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UPTAKE OF TRACE ELEMENTS AND RADIONUCLIDES FROM URANIUM MILL TAILINGS BY FOUR-WING SALTBUSH (*Atriplex canescens*) AND ALKALI SACATON (*Sporobolus airoides*)

by
David R. Dreesen[1] and M. Lynn Marple[1]

ABSTRACT

A greenhouse experiment was performed to determine the uptake of trace elements and radionuclides from uranium mill tailings by native plant species. Four-wing saltbush (*Atriplex canescens*) and alkali sacaton (*Sporobolus airoides*) were grown in alkaline tailings covered with soil and in soil alone a* controls. The tailings material was highly enriched in Ra-226, Mo, U, Se, V, and As compared with three local soils.

The shrub grown in tailings had elevated concentrations of Mo, Se, Ra-226, U, As and Na compared with the controls. Alkali sacaton contained high concentrations of Mo, Se, Ra-226 and Ni when grown on tailings. Molybdenum and selenium concentrations in plants grown in tailings are above levels reported to be toxic to grazing animals. These results indicate that the bioavailability of Mo and Se in alkaline environments makes these elements among the most hazardous contaminants present in uranium mill wastes.

INTRODUCTION

The release of hazardous radionuclides and toxic chemicals from uranium mill tailings disposal sites is receiving increased naticnal attention (Carter 1978) as a result of a six-fold increase in uranium production anticipated by the year 2000 (Nuclear Regulatory Commission 1979). These concerns are illustrated by the inadequate stabilization of inactive uranium mill tailings impoundments in the past which have allowed appreciable gaseous (Rn-222) and particulate emissions and aqueous contaminants to enter the environment (U.S. Atomic Energy Commission 1974). Extremely strict guidelines for stabilization have been proposed (Nuclear Regulatory Commission 1979) to reduce most of the potential adverse health and ecological effects resulting from tailings disposal. The long-term integrity of any stabilizing cover or cap is in doubt because of the erosive action of wind and water, the possible existence of structural defects in the cover material or impoundment (Shepherd and Nelson 1978), and the possible biological penetration of the cover material (Whicker 1978). The penetration of the stabilizing

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cover by plant roots could provide channels for more rapid diffusion of Rn-222 gas as well as being a mechanism for the translocation of contaminants into the aboveground environment.

Previous studies have shown elevated levels of As, Pb, Se, and Ra-226 in native plant species growing on inactive tailings piles that had not been stabilized or only meagerly stabilized (Dreesen et al. 1978; Kelley et al. 1978; Kelley 1978). However, the elevated concentrations found in aboveground biomass may not only represent assimilation by roots and translocation to stems and leaves but also surficial contamination of foliage by wind blown tailings particles containing elevated concentrations of these elements. The evidence of elevated U concentrations in plants growing 20 m above uranium deposits (Cannon 1957) further suggests the possibility of plant translocation of contaminants through thick cover materials.

An experiment was planned to determine the uptake of trace elements and radionuclides from tailings materials under controlled environmental conditions where surficial contamination of foliage could be drastically reduced and homogeneous soils and tailings could be used as substrates. The experimental design provided control treatments to be used as baseline or background estimates of uptake of these elements from uncontaminated soils. The goal of this study was to determine the propensity for native plant species to translocate tailings contaminants but not to address the likelihood of these species to penetrate thick soil or clay covers. Results of this experiment provide information regarding the bioavailability of these contaminants in western ecosystems should uranium mill tailings be released into the environment. In addition, this information can be used to estimate the biological mobility of contaminants in ores, in mine spoils or barren material disposed of in the surface environment, or in mine water discharged into stream channels or dispersed on soils (Kaufmann et al. 1976).

EXPERIMENTAL METHODOLOGY

The two native plant species selected for the uptake experiment were a shrub, four-wing saltbush (*Atriplex canescens*), and a grass, alkali sacaton (*Sporobolus airoides*). Four-wing saltbush is a codominant species in the Colorado Plateau shrub communities as well as being common to grassland areas, pinon-juniper woodlands, flood plains and arroyos (Wagner and Aldon 1978). This species is a valuable forage shrub in arid rangelands and one of the most important shrub species used in rehabilitation of disturbed lands and in soil stabilization (Blauer et al. 1976). Alkali sacaton is commonly seeded in revegetation programs in desert grassland, southern desert shrub, and saltbush desert ecosystems (Cook et al. 1974). This species is a common bunch grass growing in dry alkaline soils (Harrington 1964) and is used for revegetation of alkaline or saline mine spoils in dry regions (Donovan et al. 1976). Both four-wing saltbush and alkali sacaton had naturally invaded and established a modest population on one inactive alkaline (carbonate leach) tailings pile in New Mexico and were growing at a number of inactive sites in Colorado and Utah (Kelley 1978). These species may be used to revegetate stabilized tailings piles or may naturally invade such stabilized areas.

