

5. URANIUM MILL TAILINGS

5.1 INTRODUCTION

Uranium mill tailings are the residual wastes of milled ore that remain after the uranium has been recovered. The tailings are generated during the extraction of the uranium from the ore as it is fed to the mill. Depending on the chemical characteristics of the ore, uranium mill operators use either an acid leach or an alkaline leach process to recover uranium. Currently, all operable U.S. mills are designed to use the acid leach process. Mill tailings from both processes consist of slurries of sands and clay-like particles called slimes; the tailings slurries are pumped to tailings impoundment ponds for disposal.

5.2 BY-PRODUCT MATERIAL

Uranium mill tailings are part of a broad category of radioactive wastes called by-product materials. As defined in DOE Order 5820.2A, by-product material includes two major waste groups:

- (1) any radioactive material [except special nuclear material (SNM) such as plutonium or fissile uranium] yielded in, or made radioactive either by exposure to incident radiation or by the process of producing or utilizing SNM; and
- (2) the tailings or waste produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material (i.e., uranium, thorium, or both) content. This excludes underground ores depleted by uranium solution extraction operations (in situ leaching) that continue to remain underground.

The basis for the definition of the second group of by-product materials is Sect. 11e(2) of the Atomic Energy Act (AEA) of 1954 (P.L. 83-703, as amended). For this reason, these wastes, which, of course, include uranium mill tailings, are referred to as 11e(2) by-

product materials.

Uranium mill tailings are the only by-product materials considered in this chapter. Additional information and data on 11e(2) by-product materials from DOE Environmental Restoration Program activities are provided in Chapter 6, which also reports the volumes of mixed DOE Environmental Restoration 11e(2) by-product materials, which have both hazardous and radioactive components. The 11e(2) by-product materials at the Wayne and Maywood FUSRAP sites (see Chapter 6) are thorium mill tailings. For this chapter, information on thorium mill tailings or other by-product materials is not considered.

5.3 COMMERCIAL URANIUM MILL TAILINGS

This section describes the inventories and characteristics of uranium mill tailings generated from uranium ore production at commercially licensed facilities.

5.3.1 Uranium Ore Production

U.S. uranium production from conventional milling has declined since 1980; as a consequence, the quantity of mill tailings generated each year has declined (Table 5.1). During a part of 1996, one conventional mill in the United States was commercially producing uranium concentrates from stockpiled ore mined before 1993. This mill accounted for sole generation of 48,519 t of mill tailings (Table 5.2). At the end of 1996, however, none of the U.S. mills were operational. Six of the 27 mills were on standby status, and the rest were decommissioned or undergoing various stages of decommissioning. The location and status, respectively, of each of these mills are indicated on the map shown in Fig. 5.1 (ref. 1). The nonutilization of U.S. uranium mill capacity can be attributed, in large part, to nuclear power plant cancellations and deferments. Since the late 1970s, these have led to lower uranium demand, which, in turn, has contributed to lower uranium prices and a steady

decline in domestic uranium mining. In addition, cost increases for domestic uranium mining and milling have led to increased reliance on importing less expensive uranium.

In the history of U.S. uranium production, 1993 and 1994 were the only years with no production from conventional milling of ore. Nonconventional concentrate production in 1996 increased to about 2,477 t U_3O_8 , or 23% above 1995 production.^{2,3} Nonconventional concentrate production includes by-product processing resulting from the mining of phosphate ore as well as the processing of in situ leach-mining solutions, heap-leach solutions, mine water, and other solutions from reclamation activities. In situ leaching (ISL) technology has been increasingly applied in recent years to mining operations. Of the total 1996 \$80/kg-U uranium reserves estimated by the Energy Information Administration (EIA), the amount for which ISL is the proposed mining method was about 41%. Because ISL mining usually is successful at lower costs as compared with conventional mining methods, it could gain even wider use in the near future. ISL and by-product (from phosphate ore) production methods do not generate uranium mill tailings. Residual wastes from nonconventional methods are not considered in this chapter.

5.3.2 Inventories

The status of the licensed mills, including their estimated commercial and government-related tailings inventories at the end of 1996, is shown in Table 5.2 (data based on refs. 1–11). For each mill, the amount of tailings generated depends on the amount of ore processed, the ore-feed grade (U_3O_8 assay), and the percentage of U_3O_8 recovered. Table 5.1 lists the annual milling rate, ore grade, and U_3O_8 recovery. Through 1996, 189.7×10^6 t (118.7×10^6 m³) associated mill tailings were generated.

