PLANT IODINE-131 UPTAKE IN RELATION TO
ROOT CONCENTRATION AS MEASURED IN MINIRHIZOTRON
BY VIDEO CAMERA: STATUS REPORT FOR FY 1989

K. J. Moss

September 1990

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

SUMMARY

Glass viewing tubes (minirhizotrons) were placed in the soil beneath native perennial bunchgrass (*Agropyron spicatum*). The tubes provided access for observing and quantifying plant roots with a miniature video camera and soil moisture estimates by neutron hydroprobe. The radiotracer I-131 was delivered to the root zone at three depths with differing root concentrations. The plant was subsequently sampled and analyzed for I-131. Plant uptake was greater when I-131 was applied at soil depths with higher root concentrations. When I-131 was applied at soil depths with lower root concentrations, plant uptake was less. However, the relationship between root concentration and plant uptake was not a direct one. When I-131 was delivered to deeper soil depths with low root concentrations, the quantity of roots there appeared to be less effective in uptake than the same quantity of roots at shallow soil depths with high root concentration.

Key finding for FY 1989 are listed below.

- Installation of minirhizotrons by slurry and backfill in silt loam soils at the Arid Lands Ecology Reserve was ineffective due to compaction at the soil tube interface. A more effective installation involved closer matching of the hole and minirhizotron dimensions, eliminating the need for backfilling. By lowering a miniature video camera into the minirhizotron, root concentration was quantified by root counting and calculation of root length density.
- Following I-131 uptake by the plant, the activity was not distributed homogeneously in the above-ground plant material. I-131 activity was greatest in the plant part nearest to the location where the radiotracer was applied. It appears the small fraction of roots that had access to the radiotracer, translocated the I-131 to a small portion of associated above-ground plant material.

ACKNOWLEDGMENTS

The author wishes to express sincere appreciation to Dr. L. L. Cadwell, Joe Harris, Pete Test, and Larry M. Moss for their unfailing encouragement and support, especially during the arduous field work. A special thanks to Charles A. Westlund for his ideas and contacts which made the video camera available; and Dr. J. H. Richards and Dr. S. O. Link for their direction and advice regarding the use of minirhizotrons. Thanks also to Jerry Powers, Bobbie Webster and Roger Terpstra whose many years of valuable experience in handling and analysis of radioisotopes resulted in a safe and sound operation.

CONTENTS

SUMMARY	iii
ACKNOWLEDGMENTS.	v
INTRODUCTION	1
PROBLEM	1
PURPOSE	3
METHODS AND MATERIALS	5
APPROACH	5
MINIRHIZOTRON	5
VIDEO CAMERA AND VIDEO CASSETTE RECORDER (VCR)	8
SOIL MOISTURE	10
PLANT SPECIES	12
ROOT OBSERVATIONS	13
RADIOTRACER APPLICATION	15
PLANT SAMPLING AND ANALYSIS	18
RESULTS AND DISCUSSION	19
ROOT OBSERVATIONS	19
PLANT UPTAKE ANALYSIS	22
SOIL MOISTURE	28
MINIRHIZOTRON	30
VIDEO CAMERA AND VCR	30
CONCLUSIONS	33
REFERENCES	35
APPENDIX A - PLANT IODINE-131 UPTAKE IN RELATION TO ROOT CONCENTRATION AS MEASURED IN MINIRHIZOTRON BY VIDEO CAMERA	A.1

FIGURES

1	Depiction of Minirhizotron Observation Tube for Viewing Plant Roots and Access Pipe used to Deliver I-131 Solution to the Root Zone.	7
2	Neutron Hydroprobe Calibration to Establish the Relationship between Hydroprobe Counts and Percent Gravimetric Soil Moisture so that Subsequent Hydroprobe Counts could be used to Estimate Soil Moisture.	11
3	Photograph (of a Projection from Video Tape) of Root Observations as taken via Minirhizotron with Video Camera. The Light Straight Vertical Line near the Center is a Reference Line on the Minirhizotron and the Remaining Light Lines are Roots Intersecting the Minirhizotron.	14
4	April 27 Individual RLD (from Root Counts) and Individual Plant I-131 Activity for 15 Tubes.	24
5	April 27 Mean Plant I-131 Activity, Mean RLD for 5 Tubes, and Mean RLD for 15 Tubes.	25
6	April 27 Mean RLD for 15 Tubes and Mean Plant I-131 Activity for Samples Nearest the Access Tube taken April 27 and May 11. April 27 Activity has been Time Corrected to May 11.	28

TABLES

1	Preliminary Soil Moisture Estimates by Neutron Hydroprobe before and after the Application of 100 ml I-131 Solution for 4 Hydroprobe Measurements at Each Depth (n=4).	12
2	April 12 Root Counts were taken by Video Camera for 10 Tubes and Mean RLD was Calculated to Identify Depths with Distinctively Different RLD for Radiotracer Application (i.e., 21 cm, 48 cm and 84 cm).	16
3	April 22 Initial Individual Tube RLD and Mean RLD Calculated by $RLD=N/A$ or RLD Equals Root Counts (N) Divided by Tube Area (A) for I-131 Application Soil Depths of 21, 48, and 84 cm.	20
4	April 27 Final Individual Tube RLD and Mean RLD Calculated by $RLD=N/A$ or RLD Equals Root Counts (N) Divided by Tube Area (A) for I-131 Application Soil Depths of 21, 48, and 84 cm.	21
5	April 27 Plant I-131 Activity (cpm) for Clippings at 3 Plant Locations (i.e., Nearest Radiotracer Access Pipe, at the Plant Center, and Farthest from the Access Pipe).	23
6	April 27 Individual RLD and Individual Plant I-131 Activity from Samples Nearest the Access Pipe with 30 cpm/g Background Subtracted.	23
7	April 27 Mean RLD from 15 Tubes, Mean RLD for 5 Tubes, and Mean Plant I-131 Activity for 3 Radiotracer Application Soil Depths.	24
8	May 11 Gross Plant I-131 Activity for Each of 15 Plants Clipped at 4 Different Plant Locations (i.e., Combining Center Clipping with Clippings from 4 Compass Points at Plant Circumference, Clipping Nearest the I-131 Access Tube, Clipping at the Plant Center, and Clipping Farthest from the Access Tube).	26
9	May 11 Plant I-131 Activity from Clippings taken Nearest the I-131 Access Pipe with 30 cpm/g Background Subtracted. From Table 6, April 27 Plant I-131 Activity for the same Sampling Location, Time Corrected to May 11 for Comparison Using $A_t=A_0e^{-\lambda t}=(A_0)\cdot(0.2973)$	27
10	Mean RLD for 15 Tubes (from April 27 Root Counts) at 3 Radiotracer Soil Depths and Mean Plant I-131 Activity from Samples Nearest the Access Tube taken April 27 and May 11. The April 27 Activity has been Time Corrected to May 11.	27

11	The Percent Increase or Decrease in Neutron Hydroprobe Counts (Taken at Soil Depths of 30, 45, 80 and 125 cm) from Measurements Taken April 22 and 27.	29
A.1	April 12 Root Counts Taken by Video Camera for Tube Numbers 1-10 (n=10) at 10 cm Tube increments.	A.1
A.2	Plant Uptake of I-131 with Different KI Carrier Treatments. . . .	A.2
A.3	April 22 Root Counts Taken by Video Camera for Each Tube at 10 cm Tube Increments.	A.3
A.4	April 27 Root Counts Taken by Video Camera for Each Tube at 10 cm Tube Increments.	A.4
A.5	April 27 Plant Wet to Dry Weight Conversion Determination by Weighing, Drying and Reweighing for 6 Plant Samples.	A.5
A.6	April 27 Plant I-131 Activity, Measured Plant Sample Wet Weight, Calculated Plant Dry Weight, and Wet to Dry Weight Conversion. .	A.6
A.7	May 11 I-131 Plant Activity, Measured Plant Sample Wet Weight, Calculated Plant Dry Weight, and Wet to Dry Weight Conversion. .	A.7
A.8	Neutron Hydroprobe Readings for 15 Tubes Taken April 22 and April 27 at Vertical Soil Depth Locations of 30, 45, 80, 125 cm.	A.8

INTRODUCTION

PROBLEM

Liquid and solid radioactive wastes are produced during various stages of the nuclear fuel cycle. In the past, some of these wastes were disposed of just below grade in solid waste trenches and liquid waste drain fields. These types of disposal generally resulted in a non-uniform distribution of radioactive waste material in the soil.

