United States
Environmental Protection
Agency

Office of
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Washington DC 20460

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Radiation

Final
Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192)

Volume I

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SUMMARY

( ) Draft
(X) Final Environmental Statement

Environmental Protection Agency
Office of Radiation Programs

1. This action is administrative.

2. The Environmental Protection Agency is establishing standards (40 CFR 192) for cleanup and long-term control of uranium mill tailings at inactive mill sites that qualify for remedial actions under the Uranium Mill Tailings Radiation Control Act of 1978 (PL 95-604). Sites are located in Arizona, Colorado, Idaho, New Mexico, North Dakota, Oregon, Pennsylvania, Texas, Utah, and Wyoming.

These standards are issued to reduce and control the hazards associated with uranium mill tailings. Two types of remedial actions are required: cleanup of tailings that have spread from the original site or have been removed for use elsewhere, and control to assure environmentally sound long-term stabilization of the tailings.

These standards will be implemented by the Department of Energy and affected States with the concurrence of the Nuclear Regulatory Commission in consultation, as appropriate, with Indian Tribes and the Department of Interior. The total cost is estimated to be approximately $320 million (1981 dollars) over a period of seven years.

3. These standards have the following public health and environmental benefits:

(a) Under the control standards, radon emission rates from tailings piles will be reduced by about 96 percent for at least 200 and up to 1,000 years. The measures used to achieve this will prevent spreading of tailings by wind and water erosion and should discourage misuse of tailings by providing a significant barrier against intrusion. With such controls, we believe these tailings piles will not generally threaten water quality, so we recommend site-specific consideration of water protection measures.

(b) Cleanup standards will require remedial actions for buildings that have unusually high levels of indoor radon and removal of tailings from contaminated land when specified criteria are exceeded. These actions will reduce or avoid the public's exposure to significantly elevated radiation levels from tailings.

4. The following alternatives were considered:

(a) No standards,

(b) Standards to provide minimum acceptable health protection at the least cost,

(c) Standards to provide the maximum long-term benefits relative to the cost, and

(d) Standards based primarily on nondegradation, offering maximum protection with only moderate consideration of cost.

EPA has selected alternative (c).

5. The following are the major points raised in public comments on the proposed standards and EPA's resolution of them:

(a) Estimated risk from radon--Some commenters thought our estimates were too high. We believe our risk estimates are reasonable, and in any case, that uncertainties in these risk estimates would not lead to different standards.

(b) Cost of the standards are high relative to their benefits--Some commenters thought that the cost of satisfying the proposed standard was too high relative to the benefits. We selected final standards that we believe will provide nearly as great long-term benefits as those we proposed, but at significantly lower costs.

(c) Longevity of controls--Some commenters suggested that 100-200 years of control would be adequate and that institutional methods should be used. We have selected final standards designed for long-term protection (many thousands of years) relying primarily on physical control methods. We believe this was the intent of Congress, is appropriate to the nature of the potential hazard, and is practical to achieve.

(d) Protecting groundwater--Commenters felt the proposed numerical water standards were inappropriate or unnecessary. The final standards do not specify numerical limits for radioactive and toxic materials in groundwater. Rather, the implementing agencies will site-specifically assess the potential for future groundwater contamination and take any appropriate action.

(e) The need for flexibility--Commenters argued that the proposed standards were too close to background levels for reasonable implementation. The final standards are at levels that are readily distinguishable from background levels. This provides the flexibility needed for unusual circumstances and complications due to high natural background levels.

6. The following Federal Agencies have commented on the Draft Environmental Statement:

Department of Energy
Nuclear Regulatory Commission
Tennessee Valley Authority
Federal Energy Regulatory Commission
Department of Agriculture
Department of the Interior
Department of Health and Human Services
Department of Justice

7. This Final Environmental Impact Statement was made available to the public in December 1982; single copies are available from the Director, Criteria and Standards Division (ANR-460), Office of Radiation Programs, U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, D.C. 20460, or National Technical Information Service, 5285 Port Royal Road, Springfield, Va., 22161.

Chapter 1: INTRODUCTION

In enacting the Uranium Mill Tailings Radiation Control Act of 1978 (Public Law 95-604, 42 USC 7901), the Congress found that:

- "Uranium mill tailings located at active and inactive mill operations may pose a potential and significant radiation health hazard to the public, and that...
- "Every reasonable effort should be made to provide for the stabilization, disposal, and control in a safe and environmentally sound manner of such tailings in order to prevent or minimize radon diffusion into the environment and to prevent or minimize other environmental hazards..."

