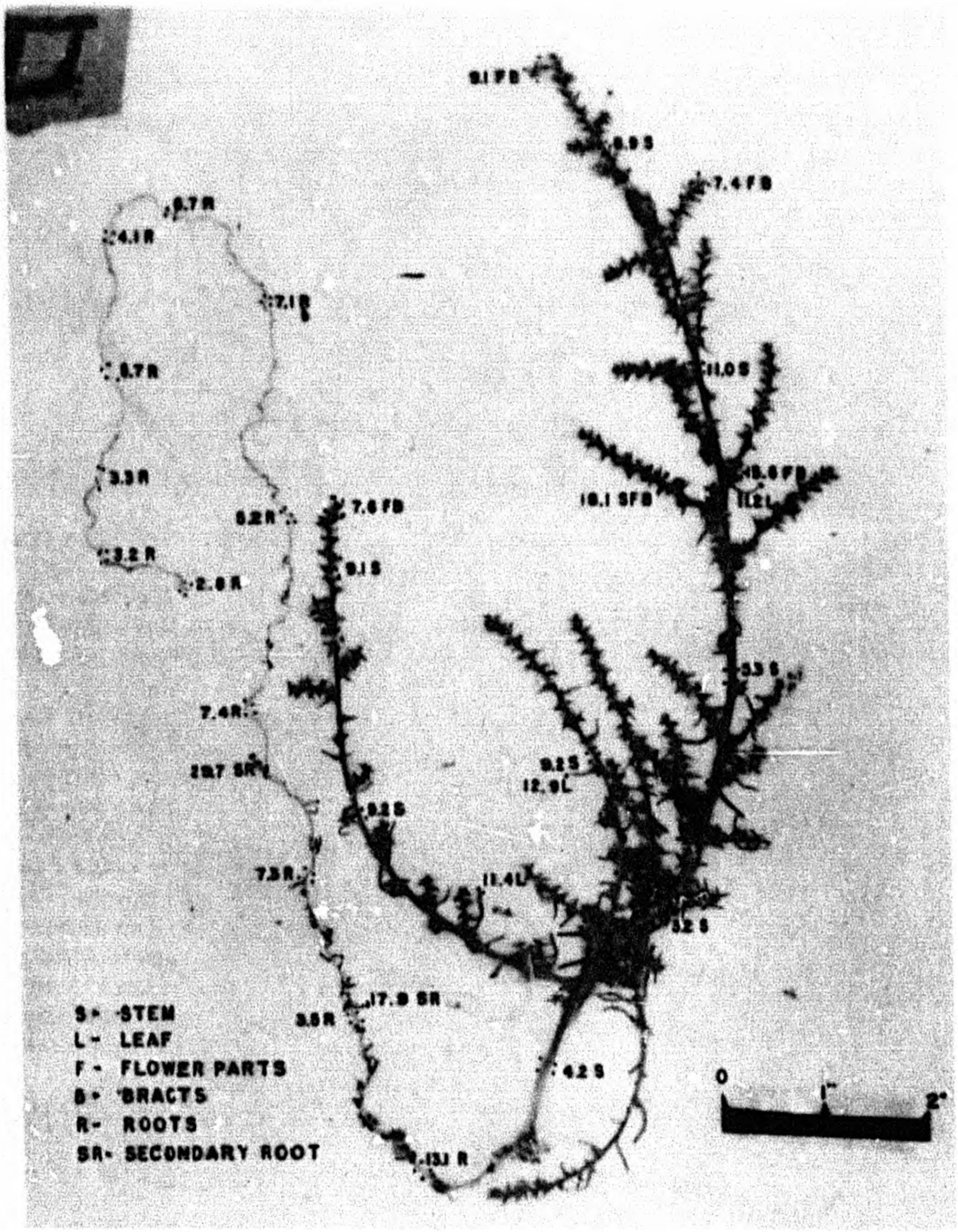

Figure 1. Beta activity in microcuries per gram for different portions of a Russian thistle plant (3/4 natural size).