The tailings material used in this experiment was collected from an inactive alkaline (carbonate leach) tailings pile in northwestern New Mexico. This tailings site (Site C) has been previously described (Purtymun et al. 1977; Dreesen et al. 1978). Tailings sands and slimes were mixed in an effort to represent average surface tailings material. The tailings material was split and recombined in the field to homogenize the material. These tailings had a field capacity of 21% moisture.

Three soils were collected in the Grants Mineral Belt region and represent a range of textures. A dune sand was collected near the Rio Puerco drainage east of Laguna, New Mexico (field capacity 6.7%). A sandy clay loam was gathered in the Ambrosia Lake area north of Grants, New Mexico about 1 km from the inactive tailings site C (field capacity 27%). A clay soil was collected near Bluewater, New Mexico about 2 km from an active uranium mill (field capacity 40%).

The experimental design consisted of two plant species, three soils, and two substrate treatments (six replicates with tailings and four replicates with controls for each species and each soil). The tailings and control treatments are illustrated in Fig. 1. The tailings treatments were set up with 800 g of moist, homogenized tailings in the bottom of a clay pot (15 cm diameter and 15 cm height) with appropriate amounts of one soil applied to achieve a consistent cover thickness of about 5 cm. The control treatments contained only soil of one of the three types.

Approximately 2 g of *Atriplex* seed and 0.2 g of *Sporobolus* seed were sown. Seeds were covered with the particular soil to a depth of about one seed diameter. After the soil was packed, a layer of perlite about 1 cm thick was applied to reduce desiccation of the seedbed. The pots were placed according to a randomized design in a greenhouse during March 1978 and watered by weight to the field capacity of the soil only. Pots were watered at three to five day intervals for one month and then at five to seven day intervals until October. Beginning in late May, all pots were given equal amounts of dilute Hoagland's solution on a weekly basis to provide nutrients. Pots were rotated systematically after every other watering. During March and April, some pots were reseeded because of mortality due to a fungal disease. All treatments were eventually thinned to 12 seedlings per pot.

The aboveground biomass was harvested during early October, washed vigorously with distilled water, blotted dry, and air-dried for four days in paper bags. After biomass yields on an air-dried weight basis were determined, the samples were ground in a Wiley mill with a 20-mesh screen. Following the biomass harvest, the soil was removed from the pot and the penetration and number of roots were recorded. The root biomass was insufficient for analysis.

Analytical methods for soils, tailings, and vegetation were as follows: Ra-encapsulation and gamma spectroscopy; Mo-instrumental epithermal neutron activation; U - delayed neutron assay technique; Se,