Pathway analysis and dose assessment models for radionuclides are used to evaluate radioactive waste management practices. The BIOPORT model calculates a quantity of radioactive material that is incorporated into plant tissue as a result of plant roots penetrating an overburden of originally clean soil and intruding into the waste zone (McKenzie et al., 1984). Soil-to-plant concentration factors (Ng et al., 1982), or concentration ratios (CRs), are used to calculate the quantity of a particular radionuclide expected to accumulate in the plant tissue, based on a specified quantity of that radionuclide in the soil. The CR is calculated as follows (Rickard and Klepper, 1976):

$$CR = \frac{\text{plant radioactivity per gram of plant}}{\text{soil radioactivity per gram of soil}}$$

The CRs used in models are typically determined in the laboratory and radionuclides are mixed uniformly throughout the soil volume. Not all experimental designs determining concentration ratios have used identical plant root configurations relative the volume of contaminated soil. These configurations may result in all the roots in contact with the nuclide or the surface roots contacting the radioactive material and some small percentage of the deeper roots extending beyond the contaminated zone. Additionally, the CR of an isotope varies in a complex manner with soil texture, cation exchange capacity, exchangeable calcium, exchangeable potassium, pH, and organic matter. The CR varies with plant variety, stage of growth, plant part, and experimental conditions such as the manner in which the isotope is introduced into the soil (Ng et al., 1982).

In natural systems, genetic and environmental factors operate to produce great variability in the form of plant root systems. Root system development

is a process in which expression of the potential, genetically determined root morphology is usually controlled more by the physical properties of the soil and the environmental conditions during the growth of the plant than by the genetic constitution of the plant. This allows the plant to adapt to a range of growing conditions. Environmental factors controlling root development include water, nutrient availability, temperature, and soil physical characteristics such as pore size, hardness, and aeration. In most plant communities, plant root systems sample the upper meter (or two) of soil. Fewer roots are found at greater depths and the importance of these roots in uptake is probably small. Data verifying this are limited (Richards, 1986).

Rooting depth affects the degree of plant uptake of radioisotopes from soil if the entire soil profile is not contaminated (Christenson and Fowler, 1961). Roots must have access to soil nutrients if uptake is to occur (Klepper, 1983). Earlier studies indicated plant removal of radioisotopes from soil was regulated by the number of particles that were in contact with the root-absorbing surface (Albrecht, 1942).

The configuration of plant roots at shallow-land burial facilities is different from the configuration used to obtain estimates of plant uptake of radioactive materials. Under waste burial conditions the waste zone occurs well below the soil surface because one or two meters of uncontaminated backfill soil is used as cover (Hakonson, 1982). Deep-rooted plants that may become established on a burial site will have most roots in the nonradioactive backfill soil and only relatively few in the deeper soil containing radioactive waste. It is questionable whether or not conventional CRs can be applied to the waste burial site root-waste configuration. Napier (1982) assumed that plants having some fraction of roots in the waste zone accumulated radioactivity in proportion to the fraction of roots that actually encounter waste. But for some elements used in trace amounts by plants, a few roots may be as effective in plant accumulation of contaminants as would the entire root mass. No answers to these questions are found in scientific literature.

The dose assessment model (McKenzie et al., 1984) recognized this condition and dealt with it by providing two options. Model 1 calculates plant uptake independently of the fraction of roots in the waste. It assumes

a few deep roots contact the radioactive waste and permit the plant to accumulate the same quantity of radioactivity as would be accumulated if all the roots were in contact with the waste. Plant Model 2 effectively reduces the calculated concentration of radioactivity in the plant material in proportion to the fraction of the plant roots in the waste zone (McKenzie et al., 1984). Model 1 (more conservative) is recommended when there is uncertainty as to whether or not plant roots uptake radioactive material in proportion to root mass in the waste zone.

PURPOSE

The purpose of this investigation was to evaluate plant uptake and root density relationships for natural systems. Radioisotope uptake occurs when active absorbing roots contact soil containing radioactive material and the environmental conditions are adequate. In natural systems, root distribution varies with soil depth and plant root density is greater in shallow soil depths. This variation in root density with soil depth presents the opportunity to evaluate radionuclide uptake by plants as a function of root density.

METHODS AND MATERIALS

APPROACH

To study plant uptake and root concentration, a mature stand of fibrous-rooted plants was identified that could be utilized and observed during their active growing season. Additionally, a radioisotope to trace uptake was made available to the roots of these plants. This isotope was administered to differing root concentrations at the same time. Once uptake occurred, radio-tracer concentrations in plant tissues were measured.

To identify areas of differing root concentrations, root density was measured with a non-destructive technique using minirhizotrons (McMichael and Taylor, 1987). Glass viewing tubes (i.e., minirhizotrons) were placed in the soil beneath the plants. By inserting a miniature video camera, root counts were recorded (Brown and Upchurch, 1987). These root counts were used to determine root length density or length of root per volume of soil. Normally, root density decreases with soil depth so specific depths could be identified with distinctly different root densities. The radiotracer was administered at these soil depths, in order to study any difference that might occur in plant uptake.

Root growth and configuration are strongly influenced by available soil moisture. The radiotracer was administered in solution. For these reasons, a non-destructive measure of soil moisture was made using a neutron hydroprobe.

At soil depths for which differing root densities had been determined, a known amount of radiotracer was administered. After a period of plant growth and uptake, plants were sampled and analyzed for radiotracer concentration. The relationship between root density and plant uptake was evaluated.

MINIRHIZOTRON

A transparent tube that intercepts a portion of a plant root system growing in soil and is used to observe roots is referred to as a minirhizotron. Bates (1937) first described the use of glass tubes inserted in the soil to observe root growth. This method was mentioned again in the literature in 1971 when Waddington described a similar technique for observing

the growth of wheat roots. Since then both glass and acrylic tubes have been used (Vos and Groenwold, 1983; Bragg et al., 1983). Minirhizotron tubes have ranged in diameter from 6 to 150 mm depending on available soil coring devices and root observing devices to be used. The dominant size for round tubes is 50 mm (Brown and Upchurch, 1987). Most tubes have been round and marked at various intervals (McMichael and Taylor, 1987).

Glass viewing tubes (minirhizotrons) were fabricated from 5.1 cm outside diameter glass stock. This diameter was chosen to allow miniature video camera and neutron hydroprobe access; accommodate the camera field of view (i.e., 2.4 cm width); and provide adequate surface area for root intersection. The tubes were 182 cm in length to enable viewing at the lower limits of rooting for *Agropyron spicatum*. One end of the tube was closed (bottom). The other end was left open and a rolled lip formed (top). The tubes were marked the full length with one longitudinal line. Horizontal divisions were marked every 10 cm, beginning at the tube top. These were numbered and used for reference once the tube was in the ground (Upchurch and Ritchie, 1983).

The most critical part of the minirhizotron technique is the installation of the observation tube. The tube must contact the soil enough to minimize voids at the soil tube interface, but the tube wall should not be smeared or broken by forcing it into a hole that is too small (Brown and Upchurch, 1987). Installation angles of observation tubes relative to the soil surface have varied from vertical to horizontal.

Upchurch and Ritchie (1983) installed tubes at an angle of 30 degrees from vertical to limit roots following the tubes. Bragg et al. (1983) and Vos and Groenwold (1987) evaluated the inclination angle of minirhizotrons and found angled tubes minimized root growth down the interface that occurred in vertical tubes.

Two tube installation methods were used. For the initial method, a soil auger was used to core a hole at a 30 degree angle to the vertical, beneath each plant (Bragg et al., 1983). Each hole was started at 15 cm from the base of the plant and extended beneath the center of the plant (See Figure 1). A tube was inserted into each hole with the longitudinal line facing upwards. A slurry of water and sieved soil (removed during coring) was backfilled around

FIGURE 1. Depiction of Minirhizotron Observation Tube for Viewing Plant Roots and Access Pipe used to Deliver I-131 Solution to the Root Zone

the tube to eliminate voids at the soil tube interface (Richards, 1984). Root proliferation in the soil tube interface voids could result in nonrepresentative root counts (Taylor and Bohm, 1976). About 14 cm of the tube extended above the soil surface and was taped with dark tape.

An opened aluminum can (which extended to the soil surface) was placed over the tube top to further exclude light and minimize adverse effects on root growth (Pearson, 1974). The cans also kept debris out of the tubes.