To these ends, the Act requires the Environmental Protection Agency (EPA) to set generally applicable standards to protect the public against both radiological and nonradiological hazards posed by residual radioactive materials at the twenty-two uranium mill tailings sites designated in the Act and at additional sites where these materials are deposited that may be designated by the Secretary of the Department of Energy (DOE)[1]. Residual radioactive material means (1) tailings waste resulting from the processing of ores for the extraction of uranium and other valuable constituents, and (2) other wastes, including unprocessed ores or low grade materials, as determined by the Secretary of Energy, at sites related to uranium ore processing. We will use the term tailings to refer to all of these wastes.

All but one of the 22 inactive mill tailings sites designated in the Act are located in the western United States; the other is at a former rare-metals processing plant in Canonsburg, Pa. The DOE has designated two additional uranium processing locations as sites that require remedial action. These are located near Bowman and Belfield, North Dakota.

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(1) The Act also requires EPA to set generally applicable standards for tailings from active uranium mills. However, the standards discussed in this FEIS do not address active mills.

In this Final Environmental Impact Statement (FEIS), we examine (1) alternative standards for disposal of uranium mill tailings produced at the 24 designated sites, and (2) alternate standards for cleaning up lands and buildings contaminated with tailings from these sites. Nonradioactive toxic substances are also considered. In developing this FEIS, we evaluated potential effects of tailings on public health and considered the effectiveness and permanence of different approaches to control those effects. We also developed cost estimates for specific control options.

In Chapter 2 we summarize the history of the uranium milling industry and briefly review information on the current status of the designated sites. Chapter 3 contains a review of the radiological and nonradiological characteristics of the sites and our estimates of how much contamination there is in nearby land and buildings. Chapter 4 contains an analysis of the potential health hazards posed by uranium mill tailings, including estimates of the risks to individuals living close to the piles, to populations in the local region, and to the population of the continental United States.

In Chapter 5 we examine the efficacy and longevity of the principal methods for disposal and cleanup of tailings. In Chapter 6 we estimate costs and benefits for tailings piles control options and discuss other significant factors such as duration and effectiveness of controls and occupational hazards when controls are put into use.

Chapter 7 contains an examination of the costs and benefits for specific alternatives for cleaning up contaminated land and buildings. In Chapter 8 we review the results of Chapters 6 and 7 and show how those results provide a basis for choosing standards. Chapter 9 contains a discussion of how these standards could be implemented and the anticipated effects of such implementation.

Chapter 2: HISTORY AND CURRENT STATUS OF THE INACTIVE URANIUM MILLING SITES

2.1 Early History

The following brief history of uranium milling appeared in the Nuclear Regulatory Commission's Final Generic Environmental Impact Statement on Uranium Milling (NRC80). It summarizes lengthier papers by Merritt (Me71) and by Facer (Fa76).

> "In the past 35 years the uranium industry has undergone a series of transformations, uranium changing almost overnight from a commodity of only minor commercial interest to one vital for nuclear weapons and, now, to its important peaceful use as a fuel for generation of electrical energy. With each change there has been a surge of interest in ore exploration and development and in new and expanded production facilities.
>
> "The military demand for uranium beginning in the early 1940s had to be met from known sources of supply. The rich pitchblende ores of the Shinkolobwe deposit in the Belgian Congo and the Great Bear Lake deposit in Canada supplied uranium during the war years and were supplemented by production from treatment of old tailings dumps and a few small mines in the Colorado Plateau area. These high-grade ores and concentrates were refined by an ether extraction technique adapted from analytical procedures. Crude ore milling processes for low-grade ores used during this period reflected little change from methods used 40 years earlier (at the turn of the last century) with uranium recovery from the leach solutions based on several stages of selective precipitation. Milling costs were high and overall recovery was low, as judged by current standards.
>
> "With passage of the Atomic Energy Act of 1946, a strong emphasis was placed on the discovery and development of new worldwide sources of uranium. At the same time, the research efforts begun earlier were expanded in scope and magnitude to advance the process technology. These efforts led to greater use of lower grade ores than previously had been considered feasible, such as the uranium-bearing gold ores in South Africa, as a source of uranium, and to the discovery and development of large,

low-grade deposits in the Beaverlodge, Elliot Lake, and Bancroft regions of Canada.