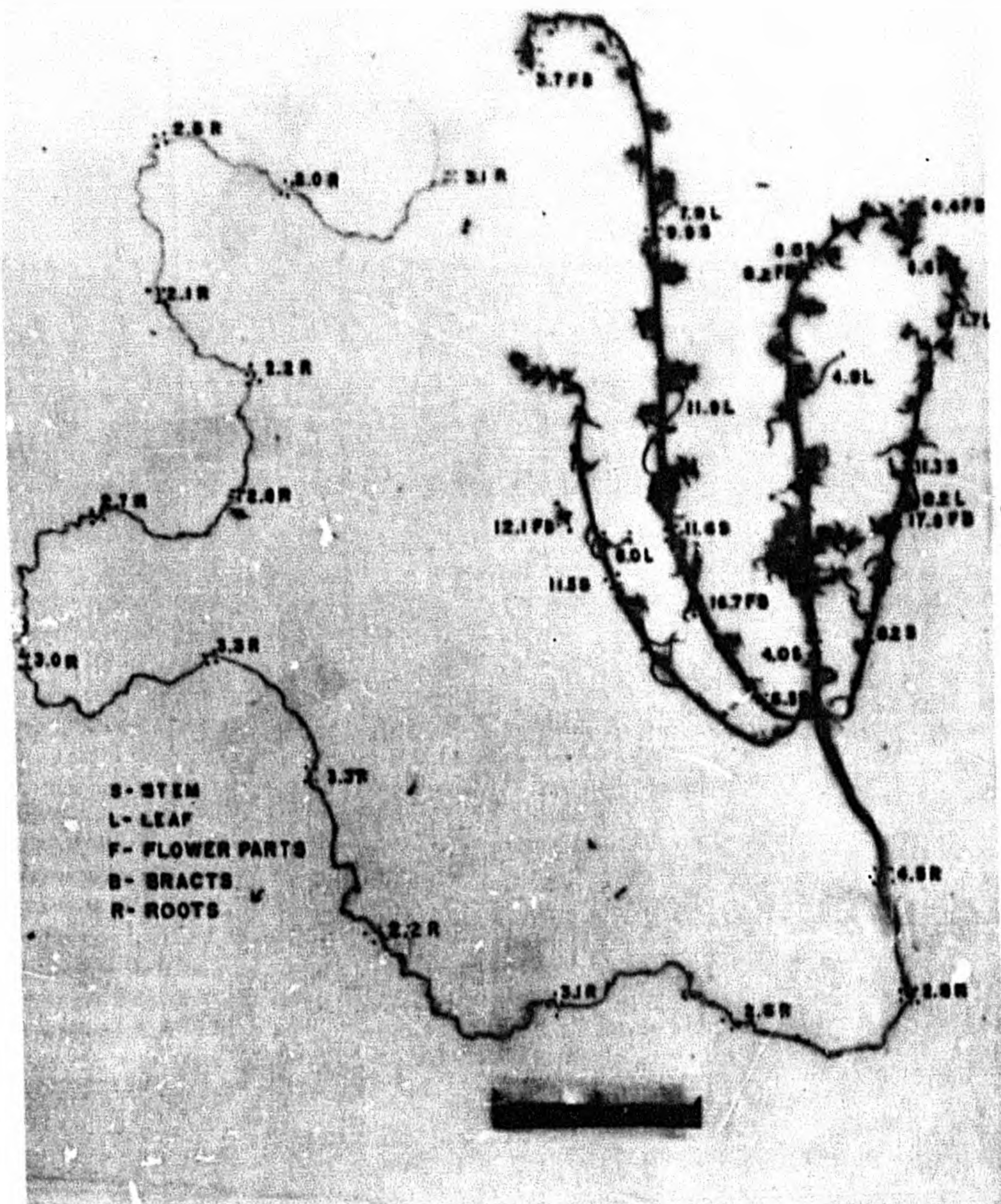

Figure 2. Beta activity in microcuries per gram for different portions of a Russian thistle plant (3/4 natural size).

Figure 3. Autoradiograph of a Russian thistle branch (natural size).

