MASTER

An Integrated Assessment of the Impacts Associated with Uranium Mining and Milling

D. C. Parzyck   D. K. Halford
C. F. Baes III   L. M. McDowell-Boyer
L. G. Berry   R. E. Moore
S. A. Carnes   M. L. Randolph
S. J. Cotter   C. C. Travis
D. J. Crawford   F. G. Taylor
K. A. Hake   A. P. Watson

J. P. Witherspoon

HEALTH AND SAFETY RESEARCH DIVISION

OAK RIDGE NATIONAL LABORATORY

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION · FOR THE DEPARTMENT OF ENERGY

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ORNL/TM-6677

Contract No. W-7405-eng-26

Health and Safety Research Division

AN INTEGRATED ASSESSMENT OF THE IMPACTS ASSOCIATED WITH
URANIUM MINING AND MILLING

D. C. Parzyck D. K. Halford
C. F. Baes III* L. M. McDowell-Boyer
L. G. Berry† R. E. Moore
S. A. Carnes† M. L. Randolph
S. J. Cotter C. C. Travis
D. J. Crawford F. G. Taylor*
K. A. Hake† A. P. Watson
J. P. Witherspoon

*Environmental Sciences Division

†Energy Division

Date Published: July 1979

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee   37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

PAGES __1__ to __2__

WERE INTENTIONALLY

LEFT BLANK

Table 1.1. Frequency of industrial injuries and statistically
estimated cancers in uranium mining and milling industry
(per nuclear power generation of 1 GW_e-year)

	Fatalities	Injuries	Lung cancers[a]
Mines			
Underground	0.04-0.09	3.3-7.7	0.05
Open pit	0.002	0.20-0.32	
Mills	0.006	1.21-1.94	0.02

[a]These are statistical impacts derived from calculated exposures
to large populations and use of dose-to-health effects conversion
factors.

The risk of accidental fatality in underground mines is approximately
the same as the risk of lung cancer. The risk of lung cancer is based on
epidemiological studies of miners who were exposed in the late 1940s,
1950s, and early 1960s, prior to reduction of radiation exposure standards
for miners. Thus, the estimates are probably high for projecting impacts
of current or future mining activities. The frequency of fatalities is
based on data collected in a five-year period (1973 through 1977).

1.1.2 Milling impacts

Environmental impacts associated with uranium milling are somewhat
a function of the ore characteristics and the mill process used. The
two most common methods of extracting uranium from the ore are acid
leach-solvent extraction and alkaline leach.

Because of its long half-life, relative abundance and toxicity, the
nuclide of principal environmental concern in the radioactive wastes from
uranium milling operations is ^{226}Ra. Radium-226, its parent ^{230}Th and
its daughter ^{222}Rn present long-term environmental hazard from low-level
waste disposal. Radon-222, which is an inert gas continuously emitted
from tailings, is more difficult to control than the other radionuclides
that occur as particulates or that are in the liquid wastes. Virtually
all of the ^{226}Ra in uranium ore appears in mill tailings, regardless of
the method used to extract uranium.

Other radionuclides, such as ^{230}Th, ^{210}Po, and ^{210}Pb, are particulates that are released to the atmosphere during periods of active milling, either by blowing from dry tailings piles or as products from ^{222}Rn decay. Release of these nuclides to the atmosphere from mill process operations can be reduced to acceptable levels by conventional dust-collection techniques and by keeping the tailings piles moist or covered.

Tailings ponds are used to dispose of liquid and solid wastes from milling operations. Liquid containing the leached ore is sent to large ponds where the liquid either evaporates or is recycled, gradually building up a semisolid residue. Depending on soil type, age of the mill, and efforts to seal tailings ponds, some seepage may occur into the underlying soil and ultimately to the groundwater. The area of mill tailings is estimated to be 0.1 m^2 per metric ton (MT) of 0.2% U$_3$O$_8$-bearing ore processed. Table 1.2 summarizes the estimated waste from processing a nominal 1814 MT/day [2000 short tons (ST) per day] of 0.2% ore. As indicated in Table 1.2, solution mining effluents and impacts have also been evaluated because (1) solution mining chemicals are similar to those used in the milling process; (2) the waste effluents are ponded and are chemically similar to mill wastes; and (3) solution mining eliminates the need for ore milling. Thus, where ore characteristics and location are favorable, solution mining will reduce the environmental impacts associated with tailings disposal, although other possible chemical impacts on the local aquifers may occur.

Release of ^{222}Rn from the tailings pile results in both local and more distant exposures. By the end of the assumed 20-year life of the mill, the ^{222}Rn release from the tailings is estimated to be 3700 Ci/year.

Table 1.3 shows the dose per year of facility operation to an individual assumed to be exposed continuously over a 50-year period at a distance of 1.6 km (1 mile) from a mill, typically located in a semi-arid, mountainous region in southwestern United States. The dose commitments shown are believed to be conservative estimates because of the assumed continuous occupancy at 1.6 km (1 mile) and other calculational model assumptions regarding various exposure pathways.

The largest dose commitment is to the lung (whole organ) and is estimated to be 28 millirem/year, with 70% of the dose resulting from

Table 1.2. Annual uranium mill and solution mining waste residuals

Extraction method	Ore — U_3O_8		Waste quantity		Area[b]		Radium-226 (Ci)
	(MT)[a]	(ST)	(MT)	(ST)	(m²)	(ft²)	
Acid leach	970	1070	500,000	551,268	50,000	538,196	280
Alkaline leach	990	1092	500,000	551,268	50,000	538,196	280
Solution mining	227	250	450	496			0.5

[a]Assumed 80% annual utilization of the 1814-MT/day (2000-ST/day) production.

[b]Mill tailings area estimated at 0.1 m² per MT of 0.2% U_3O_8-bearing ore processed.

5

Table 1.3. Calculated annual 50-year dose commitments to an
individual 1.6 km (1 mile) from a uranium mill^a

Source	Dose (millirem)				
	Whole body	Bone	Lung	Kidney	Spleen
Ore crusher and bin	1.2	5.7	0.9	1.5	2.3
Yellowcake process	0.5	2.3	7.7	0.2	0.1
Tailings pond and beach	0.4	0.5	19.3	0.7	0.2
	2.1	8.5	27.9	2.4	2.6

^{a}Assumed milling plant characteristics: production capacity —
1814 MT/day (2000 ST/day); ore grade — 0.2% uranium as U_3O_8; annual
utilized capacity — 80%; local meteorology — typical of arid, south-
western United States. The listed doses should be divided by the
factor 5.2 to obtain dose per GW_e.

^{222}Rn emanating from the tailings. The remaining doses are contributed
from other mill process releases. Doses from ^{222}Rn and daughters to the
bronchial epithelium may be an order of magnitude greater than doses to
whole lung.

The maximum calculated collective dose to a population of 53,000
located within 88 km (55 miles) of a typical southwestern mill is 6.5
man-lung rem/year (man-lung rem is the sum of the dose to the lung of
a specifically defined population), 89% of which is from ^{222}Rn emitted
from mill tailings. The 88 km (55 miles) is typically used to differ-
entiate regional from national exposures, even though larger-scale
exposures will occur. To place the collective dose commitments into
perspective, estimates are provided of the annual collective doses
from exposure to other sources of ^{222}Rn for the United States population.
From combined mining and milling operations, the dose to the United
States population is estimated to be 6×10^4 man-lung rem. This may
be compared with 4.4×10^7 man-lung rem from building interiors.

Population change should be considered when assessing socioeconomic
impacts of uranium mine development projects. The amount of immigration
varies directly with the quantity of impacts. In contrast with other

energy development projects (coal-fired or nuclear power plant and synfuels plant), a typical uranium mine or mill employs less than or equal to 600 persons. Large power plants or synfuels plants employ up to 3000 persons during the construction phase. Due to the more permanent status of the work force, socioeconomic impacts of uranium mining and milling tend to be less severe. Generally, most of the socioeconomic impacts of uranium mining and milling are similar to those of other resource development projects. Depending upon the level of immigration and the degree of interpopulation differences and similarities, there will be impacts upon the provision of public and private goods and services. These impacts will be in the nature of competition for scarce resources or demand for new and different resources. Since the scale of employment for uranium mining and milling is so much less than for other energy development projects, impacts on local services should be low. The kinds of impacts uranium mining and milling will have on parameters of social organization, attitudes and values should be similarly less.

Adverse ecological impacts of a uranium mill site are most severe during the construction phase. In the immediate mill site area (250 ha for our model mill), primary production is completely lost, while seed production and mammal and bird biomass are depleted over 90%. The impacts are minor or nonexistent in the entire 500,000-ha (1.2 x 10^6 acre) area potentially affected by the site. Other possible impacts include loss of organic matter from soils, salinization of soils, soil erosion and ground water contamination. There appears to be no radiological impact on the uranium mill environment. However, subtle changes in ecosystem structure may result in significant impacts over the entire site. Therefore, further investigation into potential radiological and other impacts to ecosystem structure and impacts to individual species.

In addition to exposures from radionuclides, other potentially harmful exposures may occur due to arsenic, selenium, vanadium, and molybdenum, which are in wastes from uranium mills. The quantities of these materials in wastes are strongly determined by the type of ore processed. The potential impact on the environment due to these materials is being investigated.

Considerable attention is also being given to stabilizing mill tailings to minimize potential exposures after mills are decommissioned. Particular concern is directed at ensuring long-term stabilization and retardation of ^{222}Rn and ^{226}Ra releases to the environment.

Uranium mining and milling processes lead to a variety of exposures, the magnitude of which depend on the quantity of the ore. Both the uranium and actinium decay chains contain radionuclides which emit beta and gamma radiations. The beta and gamma emitters may pose a health hazard due to either external exposure or internal dose. The greatest hazard to the general public results from the inhalation of ^{222}Rn, followed by external exposure to gamma radiation originating in radium bearing soils and ores, and by intake of contaminated particles, water or food. Any radiological survey of a mining and milling operation should account for all modes of exposure.

Two basic methods can be used to determine the amount of radon being transported to a given location. One involves direct measurement of the radon concentration at the point of interest and the other requires the development of a source term followed by the use of transport models. Interest in the dosimetry of radon has been centered on the daughters of radon rather than on radon itself which has led to the development of devices which measure the concentration of radon daughters.

The unit for the determination of exposure to radon daughters is the working level (WL) which is "any combination of radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 Mev of potential alpha energy." The monitoring of uranium mines requires that determination be made of the working level existing at a particular place and time as well as the cumulative exposure to a worker in a particular area.

Future needs should center on the development of sensitive personnel monitors for the measurement of cumulative exposure to radon and its daughters. These developments would be supplemented by an increased sophistication in the ability to predict exposure from in vivo counting and bioassay.

2. URANIUM RESOURCES AND DOMESTIC MILL LOCATIONS

The uranium resources reported by the Atlantic Council's Nuclear Fuels Working Group are given in Table 2.1. The environmental, health, and safety impacts identified in this assessment are based on an assumed uranium mill located in arid southwestern United States. The environmental impacts associated with uranium mining and milling will vary somewhat with the location of the facilities; however, as indicated in Tables 2.2 and 2.3, the uranium mills in the United States are generally located in arid western and southwestern portions of the country. This characteristic is expected to continue because the known, richer uranium reserves are in these areas.

According to estimates of uranium reserves and resources, there should be no great problem in meeting the expected demand by utilities for uranium for nuclear power generation in the United States. As shown in Tables 2.4 and 2.5, "total reserves" and "probable resources" approximately match requirements of the 30-year life of installed capacity (at year 2000) of most demand scenarios, and the addition of "possible resources" to the base figures more than compensates for the requirements of higher demand forecasts.

Although the bulk of these requirements will be supplied by conventional mining and milling operations, the industry is exploring alternative resources and technologies which will supplement these conventional sources. As shown in Table 2.6, these sources include by-products from phosphate and copper mining, in situ mining, and imports. Excluding imports, which will be balanced by exports by 1990, the contribution of these sources to total requirements will peak in 1980 at 36.7% and decline gradually until by the year 2000 only 14.1% of gross requirements will be met by unconventional resources (Table 2.6). The probable need for and distribution of new conventional uranium mills is presented in Table 2.7. Of the unconventional resources, only those which are a by-product of phosphate mining ore seem to make substantial contributions to uranium requirements. Other changes in the industry, such as Kerr-McGee's recent development in slurrying yellowcake from mills to its uranium hexafluoride conversion facility at its Sequoyah Plant,[1] make the prediction of future mill characteristics problematic.

Table 2.1. Uranium (U_3O_8) reserves and production
capacities of various countries

Country	Reserves		Attainable production capacity — 1978[a]	
	(ST)	(MT)	(ST)	(MT)
Argentina	54,000	48,978	670	608
Australia	270,000	244,890	2,600	2,358
Canada	716,000	649,412	11,050	10,022
France	106,000	96,142	2,860	2,594
Gabon	30,000	27,210	1,560	1,415
Niger	80,000	72,560	1,950	1,769
Germany			320	290
Italy	5,400	4,898		
Japan	7,000	6,349	40	36
Mexico	1,900	1,723	320	290
Portugal			140	127
Spain	16,200	14,693	440	399
South Africa	298,000	270,286	14,300[b]	12,970[b]
Sweden	310,000	281,170	120[c]	109[c]
United States	1,240,000	1,124,680	24,700	22,403

[a]Production values for 1978 are projected from 1975.

[b]South African production tied to gold production: low gold price, low uranium production; high gold price, high uranium production.

[c]Planned capacity in 1975.

Source: "Nuclear Fuels Policy," report of the Atlantic Council's Nuclear Fuels Policy Working Group, Westview Press, 1976.

Table 2.2. Active uranium mills in the United States (1976)

Mill	Location
Anaconda Co.	Bluewater, N. Mex.
Atlas Corp.	Moab, Utah
Conoco & Pioneer Nuclear, Inc.	Falls City, Tex.
Cotter Corp.	Canyon City, Colo.
Dawn Mining Co.	Ford, Wash.
Exxon Co.	Powder River Basin, Wyo.
Federal American Partners	Gasttills, Wyo.
Kerr-McGee Nuclear Corp.	Ambrosia Lake, N. Mex.
Rio Algom Corp.	La Sal, Utah
Sohio Petroleum	L Bar Ranch, N. Mex.
Union Carbide Corp.	Uravan, Colo.
Union Carbide Corp.	Natrona County, Wyo.
United Nuclear—Homestake Partners	Grants, N. Mex.
Utah International, Inc.	Gas Hills, Wyo.
Utah International, Inc.	Shirley Basin, Wyo.
Western Nuclear, Inc.	Jeffrey City, Wyo.
United Nuclear Corp.	Ambrosia Lake, N. Mex.

Table 2.3. Inactive uranium mills in the United States (1976)

Mill	Location
Foote Mineral Co.	Durango, Colo.
Amax Uranium Corp.	Grand Junction, Colo.
Kermac Nuclear Fuels	Gunnison, Colo.
Union Carbide Corp.	Maybell, Colo.
Foote Mineral Co.	Naturita, Colo.
Union Carbide Corp. (old and new)	New Rifle, Colo.
North Continent Mill	Slick Rock, Colo.
Union Carbide Corp.	Slick Rock, Colo.
Foote Mineral Co.	Monument Valley, Ariz.
El Paso Natural Gas Co.	Tuba City, Ariz.
Michigan Chemical Corp.	Lowman, Idaho
United Nuclear Corp.	Ambrosia Lake, N. Mex.
Foote Mineral Co.	Shiprock, N. Mex.
Atlantic Richfield Co.	Lakeview, Ore.
Susquehanna Western, Inc.	Falls City, Tex.
Exxon Co.	Ray Point, Tex.
Wyoming Mining and Milling Co.	Converse County, Wyo.
Union Carbide Corp.	Green River, Utah
Atlas Corp.	Mexican Hat, Utah
Vitro Corporaton of America	Salt Lake City, Utah

Table 2.4. Summary of uranium production, reserves, and potential resources
by National Uranium Resource Evaluation Regions[a]

($14 per kilogram of uranium forward costs as of January 1, 1977)

Region (chief producing states)	Past production (MT)	Reserves (MT)	Potential resources (MT)		
			Probable	Possible	Speculation
Colorado Plateau (New Mexico, Colorado, and Utah)	182,242	342,914	494,413	553,380	81,646
Wyoming Basins (Wyoming)	57,697	190,599	272,154	45,359	27,215
Coastal Plain (Texas)	8,074	39,825	104,325	54,431	22,680
Northern Rockies (Washington)		18,144	24,494	57,152	44,452
Colorado and Southern Rockies (Colorado and Nebraska)		8,527	41,730	34,473	18,144
Great Plains (Colorado and Nebraska)	14,968	5,715	20,865		
Subtotal	267,981	605,724	957,982	744,795	194,137
Basin and Range		9,897	26,308	206,837	46,266
Pacific Coast and Sierra Nevada	907	1,270	3,629	10,886	7,257
Central Lowlands	907	0			64,410
Appalachian Highlands	907	0			70,760
Columbia Plateaus	907	0			19,051
Total	268,888	616,882	987,919	962,518	401,881

[a]This does not include an additional 140,000 tons of U_3O_8 from by-product sources (phosphate and copper mining) which are projected to be available through the rest of the century.

Source: Draft of Generic Draft EIS on Uranium Milling Operations (Argonne National Laboratory, personal communication, October 11, 1978), pp. 3-12.

Table 2.5. Uranium requirements under various scenarios, 1976–2000[a]

Year	Nuclear generating capacity (GWe)	Annual requirements U₃O₈ MT 1[b]	Annual requirements U₃O₈ MT 2[c]	DOE, September 1978[e] Low forecast — Nuclear generating capacity (GWe)	Low forecast — U₃O₈ needed at tails of 0.25% (MT)	Mid forecast — Nuclear generating capacity (GWe)	Mid forecast — U₃O₈ needed at tails of 0.25% (MT)	High forecast — Nuclear generating capacity (GWe)	High forecast — U₃O₈ needed at tails of 0.25% (MT)
1976	43	9,350							
1977	49	9,751	11,700	13,200					
1978	53	9,989	16,900	15,500	53	10,886	53	11,794	53	11,794
1979	57	11,079	19,200	23,400	57	11,794	58	12,701	58	12,701
1980	61	11,085	25,400	25,800	62	12,701	66	14,515	66	14,515
1981	74	17,435	28,300	30,900	66	14,515	71	17,237	71	17,237
1982	87	18,160	30,100	31,700	71	16,330	81	18,144	81	19,958
1983	100	20,523	31,700	33,200	78	19,958	89	21,773	89	24,494
1984	112	22,339	36,600	33,300	85	21,773	97	24,494	100	25,402
1985	127	26,335	36,800	37,100	100	23,587	111	27,216	123	28,123
1986	141	27,969	38,400	38,000	111	25,402	127	28,123	134	30,845
1987	154	30,148	39,300		124	28,123	143	30,845	151	32,659
1988	167	32,657	39,700		135	29,938	153	32,659	163	37,195
1989	181	35,527	39,700		148	31,752	164	36,288	176	39,917
1990	195	37,993	40,500		158	33,566	172	39,010	193	42,638
1991	210	41,066			169	35,381	188	41,731	209	46,267
1992	225	43,532			180	38,102	204	44,453	225	49,896
1993	240	46,350			190	39,917	219	47,174	243	53,525
1994	260	51,740			200	41,731	235	49,896	262	57,154
1995	280	54,485			210	43,546	250	52,618	282	61,690
1996	300	57,936			220	45,360	265	56,246	302	66,226
1997	320	61,331			229	46,267	280	58,968	324	70,762
1998	340	65,325			238	48,082	295	61,690	347	75,298
1999	360	68,470			247	49,896	310	64,411	371	79,834
2000	380	71,320			256	51,710	325	67,133	396	83,462
Total requirements for 30-year life of operating and planned capacity		1,861,000				1,500,000		1,813,000		2,071,383

[a]These estimates are based on long-term fixed-commitment contracts, with a 0.20% tails assay prior to Oct. 1, 1980, and a 0.25% assay thereafter.

[b]Source: Draft of Draft Generic EIS on Uranium Milling Operations (Argonne National Laboratory, personal communication, October 11, 1978).

[c]Source: Energy Information Administration, DOE, *Quarterly Report Energy Information: Report to Congress* [DOE/EIA-0003/1 (78) July 1978 NTISUB/D/027-01].

[d]George White, Jr., "Uranium: Prices Steady at High Levels in '77," *Eng. Min. J.* 179: 130 (1978). His figures are based on a study by Nuclear Exchange Corporation.

[e]"DOE Slashes Estimates of U₃O₈ Demand Below Those Made a Few Months Ago," *Nucl. Fuel* 3(19): 3 (1978).

14

Table 2.6. Effect of unconventional sources of uranium on conventional milling requirements, 1978-2000

(All material quantities expressed as thousands of metric tons)

Year	Phosphate	In situ mining	Copper dump	Total	Imports	Exports	Net total (imports minus exports)	Amount supplied by nonconventional sources	Amount supplied by heap leaching	Gross requirements	Net production required from conventional mills
1978	200	1000	300	1,500	2400	800	1600[a]	3,100	100	10,000	6,800
1979	900	1950	350	3,200	3000	800	2200	5,400	200	11,000	5,400
1980	1250	2700	450	4,400	3800	1500	2300	6,700	200	12,000	5,100
1981	1400	3150	550	5,100	3900	1500	2400	7,500	200	17,000	9,300
1982	1550	3500	550	5,600	3700	1500	2200	7,800	300	18,000	9,900
1983	1700	3450	550	5,700	3700	1500	2200	7,900	300	21,000	12,800
1984	1750	3300	550	5,600	3400	1500	1900	7,500	300	22,000.	14,200
1985	1900	3550	650	6,100	3200	1500	1700	7,800	300	26,000	17,900
1986	2100	3700	700	6,500	2300	1500	800	7,300	300	28,000	20,400
1987	2100	3800	700	6,600	1600	1500	100	6,700	300	30,000	23,000
1988	2450	4000	700	7,150	1550	1500	50	7,200	300	33,000	25,500
1989	2700	4000	700	7,400	1500	1500		7,400	300	36,000	28,300
1990	2900	4000	700	7,600	1400	1500	-100	7,500	300	38,000	30,200
1991	3200	4000	700	7,900			b	7,900	300	41,000	32,800
1992	3500	3400	700	7,600			b	7,600	200	44,000	36,200
1993	4050	3600	450	8,100			b	8,100	200	46,000	37,700
1994	4300	3750	450	8,500			b	8,500	200	52,000	43,300
1995	4800	3650	450	8,900			b	8,900	200	55,000	45,900
1996	5250	3600	450	9,300			b	9,300	200	58,000	48,500
1997	5650	3200	450	9,300			b	9,300	200	61,000	51,500
1998	6150	3000	450	9,600			b	9,600	200	65,000	55,200
1999	6650	2700	450	9,800			b	9,800	200	68,000	58,000
2000	7100	2450	450	10,000			b	10,000	200	71,000	60,800

[a]Assumes mills currently operating or planned will have sufficient capacity to supply requirements through 1988.

[b]Assumes no net difference (imports and exports are balanced) after 1990.

Table based on modification of information provided in J. Kleminic, "Analysis and Trends in Uranium Supply," p. 26, presented at the Grand Junction Office Uranium Industry Seminar, U.S. Energy Research and Development Administration, October 1975.

Source: Draft of Draft Generic EIS on Uranium Milling Operations (Argonne National Laboratory, personal communication, October 11, 1978).

15

Table 2.7. Probable need for and distribution of new conventional uranium mills, 1977-2000

.NURE[a] Region	Reserves and probable resources, 10^3 MT U_3O_8	Percentage of U.S. total in region	Number of new mills[b]	States with mills in 1977[c]
A	690	48	21	New Mexico, Colorado, and Utah (Arizona)
B	495	34.5	15	Wyoming (Montana)
C	131	9.1	4	Texas (14 other states)
D	427	3	1	Washington (Idaho and Montana)
E	48.1	3.4	1	Colorado and New Mexico
F	29.3	2	1	Wyoming and South Dakota (8 cther states)
Total	1820.4	100	43	

[a]National Uranium Resource Evaluation Region.

[b]Assumed capacities of 1800 MT/day each.

[c]States in parentheses are in the given NURE region, but had no mills cperating in 1977.

Source: Draft of Draft Generic EIS on Uranium Milling Operations (Argonne National Laboratory, personal communication, October 11, 1978).

A series of tables and maps is presented which depict the locations and production levels for the uranium mining and milling industry Tables 2.8-2.10, Figs. 2.1-2.12).* The maps indicate current facilities as of 1975 and show projections of locations and production levels for 1985, 1990, and 2000. The data presented do not necessarily represent firm government or industry commitments since future sociopolitical influences cannot be accurately determined. Even so, economic and physical limitations inherent to uranium extraction constrain the industry to a relatively predictable framework.

Data for the uranium cycle maps were derived from the Strategic Environmental Assessment System (SEAS).† This model regionalizes information available for supply technologies, including the uranium fuel cycle, at the county level. A working paper documenting the methodology behind SEAS provided the actual values displayed.[2] Estimates of production at each stage of the cycle were documented from published records of the mining industry and the U.S. Geological Survey available through 1975. Validity of projections through 1985 are considered reasonable given that the uranium industry responds to future demands in an historically established manner. Projections beyond 1985 assume various locational decisions relative to mining and milling operation proximities. National production levels of conversion, enrichment, and reprocessing expect to equalize production shares through time. Each of the displayed data sets take the form of county shares of a national total. Individual mine and mill sites are therefore not aggregated to the county level and their production confined to form one county's proportion of national uranium production.

---

*This information was displayed through the aid of an improved computer mapping system developed by the Resource Analysis Group at ORNL. A wide range of options is available to the user including displaying line, point, or regional data, labeling of data, varying map scale, and various other useful tools.

†Strategic Environmental Assessment System is a computer model currently under the auspices of the MITRE Corporation for the U.S. Department of Energy. For the purpose of this study, SEAS provides information on regional production locations of the uranium cycle.

Table 2.8. Surface uranium mining[a]

(County shares of national production total)

State	County	Year			
		1975	1985	1990	2000
N. Mex.	McKinley	0	0	0	0
	Velencia	0.197	0.207	0.148	0.113
	San Juan	0	0	0.049	0.113
Wyo.	Carbon	0.129	0.076	0.050	0.043
	Converse	0	0.102	0.100	0.086
	Fremont	0.309	0.153	0.151	0.128
	Natrona	0.077	0.076	0.050	0.043
	Johnson	0	0.051	0.075	0.064
	Sweetwater	0	0.051	0.075	0.064
Utah	Emery	0.015	0.017	0.010	0.007
	Grand	0.015	0.017	0.010	0.009
	San Juan	0.015	0.017	0.011	0.009
	Garfield	0.016	0.017	0.011	0.007
	Wayne	0	0	0	0.004
Colo.	Garfield	0.010	0.007	0.006	0.005
	Jefferson	0.040	0.029	0.017	0.013
	Mesa	0.010	0.007	0.006	0.004
	Montrose	0.010	0.007	0.006	0.004
	San Miguel	0.030	0.022	0.012	0.009
	Weld	0	0	0.011	0.009
Tex.	Live Oak	0.038	0.029	0.030	0.036
	Karnes	0.038	0.025	0.025	0.028
	Atascosa	0	0.008	0.015	0.029
	Duval	0	0.008	0.010	0.022
	Webb	0	0.013	0.020	0.029
Wash.	Stevens	0.052	0.046	0.050	0.046
Ark.	Garland	0	0.004	0.008	0.011
S. Dak.	Custer	0	0.011	0.016	0.016
	Fall River	0	0	0.004	0.005
	Harding	0	0	0	0.005
Ariz.	Apache	0	0	0.012	0.012
	Coconino	0	0	0	0.004
Oreg.	Lake	0	0	0.012	0.012
N. Dak.	Billings	0	0	0	0.003
	Slope	0	0	0	0.003
	Bowman	0	0	0	0.005

[a]Strategic Environmental Assessment System Sector 13.01.