5.3.3 Waste Characterization

Because the amount of uranium (by weight) extracted from the ore during milling is relatively small, the dry weight of the tailings produced is nearly equal to the dry weight of the ore processed. Dry tailings typically are composed of 70 to 80 wt % sand-sized particles and 20 to 30 wt % finer-sized particles. Acid leaching is preferred for ores with low lime content (12 wt % or less). Those with high lime content require excessive quantities of acid for neutralization and, for economic reasons, are best treated by alkaline leaching. In either leach process, most of the uranium is dissolved, together with the other materials present in the ore (e.g., iron, aluminum, and other impurities). After the ore is leached, the uranium-laden leach liquor is removed from the tailings solids by decantation. After thorough washing, the tailings are pumped as a slurry to a tailings pond. The waste liquid accompanying the tailings solids to the disposal pond is approximately 1 to 1.5 times the weight of the processed ore. Typical characteristics of the tailings solids and liquid are outlined in Table 5.3 (ref. 8).

The tailings pile must have a cover designed to control radiological hazards for a minimum of 200 years and for 1,000 years to the greatest extent reasonably achievable. It must also limit radon (²²²Rn) releases to 20 pCi/m²/s averaged over the disposal area. Radon release limitation requirements apply to any portion of the tailings disposal site unless radium concentrates do not exceed 5 pCi/g in the first 15 cm below the surface and 15 pCi/g in layers more than 15 cm below the surface.¹¹

5.4 DOE URANIUM MILL TAILINGS

DOE uranium mill tailings include those resulting from uranium ore milled for defense purposes as well as those at inactive sites no longer licensed that are administered under the DOE Uranium Mill Tailings Remedial Action Project, which is discussed in Chapter 6.

5.5 REFERENCES

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2. U.S. Department of Energy, Energy Information Administration, "Uranium Industry Annual Survey," Form EIA-858, Washington, D.C. (1996).

3. U.S. Department of Energy, Energy Information Administration, *Uranium Industry Annual 1996*, DOE/ EIA-0478(96), Washington, D.C. (April 1997).
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6. W. S. White, *Directory and Profile of Licensed Uranium Recovery Facilities*, NUREG/CR-2869 (ANL/ES-128), Rev. 1, U.S. Nuclear Regulatory Commission, Washington, D.C. (March 1984).
7. U.S. Environmental Protection Agency, “National Emission Standard for Radon-222 Emissions from Licensed Uranium Mill Tailings,” *Code of Federal Regulations*, 40 CFR Part 61, Subpart W (September 1986).
8. U.S. Nuclear Regulatory Commission, *Final Generic Environmental Impact Statement on Uranium Milling, Project M-25*, NUREG-0706, Washington, D.C. (September 1980).
9. U.S. Department of Energy, Grand Junction Office, *Statistical Data of the Uranium Industry*, GJ0-100(73), Grand Junction, Colorado (Jan. 1, 1973).
10. U.S. Congress, House of Representatives, Committees on Energy and Commerce; Interior and Insular Affairs; Science, Space, and Technology; and Ways and Means, *Uranium Revitalization, Tailings Reclamation and Enrichment Act of 1988: Hearing on H.R. 4489*, 100th Congress, 2nd sess., pp. 19–21 (Apr. 28, 1988).
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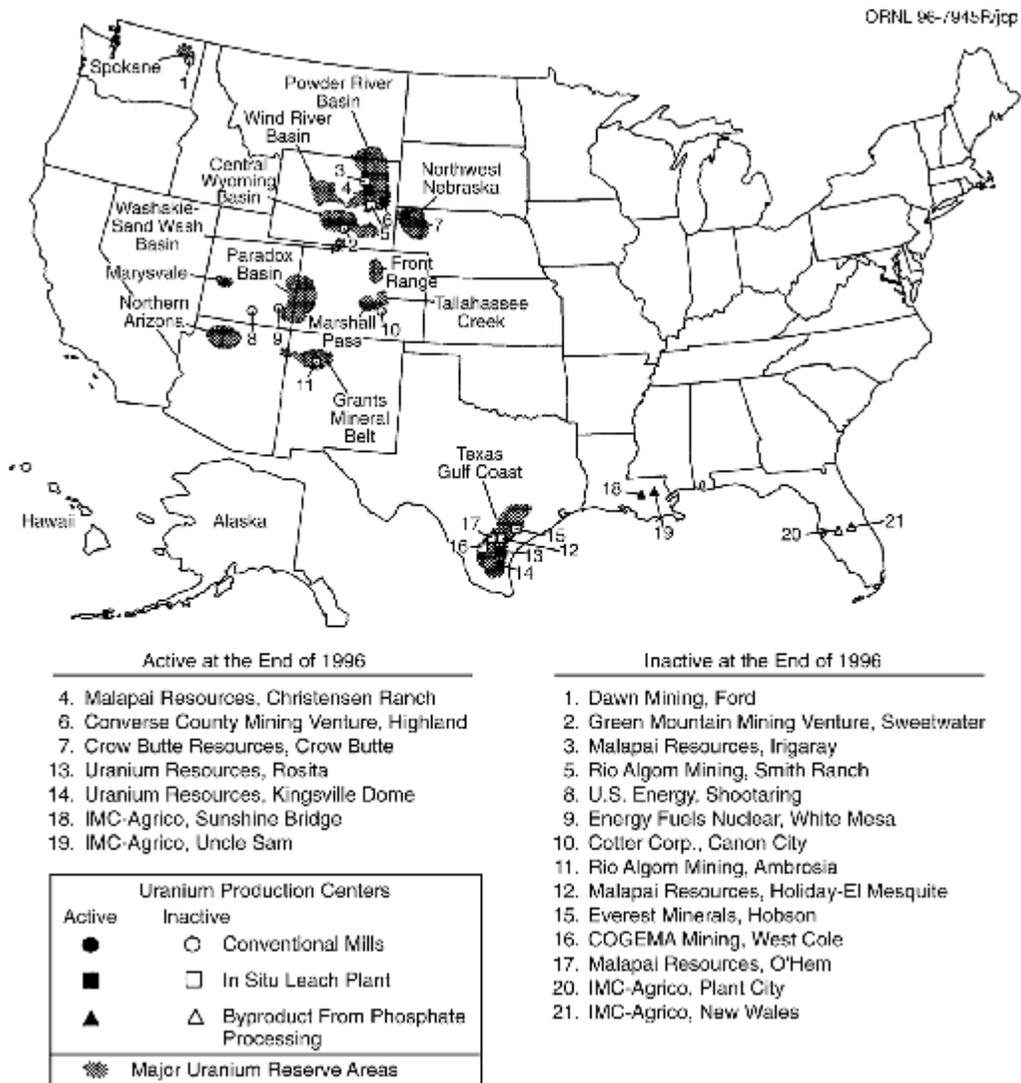


