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**Vegetational Stabilization of Uranium
Spoil Areas, Grants, New Mexico**

University of California

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Vegetational Stabilization of Uranium Spoil Areas, Grants, New Mexico

Nathan Edmund Kelley*

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VEGETATIONAL STABILIZATION OF URANIUM SPOIL AREAS, GRANTS, NEW MEXICO

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The University of New Mexico, 1978

Factors that could be detrimental to vegetative stabilization of uranium mine and mill waste material were examined. Physical and chemical analyses of materials from an open-pit uranium mine and material from three inactive mill tailing piles in New Mexico were performed. Analyses for selected trace elements in mill tailing material and associated vegetation from piles in New Mexico, Colorado, and Utah were also performed. Field and laboratory experiments identified problems associated with establishing vegetation on spoil material. Problems of uptake and concentration of toxic elements by plants growing on specific spoil material were also identified.

Ecological observations in conjunction with physical and chemical analyses of specific geologic units, which form the overburden and waste dumps at the open-pit mine, identified a specific geologic material that, if segregated and placed on the surface of the dumps, would pose the least set of problems for a revegetation program. A pilot revegetation project verified that segregation and use of specific geologic material in the overburden could be utilized successfully and economically for re-establishment of native vegetation on mine waste material.

INTRODUCTION

The birth of the uranium industry in New Mexico occurred in the 1950s when a Navajo Indian named Paddy Martinez discovered uranium on land owned by the Santa Fe Railway (NMEI 1976). The Anaconda Company was hired by the railway to develop and mine this uranium ore. Anaconda, inspired by the Martinez find, initiated an exploration project and subsequently discovered the now famous Jackpile Mine. Interest in New Mexico uranium deposits, stimulated by the previous discoveries, started a uranium exploration boom in the Grants mineral belt of west-central New Mexico. Numerous private individuals and other mining concerns joined in the search for uranium deposits. During this time, Anaconda built the first uranium processing mill in New Mexico and launched the state's uranium mining and milling industry on its present day course (NMEI 1976).

The uranium industry in New Mexico is presently experiencing rapid growth in both mining and milling. Mining rights in the state are held by the Anaconda Company, Bokum Resources, Conoco Petroleum Co., Exxon Co., Gulf Resources and Chemical Corp., United Nuclear-Homestake Partners, Kerr-McGee Corp., Mobil Oil Co., Pioneer Nuclear Inc., Ranchers Exploration and Development Corp., Reserve Oil and Minerals, SOHIO Petroleum Co., United Nuclear Corp. (UNC), and Western Nuclear. Mills currently operating in New Mexico are owned by Anaconda, Kerr-McGee, SOHIO, UNC-Homestake Partners, and UNC. Mills planned for New Mexico include those of Bokum, TVA-Mobil-UNC, Gulf, and Phillips Petroleum Co. The above information was obtained from B. Perkins (Personal communication, New Mexico Department of Energy and Minerals, Santa Fe). In addition to the operational and proposed mill sites, there are two inactive mills in the state. The Shiprock mill has been closed and the tailing pile covered with river rock and sand. The old Phillips mill site, now under control of UNC, has been converted to an ion-exchange facility and ore is no longer processed at this site. No stabilization work has been attempted on this old tailing pile.

Federal legislation and the recent increased activity of the uranium industry have focused attention on the need for environmental considerations other than radiation safety for the industry's employees. Recognition of some of the environmental problems facing the uranium industry and an attempt to mitigate them occurred around 1960. At that time a government-owned mill at Monticello, Utah, was shut down. After the closure, the tailings gradually dried out and were subject to wind and water erosion (U.S. AEC 1963). A stabilization project was undertaken to eliminate: (1) the public nuisance of dust blowing over the surrounding area, (2) stream silting, and (3) the possibility of radioactive contamination from the wind-blown and water-transported tailing material. The project involved grading and contouring of the tailing piles, covering them with local rock and soil material, fertilizing, and seeding the new soil surface with a variety of grass species (U.S. AEC 1963). Vegetation is well established, erosion is minimal, and there is little if any transport of radioactive material from this site (U.S. AEC 1966).

Since completion of the Monticello project, 20 other uranium mill sites have been shut down in western United States (Anonymous 1974). Stabilization has been accomplished, or attempted, on 14 of these abandoned mill tailing piles. Problems identified from these projects include blowing sand, low water-holding capacity, nutrient deficiencies, acidity, alkalinity, salinity, toxic elements, and steep slopes and soft spots that cannot be worked by machinery (Berg 1971).

Stabilization methods include covering with rock and soil (U.S. AEC 1963; Beverly 1968; Beverly 1974), mulching (Vivyrka 1975), establishment of windbreaks (Dean et al. 1974), chemical stabilization (Havens and Dean 1969; Dean and Havens 1971; Dean et al. 1974; Vivyrka 1975), and establishment of vegetation directly on the tailings with the aid of fertilizer and sprinkler irrigation systems (Berg 1971; Moffett et al. 1977). More recently the problems of ground water contamination (U.S. EPA 1975; Kaufman et al. 1976; Purtymun et al. 1977) and radon emission from these tailing piles have been investigated (Ramsay 1976; Bernhardt et al. 1975; Marple and Clements 1977).

Legislative action for coal strip mine reclamation has resulted in the initiation of research and reclamation projects on uranium mine spoils in anticipation of reclamation regulations pertaining to open-pit uranium mining. The bulk of the literature dealing with strip mine reclamation is associated with coal mining operations (Frawley 1971; USDA For. Serv. 1977-1978). Literature dealing specifically with open-pit uranium mine reclamation is either not available or is non-existent.

Research conducted for reclamation and revegetation of coal strip mine spoils has identified the common problems of limited moisture, salinity, lack of fine soil particles, very high clay content, acidity, deficiency of nitrogen and/or phosphorus, blowing sand, grazing, and browsing (Berg 1971). Some of the procedures and techniques tested in western United States for strip mine reclamation include evaluation of the spoil material as a growing medium (Aldon 1973; Aldon 1975; Aldon et al. 1975; Aldon et al. 1976; Yamamoto 1975), surface manipulations such as contouring, forming dozer basins, grading, etc. (Hodder 1977), and methods of increasing the moisture supply with the use of snowfences, mulches, and various surface coverings (Jacoby 1969). Sprinkler and drip irrigation techniques have been utilized in aiding the establishment of vegetation on spoil materials (Aldon and Springfield 1977; DeRemer and Bach 1977). Soil amendments and fertilizer treatments have been tested (Aldon et al. 1975; Cook et al. 1974), and effects of toxic elements on plant growth have been evaluated (Berg 1965; Berg and Vogel 1968). Seed mixtures and seeding techniques have been proposed for various areas and soil types of western United States (Cook et al. 1974; Monsen 1974; Kay 1977; Nord 1977; Plummer 1977).

Since semi-arid and arid regions represent situations where critical levels of a variety of environmental factors are in a delicate balance with the tolerance levels of vegetational species, it is important to determine those factors that would be detrimental to a revegetation project.

Revegetation of waste materials from mining and milling operations in the Grants mineral belt is especially difficult because of the nature of the climatic regime and the slowness of natural plant succession in this area of the state. The frequency of drought,

with most years having less than the mean amount of annual precipitation, creates an erratic, undependable moisture supply. Surface and ground water supplies are generally not available in this area for supplemental watering of reclaimed areas. High temperatures and desiccating winds add to the problems of moisture relationships and affect the reestablishment of vegetation, either by natural or artificial seeding, on the waste materials.

In addition to the vagaries of the weather, there are complications relating to soil. Soil profiles are thin and poorly developed in most of the areas where open-pit mining is employed. Therefore, stockpiling the surface layer to be redistributed across the disturbed area is not practical. Frequently, the mine and mill waste materials have one or several properties acting as limiting factors for plant growth when combined with the climatic conditions.

Mine reclamation research was conducted at the open-pit Jackpile Mine operated by the Anaconda Company. Research concerning vegetative stabilization of uranium mill tailings was conducted at three inactive sites in the Grants mineral belt of New Mexico. The principal objectives of this research were to identify the limiting physical and/or chemical factors of the environment of uranium mine and mill wastes and to determine methods of overcoming these limitations allowing for successful establishment of vegetation.

MATERIALS AND METHODS

Floristic surveys were conducted in the areas surrounding the Jackpile mine and the three New Mexico mill sites. Nomenclature of plant species follows that of Arizona Flora (Kearny and Peebles 1969), Flora of New Mexico (Martin unpublished), and Manual of the Plants of Colorado (Harrington 1964). Vegetative foliage cover and frequency data were collected by the line intercept method and density data were collected by the quadrat method (Woodin and Lindsey 1954; Potter 1957; Smith 1966; Daubenmire 1963).

The geology of the Grants mineral belt has been investigated and discussed by numerous authors (Kelley 1955; Gordon 1961; Hilpert 1963; Kittle 1963; Schlee and Moench 1963a; Schlee and Moench 1963b; Santos 1963; Santos and Thaden 1966; Kittle et al. 1967). The geologic information was used to identify the various overburden materials at the mine.

Samples of soils, overburden material, and mill tailings were collected and analyzed. Texture, water-holding capacity, and electrical conductivity (Black 1965) were determined for most samples. A modification of the procedures found in Black (1965) was used for cation and metal extraction and cation exchange capacity (Appendix). Mercury was extracted using the U.S. EPA (1976) sulfuric acid-hydrogen peroxide digestion procedure. Anion analyses were performed following standard procedures for the Technicon Autoanalyzer II (Appendix). Analyses for all cations and metals were performed on a Perkin-Elmer Atomic Absorption Spectrophotometer Model 306 (Appendix).

Plant samples were collected and analyzed for selected trace elements. The plant material was ground to less than 40-mesh size, digested with $\text{HNO}_3\text{-HCl}$, and analyzed by atomic absorption spectrophotometry (Appendix).

Data presented in a statistical format in the text were first analyzed by g1 and g2

tests for normality. If the evidence from the g1,g2 tests indicated that the data did not fit the assumptions for parametric statistics, the data were transformed using logarithmic, square root, and/or arcsine transformations (Sokal and Rohlf 1969) and tested again for normality with the g1,g2 tests. If the transformed data fit the assumption for parametric statistics, the data were then tested for significant differences between the means at the .05 level using Duncan's New Multiple Range Test. If the transformed data did not fit the assumptions, the data were analyzed by the nonparametric Kruskal-Wallis test (Sokal and Rohlf 1969) and with Duncan's test for comparison of results. If the results of these tests agreed, Duncan's was used to present the data.

DISCUSSION

Open-pit Uranium Mine

Revegetation of Mine Overburden

The Anaconda open-pit uranium mine is located approximately 96 highway km west of Albuquerque, New Mexico, on the Laguna Indian Reservation. The mining area is characterized by broad mesas and plateaus separated by deep canyons, dry washes, and wide alluvial valleys. The elevation in the vicinity of the mine ranges from 1760 to 1960 meters.

The area has a semi-arid climate with an average of 27.3 cm of precipitation per year. Approximately 70 percent of the precipitation results from thunderstorms between June and October. Monthly temperature means range from near-freezing in the winter months to 23° C during the summer. Winter low temperatures may reach -20° C and summer highs can exceed 37° C.

The shallow, rocky soils of the mesas, plateaus, and steep slopes support a blue grama (Bouteloua gracilis) – galleta (Hilaria jamesii) grassland with scattered one-seed juniper (Juniperus monosperma) and pinyon (Pinus edulis) occurring on the higher elevation sites and in sheltered areas along the north-facing slopes. The deeper, finer, alluvial soils in the valleys support an alkali sacaton (Sporobolus airoides) grassland with scattered stands of four-wing saltbush (Atriplex canescens), shadscale (Atriplex confertifolia), and black greasewood (Sarcobatus vermiculatus). These plant associations are the potential natural communities for the approximately 1052 ha surface area that will have been disturbed when the mining operations cease.

Prior to mining, the land was used primarily for livestock production by the Laguna people. Cattle and sheep are of economic importance to the pueblo and a traditionally important commodity for their lifestyle. Therefore, much of the mining area will be rehabilitated for use as rangeland.

The mine is the largest open-pit uranium mine in the world. Over 181,560,000 metric tons of overburden or mine waste material have accumulated in the form of 28 dump sites representing over 445 surface ha (Reynolds et al. 1978). The waste dumps are composed of various mixtures of the stratigraphic materials overlying the ore body. Channels of ore-bearing material occur within the Jackpile sandstone which belongs to the Jurassic age Morrison Formation (Fig. 1). The Jackpile sandstone is overlain by a hard sandstone that grades upward into a carbonaceous and shaly limestone of the Dakota Formation referred to as the Dakota sandstone. Above this Dakota bed lies the black Mancos Shale Formation with three interbedded sandstone units of the Dakota Formation called the Tres Hermanos sandstone unit.

The sequence of overburden removal and dump construction has resulted in the stratification of the waste material in inverse sequence to the natural stratigraphy. This stratification has produced dumps with a relatively uniform surface composed of the geologic unit last removed from the mine and dumped on a particular pile. The most common geologic materials forming the dump surfaces are principally from the Jackpile sandstone and the Mancos shale beds. The basal unit of the Dakota sandstone is very thin in this area and therefore it is not a major portion of the overburden material.

Several of the waste dumps had not been disturbed since deposition approximately 20 years ago (Reynolds et al. 1978). It was noted during the floristic survey of the mine that some of these waste dumps supported good stands of invading native and naturalized plant species, while other dumps of the same age supported only a few scattered plants or no vegetation at all. These observations were recorded along with the number of years since the last surface disturbance and the type of geologic material forming the surface (Table 1).

The 20 years of overburden deposition created a situation for first-hand observation of the invasion and establishment of plant species from the adjacent landscape onto specific geologic material forming the surfaces of the dumps.