Fig. 2.1. SURFACE URANIUM MINES IN 1975
COUNTY SHARES OF NATIONAL PRODUCTION TOTAL

● 0.010 SHARE   ● 0.050 SHARE   ● 0.150 SHARE   ● 0.300 SHARE
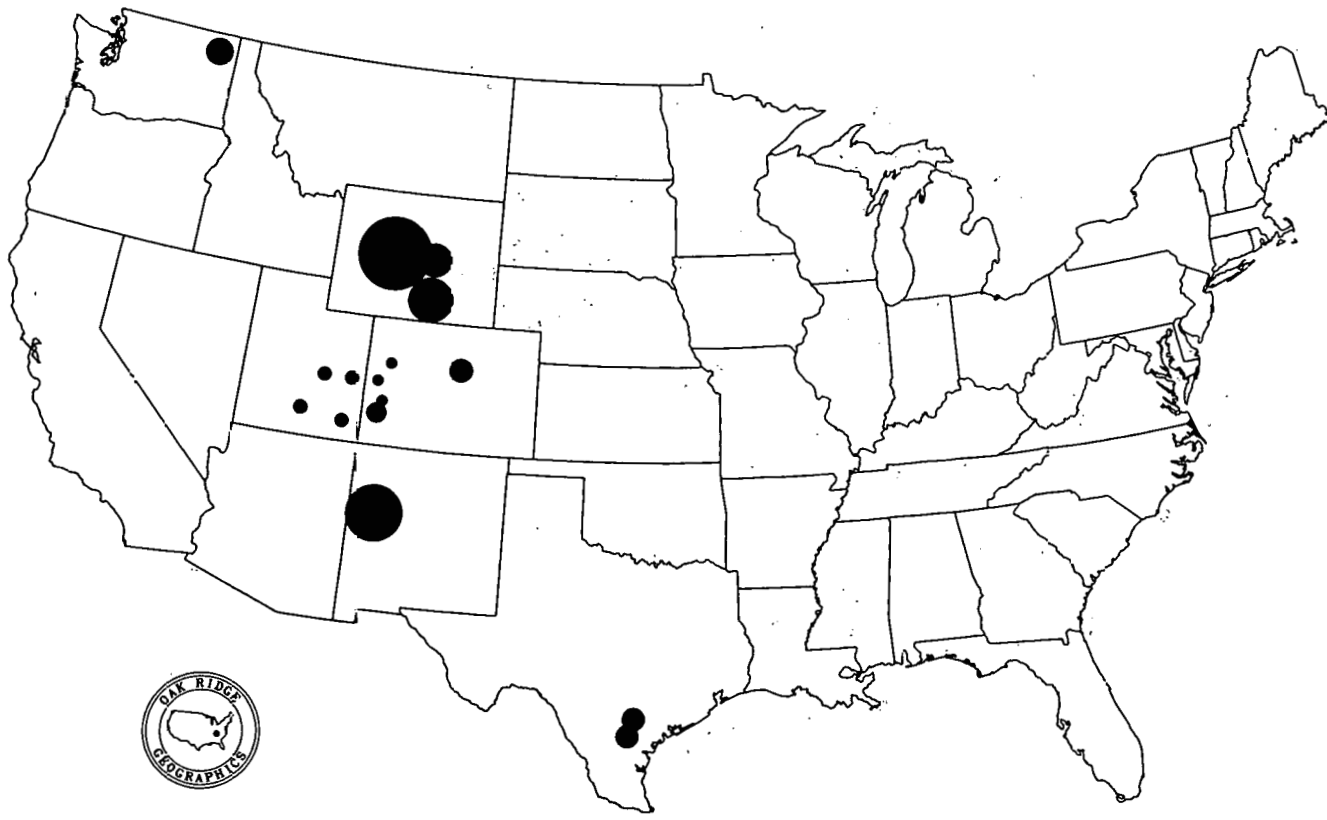
Fig. 2.2. **SURFACE URANIUM MINES IN 1985**
COUNTY SHARES OF NATIONAL PRODUCTION TOTAL

• 0.010 SHARE   ● 0.050 SHARE   ● 0.150 SHARE   ● 0.300 SHARE
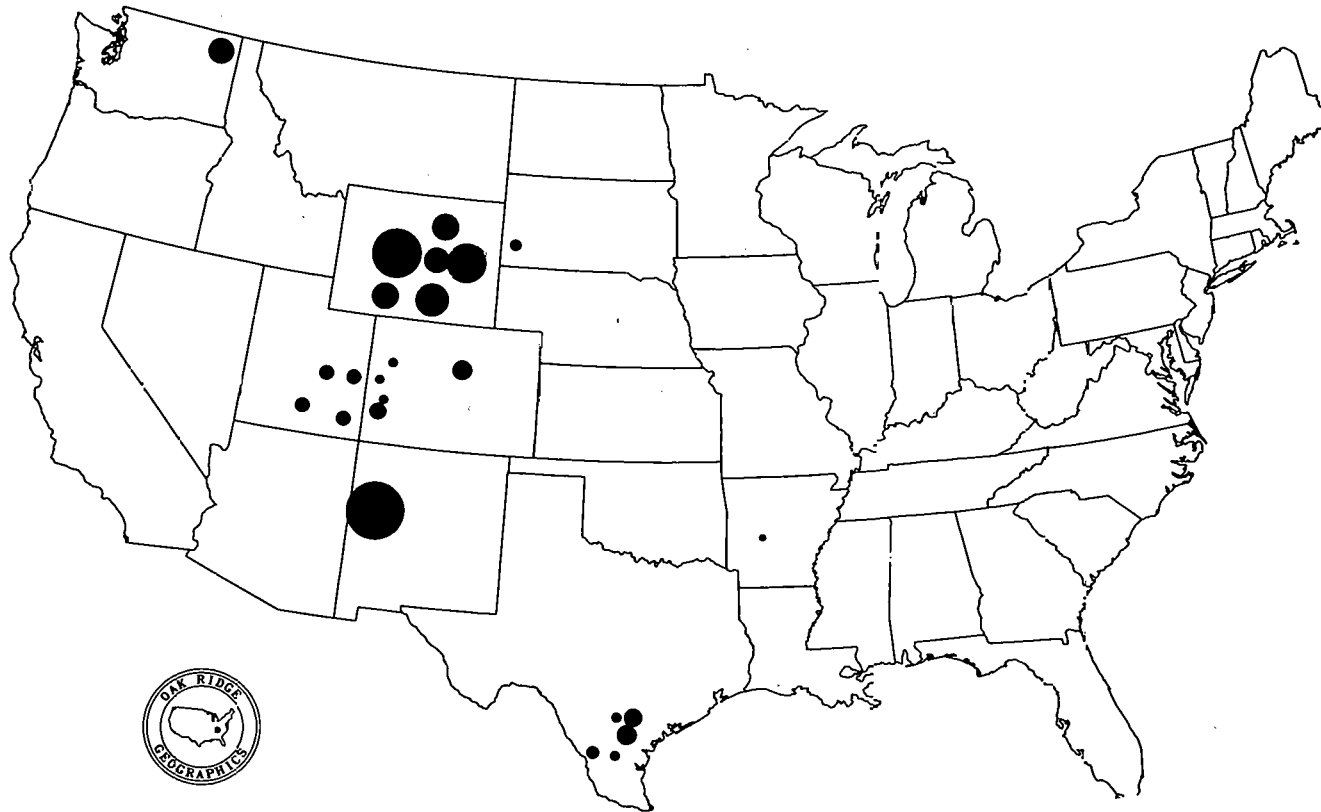
Fig. 2.3. SURFACE URANIUM MINES IN 1990
COUNTY SHARES OF NATIONAL PRODUCTION TOTAL

● 0.010 SHARE   ● 0.050 SHARE   ● 0.150 SHARE   ● 0.300 SHARE
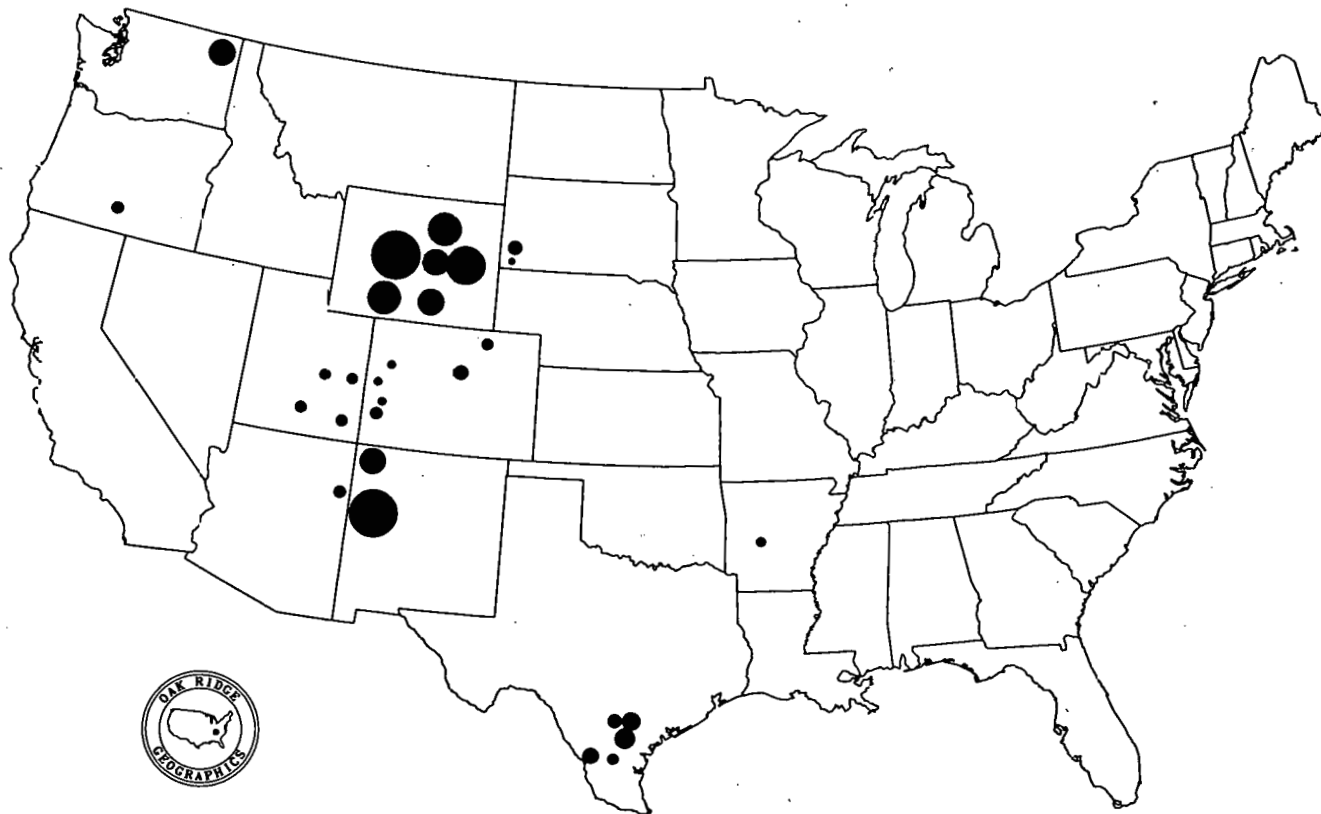
Fig. 2.4.   SURFACE URANIUM MINES IN 2C00
COUNTY SHARES OF NATIONAL PRODUCTION TOTAL

● 0.010 SHARE   ● 0.050 SHARE   ● 0.150 SHARE   ● 0.300 SHARE

Table 2.9. Underground uranium mining[a]

(County shares of national production total)

State	County	Year			
		1975	1985	1990	2000
N. Mex.	McKinley	0.493	0.467	0.370	0.370
	Velencia	0.211	0.200	0.123	0.102
	San Juan	0	0	0.123	0.152
Wyo.	Carbon	0.015	0.021	0.022	0.024
	Converse	0.021	0.032	0.032	0.040
	Fremont	0.019	0.032	0.032	0.048
	Natrona	0.019	0.021	0.022	0.024
	Johnson	0	0	0	0.016
	Sweetwater	0	0	0	0.008
Utah	Emery	0.037	0.030	0.035	0.025
	Grand	0.028	0.030	0.035	0.031
	San Juan	0.045	0.042	0.048	0.031
	Garfield	0.028	0.018	0.022	0.025
	Wayne	0	0	0	0.013
Colo.	Garfield	0.017	0.014	0.016	0.016
	Jefferson	0.017	0.019	0.016	0.016
	Mesa	0.017	0.015	0.016	0.016
	Montrose	0.017	0.014	0.016	0.016
	San Miguel	0.017	0.019	0.016	0.016
	Weld	0	0.015	0.027	0.026
Calif.	Kern	0	0.011	0.022	0.027
	Lassen	0	0	0.007	0.014
	Tuolumne	0	0	0	0.013
S. Dak.	Custer	0	0	0	0.008
	Fall River	0	0	0	0.004
	Harding	0	0	0	0.004
Ariz.	Apache	0	0	0	0.010
	Coconino	0	0	0	0.003
Oreg.	Lake	0	0	0	0.009
N. Dak.	Billings	0	0	0	0.003
	Slope	0	0	0	0.003
	Bowman	0	0	0	0.004

[a]Strategic Environmental Assessment System Sector 13.02.

Fig. 2.5. UNDERGROUND URANIUM MINES IN 1975
COUNTY SHARES OF NATIONAL PRODUCTION TOTAL

• 0.010 SHARE   ● 0.100 SHARE   ● 0.250 SHARE   ● 0.500 SHARE
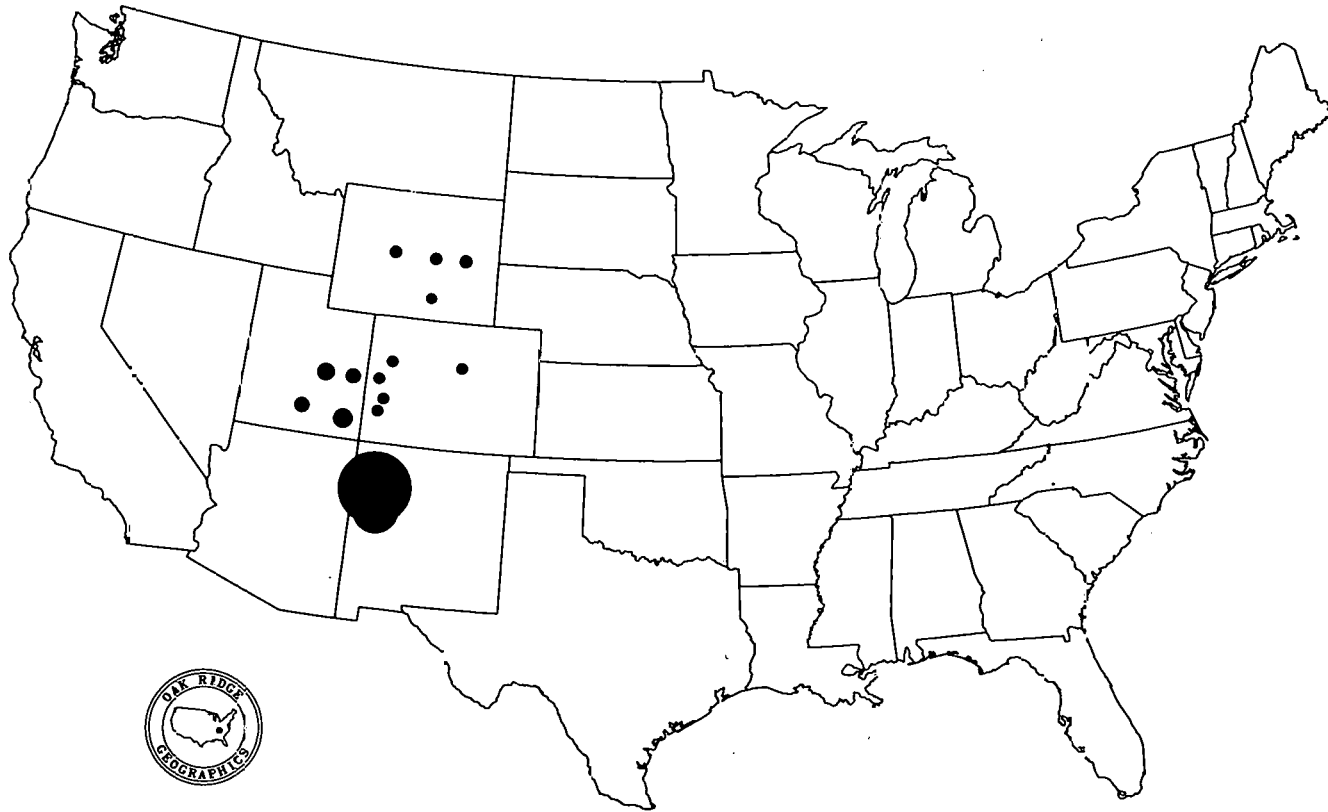
Fig. 2.6   UNDERGROUND URANIUM MINES IN 1985
COUNTY SHARES OF NATIONAL PRODUCTION TOTAL

• 0.010 SHARE   ● 0.100 SHARE   ● 0.250 SHARE   ● 0.500 SHARE
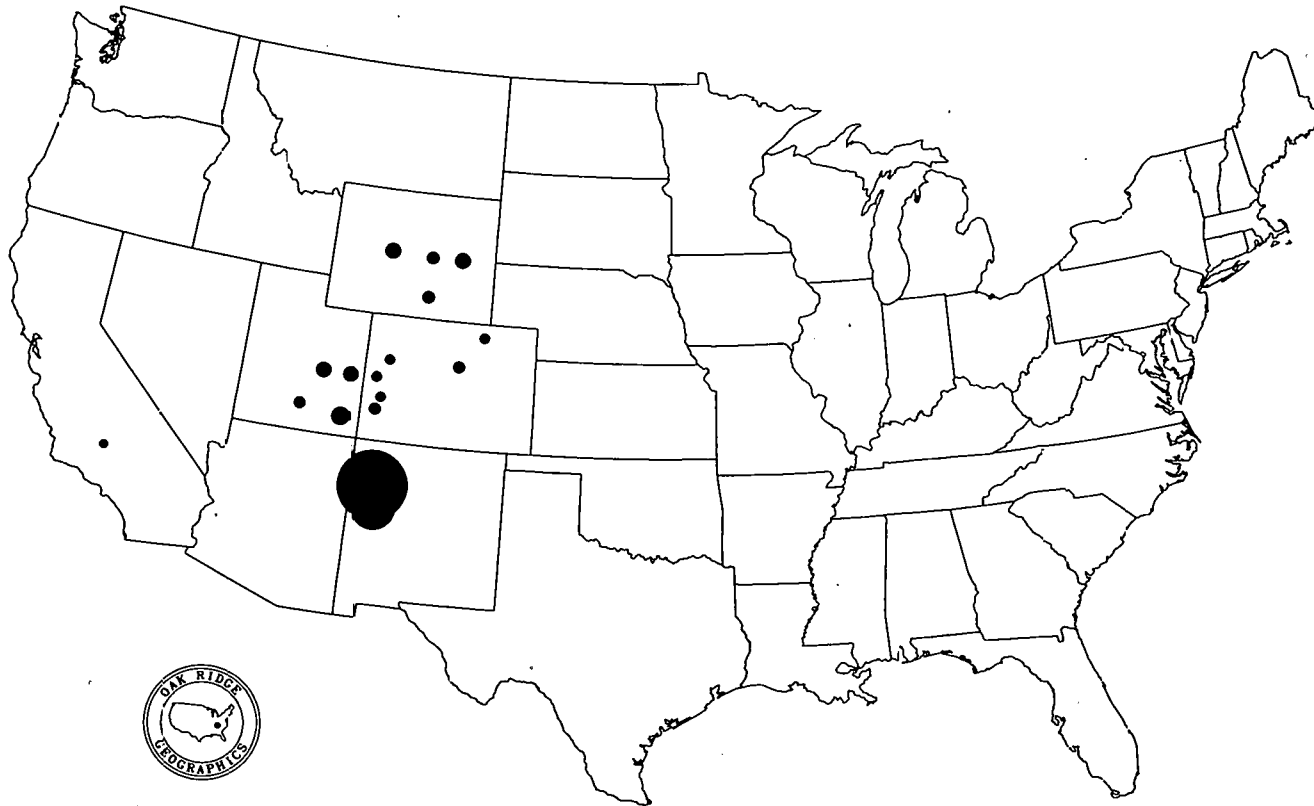
Fig. 2.7. UNDERGROUND URANIUM MINES IN 1990
COUNTY SHARES OF NATIONAL PRODUCTION TOTAL

• 0.010 SHARE   ● 0.100 SHARE   ⬤ 0.250 SHARE   ⬤ 0.500 SHARE
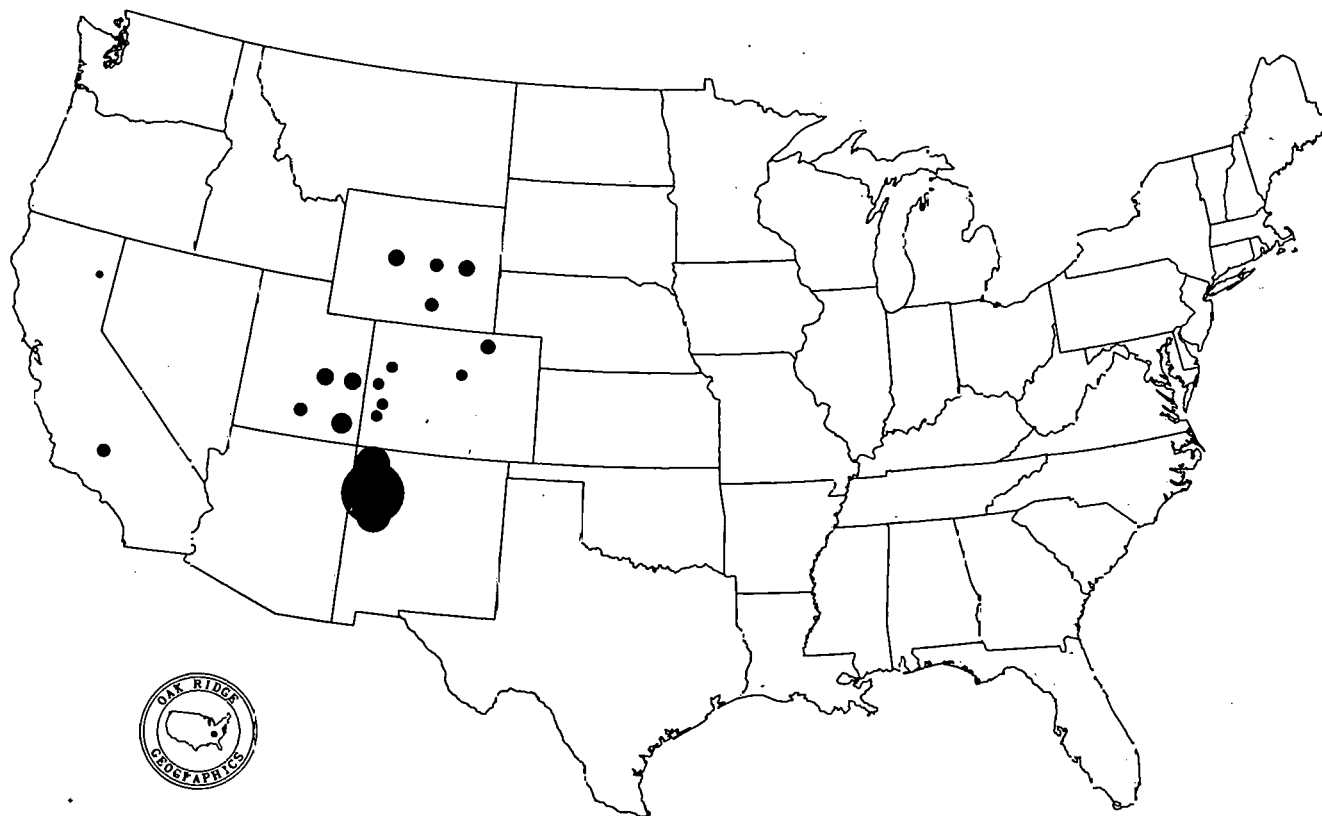
Fig. 2.8. **UNDERGROUND URANIUM MINES IN 2000**
COUNTY SHARES OF NATIONAL PRODUCTION TOTAL

● 0.010 SHARE   ● 0.100 SHARE   ● 0.250 SHARE   ● 0.500 SHARE
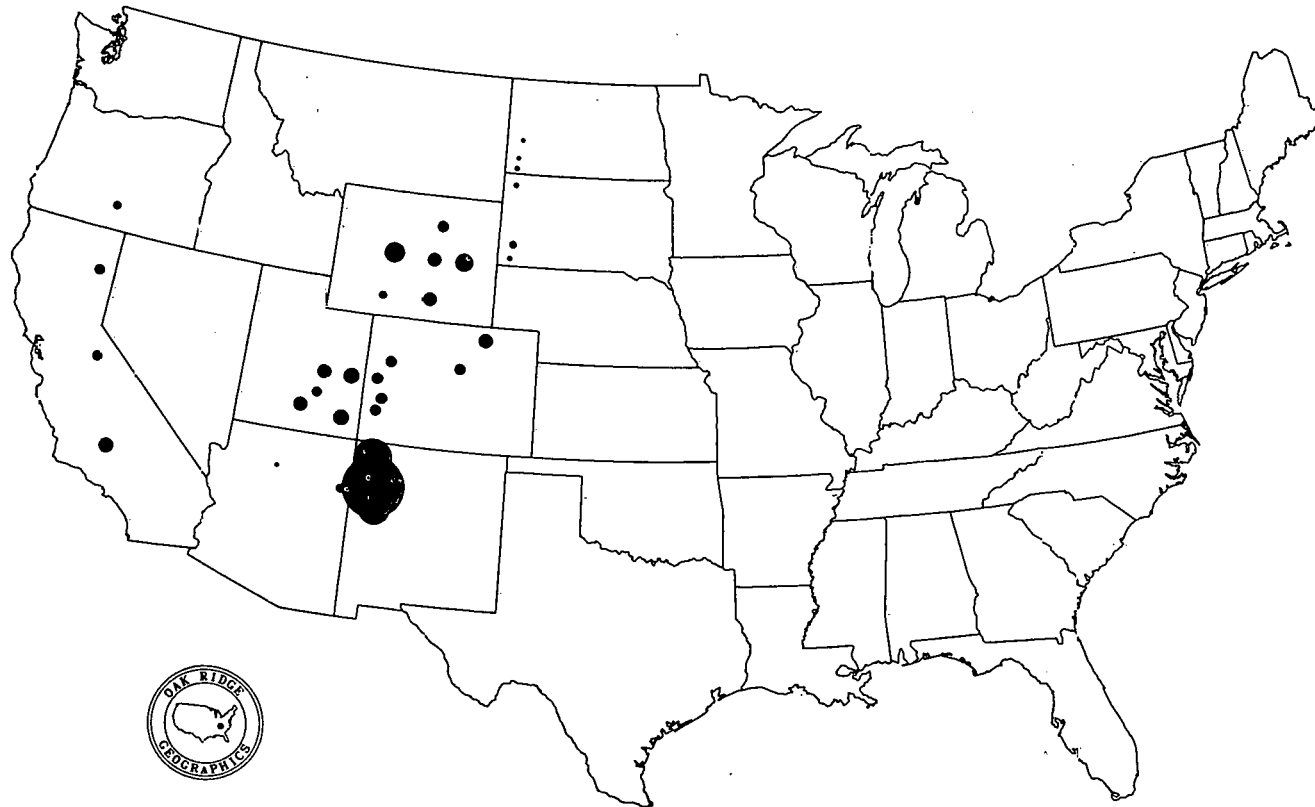
Table 2.10. Uranium milling[a]

(County shares of national production total)

State	County	Year			
		1975	1985	1990	2000
N. Mex.	Velencia	0.507	0.400	0.350	0.300
	McKinley	0	0.050	0.056	0.080
Wyo.	Converse	0.075	0.033	0.035	0.032
	Fremont	0.045	0.078	0.095	0.085
	Natrona	0.148	0.045	0.050	0.046
	Carbon	0	0.125	0.125	0.117
Utah	Grand	0.055	0.055	0.050	0.043
	San Juan	0.019	0.025	0.040	0.042
Colo.	Fremont	0.017	0.020	0.028	0.026
	Montrose	0.049	0.052	0.045	0.042
	Weld	0	0	0.010	0.010
Tex.	Karnes	0.066	0.066	0.040	0.047
	Live Oak	0	0	0.010	0.017
Wash.	Stevens	0.019	0.025	0.025	0.020
Ark.	Garland	0	0.004	0.004	0.005
Calif.	Kern	0	0.011	0.010	0.015
	Lassen	0	0	0.005	0.008
	Tuolumne	0	0	0	0.007
S. Dak.	Custer	0	0.011	0.010	0.016
	Harding	0	0	0	0.004
Ariz.	Apache	0	0	0.006	0.011
	Coconino	0	0	0	0.005
Oreg.	Lake	0	0	0.006	0.011
N. Dak.	Slope	0	0	0	0.011

[a]Strategic Environmental Assessment System Sector 13.03.

Fig. 2.9. URANIUM MILLS IN 1975
COUNTY SHARES OF NATIONAL PRODUCTION TOTAL

• 0.010 SHARE   ● 0.100 SHARE   ● 0.250 SHARE   ● 0.500 SHARE
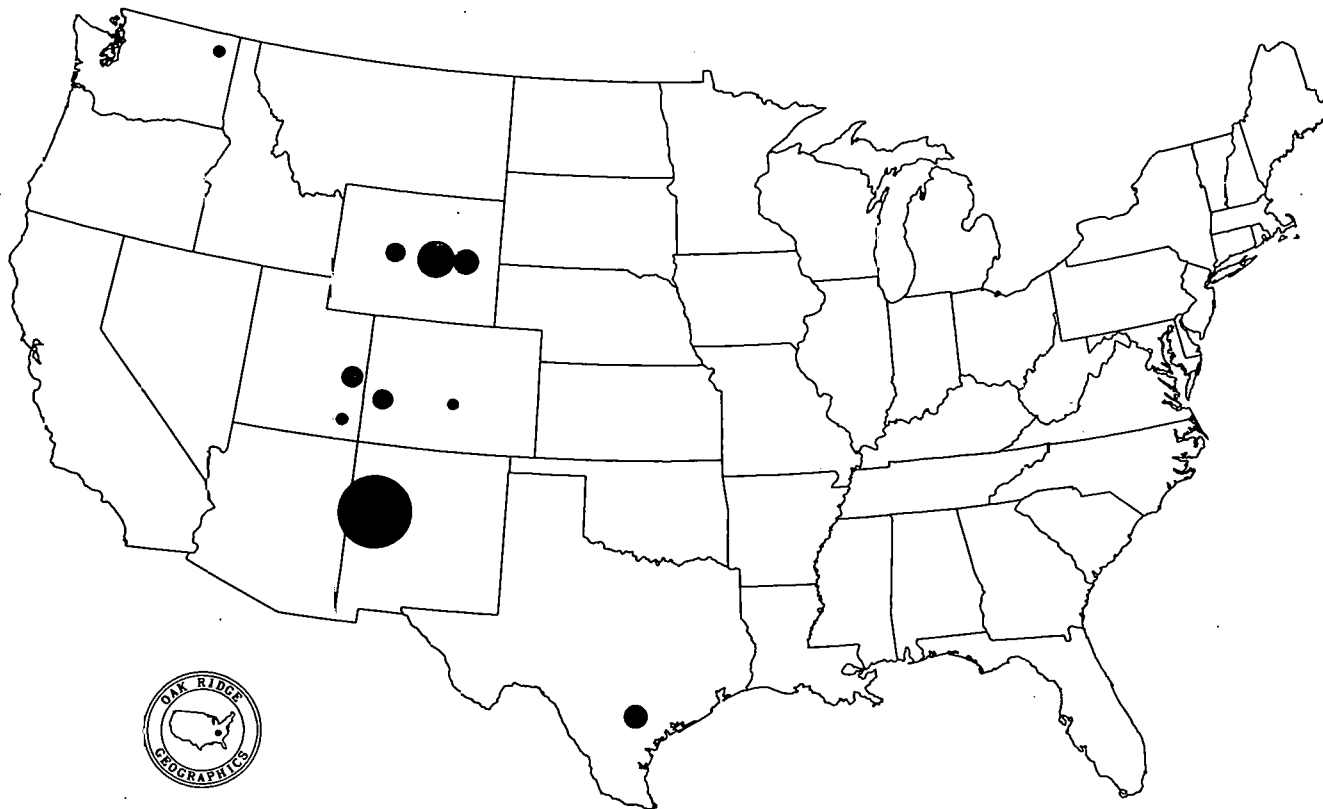
Fig. 2.10. **URANIUM MILLS IN 1985**
COUNTY SHARES OF NATIONAL PRODUCTION TOTAL

• 0.010 SHARE   ● 0.100 SHARE   ● 0.250 SHARE   ● 0.500 SHARE

Fig. 2.11. URANIUM MILLS IN 1990
COUNTY SHARES OF NATIONAL PRODUCTION TOTAL

• 0.010 SHARE   ● 0.100 SHARE   ● 0.250 SHARE   ● 0.500 SHARE
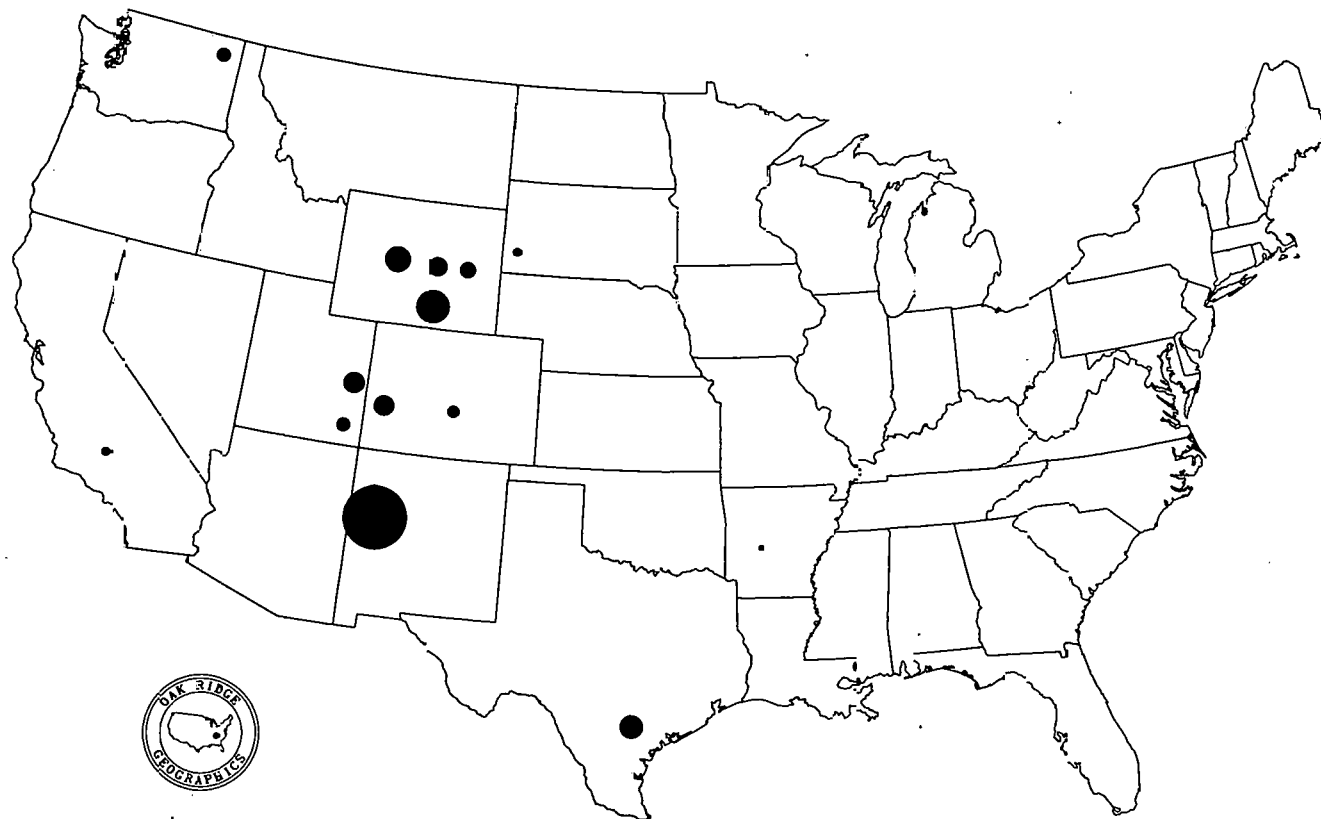
Fig. 2.12. URANIUM MILLS IN 2000
COUNTY SHARES OF NATIONAL PRODUCTION TOTAL

• 0.010 SHARE   ● 0.100 SHARE   ● 0.250 SHARE   ● 0.500 SHARE
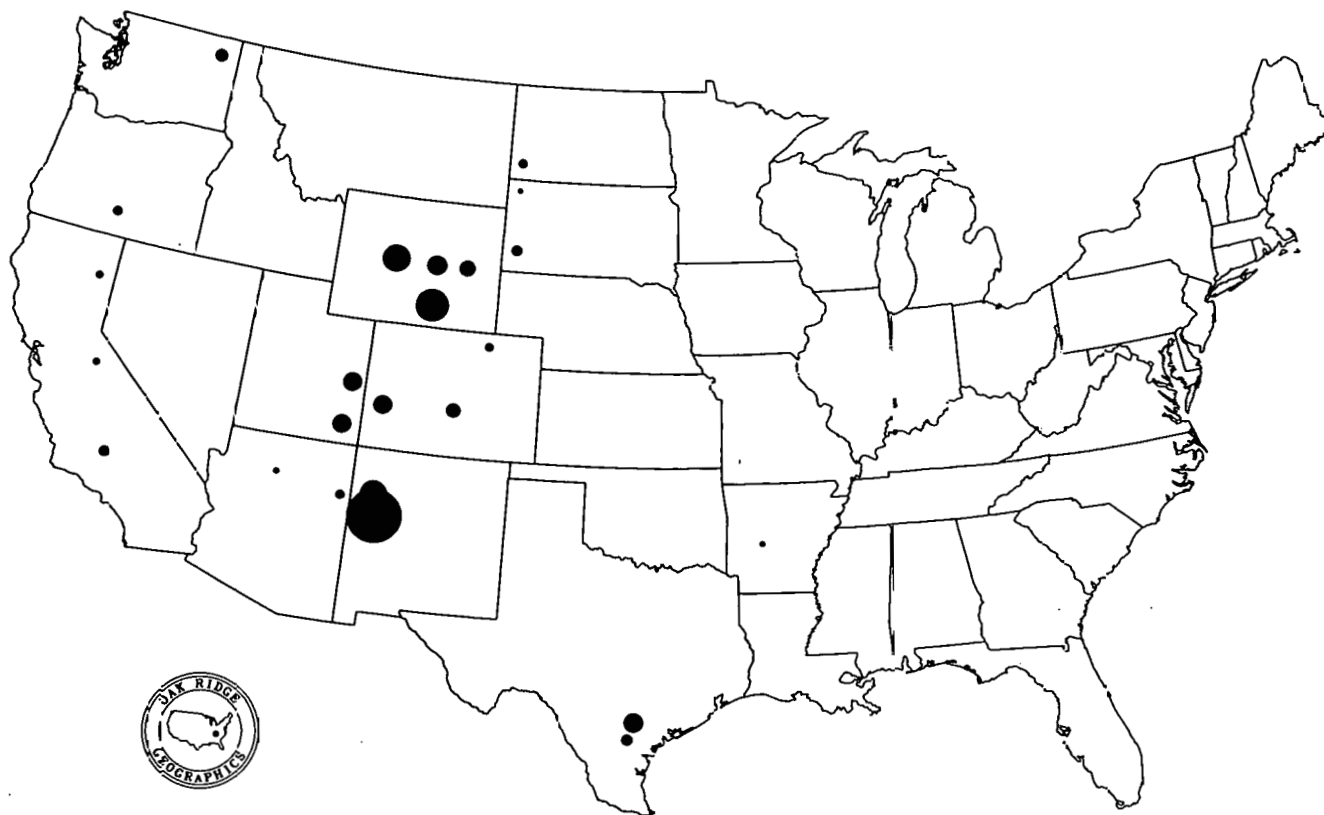
Miscellaneous forms of uranium extraction are not contained within the SEAS model. Those uranium sources not included relate to by-products from the processing of phosphates and euxenites. Current sites for these forms of uranium production center around Polk and Hillsborough counties in Florida and St. James parish in Louisiana.[3]

REFERENCES FOR SECTION 2

1. *Nucl. Fuel* 3:1 (August 21, 1978).