Fig. 5.1. Location and status of currently available uranium mills and plants at EOY 1996. Courtesy of U.S. Department of Energy, Energy Information Administration, Washington, D.C.

Table 5.1. Uranium ore processed, U₃O₈ recovery rate, and tailings generated through 1996^{a,b}

End of calendar year	Ore processed		U ₃ O ₈ recovery rate		Tailings generated	
	Mass ^c (10 ⁶ t)	Grade (% U ₃ O ₈)	Recovery from ore (%)	Product ^d (10 ³ t)	Mass ^e (10 ⁶ t)	Volume ^f (10 ⁶ m ³)
Prior to 1978	g	g	g	g	108.8	68.0
1978	12.5	0.134	91	15.6	12.6	7.9
1979	14.6	0.113	91	15.3	14.5	9.1
1980	15.3	0.118	93	17.2	15.2	9.5
1981	13.2	0.115	94	14.5	13.2	8.2
1982	7.9	0.119	96	9.9	8.1	5.0
1983	5.4	0.128	97	7.0	5.4	3.4
1984	3.9	0.112	95	4.4	4.0	2.5
1985	1.6	0.161	96	2.8	1.6	1.0
1986	1.2	0.338	97	4.0	1.2	0.7
1987	1.3	0.284	96	3.8	1.3	0.8
1988	1.1	0.288	95	3.2	1.1	0.7
1989	1.1	0.323	95	3.7	1.0	0.7
1990	0.7	0.293	94	2.1	0.7	0.4
1991	0.6	0.188	92	1.2	0.6	0.4
1992	0.2	0.229	96	0.6	0.2	0.2
1993	0.0	0.000	0	0.0	0.0	0.0
1994	0.0	0.000	0	0.0	0.0	0.0
1995	0.1 ^h	0.531	93	0.8	0.1	0.1
1996	<0.1 ^h	0.524	87	0.7	<0.1	<0.1
Total ⁱ					189.7	118.7

^aSources: Prior to 1984—U.S. Department of Energy, Grand Junction Area Office data files. 1984–1996—Energy Information Administration, “Uranium Industry Annual Survey,” Form EIA-858.