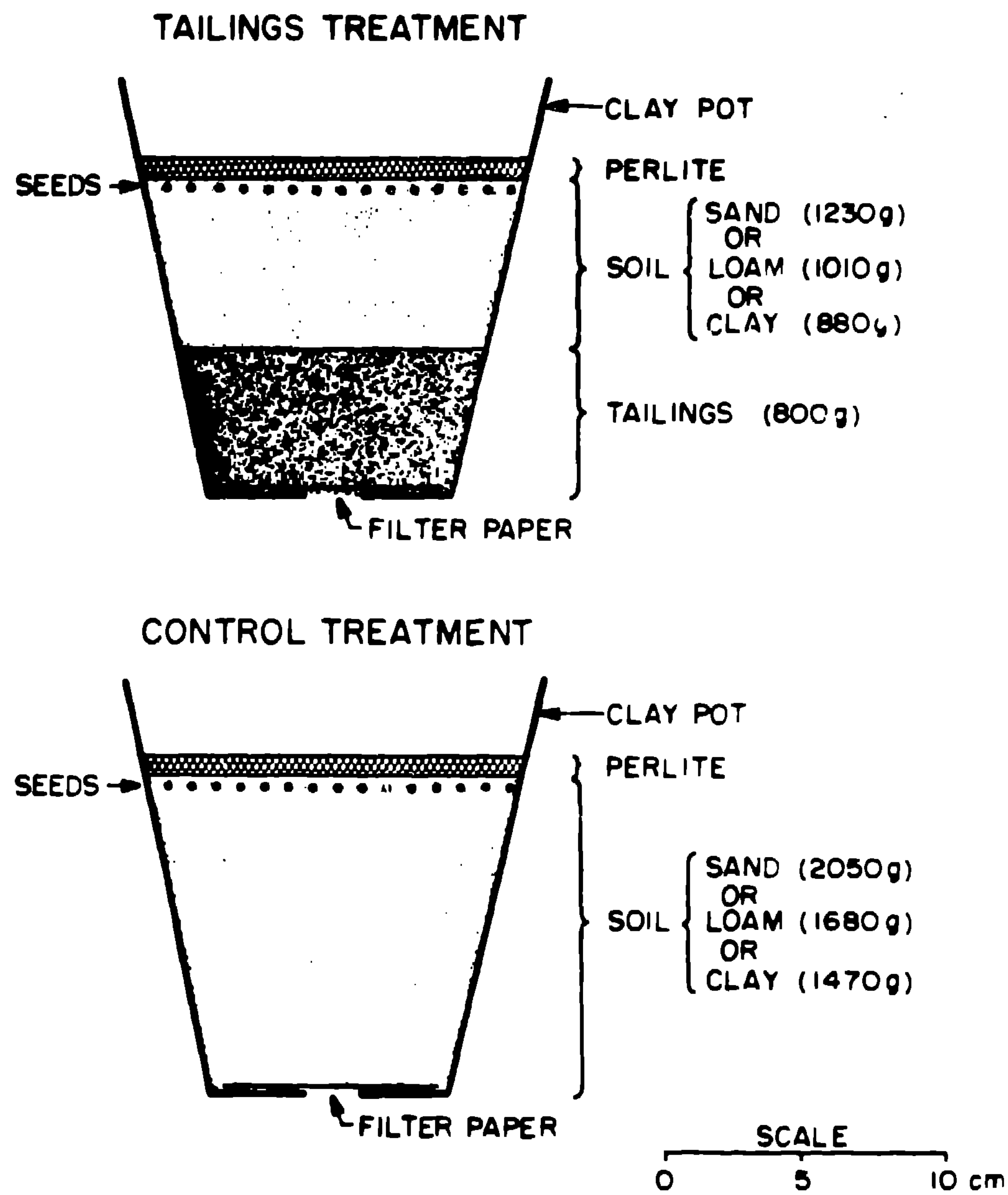

Figure 1. Design of experimental treatments for soils over tailings and for soils alone.

V, As (for soils and tailings), Sb, Mn, Co, Cr, Ca, Na, K, Al - instrumental thermal neutron activation; and As (for vegetation) Cu, Pb, Ni - flameless atomic absorption spectrophotometry. Composites of replicates were required to provide sufficient mass for analyses for Ra-226, As, Ni, Cu, and Pb. For all other analyses individual replicates were analyzed separately. Replicates did not always number four or six since in some pots all plants died during the course of the experiment.

The t-test for the equality of means of two samples with unequal variances was used to test significant differences between control and tailings treatments (Sokal and Rohlf 1969).

RESULTS AND DISCUSSION

Tailings and Soil Composition

The trace and major element and radionuclide composition of the tailings and soils used in this experiment is presented in Table 1 as well as the ratio of mean tailings concentration to mean soil concentration. The composition of typical soils for these elements is given as the mean concentration reported by Bowen (1966). The elements highly enriched in these tailings versus local soils are Ra-226, Mo, U, Se, and V; As, Cu, Sb, and Ca are somewhat enriched. The Ra-226 activity and U concentration correspond well with the estimated average composition for this tailings material of 645 pCi/g (US Atomic Energy Commission 1974) and 120 μg/g (Ford, Bacon, and Davis, Utah Inc. 1977), respectively. In addition to the radionuclides of the U-238 decay series, the trace elements Mo, Se, V, and As are enriched in these tailings. Squyres (1970) reports the following average accessory element concentrations in the uranium ores from the Ambrosia Lake Mining District of New Mexico milled at site C: Mo - 400 μg/g, Se - 200 μg/g, V - 1500 μg/g, and As - 100 μg/g. The presence of enriched levels of these trace elements in sandstone uranium ores has been postulated to result from the reduction and deposition of mobile oxyanions of these elements in groundwater when a reducing zone is encountered (Brookins et al. 1977; DeVoto 1978). Copper and antimony are somewhat enriched in these tailings. Copper has been previously reported at elevated concentrations in epigenetic sandstone ores (DeVoto 1978) and possibly present as sulfides associated with pyrites (Brookins et al. 1977). Antimony may behave as the other oxyanions and be deposited at the reduction interface (Brookins et al. 1977). Other heavy metals such as Pb, Mn, Co, Ni, and Cr are not present at high concentrations in these tailings compared with local soils.

The local soils appear to be somewhat enriched in U, Se, Pb, and Ca compared with the average typical soil value and somewhat depleted in Mo, V, Mn, Ni, As, and Cr. However, these differences are not large and considerable variability between the three soils used in this experimental study preclude any general conclusions about local soil concentrations.

The mean concentrations reported for the three soils and tailings represent fairly homogeneous samples. The coefficients of variation (one standard deviation/mean) are generally less than 20% for two replicates of tailings and four replicates of each soil. The elements for which

TABLE 1.
ELEMENTAL COMPOSITION OF TAILINGS AND SOILS USED IN THE UPTAKE EXPERIMENT, TAILINGS/SOIL CONCENTRATION RATIO, AND COMPOSITION OF TYPICAL SOIL