2. D. Medville, A. Lawrence, and S. Dosky, *Regionalization of Energy Technologies for the Strategic Environmental Assessment System*, Working Paper: U.S. Department of Energy, 1978.

3. U.S. Department of Energy, *Statistical Data of the Uranium Industry*, Grand Junction Office Report GJO-100(78), 1978.

3. MILLING PROCESSES

3.1 Characterization of Processes

The process of uranium extraction varies among mills partly due to differences in the chemical composition of ores. Steps basic to all mills are crushing, grinding, chemical leaching, and recovery of uranium from leaching solutions. Mill processes fall into three general types: acid leach-solvent extraction, acid leach-ion exchange, and alkaline leach. Although process details may vary in any one process, the acid leach-solvent extraction and the alkaline leach processes are considered here because they generate different wastes with regard to liquid volume, bulk chemicals, and radionuclide concentration. These processes are described for model mills having a daily capacity of 1814 MT of ore containing 0.2% U_3O_8.[1]

3.1.1 Acid leach-solvent extraction

The acid leach process utilizing an amine solvent extraction with an ammonium sulfate strip seems to be the trend of current mills because of domestic ore characteristics. About 80% of current annual production of U_3O_8 is by the acid leach process. In this process the ore is dumped from trucks and passed through a screen to a primary crushing circuit. Here the ore is crushed to 1.3 cm (1/2 in.) and screened, and the oversize material is recycled to the crusher. The fine ore is elevated to storage bins that are vented through a dust collector to a short stack on the roof. Air exhaust hoods are located on the crusher, at the screens, and at each transfer point.

The ore is then wet-ground (less than 28 mesh) in rod mills to a slurry containing 65% solids. Sulfuric acid and an oxidant (sodium chlorate) are added continuously. The solution containing the dissolved uranium is separated from the solids by countercurrent washing in a decantation circuit. The slurry is passed through hydroclones to separate the coarse sand fraction, and the sand is washed in a series of six classifiers. The overflow from the classifier joins the hydroclone over-flow, and the slimes are washed in a series of six thickeners. Flocculants

35

are added to promote settling. The solids are washed with fresh water and recycled raffinate from the solvent extraction circuit. The washed slimes and sands are pumped to a tailings pond. The sands are 70% by weight of the ore processed; the slimes are 30% by weight. The total weight of waste solution accompanying the sands and slimes to the tailings pond is 150% of the ore processed.

The uranium is recovered from the leach liquor by countercurrent contact in four extraction stages with a long-chain amine dissolved in kerosene. The uranium is stripped from the solvent in four stages with an aqueous solution of ammonium sulfate. The solvent is then recycled to the extraction circuit. The uranium is precipitated by addition of gaseous ammonia, concentrated, partially washed in thickeners, and collected on filters. The washed precipitate is dried in a continuous steam-heated dryer. The dried uranium precipitate, commonly called yellowcake, is packaged in 208-liter (55-gal) steel drums for shipment to a refinery. Overall recovery of uranium as product is about 90% of that contained in the ore. For the purpose of this assessment, the thorium content of the yellowcake is assumed to be 1.4×10^{-2} μCi/per g of U_3O_8 (5% of the total), and the radium content is assumed at 5.5×10^{-4} μCi/per g of U_3O_8 (0.2% of the total). No other significant radionuclide impurities are present. The air streams from the dryer and hoods over the packaging area are combined and passed through a dust collector. A small, liquid-bleed stream from the uranium precipitation circuit is sent to the leach circuit. Any liquid spillage or leakage throughout the mill is collected in floor sumps and returned to the appropriate circuit. The only liquid-waste stream is that leaving with the sands and slimes to the tailings area. The chemical consumption of the model uranium mill is given in Table 3.1.

3.1.2 Alkaline leach

The ore receiving, crushing, conveying, and fine-ore storage facilities are the same as those described for the acid leach mill. The wet-grinding system consists of a ball mill operated in closed circuit with a classifier.

Table 3.1. Annual chemical consumption for model uranium mill

	Acid leach–solvent extraction		Alkaline leach	
	(MT)	(ST)	(MT)	(ST)
Sulfuric acid	2400	2646		
Sodium chlorate	720	794		
Ammonia	560	617		
Flocculant	32	35	5	5.5
Amine (long chain)	8	9		
Alcohol	19	21		
Kerosene	240	265		
Iron (rods for grinding)	130	143	130	143
Sodium carbonate			690	761
Sodium hydroxide			6600	7277
Potassium permanganate			2000	2205
Filter aid			13	14

Source: M. B. Sears et al., *Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low As Practicable" Guides: Part III — Milling of Uranium Ores*, ORNL/TM-4903 (May 1975).

The grinding is done at 65% solids in a sodium carbonate–bicarbonate solution. The ore is ground finer than for acid leach (i.e., 35% less than 200 mesh). The uranium is leached with potassium permanganate from the ore in two stages consisting of a 5-hr leach at 65 psig and 93°C (200°F), followed by an 18-hr leach at atmospheric pressure and 85°C (185°F). The solids are separated and washed free of uranium by three stages of countercurrent filtration. The solids, which consist of a 50-50 mixture of sands and slimes, are mixed with fresh water and pumped to a tailings pond. The weight of waste solution sent to the pond is 105% of the ore processed.

The uranium is recovered from the leach solution by addition of sodium hydroxide, which forms insoluble sodium diuranate (yellowcake).

The precipitate is filtered, washed and dried in a steam-heated dryer. The product is packaged in 208-liter (55-gal) drums for shipment. Effluents from the dryer and packaging areas are passed through a dust collector before discharge to a roof stack. Overall recovery of uranium is 93% of that contained in the ore. The radium content of the yellow-cake is 5.5×10^{-3} μCi/per g of U_3O_8, representing about 1.8% of that in the ore. No other significant radionuclide impurities are present.

The consumption of chemicals for this process is given in Table 3.1.

3.1.3 Solution mining of uranium

Although it is technically a mining process, in situ leaching of uranium, with separation of uranium from the leach solution by a conventional ion exchange milling operation, is included here for comparative purposes.

Solution mining appears to result in an impact on the environment that is less than the conventional mineral extraction methods. Compared with the conventional uranium mining and milling operations, in situ leaching will also permit economical recovery of currently unrecoverable low-grade uranium deposits, thereby enhancing uranium reserves.

In conventional uranium recovery techniques, the ore is mined (open pit or underground) and processed as described previously. In solution mining, an acidic or basic oxidizing solution is injected into the naturally situated ore body via wells to extract the uranium. The chemicals associated with solution mining and milling are about the same in both cases. In solution mining, however, no ore mining, trans-porting, and grinding operations are needed before chemical processing to recover the uranium. Moreover, there are no mill tailings that require disposal, although wastes are generated that would require controlled disposal because there is a potential for groundwater contamination.

In conventional uranium mining, more than 95% [862 kg (1900 lb)] of solid waste (tailings) are produced for each short ton of mined ore, containing essentially all of the associated ^{226}Ra and other daughter products. With solution mining, less than 5% of the radium from an ore body would.be brought to the surface.

Basically, the in situ leaching method involves (1) injection of a leach solution into a uranium-bearing ore body to complex the contained uranium, (2) mobilization of the uranium complex formed, and (3) surface recovery of the solution bearing the uranium complex via production wells. Uranium is then separated from the leach solution by conventional milling unit operations (ion exchange).

This process can be used with roll-type uranium deposits that are generally associated with fluvial sandstones and conglomerates. The mineral in the ore is concentrated by a liquid oxidizing front moving down the hydrologic gradient in the reduced host zone (sands). Uranium is thereby precipitated along the interface of the oxidizing and reducing sides of the front. The physical shape of an ore roll is dependent on the local permeability of the matrix material and its continuity and distribution in the geologic unit. Such ore bodies are prevalent in most of the established uranium mining districts in the western United States. In situ leaching, however, can be conducted only on those ore deposits that meet certain criteria. These criteria generally include four conditions: (1) The ore deposit must be located in a saturated zone. (2) The ore deposit must be confined both above and below by impervious layers. (3) The deposit must have adequate permeability. (4) The deposit must be amenable to chemical leaching.

Estimated consumptive use of chemicals for a 20-ha (50-acre) well field producing 227 MT/year (250 ST/year) of U_3O_8 is given in Table 3.2. These data for the Wyoming Mineral Corporation's Irigaray Project[2] represent chemical feed requirements for a project of this size. Solvent chemicals vary depending on the chemical nature of the ore body in other situations.

3.2 Radioactive Wastes and Effluents

3.2.1 Uranium mills

Airborne effluents from active mills include ore dusts from crushing and grinding operations, yellowcake dust, tailings dust, and radon gas from both processing operations and tailings. The airborne releases from a model mill processing 1814 MT/day (2000 ST/day) of ore are given in Table 3.3.

Table 3.2. Estimated annual chemical feed rates for the
Irigaray uranium recovery process

Compound	Feed rate range[a]	
	(MT)	(ST)
Solvent chemicals for 800 gpm injection		
Carbon dioxide (CO_2)	300–900	331–992
Ammonia (NH_3)	160–480	176–529
Hydrogen peroxide (H_2O_2) — 50%	300–1000	331–1103
Elution and precipitation reagents for 4.5 gpm total eluant bleed		
Ammonium bicarbonate (NH_4HCO_3)	140–400	154–441
Ammonium chloride (NH_4Cl)	300–800	331–882
Hydrochloric acid (35% HCl)	100–280	110–309
Ammonia (NH_3)	20–82	22–90
Fuel		
Propane (C_3H_8)	82–240	90–265

[a]Feed rate for production of 227 MT/year (250 ST/year) of U_3O_8.

Source: U.S. Nuclear Regulatory Commission, *Draft Environmental Statement, Wyoming Mineral Corporation Irigaray Solution Mining Project*, NUREG-0399, April 1978.

The concentrations of radionuclides in tailings (liquid and solid wastes) for the model mill are given in Table 3.4. Methods for controlling releases of dust from tailings during mill operation include keeping the tailings piles wet or covering dry portions with chemical sprays or mine wastes.

Radioactive-waste treatment technology for operating mills consists of systems that (1) reduce the amounts of airborne radioactive dusts and radon released from the mill and tailings areas and (2) reduce the amount of radioactive liquid lost as seepage from tailings areas.

Table 3.3. Annual airborne radioactive materials released from the
acid leach–solvent extraction uranium mill

Source	Radionuclide (Ci)										
	^{234}U	^{235}U	^{238}U	^{234m}Pa	^{226}Ra	^{230}Th	^{234}Th	^{210}Pb	^{210}Po	^{210}Bi	^{222}Rn
Ore crusher and bins	1.5E-3[a]	6.9E-5	1.5E-3	1.5E-3	1.5E-3	1.5E-3	1.5E-3	1.5E-3	1.5E-3	1.5E-3	3.7E1
Yellowcake process	2.2E-2	1.0E-3	2.2E-2		4.3E-5	1.1E-3	1.1E-3				
Tailings pond and beach[b]											3.7E3
	2.4E-2	1.1E-3	2.4E-2	1.5E-3	1.5E-3	2.6E-3	2.6E-3	1.5E-3	1.5E-3	1.5E-3	3.7E3

[a]Read as 1.5×10^{-3}.

[b]Near the end of a 20-year life of a mill in the Southwest, tailings are either under pond water or covered with a chemical spray or mine waste to prevent blowing of dusts.

Source: M. B. Sears et al., *Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low as Practicable" Guides: Part III — Milling of Uranium Ores*, ORNL/TM-4903 (May 1975).

Table 3.4. Concentrations of radionuclides in tailings
from the model uranium mill

Radionuclide	Sand, >200 mesh (pCi/g)	Slime, <200 mesh (pCi/g)
Acid leach–solvent extraction		
U_{nat}	10	150
^{226}Ra	120	1610
^{230}Th	60	1750
^{234}Th	10	150
^{210}Pb	120	1610
^{210}Po	120	1610
^{210}Bi	120	1610
Alkaline leach		
U_{nat}	10	70
^{226}Ra	170	950
^{230}Th	170	960
^{234}Th	10	70
^{210}Pb	170	960
^{210}Po	170	960
^{210}Bi	170	960

Source: M. B. Sears et al., *Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low As Practicable" Guides: Part III — Milling of Uranium Ores*, ORNL/TM-4903 (May 1975).

Effective effluent control of process dusts is dependent upon the moisture content of ore, as well as the type of dust collector used. Tables 3.5 and 3.6 show the annual dust release and cost of radioactive-dust emission treatments for ore and yellowcake, respectively, in the model mill.

Costs of treatments to reduce seepage of radioactive liquids from tailings areas during mill operation are given in Table 3.7. Careful siting of tailings areas with respect to the groundwater table and surface

Table 3.5. Ore dust release rates (annual) and costs of treatments to reduce
cre dust emissions from a model uranium mill[a]

Treatment — type of dust collector	Ore dust release rate, ^{238}U[b] (Ci)		Treatment cost (10^3)	
	Moisture in ore — 6%	Moisture in ore — 9–10%	Capital	Annual
Orifice or baffle scrubber	4.5E-3[c]	5.1E-5	91	31
Wet impingement scrubber	1.5E-3	1.7E-5	109	37
Low-energy venturi scrubber	3.5E-4	4.4E-6	164	61
Reverse-jet bag filter	7.1E-5	8.8E-7	320[d]	107[d]
Bag filter plus HEPA filter	3.5E-8	4.3E-10	646[d]	214[d]

[a]Model mill is a 1814-MT/day (2000-ST/day) uranium mill (acid leach process) in the southwestern United States operating at 80% of capacity.

[b]In secular equilibrium with 13 radioactive daughters.

[c]Read as 4.5×10^{-3}.

[d]Includes capital and annual costs for wind breaks around ore unloading yard.

Source: M. B. Sears et al., *Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low As Practicable" Guides: Part III — Milling of Uranium Ores*, ORNL/TM-4903 (May 1975).

Table 3.6. Ore dust release rates (annual) and costs of treatments to reduce yellowcake dust emissions from a model uranium mill[a]

Treatment	Ore dust release rate, ^{238}U (Ci)	Treatment cost (10^3)	
		Capital	Annual
Wet impingement scrubber	8.5E-2[b]	36	12
Venturi scrubber			
Low energy	2.2E-2	50	19
Medium energy	8.4E-3	53	23
High energy	4.4E-3	58	29
High-energy venturi scrubber			
and HEPA filter	2.2E-6	132	51

[a]Model mill is a 1814-MT/day (2000-ST/day) uranium mill (acid leach process) in the southwestern United States operating at 80% of capacity.

[b]Read as 8.5×10^{-2}.

Source: M. B. Sears et al., *Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low as Practicable" Guides: Part III — Milling of Uranium Ores,* ORNL/TM-4903 (May 1975).

44

Table 3.7. Costs of treatments to reduce seepage of radioactive materials
from tailings area of an operating model uranium mill[a]

Tailings control procedure	Radionuclides in liquid lost by seepage[b] (%)	Treatment cost (10^3)	
		Capital	Annual
Evaporation pond [32 ha (80 acres)] and dry beach [15 ha (36 acres)]; earth dam	10	236	92
Carefully sited pond [35 ha (87 acres)] and dry beach [12 ha (29 acres)]; earth dam with a clay core	2	2568	651
Asphalt-lined pond [36 ha (89 acres)] and dry beach [11 ha (27 acres)]; earth dam with a clay core; lime neutralization of acid effluents	0.1	4817	1510
No conventional tailings impoundment; liquids recycled to mill, evaporated, and solids sent to a landfill	0	5015	2405

[a]Near the end of mill lifetime when tailings area is largest; mill is a 1814-MT/day (2000-ST/day) uranium mill (acid leach process) in the southwestern United States operating at 80% of capacity.

[b]This loss does not necessarily reach surface water and lead to radiation exposure to man.

stream can minimize the radiological hazard of tailings during mill operation and after decommissioning.

The tailings area associated with typical milling practices is about 0.1 m^2 (1.1 ft^2) per MT of tailings.[3] This corresponds to about 7.7 m^2 (82.9 ft^2) and 0.31 Ci of alpha activity in tailings in order to support electric power production of one megawatt electric (MW$_e$) per year with no fuel recycle. With reprocessing and plutonium recycle, the corresponding values are 4.3 m^2 (46.3 ft^2) and 0.17 Ci of alpha activity per MW$_e$ per year. For lower-grade ores, the waste volume would increase proportionately to the decease in ore grade.[3]

The actual choice of radioactive-waste treatments for a given mill is determined by site-specific criteria. In general, current mills use some combination of the first one or two treatments given in Tables 3.5 and 3.6. The use of more advanced treatments is expensive and, since human populations are relatively sparse within 80.5 km (50 miles) of most mills, the expense is usually considered excessive in "as low as reasonably achievable" determinations for effluent control.

The capital costs of a mill producing 1814 MT/day (2000 ST/day) of ore is estimated to be $13 million. For current radioactive-waste treatment practices, a capital cost of $357,000 and an annual operating cost of $180,000 are estimated. This is equivalent to $0.07 per lb of U$_3O_8$ and 0.003 mills per kilowatt-hour (kWhr) of nuclear-generated electricity.[1]

3.2.2 Solution mining

Liquid and solid waste and atmospheric effluents will result from solution mining activities. Liquid wastes from well-field overpumping (i.e., production flow in excess of injection flow), elution and precipitation circuit bleeds, and subsequent aquifer restoration represent the major waste streams to be managed from solution mining activities. Since the dissolved-solids content of the wastewater precludes any uncontrolled releases, some form of waste management is necessary. Generally, evaporation ponds are utilized for liquid-waste management; however, deep well disposal has been used in Texas. The ponds vary in size

depending on the flow rate of liquid-waste streams to the pond and the rate(s) of water evaporation and seepage from the pond. To minimize unwanted seepage of the wastewater, the ponds are lined during construction with clay, asphalt, or continuous plastic membranes. The specific method used is dependent on the conditions at each solution mining operation.

Solar evaporation is a consumptive use of water. This is of particular concern in the arid southwestern United States. When recycle of wastewater is desirable, water reclamation by reverse osmosis, ion exchange, chemical treatment, or multieffect distillation may be used.

Solid wastes generated, for example, from calcium-control units in the solvent-sorption circuits and from the contaminant-control unit in the elution and precipitation circuit also require controlled management. During the life of a solution mining operation, solids may be impounded in specific storage ponds as a slurry and may be maintained and monitored under a liquid seal to minimize particulate emissions and radon gas evolution. Permanent disposal techniques, in accord with the Nuclear Regulatory Commission (NRC) and/or responsible State agency regulations under development will be designed to isolate the solids from the environment.

Radioactive emissions occur from uranium recovery process facilities and from waste storage ponds and tanks. For the Irigaray Project,[2] for example, it is estimated that annual atmospheric releases will amount to 450 kg (992 lb) of U_3O_8 (0.15 Ci of ^{238}U with daughters and 76.0 Ci of ^{222}Rn). Solid wastes will be generated from three principal sources in the recovery process: (1) the calcium removal unit, (2) supplemental contaminant control incorporated in the elution and precipitation circuit of the recovery process, and (3) liquid-waste concentration by evaporation during impoundment. Additional solid wastes will be produced in conjunction with the water treatment methods utilized to accomplish aquifer restoration. The latter would generally be similar to the solid wastes produced in the uranium recovery process. This solid waste, primarily

calcite, is generated at the rate of 2 kg (4.4 lb) of waste per kg of U_3O_8 recovered and can contain ^{226}Ra in concentrations from 5×10^{-4} to 1.2×10^{-3} µCi/g. For an operation such as that proposed in the Irigaray Project, about 450 MT/year (496 ST/year) of solid waste (mostly calcite) containing 0.5 Ci of ^{226}Ra is produced.

3.3 Nonradioactive Wastes and Effluents

3.3.1 Uranium mills

The annual releases of chemical and thermal effluents from the model uranium mill are given in Table 3.8. The gaseous chemical effluents come from milling processes in which combustion products, acid fumes, and vaporized organic reagents are released from mill buildings. The most significant chemical effluent is the slurry, which contains waste solutions and solid mill tailings. The liquid portion (Table 3.9) contains spent chemicals from the leaching process and trace quantities of soluble metals and organic solvents. Trace metals may include toxic elements such as arsenic, selenium, vanadium, and molybdenum. The composition of these trace metals in the effluent is dependent on the ore body and the mill process. Ecological impacts from these trace metals have yet to be fully defined. The thermal effluent released to the atmosphere is waste heat from the burning of natural gas used to dry the mill product.

3.3.2 Solution mining

Depending upon the chemical processes used, various nonradioactive materials are released to the atmosphere from solution mining operations. Table 3.10 gives estimates of annual releases from the Irigaray Project,[2] and these data serve to indicate the magnitude of releases associated with a solution mining facility.

Table 3.8. Nonradioactive effluents from the model uranium mill

Effluent	Annual release
Gases, MT (ST)	
SO_x	200 (220.5)
NO_x	87 (96)
Hydrocarbons	5 (5.5)
CO	1.7 (1.9)
Liquids, 10^3 MT (10^3 ST)	
Tailings solutions	1300 (1433)
Solid tailings, 10^3 MT (10^3 ST)	500 (551)
Thermal, 10^9 Btu	390

Source: Directorate of Licensing, U.S. Atomic Energy Commission, *Environmental Survey of the Uranium Fuel Cycle*, WASH-1248, April 1974.

3.4 Stabilization of Tailings

The tailings area can be a long-term source of release of radionuclides to the environment via erosion by wind or water and emanation of radon gas. The releases of particulate (windblown), liquid (seepage) or gaseous (diffusion) forms of radionuclides in tailings can be reduced by various means of stabilization or treatment of tailings. During mill operation, releases of particulates can be controlled by keeping the tailings wet and using chemical sprays or earth covers over dry portions of tailings areas. Seepage can be controlled by proper siting of tailings with respect to elevation and surface waters, properly constructed dams, and use of liners in the tailings pond. These methods of reducing transport of radioactivity via seepage or windblown dust do not, however, greatly reduce emissions of radon during mill operation.

Some stabilization of uranium mill tailings is required by current NRC policy and by Arizona, Colorado, Oregon, Texas, and Washington. There are many techniques for stabilization of tailings, and the effectiveness of the treatment is directly correlated with cost (i.e., the methods that most reduce radioactive emissions and that ensure the greatest tailings stability are the most expensive). Regulatory criteria

Table 3.9.   Composition of liquid waste from the model uranium mill

	Concentration (g/liter)	
	Acid leach–solvent extraction[a]	Alkaline leach[b]
Calcium	5.0E-1[c]	
Iron	1.0E0	5.0E-4
Aluminum	2.0E0	1.0E0
Ammonia	5.0E-1	
Sodium	2.0E-1	3.0E0
Arsenic	2.0E-4	2.0E-4
Fluoride	5.0E-3	2.0E-3
Vanadium	1.0E-4	1.0E-4
Sulfate	3.0E+1	2.0E0
Chloride	3.0E-1	1.0E0
Carbonate		6.0E0
Total dissolved solids	3.5E+1	1.2E+1

[a]Acid leach–solvent extraction pH = 2.0.

[b]Alkaline leach pH = 10.

[c]Read as 5.0×10^{-1}.

Source: M. B. Sears et al., *Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low As Practicable" Guides: Part III — Milling of Uranium Ores*, ORNL/TM-4903 (May 1975).

specifying the length of time tailings must remain stabilized and the manner and degree of surveillance required to ensure stability are currently being developed.

Some relatively simple landscaping techniques are available to reduce wind and water erosion of tailings. After mill operatons have ceased and the pond has evaporated or has been drained, the pile can be graded to provide a gradual slope and eliminate depressions where water might collect. Side slopes can be stabilized with riprap, dikes, and grade reduction. Drainage ditches can be provided around the pile edges to prevent surface runoff from neighboring land from reaching the

Table 3.10. Nonradioactive emissions to the atmosphere from a solution mining facility

Source	Annual emission ranges [MT (ST)]			
	NH_3	CO_2	NH_4Cl	H_2O
Recovery processes	2.7–4.1 (3.0–4.5)	680–1400 (750–1545)	14–25 (15.4–27.6)	
Calcium control unit	0.9–1.8 (1.0–2.0)	2.7–4.1 (3.0–4.5)	<0.5 (<0.55)	180–210 (198–232)
Calcite storage pond	1.1–1.6 (1.2–1.8)	4.1–4.5 (4.1–5.0)	0.2–4.8 (0.22–5.3)	3600 (3969)
Liquid waste ponds	4.1–5.0 (4.5–5.5)	3.2–3.6 (3.5–4.0)	12–14 (13.2–15.4)	4200 (4631)

51

tailings. The tailings then can be covered with 15 cm (6 in.) or more of earth topped by 15 cm of either coarse rock or vegetation. Rock can be used in some areas where the natural precipitation [15 to 20 cm/year (6 to 8 in./year)] will not support a vegetation cover. Experience in reclaiming two tailings piles in the semiarid western United States indicates that the 36-cm (14-in.) annual precipitation is sufficient to maintain vegetation without irrigation. Some maintenance will probably be required, such as repair of storm or animal damage, cleaning out diversion ditches, replacing fences, and occasional reseeding. Access can be restricted by appropriate fences and signs. Inspection at regular intervals and following floods, avalanches, earthquakes, or other natural events of significance, is necessary to ensure that the integrity of the cover is maintained.

3.4.1 Covering tailings

After mill closure and when tailings dry, radon gas, which emanates at a rate of 5×10^{-10} Ci m^{-2}s^{-1} from typical tailings, is a major radiological concern. About 90% of the ^{222}Rn emitted originates in the top 2 m (6.6 ft) of a pile.[4] Radon-222 gas will emanate from the tailings pile unless both the ^{226}Ra parent (half-life of 1620 years) and thorium grandparent (half-life of 83,000 years) are removed or a radon diffusion barrier is placed over the pile to retard the rate of diffusion. While reduction of airborne particulates is related to site-specific factors such as local meteorological conditions and distributions of local populations, the reduction of ^{222}Rn emissions is of concern because population radiation doses (and presumably health effects) occur over the entire country.

Thick earth covers of 2.4 to 6.1 m (8 to 20 ft) will reduce the radon emanation by 80 to 98% and will also stabilize the pile from surface water and wind erosion. The earth covers can be topped by either coarse rock or vegetation. In source-term calculations to determine the amounts of ^{222}Rn released, it can be assumed that the earth cover has attenuation properties for retarding the release of ^{222}Rn similar to

coarse building sand containing 4% moisture.[1] In areas where the soils
are likely to contain more moisture, the radon attenuation factor may be
higher. The radon attenuation factor is a logarithmic function such that
the thinner earth covers !15 to 61 cm (6 in. to 2 ft)1, which eliminate the
release of windblown dusts, have little effect on the radon emanation rate.

Asphalt is an excellent radon diffusion barrier.[5] An 8.4-mm (1/3-in.)-
thick asphalt membrane topped by a 61-cm (2-ft) earth cover is equivalent
to 6.1 m (20 ft) of earth containing 4% moisture; an 8-mm (5/16-in.)-thick
membrane is equivalent to 4.9 m (16 ft) of earth. A 6.4-mm (1/4-in.)
membrane has been satisfactory for lining a leach dump.[6] The 4 mm (1/4-in.)
membrane appears to be about the minimum thickness that materially reduces
the radon emanation,[7] and it also appears to be about the minimum that can
be applied. Thicker membranes provide increased durability and increased
radon attenuation. An earth cover would protect the asphalt from
weathering, especially from freezing and thawing. The earth cover could
be topped by coarse rock or vegetation. Periodic inspection, including
air sampling for radon or radon daughters and occasional patching of
cracks, would be necessary.

3.4.2 Burial of tailings

Unlike other phases of the nuclear fuel cycle in which solid radio-
active wastes are packaged and shipped off site to an approved repository,
the uranium milling industry is concerned with permanent, onsite, solid-
waste disposal. Solid radioactive waste could be buried in landfills or
mine excavations. However, burial could result in contamination of ground-
water through leaching by natural waters of radioisotopes, trace metals,
and process chemicals. The surface could be contoured to minimize wind and
water erosion and topped by vegetation or coarse rock. This returns
the surface land to limited use, such as grazing. Burial would minimize
the long-term maintenance and inspection that are necessary to ensure
the integrity of the pile and to reduce the likelihood that an individual

would inadvertently dig into a pile. The location of the pile and restrictions on excavation and construction projects could be noted on the deed. Sixty-one centimeters (2 ft) of earth could be removed from the tailings basin before milling operations are started in order to provide a readily accessible supply of earth for part of the cover. Topsoil is saved separately. The remaining cover must be hauled from mine waste dumps or other sources.