Composite soil samples were collected from depths of 0-15 cm at 10 m intervals

**Fig. 1 Typical stratigraphic column at Jackpile mine
(Kittle 1963)**

Table 1. Geologic material forming waste dump surfaces, years undisturbed, and observations about vegetation growing on each type surface

GEOLOGIC MATERIAL	YEARS UNDISTURBED	VEGETATION ON DUMP SURFACE
Jackpile sandstone	0.5	No vegetation
Dakota sandstone — Mancos shale mixed	0.5	No vegetation
Dakota sandstone ¹	20.0	No vegetation
Mancos shale	0.5	No vegetation
Mancos shale	20.0	Plants very rare: annual forbs and grasses
Dakota sandstone ²	20.0	Plants rare: annual and perennial grasses
Tres Hermanos sandstone — Dakota sandstone mixed	2.0	Plants rare: annual and perennial grasses, some forbs and very few shrubs
Jackpile sandstone	20.0	Plants rare: annual and perennial grasses, few shrubs
Tres Hermanos sandstone ³	20.0	Plants common: perennial grasses, annual grasses and forbs, several shrub species
Tres Hermanos sandstone ⁴	4.0	Plants abundant: perennial grasses and forbs, annual grasses and forbs, and numerous shrubs of several species

¹Material dumped by truck and left as mounds

²Depressions between mounds

³Natural succession area

⁴Surface ripped by bulldozer and hand seeded 1972, surfaces leveled on all other sites

along a 200 m transect across each dump surface, representing each type of geologic material found on the waste dumps. These samples were analyzed for texture, pH, electrical conductivity (ECe), percentage organic matter (OM), cation exchange capacity (CEC), and water-holding capacity expressed as field capacity (FC) (Table 2).

The analyses were performed to identify those factors which might have been important in influencing the natural invasion and establishment of plant species on the various overburden materials. The low pH of the basal Dakota sandstone bed would be unsuitable as a surface substrate for revegetation and therefore it was eliminated from further analytical tests.

Elemental analyses were performed on samples from the Tres Hermanos sandstone, Jackpile sandstone, Mancos shale, and a soil collected from a vegetated area of an alluvial valley floor (Tables 3 and 4). These analyses indicated that the Jackpile sandstone and the Mancos shale had relatively low amounts of the major nutrients, e.g., calcium, magnesium, potassium, phosphorus, and nitrate. In comparison to the other materials the Mancos shale had a relatively high amount of sodium (610 ppm) which could become a problem for establishing vegetation on this material. Other elements did not appear to be of major concern to the project (Tables 3 and 4).

The low cation exchange capacity and relatively poor water-holding capacity (Table 2) of the Jackpile sandstone samples further indicated that this material would not be suitable for sustaining vegetation in this arid area. The results revealed that the Tres Hermanos sandstone material offered superior properties for the establishment of native plant species and the realization of the reclamation goal to restore the area to a productive rangeland.

As a result of these findings, the Anaconda Company began a pilot revegetation project in the spring of 1976 on a 20-ha site referred to as the North Dump. The surface of this dump was covered with large piles (18-45 metric tons per pile) of Tres Hermanos rocks and boulders (Reynolds et al. 1978). Two alternatives were considered for the preparation of the seed bed.

The first alternative was to cover the site with stockpiled alluvial soil to a

Table 2. Analyses of physical characteristics of mine-spoil material*

<u>GEOLOGIC MATERIAL</u>	<u>YEARS UNDISTURBED</u>	<u>TEXTURE</u>	<u>pH</u>	<u>ECe (mmhos/cm)</u>	<u>OM (%)</u>	<u>CEC</u>	<u>FC (%)</u>
Tres Hermanos sandstone (natural succession area)	20.0	Sandy clay loam	7.6	2.6	0.1	8.8	31.7
Tres Hermanos sandstone (seeded 1972)	4.0	Sandy clay loam	7.2	0.8	0.5	12.4	35.9
Jackpile sandstone	20.0	Sandy loam	7.7	0.6	0.0	2.7	14.8
Dakota sandstone (depressions)	20.0	Sandy loam	6.2	2.5	0.1	xx	xx
Tres Hermanos (mixed with Dakota)	2.0	Loam	5.7	3.2	0.1	xx	22.2
Stockpiled alluvial soil	1.0	Clay loam	7.1	5.1	0.1	35.3	39.2
Mancos shale	20.0	Sandy clay loam	6.3	5.8	0.4	21.3	33.4
Jackpile sandstone	0.5	Loamy sand	5.4	3.1	0.0	2.1	14.1
Jackpile sandstone (fresh from pit)	0.0	Sandy loam	7.5	2.0	0.0	2.6	11.3
Dakota sandstone & Mancos shale mixed	2.0	Sandy loam	3.6	5.7	0.3	xx	xx
Mancos shale	0.5	Sandy clay loam	7.8	5.7	0.2	20.7	35.0
Dakota sandstone (ridges)	20.0	Sandy loam	3.0	18.8	0.2	xx	xx

* See Appendix for analytical methods

xx Analysis not performed

Note: pH — saturation paste
 ECe — saturation extract
 OM — Organic Matter

CEC — Cation Exchange Capacity
 FC — Moisture Content at Field Capacity

Table 3. Analyses of chemical characteristics of mine spoil material *

<u>MATERIAL</u>	<u>CONCENTRATIONS (ppm)</u>					
	<u>Ca</u>	<u>Mg</u>	<u>Na</u>	<u>K</u>	<u>P</u>	<u>NO₃</u>
Tres Hermanos sandstone	7,850	1,465	40	238	4.1	24.6
Jackpile sandstone	670	140	130	73	0.0	3.9
Mancos shale	815	230	610	106	0.3	0.9
Vegetated natural soil (valley alluvium)	17,400	800	440	247	xx	16.1

* See Appendix for analytical methods

xxAnalysis not performed

Table 4. Analyses of potential problem elements of mine spoil material *

MATERIAL	CONCENTRATIONS (ppm)												
	<u>Fe</u>	<u>Zn</u>	<u>Cd</u>	<u>Cu</u>	<u>Mn</u>	<u>Pb</u>	<u>Hg**</u>	<u>Co</u>	<u>Cr</u>	<u>Ni</u>	<u>As</u>	<u>Se</u>	<u>Cl</u>
Tres Hermanos sandstone	.02	.25	.28	.5	18.0	1.0	.005	.12	.05	.45	.3	.03	15.7
Jackpile sandstone	.02	.10	.09	.5	3.0	1.1	.005	.02	.11	.005	.5	.10	5.8
Mancos shale	1.6	.08	.04	.4	0.3	1.5	.005	.09	xx	.38	.3	.11	4.0
Vegetated natural soil (alluvium)	25.0	.10	.06	.1	52.0	1.4	.005	.08	.08	.08	.2	.05	40.0

* See Appendix for analytical method

** Hg — Sulfuric acid-hydrogen peroxide digestion analyzed by AA (U.S. EPA 1976)

xx Analysis not performed

recommended depth of 46 cm. A cost estimate indicated that this procedure would be approximately \$110,000 per 20 ha. The equipment necessary to load and haul the soil material would have to come from the mining operation, effectively reducing ore production, and thereby increasing the cost even more (Reynolds et al. 1978).

The second alternative was to attempt to form a coarse soil-like material by crushing in place the Tres Hermanos sandstone rocks and boulders strewn over the dump surface. This procedure would not require the use of equipment from the mining operation nor the use of relatively scarce alluvial material. This was the alternative chosen.

The surface preparation was done with four D-9 Caterpillar bulldozers which worked the material down, broke up the boulders and rocks, and pushed the very large 3 to 6 m diameter boulders off the site or into piles while contouring the surface. A 44-ton Caterpillar compactor Model 825-B was driven repeatedly over the leveled surface to crush the broken boulders, slabs, and rock material until a texture that could be seeded by a range drill was achieved. The end result was a mixture of rock and soil size particles with the rock size comprising 20-40 percent of the profile developed by the impactor. The rocks proved to be effective in concentrating moisture from precipitation into the soil portion of the profile as reported by Epstein et al. (1976). Evaporation of moisture trapped beneath the rocks was less rapid than that from the open soil areas effectively increasing the length of time moisture would be available for plant growth. In addition, the compactor tracks left a pock-marked surface which helped retard wind and water erosion and provided numerous small catchment basins to collect rain and wind-blown soil material. The cost for this procedure was \$40,000 per 20 ha (Reynolds et al. 1978).

The area was seeded with a mixture of nine grass species and one legume species (Table 5) typical of the surrounding rangelands. The seeding was done during July 1976 at a rate of 8 kg per ha. The grass species were selected on the basis of forage value and ability to become established without irrigation. The legume, yellow sweetclover (Melilotus officinalis) inoculated with Rhizobium melilotum, was included for its

Table 5. Seed mixture applied on the 20-ha North Dump - 1976

<u>GENUS AND SPECIES</u>	<u>COMMON NAME</u>	<u>MIXTURE (%)</u>
<u>Bouteloua gracilis</u>	blue grama (Lovington)	30
<u>Sporobolus cryptandrus</u>	sand dropseed	15
<u>Bouteloua curtipendula</u>	sideoats grama (Vaughn)	4
<u>Sporobolus airoides</u>	alkali sacaton	5
<u>Oryzopsis hymenoides</u>	Indian ricegrass (Paloma)	5
<u>Eragrostis curvula</u>	weeping lovegrass	10
<u>Andropogon scoparius</u>	little bluestem (Pastura)	15
<u>Agropyron smithii</u>	western wheatgrass	5
<u>Andropogon hallii</u>	sand bluestem	6
<u>Melilotus officinalis</u>	sweetclover	5

nitrogen-fixing ability (Reynolds et al. 1978).

A barley (*Hordeum vulgare*) straw mulch was applied to the seeded surface at a rate of 4.94–6.18 tons per ha (2–2.5 tons per acre). The mulch was crimped into the surface to prevent wind loss (Reynolds et al. 1978). Germination of the seeded species and barley from the mulch began between August 20 and August 27, 1976 in response to approximately 5 cm of precipitation received from August 1 to August 20.

Five permanent line transects of 100 m each were established on the reclaimed dump prior to germination and data were collected in the third week of October 1976 for total foliage cover and relative cover. Data for density values were obtained with the use of a 0.5 x 1 m quadrat frame placed along the permanent line transects at 10 m intervals. The 13 cm of precipitation received at the site by the October sampling period had allowed the seedlings to become established.

Foliage cover and density data were again collected during the third week of October 1977 from the permanent sampling sites for comparison to the data from 1976 (Table 6). The 5.3 cm of precipitation received between November 1, 1976 and April 30, 1977 was equal to a seven-year average for these months. The precipitation received during the 1977 growing season of March through October was 7.5 cm less than the seven-year average of 22 cm for these months.

The effect of the dry 1977 growing season was a slight decrease in density for seedlings of some of the less drought-tolerant species. The precipitation was sufficient to allow germination and growth of the more drought-tolerant species (Table 6). All the planted species growing on the North Dump increased in the amount of foliage cover as would be expected of seedlings growing in a suitable environment. The precipitation received during the 1977 growing season, although below average, was sufficient to allow growth and seed production of the species surviving from the July 1976 planting.

Of the total vegetative cover of 0.75 percent in 1976 and 6.8 percent in 1977, the relative foliage cover for all the planted species was 64.4 percent and 78.3 percent

Table 6. Comparison of foliage cover and density values on the North Dump from October 1976 to October 1977

SCIENTIFIC NAME (Common Name)	FOLIAGE COVER				DENSITY	
	Total (%) ^a		Relative (%) ^a		No/m ^{2b}	
	1976	1977	1976	1977	1976	1977
<u>Bouteloua curtipendula</u> * (side-oats grama)	.15	1.78	19.6	26.0	14.8	12.5
<u>Sporobolus airoides</u> * (alkali sacaton)	.06	1.53	8.4	22.3	2.0	7.0
<u>Salsola kali</u> (Russian thistle)	<.01	.41	0.1	6.0	0.3	0.8
<u>Melilotus officinalis</u> * (yellow sweetclover)	.05	.73	6.4	10.7	2.5	5.8
<u>Hordeum vulgare</u> (barley)	.24	.65	31.4	9.5	7.4	5.8
<u>Agropyron smithii</u> * (western wheatgrass)	.08	.58	11.0	8.5	6.4	7.4
<u>Kochia scoparia</u> (summer-cypress)	.02	.33	2.0	4.8	0.2	0.7
<u>Bouteloua gracilis</u> * (blue grama)	.07	.46	9.2	6.7	6.2	4.8
<u>Eragrostis curvula</u> * (weeping lovegrass)	.07	.26	9.6	3.8	4.4	3.1
<u>Atriplex canescens</u> (four-wing saltbush)	.01	.05	0.6	0.7	0.2	0.2
<u>Amaranthus sp.</u> (pigweed)	<.01	<.01	0.1	0.2	0.1	0.1

Table 6. Continued

SCIENTIFIC NAME (Common Name)	FOLIAGE COVER				DENSITY	
	Total (%) ^c		Relative (%) ^a		No/m ² ^b	
	1976	1977	1976	1977	1976	1977
<u>Setaria sp.</u> (bristlegrass)		.02		0.3		0.2
<u>Oryzopsis hymenoides*</u> (Indian ricegrass)	<.01	.02	0.2	0.3	0.2	0.3
<u>Haplopappus spinulosus</u> (ironplant goldenweed)		.02		0.3		< 0.1
<u>Astragalus kentrophyta</u> (locoweed)		<.01		0.2		< 0.1
<u>Chenopodium berlandieri</u> (goosefoot)	<.01	<.01	0.1	< 0.1	0.3	< 0.1
<u>Agropyron trachycaulum</u> (slender wheatgrass)	<.01	<.01	0.1	< 0.1	< 0.1	< 0.1
<u>Avena sativa</u> (common oat)	<.01	<.01	< 0.1	< 0.1	0.1	< 0.1
<u>Sitanion hystrix</u> (bottlebrush squirreltail)	<.01	<.01	0.2	< 0.1	0.1	< 0.1
<u>Gutierrezia sarothrae</u> (broom snakeweed)	<.01	<.01	< 0.01	< 0.1	< 0.1	< 0.1
TOTALS	0.75	6.85	100	100	45.0	48.8

^aData based on 5 lines each 100 m long^bData based on 50 quadrats of .5 x 1m size

*Species planted during reclamation project

respectively, indicating a reduction in the relative coverage of invading species. Side-oats grama grass (Bouteloua curtipendula) provided the greatest cover and density values in both sampling periods. Alkali sacaton had the greatest increase in cover (relative and absolute) and density for the planted species over the one-year period.