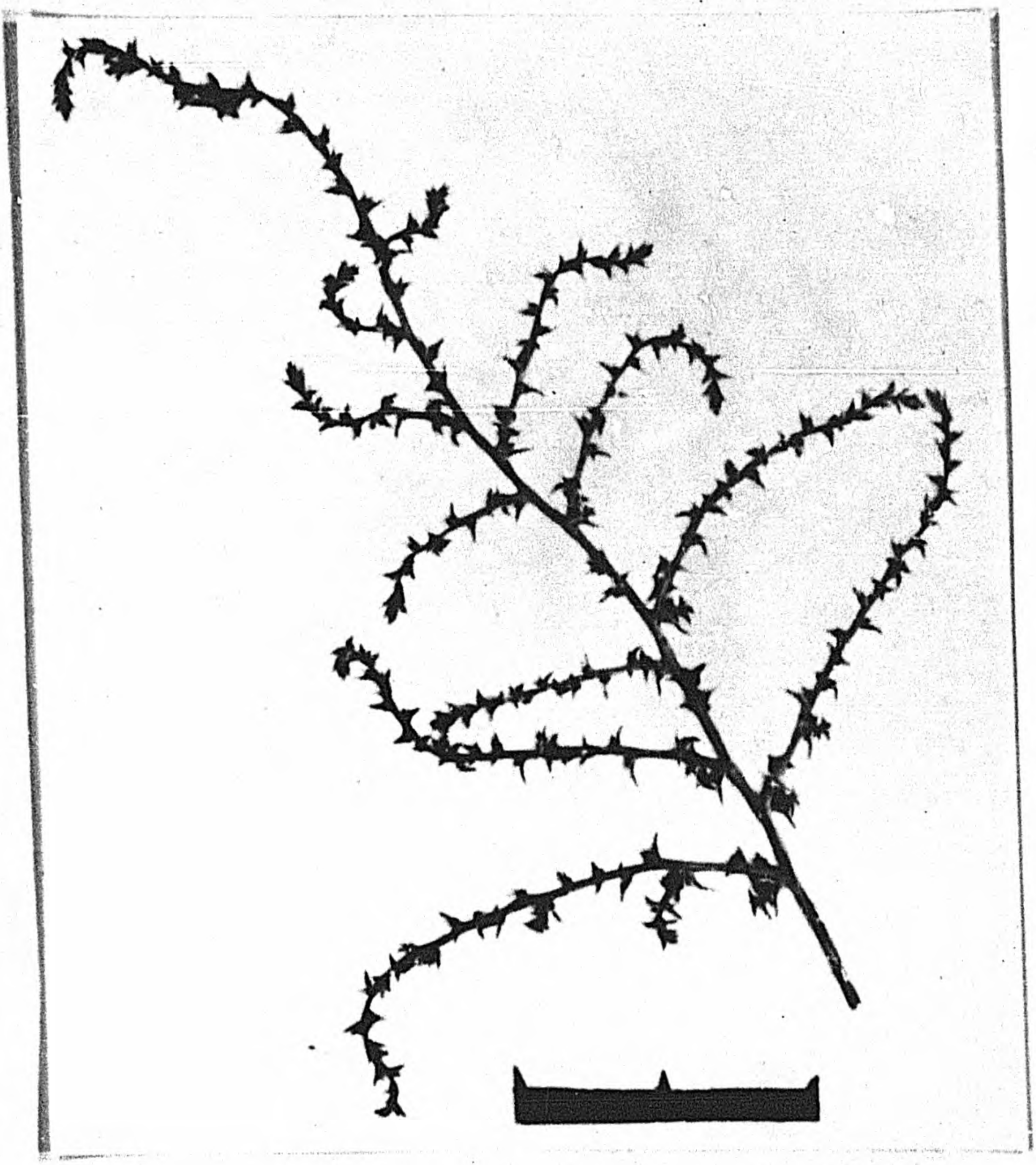

Figure 4. Photograph of Russian thistle branch (natural size). Autoradiograph is shown in Figure 3.