The possibility of returning wastes to the mine could also be considered. Where mills are located near the open pit mines, it may be possible in later years to return some tailings to the mine. After ore has been mined from the first pit, the pit could be partially backfilled well above the water table and then sealed with the asphalt membrane to retard liquid seepage. Underground mines are generally wet and, therefore, are not usually suitable for burial of untreated wastes because of the leaching problem.

3.4.3 Alternative disposal technologies

3.4.3.1 Asphalt fixation.[1] Incorporation of a variety of industrial wastes in asphalt has been demonstrated in pilot-plant studies and applied in small plants.[8] Asphalt provides an impervious coating on the solid particles so that water penetration is low; consequently, leach rates of water-soluble salts are low. Leaching of slightly soluble salts such as radium sulfate would be extremely low. The asphalt coating is also an effective barrier to the diffusion of radon, thereby reducing its release to the environment. As applied to the wastes from uranium mill, only the slimes fraction and solution wastes would be incorporated in asphalt. The sand fraction accounts for 50 to 70% of the solid waste but contains only about 15% of the radioactive materials.

Waste solutions and slime underflow from the mill thickeners are neutralized with slaked lime, and the solids are dewatered in a thickener followed by a continuous filter. The filter cake is mixed with asphalt in a continuous wiped-film evaporator operated at 160°C (320°F) to yield

a water-free product. It is important to minimize the moisture content
of the filter cake in order to avoid a large evaporation load on the
evaporator. Agitator paddles wipe the heated walls of the evaporator
at ∿200 rpm and provide effective mixing and satisfactory heat transfer.
The product, which can contain up to 60% slime solids, is fluid at the
operating temperature and can be pumped to the final disposal site.

3.4.3.2 Cement fixation. Incorporation in cement could be applied
to milling wastes. The cemented wastes could be pumped as a grout below
ground into mined-out areas onsite. Mill tailings stabilized with
Portland cement to make a "weak" concrete have been used as backfill
in Canadian mines to support the mine roof and walls. Prior experience
with cemented backfill in mines has been confined to nonradioactive
tailings and mostly the sand fraction, although one nickel mine has
successfully incorporated 50% minus 325 mesh slimes in cement and used
the cemented product as backfill in mines. Application of the cemented-
backfill technique to uranium mill tailings could serve the dual functions
of mine support and tailings disposal.

In this method the waste slurry is dewatered to obtain at least 60%
solids before being mixed with Portland cement. The ratio of cement to
waste solid affects strength, leach rate of radioactive materials, and
cost. Preliminary laboratory tests have shown that the ratio must be
at least one part cement to twenty parts tailings to obtain a minimum
strength. Resistance to leaching is also minimum. A 1-to-5 ratio yields
better strength and leach resistance at higher cost. Cement products
made with only slimes have less strength and less permeability than those
made with both sand and slimes. Leaching data are not available for
cemented products made from slimes. However, data are available relative
to the leaching of ^{90}Sr from cement products containing Oak Ridge National
Laboratory low-level waste.[9] Additional study is needed to evaluate the
use of cement for fixation of uranium mill wastes.

3.4.3.3 <u>Nitric acid mill</u>.[1] Nitric acid treatment differs from the other cases in that it is not a treatment of a mill effluent but a replacement for the entire sulfuric acid leach–solvent extraction process used in the mills for the recovery of uranium. The purpose is to leach most of the radionuclides from the ore so that the bulk of the solid residue is less hazardous and, consequently, requires less treatment. A concentrated, liquid radioactive waste that can be converted to a form suitable for permanent storage is generated from the leach solution. Pilot studies of the process have not been made. Consequently, the efficiency and cost for the process are subject to more uncertainty than are other options. Leaching of radium from sulfuric acid–leached tailings with acid and salt solutions has been studied but appears to be less attractive than the direct nitric leach of the ore, which removes uranium, radium, and other radionuclides together in one step.

In this process, ground ore is leached with 3 M nitric acid at 85°C (185°F) in a series of agitated tanks. Countercurrent washing is accomplished in ten thickeners. The washing is done very thoroughly so that the losses of soluble radionuclides and nitrate with the discarded sands and slime tails are only 0.02% of that present in the leach solution. The leached and washed sand and slime tailings are deposited where they are unobtrusive and are covered with 61 cm (2 ft) of earth topped by vegetation or coarse rock. The uranium-bearing solution is concentrated by evaporation, and the uranium is extracted with tributyl phosphate in a kerosene diluent. The vapor from the evaporator is fractionated into water and 13 M HNO_3, which are recycled to the wash and leach circuits. Uranium is stripped from the organic phase with water and, after evaporation, is shipped as a concentrated aqueous nitrate solution. The waste raffinate is treated in a continuous calciner to convert the metal nitrates (largely calcium, iron, aluminum, and radioactive elements) to oxides and to recover the oxides of nitrogen for recycle as nitric acid. Calcined solids are fixed in asphalt before burial by the method previously described. Most of the equipment is constructed of stainless steel to handle nitric acid.

The expense of tailings fixation in asphalt or cement and, perhaps, the added costs of a nitric acid mill may be great, but these options offer solutions to the problem of long-term control of ^{222}Rn emissions, and they should be weighed against other disposal alternatives.

REFERENCES FOR SECTION 3

1. M. B. Sears et al., *Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low As Practicable" Guides: Part III — Milling of Uranium Ores*, ORNL/TM-4903 (May 1975).

2. U.S. Nuclear Regulatory Commission, *Draft Environmental Statement, Wyoming Mineral Corporation Irigaray Solution Mining Project*, NUREG-0399, April 1978.

3. Comision Nacional de Energia Atomica-Argentina, *Radiological Source Terms in the Management of Uranium Mill Wastes*, COC-WG7/17 (May 1978).

4. U.S. Environmental Protection Agency, *Environmental Analysis of the Uranium Fuel Cycle: Part I — Fuel Supply*, EPA-520/9-73-003-B, Office of Radiation Programs, Washington, D.C., October 1973.

5. H. W. Godbee and D. S. Joy, *Assessment of the Loss of Radioactive Isotopes From Radioactive Waste Solids in the Environment: Part I — Background and Theory*, ORNL/TM-4333 (February 1974).

6. G. W. Parker, "Leach Dump Operations in Butte, Montana," presented at the Pacific Northwest Minerals and Metals Region Conference, North Pacific Section AIME, April 1966.

7. R. Havens and K. C. Dean, *Chemical Stabilization of the Uranium Tailings at Tuba City, Arizona*, Report 7288, U.S. Bureau of Mines, August 1969.

8. R. E. Blanco, H. W. Godbee, and E. J. Frederick, "Incorporating Industrial Wastes in Insoluble Media," *Chem. Eng. Prog.* 66: 51-56 (1970).

9. W. De Laguna et al., *Engineering Development of Hydraulic Fracturing as a Method for Permanent Disposal of Radioactive Wastes*, ORNL-4259 (August 1968).

4. OCCUPATIONAL HEALTH

This section addresses the question of occupational safety from the standpoint of fatalities and disabling and nondisabling injuries. An attempt is made to put the data on injuries and fatalities into perspective by comparing information on uranium mining and milling with information from other metallic-mineral industries. The question of occupational health is addressed from the standpoint of the risk associated with ambient levels of radon and radon daughters in underground uranium mines. Risks associated with other radiological hazards are also discussed. Information on the numbers of occupational injuries and fatalities associated with the mining and milling of uranium have been presented in a number of publications.[1-5] Data presented in this section (Tables 4.1 through 4.6) were taken from documents prepared by the U.S. Department of Labor under the provisions of the Federal Metal and Non-metallic Mine Safety Act (Section 13, Public Law 89-577).

The number of active uranium mines and mills in the Unites States for 1973 through 1977 are listed in Table 4.1. From 1973 to 1977 there was a steady growth in the total number of uranium mining and milling activities. The fatalities and disabling and nondisabling injuries reported for these mining and milling activities for 1973 to 1977 are listed in Table 4.2.

Table 4.1. Number of active uranium mines and mills in the United States

Year	Mines			Mills	Mines and mills
	Underground	Open pit	Total		
1973	87	32	119	27	146
1974	102	23	125	20	145
1975	128	32	162[a]	19	181
1976			211	31	242
1977			231	32	263
	317	87	848	129	977

[a]Includes types of surface mining other than open pit.

Source: *Injury Experience in the Metallic Mining Industries, 1973-1977* (refs. 1-5).

59

Table 4.2. Injury experience for uranium mines and mills
located in the United States

Injuries	Mining activities		Mill	Mines and mills
	Underground	Open pit		
Fatal (31)				
1973	2			2
1974	2			2
1975	5			5
1976	8			8
1977	8	4	2	14
Disabling (1360)				
1973	97	34	33	164
1974	115	17	23	155
1975	169	28	31	228
1976	230	34	57	321
1977	348	73	69	492[a]
Nondisabling (1452)				
1973	155	10	58	223
1974	255	19	35	309
1975	238	6	42	286
1976	84	13	46	143
1977	395	16	80	491
	2111	254	476	2843[a]

[a]Includes two injuries associated with independent yards and shops.

Source: *Injury Experience in the Metallic Mining Industries,*
1973–1977 (refs. 1–5).

Table 4.3 lists the fatalities and injuries for uranium mining and milling activities in terms of frequency rates per million man-hours worked. An examination of Table 4.3 reveals that the frequency of total fatalities tends to increase. However, as shown in Table 4.2, the number of fatalities was small in any given year, and the significance of the frequencies is questionable. Frequencies of total disabling injuries were 13 and 32% higher in 1976 and 1977, respectively, than the mean for the previous three years. In the case of the frequency of nondisabling injuries, no trend with time is apparent. What is clear is that underground mining has been the cause of the majority of injuries and fatalities. Over the five-year period, underground mining accounted for 81% of the fatalities, 71% of the disabling injuries, and 78% of the nondisabling injuries. The majority of the disabling injuries associated with underground mining activities stems from rock falls within the mine, material handling, haulage, and machinery use.[1-5] In many cases, disabling and nondisabling injuries in open pit mines result from machinery use and personal falls (as opposed to rock falls), and mill injuries often result from falls and material-handling accidents.

Table 4.4 presents data on the ratio of injury frequency per million man-hours for uranium mines and mills to the injury frequency for the entire metallic mining industry (including uranium). The ratio of frequencies for fatalities in the uranium industry was higher from 1975 through 1977. However, part of this was due to a decrease in fatalities in the entire metals mining and milling industry. The five-year average frequency of fatalities per million man-hours in the uranium mining and milling industry was 37% higher than that of the entire industry; considering the small number of fatalities in the uranium industry (Table 4.1), it is not known whether the increase is significant. Table 4.4 shows that the frequency of disabling injuries was generally greater in uranium mining and milling in comparison with the mining and milling of all metals. Although there are small differences, it appears that the safety risk to uranium mining and milling workers is within the same order of magnitude as the safety risk to workers mining and milling all metals.

Table 4.3. Injury experience for uranium mining and milling
(injury frequency per million man-hours worked)[a]

Injuries	Mining activities		Milling activities	Mines and mills
	Underground	Open pit		
Fatal				
1973	0.69			0.22
1974	0.52			0.21
1975	0.86			0.39
1976	0.99			0.49
1977	0.78	0.67	0.39	0.65
Disabling				
1973	33.54	11.62	9.83	17.87
1974	29.76	6.35	7.40	16.07
1975	29.15	8.36	8.82	17.94
1976	28.47	8.72	12.83	19.49
1977	33.98	12.23	13.28	22.81[b]
Nondisabling				
1973	53.60	3.42	17.27	24.31
1974	65.99	7.10	11.27	32.03
1975	41.06	1.79	11.95	22.50
1976	10.40	3.33	10.36	8.68
1977	38.56	2.68	15.40	22.76

[a]Total frequency based on total million man-hours worked in underground and open pit mining activities and in milling activities.

[b]Includes injuries associated with independent yards and shops.

Source: *Injury Experience in the Metallic Mining Industries*, 1973-1977 (refs. 1-5).

Table 4.4. Ratio of injury frequency per million man-hours
for uranium mines and mills to that of the entire
mining and milling industry

Injuries	Mining activities		Milling	Mines and mills[a]
	Underground	Open pit		
Fatal				
1973	0.78			0.61
1974	0.71			0.62
1975	1.46			1.44
1976	1.83			2.33
1977	1.00	3.94	2.60	1.86
Disabling				
1973	0.61	0.88	1.13	0.73
1974	0.55	0.41	0.79	0.63
1975	0.63	0.67	0.77	0.77
1976	0.66	0.77	1.07	0.93
1977	0.83	1.13	1.14	1.10
Nondisabling				
1973	2.43	0.19	1.22	1.38
1974	3.57	0.47	0.99	2.18
1975	2.46	0.15	0.93	1.65
1976	0.80	0.37	0.93	0.79
1977	1.00	0.29	1.23	1.15

[a]Total frequency based on total million man-hours worked in underground and open pit mining activities and in milling activities.

Source: *Injury Experience in the Metallic Mining Industries,*
1973-1977 (refs. 1-5).

It is possible to convert data on fatalities and injuries to estimates of injury experience per GW_e-year produced. This process requires that assumptions be made regarding the number of mining and milling employees required to produce fuel to support 1 GW_e of nuclear power generation. It is assumed that 1.40×10^5 MT (1.54×10^5 ST) of ore (0.2% U_3O_8) are required per GW_e-year[6]. On the assumption that underground mine productivity is 1.9×10^3 MT/man-year (2.1×10^3 ST/man-year) and open pit mine productivity is 5.4×10^3 MT/man-year (6.0×10^3 ST/man-year), it is possible to estimate the employee man-years required from mining and milling activities to support nuclear power generation of 1 GW_e-year. If 60% of the mined ore comes from underground mines, 44 underground miners and 10.5 open pit miners are required to provide the ore necessary to produce 1 GW_e-year. Table 4.5 presents the data on injury experience in the uranium mining and milling industry expressed in terms of fatalities and disabling and nondisabling injuries (based on U.S. Department of Labor statistics).[4,5]

The question of health risk associated with exposure to radon daughter products in the mine atmosphere can also be addressed assuming the previously supplied man-year requirements for mining and milling. The percent increase in the expected number of lung cancers (70) in a population of 10^5 individuals is 1% per working level month (WLM).[6] The current standard for exposure of occupational workers is 4.0 WLM per year. Assumption of this relatively high level of exposure, while conservative, provides for an upper limit of occupational exposure. On the basis of this assumption and the estimate that 44 underground miners are required to mine ore to meet the requirements of a 1-GW_e-year plant, it is possible to calculate the total occupational exposure of 176 WLM/yr. This level of exposure would yield about 0.047 mine-worker lung cancers over a 30-year working period.

The health risk associated with milling activities can be approximated by assuming that 34 man-years are needed to process 1.40×10^5 MT (1.54×10^5 ST) of ore.[7] If each employee is assumed to receive an external dose of 5 rem (the occupational standard), then the total external dose is 170 man-rem. While this upward estimate is used as a measure of effect, it is acknowledged that only a few employees may actually receive this level of dose. Use of cancer risk estimators[8] implies that 2.7×10^{-3} cancers

Table 4.5. Injury experience for uranium mines and mills
per 1.40×10^5 MT (1.54×10^5 ST) of 0.2%
ore mined and milled[a]

Injuries	Mining		Milling
	Underground	Open pit	
Fatal			
1973	0.06	0.00	0.00
1974	0.04	0.00	0.00
1975	0.08	0.00	0.00
1976	0.09	0.00	0.00
1977	0.08	0.01	0.03
Disabling			
1973	2.7	0.19	0.58
1974	2.4	0.12	0.48
1975	2.7	0.16	0.59
1976	2.4	0.18	0.85
1977	3.3	0.26	0.90
Nondisabling			
1973	4.4	0.06	1.02
1974	5.3	0.14	0.73
1975	3.7	0.04	0.80
1976	0.9	0.07	0.69
1977	3.7	0.06	1.04

[a]It is assumed that 1.40×10^5 MT (1.54×10^5 ST) of 0.2% U_3O_8-bearing ore are mined and milled to support nuclear power generation of 1 GW_e-year.

would result from external radiation from both mining and milling activities. Information in one report[9] states that mill employees may be exposed to air containing 5×10^{-12} mCi of uranium activity per liter of air. An exposure of this magnitude will produce an annual dose commitment of approximately 11 rem to the employee's lung.[10] Therefore the 34 mill employees would receive 374 man-rem to the lung. Use of the appropriate conversion factor suggests that this dose would result in 0.014 mill-worker lung cancers. Table 4.6 presents the estimated impacts on uranium miners and millers from activities to support nuclear power generation of $1\text{-}GW_e\text{-year}$.

Table 4.6. Estimated impacts on uranium mine and mill workers
from mining and milling activities to support nuclear
power generation of 1 GW_e-year

	Fatalities	Injuries	Lung cancers
Mines			
Underground	0.04—0.09	3.3—7.7	0.047^a
Open pit	0.002	0.20—0.32	
Mills	0.006	1.21—1.94	0.014^b

^{a}Based on (1) 1 WLM = 7.1 rem (radon and daughters), (2) each miner exposed 4 WLM/year, (3) 44 mine workers required to meet 1 GW_e-year requirement, and (4) 1 man-rem = 3.74×10^{-5} lung cancers.

^{b}Based on (1) 34 mill workers required to meet 1 GW_e-year requirement, (2) an annual dose commitment of 11 rem to the lung, and (3) man-rem = 3.74×10^{-5} lung cancers.

REFERENCES FOR SECTION 4

1. U.S. Department of Labor, *Injury Experience in the Metallic Mineral Industries, 1973,* MESA Information Report 1086, Denver, Colo., 1978.

2. U.S. Department of Labor, *Injury Experience in the Metallic Mineral Industries, 1974,* MESA Information Report 1087, Denver, Colo., 1978.

3. U.S. Department of Labor, *Injury Experience in the Metallic Mineral Industries, 1975,* MESA Information Report 1088, Denver, Colo., 1978.

4. U.S. Department of Labor, *Injury Experience in the Metallic Mineral Industries, 1976,* provided by W. R. Grimes, ORNL, personal communication, July 1978.

5. U.S. Department of Labor, *Injury Experience in the Metallic Mineral Industries, 1977,* provided by W. R. Grimes, ORNL, personal communication, September 1978.

6. P. J. Walsh, Dose Conversion Factors for Radon Daughters. *Health Phys.* (in press).

7. W. R. Grimes, ORNL, personal communication, 1978.

8. National Academy of Sciences, *Effects on Populations of Exposure to Low Levels of Ionizing Radiation,* November 1972.

9. U.S. Atomic Energy Commission, *Generic Environmental Statement — Mixed Oxide Fuel Facility,* WASH-1327, August 1974.

10. D. E. Dunning, Jr. et al., *Estimates of External Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities, Vol. 2,* NUREG/CR-0150 Vol. 2 (in press).

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

5. LOCAL HEALTH IMPACTS

Dose commitments to man resulting from atmospheric releases of radionuclides were estimated for a model acid leach-solvent extraction uranium mill. The mill was assumed to be located in southwestern United States with an annual-average meteorology and a surrounding population distribution representative of a typical western mill site (see Table 5.1, note a).

Table 5.1. Maximum annual individual 50-year dose commitments to the nearest potential resident from the airborne releases of a model acid leach-solvent extraction uranium mill[a]

Source	Dose (millirem)				
	Whole body	Bone	Lung	Kidney	Spleen
Ore crusher and bin[b]	1.2	5.7	0.9	1.5	2.3
Yellowcake process[c]	0.5	2.3	7.7	0.2	0.1
Tailings pond and beach[d]	<u>0.4</u>	<u>0.5</u>	<u>19.3</u>	<u>0.7</u>	<u>0.2</u>
	2.1	8.5	27.9	2.4	2.6

[a]The dose commitments are for a typical mill site in southwestern United States. The nearest potential resident is assumed to live 1.6 km (1 mile) from the mill; dose commitments are less at greater distances. The ingestion component of the dose commitment is based on the assumption that all food is grown and consumed at the reference location. An annual 50-year dose commitment is the dose received by an individual over a 50-year period as a result of an exposure of one year.
    The doses listed above should be divided by 5.2 to obtain dose per GWe. The use of an assumed linear relationship between dose and nuclear generating capacity, however, may be subject to considerable uncertainty.

[b]A release height of 10 m (33 ft) with no plume rise was assumed.

[c]A release height of 20 m (66 ft) with no plume rise was assumed.

[d]A 1-m (3.3-ft) release height from a 32-ha (80-acre) tailings pond and tailings beach was assumed.

Calculated release rates of radionuclides to the atmosphere used for the dose calculations were based on state-of-the art management of radioactive wastes. The assumed annual release rates for each of the three main components of the mill are given in Table 3.3. Typical release heights of 10 and 20 m (33 and 66 ft), with no plume rise, were assumed for the ore crusher and bin and for the yellowcake process, respectively. A 1-m (3.3-ft) release height from a 32-ha (80-acre) tailings pond and tailings beach was assumed for ^{222}Rn.

The AIRDOS-II computer code[1] was used to estimate (1) annual-average concentrations of the radionuclides in air and rates of deposition on ground surfaces in the environment surrounding the mill and (2) consequent 50-year dose commitments to man. Exposure modes included inhalation of air, air immersion, water immersion, exposure to contaminated ground surfaces, and ingestion of food produced on contaminated agricultural land. A deposition velocity of 1 cm/sec (0.4 in./sec) was used to calculate the rate of dry deposition of the radionuclide particulates, and a scavenging coefficient of 4.6×10^{-6} sec^{-1} was used to calculate the wet deposition rate resulting from an annual rainfall of 20 cm (8 in.). The selection of these deposition parameters was based on the discussion and procedures in *Meteorology and Atomic Energy* (1968).[2]

Dose calculation for ^{222}Rn poses a special problem because its daughters (^{210}Po, ^{214}Pb, and ^{214}Bi) build up in the airborne plume after its release and account for a significant fraction of its dose. The problem is complicated because the daughters are produced as particulates or ions that can attach to dust particles and that will be deposited on ground surfaces through both wet and dry deposition processes. A computer code (HARAD) was written to estimate the buildup and decay, as well as ground deposition, of ^{222}Rn daughters.[3] This code was used to determine appropriate release rates for the daughters to be used in the AIRDOS-II computer runs to account for these simultaneously occurring processes.

The population dose within an 88-km (55-mile) radius of the mill and the individual dose to the nearest potential resident at a distance of 1.6 km (1 mile) were estimated (a population of 53,000 was assumed). Results of the dose calculations are presented in Sect. 6.

Table 5.1 lists the maximum individual 50-year dose commitments (estimated for the nearest potential resident) resulting from airborne releases of radionuclides from the model uranium mill. Population dose commitments within a radius of 88 km (55 miles) are listed in Table 5.2. Table 5.3 gives the percentage contributions of the major exposure pathways and the major dose contributors for the maximum individual dose calculation. Table 5.4 gives comparable percentages for population dose commitments.

Table 5.2 Annual 50-year dose commitments from airborne releases to a population within an 88-km (55-mile) radius of a model acid leach-solvent extraction uranium mill^a

Source	Dose (man-rem)			
	Whole body	Bone	Lung	Kidney
Ore crusher and bin^b	0.06	0.33	0.12	0.10
Yellowcake process^c	0.05	0.21	0.69	0.02
Tailings pond and beach^d	0.16	0.18	5.73	0.27
	0.27	0.72	6.54	0.39

^{a}The population dose commitments are for a typical mill site in the southwestern United States with a total population of 53,000. The ingestion components of the dose commitment are based on the assumption that all food is grown and consumed within the reference location. An annual 50-year dose commitment to the population is the dose (man-rem) received by the population over a 50-year period as a result of an exposure of one year.

The listed doses should be divided by the factor 5.2 to obtain doses for GWe. The use of an assumed linear relationship between dose and nuclear generating capacity, however, may be subject to considerable uncertainty.

^{b}A release height of 10 m (33 ft) with no plume rise was assumed.

^{c}A release height of 20 m (66 ft) with no plume rise was assumed.

^{d}A 1-m (3.3-ft) release height from a 32-ha (80-acre) tailings pond and tailings beach was assumed.

Table 5.3. Contributions of major pathways and radionuclides to maximum individual dose commitments to the nearest potential resident from the airborne releases of a model acid leach-solvent extraction uranium mill

	Whole body	Bone	Lung	Kidney	Spleen
Major pathway contribution, %					
Ingestion	57	72		63	89
Inhalation	32	24	>99	29	
Major contributors, %					
Radium-226	40	26			
Uranium isotopes	19	16	28		
Radon-222 and short-lived daughters	19		70	29	
Thorium-230		23			
Lead-210		23			
Polonium-210				55	85

Table 5.4. Contributions of major pathways and radionuclides to population dose commitments from the airborne releases of a model acid leach-solvent extraction uranium mill

	Whole body	Bone	Lung	Kidney
Major pathway contribution, %				
Inhalation	48	32	99	58
Ingestion	19	53		25
Surface exposure	22	11		
Air submersion	7			
Major contributors, %				
Radium-226	13	13		
Uranium isotopes	15	17	11	
Radon-222 and short-lived daughters	59	25	88	69
Thorium-230	5	21		
Lead-210	4	18		
Polonium-210				22

The critical organ is the lung. The nearest potential resident would receive 28 millirem/year to the lung, mostly through inhalation. Approximately 70% of the lung dose is contributed by ^{222}Rn released from the tailings pond and tailings beach. Uranium isotopes released in the yellowcake process account for nearly all of the remainder of the lung dose. About 85% of the dose from ^{222}Rn and its short-lived daughters results from exposure to ^{218}Po and ^{214}Pb, which build up in the airborne plume as it is blown downwind from the point of release. The population dose commitment to lungs is ~6.5 man-rem/year, of which 89% is attributed to ^{222}Rn released from the tailings pond and tailings beach.

The tabulated lung doses are for whole lung. However, the bronchial epithelium is the site of daughter buildup and may be considered the critical tissue. Dose conversion factors for the bronchial epithelium are currently being debated, but doses from ^{222}Rn and daughters to the bronchial epithelium[4] may be an order of magnitude greater than doses to whole lung.

REFERENCES FOR SECTION 5

1. R. E. Moore, *The AIRDOS-II Computer Code for Estimating Radiation Dose to Man From Airborne Radionuclides in Areas Surrounding Nuclear Facilities*, ORNL-5245 (April 1977).

2. I. Van der Hoven, "Deposition of Particles and Gases," *Meteorology and Atomic Energy - 1968.* (D. Slade, Ed.), USAEC TID-24190, 1968, pp. 202-208.

3. R. E. Moore, *HARAD — A Computer Subroutine for Calculating the Simultaneous Buildup, Decay and Ground Deposition of Short-life Progeny of ^{222}Rn in Air*, to be published as an ORNL report.

4. K. J. Schiager, "Radwaste Radium-Radon Risk," in *Proceedings: A Workshop on Policy and Technical Issues Pertinent to the Development of Environmental Protection Criteria for Radioactive Wastes*, ORP/CSD-77-2, U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, D.C., 1977, pp. 2-45.

6. NATIONAL HEALTH IMPACTS

6.1 Population Exposures and Doses From Inhalation of ^{222}Rn and Its Daughters and Ingestion of ^{210}Pb

Potential exposures and doses were estimated[1] for inhalation of ^{222}Rn and its daughters and ingestion of ^{210}Pb, which is deposited on soil and vegetation after formation in air by decay of ^{222}Rn dispersed from uranium mill activities in the United States in 1978. Four generic mill sites in western United States representing areas of active milling as described by the Nuclear Regulatory Commission (NRC) recent draft environmental impact statement on uranium milling[2] were considered for the study. Tailings accumulations at active mill sites constitute approximately 3/4 of the total accumulation in the United States. Estimated ^{222}Rn releases in 1978 from tailings piles at sites in Wyoming, Texas, New Mexico and Washington of 47.6, 18.2, 85.4 and 8.4 kCi/year respectively, were obtained from the NRC's impact statement[2] for, this assessment. Population doses resulting from ^{222}Rn releases during 1978, following inhalation exposure to ^{222}Rn and daughters, and ingestion exposure to ^{210}Pb, were estimated for the United States.

Air concentrations of ^{222}Rn and ^{210}Pb were initially estimated by the National Oceanic and Atmospheric Administration (NOAA) based on a unit release of ^{222}Rn for each site of 1 kCi/year.* The atmospheric dispersion model used by NOAA (ARL model)[3] combined a transport model, which calculated trajectories for ^{222}Rn and ^{210}Pb emissions from a uniform, continuous point source, with a Gaussian plume model, deposition rates, and radioactive decay data to compute ground-level air concentrations of these nuclides. The trajectories, which were initiated every 6 hr and followed for ten days, were characterized by wind data descriptive of the areas of interest. These trajectories were then oriented on a gridded map, and concentrations of ^{222}Rn and ^{210}Pb were calculated, accumulated, and averaged over a month for each grid box transversed by a trajectory.

---

*To calculate exposure and doses for different release rates, it was assumed that exposure and dose are linearly related to the amount of release.

The desposition model, accounting for wet and dry deposition of ^{210}Pb, was used by NOAA, in conjunction with the transport model, to calculate soil concentrations of ^{210}Pb subject to resuspension. Thus, the contribution of resuspension to air concentrations of ^{210}Pb and ^{210}Po, to which the populations of concern might be exposed, could be estimated. The resuspension factor, relating concentration in air of the resuspended ^{210}Pb or ^{210}Po to the surface deposition per unit land area, was assumed to initiate at 10^{-5} m^{-1} for freshly deposited material and to decay with a half-life of 50 days to a value of 10^{-9} m^{-1} for the life of ^{210}Pb in the soil, based on literature reviewed.[1]

Relationships between ^{210}Pb concentrations in air and those in food-stuffs consumed by man in 1978 were estimated by assuming that ^{210}Pb found in dietary items originates from foliar deposition. Results of market-basket survey of ^{210}Pb in urban dietary items in the United States and of measurements of average ^{210}Pb air concentrations in the United States were used to develop air-to-diet conversion factors and air-concentration data for ^{210}Pb to be used directly in determining dietary concentrations of the nuclide.[1] Integrated population exposures during 1978 to dietary ^{210}Pb were estimated by coupling these conversion factors with standard diets, based on available literature on consumption in the United States, current agricultural productions of ^{210}Pb provided by NOAA.

Inhalation dose estimates were based on conversion factors distinguishing dose from ^{222}Rn and its short-lived daughters and dose from its long-lived daughter (^{210}Pb) and associated ^{210}Bi and ^{210}Po isotopes.[4] A dose conversion factor of 1.0 millirem pCi^{-1} m^{-3} of ^{222}Rn per year was used for continuous annual exposure to ^{222}Rn and its short-lived daughters. This value was based on an assumption of equilibrium conditions for ^{222}Rn progeny such that 0.5 working level of short-lived daughters is associated with every 100 pCi/liter of ^{222}Rn. The fraction of "free" ions (daughters not attached to aerosol particulates) present in the aerosol was assumed to be 0.1 consistent with measurements made in uranium-mine atmospheres and typical dwellings, when available.[4] The fractio of post-deposition radiation penetrating critical cells was assumed to be unity.

Fifty-year ingestion and inhalation dose commitments for ^{210}Pb were calculated utilizing the INREM-II computer codes recently developed by G. G. Killough et al. at Oak Ridge National Laboratory.[5] This code incorporates current metabolic data for radionuclides (including ^{210}Pb, ^{210}Bi, and ^{210}Po) into recent metabolic models to determine dose conversion factors for various organs. Table 6.1 lists the 50-year dose commitment values for ^{210}Pb and ^{210}Po.