Root growth observations for the 1987 growing season were limited and tubes were removed from the soil, cleaned, and remarked. It was determined that root growth at the soil tube interface was inhibited due to compaction from installation backfilling (Upchurch, 1987).

For the 1988 field season, a different installation method was used to eliminate the need for backfilling around the tube. A jig was devised to hold the soil auger and to facilitate the coring of straight, smooth holes at a consistent 25 degree angle. In addition, the soil auger was modified to core a hole approximately the same size as the outside glass tube diameter. A soft brush on a long handle was used to loosen and scarify the packed soil wall (Maertens, 1987). The tubes were inserted in the holes with the longitudinal line facing upwards. A shim was placed between the soil and backside of the tube to force the topside of the tube tightly against the soil. This was done to minimize void spaces at the soil tube interface. A total of 21 tubes were installed using this technique. About 27 cm of the tube extended above the soil surface. This was taped with dark cloth tape. A soil fixative was applied around the collar of the tube where it entered the ground to limit water entry. A metal cover was placed over the tube top to exclude light and keep moisture and debris out of the tube. The metal cover extended to the soil surface.

VIDEO CAMERA AND VIDEO CASSETTE RECORDER

Many different devices have been used to observe roots that intersect minirhizotrons. With each of these tools, light must be provided inside the tube and the image transferred to the surface (Brown and Upchurch, 1987). Viewing equipment that has been used includes a mirror mounted on a pole with

a lamp (Bates, 1937), fiber optic bundles (Waddington, 1971), a duodenoscope with fiber optics (Sanders and Brown, 1978), rigid borescope (Upchurch and Ritchie, 1983), and video cameras (Upchurch and Ritchie, 1984). Video cameras and viewing scopes (e.g. endoscopes, duodenoscopes, arthoscopes, cystoscopes) give the clearest picture, best detail, and ample magnification.

Originally in this study a borescope made over 15 years ago by American Cystoscope Makers, Inc. was used to view roots in the minirhizotrons. The scope could only be viewed with one eye directly on the eyepiece. There was no magnification and the optics were poor resulting in a view that lacked clarity and detail.

Next a Westinghouse black and white miniature video camera, Model ETV 1253, was used in the minirhizotron to view the root zone. The unit was powered by a solar collection and battery storage system used in conjunction with an inverter. The miniature camera head was 3.8 cm in diameter and allowed for viewing at 90 degrees to the vertical. The camera head was attached to about 25 feet of cable. The cable connected the camera to the control unit and monitor. The monitor was 7.5 cm wide and the camera field of view 2.4 cm wide, resulting in about a three times magnification. A shroud or sun shade was used around the monitor to improve viewing in strong sunlight. The focus and rotation controls were located on the control unit.

Three methods have been used for permanently recording observations of roots in minirhizotrons. Hand-drawn pictures of intersecting roots were originally used (Waddington, 1971). Sanders and Brown (1978) connected their duodenoscope to a 35-mm reflex camera to photograph intersecting roots. Dyer and Brown (1980) recorded images of intersecting roots using a video camera attached to a duodenoscope.

A portable Panasonic VCR was used in this study to record root observations. The unit could be powered by AC or DC, but was generally used on the internal battery system. The format was one-half inch VHS. Recordings were used for backup counting and demonstration purposes.

SOIL MOISTURE

A Campbell Scientific neutron hydroprobe was used to estimate soil moisture. The neutron hydroprobe consists of three main parts, the probe, about 2 m of electrical cord, and the control unit. The probe is connected to the control unit by the electrical cord. The probe is comprised of a neutron source and radiation detector. The control unit has a power switch, count initiator button, counting system, and digital readout of counts. The probe normally resides in the shielded well that is attached to the control unit. When in use, the probe is dispatched from the shielded well into the minirhizotron. Neutrons from the source (Americium/Beryllium) are projected into the area surrounding the probe. Counting is initiated via the button on the control unit. Hydrogenous material (e.g., soil moisture) surrounding the probe and neutrons interact (neutrons are moderated). The resulting radiation is measured by the radiation detector in the probe (Boron Trifluoride). The detector sends the signal to the counting system in the control unit. Counts are displayed on the digital meter.

Prior to use, the hydroprobe was calibrated with actual soil samples to correlate hydroprobe readings and actual percent gravimetric soil moisture. This calibration ranged from approximately 9% to 15% actual gravimetric soil moisture. Soil samples were taken with an auger, oven dried (for 24 hours at 110 degrees Centigrade), and reweighed. Neutron hydroprobe readings were taken at the same soil location but prior to the actual soil sampling process. Percent gravimetric soil moisture [$\% = (\text{wet-dry}/\text{dry}) \cdot 100$] was calculated for the actual soil samples (Gardner, 1986). A graph of hydroprobe counts and percent soil moisture was developed (Figure 2). From this graph, an estimate of percent soil moisture could be made for a given hydroprobe count.

During preliminary field tests, the difference in soil moisture before and after the application of 100 ml I-131 solution was evaluated by neutron hydroprobe (See Table 1). This was done to determine when neutron hydroprobe readings should be taken to best represent soil moisture conditions. There didn't appear to be any significant difference in hydroprobe readings before and after I-131 solution application.

FIGURE 2. Neutron Hydroprobe Calibration to Establish the Relationship Between Hydroprobe Counts and Percent Gravimetric Soil Moisture so that Subsequent Hydroprobe Counts Could be Used to Estimate Soil Moisture

During the actual study, soil moisture estimates by neutron hydroprobe were made prior to the application of I-131 solution. Neutron hydroprobe readings were taken April 22 (day of I-131 application) and April 27 (day of plant sampling). With soil moisture estimates for day 0 and day 5, change in moisture was evaluated relative to plant transpiration and growth for 5 days in the presence of I-131.

TABLE 1. Preliminary Soil Moisture Estimates by Neutron Hydroprobe Before and After the Application of 100 ml I-131 Solution for 4 Hydroprobe Measurements at Each Depth (n = 4)

<u>Vertical Soil Depth (cm)</u>	<u>Hydroprobe Counts Before Solution</u>	<u>Hydroprobe Counts After Solution</u>
30	1198 (± 39)	1183 (± 4)
45	1349 (± 5)	1396 (± 46)
80	1694 (± 70)	1707 (± 52)
125	1707 (± 15)	1723 (± 43)

PLANT SPECIES

The plant species chosen for this study was *Agropyron spicatum*, a native perennial bunchgrass of the Columbia Basin in Washington state. The climate of the basin is characterized by moderately cold winters and warm to hot summers. Effective precipitation is mainly in the cold season, with rains starting about the time frost comes in autumn (Daubenmire, 1970). This grass species exhibits greatest growth during fall and spring with the onset of adequate soil moisture and temperature. It is a drought resistant plant found in dry soils.

Typically plant height ranges from 60 to 100 cm (Hitchcock, 1971). The roots are fibrous with little variation in diameter. Rooting depth in soil does not usually extend beyond 150 cm. The uniform size of the roots and the presence of roots within range of the minirhizotron were advantageous for the purposes of this study.

The study took place at the Arid Lands Ecology (ALE) Reserve, northwest of Richland, Washington. The original study site vegetation was sagebrush/ bunchgrass that burned in 1981, and presently supports a plant community dominated by *Agropyron spicatum*, a native perennial bunchgrass. The study was conducted during April and May when this plant was actively growing. The soil is a silt loam.

ROOT OBSERVATIONS

Four approaches have been reported for quantifying the intersections between roots and the observation tubes. They include hand-drawn pictures of the intersecting roots; measuring root length in contact with the root observation tubes; counting the number of roots growing against the observation tubes; and counting the number of roots in contact with the observation tube within a given area of the tube (Upchurch, 1987). The last method (i.e., counting the number of roots in contact with the observation tube within a given tube area) minimizes the effect of the interface on results. The number of individual roots that arrive at the interface is quantified, independent of any property expressed by the root after intersection. This was the method used in this study.

For root observations a video camera was lowered into each minirhizotron and the longitudinal line traced. Roots that intersected the tube within the 2.4 cm wide strip (i.e., camera field of view width) were counted (see Figure 3). The counts were recorded for each 10 cm length segment on the tube. Roots were not counted above the 20 cm depth because actual root length and root-count-determined root length correlate poorly at shallow depths (Bragg et al., 1983).

One count was recorded for each root. Counts were independent of the length or diameter of the root at the interface. Branched roots received one count for the primary root and an additional count for each branch. Whenever a root crossed a horizontal depth line (i.e., 10 cm increment), it received one count for each depth interval (Upchurch and Ritchie, 1983).