Barley, introduced with the mulch, germinated and grew rapidly in response to the August rains. Many barley plants had produced seed by the October 1976 sampling period. Because of the late fall germination, numerous plants died back to the ground during the winter, regrew from the rootstock like winter annuals the next spring, and produced seed by early summer. Plants that produced seed by October 1976 did not regrow in the spring. The total foliage cover of barley increased over the first year but the relative cover and density values decreased. The growth of the barley has added rapidly to the organic matter of the surface material on the dump resulting in a better soil for growth of native plants. Barley is expected to remain a component of the North Dump flora for several years.

Yellow sweetclover increased in both cover and density values over the first year. Many plants had produced seed by the October 1976 sampling period, though this species is usually a biennial. New and old plants grew during the following spring and summer producing seed by the second sampling date. Yellow sweetclover appears to be well established and is a valuable species in the North Dump flora. However, it is known to be erratic in its success.

Weedy grasses and forbs, some introduced with the mulch and some introduced by wind-blown seed from the surrounding rangeland, have become established on the dump. Both cover and density values have increased for the weedy species. The density of the weedy species increased from 1.2 to 1.8 plants per square meter from 1976 to 1977. Relative foliage cover increased from 2.7 percent to 11.9 percent. This increase in cover was due to the large size, up to 1 m in diameter, of Russian thistle (Salsola kali) and summer-cypress (Kochia scoparia)—two fast-growing exotic annuals. While the total cover of the weedy species has increased 4.4 times, that of the planted species has increased by 11.3 times. If this trend continues, the grasses will

probably out-compete the taprooted weedy species and remain dominant on the site. The other weedy species have not shown any significant change in either cover or density.

Only two shrub species have invaded the North Dump. Four-wing saltbush, a valuable browse species, increased in size, but new plants did not occur along the transects. The saltbush plants increased in height from 20–30 cm in 1976 to 90–110 cm in 1977. One plant had flowered and produced seed by October 1977. The browse value and rapid growth make this species an important component of the North Dump flora although it was not included in the planting mixture. Broom snakeweed (Gutierrezia sarothrae), a noxious, weedy low shrub, has increased slightly in size but not in density and does not appear to be a problem at this time.

In the areas adjacent to the mine there are other browse shrubs which are potential natural invaders of the North Dump: shadscale, slender gray sagebrush (Artemisia bigelovii), winterfat (Eurotia lanata), pale wolfberry (Lycium pallidum), and squawberry (Rhus trilobata). Shrubby species considered undesirable invaders are broom snakeweed, cane cholla (Opuntia imbricata), club cactus (Opuntia clavata), prickly pear cactus (Opuntia polyacantha), and small soapweed yucca (Yucca glauca). Continued monitoring of the reclaimed area should provide information on the rate of invasion by these shrub species.

Seed Mixture Evaluation

Seed germination tests, using three replicates with 50 seeds each, were conducted in growth chambers adjusted for optimum temperature and light (Sabo 1977; Stubbendieck et al. 1972, 1976; Toole 1941). Standard procedures were followed for breaking dormancy for sand dropseed (Sporobolus cryptandrus) and Indian ricegrass (Oryzopsis hymenoides) (Huntamer 1934; Toole 1941). Results from these tests indicated that sand dropseed, Indian ricegrass, and sand bluestem (Andropogon hallii) may have been in a dormant state which was not broken by the procedures followed or that the seed had low viability (Table 7).

Table 7. Average seedling germination, 6 weeks after planting, for nine grass and one legume species grown under optimum temperature and photoperiod

SCIENTIFIC NAME (Common Name)	TEMPERATURE (°C)		HOURS		GERMIN- ATION (%)
	Light	Dark	Light	Dark	
<u>Agropyron smithii</u> (western wheatgrass)	18.5	10.0	8	16	82.0
<u>Andropogon hallii</u> (sand bluestem)	26.0	15.0	8	16	.6
<u>Andropogon scoparius</u> (little bluestem)	27.0	16.5	8	16	44.0
<u>Bouteloua curtipendula</u> (side-oats grama)	31.0	12.0	16	8	94.0
<u>Bouteloua gracilis</u> (blue grama)	37.0		24		96.6
<u>Eragrostis curvula</u> (weeping lovegrass)	25.0	14.0	8	16	94.0
<u>Melilotus officinalis</u> (yellow sweetclover)	16.0	16.0	8	16	76.0
<u>Oryzopsis hymenoides</u> (Indian ricegrass)	26.0	15.0	8	16	.6
<u>Sporobolus airoides</u> (alkali sacaton)		33.0		24	58.6
<u>Sporobolus cryptandrus</u> (sand dropseed)	36.0	18.0	8	16	5.3

The low germination for these species was reflected in the flora on the North Dump. Estimates of seeds planted per square meter (Table 8) compared to density values of these species growing on the North Dump show that the species with less than 50 percent germination in the growth chambers (Table 7) did not germinate well in the field. Indian ricegrass germinated slightly better in the field than in the growth chamber. Western wheatgrass (Agropyron smithii) and side-oats grama grass had the best germination and survival percentages in the field. Side-oats grama was first and western wheatgrass was fourth in germination percentages in the growth chamber tests. Weeping lovegrass (Eragrostis curvula), blue grama, yellow sweetclover, and alkali sacaton had comparatively low survival rates in the field but they provided 43.5 percent of the relative cover on the North Dump in October 1977 and are important components of the flora.

A revision of the seed mixture is suggested by the data gathered from the germination tests and the vegetational survey on the North Dump. The most efficient seed mixture for rapid establishment should probably include side-oats grama, alkali sacaton, western wheatgrass, and yellow sweetclover. Weathering may change the parent soil material over a period of time and allow better germination and growth of blue grama or Indian ricegrass. Blue grama and Indian ricegrass should be included in the seed mixture since they did germinate and grow on the North Dump and both are important range species. Seeds of these species are not easily disseminated by wind and the plants growing on the dump will provide a local seed source. Galleta grass, although abundant in the surrounding rangeland, was not included in the seed mixture because of its potential for natural invasion from wind-blown seed.

Vegetational Composition of Reclaimed Site and Native Range

The two types of range lands in the vicinity of the mine were sampled for comparison to the North Dump. These sample sites had very few shrubs. Clumps of shrubs are conspicuous on specific soils in both rangeland types and would be considered as a

Table 8. Seeding rate and survival after one year's growth for species planted on the North Dump

<u>SCIENTIFIC NAME</u> <u>(Common Name)</u>	<u>SEEDS*</u> <u>(per g)</u>	<u>GRAMS</u> <u>(per ha)</u>	<u>SEEDS</u> <u>(per ha)</u>	<u>SEEDS</u> <u>(per m²)</u>	<u>PLANTS</u> <u>(per m²)</u>	<u>SURVIVAL</u> <u>(%)</u>
<u>Agropyron smithii</u> (western wheatgrass)	278	392	108,927	11	7.4	67.3
<u>Andropogon hallii</u> (sand bluestem)	249	471	117,226	12	0	0
<u>Andropogon scoparius</u> (little bluestem)	562	1176	661,342	66	0	0
<u>Bouteloua curtipendula</u> (side-oats grama)	421	314	149,385	15	12.5	83.3
<u>Bouteloua gracilis</u> (blue grama)	1568	2353	3,687,957	368	4.8	1.3
<u>Eragrostis curvula</u> (weeping lovegrass)	14330	784	11,234,720	1123	3.1	0.3
<u>Melilotus officinalis</u> (yellow sweetclover)	573	392	224,616	22	5.8	26.4
<u>Oryzopsis hymenoides</u> (Indian ricegrass)	414	392	162,576	16	.3	1.9
<u>Sporobolus airoides</u> (alkali sacaton)	3858	392	1,572,875	157	7.0	4.5
<u>Sporobolus cryptandrus</u> (sand dropseed)	11023	1176	12,967,500	1297	0	0

* Data derived from Cook 1976 and Anderson 1973.

subtype in a general vegetational survey. Since the North Dump has very few shrubs, these subtypes were not sampled for comparison.

A total of 47 species was encountered on the three sites sampled, with 20 species occurring on the North Dump, 24 on the shallow soil site, and 23 on the valley site. There were 10 species common to both the mesa and valley sites. Five species were common to all three sites: blue grama, alkali sacaton, ironplant goldenweed (Haplopappus spinulosus), bottlebrush squirreltail grass (Sitanion hystrix), and four-wing saltbush. Locoweed (Astragalus kentrophyta) and broom snakeweed are common to both the dump and the mesa site. Goosefoot (Chenopodium berlandieri), summer-cypress, and Russian thistle are common to the dump and valley site. All common species except blue grama, alkali sacaton, and four-wing saltbush are weedy pest species (Thornton et al. 1974). Weedy species comprise 40 percent of the total species on the North Dump, 29 percent on the mesa site, and 61 percent in the valley site which is heavily overgrazed.

Foliage cover and frequency data (Table 9) were collected from the three sites to evaluate the progress of vegetative growth on the North Dump. The total foliage cover for forbs and grasses on the North Dump is 6.8 percent, with 78.0 percent of the cover being grasses. The mesa site has 11.8 percent total cover, with 99.3 percent grasses. Grasses account for 89.1 percent of the 11.8 percent total cover in the valley site. The floristic composition, foliage cover, and frequency values indicate that the North Dump has a closer affinity to the valley site than to the mesa at this time.

Four-wing saltbush has the highest cover and frequency values for shrubs in the valley site. This species has invaded the North Dump and already has a higher cover value on the dump than on the mesa site. It is expected that this valuable browse plant will continue to invade and become established on the reclaimed area. Four-wing saltbush has been added to the seed mixture to be used in future reclamation work. Broom snakeweed has the greatest cover and frequency value for shrubs on the mesa site. This pest species has invaded the North Dump and may need to be controlled if its density increases rapidly.

Table 9. Foliage cover and frequency values for species growing on the North Dump and two types of rangeland adjacent to the mine (Data based on 5 transects each 100 m long)

SCIENTIFIC NAME	NORTH DUMP				MESA TOP RANGELAND				VALLEY RANGELAND			
	Total Foliage Cover (%)	Relative Foliage Cover (%)	Frequency Index (%)	Relative Frequency (%)	Total Foliage Cover (%)	Relative Foliage Cover (%)	Frequency Index (%)	Relative Frequency (%)	Total Foliage Cover (%)	Relative Foliage Cover (%)	Frequency Index (%)	Relative Frequency (%)
Forbs and Grasses:												
<u>Abronia</u> sp.									.02	.17	6	1.44
<u>Agropyron smithii</u>	.58	8.53	98	14.76								
<u>Agropyron trachycaulum</u>	<.01	.01	2	.30								
<u>Amaranthus</u> sp.	<.01	.20	6	.90								
<u>Aristida</u> sp.					.64	5.44	36	10.71	.40	3.39	12	2.88
<u>Astragalus kentrophyta</u>	<.01	.20	2	.30	<.01	.04	2	.60				
<u>Avena sativa</u>	<.01	.01	2	.30								
<u>Bouteloua barbata</u>									2.16	18.30	90	21.58
<u>Bouteloua curtipendula</u>	1.78	28.17	90	13.55								
<u>Bouteloua eriopoda</u>					.04	.34	6	1.78				
<u>Bouteloua gracilis</u>	.46	6.76	80	12.05	5.56	47.28	100	29.76	.14	1.19	10	2.40
<u>Chenopodium berlandieri</u>	<.01	.01	2	.30					.02	.17	10	2.40
<u>Cirsium</u> sp.									<.01	.04	2	.48
<u>Dithyrea wislizeni</u>									.01	.08	12	2.88
<u>Eragrostis curvula</u>	.26	3.82	64	9.64								
<u>Erigeron canadensis</u>									.01	.08	2	.48
<u>Euphorbia serpens</u>					.01	.08	4	1.19				
<u>Gilia multiflora</u>					.02	.17	6	1.78				
<u>Haplopappus spinulosus</u>	.03	.03	2	.30	.04	.34	20	5.95	.02	.17	2	.48
<u>Hilaria jamesii</u>					2.91	24.74	82	24.40	.57	4.83	22	5.28
<u>Hordeum vulgare</u>	.65	9.56	80	12.05								
<u>Kochia scoparia</u>	.33	4.85	20	3.01					.30	2.54	32	7.68
<u>Leucelene ericoides</u>					<.01	.04	2	.60				
<u>Lycurus phleoides</u>					.05	.42	6	1.78				

Table 9. Continued

SCIENTIFIC NAME	NORTH DUMP				MESA TOP RANGELAND				VALLEY RANGELAND			
	Total Foliage Cover (%)	Relative Foliage Cover (%)	Frequency Index (%)	Relative Frequency (%)	Total Foliage Cover (%)	Relative Foliage Cover (%)	Frequency Index (%)	Relative Frequency (%)	Total Foliage Cover (%)	Relative Foliage Cover (%)	Frequency Index (%)	Relative Frequency (%)
<u>Melilotus officinalis</u>	.73	10.73	80	12.05					2.01	17.03	42	10.07
<u>Muhlenbergia torreyi</u>					1.41	11.99	34	10.12	.48	4.07	66	15.53
<u>Oryzopsis hymenoides</u>	.02	.29	14	2.11					.09	.76	2	.48
<u>Salsola kali</u>	.41	6.03	30	4.52								
<u>Schedonnardus paniculatus</u>												
<u>Setaria lutescens</u>	.02	.29	12	1.81								
<u>Sitanion hystrix</u>	<.01	<.10	2	.30	<.01	.04	2	.60	<.01	.04	2	.48
<u>Sporobolus airoides</u>	1.53	22.50	78	11.75	.16	1.36	8	2.38	5.46	46.27	86	20.62
<u>Sporobolus cryptandrus</u>					.90	7.65	28	8.33				
<u>Tragus berteronianus</u>									<.01	.04	2	.48
<u>Tribulus terrestris</u>									.02	.17	5	1.20
<u>Tridens pulchella</u>									.08	.68	12	2.88
TOTAL	6.80	100	664	100	11.76	100	336	100	11.80	100	417	100
Shrubs:												
<u>Artemisia bigelovii</u>					.24	5.04	14	9.33				
<u>Atriplex canescens</u>					.03	.63	2	1.33	.92	50.00	5	26.32
<u>Atriplex confertifolia</u>		83.33	10	83.33					.62	33.70	9	47.37
<u>Eurotia lanata</u>					.03	.67	2	1.33				
<u>Gutierrezia sarothrae</u>			2	16.67	3.54	78.84	98	65.33				
<u>Lycium pallidum</u>	<.01	16.67			.16	3.56	6	4.00				
<u>Opuntia clavata</u>					.04	.89	2	1.33	.03	1.63	1	5.26
<u>Opuntia imbricata</u>					.03	.67	4	2.67	.27	14.67	4	21.05
<u>Opuntia polyacantha</u>					.22	4.90	12	9.00				
<u>Rhus trilobata</u>					.35	7.80	2	1.33				

Table 9. Continued

SCIENTIFIC NAME

VALLEY RANGELAND	Relative Frequency (%)			
	Frequency Index (%)			
	Relative Foliage Cover (%)			
	Total Foliage Cover (%)			
MESA TOP RANGELAND	Relative Frequency (%)	5.33	100	
	Frequency Index (%)	8	150	
	Relative Foliage Cover (%)	2.67	100	
	Total Foliage Cover (%)	.12	4.49	
NORTH DUMP	Relative Frequency (%)		100	
	Frequency Index (%)		12	
	Relative Foliage Cover (%)		100	
	Total Foliage Cover (%)		.05	
				TOTAL

Yucca glauca

Side-oats grama is a minor component of the blue grama grasslands. It is found growing on the steep, rocky slopes and on the rock outcrops of the mesa tops. This grass appears to be well adapted for growth on the rocky soil of the North Dump. The cover and frequency data indicate that it has become a co-dominant with alkali sacaton on the reclaimed site.