Element	Mean Conc.[a] in Tailings	Mean Conc. in Sand	Mean Conc. in Loam	Mean Conc. in Clay	Mean Soil Conc.	Concentra-Ratio[b]	Conc. in Typical Soil[c]
Ra-226	613	0.14	2.6	0.35	1.0	613	0.8
Mo	65.5	0.4	1.9	0.3	0.9	73	2
U	176	1.5	3.6	2.4	2.5	70	1
Se	32.5	0.6	1.1	1.2	1.0	33	0.2
V	960	24	32	45	34	28	100
As	28.5	3.2	7.0	2.0	4.1	7	6
Cu	69.0	9.5	19.2	23.5	17	4	20
Sb	1.95	0.51	0.78	0.65	0.65	3	0.5[d]
Pb	70.5	30.2	43.2	38.5	37.3	1.9	10
Mn	345	275	202	482	320	1.1	850
Co	4.4	3.7	7.4	9.0	6.7	0.7	8
Ni	4.5	4.7	10.2	13.2	9.4	0.5	40
Cr	10.5	12.9	32.7	38.6	28.1	0.4	100
Ca	5.7%	1.5%	0.96%	2.0%	1.5%	4	1.37%
Na	1.8%	1.9%	0.65%	0.47%	1.0%	1.8	0.63%
K	1.8%	1.8%	1.6%	1.1%	1.5%	1.2	1.4%
Al	5.6%	5.7%	6.5%	6.4%	6.2%	0.9	7.1%

[a] Concentration units are μg/g or pCi/g for Ra-226 unless otherwise indicated.
[b] Mean concentration in tailings divided by mean concentration in soil.
[c] Source Bowen (1966).
[d] Source Brooks (1972).

TABLE 2.

CONCENTRATION[a] OF TRACE ELEMENTS, RADIONUCLIDES, AND MAJOR ELEMENTS IN ABOVEGROUND BIOMASS OF GRASS (*Sporobolus airoides*) GROWN IN TAILINGS AND SOILS

	Sand Treatments		Loam Treatments		Clay Treatments		
Element	Conc. Grown In Tailings	Conc. Grown In Sand	Conc. Grown In Tailings	Conc. Grown In Loam	Conc. Grown In Tailings	Conc. Grown In Clay	Mean[b] Ratio
Ra-226	25	1.3	2.9	3.1	9.4	2.7	3.7
Mo	147	6	173	8	78	13	14.7
U	0.17	0.05	0.17	0.10	0.15	0.05	2.5
Se	52	2.1	64	3.1	37	1.9	21.6
V	0.21	0.55	0.34	0.48	0.48	1.25	0.5
As	<0.01	<0.01	0.30	0.03	<0.07	<0.07	---
Cu	29	40	40	32	30	34	0.9
Sb	0.29	0.24	0.26	0.12	0.28	0.24	1.4
Pb	7.9	6.1	62	13	10	17	2.2
Co	0.34	0.20	0.87	0.15	0.44	0.55	1.8
Ni	18	1.9	64	12	6.5	3.3	5.2
Cr	2.5	3.7	2.0	2.0	2.1	2.0	0.9
Al	98	84	114	124	130	135	1.0
Ca	0.29%	0.36%	0.18%	0.41%	0.37%	0.53%	0.7
Na	0.13%	0.53%	0.74%	0.23%	0.69%	0.42%	1.3
Cl	0.94%	1.06%	0.72%	0.32%	0.67%	0.11%	1.6

[a] In μg/g (air-dried weight basis) or pCi/g for Ra-226 unless otherwise indicated.
[b] Conc. ratio of the means (mean conc. plants grown in tailings/mean conc. plants grown in soils).

TABLE 3.

CONCENTRATION[a] OF TRACE ELEMENTS, RADIONUCLIDES, AND MAJOR ELEMENTS IN ABOVEGROUND BIOMASS OF SHRUB (*Atriplex canescens*) GROWN IN TAILINGS AND SOIL

	Sand Treatments		Loam Treatments		Clay Treatments		
Element	Conc. Grown In Tailings	Conc. Grown In Sand	Conc. Grown In Tailings	Conc. Grown In Loam	Conc. Grown In Tailings	Conc. Grown In Clay	Mean[b] Ratio
Ra-226	30	1.1	12	2.9	48	1.8	15.5
Mo	273	10	181	12	147	2	25.0
U	3.00	0.01	1.40	0.05	0.93	0.07	41.0
Se	74	2.4	63	1.9	35	1.0	32.5
V	1.04	1.19	0.40	0.50	0.65	1.5	0.7
As	0.42	<0.07	0.22	0.15	0.66	<0.07	4.3[c]
Cu	15	13	11	15	21	23	0.9
Sb	0.24	0.21	0.16	0.24	0.28	0.21	1.0
Pb	0.7	1.9	<0.4	<1.0	<0.1	3.2	0.2[c]
Co	0.35	0.52	0.26	0.30	0.58	0.64	0.8
Ni	2.8	3.4	7.3	2.6	4.0	9.2	0.9
Cr	2.4	1.2	1.2	1.3	1.8	2.2	1.2
Al	105	129	155	155	138	233	0.8
Ca	2.5%	3.1%	2.1%	2.8%	3.8%	3.9%	0.9
Na	3.2%	1.1%	1.8%	0.1%	4.1%	1.8%	3.0
Cl	1.7%	1.4%	1.0%	1.4%	1.1%	0.6%	1.1

[a] In μg/g (air-dried weight basis) or pCi/g on Ra-226 unless otherwise indicated.
[b] Conc. ratio of the means (mean conc. plants grown in tailings/mean conc. plants grown in soils).
[c] Upper limits were used in calculating concentration ratios.

analytical results have coefficients greater than 20% are Co for tailings; Se, Mo, V, [illegible] and Mn for sand; Se, Mo, V, Sb, and Ca for loam; and Se, Mo, V, A[illegible]a, Na, and Ni for clay.