"In the United States, prospecting and mining for uranium were encouraged by the Atomic Energy Commission (AEC) through guaranteed fixed prices for ore, bonuses, haulage allowances, establishment of ore-buying stations and access roads, and other forms of assistance. These incentives led directly to an increase in the known mineable reserves of ore in the western United States from about 9 x 10^5 metric tons (MT) (1 x 10^6 short tons (ST)) in 1946 to 8.1 x 10^7 MT (8.9 x 10^7 ST) in 1959. Programs also were initiated to examine other possible sources of uranium and to develop methods for processing these materials. AEC purchases from 1948 through 1970 totalled approximately 3 x 10^5 MT (3.3 x 10^5 ST) of U_3O_8, of which nearly 1.6 x 10^5 MT (1.8 x 10^5 ST) with a value of about $3 billion were supplied from domestic sources...

"During the peak production years in the United States, from 1960 through 1962, the number of operating mills (excluding plants producing by-product uranium from phosphates) varied from 24 to 26, with total annual production exceeding 1.5 x 10^4 MT (1.7 x 10^4 ST) of U_3O_8 from the treatment of about 7 x 10^6 MT (8 x 10^6 ST) of ore.

"In 1957, it was apparent that very large ore reserves had been developed, and that additional contracts, which were the main incentive for exploration by potential producers, would lead to commitments exceeding government requirements through 1966. In 1958, the AEC withdrew its offer to purchase uranium from any ore reserves developed in the future. This led to shutdowns of mills after expiration of contracts and to stretching out of deliveries under long-term contracts in the United States, Canada, and South Africa...

"Total production of U_3O_8 through 1979 from U.S. sources is estimated at about 2.75 x 10^5 MT (3.1 10^5 ST). The amounts of ore used in the production of this U_3O_8, and the approximate amount of tailings produced, were expected to reach 1.5 x 10^8 MT (1.6 x 10^8 ST) by the end of 1979. Of this total, about 20%, or 2.5 x 10^7 MT (2.8 x 10^7 ST), is located at inactive mill sites and the balance (80%) is located at currently active mill sites..."

2.2 The 1974 Congressional Hearings

The hazards posed by mill tailings were not completely recognized in the uranium industry's early years, and, while the Atomic Energy Act of 1954 instituted licensing of mill operations, tailings remained free of controls. Even though numerous studies had assessed tailings hazards and several Federal agencies and States (e.g., Colorado) had acknowledged a need for controls, a comprehensive control program was not started until the late 1970's.

On March 12, 1974, the Subcommittee on Raw Materials of the Joint Committee on Atomic Energy conducted hearings to discuss S. 2566 and H.R. 11378, identical bills. The bills proposed that the U.S. Atomic Energy Commission (later the Energy Research and Development Administration and now the Department of Energy) and the State of Utah jointly assess and act to limit public exposure to radiation from the Vitro uranium mill tailings site at Salt Lake City, Utah.

EPA endorsed the bills' objectives but, with the AEC, recommended instead that the two agencies, in cooperation with the states, assemble comprehensive studies of all inactive mill sites. The studies would be divided into two phases. Phase I studies would establish the sites' condition, ownership, and surroundings and the need, if any, for more detailed studies. Phase II studies would, as needed, evaluate the hazards and analyze disposal alternatives and their costs.

Congress accepted this proposal. In May 1974, the Phase I studies began (AEC74), followed by the first Phase II studies in 1975 (FB76-78). All the studies were completed by 1978.

2.3 Current Status of the Inactive Sites

A typical inactive site contains the mill buildings where ore was processed to remove the uranium, ore storage areas, and a tailings pile covering approximately 50 acres. The tailings pile was usually made by depositing slurried sand wastes on flat ground to form a pond into which there was further deposition of slurried sand, finer grained wastes ("slimes"), and process water. The water has since evaporated or seeped into the ground, leaving a large pile of mostly sand-like material. Some inactive sites also contain dried-up raffinate ponds, special ponds where contaminated process water was stored until it evaporated. Mill buildings, ore storage areas, and dried-up raffinate ponds are usually heavily contaminated with radioactive material. The amount of tailings produced by a mill is about equal in both weight and volume to the ore processed, because the recovered uranium is only a small part of the ore.