Western wheatgrass, weeping lovegrass, and yellow sweetclover grow in both the valley and mesa sites where there is an increase in the moisture supply from runoff. They are usually found along roadsides, stream banks, and pond areas. They are included in the seed mixture because of their ability to become established on disturbed sites, either natural or man-made, and for their value as forage plants. These species provide 49.2 percent of the total cover on the North Dump at the present time. Continued monitoring of the vegetation would be necessary to determine the successional rate and pattern on the North Dump.

Uranium Tailing Piles

The extraction of uranium involves either acid or carbonate leaching of the ore after preparation by crushing, grinding, and in some cases roasting. Soluble uranium is recovered by ion exchange, solvent extraction, or by caustic precipitation (Beverly 1968; Merritt 1971). The waste liquids and solids are slurried to a tailing pond. The tailing pile develops from the sand, silt, and clay-sized particles that settle from the slurry.

The slurry is deposited in the pond area from different points around the perimeter at various times. This maintains a relatively uniform surface elevation of the tailing pile within the retaining dikes. Because of the sequence of slurry deposition and the different settling rates of the solids, the tailing piles generally have a random stratification, both vertically and horizontally, of sand layers and silt-clay layers (slimes). Some tailing piles may be predominantly sandy material while others may contain mostly silt and clay-sized particles. The textural composition of each tailing pile is dependent upon the type of geologic material from which the ore is extracted.

The liquids in some instances are retained on the surface of the tailing pile by dikes. A small percentage of the waste liquid evaporates and the rest seeps into the ground. Some mills recycle the pond water for re-use in the milling process. Waste water also has been disposed of by a deep-well injection method or discharged to streams and rivers through decontamination circuits by some mills (Beverly 1968). Plastic-lined evaporation ponds adjacent to the tailing pile are currently being used to dispose of the excess liquid by several mills in New Mexico.

Previous research has identified health hazard problems resulting from the radioactive elements and toxic chemicals from uranium mill tailings entering the environment as wind blown material or through leaching and erosion into water systems (U.S. AEC 1963; Nielson and Peterson 1972; Anonymous 1974; Beverly 1974; Hanson 1974; U.S. EPA 1975;

Donovan et al. 1976; Kaufmann et al. 1976; Purtymun et al. 1977; Dreesen 1978).

This study concentrates on problems associated with vegetative stabilization of the solid waste materials at three inactive uranium mill tailing sites in New Mexico. The tailing material at Site A is from an acid leach process mill and the tailings at Sites B and C are from carbonate leach process mills. The last deposition of tailings at Site A occurred two years before the start of the study. The last depositions at Sites B and C were approximately 15 years and 20 years prior to the study.

Floristic Surveys of Sites A, B, and C

The three sites studied are located in blue grama–galleta grasslands of the Grants mineral belt of New Mexico. A floristic survey of each of the tailing piles was conducted during September 1975. This survey indicated that a limited number of plant species and very few individuals of these species were able to invade and become established naturally on the mill waste material. Each tailing pile was surveyed at least once each month from May to October during 1976 and 1977 for new invading plant species.

A floristic survey was conducted around each of the three sites during May, July, and September of 1976 and 1977 to identify plant species that could be potential natural invaders on the mill waste materials. A list of 68 species was compiled for the area around Site A, 72 species for Site B, and 73 species for the flora adjacent to Site C (Table 10).

Plants from the surrounding area were not able to invade and become established on the acid tailing material at Site A. Bottlebrush squirreltail grass, alkali sacaton, bee spiderflower (Cleome serrulata), summer-cypress, Russian thistle, and four-wing saltbush were able to invade and become established on Site B. These species represent 8.3 percent of the floristic composition identified in the adjacent rangeland. Site C supported 5.5 percent of the species found in the adjacent flora. These occurred as a few scattered clumps or individuals of bottlebrush squirreltail grass, summer-cypress, and Russian thistle. The floristic composition for the three tailing piles remained the same

Table 10. Plant species growing in vicinity of New Mexico mill tailing Sites A, B, and C

SCIENTIFIC NAME (Common Name)	Site A (acid)	LOCATION Site B (carbonate)	Site C (carbonate)
<u>Agropyron cristatum</u> (crested wheatgrass)			X
<u>Agropyron smithii</u> (western wheatgrass)	X	X	X
<u>Andropogon hallii</u> (sand bluestem)	X		
<u>Andropogon scoparius</u> (little bluestem)	X	X	
<u>Argemone platyceras</u> (pricklepoppy)			X
<u>Aristida fendleriana</u> (Fendlers three-awn grass)	X	X	X
<u>Artemisia dracunculus</u> (false tarragon)	X	X	X
<u>Artemisia filifolia</u> (sand sagebrush)	X	X	X
<u>Artemisia frigida</u> (fringed sagebrush)	X	X	X
<u>Artemisia ludoviciana</u> (Louisiana wormwood)			X
<u>Artemisia tridentata</u> (big sagebrush)	X	X	X
<u>Asclepias latifolia</u> (milkweed)			X
<u>Aster sp.</u> (aster)	X	X	X
<u>Astragalus sp.</u> (loco weed)	X	X	X
<u>Atriplex canescens</u> (four-wing saltbush)	X	X	X
<u>Bahia neomexicana</u> (New Mexico bahia)			X

Table 10. Continued

SCIENTIFIC NAME (Common Name)	Site A (acid)	LOCATION Site B (carbonate)	Site C (carbonate)
<u>Bouteloua curtipendula</u> (side-oats grama)	X	X	X
<u>Bouteloua gracilis</u> (blue grama grass)	X	X	X
<u>Brickellia grandiflora</u> (tassel brickellia)	X	X	
<u>Bromus tectorum</u> (cheatgrass)	X	X	X
<u>Chenopodium sp.</u> (goosefoot)	X	X	X
<u>Chrysopsis sp.</u> (goldaster)		X	X
<u>Chrysothamnus nauseosus</u> (rubber rabbitbrush)	X	X	X
<u>Cirsium sp.</u> (thistle)	X	X	X
<u>Cleome serrulata</u> (bee spiderflower)	X		X
<u>Conyza canadensis</u> (horseweed)	X	X	X
<u>Corypantha sp.</u> (corypantha cactus)	X	X	
<u>Cryptantha sp.</u> (hiddenflower)	X	X	X
<u>Curcubita foetidissima</u> (calabazilla)			X
<u>Datura meteloides</u> (sacred thornapple)			X
<u>Descurainia pinnata</u> (tansymustard)	X	X	X
<u>Draba sp.</u> (whitlowwort)			X
<u>Echinocereus triglochidiatus</u> (claretcup cactus)	X	X	

Table 10. Continued

SCIENTIFIC NAME (Common Name)	Site A (acid)	LOCATION Site B (carbonate)	Site C (carbonate)
<u>Elaeagnus angustifolia</u> (Russian Olive)		X	X
<u>Ephedra</u> sp. (green ephedra)	X	X	X
<u>Erigeron</u> spp. (fleabane)	X	X	X
<u>Eriogonum jamesii</u> (antelope sage)	X	X	
<u>Eurotia lanata</u> (winterfat)	X	X	X
<u>Fallugia paradoxa</u> (Apache plume)	X	X	
<u>Festuca</u> sp. (fescue grass)	X	X	
<u>Gilia</u> sp. (gilia)	X	X	X
<u>Grindelia squarrosa</u> (curlycup gumweed)	X	X	X
<u>Gutierrezia sarothrae</u> (broom snakeweed)	X	X	X
<u>Haplopappus spinulosus</u> (ironplant goldenweed)	X	X	X
<u>Helianthus annuus</u> (common sunflower)	X	X	X
<u>Helianthus petiolaris</u> (prairie sunflower)	X	X	X
<u>Hilaria jamesii</u> (galleta grass)	X	X	X

Table 10. Continued

SCIENTIFIC NAME (Common Name)	Site A (acid)	LOCATION Site B (carbonate)	Site C (carbonate)
<u>Hymenoxys acaulis</u> (no-stem rubberweed)			X
<u>Hymenoxys richardsonii</u> (pingue)	X	X	X
<u>Kochia scoparia</u> (summer-cypress)	X	X	X
<u>Lactuca serriola</u> (prickly lettuce)			X
<u>Lappula redowskii</u> (stickseed)	X	X	X
<u>Lepidium montanum</u> (pepper grass)	X	X	X
<u>Lycium pallidum</u> (pale wolfberry)	X	X	X
<u>Melilotus alba</u> (white sweet clover)	X	X	X
<u>Melilotus officinalis</u> (yellow sweet clover)	X	X	X
<u>Mentzelia sp.</u> (stickleaf)			X
<u>Mirabilis multiflora</u> (silvestre four-o'clock)	X	X	
<u>Muhlenbergia torreyi</u> (ring muhly)	X	X	X
<u>Oenothera caespitosa</u> (tufted evening-primrose)	X	X	X
<u>Oenothera sp.</u> (evening-primrose)	X	X	X

Table 10. Continued

SCIENTIFIC NAME (Common Name)	Site A (acid)	LOCATION Site B (carbonate)	Site C (carbonate)
<u>Opuntia polyacantha</u> (plains prickly pear)	X	X	X
<u>Oryzopsis hymenoides</u> (Indian ricegrass)	X	X	X
<u>Plantago purshii</u> (woolly Indianwheat)		X	X
<u>Portulaca oleracea</u> (pursley)	X	X	
<u>Ratibida columnaris</u> (headflower)			X
<u>Rhus trilobata</u> (squawberry)	X	X	
<u>Ribes cereum</u> (wax current)	X	X	
<u>Ribes sp.</u> (current)	X	X	
<u>Salsola kali</u> (Russian thistle)	X	X	X
<u>Senecio sp.</u> (groundsel)	X	X	X
<u>Sisymbrium altissimum</u> (tumblemustard)	X	X	X
<u>Sisymbrium linearifolium</u> (tumblemustard)		X	X
<u>Sisymbrium linifolium</u> (tumblemustard)			X
<u>Sitanion hystrix</u> (bottlebrush squirreltail grass)	X	X	X

Table 10. Continued

SCIENTIFIC NAME (Common Name)	LOCATION		
	Site A (acid)	Site B (carbonate)	Site C (carbonate)
<u>Solanum elaeagnifolium</u> (white horse-nettle)		X	X
<u>Sphaeralcea coccinea</u> (globe mallow)	X	X	X
<u>Sporobolus airoides</u> (alkali sacaton)	X	X	X
<u>Sporobolus cryptandrus</u> (sand dropseed)	X	X	X
<u>Stanleya pinnata</u> (desert plume)			X
<u>Stipa comata</u> (needle and thread grass)	X	X	
<u>Stipa neomexicana</u> (New Mexico feathergrass)	X	X	
<u>Tamarix pentandra</u> (saltcedar)	X	X	X
<u>Tragopogon sp.</u> (salsify)	X	X	X
<u>Typha latifolia</u> (common cattail)		X	X
<u>Verbena ciliata</u> (verbena)	X	X	X
<u>Yucca glauca</u> (small soapweed)	X	X	X
<u>Zinnia grandiflora</u> (Rocky Mountain zinnia)	X	X	X

throughout the study period except for the addition of two specimens of bee spider-flower at Site C in 1977.

In the vicinity of each tailing pile are areas that have been disturbed by trenching, grading, soil removal, or soil deposition for construction purposes. Some of these areas were disturbed 5 to 10 years ago while others were disturbed within the last year of the study. The areas disturbed between 5 and 10 years ago near Site A had 40 percent of the species found in the surrounding area. The older disturbed areas near Site B supported 23 species (32%) and near Site C 35 species (48%) from the adjacent flora. The more recently (one year or less) disturbed areas near Site A had 10 species (15%) and the areas near Sites B and C had 12 species (17%) and 8 species (11%) respectively, from the surrounding flora.

The results of these surveys show that plant succession is much slower on the mill tailing material than on disturbed soils in the natural landscape of the area. The natural invasion and establishment of vegetation on mill waste piles is not dependable for stabilization purposes at any of these sites.

Physical and Chemical Properties

Previous uranium mill tailing revegetation projects in Colorado had identified numerous physical and chemical problems (Berg 1971). Consequently, samples were collected from Sites A, B, and C and analyzed for pH, electrical conductivity (ECe), percentage moisture content at field capacity (FC), cation exchange capacity (CEC), 16 elements, nitrate, and chloride (Tables 11 and 12). Four composite samples of a soil from near Sites A and B were collected and analyzed for these physical and chemical factors for comparative purposes. These results are also included in Tables 11 and 12.