Upchurch and Ritchie (1983) proposed an equation to relate the number of roots at the interface to the root length density in the surrounding soil. The density of roots in surrounding soil determines the number of arrivals of roots at the interface. The length of root at the interface is a function of both the arrival of the root and the growth of the root after the intersection.

Root counts obtained by this technique were used to determine root length density (RLD) or length (cm) of root per volume (cubic cm) of soil (Upchurch and Ritchie, 1983). The $RLD = Nd/Ad$ (or N/A) where N = number of

FIGURE 3. Photograph (of a Projection from Video Tape) of Root Observations as Taken Via Minirhizotron with Video Camera. The light straight vertical line near the center is a reference line on the minirhizotron and the remaining light lines are roots intersecting the minirhizotron

intersecting roots, A = area of the tube observed, and d = outside tube diameter (i.e., 5.1 cm). In using this equation it is assumed that roots growing, intersect the tube at various angles with equal probability; and the average length of root displaced by tube, if the roots could continue to grow, would be equal to the tube outside diameter. Each root intersection then corresponds to a root length d , therefore the total root length displaced is Nd . The volume associated with this length is Ad .

Upchurch and Ritchie (1983) report that minirhizotron observations and soil core estimates of rooting are highly correlated when a number of tubes are averaged. When the number of tubes was increased from 2 to 8, the correlation coefficient (r) increased from 0.17 to 0.80. However, the variance for minirhizotron observations is high; therefore a large number of tubes is

required to detect small differences in rooting. This high variability is not related to limitations in the techniques used for studying roots but to inherent properties of the soil-plant system (Upchurch, 1987). The soil properties are not uniform throughout the profile because planes of weakness exist in structured soil. Roots tend to follow the path of least resistance as they grow throughout the soil; therefore roots are not uniformly distributed. Sampling techniques are designed to obtain an average value for root length density by observing the density at a finite number of points resulting in high variances.

Root counts were made April 22, the day of I-131 application to the root zone and five days later at the time of plant sampling, April 27. Root counts were made at these times in order to determine root growth during the period of I-131 uptake by the plants. Root counts were taken along each of 15 tubes at 10 cm increments for associated vertical soil depths ranging from 21 cm to 129 cm.

Ten days before radiotracer application (April 12), root counts were taken at each depth for 10 tubes. Appendix A gives root count data. From this data, mean RLD was determined for 10 tubes; and used to identify specific soil depths for I-131 application with distinctly different RLD (see Table 2). The soil depths of 21 cm, 48 cm, and 84 cm were identified as having distinctively different RLD; and five replicate tubes were assigned to each soil depth for application of I-131 solution.

RADIOTRACER APPLICATION

I-131 was the radiotracer chosen for the study because it is chemically available from soil to plant, has a short half-life (i.e., 8 days), and is energetic enough to be detected without laborious sample processing but can be easily shielded for field use (Price, 1965). Preliminary field tests were performed with small amounts of I-131 that were on hand from other experiments. For the actual soil application, 10 milliCuries of I-131 were specially ordered. The assay date was April 5, 1988 and it came as sodium iodide in 0.02667 ml basic solution. Throughout the process of dilution, the I-131 solutions were kept at pH greater than 8 with NaOH to limit volatilization.

TABLE 2. April 12 Root Counts Were Taken by Video Camera for 10 Tubes and Mean RLD was Calculated to Identify Depths with Distinctively Different RLD for Radiotracer Application (i.e., 21 cm, 48 cm and 84 cm)

<u>Vertical Soil Depth (cm)</u>	<u>Mean RLD (cm/cm³)</u>
21-30	0.20
30-39	0.23
39-48	0.12
48-56	0.10
56-66	0.06
66-75	0.07
75-84	0.03
84-93	0.05
93-102	0.03
102-111	0.04
111-120	0.05
120-129	0.02

$$A = \text{Area} = (2.4 \text{ cm}) \times (10 \text{ cm}) = 24 \text{ cm}^2$$

$$D = \text{diameter} = 5.1 \text{ cm}$$

N - See Appendix A

$$\text{RLD} = N_d/A_d = N/A$$

In preliminary field tests, 200 microCuries I-131 was diluted in 50 ml of NaOH. This solution was administered to one plant. Uptake was not measurable after 5 days of growth. Earlier studies indicated that uptake could be enhanced in the presence of carrier (Price, 1965). A laboratory study was conducted that evaluated I-131 uptake in relation to the presence of different amounts of KI carrier. Six pots of cheatgrass were grown in a growth chamber to about 20 cm height. An access pipe was inserted in the soil of each pot and solution of I-131 was pipetted into each access pipe. After the radiotracer was added, a chaser solution was pipetted into the access pipe. The treatments included I-131 and no carrier (only NaOH); I-131 in 5 ppm KI, chased by 2 ppm KI; I-131 in 5 ppm KI, chased by 5 ppm KI; I-131 in

5 ppm KI, chased by 10 ppm KI; no carrier or I-131 (only NaOH); and 5 ppm KI and no I-131. After 5 days of growth the plants were sampled and counted. Uptake was greatest for the treatment of I-131 in 5 ppm KI, and 10 ppm KI chaser (See Appendix B). It was decided to dilute I-131 in basic 10 ppm KI carrier solution. This would facilitate uptake but without the use of large amounts of the radioactive I-131. Contamination and human dose potentials would be minimized.

Three depths were identified for root zone application of I-131 solution: 21 cm, 48 cm, and 84 cm. At these depths, root densities were distinctively different as determined by video camera root counting technique completed April 12 (See Table 2 for RLD and Appendix A for field data). In order to study uptake as a function of the root density, it was necessary to apply the radiotracer at different RLD.

A 2 cm diameter soil auger was used to core a hole adjacent to each plant. The hole was located so that the bottom of the access pipe was in the nearest vicinity to the minirhizotron where root counts were taken. A 2 cm diameter access pipe was inserted in each hole (See Figure 1). The radiotracer solution was poured down each access pipe.

Radiotracer solutions were placed in separate polybottles. Each bottle contained 100 ml solution of 280 microCuries of I-131 in 10 ppm KI. Bottles were prepared and transported to the ALE site. One bottle of radiotracer solution was drained into each access pipe and the pipe was stoppered. This was completed for fifteen plants or five replicates at each of the three depths.

The I-131 solution was applied at predetermined soil depths of 21 cm, 48 cm, and 84 cm. After vegetation sampling and root counting were complete, the area around the two access tubes was excavated to determine generally the extent of soil that was wetted by the 100 ml of I-131 solution. Portable GM and Ludlum radiation detection instruments were used to survey the soil as it was removed.

Destructive sampling indicated that the solution wetted to a depth of approximately 7 cm below the bottom of the access pipe. The lateral spread

was about 5 cm. The RLDs of concern, at the points of radiotracer application are included in the segments immediately below the 21 cm, 48 cm and 84 cm depth.

PLANT SAMPLING AND ANALYSIS

Five days after administering the radiotracer solution, the plants were surveyed with a Geiger-Mueller (GM) instrument and sampled. About 2 grams of foliage (wet weight) were clipped from the area of the plant nearest to the access pipe. In addition, clippings were taken from other plant locations (e.g., the center of the plant and the plant portion farthest away from the access pipe).

Plant clippings were placed in labelled tare-weighed culture tubes and the tubes were stoppered. For each sample, a wet weight was taken. Samples were counted for 10 minutes in a Model 5230 Packard Auto-Gamma Scintillation Spectrometer. The spectrometer utilized the 364 keV gamma of I-131 that is 82% of total emissions. After counting, six samples were dried and reweighed to determine wet to dry weight conversions. Fourteen days later, the sampling and counting process was repeated.

RESULTS AND DISCUSSION

ROOT OBSERVATIONS

On the day of I-131 application, root counts were taken to obtain the initial root density for each of the 15 tubes (See Appendix C). Tube numbers 1 through 18, excepting 5, 13, and 14, were counted. A burrowing animal had disturbed the soil around tube 5. The number 13 was not assigned to any tube. Tube 14 was held as a spare. Root length density was calculated using Appendix C root count data, at the depths of radiotracer application (i.e., 21, 48, and 84 cm) using the equation $RLD=N/A$ or root length density equals the root count (N) divided by the tube area ($A=24\text{ cm}^2$). Table 3 presents the initial RLD and the mean RLD for the three depths. Root length densities at the 21 cm depth ranged from 0 to 0.92 cm/cm^3 ; at 48 cm depth from 0 to 0.67 cm/cm^3 ; and at 84 cm depth from 0 to 0.13 cm/cm^3 .