Table 2-1 shows the number of inactive uranium milling sites (and, for comparison, active sites) at 5-year intervals. This listing omits several small pilot facilities that produced uranium before 1950.

Table 2-2 lists all of the inactive uranium mill and ore processing sites and indicates those included in the Phase I and Phase II studies as well as those designated under the Act.

The Phase I Studies

The Phase I studies, completed during 1974, summarized conditions at 21 of the inactive sites and outlined detailed engineering

TABLE 2-1. NUMBER OF URANIUM MILL SITES BY YEAR[a]

Year	Inactive	Active	Total
Though 1940	0	4	4
1945	1	5	6
1950	1	9	10
1955	2	12	14
1960	4	30	34
1965	13	21	34
1970	20	15	35
1975	24	15	39
1980	25	22	47

[a] Jo77, Au70, and DOE81.

assessments to be performed later. Phase I excluded several inactive sites: Monticello, Utah (owned by the Department of Energy); Edgemont, South Dakota (owned by the Tennessee Valley Authority); Hite, Utah (after high-grade tailings were removed, the site was covered by Lake Powell which was created by the construction of the Glen Canyon Dam in 1963); Riverton, Wyoming (licensed by the AEC to a private owner at the time of the Phase I studies, but later added to the Phase II studies); Bowman, North Dakota; Belfield, North Dakota; Baggs, Wyoming; and Canonsburg, Pennsylvania.

Following are four excerpts from the Phase I summary, covering: (1) the Vitro site at Salt Lake City; (2) tailings stabilization; (3) offsite radiation from tailings; and (4) the various uses that have been made of inactive mill sites (AEC74). These provide examples of conditions found at the inactive uranium mill sites.

The Vitro Site, Salt Lake City

"The existing conditions at the Vitro site in Salt Lake City are completely unsatisfactory. The tailings pile, located at the center of population of Salt Lake valley, is largely uncovered and subject to continuing wind and water erosion. While the extent of exposure of the population to radiation from this source may be difficult to quantify, the spread of radioactivity is readily detectable for considerable distances offsite. Because of the continued industrial growth in the area, the population exposure can be expected to increase. The site is only partially fenced and is readily accessible to the public. If the tailings pile were to be stabilized by covering and vegetation at the present site, their integrity would be difficult to maintain. While contamination of surroundings from blowing dust could be reasonably well controlled, the emanation of radon gas and leaching of radium into ground waters would be expected to continue. The representative of AEC, EPA and the State of Utah concur that the present site is unsuited to long-term radioactive tailings storage, and the Phase II study of the Vitro site should be directed principally toward a plan for removal to a more suitable location.

Tailings Stabilization

"Tailings stabilization at six sites had not been attempted at all. However, following the site visit, the State of Oregon notified the owner that stabilization should be undertaken as soon as possible at Lakeview. The chemical surface coating used at Tuba City, Arizona, has broken up after only a few years weathering and is considered unsuccessful. The conditions at Shiprock, New Mexico, on the Navajo Reservation have been considerably aggravated as a result of the operation of a heavy earth-moving-equipment school on the site. The State of Colorado adopted regulations in 1966 for stabilization and control of uranium mill tailings by the mill owners. The substantial efforts made in that state have been fairly successful. In no case, however, was it found that the results could be considered entirely satisfactory. Some erosion and loss of cover was noted in all cases, and the vegetation was generally not self-sustaining without continued maintenance, usually including watering and fertilization. Thus, the stabilization work done to date represents a holding action, sufficient for the present, but not a satisfactory answer for long-term storage.

Offsite Radiation

"The mechanisms known to cause spread of radioactivity from the sites are:

1. Windblown solids.
2. Radon gas and its decay products.
3. Deliberate removal of tailings and other materials for offsite use.
4. Water erosion and dissolution.
5. Ground water and soil contamination.

In addition, low grade ores and mine wastes have occasionally been spilled or dumped offsite.

