LEAD-210 AND TOTAL LEAD UPTAKE IN PLANTS GROWING ON ABANDONED OR INACTIVE URANIUM MILL TAILINGS.

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ABSTRACT

Samples of wetland plants: cattails (Typha latifolia), sedges (Scripus cyperinus), trees [Trembling Aspens (Populus tremuloides) and White Birches (Betula papyrifera)] and two species of grasses Foxtail Barley (Hordeum jubatum) and Reflexed Saltmarsh Grass (Puccinellia distans) growing on abandoned or inactive uranium mill tailings sites have been collected for the study of uptake of long-lived radionuclides belonging to the 4n+2 series starting from U-238. The plants were excavated and immediately segmented into aerial parts and below ground parts. Each part was analyzed for Pb-210 by following radiochemical techniques and for total lead by the atomic absorption spectrophotometry. A tailings sample was collected around the stem of each plant and another one collected from the root region of the plant and Pb-210 and total lead were determined in each sample.

The ratio of Pb-210 to total lead, R, in various parts of plants and in the tailings has not been found to be significantly different. The transport of lead from the roots to the leaves and other aerial parts is found to be very small in cattails and sedges. In White Birches and Trembling Aspens the concentration of lead transported to aerial parts is higher than that in wetland plants. The concentration factor (roots/tailings concentration) in roots of the trees is lower by an order of magnitude in comparison to that in wetland plants. The absorption of lead by the aerial parts of the plants is not found to be a significant pathway of Pb-210 in vascular plants growing on uranium mill tailings.

INTRODUCTION

It has been reported that lead is not taken up to any great extent from the soil by plants [1,2,3]. Most studies indicate that lead tends to accumulate in roots and only a small amount is translocated to the aerial parts of the plant. It has also been reported that foliar absorption of lead in lettuce leads to some translocation to other parts of the plant [4]. Our earlier studies on the uptake of Pb-210 by Typha latifolia growing on uranium mill tailings have indicated that Pb-210 primarily accumulates in the roots and only a small amount of Pb-210 is present in leaves, stems and fruits [5].

The uranium mine tailings are by-products from the mining and milling of uranium oxide and thus contain daughter products of uranium and thorium, including 'so called' radiogenic stable isotopes of lead. The amount of radiogenic lead in the tailings depends on the age and composition of the mineral in a mining district. For example, the age of the mineral in the Bancroft district is approximately one billion years and in the Elliot Lake district it is known to be approximately two billion years. The radioactive products from the decay of uranium and thorium are present in secular equilibrium in the ore. It is, therefore, expected that the ratio of Pb-210 to radiogenic lead will be constant in a mining district. It has been shown that the amount of natural lead in uranium bearing ore in the Bancroft district is relatively small and thus the ratio of Pb-210 to total lead, R, has been found to be almost constant. Similarly, our limited studies have revealed that the R value in the

Elliot Lake district is also nearly constant although the ore has a higher amount of lead (natural) in it [6]. Fresh tailings samples containing all radioactive decay products including Pb-210 and radiogenic and natural lead is expected to have a constant value of R.

The plants growing on the tailings can absorb Pb-210 along with stable lead isotopes through their roots and transport some fraction to aerial parts of the plant. While it is known that the transport of lead is very little from roots to the aerial parts of plants, it is not clear whether the uptake of lead to aerial parts takes place only through the roots or it is also absorbed by the foliage in aerosol form or accumulated in particulate form on the foliage from aerial fallout. The R value should be constant in all parts of the plants if the uptake of lead is through the roots. In tailings some Rn-222 diffuses into the atmosphere [7]. It is removed from the atmosphere through its decay to other products like Pb-210. The decay products are formed as highly charged species and tend to adhere strongly to dust particles [8]. The rate of diffusion of Rn-222 is dependent on a variety of conditions such as atmospheric variables, porosity of the tailings, presence of clay minerals and moisture content in the tailings. The concentration of Pb-210 in dust particles will vary considerably depending on the concentration of its parent Rn-222. The R value will vary accordingly, assuming that natural lead content in the atmosphere is nearly constant in a particlar area. It is very unlikely to be the same as found in the tailings. The determination of the R value in various parts of a plant growing on the tailings can be helpful in delineating the uptake by the two pathways.