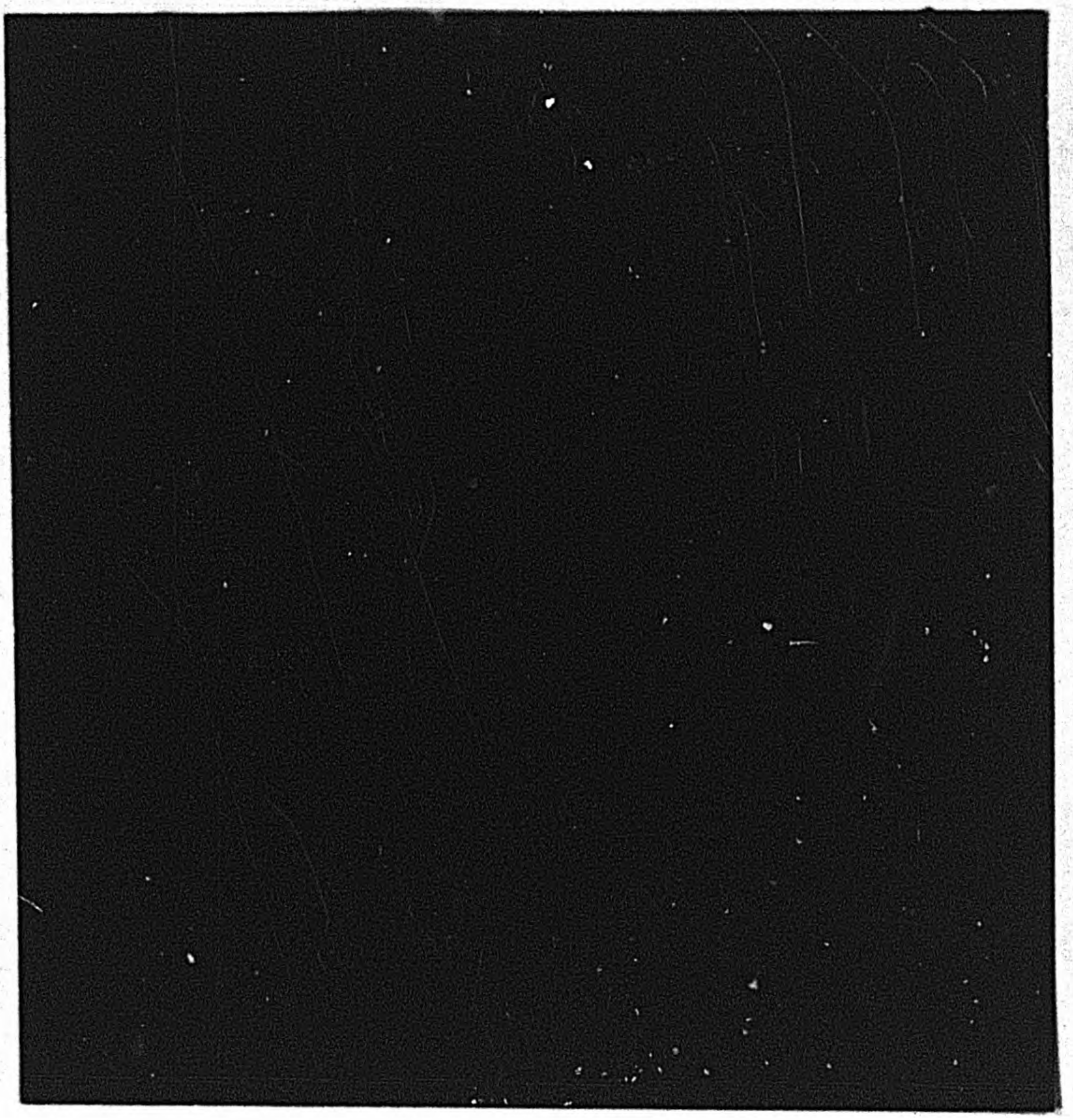

Figure 5. Autoradiograph of a Russian thistle branch (natural size).