Five days after I-131 application (when plants were sampled), root counts were taken again to reflect final root density (See Appendix D). Table 4 gives the calculated final RLD for each tube and mean RLD for each of the three soil depths. Root length densities at the 21 cm depth ranged from 0 to 0.92 cm/cm^3 ; at the 48 cm depth from 0 to 0.67 cm/cm^3 ; and at the 84 cm depth from 0 to 0.17 cm/cm^3 .

Over the five day growth period, most root counts remained unchanged. Of the individual counts that changed, 5 increased and 5 decreased. In addition to attributing root elongation to increased root counts, some minor root movement in soil may account for small increases or decreases in root counts. This has been observed in similar studies (Maertens, 1987).

The technique used in this study was not able to determine whether the very small decreases and increases were due to root elongation or root movement. Because the change in RLD over the five day period was very small and in both the positive and negative direction, it is assumed to be insignificant to this study. The only difference in mean root counts between day 0 and day 5 was at the 21 cm depth. At the 21 cm depth the day 0 mean RLD was 0.46 and day 5 was 0.44 (See Tables 3 and 4).

TABLE 3. April 22 Initial Individual Tube RLD and Mean RLD Calculated by $RLD=N/A$ or RLD Equals Root Counts (N) Divided by Tube Area (A) for I-131 Application Soil Depths of 21, 48, and 84 cm

Tube Number	RLD for Vertical Soil Depths		
	21-30 cm	48-56 cm	84-93 cm
1	0.71	0.33	0
2	0.58	0.13	0.08
3	0.17	0.25	0.13
4	0.38	0.04	0
6	0.67	0.04	0.04
7	0.08	0.08	0
8	0.71	0.67	0
9	0.63	0.13	0.13
10	0.83	0.17	0.13
11	0.92	0	0.13
12	0	0	0
15	0.29	0.17	0.04
16	0.17	0.13	0
17	0.33	0.08	0
18	0.50	0	0.04
Mean RLD (cm/cm ³)	0.46 (± 0.29)	0.15 (± 0.17)	0.05 (± 0.06)

TABLE 4. April 27 Final Individual Tube RLD and Mean RLD Calculated by RLD=N/A or RLD Equals Root Counts (N) Divided by Tube Area (A) for I-131 Application Soil Depths of 21, 48, and 84 cm.

Tube Number	RLD for Vertical Soil Depths		
	21-30 cm	48-56 cm	84-93 cm
1	0.71	0.33	0
2	0.42	0.17	0.13
3	0.21	0.25	0.17
4	0.29	0.04	0
6	0.67	0.04	0.04
7	0.08	0.08	0
8	0.63	0.67	0
9	0.63	0.13	0.13
10	0.75	0.21	0.08
11	0.92	0	0.13
12	0	0	0
15	0.29	0.17	0.04
16	0.17	0.13	0
17	0.33	0.08	0
18	0.50	0	0.04
Mean RLD (cm/cm ³)	0.44 (±0.27)	0.15 (±0.17)	0.05 (±0.06)

PLANT UPTAKE ANALYSIS

On the fifth day after the radiotracer solution was introduced to the root zone, the plants were surveyed with a GM radiation detection instrument. Radiation above background could be detected in most plants. Instrument readings ranged from background to 20,000 counts per minute (cpm). Additional surveying with the GM instrument, showed that generally the radioactivity was confined to a portion of the plant closest to the access pipe used for radiotracer solution application. It appeared that the small portion of roots in the radiotracer-containing soil translocated the I-131 selectively to an associated above ground portion of the plant. To verify the field readings, a representative tube from each depth was chosen. Plant samples were clipped from 3 plants from the area of highest activity (adjacent to the access pipe), the middle of the plant, and the area farthest away from the highest activity. These samples were analyzed for I-131 (See Table 5). Activity of the clippings taken at the middle and far plant locations was less than the activity of clippings taken from the area closest to the radiotracer access pipe; confirming that the I-131 in the plant material was not homogeneously distributed after 5 days of growth.

For 15 plants, clippings were taken in the area nearest the access pipe. Samples were counted and weighed. Wet and dry weights were taken for 6 plants to be used in calculating wet to dry weight conversions. Appendix E contains this data and calculations. Appendix F contains the gross plant activity, the measured wet plant sample weight, and calculated dry plant sample weight. From this information, plant activity in cpm/g was calculated by dividing gross I-131 activity by the dry plant sample weight. The individual plant activity and associated individual RLD for the April 27 plant sampling and root counting are presented in Table 6. A plot of the individual RLD and plant I-131 activity is shown in Figure 4.

Information for tubes 9, 12, and 15 are not included in Figure 4 as they have zero intercepts. There doesn't appear to be a particular identifiable relationship between individual RLD and individual plant I-131 activity. However, if the mean RLD and mean plant I-131 activity are calculated for each of the three soil depths where I-131 was applied, a relationship emerges. The

TABLE 5. April 27 Plant I-131 Activity (CPM) for Clippings at 3 Plant Locations (i.e., Nearest Radiotracer Access Pipe, at the Plant Center, and Farthest from the Access Pipe).

Tube Number	Soil Depth I-131 (cm)	Clipping Location and I-131 (cpm)		
		Near	Middle	Far
3	21	109,996	742	24
1	48	72,006	3,081	5,089
10	84	7,856	24	24

TABLE 6. April 27 Individual RLD and Individual Plant I-131 Activity from Samples Nearest the Access Pipe with 30 CPM/G Background Subtracted

I-131 Depth cm	RLD ₃ cm/cm ³	Tube Number	Plant I-131 Activity cpm/g
21	0.21	3	167,903
	0.67	6	36,890
	0.08	7	284,730
	0.17	16	66,123
	0.33	17	75,539
48	0.33	1	77,396
	0.67	8	3,724
	0.13	9	0
	0	12	0
	0	18	1,982
84	0.13	2	562
	0	4	9
	0.08	10	7,997
	0.13	11	47
	0.04	15	0

mean RLD for each depth was calculated (using root counts taken at each of the three depths) for all 15 tubes. From information in Table 6, the mean RLD was calculated using root counts for only the 5 tubes installed at each specified depth. Mean plant I-131 activity was calculated. This is presented in Table 7. The mean RLD calculated for 5 tubes at each soil depth has larger standard deviation and shows a smaller difference in RLD between the three soil depths. The RLD determined for 15 tubes is probably the better estimate. Figure 5 is a graph of mean plant I-131 activity and mean RLD for this April 27 information.

FIGURE 4. April 27 Individual RLD (from Root Counts) and Individual Plant I-131 Activity for 15 Tubes

TABLE 7. April 27 Mean RLD from 15 Tubes, Mean RLD for 5 Tubes, and Mean Plant I-131 Activity for 3 Radiotracer Application Soil Depths

I-131 Depth (cm)	Mean RLD for 15 Tubes cm/cm ³	Mean RLD for 5 Tubes cm/cm ³	Mean I-131 Plant Activity cpm/g
21	0.44 (±0.27)	0.29 (±0.23)	126,237 (±101,271)
48	0.15 (±0.17)	0.23 (±0.28)	16,620 (±34,010)
84	0.05 (±0.06)	0.08 (±0.06)	1,723 (±3,515)

FIGURE 5. April 27 Mean Plant I-131 Activity, Mean RLD for 5 Tubes, and Mean RLD for 15 Tubes

Nineteen days after I-131 application, plants were clipped again to evaluate how much additional uptake occurred. For each plant, four samples were taken. One sample combined clippings from the middle of the plant and from the four compass points at the plant's outer circumference. The remaining 3 samples were taken nearest to the I-131 access tube, at the plant center, and farthest from the access tube. The samples were weighed and counted. Table 8 presents the gross I-131 activity for the four samples taken of each plant. From this it can be seen that I-131 activity is still not

TABLE 8. May 11 Gross Plant I-131 Activity for Each of 15 Plants Clipped at Four Different Plant Locations (i.e., Combining Center Clipping with Clippings from 4 Compass Points at Plant Circumference, Clipping Nearest the I-131 Access Tube, Clipping at the Plant Center, and Clipping Farthest from the Access Tube).