TABLE 2-2. STUDIES AND STATUS OF INACTIVE MILL AND ORE PROCESSING SITES

Site	Studies carried out		Site status under PL 95-604
	Phase I	Phase II	Designated
Arizona			
Monument Valley	x	x	x
Tuba City	x	x	x
Colorado			
Durango	x	x	x
Grand Junction	x	x	x
Gunnison	x	x	x
Maybell	x	x	x
Naturita	x	x	x
New Rifle	x	x	x
Old Rifle	x	x	x
Slick Rock (NC Site)	x	x	x
Slick Rock (UC Site)	x	x	x
Idaho			
Lowman	x	x	x
New Mexico			
Ambrosia Lake	x	x	x
Shiprock	x	x	x
North Dakota			
Belfield	-	-	x
Bowman	-	-	x
Oregon			
Lakeview	x	x	x
Pennsylvania			
Canonsburg[a]	-	[b] x	x
South Dakota			
Edgemont[c]	-	-	-
Texas			
Falls City	x	x	x
Ray Point[d]	x	x	-

See footnotes at end of table.

TABLE 2-2. STUDIES AND STATUS OF INACTIVE MILL AND ORE PROCESSING SITES (Continued)

Site	Studies carried out Phase I	Studies carried out Phase II	Site status under PL 95-604 Designated
Utah			
Green River	x	x	x
Hite[e]	-	-	-
Mexican Hat	x	x	x
Monticello[f]	-	-	-
Salt Lake City	x	x	x
Wyoming			
Baggs[g]	-	-	-
Converse County	x	x	x
Riverton	-	x	x
Totals	21	23	24

[a] Former rare-metals plant; not an inactive uranium mill site.
[b] Study done under Formerly Utilized MED/AEC Sites Remedial Action Program.
[c] Owned by TVA.
[d] Uranium not sold to U.S. Government.
[e] Covered by waters of Lake Powell.
[f] Owned by Department of Energy.
[g] On U.S. Bureau of Land Management (BLM) property.

"Evidence exists of all these mechanisms causing some degree of increase in radioactivity above natural background. In no other location was there evidence of the widespread use of tailings in building construction such as occurred in Grand Junction, Colorado. Nevertheless, there are some habitable structures in several other locations where tailings use is suspected.

"Measurements of dust concentrations in air made near tailings piles in the past have not indicated significant hazard from inhalation. However, the significance of blowing dusts settling out in the general vicinity over a period of many years has not been thoroughly evaluated.

"The EPA has held the position for some time that radon gas emanating from a tailings pile may cause a detectable increase in airborne radiation levels in the vicinity of a tailings pile, roughly within half a mile. The gas will diffuse readily into existing structures, but its particulate decay products would tend to remain inside, possibly causing a buildup in radioactivity within the structure. There is little data available to support this hypothesis, but it needs to be checked carefully, as it could have significant bearing on decisions regarding removal of tailings piles from populous areas. High radon decay product levels were found in structures close to the Vitro pile, but the possibility of their having been built over tailings has not been excluded.

"Water erosion does not appear to have been a significant factor in the off site migration of tailings. However, the movement of radium and soluble salts into the subsoil in areas with high water table needs further evaluation. In a few locations tailings piles are located near water courses where flooding can be a problem.

Use of Mill Sites

"Where housing and other structures remain from the milling operations they have been frequently put to use. Housing at Tuba City, Naturita, Slick Rock, Shiprock and Mexican Hat is occupied. Buildings on the mill sites at Gunnison, Naturita, Shiprock, Green River and Mexican Hat are being used for warehousing, schools and other purposes. At several sites, buildings are still used for company activities. At Salt Lake City a sewage disposal plant is operating on the site. Construction of an automobile race track was begun in the middle of the tailings pile. It was subsequently stopped by the State upon recommendations of AEC and EPA. The pressure for use of sites in urban areas is likely to increase with time consistent with projected population growth. None of the areas formerly occupied by milling facilities, ore stockpiles, etc., have been examined to determine the depth of soil contamination, or suitability for future unrestricted use."

Table 2-3 contains a summary of the widely varying site conditions at the time of the Phase I site visits (AEC74, Table I). Tables 2-4 and 2-5 contain summaries of basic Phase I findings and the contractor's recommendations for potential remedies at each site, respectively (AEC74).

Since the Phase I studies, the Naturita pile has been moved to a new site and reprocessed; the new site is considered active and the tailings are not covered under Title I of PL 95-604. The Shiprock site has been substantially cleaned up, with all buildings removed and the pile stability improved. At some sites, buildings and other architectural features, such as fences, have been changed. Finally, at all sites further wind and water erosion of tailings has occurred.