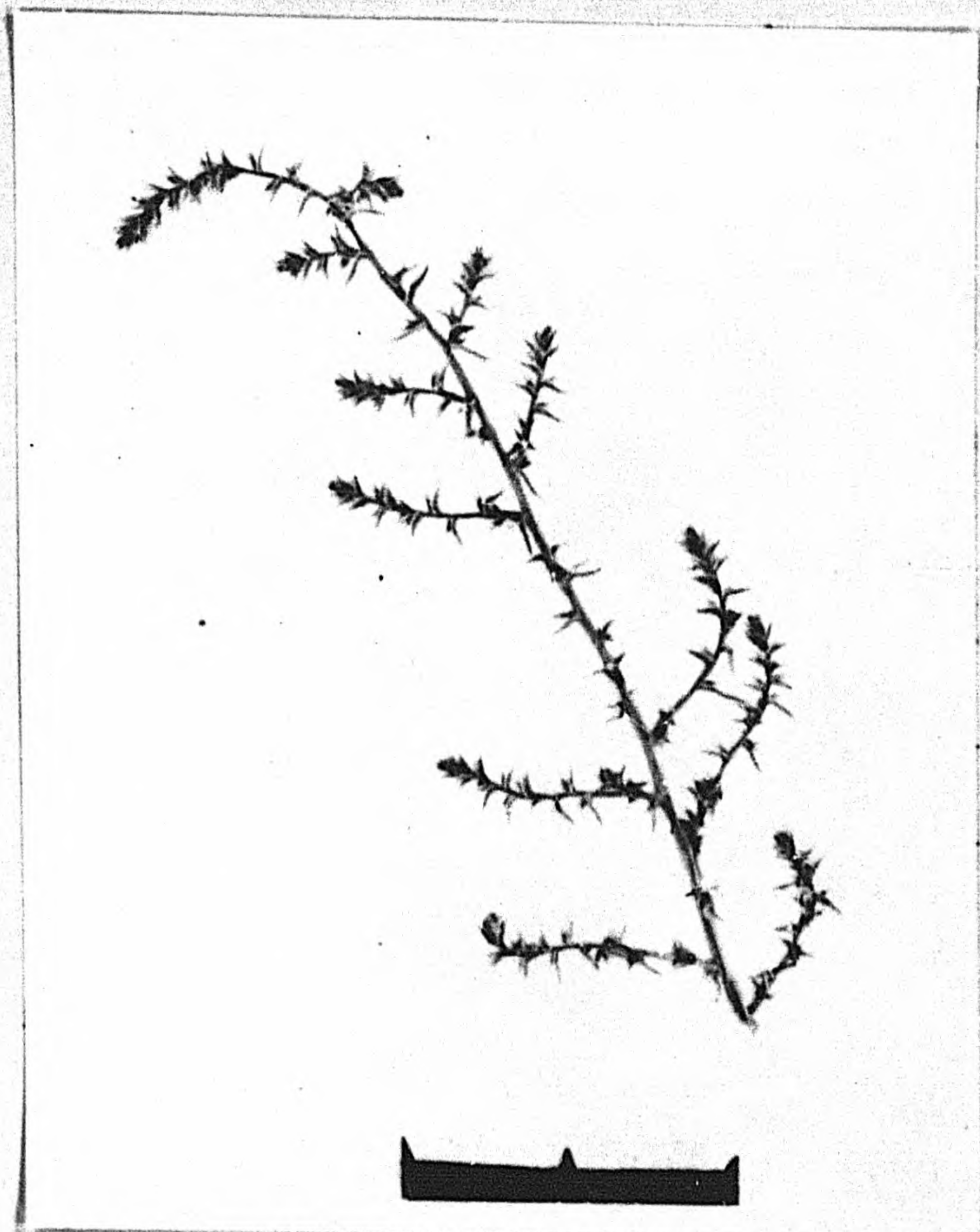

Figure 6. Photograph of Russian thistle branch (natural size). Autoradiograph is shown in Figure 5.

TABLE 2

BETA ACTIVITY IN INDIVIDUAL PARTS OF RUSSIAN

THISTLE BRANCHES SHOWN IN FIGURES 3, 4, 5, AND 6

Parts Sampled	Branch in Figures 3 and 4	Branch in Figures 5 and 6
	Average* microcuries/gram	Average* microcuries/gram
Stem	$9 \pm 5 \times 10^{-3}$**	4.3 ± 1.6**
Flowers	$24 \pm 9 \times 10^{-3}$	10.0 ± 3.4
Bracts	$26 \pm 9 \times 10^{-3}$	5.6 ± 1.2
Leaves	$26 \pm 7 \times 10^{-3}$	6.0 ± 1.3

* Average of five samples.

** Plus and Minus factor is for the 90% Probability Error.

Figure 7. A photomicrograph of an autoradiograph of a longitudinal section of the embryo of Russian thistle (100X). N.T.B. film.

crystals might be strontium oxalate. Although the highest concentration of radioactivity is in the crystal formations, Figure 9 shows the activity to be present in all tissue.

A microscopic comparison was made between the cells in the growing tip used in autoradiographs, which had beta activity of 7.1 microcuries per gram, and cells in a growing tip having less than 1 x 10^{-5} microcuries per gram. No differences were to be found in the cells or cell structure.

Direct counts of soil samples from the first collection showed the activity for the layer of washed gravel to be less than 2 x 10^{-4} microcurie per gram. At the three and one-half foot depth, the average activity for 10 samples was 0.08 microcuries per gram. The average beta activity for 10 samples at the four foot depth was 8.5 microcuries per gram. The samples from the three and one-half and four foot depths were of the original sandy soil present at the time the waste break occurred. Radiochemical analyses were made on the active elements in the sandy soil at the two levels, the results of these analyses are given in Table 3.

The radiochemical analyses of the soil from the three and one-half foot depth indicates that there was not an even distribution of the elements. However indications are that these elements are evenly distributed at the four foot depth.