^bThis table has been revised based on a detailed study of milling data from the Grand Junction Project Office and EIA files. The values shown include all tailings.

^cBefore in-process inventory adjustments.

^dConventional U₃O₈ concentrate production.

^eIncludes adjustments to ore-fed amounts for annual mill circuit inventory changes and uranium concentrate production.

^fCalculated assuming that the average density of tailings is 1.6 t/m³.

^gNot available.

^hStockpiled ore mined before 1993.

ⁱBecause of independent rounding, totals may not equal the sum of components.

Table 5.2. Status of conventional uranium mill sites at the end of 1996^a

Location	Operator	Rated capacity ^b (t/d ore)	Status Tailings		Total tailings			Government portion ^f (10 ⁶ t)
			Operations ^b	Tailings ^c	storage area (ha) ^d	Volume ^e (10 ⁶ m ³)	Mass (10 ⁶ t)	
Colorado								
Canon City	Cotter	1,090	Shut down, 1987		66Rg	1.3	2.0	0.3
Uravan	Umetco Minerals	1,180 ^h	Decommissioning	Partially stabilized	34R	5.9	9.5	5.2
Subtotal		1,090			100R	7.2	11.5	5.5
New Mexico								
Ambrosia Lake	Quivira Mining	6,350	Shut down, 1985	Fenced	131R	18.8	30.1	9.1
Bluewater	Anaconda	5,440 ^h	Decommissioning	Partially stabilized	199	13.6	21.7	8.0
Church Rock	United Nuclear	2,720 ^h	Decommissioning	ⁱ	40R	2.0	3.2	0
Grants	Homestake Mining	3,080 ^h	Decommissioning	Unstabilized	86R	12.7	20.2	10.4
L-Bar	Sohio Western Mining	1,450 ^h	Decommissioning	ⁱ	46R	1.2	1.9	0
Marquez	Bokum Resources	1,820 ^{h,j}	New (on standby)	Never operated	0	0	0	0
Subtotal		6,350			502R	48.3	77.1	27.5
South Dakota								
Edgemont	Tennessee Valley Authority	680 ^h	Decommissioned	Stabilized	50	1.2	1.8	1.5
Subtotal		0			50	1.2	1.8	1.5
Texas								
Falls City	Continental Oil/ Pioneer Nuclear	3,080 ^h	Decommissioned	Stabilized	89	6.5	10.5	0
Panna Maria	Rio Grande Resources	2,720 ^h	Decommissioned	Stabilized	101	3.9	5.9	0
Ray Point (Felder Facility)	Exxon	1,000 ^h	Decommissioned	Stabilized ^k	18	0.2	0.41	0
Subtotal		2,720			208	10.6	16.8	0

Table 5.2 (continued)

Location	Operator	Rated capacity ^b (t/d ore)	Status Tailings		Total tailings			Government portion ^f (10 ⁶ t)
			Operations ^b	Tailings ^c	storage area (ha) ^d	Volume ^e (10 ⁶ m ³)	Mass (10 ⁶ t)	
Utah								
Lisbon	Rio Algom	680	Decommissioning	ⁱ	14	2.2	3.5	0
Moab	Atlas	1,270 ^h	Decommissioning	Relocation sought	>80	6.0	9.6	5.4
Shootinger	Plateau Resources	910	New (on standby)	Never operated	28	0	0	0
White Mesa	Energy Fuels	1,810	Shut down, 1990; restarted, 1995; shut down, 1996	Partially stabilized	135	2.0	3.4	0
Subtotal		3,400			>257	10.2	16.5	5.4
Washington								
Ford	Dawn Mining	410	Shut down, 1982	Wood chip covering	53R	1.8	2.8	1.1
Sherwood	Western Nuclear	1,810 ^h	Decommissioning	ⁱ	17	1.6	2.6	0
Subtotal		410			70R	3.4	5.4	1.1
Wyoming								
Bear Creek	Rocky Mountain Energy	1,810 ^h	Decommissioning	Unstabilized	61	2.7	4.3	0
Gas Hills	American Nuclear	860 ^h	Decommissioning	Unstabilized	47R	3.3	5.4	2.0
Gas Hills	Umetco	1,270 ^h	Decommissioning	Unstabilized	58R	4.6	7.3	1.9
Highland	Exxon	2,900 ^h	Decommissioning	Partially stabilized	116R	6.4	10.3	0
Lucky Mc	Pathfinder	2,540 ^h	Decommissioning	Unstabilized	99R	6.6	10.6	2.6
Petrotomics	Petrotomics	1,360 ^h	Decommissioning	Unstabilized	65	3.9	6.3	0.7
Shirley Basin	Pathfinder	1,630 ^h	Decommissioning	ⁱ	105R	4.7	7.4	0
Split Rock	Western Nuclear	1,540 ^h	Decommissioning	Interim stabilization	67R	4.4	7.0	3.0
Sweetwater	Minerals Exploration/ Union Energy Mining	2,720	Shut down, May 1983	Partially stabilized	121	1.3	2.1	0
Subtotal		4,350			739R	37.9	60.7	10.2
1996 total for all sites ^{b,m,n}		18,320 ^o			>1,926R	118.7	189.7	51.2 ^p