Table 6.1. Fifty-year dose commitment factors for ^{210}Pb and ^{210}Po inhalation and ^{210}Pb ingestion

	Whole body	Bone	Kidney	Liver	Lung
Ingested, rem/µCi					
Lead-210	3.8	52	0.49	0.75	
Inhaled,[a] millirem pCi^{-1} m^{-3} per year					
Polonium-210	8.6	3.4	340	10	60
Lead-210	71	940	47	15	19

[a]An inhaled particle size of 0.3 activity median aerodynamic diameter (AMAD) was assumed.

By combining these dose conversion factors with previously derived population exposures, integrated man-rem and organ-rem doses were obtained for inhalation of ^{222}Rn (Table 6.2), inhalation of ^{210}Pb (Table 6.3), and ingestion of ^{210}Pb (Table 6.4). The values obtained for the integrated population exposures and doses were derived from data outlined above for total estimated annual ^{222}Rn and ^{210}Pb releases from each of the four generic mill sites. Resuspended ^{210}Pb and ^{210}Po account for approximately 33% of the total lung dose from ^{210}Pb, but they account for less than 16% of the critical organ (or bone) dose for inhalation. There is a high degree of uncertainity associated with estimates of total population exposure and dose from ingestion of ^{210}Pb because the relative significance of atmospheric and soil concentrations of ^{210}Pb as sources of the nuclide in vegetation have not been determined.

Table 6.2. Estimated population exposures and doses from
inhalation of ^{222}Rn and progeny in 1978

Release site	Total release (kCi/year)	Population exposures (man–pCi/m^3)^a	Population dose — lung (man–lung rem)
1	47.6	4.0E6^b	4.0E3
2	18.2	2.0E6	2.0E3
3	85.4	6.0E6	6.0E3
4	8.4	5.0E5	5.0E2
	159.6	1.3E7	1.3E4

^{a}pCi/m^3 refers to ^{222}Rn concentrations.

^{b}Read as 4.0×10^6.

6.2 A Radiological Assessment of Natural and Technologically Enhanced Sources of ^{222}Rn

The purpose of this assessment is (1) to estimate annual releases of ^{222}Rn from the major natural and technologically enhanced sources, and (2) to use these estimates to determine the resulting exposure (man–pCi/m^3) and average inhalation dose (man–rem) to the 1978 population of the United States for each source. A summary of results is presented in Table 6.5. The various natural and technologically enhanced sources are listed in descending order of magnitude according to estimated inhalation.

The most important natural source of ^{222}Rn is emanation from soil. Since exhalation of radon from soil is strongly influenced by local soil and atmospheric conditions, soil radon flux and resulting atmospheric concentrations show considerable variation with respect to location and time of day. Sufficient data exist, however, to make reliable average estimates. Air concentrations from which population exposures were determined were made on the basis of a ^{222}Rn flux of 1.2×10^8 Ci/year derived from several published flux measurements.[1] An average United States air concentration was estimated to be 120 pCi/m^3, which falls in the range of reported empirical values.[1]

Evapotranspiration, the collective release of water vapor from soil surfaces and vegetation, was estimated to contribute no more than

Table 6.3. Estimated United States population exposures and doses from inhalation of ^{210}Pb and resuspended ^{210}Po in 1978

Release site	Total release (kCi/year)	Population exposures (man-pCi/m^3)	Population dose (man-rem) Whole body	Population dose (organ-rem)			
				Lung	Bone	Kidney	Liver
1	47.6	1200					
Primary dose			85	57	1100	19	19
Resuspended dose			19	29	210	4.8	4.8
			104	86	1310	23.8	23.8
2	18.2	400					
Primary dose			27	18	380	7.3	7.3
Resuspended dose			7.3	9	73	1.8	1.8
			34.3	27	453	9.1	9.1
3	85.4	1800					
Primary dose			120	85	1700	26	34
Resuspended dose			20	43	320	8.5	8.5
			140	128	2020	34.5	42.5
4	8.4	180					
Primary dose			13	8.4	170	3.4	3.4
Resuspended dose			3.4	4.2	32	0.8	0.8
			16.4	12.6	202	4.2	4.2
All sites	159.6	3580	294.7	253.6	3985	71.6	79.6

79

Table 6.4. Estimated total population exposures and doses to the United States population from ingestion of ^{210}Pb in 1978

Release site	Total release (kCi/year)	Population exposures (man-pCi/m^3)	Population dose (man-rem) Whole body	Population dose (organ-rem) Bone	Kidney	Liver
1	47.6	3.4E7[a]	130	1800	17	26
2	18.2	7.1E6	27	370	3.5	5.3
3	85.4	5.4E7	210	2800	26	41
4	8.4	6.8E6	26	350	3.3	5.1
	159.6	1.0E8	393	5320	49.8	77.4

[a]Read as 3.4×10^7.

Table 6.5. Estimated exposures and doses to the population of the United States in 1978 from various natural and technologically enhanced sources of ^{222}Rn[a]

Source	Estimated annual release (Ci/year)	Estimated air concentration (pCi/m³)	Estimated population exposure (man-pCi/m³)	Estimated population dose (man-rem)
Natural soil	1.2E8[b]	1.2E2	2.6E10	2.6E7
Building interiors				
Radon flux through floor	1.4E4	9.7E1[c]	1.5E10	1.5E7
Potable water	9.8E3	6.7E1[c]	1.5E10	1.5E7
Building materials	4.4E3	8.9E1[c]	1.4E10	1.4E7
Evapotranspiration	2.2E7	2.4E1	5.2E9	5.2E6
Natural gas				
Ranges	2.0E2	3.0[c]	4.0E8	4.0E5
Unvented heaters	8.0E1	1.0E1[c]	1.7E8	1.7E5
Uranium				
Mining	2.0E5	2.2E-1	4.8E7	4.8E4
Milling	1.6E5	5.5E-2	1.2E7	1.2E4
Nonuranium mining				
Phosphates				
Reclaimed lands	3.6E4	3.9E-2	8.6E6	8.6E3
Mining	2.1E4	2.3E-2	5.0E6	5.0E3
Beneficiation and processing				
Coal	1.4E4	1.5E-2	3.3E6	3.3E3
Liquified petroleum gas				
Ranges	1.8	1.6E-1[c]	3.6E6	3.6E3
Unvented heaters	1.3	9.2E-1[c]	2.6E6	2.6E3
Natural gas				
Commercial and industrial uses	1.1E4	1.2E-2	2.6E6	2.6E3
Coal-fired power plants	4.7E3	4.7E-3	1.0E6	1.0E3

81

Table 6.5. (continued)

Source	Estimated annual release (Ci/year)	Estimated air concentration (pCi/m^3)	Estimated population exposure (man-pCi/m^3)	Estimated population dose (man-rem)
Geothermal Power facilities Liquid-dominated fields	5.8E2	6.3E-4	1.4E5	1.4E2
Wells Gas and oil Water	2.3E2	2.5E-4	5.5E4	5.5E1
Fertilizer use	1.7E3	1.7E-3	3.8E5	3.8E2

[a]Population exposures and doses are based on United States projected population figures for 1978 and a dose conversion factor for ^{222}Rn inhalation of 1 millirem pCi^{-1} m^{-3} per year, assuming a daughter equilibrium of 50%.

[b]Read as 1.2×10^8.

[c]Air concentration in building interiors.

2.2×10^7 Ci of ^{222}Rn annually to the atmosphere, based on an average ^{222}Rn groundwater concentration of 5 nCi/liter.[1] The resulting United States ^{222}Rn air concentration of 24 pCi/m^3 produced the population exposure listed in Table 6.5.

The largest technologically enhanced contributor to population exposure and dose was estimated to be ^{222}Rn confined within building interiors. Average radon concentrations within buildings have been found to be several times the background atmospheric concentrations.[4] These elevated concentrations can be traced to several independent sources: (1) radon fluxes through the floor of the building from soil emanation, (2) the use of potable water for domestic purposes, and (3) natural radioactivity in building materials. The first source is the major contributor of ^{222}Rn concentrations in building interiors, where ^{222}Rn concentrations may range from 100 to 1000 pCi/m^3.[1]

Radon-222 releases from other sources were calculated in a manner similar to those described above. Available data on all sources were thoroughly reviewed. Atmospheric concentrations of ^{222}Rn from each source were estimated assuming the immediate and uniform distribution of gas following release into a fixed volume of air over the United States. The natural background ^{222}Rn air concentration was compared to the natural soil emanation rate to derive a factor describing the relationship between air concentration and release rate. This factor was then applied to release rates for each source to estimate resulting air concentration, and related population doses.[1] Except for the domestic use of natural gas, technologically enhanced source activities result in a population dose at least three orders of magnitude less than the population dose resulting from natural, soil radon flux.

The possibility of persistent, future emanation is a unique aspect of many technologically enhanced natural radiation (TENR) activities. Even after termination of the technology associated with the commencement of the source, ^{222}Rn may continue to be released to the environment. Examples include (1) tailings from uranium mining and milling activities, (2) ash ponds associated with the operation of coal-fired power plants, (3) land reclamation following surface mining for phosphates, and (4) agricultural soils to which phosphate fertilizers have been applied.

A number of radon sources are listed in Table 6.5 for which data were insufficient to develop an estimate of release. These include liquid-dominated geothermal fields, phosphate-fertilizer production, water wells, and land disturbance due to construction and other major perturbations. Although the radon contribution of these ill-defined sources may be orders of magnitude less than that of natural soil, no meaningful estimate of their ^{222}Rn release can be calculated without further field measurement of ^{222}Rn emanation rates.

REFERENCES FOR SECTION 6

1. C. C. Travis et al., *A Radiological Assessment of Radon-222 Released from Uranium Mills and Other Natural and Technologically Enhanced Sources*, NUREG/CR-0573 (February 1979).

2. U.S. Nuclear Regulatory Commission, Draft Environmental Impact Statement on Uranium Milling, NUREG-0511 (1979).

3. J. L. Heffter, A. D. Taylor, and G. J. Ferber, *A Regional—Continental Scale Transport, Diffusion, and Deposition Model*, NOAA Technical Memo ERL ARL-50, Air Resources Labs, Silver Spring, Md., 1975.

4. L. M. McDowell-Boyer, A. P. Watson, and C. C. Travis, *Review and Recommendations of Dose Conversion Factors and Environmental Transport Parameters for* ^{210}Pb *and* ^{226}Ra, NUREG/CR-0574, ORNL/NUREG-56 (1979).

5. G. G. Killough, D. E. Dunning, and J. C. Pleasant, *INREM II: A Computer Implementation of Recent Models for Estimating the Dose Equivalent to Organs of Man From an Inhaled or Ingested Radionuclide*, NUREG/CR-0114 (June 1978).

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

7. POTENTIAL SOCIOECONOMIC IMPACTS OF URANIUM MILLING AND MINING AND MITIGATION STRATEGIES

7.1 Introduction

The role of the nuclear fuel cycle in the energy future of the United States is important, and the role of uranium supply to that fuel cycle is fundamental. The national energy plan calls for a tripling of uranium production by 1985 to support rising demand for electricity. In order to meet this objective, policy makers, facing a host of confounding and dynamic social, economic, political, and technical environments, must consider a large array of related problems (e.g., rad waste management, siting of nuclear power plants, the timely development of commercial reactors, the improvement of enrichment technologies, and the roles of fusion and breeder reactors), which will necessarily impact decisions concerning uranium production and its various component processes. This section describes the contemporary uranium resource and supply industry and its institutional settings, assesses the socioeconomic impacts likely to emerge from high levels of uranium mining and milling, describes how and to what extent these impacts are presently being mitigated, and suggests how and when a socioeconomic impact monitoring program might be used to facilitate the amelioration of negative socioeconomic impacts.

The concentration of uranium reserves and resources in the states of New Mexico, Colorado, Utah, and Wyoming mean that development impacts will be restricted generally to isolated rural communities which cannot easily accommodate rapid increases in employment and population. Processing mills in this region currently account for 94% of production, and it is estimated that of the 43 new mills needed (each rated at 1800 MT/day or 1985 ST/day) through the end of the century, 36 will be sited in these four states (see Table 2.7).[1] Even though the number of employees needed to construct a mill and to operate a mine and mill are relatively small, as compared to other energy facilities, uranium development tends to cluster. Several hundred mines, including many very small operations, may operate simultaneously in a single county (e.g., San Juan County in Utah has over 200 mines). The colocation of mines with a mill to minimize

transport costs, and the future option of colocating mills to achieve some greater economy of scale, would mean that the cumulative social impacts of uranium development in isolated rural communities could be as great, if not greater, than the impacts due to a coal-fired generating plant, a nuclear generating plant or a coal synfuels plant.

The assessment of the socioeconomic impacts due to a specific uranium mine or mill is relatively easy. However, such an assessment is more diffi- cult when it must take into account other energy development projects in the local area. Although a method for dividing the responsibility for cumula- tive impacts among a series of projects has yet to be developed, a solution to this problem must be found if the socioeconomic impacts of any given development activity are to be equitably mitigated.

Some of the socioeconomic impacts of the uranium fuel industry on western resource states and their communities are indirect, largely unan- ticipated, and probably nonquantifiable. For instance, there is considerable uncertainty in the industry regarding the eventual outcome(s) of litiga- tion relating to Westinghouse Electric Corporation and to an alleged price fixing cartel. Until the courts make it clear what Westinghouse is obliged to do in terms of meeting its contracted commitments to utilities for nuclear fuel, and until the role of domestic producers in the cartel is substanti- ated and resolved, mining and milling developmen may be somewhat constrained. In any case uncertainty over prices and possible reformulations of the industry lead to uncertainty in planning new operations; uncertainty in planning presents a major obstacle to potential host communities as they try to plan for and mitigate socioeconomic impacts of uranium development.

7.2 Relevant Institutional Environments

Under the Atomic Energy Act of 1954, the Atomic Energy Commission (AEC) was given responsibility for licensing uranium mills. Section 274 of the Act, an amendment which passed in 1959, provided a mechanism by which states can enter into formal agreements with the AEC !now with the Nuclear Regulatory Commission (NRC)1 and can assume responsibility for regulating uranium mill development and other source, by-product and small quantities of special nuclear material.[2] Of the 25 states which have entered into formal agreements with the NRC (Table 7.1), as of 1978, the primary uranium producing states of Texas, Colorado, and New

Table 7.1. List of agreement states

Agreement state	Effective agreement date
Kentucky	1962
California	1962
Mississippi	1962
New York	1962
Texas	1963
Arkansas	1963
Florida	1964
North Carolina	1964
Kansas	1965
Oregon	1965
Tennessee	1965
New Hampshire	1966
Alabama	1966
Nebraska	1966
Washington	1966
Arizona	1967
Louisiana	1967
Colorado	1968
Idaho	1968
North Dakota	1969
South Carolina	1969
Georgia	1969
Maryland	1971
Nevada	1972
New Mexico	1974

Mexico and the secondary uranium producing states of Washington, Arizona, and Idaho have licensing programs for uranium milling activities. The nonagreement states include three uranium producing states: South Dakota, Utah, and Wyoming, and both Utah and Wyoming are considering becoming agreement states.[3] In the nonagreement states, the NRC retains the authority to regulate uranium mills and prepares environmental impact statements since licensing of such facilities constitutes a major federal action that falls under Section 102 of the National Environment Policy Act (NEPA). An environmental impact statement (EIS) may also be required, in agreement and nonagreement states, if the mine and/or mill is located on federal lands or is managed by a federal agency. Under these conditions the lead agency is the lands-administering agency. Of the 18 currently active mills in the United States, 9 are in agreement states and were licensed directly by the states, and 9 are in nonagreement states and were licensed by the NRC. To date, the NRC has never required the applicant for a mill license to mitigate socioeconomic impacts.

Under the recently passed Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978, regulatory authority has increased over the operation of uranium mills. For 20 inactive mills the Department of Energy has primary responsibility for assessing and recommending appropriate remedial action to assure the stability and control of uranium tailings in a safe and environmentally sound manner, and the NRC has primary responsibility to implement a program to regulate mill tailings at active mill operations. Further, UMTRCA confers NEPA-like responsibilities on the agreement states (Section 204). For both active and inactive mills, states may enter into cooperative agreements which must be approved by the NRC under Section 274 of the Atomic Energy Act.

Uranium mines are not presently licensed by any federal agency, although the Mining Safety and Health Administration of the Department of Labor sets and enforces the safety standards and inspects mine facilities. The NRC currently has no jurisdiction over uranium mines, but it does include mine operations in their EIS's on mills if they are colocated. If a mine is to be located on federal lands or owned by a federal agency, e.g. TVA, the federal agency with responsibility for that particular piece of land may be required to prepare an EIS and obtain a license for the mine. If the mine is not located on federal land, no federal regulation is required.

7.2.1 Regulation of mills by agreement states

In general, the mill licensing requirements of the agreement states are far less stringent in many respects than those of the NRC.[4] Neither of the major uranium producing agreement states, New Mexico and Colorado, require the preparation of EIS's, but they do have fairly extensive regulatory authority regarding pollution abatement and consider environmental impacts in mill licensing. New Mexico and Wyoming (a nonagreement state) do have state siting laws which presently do not apply to the construction and operation of uranium mills.[5] There is the possiblity, however, that the siting of future mills may come under the purview of state regulation in both agreement and nonagreement states. Most of the agreement states do consider environmental effects in the licensing process and informally invite public participation, but some have no formal procedures or regulations to enforce such consideration. Unlike the NRC, none of the agreement states prohibit prelicensing construction activities, and like the NRC, they have not required the mitigation of socioeconomic impacts as a condition of licensing. Further discussion of uranium resource states' approaches to siting and mitigation can be found in Sect. 7.3.

Even though the agreement states receive no federal funds for their mill licensing activities, all of these states wish to retain their licensing authority. Further, they want to expand their environmental assessment processes to include uranium mills, but they do not desire to be required or encouraged to prepare elaborate or extensive assessment studies. All agreement states except New Mexico indicate that at their present level of activity and responsibility additional resources are not required. UMTRCA, Section 204, amends the Atomic Energy Act by requiring agreement states to demand a written analysis of impacts to public health, water ways and groundwaters, and consideration of long-term impacts and alternatives to the proposed action before any major construction can take place for each mill license which has a significant impact on the human environment.

The future licensing role of agreement states is somewhat in doubt due to a current suit filed by the Natural Resources Defense Council (NRDC) against the state of New Mexico and the Nuclear Regulatory Com-

mission. The NRDC is seeking to require an EIS as part of the license application for a uranium mill to be operated by United Nuclear Corporation in Church Rock, New Mexico. A broader objective of the suit is to establish that, under NEPA, the federal delegation of authority to the states for regulating uranium mills (Section 274 of the Atomic Energy Act) is illegal. If NRDC wins the suit, a full EIS process sponsored by the NRC will be required for future mill licenses. The Tenth U.S. Circuit Court of Appeals, in ruling that Kerr-McGee and the American Mining Congress be allowed to intervene in the litigation, intimated that a decision in favor of NRDC "is not unlikely."[6]

7.2.2 Uranium development on Indian lands

The Council of Energy Resource Tribes (CERT) and DOE have estimated that Indians own 20-50% of U.S. uranium resources.[7] Given this degree of resource control, it is important to take into account those institutional arrangements currently undergoing change, which may seriously affect the development of uranium resources.

The leasing of Indian lands for uranium exploration and development, whether on reservation lands or individual allotted lands, must be approved by the Bureau of Indian Affairs (BIA) and the Secretary of Interior. If the lands are on an Indian reservation, the lease agreement may be studied by tribal advisory boards (e.g., Navajo Environmental Protection Commission) and must be approved by the tribal policy-making body (e.g., Navajo Tribal Council). If the lands were allotted to individual tribal members, approval of the lease by the policy-making body is not required. Until recently, the royalty leases provided the only way in which Indian tribes could participate in resource development, but attempts are being made to revise regulations to allow a variety of alternative mechanisms to tribes in contracting for uranium leases, including joint ventures and development under service or operating contracts. These new leasing arrangements will not only increase the rate of return to the Indian tribes and their members, but will also result in increased participation of individual tribes and collectivities of tribes in energy resource management, planning, and development.

Since approval by the BIA and the Secretary of Interior, as required on leasing of Indian lands, constitutes a major federal action, an EIS must be prepared under NEPA. The state government has no jurisdiction on Indian lands, so whether the state is agreement or nonagreement under Section 274 of the Atomic Energy Act, as amended, is irrelevant. An EIS must be prepared by the BIA for any uranium development on Indian lands.

The concentration of uranium resource development on Indian lands is likely to increase in the next two decades, and this colocation is likely to spawn cumulative socioeconomic impacts which can only be estimated imprecisely. The BIA has recently predicted that more than 100 new mines and 7 to 10 new mills are likely to be developed in the San Juan Basin in northwestern New Mexico on the Navajo Indian Reservation by the year 2000.[8] Although an appellate court has recently ruled that the adequacy of an EIS in predicting cumulative impacts of uranium development is not to be judged stringently, since that would require "prophecy beyond the capabilities of both scientists and courts,"[9] identification of cumulative impacts and their separate causes must be made if the socioeconomic impacts of uranium mining and milling are to be mitigated.

7.3 The Socioeconomic Impacts of Uranium Mining and Milling

A comprehensive assessment of the socioeconomic impacts of uranium mining and milling is beyond the scope of this report. Even within the fairly narrowly defined resource areas of the United States (New Mexico, Wyoming, Colorado, Utah, and Texas) there are enormous amounts of variation among the potential host communities and their salient characteristics. For projects which may involve the development of new towns, such as the Shootering Canyon project in Utah, the projection of socioeconomic impacts is particularly difficult. There is, as well, substantial variation in the scale of uranium development, all the way from individual miners who sell their small output to ore buying stations to ones much larger, such as the Kerr-McGee project in Converse County, Wyoming, which includes several strip and underground mines and a large

uranium mill. The scale of future uranium development facilities expands this range of variation even more. The staff at Argonne National Laboratory is projecting socioeconomic impacts of 12 colocated mills and ancillary development activities.[1] There is the further difficulty, in many of the uranium resource areas, of disaggregating the impacts of uranium development projects from those of other energy development facilities.

Given these constraints, this section outlines in only a very brief way the potential socioeconomic impacts of uranium mining and milling. It does not address the subject matter with anywhere near the particularity that would be required in assessing impacts for an individual project for an EIS. For that kind of analysis one should refer to other sources.[10] Rather, probable characteristics of mine and mill construction and operating work forces are addressed along with (1) characteristics of likely host communities, tribes, regions, and states; (2) an analysis of what development conditions are likely to cause conventional adverse and beneficial socioeconomic impacts; and (3) an identification of those impacts which are peculiar to uranium development projects as contrasted with other energy development projects.

7.3.1 Characteristics of uranium development labor force

One of the most important variables to be considered in assessing socioeconomic impacts of development projects is that of population change. Specifically, the amount of immigration varies directly with the quantity of impacts. In contrast with other energy development projects (coal-fired or nuclear power plant and synfuels plant), a typical uranium mine or mill employs relatively small numbers of people. As shown in Table 7.2, the peak construction labor force for large mines and mills is less than or equal to 600. In contrast, large power plants or synfuels plants employ upwards of 3000 at peak during the construction phase. The total operating work force of mines and mills varies according to output and is sometimes larger than the operating force of power plants and synfuels plants; but due to the more permanent status of an operating work force, socioeconomic impacts tend to be less severe

Table 7.2. Work force characteristics of selected uranium mines and mills

Project	Start-up date	Normal capacity (tons per day)	Construction time	Peak construction force	Total operating force[a]	Union/ Nonunion
Mines						
Surface	mid 1970's	1,700	7 months	141	141	Nonunion
Surface	mid 1950's	varies according to grade	2 years		455	Union
Surface	early 1970's	2,000	2 1/2 years (initially scrapper operation)		220	Nonunion
Underground	projected early 1980's	4,500	10 years for all construction to be complete	300	750	
Underground	early 1970's	1,100	2 1/2 years	60	164	Mixed
Underground	early 1970's	600	4 1/2 years for all construction to be complete		180	Union
Mills						
Mill (acid- leach)	mid 1950's expanding late 1970's	3,000 expanding to 6,000	11 months for expansion	600	421	Union
Mill (carbonate- leach)	early 1970's	750	20 months	60 (all surface buildings)	83	Mixed
Mill (acid- leach and akaline- leach)	mid 1950's converted mid 1970's	1,200	4 years for entire conversion	120 (conversion)	185	Nonunion
Mill (acid- leach)	mid 1970's	1,000	1 year includes 2 month delay for NRC statement)	70	51	Nonunion

[a]Includes office and maintenance personnel.

Source: Stone and Webster Engineering Corp., *Uranium Mining and Milling* (prepared for Western Interstate Energy Board under EPA Contract #68-01-4490, May 1978).

than during the construction phase. Also, in some cases, the development company attempts to maximize local employment which lessens the adverse socioeconomic impacts of the mine-mill project.[11]

7.3.2 Characteristics of host communities

A second parameter of immigration impacts is found by assessing qualitative differences and similarities between host and immigrating populations. Although the causal relationships between interpopulation differences and impacts is not well defined, it is generally thought that homogeneity and heterogeneity between host and immigrating populations both lead to socioeconomic impacts which may require mitigation. To the extent that populations are comparable there will be competition for scarce resources; to the extent that they differ, there may be a demand for new and different resources. The disribution of public and private resources to the two populations is likely to lead to some conflict in either case.

As shown in Tables 7.3-7.5, there are some parameters along which local and nonlocal populations differ which may have some serious consequences in terms of socioeconomic impacts. In general, the immigrating construction work force tends to be younger, better paid, less tied to familial responsibility, and less permanent. The operating work force tends to be younger and better educated and to have more children in school than the host population.

Referring to Table 7.6, one sees the range of impacts which may result from differences and similarities between the two populations. In general, socioeconomic impacts may be divided into three separate problem areas: the provision of local services (public and private), problems of social organization, and attitudes and values. To date, the bulk of relevant social science research and assessment has dealt with the first of these areas, and, conventionally, with but a subset of potential impacts. Most concern has been with the timely provision of sufficient educational, law enforcement, housing, utilities, and health and medical services to impacted populations. The general findings have been that, varying directly with the amount of population growth, the

Table 7.3. Profile of operational workers[a]

Parameter	Value
Age	
26-35	34%
Education	
High school	73%
Marital Status	
Married	82%
Single/widowed/divorced	19%
Average family size	3.4 people
Children school age (5-18)	38%
Type of dwelling unit	
Permanent, single-family home	63%
Mobile home	31%
Residency in area	
Expect to leave the area when work is unavailable	36%

Job tenure and previous residence	In state (but different location)	Out of state
Length of time employed (months)		
0-12	87%	104%
More than 60	21%	20%

[a]The data used is primarily from the Wyoming area; however, the staff believes that other areas can be expected to be roughly similar. Except as noted, the information has been derived principally from "The Residents of Sweetwater County, Wyoming: A Needs Assessment Survey," by Bickert, Browne, Coddington, & Associates, Inc., October 1974.

Source: Draft of Generic Drift EIS on Uranium Milling Operations (Argonne National Laboratory, personal communication, October 11, 1978).

Table 7.4. Profile of construction workers[a]

Parameter	Value[b]	
	Nonlocal[c]	Local
Source of workers	60.0%	40.0%
Age		
25-34	23.0%	14.0%
Education		
High school	46.0%	44.0%
Salary (construction/operational)		
$10,000-$14,999	18.0%	24.0%
$15,000-$24,999	58.0%	39.0%
Marital status		
Married w/family present	50.0%	82.0%
Married w/o family present		
(nonlocal only)	25.0%	
Single/widowed/divorced	25.0%	18.0%
Age of household heads		
25-34	41.0%	24.0%
35-44	16.0%	23.0%
Average family size	3.6 people	3.8 people
Children school age (5-18)		
(nonlocal only)	23.3%[d]	
Residency in area		
Take-up residency	10%	76.0%
Stay as long as work is available	51.0%	10.0%

[a]"Construction Worker Profile, Final Report," Mountain West Research, Inc., December 1975.

[b]Some percentages do not total 100 because only certain classifications were used to give pertinent information on workers.

[c]Denotes elsewhere in state and out of state.

[d]"Social Impact Assessment of the Proposed Laramie River Station," Dept. of Sociology, University of Wyoming, December 1975.

Source: Draft of Generic Draft EIS on Uranium Milling Operations (Argonne National Laboratory, personal communication, October 11, 1978).

Table 7.5. Selected characteristics of host counties/communities in uranium resource states

County/City	Population 1970	Population 1960	Sex, 1970 % female	Sex, 1970 % male	Age, 1970 % under 18 years	Age, 1970 % over 65 years	Age, 1970 Median age	Ethnicity, 1970 % foreign stock	Ethnicity, 1970 % Hispanic	Ethnicity, 1970 % Indians	Ethnicity, 1970 % Black	Education Median years	Income and employment % unemployed	Income and employment Median family income	Per capita median income	% of population receiving support[a]	Debt $ millions General debt outstanding	Debt $ General debt/capita
Fremont County, Colo.	21942	20204	49.0	51.0	6.6	17.6	35.9	11.5	8.5	0.3	1.2	11.9	4.4	6817	2261	29.4	3.9	178
Canon City, Colo.	9206	8973	46.7	53.3	22.2	23.0	40.9	1.7		0.3	2.8	11.6	6.0	6244	3011			
Valencia County, N.M.	40539	39054	50.1	49.9	38.1	5.6	21.7	5.0	55.8	15	0.4	11.3	3.8	7609	1970	15.0	3.7	91
Grants, N.M.	8768	10274	50.2	49.8	47.5	2.6	19.6	2.8		1.6	0.7	11.9	1.7	9178	2310			
Karnes County, Tex.	13462	14990	51.6	48.4	8.6	12.8	28.9	10.1	41.0	0.02		8.7	3.4	5524	1749	26.9	3.6	267
Falls City, Tex.																		
San Juan County, Utah	9606	9037	49.6	50.4	43.9	4.5	18.0	5.2	<5			10.7	3.5	6601	1705	41.0	1.0	104
Blanding, Utah	2250		50.4	49.6	50.2	5.5	18.7				0.2							
Converse County, Wyo.	4281	4588	50.0	50.0	34.7	12.8	31.4	9.4	<10	0.4	0	12.2	4.3	8947	2709	26.2	1.4	327
Douglas, Wyo.	2677	2822	52.5	47.5	32.7	16.1	35											
Average county	17966	16975	50.1	49.9	26.4	10.7	27.2	8.2	24.1	3.93	0	11.0	3.9	8100	2079	27.7	2.7	193.4

[a]Age Supplemental Disability Health Insurance recipients + old age assistance + Aid to Familes with Dependent Children.

Source: City and County Data Book, 1972, Census of the Population 1970.

Table 7.6. Sociocultural problem identification matrix

Sociodemographic differences in resident and immigrant populations	Problem areas		
	Local services	Social organization	Attitudes and values
Age	Recreation Education Law enforcement Health and medical Housing	Social participation Dependency	Social disorganization Social control Spending patterns Family life
Sex	Recreation Housing Law enforcement	Social participation Income Job opportunities	Social disorganization Social control Spending patterns Family life
Race	Law enforcement Health and medical	Educational Opportunities Job opportunities Income Social participation Political participation	Social control Social disorganization Religious needs Family life Spending habits
Education	Recreation Education Health and medical Library	Educational opportunities Job opportunities Income Political participation	Family life Spending patterns Religious needs
Occupation	Recreation Education Support institutions (occupational institutions)	Job opportunities Income	Social control Spending patterns Family life Religious needs
Income	Recreation Housing Other social services Health and medical	Educational opportunities Job opportunities Social participation Political participation Dependency	Social disorganization Social control Spending patterns Family life Religious needs

level of each of these services must be substantially upgraded to meet demand. Less often we have attended to the potential impacts on recreation, cultural, and other social services. Given the smaller scale of employment and, thus, of immigration for uranium development projects than for other energy development projects, and given the shorter time frame of construction, the expected impacts of uranium development on local services should not be as great as other projects. This is not to say that there will be no impact but simply that the impacts will be less and should be more easily amenable to mitigation.

The second order of socioeconomic impacts, social organization, is composed of a wide variety of potential problems that are dependent upon both the scale of development and interpopulation differences and may also be a function of the resolution of problems regarding the provision of adequate local services. For instance, if the immigrant population is better paid than the host population (as is likely to be the case) they are likely to make demands for high levels of opportunities for themselves and their children, participate at a higher rate than the local populace in social and political activities, and be less dependent upon public welfare. Further, through their social and political participation, the immigrant population (particularly the operating work force) is likely to make their demands known and acted upon.