The low pH value of the tailing material at Site A is a major problem for the establishment of vegetation at this site. Site A also has deficiencies of calcium, magnesium, potassium, and nitrate. These deficiencies would be expected in normal acid soils with a pH below 4 (Buckman and Brady 1969). Raising the pH above 7 by the

Table 11. Analyses of physical characteristics of uranium mill tailing samples from New Mexico Sites A, B, and C and the soil type adjacent to Sites A and B

ANALYSIS	SITE A		SITE B		SITE C		LOCAL SOIL	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
pH (extract)	3.87	0.37	9.05	0.35	8.27	0.20	8.34*	0.05
pH (paste)	3.28	0.15	9.35	0.41	8.42	0.17	7.42*	0.17
ECe (mmhos)	4.90	2.04	4.87	2.37	9.86	4.65	2.78*	0.70
CEC (meq/100g)	1.96	0.89	6.98	3.04	5.27	2.97	31.78*	7.19
FC(%)	24.00	—	23.00	—	22.00	—	54.00*	—

* See Appendix for analytical methods

Number of samples = 12 except where noted by * where n = 4.

Table 12. Analyser of chemical characteristics of uranium mill tailing samples from New Mexico Sites A, B, and C and the soil type adjacent to Sites A and B (ppm)

ELEMENT	SITE A		SITE B		SITE C		LOCAL SOIL	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
Calcium	1,400	920	86,500	10,600	32,000	8,100	18,025*	5,904
Magnesium	91	77	1,100	280	140	50	1,210*	412
Sodium	140	110	1,800	900	2,200	1,000	365*	137
Potassium	11	5	100	27	98	42	216*	48
Iron	47	21	22	9	37	13	34*	18
Zinc	0.9	0.7	0.4	0.2	3.1	3.7	0.14*	0.07
Cadmium	0.17*	0.24	0.03*	0.02	0.05*	0.04	0.04*	0.01
Copper	0.70	0.60	0.50	—	0.20	0.36	0.29*	0.41
Manganese	86	71	120	15	220	43	41*	14
Lead	3.9*	3.0	19*	4.6	10*	2.6	2.05*	0.63
Mercury	0.01	0.01	0.01	0.004	0.005	—	0.005	—
Cobalt	0.68*	0.44	0.25*	0.07	0.42*	0.45	0.08*	0.02
Chromium	0.11*	0.04	0.22*	0.06	0.09*	0.03	0.08*	0.01
Nickel	0.45*	0.36	0.39*	0.14	0.74*	1.0	0.12*	0.83
Arsenic	1.1	0.35	1.8	0.5	2.9	2.1	0.35*	0.11
Selenium	0.41	0.27	0.03	0.02	14	5.1	0.05*	0.03
NO ₃	2.0	0.59	8.0	5.4	0.88	0.68	16.30*	2.55
Chloride	160	190	77	16	58	32	98.95*	13.80

* See Appendix for analytical methods.

Number of samples = 12 except where noted by * where $n = 4$.

addition of lime would increase the availability of these elements and improve the cation exchange capacity. Field studies using large amounts of lime, in excess of 240 tons per ha, have proven to be beneficial for the establishment of vegetation on acid tailings (Nielson and Peterson 1972). Periodic addition of nitrogen and phosphorus is usually necessary to maintain the vegetative cover (Berg 1971). In comparison to the local soil, other elements were not considered to be problems for establishing vegetation on the tailings at Site A (Table 12).

Site B has a high pH and a high concentration of calcium. Excessive calcium at pH values above 7 hinders phosphorus absorption and utilization and often reduces the availability of iron, manganese, copper, or zinc (Buckman and Brady 1969). The application of sulfur to reduce the pH may be a necessary treatment for this site. Potassium and nitrate are at a much lower concentration in the tailing material than in the soil of the surrounding area. These nutrient elements are generally more available at higher pH values (Buckman and Brady 1969). Since these nutrients are necessary for growth, they should be incorporated into a fertilizer treatment for this site. Site B also contains a relatively high concentration of sodium. Leaching of the tailing material with water via a sprinkler irrigation system has been somewhat successful in reducing the sodium content to levels acceptable for plant growth (Berg 1972; Nielson and Peterson 1972).

The tailing material at Site C has a high concentration of sodium and selenium. These elements have been shown to inhibit germination of various southwestern semi-desert plant species (Ryan et al. 1975; Edgar 1977) and are a potential problem at this site. Leaching of the upper few feet would be necessary to reduce the sodium concentration and may alleviate to some degree the selenium problem. Magnesium, potassium, and nitrogen concentrations are much lower in the tailing material than in the soils of the area. These nutrient elements should be added to the tailings to increase fertility.

Low water-holding capacity of mill tailing material was cited by Berg (1971) as a major problem for establishing vegetation on the Colorado sites. The water-holding

capacity of the tailing material from all three New Mexico tailing piles examined was 50 percent less than that of the local soil. This indicates that there is less moisture available for plant growth in the tailing material than in the soils of the area. This would be a severe limiting factor to the establishment of vegetation especially during long dry periods which are common in the semi-arid environment of western New Mexico.

In addition to low water-holding capacity, the surface of all the New Mexico tailing piles dries rapidly and forms a hard crust as noted by Nielson and Peterson (1972) for acid tailings. The hard dry crust prevents root penetration resulting in death of young seedlings. Sprinkler irrigation has been employed on the tailing piles at Rifle and Durango, Colorado, to mitigate both the lack of available moisture and the formation of a hard, dry surface crust.

Observations concerning the germination and establishment of naturally invading plant species at Sites B and C indicate that the rapid drying surface is a major drawback to the successful invasion and establishment of the few species that do grow on these sites. Bottlebrush squirreltail grass, summer-cypress, and Russian thistle are the species most successful in becoming established on these sites.

These species germinate and grow on areas where blow-sand has accumulated. The sand produces a dry mulch effect and prevents the underlying tailing material from drying as rapidly as areas without the sand cover. Seeds that germinate on the sand survive if wind and water erosion do not remove the sand mulch. If the sand remains in place until the seedling root system penetrates several inches below the surface of the tailing material, the plants mature and appear to be as healthy and vigorous as those growing on the natural soils of the area.

Vegetation has become established on tailing piles covered with a thin layer of soil material at Gunnison, Grand Junction, Naturita, and Slickrock, Colorado and at Green River and Monticello, Utah. The plants growing on these sites have roots that penetrate into the underlying tailing material without any apparent detrimental effects on their growth and survival. These tailing piles were covered because natural invasion and

establishment of vegetation on the raw tailing material did not occur sufficiently to stabilize the sites. The soil cover acts as a mulch and prevents the tailing material from forming a dry surface crust. The evidence indicates that the rapid drying of the surface few inches of the tailing piles is a major limiting factor in the establishment of vegetation on these waste materials.

Seed Germination Experiments

Berg (1971) and Nielson and Peterson (1972) suggest that elements found in concentrations known to be toxic to plants could be a limiting factor to the natural invasion and establishment of the local vegetation on tailing material. Consequently, seed germination experiments were performed to evaluate how detrimental the chemistry of the tailing material from Sites A and C were to the germination of western wheatgrass, little bluestem grass (Andropogon scoparius), side-oats grama grass, blue grama grass, weeping lovegrass, alkali sacaton, four-wing saltbush, big sagebrush (Artemisia tridentata), and rough cuds (Menodora scabra). These species are found in the region of New Mexico where uranium mining and milling occurs.

Greenhouse and laboratory studies on seed germination and seedling growth produced the best results after uranium tailing material had been leached with water (Nielson and Peterson 1972; Dean et al. 1974). These results are consistent with the results obtained in field situations where leaching and continuous irrigation is employed.

A 35-kg sample of tailing material was collected from Site A and an equal size sample from Site C. Each individual sample was pulverized, thoroughly mixed, and screened through a 2-mm mesh sieve. A saturated paste of each sample was prepared with deionized distilled water, sealed, and allowed to stand for 24 hours. The liquid portion was extracted by vacuum through No. 42 Whatman filter paper. This extract was then filtered through a 1.2 μ millipore filter to remove the very fine-sized tailing material from the final product.

Plastic rings, 6 cm diameter x 2.5 cm height, covered with cheesecloth, were placed in 400 ml covered, clear, plastic containers. Three replicates of each treatment

were prepared for each species tested. Osmotic pressures (OP) were determined with a C-52 sample chamber psychrometer attached to a Wescor, Inc. Model 50 microvoltmeter. The treatments were:

1. distilled water control, pH 7.0, OP = 0 atm.
2. leachate, Site C, pH 8.3, OP = 3.2 atm.
3. leachate, Site A, pH 3.9, OP = 2.3 atm.
4. leachate + CaCO_3 , Site A, pH 6.8, OP = 2.6 atm.
5. Phosphate buffer ($\text{NaHPO}_4 + \text{KH}_2\text{PO}_4$), pH 3.9, OP = 1.3 atm.
6. Phosphate buffer ($\text{Na}_2\text{HPO}_4 + \text{KH}_2\text{PO}_4$), pH 6.8, OP = 2.0 atm.

Sabo (1977) found that osmotic pressures below 4 atmospheres were not inhibitive to the germination of seeds for most of the species used in this experiment.

Fifty seeds of a species were placed on the cheesecloth surface of the three replicates for each treatment. Each replicate received 50 ml of the appropriate liquid. The wick effect of the cheesecloth maintained a constant supply of moisture to the seeded surface. Evaporation loss from the covered containers was less than 4 percent by volume during the six-week test period.

Preliminary germination tests indicated that fungal growth would become a problem in the study. Tests were performed using seeds dusted with Thiram, a fungicide, and untreated seeds to determine if the fungicide would have any inhibitory effects on the various seeds to be used in the leachate tests. No significant difference in germination percentages were found between treated and untreated seeds. Therefore, all seeds used in testing the leachate effects were dusted with Thiram.

All replicates were placed in growth chambers adjusted for optimum light and temperature (Table 7) for the germination potential of each species (Sabo 1977; Springfield 1970). Germination was defined as combined root and shoot growth of more than 3 mm. All germination percentages were subjected to arcsine transformation prior to statistical testing for assumptions. The transformed data were tested for significant differences between the means at the .05 level using Duncan's New Multiple

Range Test. Time until germination began was not affected by the different treatments. The performance of each species on each treatment follows.

Western wheatgrass. Germination was most severely inhibited by the leachate of the pH 3.9 acid tailing (Fig. 2). The addition of calcium carbonate to the leachate, adjusting the pH to 6.8, significantly improved the germination percentage but it was still significantly less than on the pH 6.8 buffer treatment. The germination percentages on the pH 6.8 and the pH 3.9 buffer solutions were not significantly different. This indicates that low germination with the acid tailing leachate is not entirely explained by pH.

The carbonate tailing leachate inhibited germination more than the pH 6.8 adjusted acid tailing leachate but less than the pH 3.9 acid tailing leachate. Germinations on all treatments were significantly lower than on the control. Germination was inhibited for most of the species tested on the buffer solutions. This inhibition may be a response to the HPO_4 and H_2PO_4 ion concentration in these buffers.

Little bluestem grass. Untreated acid tailing leachate and the carbonate leachate inhibited germination of this species more than any other treatment (Fig. 3). There was no significant difference in germination percentages between the control and the other treatments.

Side-oats grama grass. This species germinated best on the distilled water control (Fig. 4). No significant difference in germination was found between any of the other treatments. Although there were no statistically significant differences between the other treatments, slightly better germination did occur in the pH 6.8 buffer and the calcium carbonate treated acid leachate. Leachate from both tailing types and the buffers exhibit a definite inhibitory effect on this species.

Blue grama grass. As with the side-oats grama grass, germination of this species was significantly inhibited by tailing leachate and buffer solutions (Fig. 5). Germination was slightly better on the pH 6.8 treatments than on the pH 3.9 treatments.

Fig. 2 Percentage germination of *Agropyron smithii* (western wheatgrass). Each column followed by the same letter is not significantly different ($P > .05$).

Fig. 3 Percentage germination of *Andropogon scoparius* (little bluestem). Each column followed by the same letter is not significantly different ($P > .05$).

Fig. 4 Percentage germination of *Bouteloua curtipendula* (side-oats grama). Each column followed by the same letter is not significantly different ($P > .05$).

Fig. 5 Percentage germination of *Bouteloua gracilis* (blue grama). Each column followed by the same letter is not significantly different ($P > .05$).

Weeping lovegrass. Germination for this species was significantly greater on the control than on any other treatment (Fig. 6). No significant difference in germination percentages was found between the two buffers, the carbonate tailing leachate and the calcium carbonate treated acid leachate. The lowest germination occurred on the untreated acid tailing leachate. The greater inhibition produced by this leachate does not appear to be entirely due to pH.

Alkali sacaton. Germination for this species was not significantly different between the control and the carbonate tailing leachate (Fig. 7). The other pH 6.8 treatments inhibited germination much less than the pH 3.9 treatments. The lower germination percentage on the pH 3.9 treatments indicate that pH may be a major inhibiting factor for this species.

Four-wing saltbush. This species germinated best on the calcium carbonate treated acid leachate (Fig. 8). However, no significant differences in germination were found between this treatment, the control, and the untreated acid leachate. Both buffer solutions inhibited germination more than any treatment except the leachate from the carbonate tailings.

Big sagebrush. Germination for this species was significantly greater on the control than on any other treatment (Fig. 9). No significant difference was found between the CaCO_3 treated acid tailing leachate and the pH 6.8 buffer solution. The pH 3.9 buffer most suppressed germination in this test. Germination percentages on the carbonate tailing leachate were significantly less than on the control but significantly greater than on the other treatments.

Rough cuds. This shrub species had significantly greater germination on the control (Fig. 10). No significant difference was found between the carbonate tailing leachate and the CaCO_3 treated acid tailing leachate. Germination was most inhibited on the pH 3.9 treatments suggesting that a low pH appears to be a major inhibiting factor for this species.

Fig. 6 Percentage germination of *Eragrostis curvula* (weeping lovegrass). Each column followed by the same letter is not significantly different ($P > .05$).

Fig. 7 Percentage germination of *Sporobolus airoides* (alkali sacaton). Each column followed by the same letter is not significantly different ($P > .05$).

Fig. 8 Percentage germination of *Atriplex canescens* (four-wing saltbush). Each column followed by the same letter is not significantly different ($P > .05$).

Fig. 9 Percentage germination of *Artemisia tridentata* (big sagebrush). Each column followed by the same letter is not significantly different ($P > .05$).

Fig. 10 Percentage germination of *Menodora scabra* (rough cods). Each column followed by the same letter is not significantly different ($P > .05$).