Root Penetration and Biomass Yields

The penetration of roots into the tailings was species dependent. Shrub treatments had some roots penetrate through the entire mass of tailings; whereas, the grass was only able to penetrate one to two cm into the upper layer of the tailings. The plants growing in the sand over tailings had more numerous and larger roots than those growing in the loam or clay soil over tailings. Roots in the clay tailings treatment tended to penetrate through the mass of tailings rather than down the sides of the pot as found with the loam tailings treatment. This difference may have resulted from the large desiccation cracks developing in the clay treatment promoting root growth through the cracks rather than down the sides of the pot.

The aboveground biomass yields ranged from 0.5 to 5.1 g (air-dried weight) for the grass treatments and 1.1 to 9.1 g for the saltbush treatments. No apparent differences in biomass between control and tailings treatments for individual soils were found and in general there was a large amount of variability in biomass between replicates within a treatment. Thus, effects of tailings on aboveground plant yields are not apparent.

Uptake of Trace Elements and Radionuclides

The concentration of trace, major, and radionuclide elements in the aboveground biomass for the grass and the shrub are presented in Tables 2 and 3, respectively. The concentration ratios of the means for each species (CR) (mean concentration in plants grown in tailings/mean concentration in plants grown in soils) are also reported in Tables 2 and 3. The data show elevated concentrations of Se (CR = 22), Mo (CR = 15), Ni (CR = 5.2), and Ra-226 (CR = 5.0), in the grass (*Sporobolus airoides*) grown in tailings versus in the soil control. A number of elements were enriched in the shrub (*Atriplex canescens*) grown in tailings compared with soil: U (CR = 41), Mo (CR = 25), Se (CR = 33),Ra-226 (CR = 16), As (CR = 4.3) and Na (CR = 3.0). The results for As, Ni, Pb, and Cu are more uncertain because of compositing samples by treatment. Thus, no replicate analyses were made within a treatment. Some anomalous concentrations reported for the grass growing in tailings with the loam soil cover can not be verified because replicate samples were not available. Further studies are necessary to better substantiate any uptake of these elements.

The results clearly show enrichment of Mo and Se for both species grown in tailings and U and Ra-226 for the shrub. The levels of Mo and Se found in the grass and the shrub are 26 to 91 times recommended maximum concentrations {reported by Melsted (1973, cited by Nuclear Regulatory Commission 1979)} in plant leaves for Mo and 12 to 25 times the recommended maximum for Se. The range of levels of Mo in the grass and shrub, 78 to 273 μg/g, are well above those implicated with molybdenosis in cattle in Karnes County, Texas, 15 to 45 μg/g in grass, and in North Dakota, 10 μg/g in hay (Chappell 1975). A lower threshold of toxicity to cattle and sheep of 5 to 20 μg/g has been estimated by Chappell (1975). Molybdenum toxicity to ruminants is thought to be caused by an interference with Cu metabolism; the onset of molybdenosis is suggested to occur when the Cu:Mo ratio of forage is less than two (Chappell 1975). The grass and shrub grown in tailings have Cu:Mo ratios of 0.06 to 0.39; whereas, the biomass harvested from soil controls had ratios of 1.3 to 12. Thus, the copper content of plants grown in the soils would probably prevent molybdenosis in grazing ruminants. Table 4 presents mean concentrations (± one std. dev.) of selected elements for the grass and shrub as well as maximum recommended concentrations (MRC) in plant leaves and typical plant concentrations. This data shows that the maximum recommended concentration for Mo is exceeded by the plants grown in soils and greatly exceeded for biomass harvested from tailings treatments. Molybdenosis would probably not be caused by the consumption of the control plants because the Cu:Mo ratios are close to or greater than two.

The selenium concentrations in the aboveground biomass of these two species grown in tailings range from 35 to 74 μg/g. These levels are well above the MRC, 3 μg/g, (Table 4) and greater than the concentration reported to be the lower threshold to cause chronic selenium poisoning of the alkali disease type, 5 μg/g (National Research Council 1976). Because Atriplex canescens is classified as a secondary selenium absorber (National Research Council 1976), the high Se content of the shrub was not surprising. However, there is no readily apparent difference in Se content between the shrub and the grass in this study with respective means of 57 and 51 μg/g. Most grasses rarely contain more than 30 μg/g (National Research Council 1976). Seleniferous grasses are only found in "poison areas" where large amounts of selenium are available in the soil (Rosenfeld and Beath 1964). Common native grasses growing in seleniferous soils of western South Dakota had mean Se concentrations of 1 to 12 μg/g with a maximum of 84 μg/g (Rosenfeld and Beath 1964). The concentrations of Se found in the grass grown in tailings certainly indicate that Se is quite available for uptake and these concentrations are similar or greater than those found in "poison areas."