Finally, according to the Sociocultural Identification Matrix (Table 7.6), core attitudes and values may be significantly impacted by energy development activities and by the primary impacts of these projects. It is in this realm that the social pathologies associated with the "Gillette syndrome"* may occur. Attitudes toward social control, family life, and religion may differ among the two populations, and some of these differences may be reflected by different spending patterns.

---

*"Gillette syndrome" refers to many of the changes caused by energy development observed in Gillette, Wyoming. See Institute for Social Science Research (19740, "A Comparative Case Study of the Impact of Coal Development on the Way of Life of People in the Coal Areas of Eastern Montana and Northeastern Wyoming," University of Montana, Missoula.

In some parts of uranium resource areas there are already quite
diverse cultural and ethnic groups, and the imposition of yet another
group may upset the balance of relationships which previously existed.
Specifically, Mormons (in Utah), native Americans (chiefly Navajos in
New Mexico, Utah, and Arizona) and Hispanic Americans (mainly in New
Mexico) live in these areas, and uranium development could seriously
alter the social climate and cultural heritage prevalent in many regions.

In addition to changing potentially the racial and religious com-
position of impacted communities, population growth due to uranium
development may also result in tension between host and immigrant popu-
lations. Long-time residents may feel a loss of intimacy and community,
and conflicts may arise between those who favor a more urbane lifestyle
and those who wish to preserve a small-town atmosphere.[12] However,
due to the short construction time, value conflicts will normally occur
during the operating stage of the mine and/or mill when immigrants are
more likely to settle "permanently." It is expected that there will
be a mutual adaptation between divergent values. This adaptation may,
of course, be conflictual rather than cooperative.

A special case is presented when uranium development occurs on
Indian lands. This is due not only to the special status of native
Americans in the American political system and to their ultimate control
over a vast amount of uranium resources, but also to very real dif-
ferences between native Americans and Anglos in terms of educational,
economic, and occupational achievement. Although the socioeconomic
status of native Americans is clearly improving, due in large part to
their own efforts, the relative differences between these two population
subgroups are still great. It can be expected that these differences
have serious consequences in terms of the socioeconomic impacts of
uranium development in directions other than those already mentioned.
In most cases local (tribal) services will not be severely impacted by
the immigrant population since they will, generally, be segregated
from the reservation itself. Rather, the impacts on local services will
result from demands made by tribal members at large, who wish to receive
the benefits of the leasing arrangement, and especially by those tribal
members who are employed by the developer at much higher rates of pay

than they were previously paid. Developers and tribal leaders alike
are attempting to improve occupational opportunities for Indians on
uranium development projects,[13] and, thus, to increase the beneficial
impacts of development. There are several potential unanticipated
consequences of this approach. If employees are chosen from among
those who are already employed there may be no net gain in employment.
Further, differences between income levels for project employees and
all others may be so great as to create jealousies and competition among
peoples who are not culturally attuned to such attitudes and behavior.
Finally, previous Indian employment programs related to energy develop-
ment projects have not been wholly successful due to cultural differences
in interpretation of what constitutes an appropriate role model for
employment. The PINTO program, sponsored by Westmoreland Resources for
Crow Indians, attempted to change Indian perspectives on employment to
correspond to a western European model (40-hr week and permanent
employment) rather than modifying the employer's expectations to meet
a culturally dominant model which accounts for absenteeism for religious
holidays and family obligations.

An additional impact of uranium development on Indian tribes has
been increasing professionalization of tribal capacity for resource
management and planning. Although this can be seen as a salutary impact,
the process of professionalization is encumbered by previously low
education levels among native Americans. The conjunction of professional
and rational approaches to economic development with religious and
cultural attitudes which value harmonious relationships between man and
his environment may also create conflict within the various tribes.

7.3.3 Socioeconomic impacts upon regions and states

The primary uranium resource regions in the United States correspond
roughly to those regions in the western states which have abundant
resources of other fuels (oil, oil shale, and coal). It is difficult
to separate the impacts of uranium development in southeastern Utah,
northwestern New Mexico and the Powder River Basin in Wyoming from the
impacts of massive coal development. At the regional level one is

likely to see the economic benefits of uranium and coal development
and less likely to see the adverse impacts which are more clearly
visible at the community level.

At the state level the impacts of uranium development are chiefly
governmental and administrative. As in the case of New Mexico there may
be inadequate resources to be able to assess environmental impacts of
development and, thus, a diminution of ability to plan for development
intelligently. At least in Utah, potential tax revenues seem significant:
sales, mine occupation, corporate franchise, and personal income taxes are
all collected by the state. During construction of White Mesa Mill, sales
taxes alone are projected to be approximately $450,000. All of the resource
states have initiated, relatively recently, administrative mechanisms to
facilitate energy resource planning for development, but capabilities are
uneven. Each resource state finds itself in a dilemma in terms of opti-
mizing the impacts of development for the state and the impacted communities
It is quite difficult for governments to devise optimizing development
formulae with respect to severance taxes, environmental protection (within
a federal framework), and interstate competition. These solutions are all
sought within environments which are essentially political, and, thus, not
necessarily rational.

7.3.4 Impacts peculiar to uranium development

Generally, most of the socioeconomic impacts of uranium mining and
milling are quite similar to those of other resource development pro-
jects. Depending upon the level of immigration and the degree of
interpopulation differences and similarities, there will be impacts upon
the provision of public and private goods and services, and these impacts
will be in the nature of competition for scarce resources or demand for
new and different resources. Even though the scale of employment for a
given uranium mine or mill is likely to be much less than for other
energy development projects, impacts on local services may be significant
given the considerable colocation of mines and mills.[14] The kinds of
impacts mining and milling will have on parameters of social organiza-
tion and attitudes and values will be affected by the extent of co-
location.

There may be some impacts which could be greater for uranium mining and milling than for other forms of development, and these derive, in part, from the nature of the industry. First is the impact of initial development promoting ancillary development. Mill sites are often chosen in areas with large ore concentrations that have not yet been mined. Mills are intended to stimulate mining, and mining and milling development are often planned simultaneously. For example, Kerr-McGee plans to open a 2500 MT/day mill, nine underground mines and four surface mines in Converse County, Wyoming. The colocation of mines and mills, due primarily to high transportation costs, is significantly different than many other energy facility developments and leads to cumulative socioeconomic impacts which are difficult to dissaggregate in a quantifiable fashion.

A second industry-related impact is that there may be significant increases in local traffic. This is not due so much to increases in automobile traffic as to increases in heavy truck traffic. Transport of large volumes of ore by truck places considerable stress upon local road networks that may not be adequate to the task. Not only might there be traffic problems, associated accidents, and increased needs for traffic control, but there may be accelerated road degradation.

A major impact of uranium mining and milling is withdrawal of groundwater resources and potential degradation of water resources. It is estimated that, in New Mexico alone, between 1.35 and 6.28 million acre-feet will be used by the uranium industry between 1978 and 2000.[15] Such high requirements must compete against other potential users of groundwater (e.g., agricultural, municipal). Depending upon the outcome of this conflict, development of the uranium industry may be constrained or other uses may be curtailed.

Finally, there may be increased perception of risk among both employees of the development and the proximate population. Although uranium mines and mills are required to operate in a manner which does not increase threats to public health and safety and must incorporate procedures to minimize exposure to radon daughters, some employees and some of the public have yet to be convinced that such measures are sufficient to minimize these threats.[16] Whether or not safety precautions

are actually adequate may be less important an impact than the perception of those persons in an impact region that they are at risk. This perception may well lead to local opposition and demands for compensation.

7.3.5 Summary

The socioeconomic impacts of uranium mining and milling are in most qualitative parameters comparable to those of other types of energy facilities in resource areas of western United States. For other than those impacts just noted (colocating development, transportation/ traffic, and local risk perception), impacts from mining and milling are likely to be less noticeable than for other energy resource developments. Given the quantity of resources on Indian lands and relatively great differences between tribal populations and immigrant populations on sociodemographic characteristics, special attention should be paid to impact assessment and mitigation strategies in these situations. It is clearly the responsibility of the federal government, of the developers, and of the tribes themselves to monitor development and its impacts in order to be able to minimize adverse socioeconomic impacts.

7.4 State Monitoring and Mitigation Policies

Adequate governmental programs for mitigating the socioeconomic impacts of uranium development do not operate at present at either the federal or state level. Efforts are being made by social science analysts to require monitoring of development,[17] but, to date, there is no federal effort being made to require mitigation.

In the uranium resource states of New Mexico, Wyoming, Utah, and Colorado no state requirements have been imposed either. Except for Colorado, however, each of these states has developed some mechanisms for dealing with the socioeconomic impacts of other kinds of energy development. The type and degree of state regulation of these other types of energy development is reviewed to suggest some likely state responses to uranium development in the future.

Of the four states that are most likely to experience socioeconomic impacts from mill and mine development, two (Colorado and New Mexico)

are agreement states, and two (Utah and Wyoming) are nonagreement states. While no state has yet required mitigation of the socioeconomic impacts of uranium mill or mine development, Wyoming has required extensive mitigation of coal development impacts, and is currently requiring Kerr-McGee to prepare a socioeconomic impact study of a uranium mine/mill complex it is constructing. New Mexico has a taxation system which helps to mitigate the socioeconomic impacts of energy developments, and its legislature has given serious consideration to establishing other mechanisms for handling such impacts. In Utah an Interagency Task Force on Power Plant Siting, composed of representatives of local governments as well as other parties at interest, utilizes site reports to advise the governor of the acceptability of power plant sites. Colorado's legislature has not yet passed a severance tax on minerals or any bills requiring energy industries to provide funds to impacted localities. Thus, of the four states, Wyoming has the most developed system for impact mitigation, Colorado, the least, and Utah and New Mexico somewhere in between. Some information on the mitigation mechanisms each state has used, or is considering using, is given below.

7.4.1 Colorado

Unlike most western states, Colorado has no severance tax on minerals. Governor Richard Lamm has consistently supported a severance tax, but the legislature has repeatedly voted against it. Recently, agreement on the need for such a tax has been reached, but conflict over the level of taxation has prevented legislative action.

Colorado has established a state Socio-Economic Impact Office which monitors energy activities in the state. This office has conducted research, encouraged the development of local boards and impact assessment teams, and monitored the impacts of energy development. The Socio-Economic Impact Office cannot, however, require energy industries to provide funds to mitigate impacts. In fact, Colorado has no legislation enabling any state agency to require industries to provide mitigation funds, nor to provide such funds from state revenue sources. Since local jurisdictions have little political leverage in dealing with

energy companies, they also have been unable to require any sort of mitigation payments.

A number of bills designed to provide for the mitigation of energy impacts were introduced in Colorado's 1975, 1976, and 1977 legislative sessions. None of these bills were passed. Colorado's legislature has also made the management of energy impacts more difficult by exempting power plants owned by municipalities from *ad valorem* taxes, and by refusing to raise tax rates on mobile homes. A constitutional provision that prohibits the state from incurring a debt on behalf of a locality adds a further constraint on the expansion of the state's role in impact mitigation. Because of the legislature's opposition to impact management programs, it seems unlikely that Colorado will have any mechanisms for dealing with uranium mine and mill impacts in the near future.

7.4.2 New Mexico

Half of the uranium produced in the United States over the last 20 years has come from the northwest quadrant of New Mexico. An increased pace of development is expected in this area in the next few years. Many of the new mines (probably 70 or more) will be on Indian lands where the state has no jurisdiction. Much of northwest New Mexico has a mixture of land ownership patterns including federal, state, private, Indian, and railroad lands. Responsibility for regulation of development is often unclear with such mixed ownership patterns. In the Crown Point, New Mexico, area five uranium companies are expected to begin operation before 1980 and to eventually be producing about 8% of U.S. uranium supplies. Major socioeconomic impacts are expected since very few people live in the area now. The state's main concern is with water use problems. Uranium mine dewatering results in dumping tremendous volumes of water from aquifiers onto the surface. Excessive water use might lead to state restrictions on mine openings.

The state legislature of New Mexico generally has a prodevelopment, proindustry bias, but it has authorized some funding for energy-development impact assistance. In 1977, ten million dollars were used for water and sewer expenses in communities with oil, gas, coal, and uranium developments. In 1978 a maintenance level of funding was authorized, but no

new projects were undertaken. There is about a 5% severance tax on minerals. Revenues from this tax are put into a permanent bonding fund. Community Impact Assistant loans are made from this fund to communities affected by energy development. These funds have been used mainly for highway and road building and repair. The establishment of a siting authority similar to the one in Wyoming was discussed by the legislature, but no action was taken. There was also consideration of the need for state programs that provided for (1) early planning through industry-community cooperation, (2) state assistance in planning and impact assessment, (3) flexible financing arrangements, (4) monitoring systems and follow-up studies, and (5) assistance to communities in achieving economic diversification. Even though the state legislature is aware of the need for such programs little action has been taken to date. One reason for state inaction is a belief that since energy development impacts result from federal policies the federal government should pay mitigation costs. State government is also reluctant to pay mitigation costs, because nearly all of the uranium and much of the oil, gas, and coal produced in the state is exported.

7.4.3 Utah

Utah allows for mitigating the adverse public service impacts caused by natural resource development through prepayment of sales and use taxes; however, this 1975 legislation has been used infrequently. Additionally, the state provides some flexibility for intergovernmental agreements, whereby several municipalities and counties can band together to form special districts. However, the regulations merely allow for the possibility of the action which must still be voluntary on the part of all parties. The regulations do not apply to sharing of tax revenues.

The state's Interagency Task Force on Power Plant Siting may serve as a model for Utah if it decides to pursue mining and milling questions and, more particularly, if Utah decides to become an agreement state. Although the task force at present has no regulatory authority and serves only in an advisory capacity, its broad-based composition of federal, state, and local officials and environmental, consumer, and industry groups, and its operating policies of reviewing site reports,

analyzing acceptability through a detailed siting matrix, and reaching consensus decisions, make it a mechanism which has much potential for addressing questions of socioeconomic impacts of energy development.[17]

7.4.4 Wyoming

The state of Wyoming has taken an active role in the management of the impacts of energy developments. The principal tool for controlling energy development is presently the Wyoming Industrial Development Information and Siting Act passed by the 1975 session of the state legislature. This act

> "...created an Industrial Siting Council and the Office of In-
> dustrial Siting Administration within the Office of the Governor,
> to serve as staff to the Council. The Siting Act requires all
> industrial activities with a proposed construction cost in excess
> of fifty million dollars and all energy conversion facilities in
> excess of certain capacities to apply for a permit from the Council
> prior to the commencement of construction. It requires the payment
> of substantial fees used by the Office of Industrial Siting Admin-
> istration to review the impacts of the proposed project... The
> Council has the power to refuse a permit.... and may also place
> conditions on the permits which it does grant."[16]

To date only two permits (neither related to uranium development) have been granted by the Siting Council. One was the permit for the fourth unit of the Jim Bridger Plant. This permit was granted without re-quiring any mitigation of socioeconomic impacts. The second permit application, submitted in 1976, was for the development of the Basin Electric Power Co-operative's Laramie River Station coal-fired gener-ating complex near Wheatland, Wyoming. The permit for the development at Wheatland required Basin Electric to finance a number of public services if adequate public funds were not available. The exact type and level of services to be provided was not specified in advance. Instead a monitoring board to review impacts and to implement contin-gency plans as needed was established.[18] By 1978, Basin Electric had spent 6 million dollars for housing and mobile home parks. The company

expected to recover about 4 million dollars by reselling and renting this housing.[19]

Basin Electric also acted as guarantor of a 3.4 million dollar loan granted to Wheatland by the Wyoming Farm Loan Board. The Farm Loan Board, which consists of five elected state officials (Governor, Secretary of State, Auditor, Treasurer, and Superintendent of Instruction) has granted loans to a number of energy impacted communities. Most of these loans were used for water and sewer improvements. Some were used for other purposes such as hospital, nursing home, highway, and airport expansions.

The Farm Loan Board (FLB) is authorized to disburse funds to local areas from two sources. First, under the Joint Powers Act of 1974, the FLB can grant loans (from a permanent 40 million dollar state fund) to locally formed Joint Powers Boards which enable local governments to undertake projects that they could not afford to undertake individually. These Joint Powers loans are not legally restricted to communities impacted by energy developments, although most of the loans have been granted to such communities. The second source of loan funds the FLB authorizes is from coal severance taxes. These funds must go to areas affected by coal development and must be used for highway, road or street improvements, or for water and sewer projects.[18]

The state of Wyoming has not yet acted to mitigate the socioeconomic impacts of any uranium developments. But state officials are aware of the possibility of a uranium development boom in Wyoming. The Industrial Siting Council is currently requiring Kerr-McGee to file for a permit for a proposed 600 million dollar uranium mining and milling complex in Converse County. As part of the permit application Kerr-McGee must prepare a socioeconomic impact study, and mitigation funds may be required if the council decides they are needed.[20] Loans authorized under the Joint Powers Act also could be granted to communities impacted by uranium development.

If the state of Wyoming continues to support the principle of socioeconomic impact mitigation as firmly as it has in the past, it will probably develop programs for the management of the effects of uranium development. A major difficulty at present is the requirement that

development costs exceed 50 million dollars before a project is required
to apply for a state permit. Since many, if not most, uranium mines
will not exceed this limit, they would not be regulated under current
legislation. The legislature could lower the cost limit for permits,
but the problem of handling cumulative impacts would still remain.
Typically, a single mine or mill will have relatively minor impacts.
But when the cumulative impact of all the mining and milling activity is
considered there may be major impacts. As was suggested in the intro-
duction to this section, a resolution of the issue of cumulative impacts
is crucial to successful management of the impacts of uranium develop-
ment.

7.4.5 Summary

Since uranium mines are not licensed by any particular federal
agency but are subject to the regulations of the federal agency on whose
land the mine is located, if they are located on federal land at all,
social impact mitigation programs will probably be of two kinds:
regulation by the state and/or voluntary mitigation by industry.

The four states which will probably receive the most uranium exploi-
tation in the future have a range of systems for impact mitigation,
varying between very well developed (Wyoming) to virtually undeveloped
(Colorado). There are, however, several examples of voluntary impact
mitigation whereby industry has recognized the need to deal with social
impacts as related to quality of life and worker productivity and stability.
Examples of voluntary action include (1) Colstrip, Montana; (2) Atlantic-
Richfield's development south of Gillette, Wyoming; and (3) the Ticaboo
and Blanding developments in Utah. In the absence of consistent federal
or state regulations, the encouragement of voluntary activities seems
to provide the most promise for mitigating adverse socioeconomic impacts
of uranium development.

7.5. A Monitoring Program for the Socioeconomic Impacts
of Uranium Mining and Milling

Efforts to mitigate the adverse socioeconomic impacts of uranium
mining and milling must be based upon a better understanding of the
dynamics of rural community change than we presently have. In part we
can enhance our understanding by reviewing the considerable literature
which has recently developed on socioeconomic impact assessment and
impact mitigation.[21] This literature, however, is not consistent in
its findings regarding either the identification of impacts or the best
way of mitigating them. With this degree of uncertainty in the relevant
literatures, and with the uncertainty endemic to the nature of uranium
development, it is preferable, to describe those circumstances under
which impacts may be severe enough to require mitigation. Following
this, an outline of a monitoring plan is suggested which could provide
information essential to the mitigation of those impacts.

7.5.1 Problems in impact mitigation

There are a number of basic questions which must be addressed
regarding the mitigation of socioeconomic impacts of planned social
change. Who is to benefit from mitigation? Who is to pay for mitiga-
tion? How shall mitigative responsibility be assessed when there are
multiple causes of impacts? Once these questions have been resolved,
how can mitigation best be instituted in a diverse and pluralist economy
and polity?

Recent reports from the Denver Research Institute (DRI) and the
Department of Urban Studies and Planning at MIT point out a basic con-
tention regarding the nature of socioeconomic impacts and consequent
mitigation strategies.[21] Due largely to differences in how the two
groups of studies approach the phenomenon and the assumptions they make
regarding the dynamics of rural community change, DRI favors a mitigation
plan which will benefit the entire impacted community (immigrants and
long-time residents), while MIT favors mitigation strategies which would
benefit only those persons who were long-time residents of the impacted
community. Gilmore and his associates at DRI believe that many of the

worst impacts derive from a diminution in the "quality of life" of a community which, in turn, is dependent not only on the primary impacts of an intervention (e.g., uranium mill, coal-fired power plant, or a synfuels plant), but also on the dynamic interplay of a variety of intervention characteristics. Their scenario is composed of a sequence of events and conditions which lead to a vicious circle whereby initial impacts lead to inadequate public services, which lead to diminution of quality of life, which leads to labor transience, which leads to a further lessening of the quality of life. More simply, from the notation in Table 7.6, problems in local services lead to high rates of labor turnover which leads to problems of social organization and attitudes and values. Based on their analysis and on their analytical framework, Gilmore and his colleagues naturally prescribe a mitigation strategy whereby compensation is made to public groups (i.e., local governments) so that they can improve the quality of life for all affected citizens.

The MIT studies base their analysis and their suggestions upon a more strict definition of who should benefit from mitigation. Since immigrants have the option of whether or not they will participate in the project, they should not be the beneficiaries of mitigation. Long-time residents of the impacted community have no such option and should, thus, be compensated for their loss through direct payments to the individuals.

The question of who is to pay for mitigation is equally contentious. In the case of uranium mining and milling, the viable options range from total federal government responsibility to total industry responsibility. Since the National Energy Plan,[22] a federal policy, calls for a tripling of production of uranium, some feel that the federal government should assume total financial responsibility for mitigation.[23] On the other hand, some feel that industry and its consumers should underwrite mitigation costs.

As noted in the previous section some of the most promising mitigation efforts are those in which industry plays an active role. Given NRC's present position not to require the mitigation of socioeconomic

impacts of uranium mills, the most likely strategy for financial responsibility for mitigation seems to be one in which industry and state and local governments, acting together, assume such responsibility. The degree of participation by each of these parties is ultimately a decision which rests with the respective state governments.

One of the most pressing problems in providing mitigation is institutional in nature. Even if monies can be appropriated for mitigation, the identification of mechanisms for dispensing the money to the appropriate governmental jurisdiction is often problematic. The problem is generally one of a temporal and/or a spatial mismatch. Monies are not delivered in a timely fashion so that mitigating solutions are applied at the time of greatest impact, or they are not delivered to the impacted jurisdiction but to the one which collects the project's property tax revenues.

Another problem which is particularly acute for uranium development is that of being able to disaggregate the impacts of several causal agents. If mines and mills are sited in areas which already have or are soon to have other energy development projects, it is not presently possible to assign differential responsibility for impacts or the costs of mitigating them. A corollary to this is that if other projects are in place and have not previously been required to mitigate impacts, the imposition of responsibility to a new project in the same location brings questions of equity into the situation. Resolution of these problems is essential if a rational approach to mitigation is to be found.

The basic structure of mitigation, as implied in the studies at DRI and MIT, is whether to segregate immigrants from or integrate immigrants with the preexisting community. In the case of energy development it may be wise to consider construction and operational phases separately. If construction causes a temporary immigration of more than 10 to 15% of the base population to occur, segregation of the two populations may be more appropriate than integration. In this way impacts to the preexisting community and its population may be minimized. For the operational phase of the project, where the labor force is generally not so great and where the work force is more permanent, integration of the two

populations is more advisable. In the case of uranium development some of these considerations may be largely foreclosed due to the small size of the labor force.

7.5.2 Conditions requiring monitoring and mitigation

Under some conditions of uranium development it may be necessary to develop and implement comprehensive monitoring and mitigation mechanisms. These conditions may additionally require that the mechanisms be implemented differentially (i.e., integrate the populations for some but segregate them for others). Specifically, we feel that there may be severe impacts when any of the following conditions exist: (1) colocation of uranium mills; (2) colocation of a mine and/or a mill with other energy development projects; (3) location of mines or a mill on Indian lands; (4) if road conditions are likely to be severely impacted; and (5) if the immigrant and/or the native populations feel they are at some health risk due to the presence of a uranium mine or mill.

7.5.3 Monitoring plan development considerations

Monitoring of conditions may be deemed necessary in the above situations for a number of reasons. First, monitoring impacts may facilitate the uranium development project itself. If the host population knows that conditions in their community are being monitored for adverse impacts they may be more likely to accept the development. Secondly, we have no way of knowing, with any certainty, what all of the impacts might be for a wide range of development scenarios cast against a wide and diverse range of host communities. While we do have some idea of the directionality of many of the impacts and may have some idea of the magnitude of the impacts, our knowledge is still imprecise and is likely to remain so. Finally, there may be a moral, if not legal, obligation to monitor impacts. The unequal distribution of costs and benefits of any given project to spatially separated communities does require attention and mitigation.

Once a decision to monitor socioeconomic conditions has been made, one must select which conditions to monitor. It is not feasible to monitor every condition in every impacted community, but some information is vitally important and should be monitored if we are to mitigate the most significant impacts.

In terms of potential impacts on local services the most important information is population and demographic change. Immigration should be monitored in gross terms and by age, sex, education, income, race, and occupation. If we can determine net population change and the nature of that change, policy-makers would be better able to predict and mitigate the adverse impacts of that change. There should additionally be a check on changes in the use of public services.

An effective way of designing a monitoring program would be to include local populations as early as possible in the development planning process. Ask the local population what they think will be impacted and what their needs are and might be in the future. In those communities where a construction or operating force is already present, ask them as well. It is impossible for analysts to prescribe a monitoring or mitigation program without significant input from the many parties at interest.

REFERENCES FOR SECTION 7

1. George Montet, Draft of Draft Generic EIS on Uranium Milling
    Operations (Argonne National Laboratory, personal communication,
    October 11, 1978), pp. 3-29.

2. *Final Task Force Report on the Agreement State Program*, Office of
    State Programs, U.S. Nuclear Regulatory Commission, Washington,
    D.C., NUREG-0388 (1977).

3. Stone and Webster Engineering Corp., *Uranium Mining and Milling*
    (Prepared for Western Interstate Energy Board under EPA Contract
    #68-01-4490, May 1978), pp. 4-6.

4. Much of this discussion is based upon The Center for Public Issues,
    University of Denver, *Workshop on the Federal-State Regulation of
    Uranium Mills* (Prepared for the Office of State Programs, U.S.
    Nuclear Regulatory Commission, under Contract #NRC-06-78-352;
    NUREG/CR-0029, February 1978).

5. The Wyoming Industrial Siting Council recently ordered Kerr-McGee
    to file for a permit for its proposed $600 million uranium mining
    and milling complex in Converse County. *Nucl. Fuel* 3: 12 (1978).

6. *The Energy Daily*, June 21, 1978, p. 4.

7. *Nucl. Fuel* 3: 4 (1978).

8. *Nucl. Fuel* 3: 12 (1978).

9. Manygoats vs. Kleppe, 558F.2d556 (10th Cir. 1977).

10. See the BIA's Final EIS on Exxon Uranium Mill on Navajo Tribal
    lands which was involved in the case of Manygoats vs. Kleppe;
    Nuclear Regulatory Commission, DEIS on White Mesa Uranium Mill
    (forthcoming); Stone and Webster Engineering Corporation, *Uranium
    Mining and Milling* (Prepared for Western Interstate Energy Board
    under EPA Contract #68-01-4490, May 1978).

11. R. B. Braid, Jr., "A Comparison of the Socioeconomic Impacts of Inter-
    national Fuel Service Centers Versus Dispersed Nuclear Facilities,"
    Proc. 1979 Institute of Environmental Sciences, Seattle, Washington,
    April 30-May 2, 1979.

12. *Nucl. News* 20: 70 (1977).

13. See Stone and Webster (1978) and S. A. Carnes, *Rural Community Change: A Study of the Preliminary Impacts of Two New National Parks on Peripheral Cities and Villages* (Evanston: Northwestern University, Ph.D. dissertation, 1978).

14. S. Vandevender, Sandia Laboratories, Albuquerque, N.M., personal communication, August 15, 1978.

15. Geohydrology Associates, Inc., "Water Budget," *San Juan Basin Regional Uranium Study*, Working Paper No. 19 (prepared for U.S. Department of Interior, September, 1978).

16. *High Country News,* Vol. 10, No. 5, March 10, 1978, Lander, Wyoming.

17. Southern States Energy Board, *Energy Facility Siting in the United States* (Atlanta: February 1978).

18. R. B. Foster, *State Responses to the Adverse Impacts of Energy Development in Wyoming* (Cambridge: Laboratory of Architecture and Planning, MIT, April 1977), pp. 20-33. Prepared for the U.S. Energy Research and Development Administration under Contract #E(49-18)-2295.

19. Interview with Blaine Dinger, Executive Director of the Wyoming Office of Industrial Siting Administration, August 18, 1978.

20. *Nucl. Fuel* 3: 12 (1978).

21. K. O. Moore et al., *Mitigating Adverse Socioeconomic Impacts of Energy Development* (Prepared for U.S. Department of Energy, January 19, 1978); Michael O'Hare and Debra Sanderson, *Fair Compensation and the Boomtown Problem* (Cambridge Department of Urban Studies and Planning, MIT), July 1977 (and other reports of the Energy Impacts Project); Elizabeth Peelle, *Internalizing Social Costs in Power Plant Siting: Some Examples for Coal and Nuclear Plants in the United States,* paper presented at the International Meeting of the American Nuclear Society, Washington, D.C., November 17, 1976.

22. Executive Office of the President, Energy Policy and Planning, *The National Energy Plan* (Washington, D.C., Superintendent of Documents, April 29, 1977).

23. The Department of Energy has arranged a series of policy options which range from maintaining the status quo to major federal reform initiatives costing $140 million per year. See *Inside DOE,* April 3, 1978, pp. 8-9.

8. ECOLOGICAL IMPACTS

8.1 The Mill Environment

Most uranium mill sites are located in western United States.[1] The characteristic topography is flat with moderate relief ($\sim$1200-1300 m). The climate is semiarid with mild summers and cold winters. Precipitation in this area is low, averaging $\sim$30 cm (12 in.) annually. Strong winds (4-6 m/sec average) are predominant, and dust devils are frequent. Human population density in these lands is low, but small urban centers of higher population density may be present along flood plains of rivers and streams. Air quality is generally good because of the low population density ($\sim$6 persons/km^2), lack of industrial pollution sources, and the dispersive characteristics of the region. However, high background concentrations of suspended particulates ($\sim$35 μg/m^3) are characteristic because of the high winds and sparse vegetation.

Agricultural use in western United States is limited by the available moisture. These lands are extensively grazed by livestock and may contain some croplands and orchards where moisture is available. Some of the land ($\sim$10%) along surface waters may be irrigated. Surface waters may be ephemeral streams, reservoirs, rivers, or small ranch impoundments. Groundwater is used principally for livestock.

Flora in the mountainous regions usually consists of ponderosa pine and Douglas fir, with pinyon-juniper communities at lower elevations. Vegetation characteristics of high plateaus consist of desert shrub and bunch grass communities. Cottonwoods, willows, and vegetable crops predominate at stream banks and around reservoirs. Mill sites, usually in short-grass prairie communities, are dominated by blue grama, buffalo grass, sagebrush, and rabbit brush. Mammals and birds which inhabit potential mill sites and surrounding areas include rodents, badgers, coyotes, pronghorn, mule deer, cottontail rabbits, jack rabbits, blue grouse, sage grouse, and a variety of raptors. Cattle and sheep may also be present.

8.2 Land Use

The land area used in the uranium milling industry is small compared to the combined area committed to other facets of the nuclear fuel cycle (i.e., mining and power reactors). For each metric ton of ore processed by a uranium mill, the tailings disposal area typically increases by about 0.1 m^2 (see Ref. 2). On this basis a 1814-MT/day (2000-ST/day) mill will utilize approximately 121 ha (300 acres) of land during the life of the plant for tailings disposal alone. Upon termination of milling, nearly 85% of the land originally dedicated to milling activities will have been committed to the retention of mill tailings. Upon cessation of the milling activities, the tailings areas may be stabilized by conventional reclamation practices to retard erosion and transport of tailings to the environs by wind and water. Current practice is to withhold such land from future unrestricted use in order to minimize potential exposures to man. Use of the uranium mill tailings is presently under legal control of the Nuclear Regulatory Commission, Agreement States or U. S. Department of Energy.