As a part of a long range program, the uptake of long-lived radionuclides by indigenous vegetation growing on the tailings in the Provinces of Ontario and Saskatchewan is being investigated with a view to evaluating the transport of radionuclides from the tailings to biota. In our earlier study the value of R was found to be useful in estimating the extent of diffusion of Rn-222 from the tailings. It was found that Rn-222 diffuses from the dry surfaces, whereas it tends to accumulate in wet tailings areas or those covered with water [6]. In this study, we report R values for leaves and roots of wetland plants, trees, grasses and for the tailings samples taken from the surface around the plants and from the root area of six different species of vascular plants. The R values have been used to determine the route of entry lead by the roots from the tailings or through the aerosol by the foliage of the plants in each species.

EXPERIMENTAL

During the last three years, samples of wetland plants,cattails and sedges (T. latifolia and S. cyperinus) growing in semi-aquatic areas of abandoned or inactive tailings sites and of trees [Trembling Aspen (P. tremuloides)White Birch (B. papyrifera)] in addition to grasses , Foxtail Barley (H. jubatum) and Reflexed Saltmarsh Grass (P. distans) in dry areas of the tailings sites were excavated and immediately segmented into leaves, stems etc. The roots were kept along with the substrate. A tailings sample was collected around the stem of the sample (5 - 10 cm depth) called the surface sample. A second sample of the tailings, called the root region sample was also obtained.

The separated parts were washed with tap water, followed by distilled water containing a detergent. They were then rinsed several times with distilled water to ensure that no particulate matter was present. The roots were scrubbed with a brush to remove all particulate matter and then washed in the same way than the aerial parts of the vegetation. Each sample was homogenized and dried to produce several grams of dry material for analysis. Weighed amounts of the dried material was subjected to wet oxidation by digestion with concentrated nitric acid. Weighed tailings sampels after the drying procedure, were wet oxidized with conc. nitric and perchloric acids. Details of the wet oxidation procedure are given in earlier reports [5,6]. Total lead content was determined by the atomic absorption method with a Varian A.A. No.6.6.

The procedure for the determination of Pb-210 in the tailings and plant digests has been described earlier [6]. Briefly, most cations present in the tailings sample were extracted into the aqueous phase with diethylenetriaminepenta-acetic acid (DTPA). The aqueous solution or the plant digests after adjusting the pH to 1, were passed through a cation-exchange resin column and subsequently eluted with 12M HCl. Bismuth and lead were extracted by diethylammonium diethyl dithiocarbamate (DDTC) from a 3M HCl solution. The separated sample was assayed one month after the separation so as to allow Bi-210 to secular equilibrium with Pb-210. The activity due to Bi-210 was assayed with a low-background proportional counter.

RESULTS AND DISCUSSION

The plant specimens with the associated tailings were collected from different inactive or abandoned tailings sites in the Bancroft and Elliot Lake mining district. The two grass species, however, where collected from a single tailings site in the Uranium City area, the Gunnar tailings which were abandoned in 1960.

In Tables 1, 2, 3 and 4 the radiochemical and analytical data are given for wetland plants and the trees growing in dry areas of the tailings sites in Elliot Lake and Bancroft. The activity of Pb-210 is associated with an error, reflecting the uncertainty of counting. Additional errors due to handling and chemical separation are not included. The method of Pb-210 determination was developed in our laboratory and has been compared to other methods to check reliability [9]. The determination of total lead is accurate for tailings and vegetation to ± 2 μg/g.

Table 1: Concentrations of Pb-210 and lead total in wetland plants on Elliot Lake tailings.