The Phase II studies

Phase II studies (FB76-78) of 23 sites, guided by the recommendations of the Phase I studies, began in 1975. The studies identified site ownership and determined hydrologic, meteorologic, topographic, demographic, and socioeconomic characteristics; alternative sites to which tailings might be moved were also identified. Radiological surveys of air, land, and water near the tailings sites were made, and exposures to individuals and nearby populations were estimated. The offsite uses of tailings were identified. Finally, the studies developed alternative remedial action plans for each site and analyzed each plan's cost.

This Final Environmental Impact Statement incorporates many of the results found in the Phase II reports (e.g., Chapter 3), but the reports offer more detailed, site-specific information.

TABLE 2-3. SUMMARY OF CONDITIONS AT TIME OF PHASE I SITE VISITS

Uranium Mill Tailings Site	Condition of Tailings	Condition of Buildings & Structures on Millsite	Mill Housing	Adequate Fencing, Posting, & Surveillance	Property Bounded by River or Stream	Dwellings or Industry Within 1/2 Mile	Visual Evidence Wind or Water Erosion	Possible Groundwater or Surface Water Contamination	Tailings Removed From Site for Private Use	Other Hazards On-Site
Arizona										
Monument Valley	U	R	N	No	No	Yes	No	No	No	No
Tuba City	U	PR-UO	E-O	No	No	Yes	Yes	No	No	Yes
Colorado										
Durango	PS	PR-UO	N	Yes	Yes	Yes	Yes	No	Yes	Yes
Grand Junction	S	PR-O	N	Yes	Yes	Yes	No	No	Yes	No
Gunnison	S	B-O	N	Yes	No	Yes	No	Yes	No	No
Maybell	S	R	N	Yes	No	No	No	No	No	No
Naturita[(a)]	S	PR-O	E-PO	Yes	Yes	No	Yes	Yes	No	No
New Rifle	PS	M-O	N	Yes	Yes	Yes	Yes	Yes	No	No
Old Rifle	S	PR-OU	N	Yes	Yes	Yes	No	Yes	Yes	No
Slick Rock (NC)	S	R	N	No	Yes	Yes	Yes	No	No	No
Slick Rock (UC)	S	R	E-PO	Yes	Yes	Yes	No	No	No	No
Idaho										
Lowman	U	R	N	No	Yes	Yes	No	No	Yes	No
New Mexico										
Ambrosia Lake	U	PR-O	N	Yes	No	No	Yes	No	No	No
Shiprock	PS	PR-O	E-O	Yes	Yes	Yes	No	No	Yes	Yes
Oregon										
Lakeview	U	M-OU	N	Yes	No	Yes	Yes	No	No	No
Pennsylvania										
Canonsburg[(b)]	U	B-O	N		Yes	Yes	Yes		Unknown	No
Texas										
Falls City	PS	M-OU	N	Yes	No	No	No	Yes	No	No
Ray Point	PS	M-OU	N	Yes	No	No	No	No	No	No
Utah										
Green River	S	B-O	N	Yes	No	Yes	Yes	Yes	No	No
Mexican Hat	U	B-O	E-O	No	No	Yes	Yes	Yes	No	No
Salt Lake City	U	R	N	No	Yes	Yes	Yes	Yes	Yes	Yes
Wyoming										
Converse City	U	R	N	No	No	No	No	No	No	No

(a) Pile moved to new location after this study.
(b) Not in Phase I study; study performed at later time.

B Building(s) intact.
E Existing.
M Mill intact.
N None.
NC North Continent pile.
O Occupied or used.
P Partially occupied.

P Partially occupied.
PR Mill and/or buildings partially removed.
PS Partially stabilized.
R Mill and/or buildings removed.
S Stabilized, but requires improvement.
U Unstabilized.
UC Union Carbide pile.
UO Unoccupied or unused.