The perspective regarding the uptake of U and Ra-226 from tailings is less straightforward. Maximum recommended concentrations of these elements in plant tissue have been calculated arbitrarily by multiplying typical plant concentrations by a factor of 10. The typical activity of Ra-226 in plants reported in Table 4, 0.24 pCi/g, is the mean activity of Ra-226 for 4 grass species grown in a control soil (Moffett et al. 1977). This value was selected versus typical plant activity of 0.001 pCi/g reported by Bowen (1966). Thus, we have used 0.24 pCi/g as a more conservative basis for comparison. The MRC for Ra-226 indicates that the grass and shrub grown in tailings have activities well above the MRC; whereas, the activity of plants grown in soils is about the same as the recommended level. In contrast, the U concentrations are significantly above the MRC for the shrub only and control grass and shrub are quite near typical plant concentrations. Thus, plant assimilation and translocation of radionuclides from tailings would appear to be a

TABLE 4.
COMPARISON OF MEAN CONCENTRATIONS IN GRASS AND SHRUB WITH MAXIMUM RECOMMENDED AND TYPICAL PLANT CONCENTRATIONS

Element	Mean Grass Conc. ±1 Std Dev		Mean Shrub Conc. ±1 Std Dev		Maximum[a] Recommended Conc. (MRC) μg/g	Typical[b] Plant Conc. μg/g	Grass Conc. Tailings/MRC	Shrub Conc. Tailings/MRC
	Tailings μg/g	Control μg/g	Tailings μg/g	Control μg/g				
Ra-226	12 ± 11	2.4 ± 0.9	30 ± 18	1.9 ± 0.91	2.4[c]	0.24[d]	5.0	13
Mo	133 ± 49*	9.0 ± 3.6	200 ± 65*	8.0 ± 5.3	3	0.9	44	67
U	0.16 ± 0.01*	0.07 ± 0.03	1.8 ± 1.1*	0.04 ± 0.03	0.4[c]	0.04	0.40	4.5
Se	51 ± 14*	2.4 ± 0.6	57 ± 20*	1.8 ± 0.7	3	0.2	21	19
V	0.34 ± 0.14	0.76 ± 0.43	0.70 ± 0.32	1.06 ± 0.51	2	1.6	0.17	0.35
As	0.13 ± 0.15[e]	0.04 ± 0.03[e]	0.43 ± 0.22	0.10 ± 0.05[e]	2	0.2	0.07	0.22
Cu	33 ± 6.1	35 ± 4.2	16 ± 5.0	17 ± 5.3	150	14	0.22	0.10
Sb	0.28 ± 0.02	0.20 ± 0.07	0.23 ± 0.06	0.22 ± 0.02	0.60[c]	0.06	0.47	0.38
Pb	27 ± 30	12 ± 5.3	0.4 ± 0.3[e]	2.0 ± 1.1[e]	10	2.7	2.7	0.04
Co	0.55 ± 0.28	0.30 ± 0.22	0.40 ± 0.17	0.49 ± 0.17	5	0.5	0.12	0.08
Ni	30 ± 30	5.6 ± 5.3	4.7 ± 2.3	5.1 ± 3.6	3	2.7	10	1.7
Cr	2.2 ± 0.3	2.6 ± 1.0	1.8 ± 0.6	1.6 ± 0.6	2	0.2	1.1	0.9

[a] Maximum recommended conc. reported in NRC (1979) from Melsted (1973) or see footnote c.
[b] As reported by Bowen (1966).
[c] Maximum recommended conc. calculated as 10 times typical plant concentration.
[d] Source Moffett, et al. (1977).
[e] Upper limits of less than data used in calculating means.
*Mean of tailings treatment significantly different from mean of control ($p < 0.05$).

greater potential hazard for Ra-226 than U on the basis of this experiment.

Table 4 also illustrates differences in elemental concentration between species. The elements showing little differentiation between the species are Mo, Se, V, Sb, Co, and Cr. The elements generally enriched in the grass versus the shrub are Cu, Pb, and Ni. Shrub samples are generally elevated in relation to the grass for Ra-226, U, and As for the tailings treatments.