A. Cattails*.

* #	SURFACE TAILINGS Pb-210 pCi/g	SURFACE TAILINGS Total lead μg/g	ROOT REGION TAILINGS Pb-210 pCi/g	ROOT REGION TAILINGS Total lead μg/g
1	172.8 ± 3.1	399.0	76.6 ± 2.1	366.0
2	58.2 ± 1.8	94.7	24.9 ± 1.2	72.0
3	0	191.0	62.4 ± 1.9	347.0
4	3.9 ± 0.8	24.0	4.5 ± 0.8	22.7
5	**	**	16.0 ± 1.1	198.0
6	0.3 ± 0.3	2.4	0	3.4
7	0.9 ± 0.3	9.8	3.6 ± 0.4	1.3
8	34.7 ± 1.0	383.0	22.3 ± 0.8	310.3
9	64.3 ± 1.3	383.0	17.8 ± 1.0	267
	LEAVES		ROOTS	
1	1.8 ± 1.0	7.1	489.0 ± 20.0	1286.2
2	0.6 ± 0.2	10.9	12.0 ± 0.6	297.4
3	0.5 ± 0.3	11.9	91.0 ± 2.2	851.4
4	0.3 ± 0.2	7.0	7.9 ± 0.6	227.2
5	0.4 ± 0.2	6.5	16.0 ± 0.6	630.6
6	0.2 ± 0.2	3.8	0.1 ± 0.2	9.2
7	0.1 ± 0.3	3.1	1.3 ± 0.3	41.5
8	0.8 ± 0.4	7.5	22.0 ± 5.0	694.8
9	0.3 ± 0.2	7.8	86.5 ± 2.4	567.9

B. Sedges*.

*#	SURFACE TAILINGS Pb-210 pCi/g	SURFACE TAILINGS Lead Total μg/g	ROOT REGION TAILINGS Pb-210 pCi/g	ROOT REGION TAILINGS Lead Total μg/g
1	20.4 ± 0.8	665.2	25.5 ± 0.8	521.0
2	62.9 ± 1.3	1061.5	18.9 ± 0.7	268.5
3	0.6 ± 0.3	39.2	0.2 ± 0.3	122.6
4	5.1 ± 0.4	55.9	0.9 ± 0.3	124.0
5	11.2 ± 0.5	14.0	7.7 ± 0.5	129.3
	LEAVES		ROOTS	
1	0.9 ± 0.2	8.2	88.0 ± 1.6	545.8
2	2.8 ± 0.3	19.2	11.7 ± 0.6	274.6
3	1.4 ± 0.2	8.1	24.1 ± 0.7	217.1
4	0	0	10.1 ± 4	14.3
5	3.0 ± 0.3	12.0	0	159.2

Table 2: Concentrations of Pb-210 and total lead in trees on Elliot Lake tailings sites.

A. Trembling Aspens*.

*#	SURFACE TAILINGS Pb-210 pCi/g	SURFACE TAILINGS Lead Total μg/g	ROOT REGION TAILINGS Pb-210 pCi/g	ROOT REGION TAILINGS Lead Total μg/g
1	1.3 ± 0.3	7.5	1.7 ± 0.3	31.5
2	3.7 ± 0.4	443.2	7.5 ± 0.5	279.6
3	2.3 ± 0.3	35.9	4.6 ± 0.4	59.8
4	5.0 ± 0.4	95.1	4.2 ± 0.3	194.2
	LEAVES		ROOTS	
1	0.1 ± 0.1	1.5	0	0
2	2.3 ± 0.5	8.95	7.5 ± 0.7	25.1
3	0	0	0.9 ± 0.4	0
4	1.3 ± 0.4	12.9	6.0 ± 0.7	32.9

B. White Birches*.

#	SURFACE TAILINGS Pb-210	SURFACE TAILINGS Lead Total	ROOT REGION TAILINGS Pb-210	ROOT REGION TAILINGS Lead Total
1	1.5 ± 0.3	5.7	0.2 ± 0.2	0
2	22.7 ± 0.8	584.6	17.8 ± 0.7	428.0
3	26.0 ± 0.8	596.0	5.3 ± 0.4	411.2
4	7.1 ± 0.5	266.8	4.1 ± 0.4	90.8
5	0	350.0	0	450.0
6	4.5 ± 0.3	15.3	3.5 ± 0.4	113.5
7	5.2 ± 0:4	998.4	3.5 ± 0.4	1073.4
8	5.6 ± 0.4	203.4	11.7 ± 0.6	379.5

Table 2: Concentration of Pb-210 and total lead in trees on Elliot Lake tailings sites cont'd.