The results of these tests indicate that uranium mill tailing waste material is inhibitory to the germination of seeds of most of the species tested. Only four-wing saltbush, alkali sacaton, and little bluestem responded as well to some treatments as they did to the control. Four-wing saltbush germinated best on leachate from the acid tailing material adjusted with calcium carbonate and on the untreated acid tailing leachate. Studies have indicated that sulfuric acid treatment of four-wing saltbush seeds may increase germination in some instances (Springfield 1970). A response to the sulfuric acid in the tailing material may account for the increased germination of this species on the acid leachate treatment. All other species tested were inhibited by the acid tailing leachate.

Little bluestem grass germinated on the calcium carbonate treated acid tailing leachate equally as well as on the control. The pH 3.9 buffer did not inhibit germination for this species. It would appear that some chemical factor or toxic element may be associated with the low germination percentage on the untreated acid leachate and the carbonate tailing leachate. Edgar (1977) found that high concentrations of various sulfate salts tend to inhibit germination for some species. This may be a major inhibiting factor for this species. An analysis of the test solutions indicated that the acid tailing leachate contained 2460 ppm SO_4 and the carbonate leachate contained 3340 ppm SO_4 (Table 13).

Alkali sacaton grass germinated well on the carbonate tailing leachate. Edgar (1977) found that germination of both alkali sacaton and four-wing saltbush was slightly inhibited by high levels of sulfate salts and selenium in concentrations of 30 ppm or greater. The analyses of the test solutions indicated that the carbonate tailing leachate contained 28 ppm selenium.

The inhibited germination of most of the species tested on the carbonate tailing leachate may be in part a response to the high levels of SO_4 and the high concentration of selenium. The inhibited germination on the acid tailing leachate appears to be related to pH and the SO_4 concentration. The inhibition produced by the buffer solutions may be a result of the HPO_4 and H_2PO_4 concentrations.

Table 13. Analyses of chemical characteristics of the leachate from uranium mill tailing material from New Mexico Sites A and C.

MATERIAL	ELEMENTS*										
	(ppm)										
	Ca	Mg	Na	K	Fe	Cl	Se	NH ₄	NO ₃	SO ₄	PO ₄
Site A	568	196	273	11.8	4.47	380	.010	16.7	3.26	2460	1.24
Site C	71	6.5	1825	18.1	0.02	75	27.5	0.06	192	3340	0.36

* Saturated paste extraction with deionized distilled water.

The germination data for all species on one treatment were pooled to determine which treatment had the best overall germination percentage. From highest to lowest, the rank order of results was (1) control, (2) acid leachate adjusted with calcium carbonate, (3) carbonate tailing leachate, (4) phosphate buffer pH 6.8, (5) phosphate buffer pH 3.9, and (6) acid tailing leachate pH 3.9.

Greenhouse Experiments

In conjunction with the seed germination tests, blue grama grass was planted on tailing material in the greenhouse to evaluate germination and survival on the tailing material. A composite sample of approximately 75 kg was collected from each of the three tailing piles. Each sample was air-dried, pulverized, and thoroughly mixed. Twenty-one clay pots, 12.7 cm diameter, were filled with 900 grams of material for each type of tailings. Each of the 63 total pots was seeded with 100 seeds of blue grama grass. Each pot received an initial 300 ml of distilled water and both its dry and wet weights were recorded. At three-day intervals each pot was reweighed and enough distilled water was added to bring the weight of each pot up to the initial wet weight recorded. This method was used to prevent the addition of excess water which would leach the salts from the tailing material. Data were collected for germination during the first four weeks of the test and survival data collected at the end of 12 weeks.

Germination on the acid tailings from Site A was 22.2 percent with no seedling survival. All seedlings died within the first four weeks of the test. The carbonate tailings from Site B had 37.2 percent germination with 40.9 percent of the seedlings surviving (Table 14). The tailing material at Site B supports more species and individual plants in the field than do the other two sites. Site C tailings had 31.2 percent germination with 38.3 percent of the seedlings surviving.

The results of the germination experiments for blue grama grass in the growth chamber were 23 percent germination on leachate from Site A and 48 percent on leachate from Site C. The germination results between the growth chamber and

Table 14. Percentage germination and survival of blue grama grass and four-wing saltbush on uranium mill tailing material from New Mexico Sites A, B, and C

MATERIAL	BLUE GRAMA ¹ (Unleached) Maximum		BLUE GRAMA ¹ (Leached) Maximum		FOUR-WING SALTBUSH ² (Leached) Maximum	
	Germination (%)	Survival (%)	Germination (%)	Survival (%)	Germination (%)	Survival (%)
Site A	22.2	0.0	35.0	5.72	8.19	1.81
Site B	37.2	40.9	36.1	41.6	8.02	60.19
Site C	31.2	3.8	31.0	7.68	7.80	48.28

¹Number of seeds planted = 6300

²Number of seeds planted = 8100

greenhouse experiments were not significantly different. The low survival rate is a possible explanation for the lack of natural invasion and establishment of local vegetation on these tailing piles.

A second test, with two modifications of the first test, was established in the greenhouse with blue grama grass. The 900 grams of new tailing material in each of the 63 pots were leached with 1000 ml of distilled water prior to seeding for the first modification. The second modification was the addition of nitrogen applied as ammonium nitrate (33.5–0–0) and phosphorus applied as phosphoric acid (0–46–0) at different rates as a fertilizer treatment.

Three replicates for each of the seven treatments on each type of tailing material were established. The treatments were (1) no fertilizer, (2) nitrogen at 56 kg per ha, (3) phosphorus at 56 kg per ha, (4) nitrogen at 227 kg per ha, (5) phosphorus at 227 kg per ha, (6) nitrogen and phosphorus each at 56 kg per ha, (7) nitrogen and phosphorus each at 227 kg per ha. Data for germination were collected during the first four weeks of the test and data for survival collected at the end of the 12-week test period. The arcsine transformed data were tested for significant differences between the means at the .05 level using Duncan's New Multiple Range Test.

The results of the statistical analyses showed that there were no significant differences in germination or survival between treatments on each type of tailing material. The germination data from each group of pots filled with tailing material from one site was pooled and compared to the results of the germination test on the unleached and unfertilized tailing material from the same site. These results showed an increase of 13 percent for germination on the leached acid tailings from Site A. There were no significant differences in germination percentages between the two tests on materials from Sites B and C (Table 14).

The survival data were tested for differences between the two experiments. Survival of the seedlings increased from 0 percent on the unleached material from Site A to 5.71 percent on the leached material from this site. The survival percentages

were not significantly different between the two experiments on material from Site B. The leached material from Site C had an increase of about 4 percent in survival over the unleached material (Table 14).

The results of these experiments indicate that leaching of the tailing material would aid in the establishment of vegetation on the tailing piles at Sites A and C. This is consistent with the findings of Nielson and Peterson (1972) in their greenhouse experiments.

Four-wing saltbush was grown in the greenhouse under the same conditions as the second test with blue grama grass. Two additional treatments were incorporated into this test. These were added as treatment 8 (nitrogen at 227 kg per ha plus phosphorus at 57 kg per ha) and treatment 9 (nitrogen at 57 kg per ha plus phosphorus at 227 kg per ha).

As in the second experiment with blue grama, no significant differences were found for germination or survival between any of the nine treatments for each type of tailing material. The germination percentage on the tailing material was much less than the germination on the leachate used in the germination experiment in the growth chamber. Germination was 5.4 percent with 60 percent of these seedlings surviving on the leached acid tailings from Site A (Table 14). Germination on the acid leachate for this species was 40 percent. Germination was 8.2 percent with 60 percent of these seedlings surviving on the leached material from Site B. The leached tailing material from Site C had 7.8 percent germination with 48 percent of these seedlings surviving.

Four-wing saltbush has invaded and become established on the tailing material at Site B. It also grows on the soil material comprising the dikes around the tailing pile at Site A and at Site C but has not been able to invade and become established on the raw tailing material at these sites. The results of the greenhouse experiment indicate that leaching and continual watering may be necessary for establishing even a few of these shrubs on these two sites.

Field Experiments

Nine test plots 3 m x 4 m were established on the tailing piles at Sites A and B.

The test plots were treated as (1) bare tailings, (2–5) covered with soil from the adjacent landscape to depths of 5 cm, 10 cm, 20 cm, and 30 cm, respectively, (6–7) mixtures of sandstone rock and sandstone soil to a depth of 40 cm, (8) sandstone rocks, 6–50 cm diameter size, scattered over the surface of the tailing material covering approximately 50 percent of the area of the plot, (9) straw mulch incorporated into the surface few inches of the tailing material, and (10) dune sand spread over the surface of the tailings in the plot to a depth of 5 cm.

Each plot was leveled and the area raked, fertilized with nitrogen and phosphorus at a rate of 112 kg per ha, seeded with the seed mixture presented in Table 5 plus four-wing saltbush and winterfat. The area was lightly raked again to cover the seeds and fertilizer. Artificial watering was not attempted on any of the plots.

Seven test plots were established on the tailing pile at Site C. These were treated as (1) bare tailings, (2) covered with 40 cm of shale and shale-derived soil, (3) sandstone rocks, 6–50 cm diameter, covering approximately 50 percent of the surface area of the plot, and (4–7) covered with sandstone rock and sandstone-derived soil material on slopes of 20 and 30 percent with each plot facing the cardinal compass points of north, east, south, and west. These plots were prepared, fertilized, and seeded the same as were the plots at Sites A and B.

A severe drought during the growing season of 1976 and the spring of 1977 drastically affected all the seeded species. Germination of many of the seeded species occurred on all plots covered with soil or rock and soil mixture but most survived only two weeks or less. The plots covered with sandstone and sandstone-derived soil at Site A supported a few individuals of blue grama grass, alkali sacaton, and side-oats grama grass throughout the two growing seasons of the experiment. The rest of the plots that had any type of soil, rock, or mixed rock and soil treatments had none of the seeded grass species survive. Germination of the seeded grass species did not occur in the plots established on the bare tailing material. Only four-wing saltbush germinated on all sites. Two plants survived, one on the rock-covered plot at Site A and one on the plot covered with local soil to a depth of 5 cm at Site B.

However, bottlebrush squirreltail grass, summer-cypress, and Russian thistle invaded and numerous seedlings grew on most of the covered plots at all three sites during the spring of 1976. Only the plots covered with sandstone and sandstone-derived soils at Sites A and B and the plot with rock covering 50 percent of the surface area at Site C supported these species through the entire 1976 growing season. The straw mulch and dune sand of plots 9 and 10 were removed by strong spring winds and results were not obtained from these plots.

The total above-ground vegetative growth was collected from a 5 m² area on each plot in September 1977, oven-dried at 105° C, and weighed. The small amount of above-ground growth was dominated by Russian thistle and summer-cypress on all the plots that supported vegetation (Table 15). Bottlebrush squirreltail grass accounted for 100 percent of the grass on all plots except plots 6 and 7 at Site A where it accounted for 80 percent and 90 percent, respectively, of the dry weight of the grasses.

The results of this experiment indicate that more than the 40 cm of precipitation received during the two-year period of the test is necessary to establish a good vegetative cover composed of the seeded species on either covered or bare tailing material at these sites. Sprinkler irrigation systems would best encourage growth and establishment of vegetation on soil-covered tailings as shown on several of the Colorado tailing piles.

Vegetation and Selected Trace Elements

Samples of vegetation growing on the tailing material at Sites B and C and from the rangelands adjacent to these sites were collected and analyzed for copper, lead, arsenic, and selenium. The average concentration of copper in plants has been reported to be 14 ppm (Bowen 1966) and 180 ppm in plant ash (Brooks 1972). The average concentration of lead in plants is reported to be about 2.7 ppm (Bowen 1966) and 70 ppm in the ash (Brooks 1972). Arsenic concentrations average 4 ppm in plant ash with a normal range of from 0.2 to 30 ppm (Lisk 1972). Arsenic has been shown to have phytotoxic effects when soils contain between 25 and 200 ppm (Lisk 1972). Selenium is considered to be toxic to animals when it is found in plants at concentrations above 5 ppm (U.S. EPA 1972; Oldfield 1972; Carter et al. 1970; Bisbjerg and

Table 15. Dry weight of above-ground growth for species growing on experimental plots (data expressed in g/m²)**TEST PLOTS***

	<u>Grass</u> <u>all spp.</u>	<u>Kochia</u> <u>scoparia</u>	<u>Salsola</u> <u>kali</u>	<u>Atriplex</u> <u>canescens</u>	<u>Total</u> <u>foliage</u> <u>(g/m²)</u>
Site A					
Plot 2 (soil-5cm)	0.1	5.0	4.0	0	9.1
Plot 3 (soil-10cm)	0.1	0	8.0	0	8.0
Plot 4 (soil-20cm)	0	0	7.6	0	7.6
Plot 5 (soil-30cm)	0	7.4	0	0	7.4
Plot 6 (sandstone rock-soil)	4.0	88.0	82.0	0	174.0
Plot 7 (sandstone rock-soil)	2.1	89.0	68.0	0	159.0
Plot 8 (sandstone rock only)	0.8	27.4	30.8	0.4	59.4
Site B					
Plot 1 (bare tailing)	0	35.4	0	0	35.4
Plot 2 (soil-5cm)	0	33.4	24.1	0.2	57.7
Plot 6 (sandstone rock-soil)	0	94.3	6.8	0	100.1
Plot 7 (sandstone rock-soil)	0.1	105.6	91.8	0	197.5
Plot 8 (sandstone rock only)	0	9.6	0	0	9.6
Site C					
Plot 2 (shale rock-soil)	0.1	9.3	4.2	0	13.5
Plot 3 (sandstone rock only)	7.0	51.1	87.1	0	151.2

*Plots without vegetation not listed.

Gissel-Nielsen 1969). High concentrations of selenium in the growth medium have been shown to be toxic to several species of Southwestern grasses and shrubs (Edgar 1977; Diebold 1945).

Elevated concentrations of copper, lead, or arsenic were not found in any of the plant samples analyzed (Table 16). High concentrations of selenium were found in the plant material of the plant species collected from Site C. Selenium uptake depends on several factors including the plant species, the chemical form of the selenium, the soil type, and the supply of other compounds such as sulphate and phosphate (Bisbjerg and Gissel-Nielsen 1969; Diebold 1945). Selenium as calcium selenate or sodium selenate is water soluble (Diebold 1945) and is most available for uptake by plants (Bisbjerg and Gissel-Nielsen 1969).