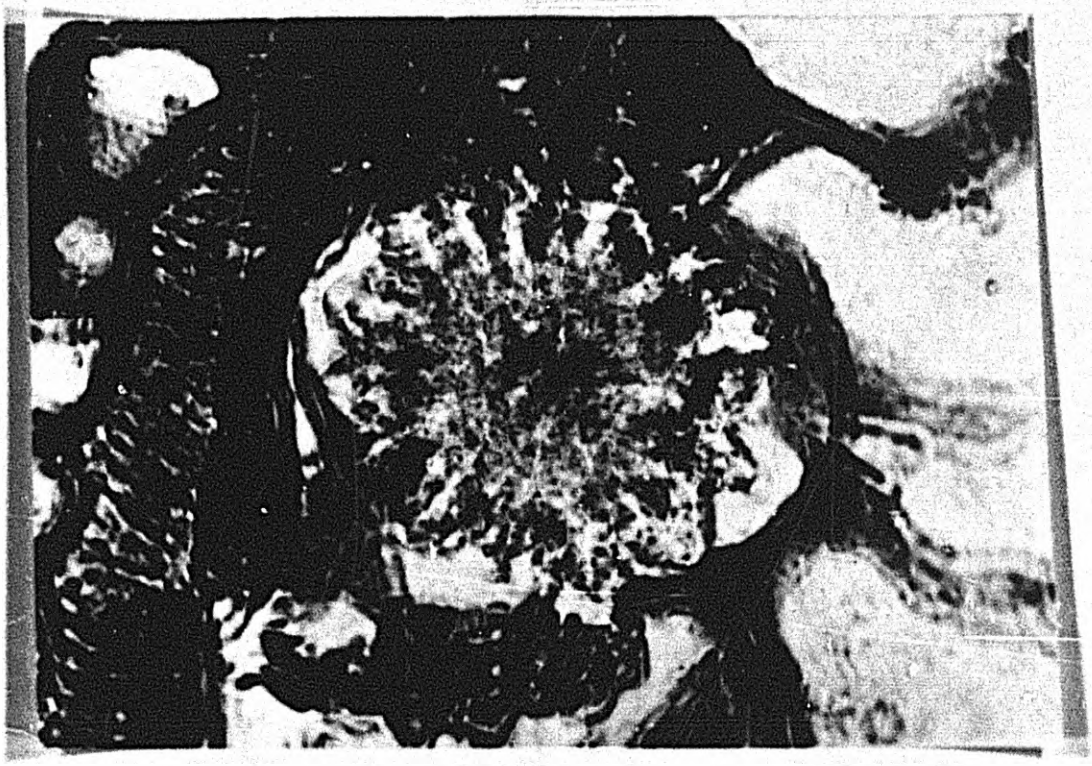

Figure 8. Photomicrograph of the crystal formation within the plant cell (430X).

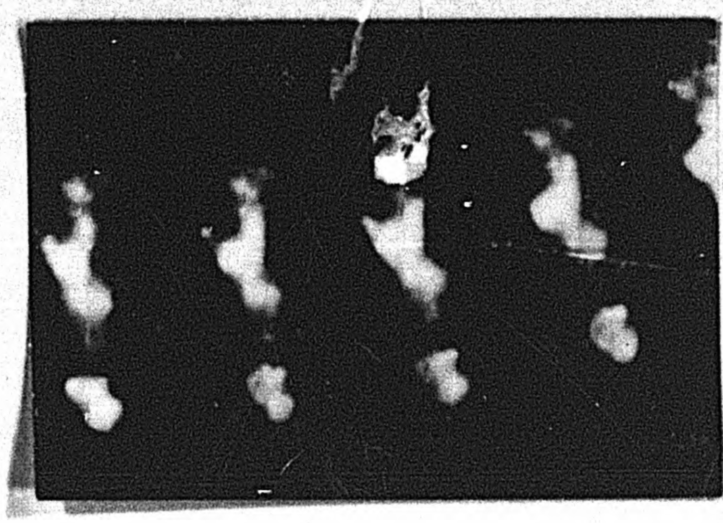

Figure 9. Autoradiograph of longitudinal sections of a growing tip showing activity in all tissue (2X). Type K x-ray film.