B. White Birches cont'd*.

	LEAVES		ROOTS	
*#	Pb-210 pCi/g	Lead Total μg/g	Pb-210 pCi/g	Lead Total μg/g
1	0.4 ± 0.4	0	0.5 ± 0.4	3.5
2	4.0 ± 0.5	15.9	16.4 ± 0.8	76.4
3	2.1 ± 0.5	5.0	7.1 ± 0.6	34.6
4	3.4 ± 0.5	7.5	6.0 ± 0.6	9.4
5	5.9 ± 0.6	30.9	24.0 ± 1.1	118.7
6	1.5 ± 0.5	6.0	0	3.5
7	1.3 ± 0.5	12.9	6.0 ± 0.7	32.9
8	0.9 ± 0.5	0	0	0

Table 3: Concentrations of Pb-210 and total lead in wetland plants on Bancroft tailings sites.

A. Cattails*.

	SURFACE TAILINGS		ROOT REGION TAILINGS	
*#	Pb-210 pCi/g	Lead Total μg/g	Pb-210 pCi/g	Lead Total μg/g
1	14.3 ± 1.0	48.5	13.2 ± 0.7	86.7
2	137.9 ± 1.9	215.0	35.0 ± 0.9	213.9
3	10.6 ± 0.6	73.1	**	272.0
4	154.0 ± 1.9	274.0	56.9 ± 1.2	303.0
5	15.5 ± 0.6	43.7	15.5 ± 0.6	90.7
	LEAVES		ROOTS	
1	1.3 ± 0.4	4.0	7.9 ± 1.0	67.2
2	2.1 ± 0.4	4.1	97.5 ± 1.5	216.6
3	0	2.9	0	107.4
4	1.5 ± 0.5	4.6	37.5 ± 6.4	514.5
5	4.8 ± 0.6	7.8	198.3 ± 6.3	147.1

B. Sedges*.

	SURFACE TAILINGS		ROOT REGION TAILINGS	
1	36.3 ± 0.9	116.1	35.0 ± 0.9	213.9
2	95.0 ± 1.5	375.9	77.8 ± 1.3	369.1
3	13.8 ± 0.6	71.4	10.3 ± 0.5	39.6
4	123.1 ± 1.7	611.9	193.5 ± 2.1	684.2
	LEAVES		ROOTS	
1	2.7 ± 0.3	7.6	**	
2	2.2 ± 0.3	5.2	11.9 ± 0.4	36.0
3	1.2 ± 0.2	10.6	5.6 ± 0.3	25.2
4	35.1 ± 0.8	26.4	147.1 ± 1.5	151.5

Table 4: Concentrations of Pb-210 and total lead in trees on Bancroft tailings sites.

A. Trembling Aspens*.

	SURFACE TAILINGS		ROOT REGION TAILINGS	
*#	Pb-210 pCi/g	Lead Total μg/g	Pb-210 pCi/g	Lead Total μg/g
1	2.6 ± 0.4	55.6	6.9 ± 0.5	86.1
2	13.4 ± 0.6	92.6	1.8 ± 0.3	136.4
3	5.1 ± 0.4	89.7	2.0 ± 0.3	117.0
4	2.3 ± 0.3	81.4	2.8 ± 0.4	60.4
	LEAVES		ROOTS	
1	2.1 ± 0.4	5.7	1.3 ± 0.5	6.8
2	2.3 ± 0.3	5.0	2.0 ± 0.5	21.8
3	1.7 ± 0.5	6.1	1.2 ± 0.4	12.6
4	0.7 ± 0.4	**	1.1 ± 0.4	**

B. White Birches*.

	SURFACE TAILINGS		ROOT REGION TAILINGS	
1[1]	2.6 ± 0.4	55.6	6.9 ± 0.5	86.1
2	1.6 ± 0.3	**	0	23.4
3[1]	5.1 ± 0.4	89.7	2.0 ± 0.3	117.0
4	6.0 ± 0.5	60.7	2.8 ± 0.4	60.4
	LEAVES		ROOTS	
1	7.4 ± 0.7	9.1	2.0 ± 0.5	4.8
2	16.0 ± 1.0	60.3	10.1 ± 0.9	49.1
3	0	5.8	2.6 ± 0.5	16.5
4	0.4 ± 0.8	5.6	0.5 ± 0.4	8.0

[1]Note: TA and WB collected at some location.
** lost sample.