Absorption and concentration of arsenic, cadmium, copper, lead, selenium, and other heavy metals by plants has been shown to be a problem where vegetation is grown on media with high levels of these potentially toxic elements (Frost 1977; Sidle et al. 1976; Sidle and Sopper 1976; Horovitz et al. 1974; Woolson et al. 1973; Lisk 1972; John et al. 1972; Carter et al. 1970; Shacklette 1970; Alloway and Davies 1970; Bisbjerg and Gissel-Nielsen 1969; Oliver and Barber 1966; Diebold 1945). The potential for trace element concentration by vegetation prompted an investigation of some selected trace elements in tailing material and vegetation from other inactive uranium mill sites.

Tailing materials and vegetation samples were collected from 12 sites in Colorado and Utah and analyzed for copper, lead, arsenic, and selenium. The results indicate that several of the Colorado and Utah tailing piles contain at least one of these elements at higher concentrations than the New Mexico sites studied. Selenium was found in high concentration in the tailing material from six of the Colorado sites and one site in Utah (Table 17). Plant species collected and analyzed from the tailing piles with high concentrations of selenium also contained large amounts of selenium (Table 18).

A list of plant species was developed from collections made in August 1977 at each of the Colorado and Utah tailing piles visited. The list provides some information

Table 16. Analyses of plant material growing on the tailing piles at the New Mexico Sites B and C and on the adjacent rangeland

LOCATION	SPECIES	ELEMENTS (ppm)			
		Cu	Pb	As	Se
Site B tailings	<u>Atriplex canescens</u>	18	1.7	0.1	3.6
	<u>Kochia scoparia</u>	11	4.7	0.1	1.9
	<u>Sitanion hystrix</u>	8	1.3	0.1	1.4
	<u>Sitanion hystrix¹</u>	7	2.4	0.1	1.9
	<u>Sporobolus airoides</u>	5	2.3	0.2	4.3
Site B rangeland	<u>Atriplex canescens</u>	9	12.8	0.1	0.8
	<u>Kochia scoparia</u>	14	11.6	0.1	0.1
	<u>Sitanion hystrix</u>	8	3.4	0.1	1.1
	<u>Sporobolus airoides</u>	3	1.4	0.1	0.3
Site C tailings	<u>Kochia scoparia</u>	45	14.4	—	42.3
	<u>Salsola kali</u>	34	8.9	—	40.4
	<u>Sitanion hystrix</u>	18	3.4	0.8	40.8
	<u>Sitanion hystrix²</u>	14	4.8	0.4	60.9
Site C rangeland	<u>Kochia scoparia</u>	6	3.4	0.1	1.5
	<u>Salsola kali</u>	3	2.9	0.1	1.5
	<u>Sitanion hystrix</u>	9	2.0	0.1	1.5

¹washed sample

²sample collected from experimental Plot 3

Table 17. Analyses of selected elements in tailing material from inactive uranium mill sites in Colorado, Utah, and New Mexico

LOCATION	ELEMENTS ¹										
	(ppm)										
New Mexico	pH ²	Na	K	Mn	Fe	Cu	Zn	As	Se	Hg	Pb
Site A	3.3	140	11	86	47	.7	.9	1.1	41	.01	3.9
Site B	9.4	1,800	100	120	22	.5	.4	1.8	.03	.01	19.0
Site C	8.3	2,000	98	220	37	.2	3.1	2.9	14.00	.005	10.0
Colorado											
Site D	4.4	1,300	7,100	.5	8	1.5	.9	2.7	.02	.55	35.0
Site E	8.3	113,600	5,300	6.0	20	2.0	1.9	13.7	1.88	.41	18.5
Site F	7.4	143,000	20,700	12.0	20	2.5	13.3	19.9	27.40	.52	326.0
Site G	7.4	18,800	7,200	9.5	8	.5	.9	2.4	.86	.65	80.0
Site H	6.3	14,000	3,100	.5	33	.5	2.7	7.2	14.99	.79	32.5
Site I	7.0	3,900	6,000	55.0	46	21.5	29.9	5.0	38.10	.49	4.0
Site J	7.6	100	900	.5	29	6.0	.1	1.2	6.27	.52	19.5
Site K	7.5	900	6,900	9.5	34	5.0	.2	1.2	2.02	1.00	.5
Site L	7.7	2,800	7,300	4.5	12	1.0	9.0	.9	15.76	.34	47.5
Site M	7.0	2,300	46,400	89.5	1	1.0	10.0	.7	.06	.44	3.5
Utah											
Site N	7.6	27,800	23,900	117.0	56	.5	1.2	.5	7.20	.40	.5
Site O	8.1	8,300	4,300	30.0	16	25.0	12.5	42.9	0.88	.40	.5

¹See appendix for analytical method

²pH saturation paste

Table 18. Analyses of selected trace elements in plant material growing on tailing piles at inactive uranium mill sites in Colorado, Utah, and New Mexico (ppm)

LOCATION	PLANT SPECIES ¹															
	<u>Sporobolus</u> <u>airoides</u>				<u>Agropyron</u> <u>elongatum</u>				<u>Sitanion</u> <u>hystrix</u>				<u>Kochia</u> <u>scoparia</u>			
	As	Cu	Pb	Se	As	Cu	Pb	Se	As	Cu	Pb	Se	As	Cu	Pb	Se ²
New Mexico																
Site B	.2	6	2.0	7.00									0.1	9	1.3	2.70
Site C									2.2	13	2.9	65.88	1.1	6	5.7	130.05
																.41 6 4.9 127.42
Colorado																
Site D					2.7	5	6.3	.01	1.4	8	9.3	.55	7.1	12	8.8	.01
Site E	2.3	2	7.6	2.02	.3	3	2.7	.92								.71 12 2.4 .34
Site F					1.7	2	5.6	18.63					.32	7	2.9	137.42
Site G									1.0	3	3.1	.37	.56	5	3.8	.28
Site H					2.3	10	14.4	6.76					.32	11	4.9	22.99
Site I	1.0	10	3.0	24.05	.8	5	5.8	8.12					.51	10	1.9	3.19
Site J	1.1	10	2.1	18.76									.29	8	3.2	18.17
Site K	.3	11	1.0	.58												.10 7 2.8 15.57
Site L					7.0	4	7.1	10.41	.8	9	6.3	6.75				.11 6 2.0 .95
Site M	1.3	8	3.8	.37	.4	3	1.4	1.04	.5	7	10.2	5.22	.32	11	4.2	2.11
																10.58 26 23.4 28.81
																.20 12 2.8 .52
Utah																
Site N																.95 7 5.4 51.62
Site O													.23	9	2.1	.42
																1.32 6 3.6 1.43

¹collected 8/25 – 8/30/1977²See appendix for analytical method

about the plant species which can root and become established on tailing piles that have been covered with a thin layer of soil or directly on the tailing material with the aid of leaching, fertilization, and sprinkler irrigation (Table 19).

Plant species growing on tailing piles with high concentrations of selenium have a high probability of being potentially toxic to the animals living in areas adjacent to these tailing piles. The problem of uptake and concentration of toxic elements by vegetation on mine and mill waste material needs to be more fully investigated. Future investigation should include radioactive elements that have been shown to accumulate in crop species (Tsivoglou 1964). Radium has been found at high concentrations in plant tissue of species growing on Sites B and C (Kelley et al. 1977).

Table 19. List of plant species collected and identified from uranium mill tailing piles in Colorado, Utah, and New Mexico

SCIENTIFIC NAME (Common Name)	SITES														
	New Mexico					Colorado							Utah		
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
Grasses:															
<u>Agropyron cristatum</u> (fairway wheatgrass)											X				
<u>Agropyron desertorum</u> (desert wheatgrass)			X					X	X					X	
<u>Agropyron elongatum</u> (tall wheatgrass)					X	X					X	X		X	
<u>Agropyron intermedium</u> (intermediate wheatgrass)				X	X	X					X	X		X	
<u>Agropyron smithii</u> (western wheatgrass)								X						X	
<u>Agropyron trachycaulum</u> (slender wheatgrass)					X			X							
<u>Aristida divaricata</u> (poverty three-awn)											X	X			
<u>Aristida</u> sp. (three-awn)			X												
<u>Avena sativa</u> (common oat)			X								X	X			
<u>Bouteloua gracilis</u> (blue grama grass)			X	X		X			X	X					
<u>Bromus inermis</u> (smooth brome grass)											X			X	
<u>Bromus</u> sp. (brome grass)								X							
<u>Danthonia californica</u> (California danthonia)						X									
<u>Echinochloa crusgalli</u> (barnyard grass)						X					X				
<u>Elymus</u> sp. (wildrye)			X	X											
<u>Festuca viridula</u> (greenleaf fescue)			X												

Table 19. Continued

SCIENTIFIC NAME (Common Name)	SITES															
	New Mexico				Colorado										Utah	
	B	C	D	E	F	G	H	I	J	K	L	M	N	O		
Grasses:																
<u>Hilaria jamesii</u> (galleta grass)			X						X	X						
<u>Hordeum jubatum</u> (foxtail barley)						X					X					
<u>Oryzopsis hymenoides</u> (Indian ricegrass)			X						X	X	X	X		X		
<u>Panicum hillmani</u> (witchgrass)											X					
<u>Panicum</u> sp. (witchgrass)					X											
<u>Setaria lutescens</u> (yellow bristlegrass)											X					
<u>Setaria viridis</u> (green bristlegrass)								X								
<u>Sitanion hystrix</u> (bottlebrush)	X	X	X			X		X			X	X				
<u>Sporobolus airoides</u> (alkali sacaton)	X		X	X		X				X						
<u>Sporobolus contractus</u> (spike dropseed)									X							
<u>Sporobolus cryptandrus</u> (sand dropseed)				X				X	X	X	X	X				
<u>Stipa</u> sp. (needlegrass)			X													
Forbs:																
<u>Acalypha neomexicana</u> (New Mexico acalypha)														X		
<u>Achillea lanulosa</u> (western yarrow)			X													
<u>Amaranthus</u> sp. (pigweed)				X					X					X		
<u>Aster</u> sp. (aster)											X	X				
<u>Brassica kaber</u> (charlock mustard)						X										

Table 19. Continued

SCIENTIFIC NAME (Common Name)	SITES														
	New Mexico		Colorado											Utah	
	B	C	D	E	F	G	H	I	J	K	L	M		N	O
Forbs:															
<u>Chenopodium album</u> (lambs quarters)			X	X	X	X					X				
<u>Chenopodium glaucum</u> (oakleaf goosefoot)				X											
<u>Chrysopsis fulcrata</u> (gold aster)														X	
<u>Chrysopsis</u> sp. (gold aster)			X								X				
<u>Cirsium arvense</u> (Canada thistle)						X									
<u>Cirsium pulchellum</u> (thistle)						X									
<u>Cirsium</u> sp. (thistle)												X		X	
<u>Clematis ligusticifolia</u> (virgins bower)								X			X				
<u>Cleome serrulata</u> (bee spiderflower)	X	X							X		X	X			
<u>Convolvulus arvensis</u> (European glorybird)									X		X				
<u>Coreopsis</u> sp. (coreopsis)			X												
<u>Erigeron canadensis</u> (horseweed fleabane)			X								X				
<u>Eriogonum inflatum</u> (trumpet buckwheat)														X	
<u>Gilia pumila</u> (dwarf gilia)			X												
<u>Glycyrrhiza lepidota</u> (wild licorice)								X							
<u>Grindelia squarrosa</u> (curlycup gumweed)			X								X	X			
<u>Haplopappus spinulosus</u> (ironplant goldenweed)										X	X				
<u>Helianthus annuus</u> (common sunflower)						X	X				X	X			
<u>Kochia scoparia</u> (summer-cypress)	X	X	X		X	X	X	X	X		X			X	X
<u>Lactuca serriola</u> (prickly lettuce)				X	X	X									

Table 19. Continued

SCIENTIFIC NAME (Common Name)	SITES														
	New Mexico		Colorado											Utah	
	B	C	D	E	F	G	H	I	J	K	L	M		N	O
Forbs:															
<u>Lepidium montanum</u> (mountain pepperweed)									X	X	X	X			
<u>Linaria vulgaris</u> (butter and egg toadflax)			X												
<u>Medicago sativa</u> (alfalfa)			X	X				X							
<u>Melilotus alba</u> (white sweetclover)				X							X	X		X	
<u>Melilotus officinalis</u> (yellow sweetclover)			X	X							X	X		X	X
<u>Mirabilis multiflora</u> (Colorado four-o'clock)											X				
<u>Oenothera</u> sp. (evening primrose)			X												
<u>Oxybaphus linearis</u> (narrowleaf umbrellawort)											X				
<u>Plantago major</u> (rippleseed plantain)			X												
<u>Portulaca oleracea</u> (common purslane)								X							
<u>Ratibida columnifera</u> (upright prairie coneflower)				X											
<u>Rumex crispus</u> (curly dock)						X									
<u>Rumex triangulivalvis</u> (sorrel)			X												
<u>Salsola kali</u> (Russian thistle)	X	X	X	X	X	X	X	X	X	X	X	X		X	X
<u>Sisymbrium altissimum</u> (tumble mustard)												X			
<u>Sphaeralcea coccinea</u> (scarlet globemallow)										X	X				
<u>Suaeda suffrutescens</u> (desert seepweed)														X	
<u>Stanleya pinnata</u> (desert princesplume)										X					
<u>Tragopogon</u> sp. (salsify)			X												
<u>Verbascum thapsus</u> (flannel mullein)				X							X				
<u>Viguiera</u> sp. (goldeneye)											X	X			
SHRUBS-TREES															
<u>Acer negundo</u> (boxelder)											X				

Table 19. Continued

SCIENTIFIC NAME (Common Name)	SITES														
	New Mexico		Colorado											Utah	
	B	C	D	E	F	G	H	I	J	K	L	M		N	O
Shrubs-Trees:															
<u>Artemisia ludoviciana</u> (Mexican Sage)											X				
<u>Artemisia tridentata</u> (big sagebrush)			X								X				
<u>Atriplex canescens</u> (four-wing saltbush)	X							X	X					X	
<u>Atriplex confertifolia</u> (shadscale)														X	
<u>Atriplex</u> sp. (saltbush)														X	
<u>Caragana</u> sp. (peashrub)				X											
<u>Chrysothamnus</u> sp. (rabbitbrush)			X						X	X	X	X			
<u>Chrysothamnus vicidiflorus</u> (Douglas rabbitbrush)														X	X
<u>Elaeagnus angustifolia</u> (Russian-olive)				X											
<u>Eurotia lanata</u> (winterfat)														X	
<u>Gutierrezia sarothrae</u> (broom snakeweed)			X							X					
<u>Juniperus scopulorum</u> (Rocky Mountain juniper)				X											
<u>Populus sargentii</u> (plains cottonwood)				X				X							
<u>Quercus gambelii</u> (Gambel oak)											X				
<u>Rhus trilobata</u> (squawberry)								X							
<u>Rosa woodsii</u> (Woods rose)								X							
<u>Salix exigua</u> (coyote willow)								X							
<u>Salix gooddingii</u> (black willow)			X												
<u>Sarcobatus vermiculatus</u> (black greasewood)				X				X	X					X	
<u>Tamarix pentandra</u> (saltcedar)			X												
<u>Ulmus</u> sp. (elm)											X				

SUMMARY AND CONCLUSIONS

Uranium mining and milling activity is increasing in New Mexico, creating problems of radioactivity and/or toxic elements entering the environment as wind-blown dust in the atmosphere or by leaching and erosion of these materials into water systems. The research for this study was designed to identify physical and/or chemical factors limiting plant growth on uranium mine and mill wastes and to determine the feasibility of establishing vegetation on these spoil materials for stabilization purposes.