8.3 Nonradiological Air and Water Quality

Uranium milling activities release nonradioactive airborne contaminants in the form of dust to the environment. Dust is generated by weathering (wind erosion) of ore stockpiles and exposed dry tailings and from vehicle traffic along unpaved roads. Process dust is derived from ore crushing and grinding activities and from the yellowcake and calcining steps. Particulate emissions are generally controlled by wet scrubbers or bag filters. Contributions of mill-associated dust to ambient dust concentrations are generally negligible with regard to total mass since sources other than milling activities (natural weathering) are largely responsible for the ambient dust concentrations. However, there is an increase in suspended particulates during heavy equipment use, dry periods, and high winds.

Natural gas is used as a source of process and building heat in the milling industry. Products of combustion include nitrogen oxides,

carbon dioxide, and water vapor. Sulfur dioxide, sulfuric acid fumes, and ammonia may be released during leaching. During the solvent extraction step, kerosene is vaporized to the environment. Compliance with State or Federal air quality regulations necessitates control of some gaseous effluents.

The liquid effluent from a nominal 1814-MT/day (2000-ST/day) ore process consists of 4898 MT/day (5405 ST/day) of slurried waste solutions which contain both soluble ore constituents and chemicals from leaching, stripping, and precipitation steps.[3] The waste milling solutions are discharged along with the solids into a tailings pond that is designed and constructed to prevent contamination of aquifers or seepage to surface waters. Effectiveness of past tailings-pond design has not been adequate to prevent seepage or periodic dam or dike failures. Contamination of surface waters by mill effluents can be prevented by careful construction and adequate maintenance of tailings ponds. However, contamination of groundwater is more difficult to control. Of major environmental concern for seepage are toxic elements, such as arsenic, vanadium, selenium, and molybdenum, which occur in trace quantities in the ore and may concentrate in mill waste solutions. Salinization of the soil via evaporation of the liquid effluent is also a major concern. Maintenance and monitoring of tailings ponds should be adequately controlled to insure long-term retention of mill effluents.

The solid wastes slurried in the liquid effluent consist of greater than 95% of the ore mill feed[4] and are composed mostly of sandstone and clay particles. As with the liquid portion of the mill effluents, toxic trace elements are of concern.

8.4 Soils

During the operation of a uranium mill, the main impact on soils results from chronic seepage of tailings pond impoundments and from deposition of windblown tailings.[5] Soils are expected to be affected by loss of organic matter, leaching of nutritive ions, and eventual salinization of the soil. Salinization destroys soil structure and increases erosion. Reclamation of salinized soils is difficult because

of the low precipitation characteristics of potential mill site regions.
Windblown tailings can lower soil pH and increase salt, SO_4, N, Na, and
As concentrations in surrounding soils.

8.5 Biota

The availability of moisture is the single most significant factor
limiting plant and animal life around uranium mills. It is not likely
that mill activities will have as significant an effect on sensitive
habitats on a regional basis as rainfall because of the great land area
and low mill density involved. However, contamination of and intrusion
upon local habitats may result in significant effects on biota. Increased
road-kills and hunting pressure may be the most significant direct
impacts of uranium mine construction and operation on mammals and birds.
Removal or destruction of animal and plant communities from the mill
environs occurs during construction and active operation of the facility
and would probably result in unavoidable loss of individuals of some
species. This impact has been assessed within an ecosystem framework
(Table 8.1). The data presented in Table 8.1 indicate that there are
significant unavoidable impacts on the biota at a 250-ha (618-acre)
model uranium mill site due to construction and site operation. A
description of the model uranium mill used in this assessment can be
found in Ref. 6. Primary production is completely lost, while seed
production and mammal and bird biomass are depleted over 90%. Secondary
production, reduced by 40%, is the least impacted ecosystem characteristic.
The loss of primary seed, secondary production, and animal biomass in
the environment within a 40-km (25-mile) radius of the mill site is less
than 1%. The unavoidable adverse environmental impacts of a uranium
mill site appear to be significant within the 250-ha (618-acre) mill
site but minor or nonexistent in the entire 500,000-ha (1.2×10^6-
acre) area potentially affected by the site. However, subtle changes in
ecosystem structure may result in significant impacts over the entire
site area. Therefore, further investigation should be made of impacts
to ecosystem structure and impacts to individual species.

Significant uptake and accumulation by plants of trace elements
contained in mill tailings is not likely if future stabilization of the
tailings precludes the availability of suspect contaminants. However,

Table 8.1. Biotic loss at a model uranium mill site

Ecosystem characteristics	Ecosystem characteristics for uranium mill sites[a]	Total loss from mill site
Primary production (5.3E9 J[b]/ha)	1.3E12 J	1.3E12 J
Seed production (1.2E10 J/ha)	3.0E12 J	2.8E12 J
Secondary production (5.9E7 J/ha)	1.5E10 J	5.9E9 J
Small mammal biomass (35-96 g/ha)	9-240 kg	8-220 kg
Bird biomass (161-174 g/ha)	40-44 kg	39 kg
Livestock		5 cows or 25 sheep displaced
Large mammals		3-5 pronghorn displaced

[a]Area = 250 ha (618 acres).

[b]One joule (J) = 4.184E3 kCal.

Sources: J. A. Wiens, "Pattern and Processes in Grassland Bird Communities," *Ecol. Monogr.* 43: 237-70 (1973); N. R. French et al., "Small Mammal Energetics in Grassland Ecosystems," *Ecol. Monogr.* 46: 201-20 (1976); and, George Montet, *Draft Generic Impact Statement on Uranium Milling Operations* (Argonne National Laboratory, personal communication November 27, 1978).

salinization of local soils is a major concern and may result in permanent alteration or destruction of the plant community if extensive corrective intervention is not done. External radiation exposures to plant life imparts a chronic, low-level dose which is generally considered insufficient to cause measurable effects.

The effects of toxic trace elements originating from uranium milling activities on the terrestrial and aquatic biota have received little attention in the past. However, in grazing and browsing animals (deer, pronghorn, cattle, and sheep), the ingestion of plant materials and soil contaminated by airborne deposits containing translocated contaminants, or ingestion of contaminated storage or irragation water may be a significant exposure pathway. Animals that drink tailings pond effluents could suffer from chronic or acute selenium, arsenic or molybdenum poisoning.

Radiological impacts to grazing wildlife has not received sufficient emphasis. Estimated doses to grazing wildlife received from ingestion are not considered excessive and are not expected to cause measurable effects. It has been suggested that transmission lines may provide perch sites for raptors and may cause them to limit their range to mill sites and thus prey predominantly on rodents which may have elevated body-burden levels of toxic contaminants.[6] This may prove to be a significant pathway; however, there is no supportive evidence for this type of impact. The transfer of radionuclides and trace elements through the food chain from plants to beef is an important concern to man and should receive detailed analysis. However, there is a general lack of data on transfer of natural radionuclides from grass in the mill environs to meat.

Impacts of uranium mill wastes are expected to be minimal on surface waters because proper tailings pond construction should minimize seepage and overflow. In worst-case situations, radiation doses to aquatic organisms have been estimated assuming direct seepage from a tailings retention pond into surface streams.[7] Estimated total internal doses from the natural uranium, radium, and thorium effluents are well below the doses known to cause significant effects. However, effects from toxic contaminants such as selenium are yet to be assessed fully. Mill effluents are not intentionally discharged to surface waters, but seepage from tailings may result in contamination of surface waters with subsequent impact on aquatic biota. Exposures (radiological and toxic metals) may also result from tailings pond seepage to ground, thence to wells used for sources of irrigation or drinking water.

REFERENCES FOR SECTION 8

1. U.S. Environmental Protection Agency, *Uranium Mining and Milling: the Need, the Processes, the Impacts, the Choices,* Administrators Guide, EPA-908/1-78-004, Western Interstate Energy Board, Denver, May 1978.

2. U.S. Environmental Protection Agency, *Environmental Analysis of the Uranium Fuel Cycle: Part I — Fuel Supply,* EPA 520/9-73-003-B, Office of Radiation Programs, Washington, D.C., 1973.

3. U.S. Atomic Energy Commission, *Environmental Survey of the Nuclear Fuel Cycle,* Directorate of Licensing, November 1974.

4. D. A. Clark, *State-of-the-Art: Uranium Mining, Milling and Refining Industry,* Office of Research and Development, U.S. Environmental Protection Agency, EPA-660/2-74-088 (1974).

5. *Environmental Effects of Present and Proposed Tailings Disposal Practices, Split Rock Mill, Jeffery City, Wyoming,* Vol. 1, D'Appolonia Consulting Engineers, Inc., Study Report 3 (1977).

6. George Montent, *Draft Generic Impact Statement on Uranium Milling Operations* (Argonne National Laboratory, personal communication November 27, 1978).

7. B. G. Blaylock and J. P. Witherspoon, "Radiation Doses and Effects Estimated for Aquatic Biota Exposed to Radioactive Releases from LWR Fuel-Cycle Facilities," *Nucl. Saf.* 17(3): 351-61 (1976).

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

9. RADIOLOGICAL MONITORING AT URANIUM MINES AND MILLS

9.1 Introduction

Previous sections have dealt primarily with the determination of health effects through the employment of various theoretical constructs such as computer modeling. While such models are certainly a desirable endpoint to any scientific endeavor, it should be recognized that they require as input a variety of parameters which may be obtained only through direct measurements. In addition, empirical verification of these models is a necessary step in their development as acceptable theoretical constructs. It should also be noted that in certain pragmatic activities, such as routine radiological monitoring at existing and/or inactive mining and milling facilities, there remains a need for techniques useful in the direct measurement of radionuclides. For this reason, it was felt that a discussion should be made of available techniques, their limitations, and areas where more research is called for. The techniques remain the same whether one is interested in model verification, development of input parameters, or the determination of standards compliance. In general, the following discussion will center on the determination of exposure fields resulting from the presence of those radionuclides which are present in any of the three naturally occurring decay chains. These exposure levels vary from site to site and must be accounted for in assessing the possible hazard resulting from mining and milling operations.

Any determination of the types of measurements to be made at a site must include an assessment of the pathways by which radionuclides may travel to the critical receptor (in this case, the human body). These exposure pathways have been described in earlier sections of this document, but it will be useful to briefly review them. The first pathway with which the discussion will deal centers around the alpha, beta, and gamma external exposure fields produced by the decay of radionuclides located in soil, on building surfaces, or in the local air (due to particle suspension). The radionuclides of primary interest in this respect are ^{234}Th, ^{234m}Pa, ^{214}Pb, ^{214}Bi, ^{210}Pb, and ^{210}Bi, with the majority of the gamma emissions resulting from the radioactive daughters of ^{226}Ra. Since most of the gamma radiation

from uranium ore results from the decay of radionuclides located below ^{226}Ra in the decay chain, the eventual extraction of ^{238}U and ^{235}U causes very little decrease in the beta and gamma intensity per unit source material.

Internal exposures will be considered to result from the intake of a radionuclide through ingestion, inhalation, or absorption through body wounds (normally considered to be an inconsequential pathway). Alphas emitting nuclides, as well as low energy beta-emitters, pose a health hazard only when there is some probability of internal exposure. Inhalation hazards result from the intake of airborne radioactive particles and gases, with primary concern being focused on ^{222}Rn and its radioactive daughters. In addition, suspension of ^{230}Th, ^{226}Ra, ^{227}Ac, and ^{228}Ra through the abrasion of contaminated surfaces or the grinding of ores must be considered as a potential exposure pathway. These radionuclides are included in the "very highly hazardous group"[1] and are subject to the most stringent controls. Their concentration (as well as that of ^{210}Pb, ^{238}U, and other radionuclides in the uranium, actinium, and thorium decay chains) must also be ascertained in local water supplies.

Contamination from mining and milling operations may enter the groundwater supply through leaching and/or ion exchange with soils containing those radionuclides. Primary concern here is placed on the transfer of ^{226}Ra and ^{238}U, although some authors have suggested that ^{226}Ra remains fairly localized in tailings piles.[2,3,4] At the present, it is difficult to determine the magnitude of contamination by uranium in groundwater whenever large quantities of uranium bearing ore are proximal, although ^{238}U has been shown to undergo leaching.[5,6] Additional research is needed to allow accurate estimates of the leaching of radionuclides from these tailings piles. The final exposure pathway consists of the ingestion of foods which contain radionuclides. This incorporation is governed by the biological uptake factors which relate soil concentration to plant concentration and airborne concentration to deposition on plant surfaces. As a result, it is necessary to determine the concentration of all radionuclides in local soil and air.

9.2 Measurement of Radon

It is generally agreed that the greatest health hazard associated with the mining and milling of uranium ores arises from the emanation of ^{222}Rn and the subsequent inhalation of radon and its daughters.[7-12] Epidemiological evidence of a potential for increased risk of lung cancer and other illnesses first became evident from studies of the lung cancer incidence among various groups of uranium and non-uranium miners,[13-20] although competing effects[19,21] make the problem difficult to resolve. A major part of any monitoring program at facilities contaminated with ^{226}Ra must focus on airborne ^{222}Rn.

Two basic methods may be used to determine the amount of radon being transported to a given location. The first involves direct measurement of the radon concentration at the place of interest, and the second requires the development of a source term followed by the use of various transport models. Studies have shown that, at a given location, radon concentration may vary by more than an order of magnitude over a period of a year.[22,24] This variation arises from a number of influences which effect the emanation of radon from the ground and the dispersion into the atmosphere. In addition, the radon concentration has been shown to vary widely within a given day.[7] As a result, radon measurements (Table 9.1) must be taken at many times of the year and averaged. For example, the Grand Junction Remedial Action Criteria,[24] requires that measurements be taken in six periods, each of at least 100-hr duration, and spaced at least four weeks apart. Single measurements may lead to gross distortions in the predicted yearly average.

A number of accurate techniques have been developed for the direct radon measurement and are reviewed in Table 9.1. Techniques involving grab samples will require that many measurements be taken at various times of the day throughout the year. For this reason, attention has recently focused on continuous devices which yield either a time-averaged concentration or a continuous output of concentration as a function of time.

The most prevalent grab sample technique appears to be the Lucas Chamber,[25,26] which is coated with a zinc sulfide scintillator that responds to the alpha particles emitted by the radon and daughter atoms. A filter placed across the inlet removes any radon daughters present

Table 9.1. Instruments for measuring radon

Instrument type	Application	Principle of operation	Sensitivity	Availability	References
Lucas cell	Grab or continuous	Scintillations	<0.1 pCi/liter	Inexpensive; easy to construct; easy to interpret	25,26
Two filter	Grab or continuous	Decay of radon in a known volume of air followed by daughter collection	<0.1 pCi/liter	Same as Lucas cell	29,30
George, George and Breslin	Continuous	Two filter-monitored by thermoluminescent-dosimeter (TLD) chip	0.05 pCi/liter when sampled for one week	Same as Lucas cell— requires a TLD reader	32,33
HASL pulse	Grab or continuous	Air admitted to sensitive volume of ion chamber	<0.1 pCi/liter	Same as Lucas cell	102
Activated charcoal	Continuous or long term	Absorption on charcoal-count using Lucas cell	0.01 pCi/liter	Requires equipment for de-emanation of radon plus collection	25,36
Activated charcoal	Continuous or long term	Absorption followed by counting on NaI	0.12 pCi/liter	Requires multichannel analyzer	36,37
Bedrosian	Continuous	ZnS over Polaroid film	200 pCi/liter	Cheapest of radon methods	38
Geiger	Continuous	Alpha track etch film	100 pCi/liter	Very cheap	39
Sill	Long term	Collection of air followed by counting	Same as Lucas cell	Easy to construct	34
George and Breslin	Continuous	Passive-TLD chip	0.03 pCi/liter over one week	Cost approximately $50	33
Wrenn and Spitz	Continuous	Passive-ZnS scintillator	0.05 pCi/liter	Moderate cost*	35a,35b
In vivo	Used to estimate body burden	Detection of either ^{210}Pb or ^{210}Po	Within a factor of 4 at 95% confidence	Expensive	40-44

*This unit has been computerized by ORNL, thereby reducing operating costs.

in the air. The Lucas Chamber has been incorporated into the design of
continuous monitors such as those reported by Harris et al.[27] and Glaude.[28]
Another short-term radon device is based upon the two filter method reported
by Fontan[29] and Thomas and LeClare.[30] Studies of this method by Breslin[31]
indicate that replication errors may approach 20%, primarily arising
from the effects of humidity and of the small amount of activity normally
retained on the filters. George[32] and George and Breslin[33] have adapted
this technique to a continuous monitor through the use of a lithium fluoride
TLD chip.

Sill[34] has described an integrating monitor which consists of a
small deflatable bag into which air is pumped at a flow of less than
125 mliter/min. The radon content of the collected air is then determined
by any of a number of techniques. A passive radon monitor consisting of
a flask into which radon atoms diffuse, has been developed by George and
Breslin[33] at HASL. A TLD chip monitors the radon emissions. A device
which has found wide use has been developed by Wrenn and Spitz.[35a,35b]
Radon diffuses through a foam cover into an inner chamber where the alpha
decay of the daughter products is detected. This continuous device has
recently been incorporated by the Off-Site Pollutant Monitoring Group
at the Oak Ridge National Laboratory into a system controlled by a
mini-computer, allowing measurements to be obtained over long periods
without the need for human attention. Other techniques for the direct
measurement of radon include collection on activated charcoal,[36,37]
exposure of Polaroid film covered by a zinc phosphor, and the use of film
badges to be worn by mine personnel (followed by a determination of
the number of alpha tracks).[39]

A number of alternative methods have been developed for the measure-
ment of radon exposure to miners. These methods involve measurements of
the amount of radioactivity residing in the miners themselves rather than
measurements of the mine atmosphere and, therefore, fall under the category
of personnel monitoring. Eisenbud et al.[40] have described a method of
in vivo measurement of the body burden of lead-210 as an indicator of
cumulative exposure to radon and its daughters. The method involves the
use of twin Cesium iodide and Sodium iodide crystals operated in anti-
coincidence with a single photomultiplier tube. It was difficult to
estimate the true exposure of his sample population, but best estimates

indicate that the method may be accurate to within a factor of two. Fisher[41] gives a good review of the model which may be used to estimate ^{222}Rn and daughter exposure from the ^{210}Pb body burden and suggests the use of an eight compartment model. He reports the accuracy to be within a factor of 2 at the 68% confidence level and to within a factor of 4 at the 95% confidence level.

The excretion of various radionuclides has also been used to measure cumulative exposure to radon. Bell and Gilliland[42] have studied the use of the ^{210}Pb content in the urine of beagle dogs exposed to atmospheres containing radon and its daughters and their results have lead them to begin studies on miners. The levels of polonium in the urine of miners has been studied by Inouye *et al.*[43] and Djuric *et al.*[44] who conclude that the method may be applicable under sufficiently high exposure conditions.

9.3 Measurement of Radon Daughters

Interest in the dosimetry of radon has been centered on the daughters of radon rather than on the radon itself. This has led to the development of devices which measure the concentration of radon daughters (Table 9.2). These daughters exist in air either as free atoms or attached to the surface of aerosols. Studies of the attachment of radon daughters to the atmospheric aerosol[45-47] and of the radioactivity on dust in typical mining and milling atmospheres[17,48,49] indicate that most of the daughters are attached to aerosols of less than 0.5 μm, with a large fraction attached to particles of less than 0.1 μm diam. In support of this hypothesis, measurements taken in mines showed that more than 60% of the daughters were attached to particles of less than 0.1 μm diam.[50,51] The unattached fraction tends to be less than 10%.[52,53] Since the MPC recommendation of the ICRP incorporates an estimation of the fraction of ^{218}Po atoms which remain unattached, it may be insufficient to simply monitor radon daughter concentrations without obtaining some estimate of the unattached fraction. Several methods are available for such a determination.

Table 9.2. Instruments for measuring radon daughters

Instrument type	Application	Principle of operation	Sensitivity	Availability	References
Kusnetz and Tsivoglou	Grab	Air drawn through filter	0.0005 ± 35% working level (WL)	Easy to use; inexpensive	58
Thomas	Grab	Modified Kusnetz — uses integration	0.0005 WL	Requires integration device	103
Martz and Others	Grab	Modified Kusnetz — alpha spectroscopy	0.0005 WL	Requires alpha spectroscopy in at least three channels	104
Rangarajan	Grab	Modified Kusnetz — monitors gamma			64
Lockhart	Grab	Modified Kusnetz — monitors beta			65
Shreve, Groer, and others	Grab	Kusnetz — monitors alpha and beta	0.01 WL	Inexpensive, portable	67,68
EASL	Dosimeter	Pump — TLD	3 working-level hours (WLH)		105
M.I.T.	Dosimeter	Pump — alpha track etch film	1 WLH		111
Colorado State University	Dosimeter	Pump — TLD	0.025 WLH		106
ORNL	Dosimeter	Pump — alpha track etch film	1 WLH		107
Franz	Dosimeter	Pump — alpha track etch film	1 WLH		108
Eberline	Dosimeter	Pump — alpha track etch film	4 WLH		111
Lovett, Becker	Dosimeter	Passive — alpha track etch film	Several WLH	Very inexpensive	109,110
General Electric	Dosimeter (Radon and daughters)	Passive — alpha track etch film	5 WLH	Inexpensive	111
New York University	Dosimeter	Passive — scintillator plus film		Inexpensive	

There is no current requirement for the measurement of the unattached fraction. There is also no requirement that the size distribution of attached particles be determined at each site. However, most recent studies in lung dosimetry show that the size distribution may have a large effect on lung doses. Therefore, it appears that some attention should be directed either towards an easy method for determining the unattached fraction or towards the development of a "standard fraction" to be used in calculations. Electrostatic precipitators, wire screens, and diffusion batteries have been used in the past to measure this fraction.[52,54-56]

The present unit for the determination of exposure to radon daughters is the working level (WL). This is defined to be "any combination of radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy."[57] Table 9.3 shows the growth of working levels in an initially pure sample of radon. The monitoring of uranium mines requires that determinations be made of the working level existing at a particular place and time as well as the cumulative exposure to a worker in a particular area. Cumulative exposure is generally expressed in working level hours (WLH) or working level months (WLM). One WLM is defined as exposure to one worker for a period of 170 working hours.

Table 9.3. Growth of working levels in an initially pure sample of 100 pCi/liter of ^{222}Rn

Time (min)	Number of working levels
10	0.18
20	0.30
30	0.41
40	0.52
50	0.61
60	0.68
70	0.74
80	0.80
90	0.83

Most of the techniques in Table 9.2 are based on the collection of radon daughters with a filter, followed by a determination of the alpha and/or beta decay rate. This method was developed by Kusnetz[58] and is now considered to be the standard method for direct measurement of the working level. Summaries of the inherent errors have been published by Breslin *et al.*[59] and by Loysen,[60] with filter efficiency having been explored by Holmgren *et al.*[61] and Inouye *et al.*,[62] who conclude that high efficiency membrane, polystyrene, or glass fiber filters perform best. A wide variety of counting schemes have been developed, with the most sensitive consisting of three counting intervals with the employment of an alpha spectroscopy system. A technique has been developed by Perdue, Leggett, and Haywood[63] which utilizes the counts in four separate energy regions to separate the contribution of the daughters of ^{219}Rn and ^{220}Rn. Other modifications of the count methods have been developed by Rangargjan *et al.*,[64] who used gamma measurements, and by Lockhart,[65] who used a method based on gross beta counting during two time intervals. However, these methods are not as sensitive as the preceding methods and require certain assumptions about the degree of equilibrium. There is some evidence[66] that the working level may be approximated by a determination of the sum of the alpha and beta activity deposited on a filter and led to the development of portable monitors by Shreve *et al.*[67] and Groer *et al.*[70] For a discussion of the general considerations in the development of an instant working level monitor, the reader is referred to articles by Harley and Pasternack[69] and Rolle.[70] To date, the most accurate method of working level estimation is the modified Kusnetz technique with three counting intervals.

9.4 Measurement of Cumulative Exposure

To determine the cumulative working level exposure, the preceding methods could be used to give an average working level concentration in an area followed by a determination of occupancy. Some work is currently being directed toward the development of a personnel dosimeter which would allow direct determination of cumulative exposure.

A number of excellent methods exist for the determination of working levels using a variety of measurement schemes. At the present, there is

a great need for an accurate, portable, and rugged personnel monitoring device which will yield cumulative exposure to radon daughters. The most promising methods use thermoluminescent dosimeter (TLD) chips, alpha-track etching, and photographic film coated with a fluorescent material.

9.5 Development of Source Terms

It is often possible to estimate radon concentrations by the development of a suitable source term followed by the use of existing computer models. Estimates of the rate of exhalation of radon from the ground may be obtained by a number of methods. Direct measurements may be obtained through the accumulator method,[71,73] which consists of collection of radon in a box followed by the use of a relation between the flux and the concentration as a function of time. This method is accurate and reproducible to within ±10%.[71] An alternate technique relies on the affinity of radon for activated charcoal. The simplest method[74] involves the spreading of a layer of the charcoal on the ground, followed by retrieval and counting of the 0.609 MeV X-rays of ^{214}Bi. A similar method uses activated charcoal in Army M11 canisters.[75-77] Calibration is performed by direct comparison with the accumulator method[77] or by placing a predetermined amount of radon in the test canister.[76] The canister technique, although subject to effects from humidity, temperature, flow rate, and surface area of the charcoal,[76,77] has the advantage that it is easy to use and economical. It should be noted that the rate of emanation depends on a variety of meteorological and soil parameters. As a result, it is necessary to make measurements at various times of the day and year as well as at many points on the site. A modified version of students "t" test has determined that the number of spatially-distinct measurements should not be less than 30[78] for typical tailings piles and contaminated areas.

It is also possible to estimate average radon emanation by a determination of subsurface ^{226}Ra contamination. This method involves a measurement at the contamination profile at a site followed by the use of graphs which relate soil contamination to emanation rate. Several such

graphs have been developed.[8,79,80] Date developed by Goldsmith[8] appear to be the most complete (Fig. 1 and Table 9.4). Schiager[81] has given an empirical relation between the average rate of exhalation from a tailings pile of infinite depth in which the flux (in $pCi/m^2/sec$) is equal to 1.6 times the ^{226}Ra concentration (in pCi/g). He includes a graph which relates the flux from a tailings pile of depth X to one with an infinite depth. Deposits at depths of greater than 0.28 m contribute very little to the flux at the surface.

Table 9.4. Relative internal hazard of tailings pile radionuclides[a]

Radionuclide	Relative inhalation hazard normalized to ^{230}Th	Relative ingestion hazard normalized to ^{226}Ra
^{238}U	2×10^{-3}	1×10^{-3}
^{234}Th	8×10^{-5}	5×10^{-2}
^{234}U	2×10^{-3}	2.5×10^{-4}
^{230}Th	1×10^{0}	5×10^{-3}
^{226}Ra	8×10^{-2}	1×10^{0}
^{210}Pb	2×10^{-2}	1×10^{-1}
^{210}Bi	4×10^{-4}	2.5×10^{-4}
^{210}Po	4×10^{-3}	1×10^{-2}
^{235}U	8×10^{-5}	1×10^{-5}
^{231}Th	8×10^{-8}	2×10^{-6}
^{231}Pa	1×10^{-1}	6×10^{-4}
^{227}Ac	5×10^{-2}	2×10^{-4}
^{227}Th	6×10^{-4}	2×10^{-5}
^{223}Ra	5×10^{-4}	7×10^{-4}

[a]Chain equilibria assumed; 10% of original uranium assumed to be in pile.

Source: W. A. Goldsmith, F. F. Haywood, and D. G. Jacobs, "Guidelines for Cleanup of Uranium Tailings from Inactive Mills," in *Proceedings: Nineth Midyear Topical Symposium of the Health Physics Society,* February 1976, pp. 735-41.
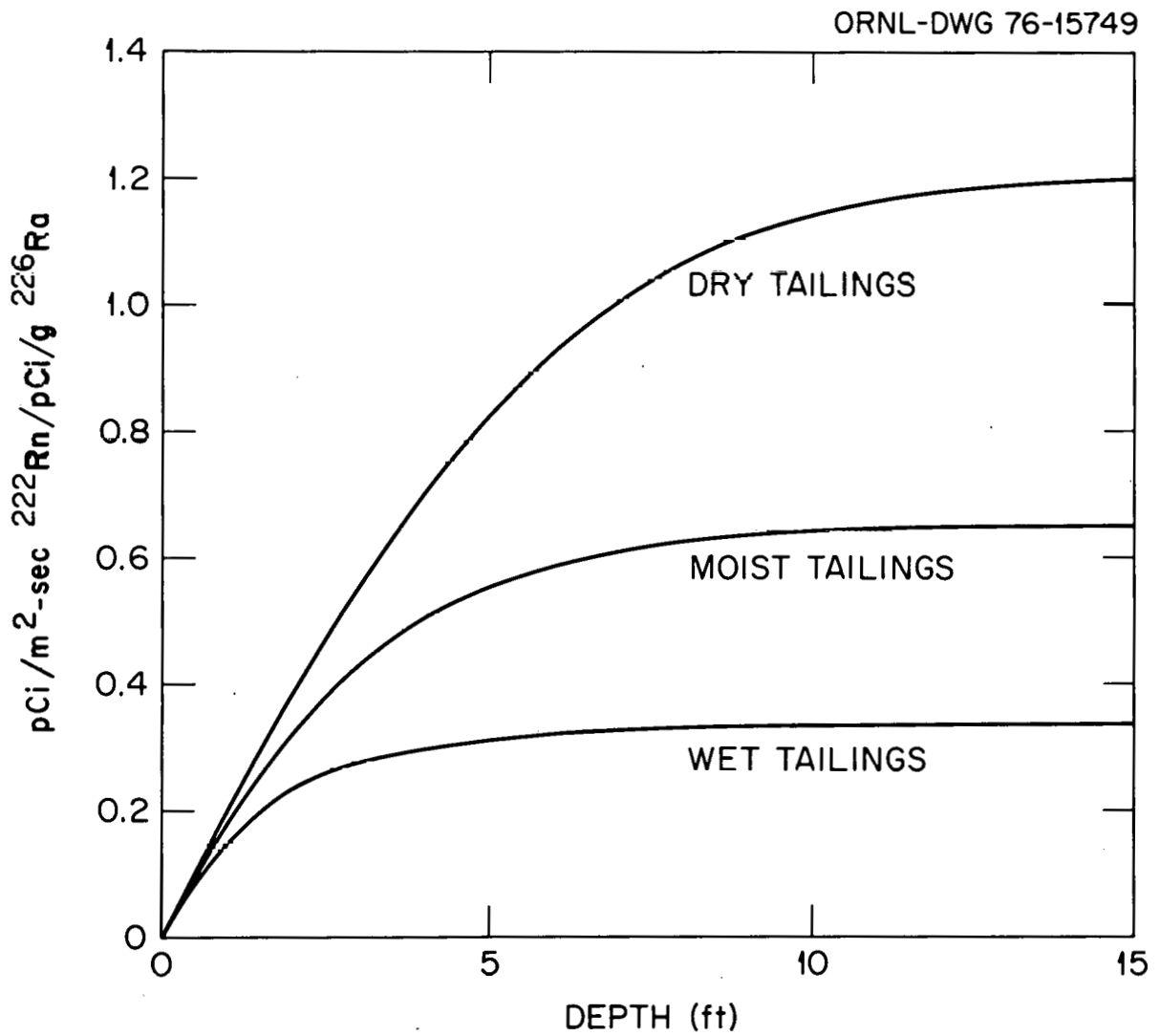
ORNL-DWG 76-15749

Fig. 1. Flux at surface from tailings piles of various depths.

The effect of uncontaminated ground cover may be estimated by the use of a series of correction factors developed by Culot et al.[79] and shown in Table 9.5. These methods were used by Haywood et al.[82] in estimating the radon concentration at points near the Salt Lake City, Utah, tailings pile, and results show the methods to be accurate to within a factor of 2.