TABLE 2-4. SUMMARY OF PHASE I FINDINGS

Uranium Mill Tailings Site	Years Mill Operated	Amount of Tailings (Thousands of tons)	Total Amount of Radium in Tailings (curies)
Arizona			
Monument Valley	1955-67	1,200	50
Tuba City	1956-66	800	670
Colorado			
Durango	1943-63	1,555	1,200
Grand Junction	1951-70	1,900	1,350
Gunnison	1958-62	540	200
Maybell	1957-64	2,600	640
Naturita	1939-63	704	490
New Rifle	1958-72	2,700	2,130
Old Rifle	1924-58	350	320
Slick Rock (NC)	1931-43	37	30
Slick Rock (UC)	1957-61	350	70
Idaho			
Lowman	1955-60	90	10
New Mexico			
Ambrosia Lake	1958-63	2,600	1,520
Shiprock	1954-68	1,500	950
Oregon			
Lakeview	1958-60	130	50
Texas			
Falls City	1961-73	2,500	1,020
Ray Point	1970-73	490	230
Utah			
Green River	1958-61	123	20
Mexican Hat	1957-65	2,200	1,560
Salt Lake City	1951-68	1,700	1,380
Wyoming			
Converse County	1962-65	187	60
Totals		25,256	13,950

NC North Continent pile.
UC Union Carbide pile.

TABLE 2-5. RECOMMENDATION FROM PHASE I ON PRINCIPAL ACTIONS TO BE STUDIED IN PHASE II

Uranium Mill Tailings Site	Remove Tailings (I)	Stabilize Tailings (II)	Decontaminate Site (III)	Improve Fencing and Posting (IV)	Remedial Actions for Buildings (V)	Groundwater Surveys (VI)	No Further Studies (VII)
Arizona							
Monument Valley				X	(a)	X	
Tuba City		X	X	X	X		
Colorado							
Durango	X	X	X		X		
Grand Junction	X	X	X		X		
Gunnison	X	X	X			X	
Maybell		X	X				
Naturita		X	X				
New Rifle	X				X	X	
Old Rifle	X	X	X		X	X	
Slick Rock (NC)		X					
Slick Rock (UC)		X	X				
Idaho							
Lowman		X		X			
New Mexico							
Ambrosia Lake		X	X	X			
Shiprock	X	X	X	X			
Oregon							
Lakeview		X	X	X			X
Texas							
Falls City		X			(a)		X
Ray Point		X			(a)		X
Utah							
Green River		X	X				
Mexican Hat		X	X				
Salt Lake City	X	X	X	X	X	X	
Wyoming							
Converse County				X			X

(a)Though not recorded in Phase I study, the use of tailings in building construction has since been reported.

Notes:

I - Remove tailings and other radioactive materials from the site to a more suitable location.
II - Stabilize tailings, complete, or improve stabilization to prevent wind and water erosion.
III - Decontaminate millsite or immediate area around tailings pile.
IV - Complete or improve fencing and posting of millsites and tailings areas.
V - Determine levels of radioactivity in structures where tailings may have been used in construction, and determine costs and measures needed for remedial action where warranted.
VI - Conduct groundwater surveys in immediate area of millsite and tailings.
VII - No phase II study proposed at this time.

NC North Continent pile.
UC Union Carbide pile.

Chapter 3: RADIOACTIVITY AND TOXIC MATERIALS IN TAILINGS

In this chapter we discuss the amounts and concentrations of radioactivity and toxic materials found in tailings piles and released to nearby air and water. We also estimate the extent to which tailings have been moved off the piles by man and by natural forces. Finally, we discuss the levels of radioactivity in buildings due to use of tailings, and, for the purpose of comparison, due to natural causes.

3.1 Radioactivity in Tailings

From 1948 through 1978 nearly 160 million tons of ore were processed at uranium mills (DOE79a) to recover some 328,000 tons of U_3O_8, a uranium-rich compound called "yellowcake." This operation produced about 160 million tons of tailings. The 24 designated sites contain about one-sixth of these tailings, roughly 25 million tons, deposited in piles covering a total of about 1,000 acres. Virtually all of the remaining tailings are at active mill sites licensed by the NRC or by States having agreements with NRC.

Most of the uranium recovered from ore is uranium-238, a radioactive isotope that decays, over billions of years, to become lead-206, a stable (i.e., nonradioactive) element. The lengthy decay process includes a number of intermediate stages (called decay products). These, too, are radioactive. Figure 3-1 traces the steps in this decay process. Since the ore was formed millions of years ago, uranium has continued to decay and an inventory of all of these decay products has built up. There are also radioactive materials from two other decay processes in uranium ore, the uranium-235 series and the thorium-232 series, but these are present in much smaller amounts, and we have concluded that it is not necessary to include them in our analysis (see Section 4.1).