I-131 Soil Depth, cm	Tube Number	Plant I-131 Activity cpm			
		Combined	Near	Middle	Far
21	3	7,963	64,400	66	28
	6	2,033	38	5,157	2,337
	7	6,988	4,483	33	121,947
	16	97	253	38	27
	17	47	6,537	59	31
48	1	1,504	381	4,991	659
	8	20,928	26	26	4,916
	9	2,508	28	3,667	103,350
	12	24	26	25	26
	18	32	25	43,370	27
84	2	1,060	482	27	26
	4	67	77	27	26
	10	62	614	282	28
	11	24	25	26	731
	15	131	115	348	51

homogeneously distributed in the plant material after 19 days growth. Some plant material was removed from close to the same clipping locations 14 days prior. This data reflects plant activity due to additional uptake that occurred as well as plant activity that remained after the first clipping April 27. Appendix G presents the gross I-131 plant activity, measured wet clipping sample weight and calculated dry plant clipping weight.

Of interest for comparison to April 27 samples are the samples taken nearest the access pipe. Plant I-131 activity from the samples taken nearest the access pipe May 11 is calculated in cpm/g and presented in Table 9. This is determined by dividing the gross I-131 plant activity by the plant sample dry weight. Additionally, the April 27 plant I-131 activity for samples nearest the access tube are time corrected to May 11 and presented in Table 9 for comparison. As demonstrated earlier, the individual plant activity and associated individual RLD do not appear to be related. Therefore mean I-131

TABLE 9. May 11 Plant I-131 Activity from Clippings taken Nearest the I-131 Access Pipe with 30 cpm/g Background Subtracted. From Table 6, April 27 Plant I-131 Activity for the same Sampling Location, Time Corrected to May 11 for Comparison Using $A_t = A_0 e^{-\lambda t} = (A_0) \cdot (0.2973)$.

<u>I-131 Depth cm</u>	<u>Tube Number</u>	<u>April 27 I-131 Activity cpm/g</u>	<u>May 11 I-131 Activity cpm/g</u>
21	3	49,931	140,275
	6	10,970	92
	7	84,673	10,371
	16	19,664	365
	17	22,454	8,949
48	1	23,016	676
	8	1,107	37
	9	0	6
	12	0	10
	18	589	30
84	2	167	550
	4	3	173
	10	2,378	1,036
	11	14	0
	15	0	149

plant activity was calculated at the three soil depths for both the April 27 and May 11 plant samplings using information in Table 9. Table 10 and Figure 6 present the mean RLD for 15 tubes (as extracted from Table 4) and mean I-131 plant activity for April 27 and May 11. The outcome is consistent

TABLE 10. Mean RLD for 15 Tubes (from April 27 Root Counts) at 3 Radiotracer Soil Depths and Mean Plant I-131 Activity from Samples Nearest the Access Tube Taken April 27 and May 11. The April 27 Activity has been Time Corrected to May 11.

<u>I-131 Soil Depth (cm)</u>	<u>Mean RLD for 15 Tubes cm/cm²</u>	<u>April 27 Mean Activity cpm/g</u>	<u>May 11 Mean Activity cm/g</u>
21	0.44 (± 0.27)	37,540 ($\pm 30,115$)	32,010 ($\pm 60,707$)
48	0.15 (± 0.17)	4,942 ($\pm 10,114$)	152 (± 293)
84	0.05 (± 0.06)	512 ($\pm 1,045$)	382 (± 418)

FIGURE 6. April 27 Mean RLD for 15 Tubes and Mean Plant I-131 Activity for Samples Nearest the Access Tube Taken April 27 and May 11. April 27 activity has been time corrected to May 11.

with the earlier findings that when mean RLD and mean plant activity are calculated for each soil depth, it appears that plant activity is higher at greater RLD.

SOIL MOISTURE

Soil moisture at 20, 45, 80, and 125 cm depths was estimated using a neutron hydroprobe. Neutron hydroprobe readings for April 22 (day of I-131 application) and April 27 (day of plant sampling) were taken for 8 tubes

(See Appendix H). It was expected that over the 5 day growth period, plants would remove soil moisture by transpiration and the soil moisture would decrease.

Neutron hydroprobe readings over this 5 day period both increased and decreased slightly (See Table 11). The change in counts range from +11% to -11%. The average increase was 4% and the average decrease was 3%. This corresponds to a calculated gravimetric soil moisture of about $\pm 0.5\%$. As seen in Table 11, increases don't appear to be related to the depth of I-131 solution application and this is the only likely mechanism for increasing soil moisture. The decreases don't appear to be related to any changes in RLD and root counts observed between April 22 and 27 (See Tables 2 and 3; Appendices C and D). The changes in soil moisture were therefore considered to be in the noise level of the hydroprobe technique and not significant. As a result hydroprobe readings were not taken April 27 for the remaining 7 tubes. It was assumed that soil moisture estimates for the April 27 observations would be the same as April 22. For 15 tubes, soil moisture at depths of 30 cm ranged from 7% to 9%; 45 cm from 9% to 12%; and 80 cm from 12% to 15%. Over the growing season, plant transpiration depletes moisture that was once present in the shallow soil depths. Deeper soils maintain higher moisture

TABLE 11. The Percent Increase or Decrease in Neutron Hydroprobe Counts (taken at Soil Depths of 30, 45, 80 and 125 cm) from Measurements taken April 22 and 27.

I-131 Soil Depth (cm)	Tube Number	Percent Increase or Decrease in Counts			
		30 cm	45 cm	80 cm	125 cm
21	3	-2	0	-1	+3
	16	-4	-5	-1	-2
	17	-1	+1	-3	-1
48	1	11	+8	+2	-1
	18	-6	-11	-1	+5
84	2	-1	+4	+2	+3
	4	+1	-1	-5	+4
	10	-1	+5	-1	0

content because fewer roots are present to remove moisture. The depths at which soil moisture was estimated are within 10 cm of the I-131 application depths of 21, 48, and 84 cm.

MINIRHIZOTRON

The field use of minirhizotrons for root observation, as described here, was the first attempt at the ALE Reserve location. Although slurry and backfill during minirhizotron installation had been successful in studies in Utah, it resulted in inhibited root growth at the soil tube interface at the ALE site. The slurry of silt loam soil and water applied to the holes following tube installation hardened to a nearly impervious layer. Root counts in 1987 were generally 0, with a few 10 cm sections of tube where up to 3 roots could be counted. The Utah soil was different from the soil at the ALE site.

The second installation method emphasized coring the hole only slightly larger in diameter than the glass tube (minirhizotron) to minimize soil tube interface voids and eliminate the need for backfilling. With this technique, there was some problem with tube breakage and moisture accumulation at the interface. Tube breakage was associated with exerting too much pressure on the glass during shim placement. The tubes were installed on a warm day and placing warm glass tubes into the cool soil may have caused moisture to form at the interface. In most cases, the moisture did not persist.

VIDEO CAMERA AND VCR

No commercial, electrical power was available at the remote ALE site. The Westinghouse miniature video camera required an AC power source. A small gas generator created too much video interference and a large trailer-mounted, gas powered, generator proved unreliable. A solar energy collection power source was eventually used successfully. Procedures for manually lowering the camera into the tube while viewing the monitor to maintain proper camera alignment, and root counting and recording required two people. The black and white aspect of the camera was adequate for the purpose of distinguishing roots from the other soil material. Overall, considering that this camera was not developed for this purpose, it performed effectively for root counting.

The portable Panasonic VCR worked well on battery power except during high temperatures. A Sony three-quarter inch U-Matic format and one-half inch beta format were also tried. They were not as convenient for field use and provided no apparent improvement in picture quality.

CONCLUSIONS

Use of minirhizotrons in conjunction with a video camera and neutron hydroprobe proved effective in determining root concentrations and soil moisture estimates. Of particular advantage was the non-destructive aspect of these techniques. Root counts observed by video camera via minirhizotron were converted to RLD using an equation proven to be representative in other studies. Variations in root counts and RLDs were observed for 5 replicates at each given soil depth. Other studies have also observed this variation and recommended calculating mean RLD of the replicates for specific soil depths. For the 5 day growth period of I-131 uptake by plants, the parameters of RLD and soil moisture remained essentially unchanged.

After KI carrier was added to I-131 solutions, I-131 proved to be effective as a radiotracer to evaluate plant uptake. Following soil application of I-131, plant I-131 activity was not distributed homogeneously in above ground plant material. The plant area closest to the I-131 access pipe had the highest activity.