Table 9.5. Fraction of the bare pile radon-222 flux transmitted by stabilization materials

Depth m (ft)	Material		
	Sand	Loam or clay	Concrete
0.15 (0.5)	9×10^{-1}	6×10^{-1}	7×10^{-3}
0.30 (1.0)	9×10^{-1}	4×10^{-1}	1×10^{-3}
0.46 (1.5)	8×10^{-1}	3×10^{-1}	1×10^{-4}
0.76 (2.5)	7×10^{-1}	2×10^{-1}	3×10^{-6}
1.52 (5.0	4×10^{-1}	2×10^{-2}	
3.05 (10.0)	2×10^{-1}	4×10^{-3}	
4.57 (15.0)	8×10^{-2}	3×10^{-4}	
6.10 (20.0)	3×10^{-2}	3×10^{-5}	
9.14 (30.0)	6×10^{-3}	2×10^{-7}	
12.12 (40.0)	1×10^{-3}		

Source: M.V.J. Culot, H. G. Olson, and K. J. Schiager, *Radon Progeny Control in Buildings*, COO-2273-1, Colorado State University, NTIS, 1973.

These methods require that an estimate be made of subsurface contamination by ^{226}Ra. This requires the drilling of auger holes on the site followed by the removal of soil samples at various depths. The samples are then ground, dried, and counted using a high-resolution germanium-lithium [Ge(Li)] detector. Data analysis is facilitated by the use of available computer routines. This same method is used to determine the concentration of other radionuclides in local soil (^{238}U is typically counted by neutron activation analysis) and results are accurate to within ±20%. An alternate technique involves the standard practice of gamma logging with a shielded scintillator. A computer program exists[83] which unfolds the effect of scattered radiation (dc convolution) and

determines the true profile of [226]Ra. Implicit in such a method is the assumption that most of the radiation results from the daughters of [226]Ra. The technique typically yields results which are accurate to within a factor of two. Emanation fractions of 20—30% are typically used in these calculations,[79,80,84] although values ranging from 14 to 50% (see Ref. 80) have been reported.

9.6 Radionuclides in Water

Descriptions of radiochemical methods for discerning the concentration of a variety of radionuclides in liquid mining and milling wastes have been published.[85-87] The nuclides are separated by chemical means and counted using beta and gamma detection systems. With samples of more than a gram, gamma spectrometric techniques are better.[7,88,89,90]

Standard radiochemical procedures may be used to analyze the concentration of radionuclides in ground- and surface-water samples. Such samples are generally taken both at the site and at offsite locations to determine the possibility of uranium and radium leaching.

Radium and radon concentrations are generally measured by the de-emanation technique.[91-93] Pretreatment of the water sample with dilute nitric acid prevents plateout of radon and daughters on the sides of the container. The sample is then filtered to remove the insoluble fraction in the water sample. This filter is analyzed by standard radiochemical means or by gross counting. The water sample is then attached to a de-emanation assembly and the radon emanation rate determined. There is a variation of this method[94] based on gamma counting, but detection limits are approximately 100 pCi/liter.

An alternative method for determining the concentration of [222]Rn is based on the high solubility of radon in toluene, which is commonly used in liquid scintillation counting.[95] The method is reported to be faster than the emanation method and less costly. Uncertainties arise in the degree of transfer from the water to toluene.

The various procedures described for measuring contamination in water and soil samples are applicable to biological samples. Any evaluation of possible health hazards from a site must recognize the potential

for contamination of the food chain. Appropriate biological samples will depend on the location of the site but, in general, both water and land plants and animals should be monitored. These biological samples may then be ground and counted either by radiochemical analysis or by gross gamma counting.

9.7 Radioactive Dusts

Dry tailings piles, ore grinding stations, and active mine shafts offer the greatest potential for exposure to airborne radionuclides. Radionuclides of principal concern in the measurement of airborne activity, aside from the daughters of radon, are ^{238}U, ^{235}U, ^{234}Th, ^{226}Ra, and ^{210}Pb. It is necessary to measure the total activity of each of these radionuclides in representatives air samples (i.e., samples which might be inhaled by a typical worker). The standard method for this analysis is to draw high-volume air samples through millipore filters. Such methods have been used[89,90,96,97] to determine the radioactive dust content in both mining and milling atmospheres. The filter is then analyzed by standard radiochemical procedures since the activity is generally too low for direct spectrometric counting. In addition, filters used in vented grinding hoods and other operations should be removed periodically and analyzed. These measurements may then be used to estimate the body burden of workers for each of the radionuclides analyzed or in vivo measurements such as those reported by Helgesor[98] and Colfield.[99] Since radium produces radon, it is possible to detect the presence of radium in the body by the exhalation of radon in the breath. This method also applies to the detection of thoron parents. The method is recognized by the NRC[100] as being a valid method for the bioassay of uranium workers.

9.8 Measurement of the External Radiation Field

External radiation exposure result from radionuclides suspended in the air and located in ore and tailings. The contribution from airborne radionuclides is negligible and will not be considered. Typical measurements of interest in dealing with contamination by the uranium series

are external gamma exposure at 1 m (3.3 ft) above the ground, total beta-gamma dose rates at 1 cm (0.4 in.) from contaminated surfaces, and direct readings of the alpha decay rates on surfaces.

Radiation detection instruments must satisfy several general requirements. For external gamma readings, the best choice would be the free-air ionization chamber. However, the size and fragility of such devices limit their use to the laboratory. It is common practice to use Geiger counters or NaI scintillation meters as a replacement. The only requirement is that they be sensitive to below 1.0 μR/hr and that the response be relatively insensitive to energy. Calibration is usually performed with a sealed radium source and compared against a standard ionization chamber.

Due to the large areas associated with mining and milling sites, it is necessary to develop a predetermined scheme for taking the necessary measurements. The best method is to divide the area by a series of grid lines spaced 15 to 30 m (50 to 100 ft). For small areas, the grid must be finer, permitting at least 30 measurements. Thirty measurements generally suffice to predict the average with 25% error at the 90% confidence level. Measurements of external gamma exposure rates at 1 m are taken at each grid point, which is located at the intersection of grid lines. This permits the taking of an unbiased and representative sample of measurements, which may then be used to estimate the average condition. A quick scan will then reveal the location of any "hot" spots and allow a determination of maximum exposure rates. It is not a good practice to attempt to determine average conditions by scanning.[78]

This scheme is also used for estimating average beta-gamma exposure rates at 1 cm (0.4 in.) above the ground. It is usually assumed that the location of maximum beta-gamma readings will be identical to the maximum gamma exposure rate at 1 m (0.3 ft). Therefore, beta-gamma readings at 1 cm above the surface are taken at each location of a maxima in the gamma exposure rate at 1 m.

Since only the exposure rates resulting from the operation of the facility are desired, it is necessary to subtract background readings from the gross readings. Background samples should be taken at numerous points located at least 0.8 km (0.5 mi) from the site. Average values

may be determined either through the use of normal or log-normal statistics.

While alpha emitters generally pose little threat from external exposure, existing criteria for the decommissioning of contaminated sites require determinations of average and maximum alpha decay rates on all accessible surfaces. These standards generally specify maximum decay rates in any area of 100 cm^2 (15.5 in.^{2}) and average rates over areas not larger than 1 m^2 (10.8 ft^2). Since the highest alpha decay rates are usually accompanied by high beta decay rates, it is sufficient (in general) to measure the maximum alpha rates at the locations of the highest beta measurements. Average values may be determined by taking at least five alpha measurements within a 1 m^2 block located at the center of each grid block. In this case, grid lines should not be separated by more than 2 or 3 m.

A review of standards for the decommissioning of contaminated sites[101] cites the existence of standards governing the allowed quantity of transferrable contamination. This will necessitate the taking of smear samples followed by appropriate counting for alpha and beta emitters. Since a large fraction of the surface contamination may result from the deposition of radon daughters, it may be necessary to count the samples twice, with the second reading separated from the first by 4 or 5 hr to allow for the decay of all daughters. However, in most active sites the primary cause of surface contamination will be deposition of airborne uranium or thorium.

9.9 Conclusions

There is a need for more studies concerning the leaching of materials into water supplies to determine the stability of the wastes being generated by uranium operations.

While instrumentation for the measurement of radon and radon daughters allows for accurate determinations at low concentrations, there is a need for small, reliable personnel dosimeters. The use of such devices would certainly be desirable in mine shafts, where radon concentration may be high. In addition to being useful for daily

monitoring, such devices could provide valuable information for
the determination of dose-effect relationships. Recent work (see
Table 9.4) indicates that monitoring requirements in this area are radidly
being satisfied. It is currently impossible to predict accurately the
effects of low concentrations of radon and daughters on the general
public. The methods described in this paper are generic and will apply
to any uranium operation.

Current monitoring programs associated with uranium mining and
milling activities measure radon in air; radon daughters in air; long-
lived radionuclides in air; contamination in soil, water and biota; and
external gamma exposure rates.

While it is not presently required that an estimate be made of the
characteristics of local aerosols, it should be recognized that present
concepts of lung dosimetry place great importance on particle size and
the fraction of radon daughters which attach to them. Since the maximum
permissible concentration in air as set forth by the ICRP includes a
determination of this fraction, aerosol sampling, which includes estimation
of the unattached fraction of radon daughters, may be necessary in the
future. Alternatively, it may be desirable to determine a standard attached
fraction to be used in lung dosimetry calculations.

REFERENCES FOR SECTION 9

1. K. Z. Morgan, W. S. Snyder, and M. R. Ford, "Relative Hazard of the Various Radioactive Material," *Health Phys.* 10: 151-69 (1964).

2. R. N. Snelling, "Environmental Survey of Uranium Mill Tailings Pile, Mexican Hat, Utah," *Radiol. Health Data Rep.* 12: 17-28 (1971).

3. R. N. Snelling, "Environmental Survey of Uranium Mill Tailings Pile, Monument Valley, Arizona," *Radiol. Health Data Rep.* 11: 511-17 (1970).

4. R. N. Snelling and S. D. Shearer, Jr., "Environmental Survey of Uranium Mill Tailings Pile, Tube City, Arizona," *Radiol. Health Data Rep.* 10: 475-87 (1969).

5. D. M. Levins, R. K. Ryan, and K. P. Strong, "Leaching of Radium from Uranium Tailings," to be published.

6. R. N. Snelling, "Environmental Survey of Uranium Mill Tailings Pile, Mexican Hat, Utah," *Radiol. Health Data Rep.* 12: 17-28 (1971).

7. R. W. Leggett *et al.*, *Radiological Survey of the Former Vitro Rare Metals Plant, Canonsburg, Pennsylvania,* DOE/EV-0005/3, Oak Ridge National Laboratory (April 1978).

8. W. A. Goldsmith, F. F. Haywood, and R. W. Leggett, "Transport of Radon which Diffuses from Uranium Mill Tailings," to be published in *Proceedings Natural Radiation Environment III,* Houston, 1978.

9. U.S. Environmental Protection Agency, *Environmental Analysis of the Uranium Fuel Cycle: Part I — Fuel Supply,* EPA 520/9-73-003-B, Office of Radiation Programs, Washington, D.C., October 1973.

10. A. W. Klement, Jr., *et al.*, *Estimates of Ionizing Radiation Doses in the United States 1960-2000,* ORP/CSD 72-1, U.S. Environmental Protection Agency, August 1972.

11. D. D. Comey, "The Legacy of Uranium Tailings," *Bull. At. Sci.* 31: 43-45 (1975).

12. J. W. Swift, J. M. Hardin, and H. W. Calley, *Potential Radiological Impact of Airborne Releases and Direct Gamma Radiation to Individuals Living Near Inactive Uranium Mill Tailings Piles*, EPA-520/1-76-001, U.S. Environmental Protection Agency, January 1976.

13. D. A. Holaday, "History of the Exposure of Miners to Radon," *Health Phys.* 16: 547-52 (1969).

14. P. J. Walsh, "Radiation Dose to the Respiratory Tract of Uranium Miners — A Review of the Literature," *Environ. Res.* 3: 14-36 (1970).

15. V. E. Archer and J. K. Wagoner, "Lung Cancer Among Uranium Miners in the United States," *Health Phys.* 25: 351-71 (1973).

16. J. Sevc, E. Kunz, and V. Placek, "Lung Cancer in Uranium Miners and Long Term Exposure to Radon Daughter Products," *Health Phys.* 30: 433-37 (1976).

17. J. K. Wagoner *et al.*, "Mortality Patterns Among United States Uranium Miners and Millers, 1950 through 1962: Preliminary Report," *Radiological Health and Safety in Mining and Milling of Nuclear Materials*, Vol. 1, IAEA, 1964, pp. 37-48.

18. A. W. Donaldson, "The Epidemiology of Lung Cancer Among Uranium Miners," *Health Phys.* 16: 563-69 (1969).

19. V. E. Archer *et al.*, "Epidemiological Studies of Some Non-Fatal Effects of Uranium Mining," *Radiological Health and Safety in Mining and Milling of Nuclear Materials*, Vol. 1, IAEA, 1964, pp. 21-36.

20. L. M. Scott *et al.*, "Mortality Experience of Uranium and Non-uranium Workers," *Health Phys.* 23: 555-57 (1972).

21. D. A. Holaday and H. N. Doyle, "Environmental Studies in the Uranium Mines," *Radiological Health and Safety in Mining and Milling of Nuclear Materials*, Vol. 1, IAEA, 1964, pp. 9-20.

22. S. D. Shearer, Jr. and C. W. Sill, "Evaluation of Atmospheric Radon in the Vicinity of Uranium Mill Tailings," *Health Phys.* 17: 77-88 (1969).

23. J. T. Tappan, "Grab Sampling: Methods and Interpretation," *Workshop on Methods for Measuring Radiation in and Around Uranium Mills,* 3(9): 157-74 (1977).

24. *Code of Federal Regulations,* Title 10, Part 712, Grand Junction Remedial Action Criteria.

25. H. F. Lucas, Jr., "Alpha Scintillation Radon Counting," *Workshop on Methods for Measuring Radiation in and Around Uranium Mills,* 3(9): 69-95 (1977).

26. H. F. Lucas, Jr., "Improved Low-Level Alpha Scintillation Counters for Radon," *Rev. Sci. Instrum.* 28: 680 (1957).

27. W. B. Harris, H. D. LeVine, S. I. Watnick, "Portable Radon Detector for Continuous Air Monitoring," *Archives of Industrial Health,* Vol. 16, 1957, p. 493.

28. M.M.V. Glaude, D. Boclet, U.S. Patent No. 3, 056, 886 (October 1962).

29. J. Fontan, "The Quantitative Determination of Gaseous Radioelements which Yield Radioactive Daughter Products," University of Toulouse, Ph.D. thesis, Translated by R. R. Inston, Argonne National Laboratory, ANL-TRANS-45 (1964).

30. J. W. Thomas and P. C. LeClare, "A Study of the Two-Filter Method for Radon-222," *Health Phys.* 18: 113-22 (1970).

31. A. J. Breslin, "Monitoring Instrumentation in the Uranium Mining Industry," 1972, unpublished report.

32. A. C. George *et al.,* "A Cumulative Environmental Radon Monitor," *Proceedings of the Ninth Midyear Health Physics Symposium,* Denver, Colorado (1976), pp. 116-20.

33. A. C. George and A. J. Breslin, "Measurements of Environmental Radon with Integrating Instruments," *Workshop on Methods for Measuring Radiation in and Around Uranium Mills,* 3(a): 105-15 (1977).

34. C. W. Sill, "An Integrating Air Sampler for Determination of ^{222}Rn," *Health Phys.* 16: 371-77 (1969).

35a. M. E. Wrenn *et al.*, "Design of a Continuous Digital-Output-Environmental Radon Monitor," *IEEE Trans. Nucl. Sci.* 22: 645-48 (1975).

35b. M. E. Wrenn and H. B. Spitz, "The Design and Application of a Continuous, Digital Readout, Radon Measuring Instrument," *Workshop on Methods for Measuring Radiation in and Around Uranium Mills,* 3(9): 119-30 (1977).

36. Intersociety Committee for a Manual of Methods for Ambient Air Sampling and Analysis, *Methods of Air Sampling and Analysis,* American Public Health Association, Washington (1972).

37. G. E. Jones and L. M. Kleppe, *A Simple and Inexpensive System for Measuring Concentrations of Atmospheric Radon-222,* UCRL-16952, Lawrence Berkeley Laboratory (1966).

38. P. H. Bedrosian, "Photographic Technique for Monitoring Radon-222 and Daughter Products," *Health Phys.* 16: 800-802 (1969).

39. E. L. Geiger, "Radon Film Badge," *Health Phys.* 13: 407-11 (1967).

40. M. Eisenbud *et al.*, "In Vivo Measurement of Lead-210 in an Indicator of Cumulative Radon Daughter Exposure in Uranium Miners," *Health Phys.* 16: 637-46 (1969).

41. H. L. Fisher, Jr., "A Model for Estimating the Inhalation Exposure to Radon-222 and Daughter Products from the Accumulated Lead-210 Body Burden," *Health Phys.* 16: 597-616 (1969).

42. R. F. Bell and J. C. Gilliland, "Urinary Lead-210 As Index of Mine Radon Exposure," *Radiological Health and Safety in Mining and Milling of Nuclear Materials,* Vol. 2, IAEA, 1964, pp. 411-22.

43. T. Inouye *et al.*, "The Level of Polonium in Urine of Japanese Uranium Miners," *Radiological Health and Safety in Mining and Milling of Nuclear Materials,* Vol. 2, IAEA, 1964, pp. 425-29.

44. D. Djuric *et al.*, "Polonium in the Urine of Miners as a Measure of Exposure to Radon," *Radiological Health and Safety in Mining and Milling of Nuclear Materials,* Vol. 2, IAEA, 1964, pp. 431-40.

45. O. G. Raabe, "The Absorption of Radon Daughters to Some Polydisperse Submicron Polystyrene Aerosols," *Health Phys.* 14: 397-416 (1968).

46. O. G. Raabe, "Concerning the Interactions that Occur Between Radon Decay Products and Aerosols," *Health Phys.* 17: 177-85 (1969).

47. V. Mohnen, "Investigation of the Attachment of Neutral and Electrically Charged Emanation Decay Products to Aerosols," *AERE Trans.* p. 1106 (1967).

48. A. C. George, L. Hinchliffe, and R. Sladowski, "Size Distribution of Radon Daughter Particles in Uranium Mine Atmospheres," *Am. Ind. Hyg. Assoc. J.* pp. 484-90 (June 1975).

49. P. G. Bergamini *et al.*, "Analysis of Particle Size and Radioactivity of Atmospheric Dust," *Health Phys.* 24: 655-63 (1973).

50. J. Pradel *et al.*, "Characteristics of Aerosols in French Uranium Mines," *Radioprotection* 5: 263 (1970).

51. F. Billard, G. Madelaine, and A. Chapuis, "Contribution to the Study of Atmospheric Pollution in Uranium Mines," *Radioprotection* 6: 45 (1971).

52. M. Raghavayya and J. H. Jones, "A Wire Screen-Filter Paper Combination for the Measurement of Fractions of Unattached Radon Daughters in Uranium Mines," *Health Phys.* 26: 417-29 (1974).

53. T. T. Mercer and W. A. Stowe, "Radioactive Aerosols Produced by Radon in Room Air," *Inhaled Particles III*, Unwin Brothers, LTD (1971) pp. 839-51.

54. A. C. Chamberlain, E. D. Dyson, *British Jounral of Radiology*, Vol. 29, 1956, p. 317.

55. R. F. Craft, J. L. Oser, and F. W. Norris, *American Industrial Hygiene Association Journal*, Vol. 27, 1966, p. 154.

56. A. Chapuis *et al.*, "Sur Les Characterisques des Aerosols Radioactifs Presents dans les Mines Francaises d'Uranium," Second International Congress of the IRPA, Brighton (1970).

57. R. L. Rock *et al.*, *Controlling Employee Exposure to Alpha Radiation in Underground Uranium Mines*, U.S. Bureau of Mines Handbook (1970).

58. H. L. Kusnetz, *Am. Ind. Hyg. Assoc. Q.* 17: 85 (1956).

59. A. J. Breslin, A. C. George, and M. S. Weinstein, HASL-220, U.S. Atomic Energy Commission Health and Safety Laboratory (now Environmental Measurements Laboratory).

60. P. Loysen, "Errors in the Measurement of Working Level," *Health Phys.* 16: 629-35 (1969).

61. R. M. Holmgren *et al.*, "Relative Filter Efficiencies for Sampling Radon Daughters in Air," *Health Phys.* 32: 297-300 (1977).

62. T. Inouye, Y. Yamada, and S. Watanabe, "Evaluating Method for Airborne Radon Daughters," *Radiological Health and Safety in Mining and Milling of Nuclear Materials,* Vol. 1, IAEA, 1964, pp. 459-70.

63. P. T. Perdue, R. W. Leggett, and F. F. Haywood, "A Technique for Evaluating Airborne Concentrations of Daughters of Radon Isotopes," to be published in *Proceedings Natural Radiation Environment III,* Houston, 1978.

64. C. Rangarajan and S. Gopalakrishnan, "The Estimation of the Relative Concentrations of Short-Lived Radon Daughters by Gamma Measurements," *Health Phys.* 24: 433-36 (1973).

65. L. B. Lockhart, R. L. Patterson, and C. R. Hosler, *Determination of Radon Concentration in Air Through Measurement of its Solid Decay Products,* U.S.N.R.L. Report 6229 (1965).

66. A. Hill, "Rapid Measurement of Radon, Decay Products, Unattached Fractions, and Working Level Values of Mine Atmospheres," *Health Phys.* 28: 472-74 (1975).

67. J. D. Shreve, Jr., R. W. Miller, and J. F. Cleveland, "A New Instrument for Quick Determination of Radon and Radon-Daughter Concentrations in Air," presented at the IRPA IVth International Congress, April 1977, Paris.

68. P. G. Groer, R. D. Evans, and D. A. Gordon, "An Instant Working Level Meter for Uranium Mines," *Health Phys.* 24: 387-95 (1973).

69. N. H. Harley, B. S. Pasternack, "The Rapid Estimation of Radon Daughter Working Levels When Daughter Equilibrium is Unknown," *Health Phys.* 17: 109-14 (1969).

70. R. Rolle, "Rapid Working Level Monitoring," *Health Phys.* Vol. 22: 233-38 (1972).

71. D. E. Bernhardt, F. B. Johns, and R. F. Kaufmann, "Radon Exhalation from Uranium Mill Tailings Piles," U.S. Environmental Protection Agency document ORP/LV-75-7A (November 1975).

72. M. Wilkening, "Measurement of Radon Flux by the Accumulator Method," *Workshop on Methods for Measuring Radiation in and Around Uranium Mills,* 3(9): 131-38 (1977).

73. A. H. Khan and M. Raghavayya, "Radon Emanation Jaduguda Uranium Mine," *Proceedings: Third International Congress of the International Radiation Protection Association,* CONF-730907-P2, 1974.

74. K. Megumi and T. Mamuro, "A Method for Measuring Radon and Thoron Exhalation from the Ground," *J. Geophys. Res.* 77: 3052 (1972).

75. A. L. West, "Respiratory Protection Equipment Developments by the U.S. Army Chemical Corps," *Am. Ind. Hyg. J.* 19: 140 (1958).

76. J. W. Thomas, *Evaluation of Activated Carbon Canisters for Radon Protection in Uranium Mines,* HASL-280, Environmental Measurements Laboratory (January 1974).

77. R. J. Countess, "Measurement of ^{222}Rn Flux with Charcoal Canisters," *Workshop on Methods for Measuring Radiation in and Around Uranium Mills,* 3(9): 139-56 (1977).

78. R. W. Leggett, H. W. Dickson, and F. F. Haywood, "A Statistical Methodology for Radiological Surveying," presented at the Symposium on Advances in Radiation Protection Monitoring, Stockholm, June 1978.

79. M.V.J. Culot, H. G. Olson, and K. J. Schiager, *Radon Progeny Control in Buildings,* COO-2273-1, Colorado State University, NTIS, 1973.

80. T. I. Sisigina, "Assessment of Radon Emanation from the Surface of Extensive Territories," *Nuclear Meteorology,* Gidrometioiz, Moscow, 1972, pp. 239-44.

81. K. J. Schiager, "Analysis of Radiation Exposures On or Near Uranium Mill Tailings Piles," *Radiat. Data Rep.* 15(7): 411-25 (1974).

82. F. F. Haywood *et al., Assessment of Radiological Impact of the Inactive Uranium-Mill Tailings Pile at Salt Lake City, Utah,"* ORNL/TM-5251 (November 1977).

83. R. W. Leggett, L. Williams, and D. J. Crawford, "A Method for Determining the Level of ^{226}Ra Contamination in Subsurface Soil," (in preparation).

84. K. Megumi and T. Mamuro, "Emanation and Exhalation of Radon and Thoron Gases from Soil Particles," *J. Geophys. Res.* 79: 3357-60 (1974).

85. C. W. Sill, "Simultaneous Determination of ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, and ^{210}Pb in Uranium Ores, Dusts, and Mill Tailings," *Workshop on Methods for Measuring Radiation in and Around Uranium Mills,* 3(9): 225-45 (1977).

86. D. R. Percival and D. B. Martin, "Sequential Determination of Radium-226, Radium-228, Actinium-227, and Thorium Isotopes in Environmental and Process Waste Samples," *Workshop on Methods for Measuring Radiation in and Around Uranium Mills,* 3(9): 247-54 (1977).

87. J. A. Terning, "Radiochemical Analysis of Radium, Thorium, and Protactinium in Uranium Milling Process Samples," *Int. J. Appl. Radiat. Isot.* 21: 507-12 (1970).

88. R. W. Perkains and C. W. Thomas, "Direct Measurement of Radio-nuclides in Uranium Tailings, Ores and Dusts," *Workshop on Methods for Measuring Radiation in and Around Uranium Mills,* 3(9): 255-74 (1977).

89. U.S. Department of Energy, *Radiological Survey of the Linde Uranium Refinery, Tonawanda, New York,* DOE/EV-0005/5, (May 1978).

90. U.S. Department of Energy, *Radiological Survey of the Seaway Industrial Park, Tonawanda, New York,* DOE/EV-0005/6 (May 1978).

91. E. Pohl and J. Pohl-Rüling, "Determination of Environmental or Occupational ^{222}Rn in Air and Water and ^{226}Ra in Water with Feasible and Rapid Methods of Sampling and Measurement," *Health Phys.* 31: 343-48 (1976).

92. J. B. Hursh, "Radium-226 in Water Supplies of the U.S.," *J. Am. Water Works Assoc.* (JAWWA) 46: 43 (1954).

93. D. E. Rushing, W. J. Garcia, and D. A. Clark, "The Analysis of Effluents and Environmental Samples from Uranium Mills and of Biological Samples for Radium, Polonium, and Uranium," *Radiological Health and Safety in Mining and Milling of Nuclear Materials,* Vol. 2, IAEA, 1964, pp. 187-231.

94. H. F. Lucas, Jr., "A Fast and Accurate Survey Technique for Both Radon-222 and Radium-226," *The Natural Radiation Environment,* Chicago, 1964, p. 315.

95. H. M. Prichard and T. F. Gesell, "Rapid Measurements of ^{222}Rn Concentrations in Water With a Commercial Liquid Scintillation Counter," *Health Phys.* 33: 577-81 (1977).

96. N. Fusamura, "Measurements of Radioactive Gas and Dust as Well as Their Prevention in Japanese Uranium Mines," *Radiological Health and Safety in Mining and Milling of Nuclear Materials,* Vol. 2, IAEA, 1964, pp. 391-410.

97. N. Fusamura, R. Kurosawa, and H. Misawa, "The Measurement of Radioactive Gas and Dust in Uranium Mines in Japan," *Health Phys.* 10: 909-15 (1964).

98. G. L. Helgesor, "In-Vivo Counting of Uranium Mill Workers," *Workshop on Methods for Measuring Radiation In and Around Uranium Mills,* 3(9): 301-11 (1977).

99. R. E. Colfield, "In-Vivo Counting As A Measurement of Uranium in the Human Lung," *Health Phys.* 2: 269-87 (1960).

100. R. E. Alexander, "NRC Rationale for Bioassay Requirements," *Workshop on Methods for Measuring Radiation in and Around Uranium Mills,* 3(9): 293-99 (1977).

101. H. W. Dickson, *Standards and Guidelines Pertinent to the Development of Decommissioning Criteria for Sites Contaminated with Radioactive Materials,* ORNL/OEPA-4 (August 1978).

102. J. Harley, ed., *HASL Procedures Manual,* HASL-300, U.S. Atomic Energy Commission Health and Safety Laboratory (1972).

103. J. W. Thomas, "Measurement of Radon Daughters in Air," *Health Phys.* 23: 1972 (1972).

104. D. E. Martz *et al.,* "Analysis of Atmospheric Concentrations of RaA, RaB, and RaC by Alpha Spectroscopy," *Health Phys.* 17: 131 (1969).

105. P. White, Jr., HASL TM 71-17, Environmental Measurements Laboratory (1971).

106. D. E. McCurdy, K. J. Schiager, and E. D. Flack, "Thermoluminescent Dosimetry for Personnel Monitoring of Uranium Miners," *Health Phys.* 17: 415-23 (1969).

107. J. A. Auxier *et al.,* "A New Radon Progeny Personnel Dosimeter," *Health Phys.* 21: 126-28 (1971).

108. G. A. Franz, "Integrated Working Level Samplers Using Thermo- luminescent Dosimeters: Operation and Interpretation," *Workshop on Methods for Measuring Radiation in and Around Uranium Mills,* 3(9): 175-80 (1977).

109. D. B. Lovett, "Track Etch Detectors for Alpha Exposure Estimation," *Health Phys.* 16: 623-28 (1969).

110. K. Becker, "Alpha Particle Registration in Plastics and its Applications for Radon and Neutron Personnel Dosimetry," *Health Phys.* 16: 113-23 (1969).

111. O. White, Jr., HASL TM 69-23A, U.S. Atomic Energy Commission Health and Safety Laboratory (1969).

INTERNAL DISTRIBUTION

1. S. I. Auerbach	21. R. E. Moore
2. C. F. Baes III	22. B. D. Murphy
3. L. Berry	23. D. C. Parzyck
4. S. Carnes	24. H. Postma
5. R. O. Chester	25. M. L. Randolph
6. S. J. Cotter	26. D. E. Reichle
7. W. B. Cottrell	27. C. R. Richmond
8. D. J. Crawford	28. P. S. Rohwer
9. R. M. Davis	29. M. W. Rosenthal
10. J. E. Dobson	30. M. B. Sears
11. W. Fulkerson	31. F. G. Taylor
12. W. R. Grimes	32. C. C. Travis
13. D. K. Halford	33. P. J. Walsh
14. K. Hake	34. A. P. Watson
15. W. F. Harris	35. J. P. Witherspoon
16. H. C. Hoy	36-37. Central Research Library
17. D. G. Jacobs	38. Document Reference Section
18. S. V. Kaye	39-43. Laboratory Records
19. C. A. Little	44. Laboratory Records — RC
20. L. M. McDowell-Boyer	45. ORNL Patent Office

EXTERNAL DISTRIBUTION

46. N. F. Barr, Office of Technology Impacts, Department of Energy, Washington, DC 20545

47. R. D. Buchanan, Department of Interior, P. O. Box 1590, Albuquerque, NM 87103

48. W. W. Burr, Jr., Office of Health and Environmental Research, Department of Energy, Washington, DC 20545

49. C. F. Carter, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545

50. R. C. Clusen, Assistant Secretary for Environment, Department of Energy, Washington, DC 20545

51. C. W. Edington, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545

52. F. Gifford, Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, TN 37830

53. T. E. Hakonson, Box 1663, Los Alamos Scientific Laboratory, Los Alamos, NM 87545

54. J. Hoch, Office of Technology Impacts, Department of Energy, Washington, DC 20545

55. P. W. House, Office of Technology Impacts, Department of Energy, Washington, DC 20545

56. J. R. Maher, Office of Technology Impacts, Department of Energy, Washington, DC 20545

57. W. A. Mills, Environmental Protection Agency, 401 M Street, S.W., Washington, DC 20460

58. D. Monti, Office of Technology Impacts, Department of Energy, Washington, DC 20545

59. Office of Assistant Manager, Energy Research and Development, Department of Energy, Oak Ridge Operations Office, Oak Ridge, TN 37830

60. R. D. Shull, Office of Technology Impacts, Department of Energy, Washington, DC 20545

61. J. Swinebroad, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545

62-88. Technical Information Center, Oak Ridge, TN 37830

89. N. Thomasson, Office of Technology Impacts, Department of Energy, Washington, DC 20545

90. R. W. Wood, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545