(Footnotes on next page.)

Table 5.2 (continued)

^aData based on refs. 1–11. Note: Subtotals and totals may not equal sum of components because of independent rounding. Ray Point, Texas (Felder Facility), site was stabilized during 1987 by Exxon Corporation. Historical data are revised based on detailed study of milling data from the Grand Junction Project Office and EIA files. The values shown include all tailings.

^bFrom refs. 2, 5, 9, and 11. Values rounded to nearest 10 t.

^cOn Aug. 15, 1986, EPA issued its final rules on ²²²Rn emissions from tailings piles. Mill owners have 6 years (subject to certain extensions) to phase out the use of large existing tailings piles. New tailings piles may be contained in small impoundments (less than 16 ha) or disposed of continuously by dewatering and burial (i.e., no more than 4 ha are uncovered at any one time). See ref. 7.

^dFrom refs. 6 and 11; 1 ha = 10,000 m² or approximately 2.5 acres.

^eCalculated from reported mass using density = 1.6 t/m³.

^fFrom ref. 5, Table 8.0. These tailings are from government contracts only and are included in the “Total tailings” column.

^gR = revised. From ref. 11.

^hEstimates provided are not included in the total. See column labeled “Operations” under “Status” for reason.

ⁱNot available.

^jMill construction has not been 100% complete.

^kFrom ref. 11.

^lFrom ref. 10.

^mThese values are cumulative totals that may not equal sum of components due to independent rounding. For annual totals see Table 5.3.

ⁿFrom ref. 2.

^oFrom ref. 2.

^pTotal at the end of government-contracted deliveries in 1970 (ref. 5).

Table 5.3. Typical characteristics of uranium mill tailings^a

Tailings component	Particle size (µm)	Chemical composition	Radioactivity characteristics
Sands	75 to 500	SiO ₂ with <1 wt % complex silicates of Al, Fe, Mg, Ca, Na, K, Se, Mn, Ni, Mo, Zn, U, and V; also metallic oxides	0.004 to 0.01 wt % U ₃ O ₈ ^b Acid leaching: ^c 26 to 100 pCi ²²⁶ Ra/g; 70 to 600 pCi ²³⁰ Th/g
Slimes	45 to 75	Small amounts of SiO ₂ , but mostly very complex clay-like silicates of Na, Ca, Mn, Mg, Al, and Fe; also metallic oxides	U ₃ O ₈ and ²²⁶ Ra are almost twice the concentration present in the sands Acid leaching: ^c 150 to 400 pCi ²²⁶ Ra/g; 70 to 600 pCi ²³⁰ Th/g
Liquids	d ²³⁰ Th/L	Acid leaching: pH 1.2 to 2.0; Na ⁺ , NH ₄ ⁺ , SO ₄ ⁻² , Cl ⁻ , and PO ₄ ⁻³ ; dissolved solids up to 1 wt % Alkaline leaching: pH 10 to 10.5; CO ₃ ⁻² and HCO ₃ ⁻ ; dissolved solids 10 wt %	Acid leaching: 0.001 to 0.01% U; 20 to 7,500 pCi ²²⁶ Ra/L; 2,000 to 22,000 pCi; Alkaline leaching: 200 pCi ²²⁶ Ra/L; essentially no ²³⁰ Th (insoluble)

^aAdapted from information in ref. 8.

^bU₃O₈ content is higher for acid leaching than for alkaline leaching.

^cSeparate analyses of sands and slimes from the alkaline leaching process are not available. However, total ²²⁶Ra and ²³⁰Th contents of up to 600 pCi/g (of each) have been reported for the combined sands and slimes.

^dParticle size does not apply. Up to 70 vol % of the liquid may be recycled. Recycle potential is greater in the alkaline process.