More than 20 years of mining at the Jackpile Uranium Mine near Grants created a unique situation for first-hand observation of the invasion and establishment of plant species from the adjacent landscape onto specific geologic material forming the surfaces of overburden dumps of varying ages. These observations indicated that natural succession occurred rapidly on the Tres Hermanos sandstone material and very slowly or not at all on other materials of the overburden.

Samples of each geologic stratum forming the overburden were collected and analyzed for those factors of significance in the natural invasion and establishment of plant species on a specific material. The results of the analyses indicated that the Tres Hermanos sandstone material offered superior properties for the establishment of native plant species. The analyses also identified in each of the other geologic units that at least one of the following factors is potentially detrimental to the successful establishment of vegetation on that material: low water-holding capacity, limited amounts of available major nutrients, and excess sodium.

As a result of the observations and analyses of the various overburden materials, the Anaconda Company cooperated in a pilot revegetation project in 1976 on a 20 ha site covered with Tres Hermanos rocks and boulders. The rocks and boulders were broken and the surface contoured by bulldozers. A coarse soil-rock mixture was

developed by repeatedly driving a 44-ton compactor over the broken rock material. The prepared site was then seeded and mulched with barley straw and left to develop under the natural environmental conditions of the area.

The precipitation received at the site during the late summer and early fall of 1976 was sufficient for germination and establishment of most of the seeded species. A drought was experienced during the growing season of 1977 without serious loss of the established seedlings. The total foliage cover on the reclaimed site 15 months after seeding was 50 percent of the total foliage cover found in the adjacent grasslands of the area.

Seed germination experiments were conducted in the laboratory with the species planted in the revegetation project. These results were compared to density data collected on the reclaimed dump for these species. This information was used to revise the seed mixture for more efficient establishment of vegetation on Tres Hermanos sandstone material which is being used to cap dumps that will be reclaimed in the near future.

It is apparent from the results of this revegetation project that certain geologic materials are more amenable than others for establishing a good cover of vegetation on disturbed sites. Ecological observations in conjunction with physical and chemical analyses of specific geologic units that form the overburden can be used to identify material that would pose the fewest problems to revegetation projects. Segregation of geologic material has been an important concept for the successful establishment of vegetation on overburden material at the Jackpile Mine and may be applicable to specific open-pit or strip mines in other areas of the Southwest.

Uranium mill tailing material was collected from an acid mill site (A) and two carbonate mill sites (B and C) in New Mexico and analyzed for physical and chemical properties. Low water-holding capacity, nutrient deficiency, and low cation exchange capacity were identified as potential limiting factors in establishing vegetation at all three sites. Low pH is an additional problem for the establishment of vegetation on

Site A. High pH with excess calcium and sodium are potential limiting factors at Site B. High concentrations of sodium and selenium were identified as problem elements for Site C.

Tailing leachate was the medium used for seed germination in growth chamber experiments. Tailing material in a greenhouse environment was utilized in germination and survival experiments. Both experiments showed definite inhibitory effects on germination and survival of the species tested. Germination and survival was most inhibited in all tests by materials from the acid tailings. Survival was significantly less on tailing material in the greenhouse experiment from Site C than on material from Site B. The addition of nitrogen and phosphorus as fertilizer treatments did not increase germination or survival significantly in these tests. However, leaching of the tailing material with water did increase germination and survival on the acid material and survival on the carbonate material from Site C.

The field experiments, using small test plots, did not produce definitive results concerning the ability of the grass and shrub species to become established with root systems growing through various depths of soil and into the underlying tailing material. The major result of this experiment identified how the vagaries of climate can affect vegetative establishment on tailing piles that have been covered with soil material. The below average precipitation received at the three mill sites during 1976 and 1977 was not sufficient to allow the seeded species to survive on any of the test plots, indicating that sprinkler irrigation may be necessary to encourage growth and establishment of vegetation on these sites.

The trace element study of vegetation and tailing materials from 15 inactive mill sites in New Mexico, Colorado, and Utah identified selenium as a major toxic element entering the environment through vegetation at Sites C, F, H, I, J, and N. Analyses for radium content were performed on plant material from Sites B and C which were found to be in high concentration. It is expected that radium would be found at high concentrations in most of the plant species found growing on all 15 sites investigated.

Bare uranium mill tailing piles can be stabilized with vegetation through adjusting pH problems, leaching, fertilizing, and sprinkler irrigation systems or by covering the tailing piles with a layer of soil material then fertilizing and watering if necessary. However, the potential hazard of selenium and radium uptake by plants and ingestion by livestock, small mammals, and seed-eating birds or birds of prey must be considered in designing a vegetational stabilization plan for any of the uranium mill tailing piles. This plan should incorporate provisions to either prevent all grazing or seed-eating animals from entering the tailing area or prevent plants from rooting into the tailing material and becoming toxic to these animals.

It is apparent that vegetational stabilization of uranium mine and mill wastes necessitates a comprehensive environmental and ecological study prior to implementation of a revegetation program.

APPENDIX
METHODS AND PROCEDURES

Mill Tailing Collection

Samples were collected from freshly dug pits, 46 cm in depth and approximately 1/3 m square. The top 58 cm was removed with a trowel and placed in code marked paper bags for transportation to the laboratory. In sequence, the next 10 cm layer and then a 15 cm layer were removed and placed in paper bags for transport.

Mine Spoils Collection

Samples were composited from 10 surface (0–15 cm deep) collection sites along a 200 m linear transect across the mine dump. Subsamples from each collection site were approximately 120 g in weight. Each of the 10 subsamples were placed in one coded paper bag to form the composite sample for each geologic material and dump area sampled. Each composite sample weighed approximately 1.2 kg.

Soil Collection

A 240 g sample of soil material (0–15 cm deep) was collected from each of four locations near Sites A, B, and C. These samples were placed in paper bags for transportation to the laboratory. Each composite sample consisted of approximately 2.4 kg of soil material.

Soil Preparation—Laboratory

Individual samples were thoroughly mixed by tumbling and spread on trays or paper towels to air dry at room temperature. A mortar and pestle was used to break up any clods, but actual grinding was kept at a minimum. The sample was screened with a square-hole 2 mm sieve.

Soil Particle Size Analysis

Bouyoucos' hydrometer method:

- I. Weigh out 50 grams of air-dry soil and place in the dispersing blender cup (100 grams for very sandy soils).

2. Add about 500 ml of distilled water.
3. Add about 20 ml of 10% sodium hexametaphosphate ("calgon") (100g/liter).
4. Add about 5 ml of 30% hydrogen peroxide. Allow solution to disperse 15–30 minutes.
5. Connect blender and its cup. Avoid having blender shaft and mixing cup baffles in contact.
6. Mix cup contents with blender for 10 minutes.
7. Pour and wash the mixture (with distilled water) into a Bouyoucos hydrometer cylinder.
8. If 50 grams of soil were used, fill the cylinder with the hydrometer in the cylinder to the lower mark (1130) with distilled water. (For 100 grams of sandy soil fill to the upper mark—1205).
9. Remove the hydrometer.
10. Insert rubber stopper and mix contents of cylinder thoroughly.
11. Immediately after cylinder is placed down, note time.
12. Remove stopper and add 2–3 drops of amyl-alcohol.
13. Insert hydrometer and Fahrenheit thermometer into cylinder and record readings at exactly 40 seconds after the cylinder has been placed down.
14. Remove and wash hydrometer and thermometer.
15. After two hours carefully insert hydrometer and thermometer and record readings.

The hydrometer readings must be corrected for temperature variations. For each degree above 68° F add 0.2 to the original hydrometer reading. For each degree below 68° F subtract 0.2.

The hydrometer is calibrated in grams of soil in suspension at the time readings were made. The original hydrometer calibration was made at 67° F, thus explaining its need for the corrected hydrometer reading. At the end of 40 seconds the sand fraction has settled out leaving the silt and clay in suspension. Thus, subtracting the 40 sec corrected hydrometer reading from the original grams of soil would indicate

the settled weight of sand. The following formula is used to determine the percentage sand:

$$\% \text{ sand} = \frac{A - B}{A} \times 100$$

A = original wt. of soil
B = 40 sec corrected hydrometer reading

After two hours the silt has settled out with only the colloidal clays remaining in suspension. Therefore the corrected 2 hour hydrometer reading indicates the weight of suspended clay in grams. The following formula is used to indicate the percentage clay:

$$\% \text{ clay} = \frac{C}{A} \times 100$$

C = 2 hr corrected hydrometer reading

The percentage silt is determined by the following formula:

$$\% \text{ silt} = 100 - (\% \text{ sand} + \% \text{ clay})$$

Cation Extraction on Cation Exchange Capacity (based on C. A. Black, Methods of Soil Analysis, 1965)

Place 5.000 grams of oven-dried soil into 50 ml centrifuge tubes (tubes should have screw caps). Extract 8 times with 27 ml portion of 1.0 N ammonium acetate (pH of ammonium acetate should be adjusted to 5.2 with glacial acetic acid to achieve greater extraction of carbonate salts). Each extraction should be performed as follows:

1. Add 25 ml of extraction solution to soil in centrifuge tube.
2. Hand shake soil and solution for 5 min.
3. Let tube of soil and solution lie on side for 10 min to achieve more complete extraction.
4. Centrifuge for 5 min to settle out clay fraction.
5. Decant off extraction solution into rinsed suction filter with a Whatman #42 filter paper.
6. Repeat above steps seven more times and after eighth extraction, filter through rinsed funnel with Whatman #42 filter paper into a 250 ml volumetric.
7. Rinse out suction flask 3 times with extraction solution and rinse funnel as often as possible.

8. Bring solution up to volume and transfer to 500 ml linear polyethylene bottles for storage prior to cation analysis.

These extractions should remove about 99 percent of the total soluble and exchangeable salts. The last extraction should contain less than 1 percent of the total amount and early tests have shown that the eighth extraction did contain less than 1 percent of the total amount of Ca and Na. The extracted soil is then leached four times with a neutral pH 1 N NH_4Cl solution and then once with 0.25 N NH_4Cl . Then rinse soils with 200 ml of isopropyl alcohol to remove all electrolytes. Finally, each soil should be leached with 8 separate extractions with 27 ml of 10 percent NaCl acidified with HCl to obtain .005 N HCl using the same extraction method used for ammonium acetate solution without the 15 min of setting before centrifuging. Make final volume of NaCl up to 250 ml and analyze this solution for ammonium to determine Cation Exchange Capacity (CEC). Express all final measurements as CEC/100 grams of soil.

The above ammonium acetate extraction was used for the following analyses: major cations (calcium, magnesium, sodium, potassium) and all heavy metals except mercury. Analysis of all cations and metals was determined on a Perkin-Elmer Atomic Absorption Spectrophotometer Model 306 with a HGA 2100 graphite furnace. Major cations were analyzed by the standard conditions set in the Handbook by Perkin-Elmer using air-acetylene flame. All metals were run on the flame where levels were high enough, and on the HGA 2100 for low levels. HGA 2100 standard conditions were used for metal analyses using the non-interrupt mode. Optimum atomization temperatures were determined for each element and percentage recoveries were performed and, when percentage recoveries were not in the 90–110 percent range, the samples were analyzed by standard methods.

Arsenic and selenium were run on a hydride generator attachment for the Atomic Absorption Spectrophotometer.

Mercury was determined with EPA procedure of sulfuric acid-hydrogen peroxide digestion followed by Atomic Absorption Analysis (U.S. EPA 1976).

Anion Analyses

Analyses for nitrate and nitrite, and chloride followed the standard procedures of Technicon Industrial Systems, Technical Publication No. TJ1-0268, Technicon Auto-analyzer II Industrial System. Industrial Method No. 99-70W (1974) was used for the analyses of chloride. Industrial Method No. 100-70W (1973) was used for the analyses of nitrate and nitrite.

Plant Digestion (HNO₃-HCl method)

Plants were ground to less than 40 mesh in a Wiley mill. Ten grams of ground, diced plant tissue were accurately weighed into a Technicon BD digestion tube to the nearest 0.1 milligram. To the tissue was added 10 ml of concentrated nitric acid. The samples were allowed to stand until the foaming subsided (usually 1-2 hours, preferably over night) and then 10 ml of concentrated hydrochloric acid was added. The samples were allowed to stand until the foaming subsided and then boiled on a block digester at 150° C until half the original volume remained (1-2 ml). The samples were then cooled and filtered through Whatman 22 filters into 100 ml volumetric flasks (the filters were rinsed with 6N HCl before the samples were filtered). The flasks were brought up to volume and appropriate dilutions were made to be analyzed by atomic absorption spectrophotometry.

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