In an effort to evaluate the contaminants regarding their enrichment in the environment, four factors have been calculated as shown in Table 5. These factors are as follows: A - Tailings Enrichment Factor - the enrichment of the element in tailings versus soil; B - Uptake Factor - the ratio representing the concentration in the biomass harvested from the tailings treatments versus the concentration in the tailings material; C - Baseline Comparison Factor - a comparison of concentrations in plants grown in tailings versus those grown in local soils; and, D - MRC Comparison Factor - the concentration in plants grown in tailings versus the maximum recommended concentration in plant leaves. Although V and, to some extent, As are enriched in these tailings (factor A), they do not seem to pose an appreciable hazard relative to Mo and Se due to their low bioavailability in tailings (factor B). Factor B illustrates that Ra-226, U, As, V, and Al could be discriminated against by plant absorption and/or translocation as indicated by values of less than 0.1. Those elements which appear to be biogenic (Factor B > 1.0) are Mo, Se, Na, and Ni. A biogenic classification implies that the element is concentrated to a appreciable degree by the plant or the element plays a physiological role in the plant's metabolism (Brooks 1972). Values for Factor C illustrate that Mo, Se, Ra-226, and U are highly concentrated in plants grown in tailings versus local soils. Factor D values show Mo and Se concentrations in plants grown in tailings greatly exceed the MRC's and Ra-226, U, and Ni are greater than two times their respective MRC's. Assuming the MRC's are reasonable measures of hazard to grazing animals, Factor D becomes one measure of relative hazard. However, assessment of hazard must not only include a measure of toxicity but also measures of bioavailability and enrichment in the environment. Thus, each of the factors (A through D) aid in assessing hazard to the ecosystem, but no one of these factors individually is an adequate indicator of overall environmental hazard.

CONCLUSIONS

Though this experiment has investigated one tailings material and two native plant species, the results can be extrapolated to some other wastes from uranium mining and milling operations. When mine spoils or barren material excavated during mining are disposed of in alkaline surface environments, mobile trace elements such as Mo and Se may be available to vegetation growing on reclaimed mine waste sites. If the bioavailability of Mo and Se indicates the aqueous mobility of these elements, then we can surmise that the disposal of mine wastes enriched in these elements could lead to the contamination of surface or ground waters by these mobile contaminants. In general, the mobility and bioavailability of Mo and Se in uranium mine or mill wastes under alkaline and oxidative conditions along with their toxicity to grazing animals

TABLE 5.

FACTORS RELATED TO PLANT UPTAKE OF TRACE ELEMENTS AND RADIONUCLIDES FROM URANIUM MILL TAILINGS

Element	A Tailings Enrichment Factor	B Uptake Factor	C Baseline Comparison Factor	D MRC Comparison Factor
Mo	73	2.5	28	55
Se	33	1.7	27	20
Ra-226	613	0.031	13	9.0
U	70	0.0055	58	2.5
Na	1.8	1.0	4.7	---
Ni	0.5	3.7	3.5	5.8
Cu	4	0.36	1.0	0.16
Co	0.7	0.10	1.8	0.10
Pb	1.9	0.19	2.3	1.4
Ca	4	0.27	0.7	---
As	7	0.013	5.5	0.14
Sb	3	0.12	1.2	0.43
Cr	0.4	0.19	1.1	1.0
V	28	0.00055	0.6	0.26
Al	0.9	0.0022	0.9	---

A - $\frac{\text{Conc. in Tailings}}{\text{Mean Conc. in Soil}}$

B - $\frac{\text{Mean Conc. of Plants Grown in Tailings}}{\text{Conc. in Tailings}}$

C - $\frac{\text{Mean Conc. of Plants Grown in Tailings}}{\text{Mean Conc. of Plants Grown in Soil}}$

D - $\frac{\text{Mean Conc. of Plants Grown in Tailings}}{\text{MRC}}$ (See Table 4 for MRC used) cause these elements to be appreciable threats to the environment.

The enrichment of trace elements or radionuclides in tailings or other wastes does not provide by itself a good measure of the hazard to ecosystems resulting from the disposal of these wastes. Thus, any assessment of waste materials must include some test of bioavailability in addition to elemental composition in order to judge the environmental hazard posed by the disposal of these wastes.

The results of this experiment show the environmental hazard posed by some trace elements and radionuclides enriched in uranium ores and mill tailings. Thus, attention must be directed toward the mobile trace elements and radionuclides when assessing the environmental impact of uranium milling operations and in developing strategies for waste management or environmental control technologies.

LITERATURE CITED

Blauer, A. C., A. P. Plummer, E. D. McArthur, R. Stevens, and B. C. Giunta, 1976. Characteristics and Hybridization of Important Intermountain Shrubs. II. Chenopod Family. Research Paper INT177, Intermountain Forest and Range Experiment Station, U.S. Forest Service.

Bowen, H. J. M. 1966. Trace Elements in Biochemistry. Academic Press, London.

Brookins, D. G., M. J. Lee, and W. C. Riese. Trace Elements as Possible Prospecting Tools for Uranium in the Southern San Juan Basin. In New Mexico Geol. Soc. Guidebook, 28th Field Conference. San Juan Basin III.

Brooks, R. R. 1972. Geobotany and Biogeochemistry in Mineral Exploration. Harper and Row, New York.

Cannon, H. L. 1957. Description of Indicator Plants and Methods of Botanical Prospecting for Uranium Deposits on the Colorado Plateau. U.S. Geological Survey Bulletin 1030-M.