There didn't appear to be a relationship between individual tube RLD and individual plant I-131 activity. But when RLDs and plant I-131 activity (for 5 replicates) are grouped for each soil depth (where I-131 was applied), a relationship was found. After 5 days and after 19 days of growth, mean plant I-131 activity was highest at soil depths with the greatest mean RLD. From the 21 cm, to the 48 cm depth, a change in mean RLD of 3 times (i.e., 0.44 to 0.15 cm/cm³) corresponded to a change in mean plant I-131 activity of 8 times (i.e., 37,540 to 4,942 cpm/g after 5 days growth). From the 48 cm to the 84 cm depth, a change in mean RLD of 3 times (0.15 to 0.05 cm/cm³) corresponds to a change in mean plant I-131 activity of 10 times (i.e., 4,942 to 512 cpm/g). It appears that tripling the RLD results in about a (3)² change in plant activity due to uptake.

If roots at all depths were equally effective in uptake, the ratio of plant activity to RLD at each depth would be the same. Dividing mean plant activity by mean RLD for each of the depths where I-131 was applied, did not yield the same ratio. At 21 cm the ratio was 85,318 cpm·cm³/g·cm; at 48 cm 32,947 cpm·cm³/g·cm; and at 84 cm 10,240 cpm·cm³/g·cm. Roots at 84 cm soil

depth are about 8 times less effective at I-131 uptake than the same quantity of roots at the 21 cm depth. Roots at the 48 cm depth are about 3 times less effective in uptake than the same quantity of roots at the 21 cm depth. The deeper the roots, the less effective they appear to be at I-131 uptake.

The RLD or root density factor appears to be only one parameter governing I-131 uptake.

Deep-rooted plants at radioactive waste sites were earlier described as having most of their roots in shallow non-radioactive backfill soil and only relatively few roots in deeper soil containing radioactive waste. Dose assessment models attempt to estimate plant radionuclide uptake based on soil radionuclide inventory. One of the BIOPORT models reduces the plant accumulation in proportion to the fraction of roots in the waste zone. The results of this study indicate that this method may overestimate plant uptake of some radionuclides because deeper roots seem to be less effective at uptake than the same amount of roots at shallow soil depths. This study, however, only evaluated I-131 plant uptake and may not necessarily be representative of uptake for other radioisotopes found in radioactive waste.

In natural systems, predictions of plant uptake of radioisotopes are complex as demonstrated here for I-131. Plant uptake of I-131 may be overestimated using published CRs when only part of the soil volume contains radioactive material.

REFERENCES

- Albrecht, W. A. 1942. "Surface Relationships of Roots and Colloidal Clay in Plant Nutrition." Am. Botany. 29:210-213.
- Bates, G. H. 1937. "A Device for the Observation of Root Growth in Soil." Nature 139:966-967.
- Bragg, P. L., G. Govi, and R. Q. Cannell. 1983. "A Comparison of Methods, Including Angled and Vertical Minirhizotrons, for Studying Root Growth and Distributions in a Spring Oat Crop." Plant Soil 73:435-440.
- Brown, D. A. and D. R. Upchurch. 1987. "Minirhizotrons: a Summary of Methods and Instruments in Current Use." In ed H. M. Taylor ASA Special Publication Number 50 Minirhizotron Observation Tubes: Methods and Applications for Measuring Rhizosphere Dynamics pp. 15-30.
- Christenson, C. W. and E. B. Fowler. 1961. "Depth of Feeding as it Affects the Concentration of Radioactivity within the Plant." J. Agric. and Food Chem. 9:98-100.
- Daubenmire, R. 1970. Steppe vegetation of Washington. Washington Agricultural Experiment Station. Technical Bulletin 62. College of Agriculture, Washington State University, Pullman.
- Dyer, D. and D. A. Brown. 1980. In Situ Root Observation Using Fiber Optic/Video and Fluorescence. Agron. Abstr. American Society of Agronomy, Madison, Wp. 80.
- Gardner, W. H. 1986. Water Content. In A. Klute (ed.) Methods of Soil Analysis Part 1 Physical and Mineralogical Methods. Second Edition. pp. 503-507.
- Hakonson, T. E. 1982. Some Interactive Factors Affecting Trench Cover Integrity on Low Level Waste Sites. LA-UR-82-1692.
- Hitchcock, A. S. 1971. Manual of the Grasses of the United States. Dover Publications, Inc., New York, New York.
- Klepper, E. L. 1983. Fertilizer Placement for Cereal Root Access. Journal of Soil and Water Conservation. 38:250-252.
- Maertens, C. 1987. Ways of Using Endoscopy to Determine Growth and Quality of Root Systems. In H. M. Taylor (ed.) ASA special publication number 50 minirhizotron observation tubes: Methods and Applications for Measuring Rhizosphere Dynamics. pp 31-37.
- McKenzie, D. H., L. L. Cadwell, L. E. Eberhardt, W. E. Kennedy, R. A. Peloquin, M. A. Simmons. 1984. Relevance of Biotic Pathways to the Long-Term Regulation of Nuclear Waste Disposal. NUREG/CR-2675, PNL-4241, Vol. 4, RW. pp. 2.5-2.7.

- McMichael, B. L. and H. M. Taylor. 1987. Applications and Limitations of Rhizotrons and Minirhizotrons. In H. M. Taylor (ed.) ASA special publication number 50 minirhizotron observation tubes: Methods and Applications for Measuring Rhizosphere Dynamics. pp. 1-13.
- Napier, B. A. 1982. A Method for Determining Allowable Residual Contamination Levels of Radionuclide Mixture in Soil. PNL-3852, Pacific Northwest Laboratory, Richland,
- Ng, Y. G., C. S. Colsher, S. E. Thompson. 1982. Soil-to-Plant Concentration Factors for Radiological Assessments. NUREG-CR-2975, UCID-19463.
- Pearson, R. W. 1974. Significance of Rooting Patterns to Crop Production and Some Problems of Root Research. In E. W. Carson (ed.) The plant root and its environment. University Press of Virginia, Charlottesville, pp 247-270.
- Price, K. R. 1965. A Field Method for Studying Root Systems. Health Physics. 11:1521-1525.
- Richards, J. H. 1984. Root Growth Response to Defoliation in Two Agropyron Bunchgrasses: Field Observations with an Improved Root Periscope. Oecologia. 64:21-25.
- Richards, J. H. 1986. Root Form and Depth Distribution in Several Biomes. In D. Carlisle, W. L. Berry, J. R. Watterson and I. R. Kaplan (eds.) Mineral exploration: biological systems and organic matter. Rubey Vol. V Prentice-Hall, Englewood, New Jersey. pp. 82-97.
- Rickard, W. H. and E. L. Klepper. 1976. Ecological Aspects of Decommissioning and Decontamination of Facilities on the Hanford Reservation. Pacific Northwest Laboratory Richland, Washington. BNWL-2033.
- Sanders, J. L. and D. A. Brown. 1978. A New Fiber Optic Technique for Measuring Root Growth of Soybeans Under Field Conditions. Agron. J. 70:1073-1076.
- Taylor, H. M. and W. Bohm. 1976. Use of Acrylic Plastic as Rhizotron Windows. Agronomy Journal. 68:693-694.
- Upchurch, D. R. and J. T. Ritchie. 1983. Root Observations Using a Video Recording System in Minirhizotrons. Agronomy Journal. 75:1009-1015.
- Upchurch, D. R. and J. T. Ritchie. 1984. Battery-Operated Color Video Camera for Root Observations in Minirhizotrons. Agron. J. 76:1015-1017.
- Upchurch, D. R. 1987. Conversion of Minirhizotron Root Intersections to Root Length Density. In H. M. Taylor (ed.) ASA special publication number 50 minirhizotron observation tubes: methods and applications for measuring rhizosphere dynamics. pp. 51-66.
- Vos, J. and J. Groenwold. 1983. Estimation of Root Densities by Observation Tubes and Endoscope. Plant and Soil. 74:295-300.

Vos, J. and J. Groenwold. 1987. The Relation Between Root Growth Along Observation Tubes in Bulk Soil. In H. M. Taylor (ed.) ASA special publication number 50 minirhizotron observation tubes: methods and applications for measuring rhizosphere dynamics. pp. 39-49.

Waddington, J. 1971. Observation of Plant Roots in situ. Can. J. Bot. 49:1850-1852.