Activities of Ra-226 and Pb-210 at the time of deposition of the tailings in the ponds have been estimated as 344 pCi/g [10]. The R value for fresh tailings for the Bancroft district is estimated to be 1.2 and for the Elliot Lake district to be 0.44. However, weathering of the tailings over 16 to 25 years and the diffusion of Rn-222 from the surface of the tailings have altered the R value in the tailings. The change of the R value in the tailings has been dealt with extensively in our earlier study [6]. It has been shown that a lower R value than the predicted one indicated the emanation of Rn-222, whereas a higher R value indicated entrapment of Rn-222 by water or in the tailings. The average R values for surface tailings and root region tailings of the plants for Elliot Lake and Bancroft district are summarized in Table 5, along with the average ratios for the roots and the leaves. It can be seen from Table 5 that the R values show a very wide range (0.01 to 1.1), which is reflected in the large standard deviations.

Table 5: R values for tailings and plants in the Elliot Lake and Bancroft area (pCi/μg).

		ELLIOT LAKE			BANCROFT		
		n	mean	sd	n	mean	sd
Surface tailings	T	11	0.09	0.1	6	0.075	0.046
	C	10	0.22	0.19	5	0.4	0.2
	S	5	0.22	0.34	4	0.23	0.05
Root region tailings	T	11	0.03	0.02	6	0.03	0.03
	C	10	0.18	0.09	5	0.27	0.2
	S	5	0.044	0.026	4	0.22	0.05
Roots	T	11	0.3	0.16	6	0.17	0.11
	C	10	0.08	0.11	5	0.5	0.59
	S	4	0.13	0.07	4	0.5	0.4
Leaves	T	11	0.27	0.11	6	0.37	0.25
	C	10	0.08	0.07	5	0.44	0.4
	S	4	0.16	0.05	4	0.5	0.5

T - trees, C - cattails, S - sedges.
n - number, sd - standard deviation.

The decay of Ra-226 or Rn-222 and Pb-210 through many daughter products results in Pb-210 having a very high positive charge [8]. However, in the tailings environment, it is unlikely that lead will have species in any other oxidation state except as Pb (II). Pb(II) will undergo isotopic exchange with other lead species and thereby Pb-210 and total lead determinations will give a reliable R value for the sample. The formation of Pb (IV) is very unlikely in the tailings ponds, whereas metallic lead will react under acidic conditions in the ponds. Our Pb-210 determination and mass spectrometric analyses performed earlier do support the above view [6].

The uptake of lead, a non-essential element by plants is governed by its solubility which is in turn related to pH of the growth substrate, i.e. the tailings. It is believed that lead is not taken up by the plant at least until a toxic threshold is reached in the growth substrate. The lead concentration in the uranium mill tailings are below generally considered toxic concentrations. However, the toxicity of lead is species specific, and in the present study, toxic concentrations for these plants are not known. The species collected exhibit considerable tolerances to harsh environments and are commonly found on waste sites. It is therefore unlikely that the concentrations of lead in the tailings will alter the uptake behaviour of the plants. Thus, it can be assumed that the uptake of lead from the tailings is within the ecological tolerances of the plants. The pH of the tailings in the Bancroft district ranges from 3.6 to 6.9, and in the Elliot Lake district from 1.8 to 6.6. Earlier studies have indicated that the uptake of lead is not directly proportional to solubility of lead. For example, a ten-fold increase in the solubility of lead in the substrate resulted in two-fold increase in raddish [11]. In the Bancroft district, the concentration of lead in the tailings ranges from 14 μg/g to 684.2 μg/g (surface and root region) with pH values of 3.6 to 6.9. The range of concentration of lead in roots of cattails is 54.5 μg/g to 514 μg/g and in sedges 2.61 μg/g to 151.5 μg/g with concentration factor defined as the ratio of concentration of total lead in roots to that in tailings, ranging from 0.5 to 2 in cattails and 0.25 to 1 in sedges. The concentration of lead in roots of the trees (White Birch and Trembling Aspen) is lower by a factor of 5 to 20 than those in the wetland plants. Due to the ranges in pH encountered in the tailings the concentration factors based on total solids analysed, again do not show any relationship to the pH of the tailings.