TABLE 3

THE RESULTS OF RADIOCHEMICAL ANALYSES OF SOIL SAMPLES

COLLECTED AT THE THREE AND ONE-HALF AND FOUR FOOT DEPTHS

Radioactive Elements*	DEPTH							
	3½ Feet				4 Feet			
	Beta Activity				Beta Activity			
	Sample 1		Sample 2		Sample 1		Sample 2	
	µc per gram	per cent	µc per gram	per cent	µc per gram	per cent	µc per gram	per cent
$Strontium^{90}$	~0.007	~27	~0.04	~3	~3.3	~25	~18.0	~20
$Yttrium^{90}$	~0.007	~27	~0.[illegible]	~3	~3.3	~25	~18.0	~20
$Cerium^{144}$ $Praseodymium^{144}$	~0.003	~10	~0.7	~58	~3.8	~29	~20.0	~23
$Cesium^{137}$	< 0.001	< 2	< 0.01	<1	~2.1	~16	~30.0	~34
$Ruthenium^{106}$ $Rhodium^{106}$	~0.01	~39	~0.3	27	~0.5	~3	~4.0	~4
$Zirconium^{95}$			0.04	~3			< 0.9	<1
Rare Earths (other than those listed)			0.01	<1			0.9	<1
Total Activity	~0.2	~105	~1.2	96	~13.1	~98	~90.0	~103

* Strontium and zirconium were counted without their daughters, whereas cerium and ruthenium were counted with their daughters.

DISCUSSION

The finding that Russian thistle plants absorb and translocate strontium, is in agreement with the results of Jacobson's and Overstreet's studies on the absorption and translocation of this element in barley and dwarf pea plants. Indications are, however, that Russian thistles can absorb and fix much higher amounts of radioactivity than barley or dwarf pea plants. In addition, the Russian thistle plants were not damaged to any detectable extent by the high radiation doses whereas Jacobson and Overstreet noted marked damage to their plants. This difference in results is assumed to be attributable to species differences, but the age of the plants at the time absorption took place may also have been a factor. The lack of damage may also be due to the fact that only part of the root system was exposed to radioactivity.

A comparison of the radioactive elements in the Russian thistle plants and those in the soil shows that the plants absorbed a very small amount, if any, of the elements ruthenium, cesium, and cerium, suggesting either that the thistle plants are selective against the absorption of these elements or that a part of the apparent selectivity against these elements might be due to their unavailability in the soil. Yttrium being present in the plant as a daughter of strontium made it impossible to determine whether it was absorbed by the plant.

The radiation hazards from the soil prevented the removal of complete root systems of the radioactive thistle plants. The actual depth of root penetration is therefore not known. However, the beta activity of the soil at the different levels and the information on the build-up of activity in the plant indicates that the penetration was three and one-half feet or more.

There were no indications that the morphology or growth habits of the aboveground parts of thistle plants were affected by the radiation received from the absorbed radioactivity. The leveling off in the amount of activity fixed by the plants after the initial surge tends to indicate that radiation damage to the absorbing roots may have occurred.

The fact that no visible differences could be found between the cells in the growing tip having an activity of 7.1 microcuries and the cells in the growing tip with less than 1×10^{-5} microcurie per gram is of interest. If it is assumed that strontium, and yttrium constitute all the activity present in the cells, the average energy would then be about 0.5 mev and the tissue of the growing tip received a dose rate of approximately 100 rep per day. In case of the secondary root with an activity of 30 microcuries per gram, the tissue received approximately 300 rep per day since much of the energy of the beta particles were expended in relatively inactive soil surrounding the secondary roots, which were less than one millimeter in diameter.

The role of plants in bringing sub-surface contamination to the surface emphasizes the need for proper control of plants growing in a contaminated area. It may be recommended that plants growing in an area containing radioactive elements be killed by spraying at appropriate intervals with an effective weed-killer.

SUMMARY

An investigation of the Russian thistle growing in the R-3 danger zone, near the 271 Building, 200-East Area has shown that:

1. Russian thistle has the ability to absorb and translocate the fission product strontium from the soil; and the plant may be selective

against the absorption and translocation of the fission products ruthenium, cesium, and cerium.

2. The active elements are not distributed in the same concentration to all plant parts nor to like parts in the same plant.
3. The concentration of active elements in the flowering parts is higher than it is in stems, leaves or bracts.
4. The presence of 10 microcuries of radioactivity per gram has no visible effects on the growth habits of the thistle under the conditions of this investigation.

ACKNOWLEDGMENTS

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