APPENDIX A

PLANT IODINE-131 UPTAKE IN RELATION TO
ROOT CONCENTRATION AS MEASURED IN MINIRHIZOTRON
BY VIDEO CAMERA

APPENDIX A

PLANT IODINE-131 UPTAKE IN RELATION TO ROOT CONCENTRATION AS MEASURED IN MINIRHIZOTRON BY VIDEO CAMERA

TABLE A.1. April 12 Root Counts Taken by Video Camera for Tube Numbers 1-10 (n=10) at 10 cm Tube Increments. Used in determining depths with distinctively different RLD.

<u>Tube 10 cm Increment</u>	<u>Vertical Soil Depth (cm)</u>	<u>Root Counts (by tube number)</u>									
		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>
50-60	21-30	5	3	4	8	4	5	2	10	2	6
60-70	30-39	5	2	3	6	5	8	6	12	1	7
70-80	39-48	3	1	1	2	2	9	3	3	0	5
80-90	48-56	8	0	1	2	1	2	2	2	3	3
90-100	56-66	1	0	3	0	2	6	0	1	1	1
100-110	66-75	4	0	1	1	0	4	2	0	3	1
110-120	75-84	0	1	0	2	1	1	0	0	1	1
120-130	84-93	0	2	3	0	0	1	2	0	1	5
130-140	93-102	0	0	1	1	0	0	1	1	1	1
140-150	102-111	0	0	4	2	1	0	0	2	0	0
150-160	111-120	4	0	2	0	1	0	0	2	0	4
160-170	120-129	1	0	0	0	1	0	1	0	0	1

TABLE A.2. Plant Uptake of I-131 with Different KI Carrier Treatments. The I-131 and KI in solution was 1 ml and the chaser 5 ml.

Treatment (6 ml total volume)			Plant Activity
I-131 (uCi)	KI soln.	KI chaser	(cpm)
300	0 ppm	0 ppm	24,003
300	5 ppm	2 ppm	1,689,550
300	5 ppm	5 ppm	1,673,198
300	5 ppm	10 ppm	3,508,772
0	0 ppm	0 ppm	36
0	5 ppm	5 ppm	28

TABLE A.3. April 22 Root Counts Taken by Video Camera for Each Tube at 10 cm Tube Increments

Vertical Depth (cm)	Root Counts (by tube number)																	
	1	2	3	4	6	7	8	9	10	11	12	15	16	17	18			
21-30	17	14	4	9	16	2	17	15	20	22	0	7	4	8	12			
30-39	28	3	6	3	13	3	20	9	9	3	3	5	4	9	10			
39-48	4	4	5	3	22	4	13	5	9	4	2	0	2	4	9			
48-56	8	3	6	1	1	2	16	3	4	0	0	4	3	2	0			
56-66	4	0	6	0	3	0	2	2	4	2	3	3	3	1	2			
66-75	4	1	1	3	2	4	2	8	1	1	0	7	2	0	0			
75-84	0	0	3	8	5	6	1	4	1	3	1	1	3	1	0			
84-93	0	2	3	0	1	0	0	3	3	3	0	1	0	0	1			
93-102	0	1	1	1	0	2	2	2	4	0	0	0	3	0	1			
102-111	1	1	6	2	0	2	0	1	0	1	0	3	3	0	2			
111-120	1	2	5	0	0	2	3	1	4	1	0	3	0	0	0			
120-129	2	0	0	0	0	0	2	1	2	1	1	0	1	2	0			

TABLE A.4. April 27 Root Counts Taken by Video Camera for Each Tube at 10 cm Tube Increments

Vertical Depth (cm)	Root Counts (by tube number)																	
	1	2	3	4	6	7	8	9	10	11	12	15	16	17	18			
21-30	17	10	5	7	16	2	15	15	18	22	0	7	4	8	12			
30-39	31	7	6	3	13	3	13	9	13	3	3	5	4	9	10			
39-48	4	3	3	3	22	4	13	5	6	4	2	0	2	4	9			
48-56	8	4	6	1	1	2	16	3	5	0	0	4	3	2	0			
56-66	4	0	3	0	3	0	3	2	3	2	3	3	3	1	2			
66-75	4	2	1	3	2	4	0	8	1	1	0	7	2	0	0			
75-84	1	1	4	4	5	6	2	4	1	3	1	1	3	1	0			
84-93	0	3	4	0	1	0	0	3	2	3	0	1	0	0	1			
93-102	0	0	1	1	0	2	0	2	4	0	0	0	3	0	1			
102-111	1	0	12	2	0	2	0	1	0	1	0	3	3	0	2			
111-120	4	1	7	0	0	2	0	1	4	1	0	3	0	0	0			
120-129	1	1	1	0	0	0	0	1	0	1	1	0	1	2	0			

TABLE A.5. April 27 Plant Wet to Dry Weight Conversion Determination by Weighing, Drying and Reweighing for 6 Plant Samples

<u>Tube Number</u>	<u>Plant Wet Weight (g)</u>	<u>Plant Dry Weight (g)</u>	<u>% Moisture (wet-dry/wet) 100</u>
2	2.2333	0.6926	69
4	2.8858	0.8629	70
9	2.8998	1.0262	65
11	2.0800	0.8272	60
12	2.6863	0.9646	64
15	2.5427	0.8940	65

Mean % moisture = 65.5%

Wet to dry weight conversion = $100\% - 65.5\% = 34.5\%$

TABLE A.6. April 27 Plant I-131 Activity, Measured Plant Sample Wet Weight, Calculated Plant Dry Weight, and Wet to Dry Weight Conversion

<u>Tube Number</u>	<u>Depth of I-131 (cm)</u>	<u>Gross I-131 Activity (cpm)</u>	<u>Plant Wet Weight (g)</u>	<u>Calculated Plant Dry Weight (g)*</u>
1	48	72,006	2.6954	0.930
2	84	456	2.2333	0.770
3	21	109,996	1.8984	0.655
4	84	39	2.8858	0.996
6	21	39,557	2.7121	0.936
7	21	161,459	1.6443	0.567
8	48	3,510	2.7090	0.935
9	48	30	2.8998	1.000
10	84	7,858	2.8389	0.979
11	84	55	2.0800	0.718
12	48	29	2.6863	0.927
15	84	26	2.5427	0.877
16	21	50,739	2.2246	0.767
17	21	67,181	2.5769	0.889
18	48	2,253	3.2476	1.120

* $(0.345) \cdot (\text{plant wet weight}) = \text{plant dry weight}$

TABLE A.7. May 11 I-131 Plant Activity, Measured Plant Sample Wet Weight, Calculated Plant Dry Weight, and Wet to Dry Weight Conversion

<u>Tube Number</u>	<u>Gross I-131 Activity (cpm)</u>	<u>Plant Wet Weight (g)</u>	<u>Calculated Plant Dry Weight (g)*</u>
1	381	1.5658	0.540
2	482	2.4075	0.831
3	64,400	1.3298	0.459
4	77	1.0995	0.379
6	88	2.0962	0.723
7	4,483	1.2505	0.431
8	26	1.1179	0.386
9	28	2.2664	0.782
10	614	1.6709	0.576
11	25	2.5905	0.894
12	26	1.9002	0.656
15	115	1.8566	0.641
16	253	1.8594	0.641
17	6,537	2.1094	0.728
18	25	1.2046	0.416

* $(0.345) \cdot (\text{plant wet weight}) = \text{plant dry weight}$

TABLE A.8. Neutron Hydroprobe Readings for 15 Tubes Taken April 22 and April 27 at Vertical Soil Depth Locations of 30, 45, 80, 125 cm.

Tube Number	<u>April 22 Hydroprobe Counts</u>				<u>April 27 Hydroprobe Counts</u>			
	30 cm	45 cm	80 cm	125 cm	30 cm	45 cm	80 cm	125 cm
1	1007	1263	1707	1809	1116	1363	1735	1856
2	1127	1349	1589	1886	1112	1405	1642	1935
3	1193	1410	1940	1983	1167	1414	1928	2040
4	1117	1299	1828	2109	1127	1281	1743	2185
6	1099	1372	1727	1927				
7	1253	1408	1765	2171				
8	1166	1301	1735	1901				
9	1207	1337	1643	1737				
10	1241	1391	1760	1817	1227	1455	1745	1822
11	1222	1436	1692	1954				
12	1243	1529	1836	1664				
15	1147	1350	1653	1641				
16	1246	1421	1763	2049	1198	1349	1748	1999
17	1210	1408	1663	1583	1193	1421	1614	1567
18	1251	1555	1807	1844	1179	1386	1784	1934

END

DATE FILMED

01 / 03 / 91