The R values in the tailings in the Bancroft district have a very wide range (0.013 to 0.64). A comparison of R values in the tailings with those in roots shows some variations but the average figure seems to indicate that the R value may be the same in the tailings and in the roots of the wetland plants and the trees, taking into consideration that there is a great deal of inhomogeneity in the samples. Two observations are worth mentioning concerning lead in the plants on tailings: (a) that the concentration of lead in the leaves is lower by almost two order of magnitudes than the corresponding concentration in roots of cattails, but in sedges and trees the concentration of lead in leaves is lower by a smaller factor (1 to 5), and (b) that the R values for the leaves are marginally higher than the corresponding ones in roots. The latter observation strongly indicates that foliar deposition of Pb-210 formed from the decay of Rn-222 is negligible in the wetland plants and trees. It appears from the present work that the uptake of Pb-210 by the foliage in plants and trees is not a very significant pathway in the dispersal of radionuclides. It may however, be stated that Pb-210 may deposit as particulate dust, but may be removed during the washing procedure, or by rainfall.

Similar comments can be made for the uptake of lead by the wetland plants and trees growing in the Elliot Lake district with one significant difference. The concentration of lead in the roots of plants (cattails and sedges) ranges from 9 µg/g to 1286 µg/g with the concentration factor ranging from 3 to 10 for cattails, 1 to 2 for the sedges and 0.1 to 0.2 for the trees. The transport of lead from roots to leaves is generally very low. Other analytical and radiochemical data on samples of stem and seeds indicate that the R value is almost constant throughout the plant. Again, the uptake of Pb-210 by plants and trees from the atmosphere is negligible in this district.

The concentration of lead in the tailings from Uranium City (Table 6) ranges from 85 µg/g to 596 µg/g, but in the grass hummocks the concentration ranges from 83 to 212 µg/g with a concentration factor ranging from 0.5 to 1. The concentration factor is approximately 1 for the plants growing in the tailings with lead concentration from 83 µg/g to 150 µg/g, and the factor is lower for the tailings having the concentration of lead higher than 200 µg/g. The transport of lead in grasses from the roots to the leaves and stems appears to be slightly higher than that in cattails or sedges. The R values (Table 7) are higher for leaves than the corresponding ones in roots, indicating that there may be slight uptake of Pb-210 from the atmosphere.

Table 6: Concentrations of Pb-210 and total lead in grasses on the Gunnar tailings - Uranium City area.

A. Foxtails*.

	SURFACE TAILINGS		ROOT REGION TAILINGS	
*#	Pb-210 pCi/g	Total lead µg/g	Pb-210 pCi/g	Total lead µg/g
1	36.3 ± 0.9	112.6	23.6 ± 0.8	109.3
2	34.1 ± 0.9	115.1	145.7 ± 1.8	215.4
3	179.3 ± 2.0	167.9	116.0 ± 1.6	149.1
4	34.7 ± 0.9	86.4	370.9 ± 1.8	85.8
5	112.0 ± 1.6	531.2	95.7 ± 1.1	307.3

Table 6: Concentrations of Pb-210 and total lead in grasses on the Gunnar tailings - Uranium City area cont'd.