Carter, L. J. 1978. Uranium Mill Tailings: Congress Addresses a Long-Neglected Problem. Science 202: 191-195.

Chappell, W. R. 1975. Transport and Biological Effects of Molybdenum in the Environment. In Heavy Metals in the Aquatic Environment, P. A. Krenkel (Ed.). Pergamon Press, Oxford.

Cook, C. W., R. M. Hyde, and P. L. Sims. 1974. Revegetation Guidelines for Surface Mined Areas. Range Science Series No. 16, Range Science Department, Colorado State University.

DeVoto, R. H. 1978. Uranium Exploration. In Seminar Proceedings Uranium Resource/Technology Update, Front End of the Nuclear Fuel Cycle, Colorado School of Mines, Golden, CO, March 14, 1978. Published by the Colorado School of Mines.

Donovan, R. P., R. M. Felder, and H. H. Rogers. 1976. Vegetative Stabilization of Mineral Waste Heaps. Prepared for U.S. Environmental Protection Agency by the Research Triangle Institute, Research Triangle Park, NC. EPA-600/2-76-087.

Dreesen, D. R., M. L. Marple, and N. E. Kelley. 1978. Contaminant Transport, Revegetation, and Trace Element Studies at Inactive Uranium Mill Tailings Piles. In Proceedings of the Symposium on Uranium Mill Tailings Management, Fort Collins. CO, Nov. 20-21, 1978. Geotechnical Engineering Program, Civil Engineering Department, Colorado State University.

Ford, Bacon, and Davis, Utah Inc. 1977. Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings Phillips/ United Nuclear Site, Ambrosia Lake, New Mexico. Prepared for the U.S. Department of Energy, Grand Junction, Colorado.

Harrington, H. P. 1964. Manual of the Plants of Colorado. Sage Books, The Swallow Press Inc., Chicago, IL.

Kaufmann, R. F., G. G. Eadie, and C. R. Russell. 1976. Effects of Uranium Mining and Milling on Ground Water in the Grants Mineral Belt, New Mexico. Ground Water 14(5): 296-308.

Kelley, N. E., L. D. Potter, and M. L. Marple. 1978. Selected Trace Elements and Revegetation of Uranium Mill Tailings Piles in the Southwest. In Biomedical and Environmental Research Program of the LASL Health Division, January-December 1977. Los Alamos Scientific Laboratory Report LA-7254-PR.

Kelley, N. E. 1978. Vegetational Stabilization of Uranium Spoil Areas, Grants, New Mexico. Ph.D. Dissertation, Department of Biology, University of New Mexico. Los Alamos Scientific Laboratory report LA-7624-T (1979).

Melsted, S. W. 1973. Proceedings of the Joint Conference on Recycling Municipal Sludge and Effluents on Land, Champaign, Ill., July 913, 1970. National Association of State Universities and Land Washington, DC.

Moffett, D., G. Zahary, M. C. Campbell, and J. C. Ingles. 1977. CANMET's Environmental and Process Research on Uranium. Canada Centre for Mineral and Energy Technology, CANMET report 77-53.

National Research Council. 1976. Selenium - Medical and Biological Effects of Environmental Pollutants. Published by National Academy of Sciences, Washington, D.C.

Nuclear Regulatory Commission. 1979. Draft Generic Environmental Impact Statement on Uranium Milling. Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission (Project M-25). NUREG-0511, Volumes I and II.

Purtymun, W. D., C. L. Wienke, and D. R. Dreesen. 1977. Geology and Hydrology in the Vicinity of the Inactive Uranium Tailings Pile, Ambrosia Lake, New Mexico. Los Alamos Scientific Laboratory report LA-6839-MS.

Rosenfeld, I. and O. A. Beath. 1964. Selenium - Geobotany, Biochemistry, Toxicity, and Nutrition. Academic Press, New York.

Shepherd, T. A. and J. D. Nelson. 1978. Long-Term Stability of Uranium Mill Tailings. In Proceedings of the Symposium on Uranium Mill Tailings Management, Fort Collins, CO, Nov. 20-21, 1978. Geotechnical Engineering Program, Civil Engineering Department, Colorado State University.

Sokal, R. R. and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co., San Francisco.

Squyres, J. B. 1970. Origin and Depositional Environment of Uranium Deposits of the Grants Region, New Mexico. Ph.D. Dissertation, Department of Geology, Stanford University.

U.S. Atomic Energy Commission. 1974. Summary Report - Phase I Study of Inactive Uranium Mill Sites and Tailings Piles, October 1974. U.S.A.E.C. Grand Junction, Colorado.

Wagner, W. L. and E. F. Aldon. 1978. Manual of the Saltbushes (*Atriplex* spp.) in New Mexico. General Technical Report RM-57, Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service.

Whicker, F. W. 1978. Biological Interactions and Reclamation of Uranium Mill Tailings. In Proceedings of the Symposium on *Uranium Mill Tailings Management*, Fort Collins, CO, Nov. 20-21, 1978. Geotechnical Engineering Program, Civil Engineering Department, Colorado State University.