A. Foxtails*.

	LEAVES		ROOTS	
*#	Pb-210 pCi/g	Total Lead µg/g	Pb-210 pCi/g	Total Lead µg/g
1	5.3 ± 0.3	16.6	16.6 ± 0.5	91.1
2	5.1 ± 0.3	18.3	13.9 ± 0.4	110.1
3	4.1 ± 0.2	11.9	34.1 ± 0.6	162.9
4	1.8 ± 0.2	6.8	12.3 ± 0.4	83.2
5	2.7 ± 0.2	12.4	33.6 ± 0.6	132.5

B. Reflexed Saltmarsh Grass*.

	SURFACE TAILINGS		ROOT REGION TAILINGS	
1	6.2 ± 0.4	108.0	47.3 ± 1.1	114.4
2	60.4 ± 1.2	215.9	202.4 ± 2.1	228.0
3	89.6 ± 1.4	151.3	56.7 ± 1.2	406.3
4	71.2 ± 1.3	596.2	189.0 ± 2.1	250.6
5	24.9 ± 0.8	220.7	25.7 ± 0.8	231.8

	LEAVES		ROOTS	
1	4.4 ± 0.25	26.4	14.9 ± 0.4	154.4
2	2.3 ± 0.2	9.8	31.8 ± 0.7	212.4
3	6.8 ± 0.3	21.5	29.3 ± 0.6	192.1
4	0.6 ± 0.15	13.1	12.1 ± 0.4	177.1
5	4.8 ± 0.3	21.8	19.1 ± 0.5	100.3
6	3.9 ± 0.2	2.7	29.5 ± 0.7	125.7
7	2.9 ± 0.2	5.4	29.8 ± 0.8	145.7
8	5.1 ± 0.3	9.3	28.3 ± 0.4	126.4
9	1.9 ± 0.2	6.6	11.9 ± 0.4	84.5

Table 7: R values for grasses on the Gunnar tailings in Uranium City (pCi/µg).

	Hordeum jubatum			Puccinellia distans		
	n	mean	sd	n	mean	sd
Surface tailings	5	0.45	0.34	5	0.23	0.22
Root region tailings	5	0.48	0.24	5	0.46	0.34
Roots of hummocks	5	0.18	0.05	9	0.16	0.05
Stems & leaves of hummocks	5	0.3	0.03	9	0.3	0.16

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REFERENCES

[1] BREWER, R.F., "Lead in diagnostic criteria for plants and soils." H.D. Chapman (ed.), University of California, 1966.

[2] NATIONAL RESEARCH COUNCIL COMMITTEE ON BIOLOGIC EFFECTS OF ATMOSPHERIC POLLUTANTS, "Lead: Airborne lead in perspective." National Academy of Science, pp. 33-46, 1972.

[3] GOUGH, L.P., SHACKLETTE, H.T. & A.A. CASE, "Element concentrations toxic to plants, animals, and man." Geo. Sur. Bull. 1466, pp. 28-31, 1980.

[4] HEMPHILL, D.D. & J.H. RULE, "Foliar uptake and translocation of Pb-210 and Cd-109 by plants." In: "International Conf. on Heavy Metals in the Environment, Volume II - Part 1, pp. 77-86, 1975.

[5] KALIN, M. & H.D. SHARMA, "Radium-226 and lead-210 in Typha latifolia growing on old abandoned uranium mill tailings in Canada." Proc., Inter. Symposium on Migration in the Terrestrial Environment of Long-Lived Radionuclides from the Nuclear Fuel Cycle. Knoxville, Tenn., (July), 1981 (In press).

[6] KALIN, M. & H.D. SHARMA, "Lead total and lead-210 in 20 year old uranium mill tailings." Proc., Inter. Conference on Radiation Hazards in Mining. Golden, CO. (October), pp. 697-700, 1981.

[7] STRONG, K.P., LEVINS, D.M. & A.G. FANE, "Radon diffusion through uranium tailings and earth cover." Proc., Inter. Conference on Radiation Hazards in Mining. Golden, CO. (October), pp. 713-719, 1981.

[8] PATTERSON, Jr., R.L. & LOCKHART, Jr., L.B., "In: Natural Radiation Environment." J.A.S. Adam and W.M. Lowder (eds.), University of Chicago Press, p. 383, 1964.

[9] VESKA, E., Personal Communication, 1981.

[10] MOFFET, D. & M. TELLIER, "Radiological investigations of an abandoned uranium tailings area." J. Environ. Qual., 7(3):310-314, 1978.

[11] LAGERWERFF, J.V., "Uptake of cadmium lead and zinc by raddish from soil and air." Soil Sci., 111:129-133, 1971.