When ore is processed most of the uranium is removed and most of the subsequent decay products become part of the tailings. As a result, thorium-230 is the radionuclide with the longest half-life of significance in tailings. Thorium decays to produce radium-226. Radium decays in turn to produce radon-222, a radioactive gas. Because radon gas is chemically inert, some of it escapes from the tailings particles in which it is produced, diffuses to the pile surface, and is

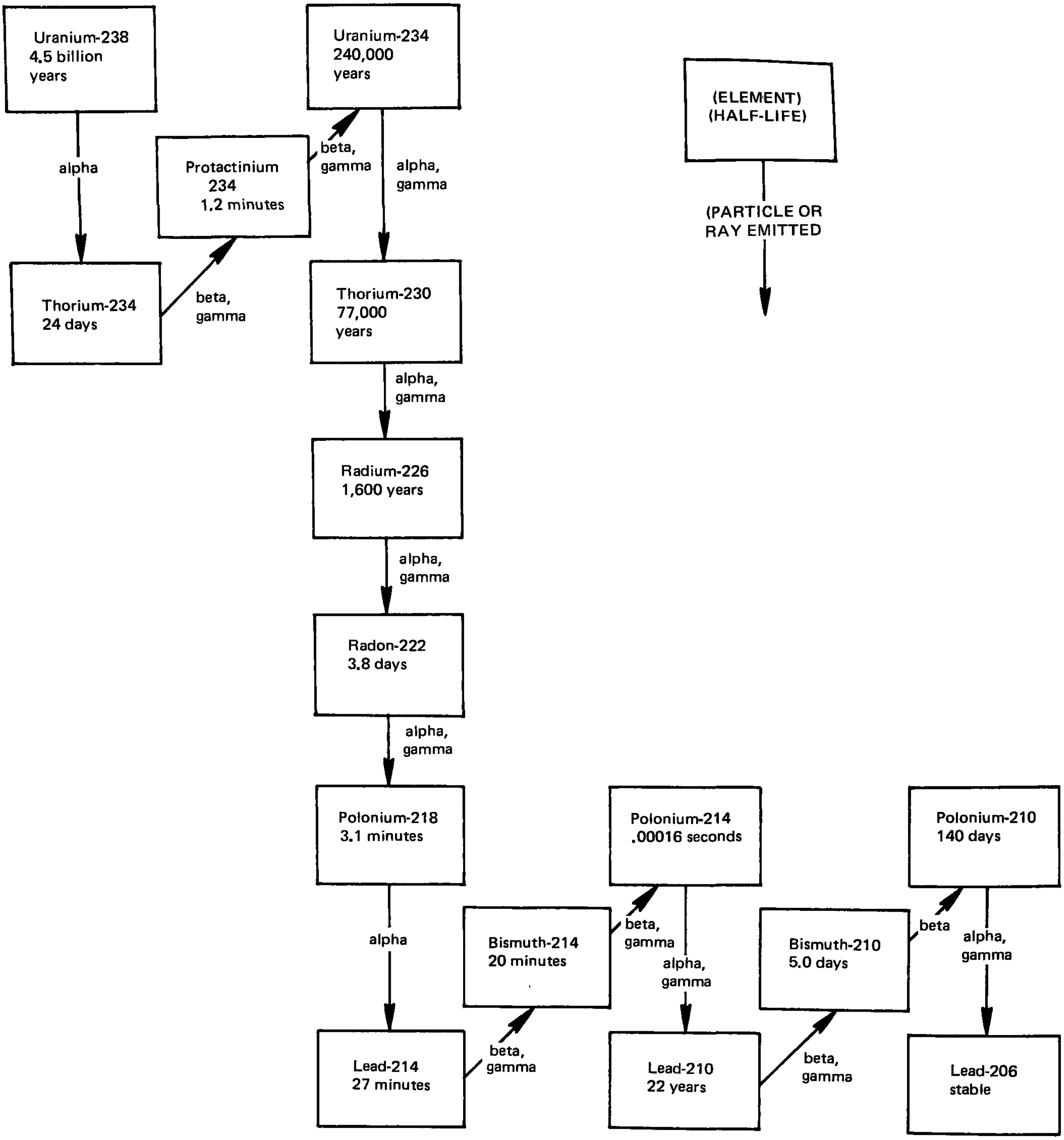

FIGURE 3-1. THE URANIUM-238 DECAY SERIES.

carried away into the atmosphere. Airborne radon produces a series of short half-life[(1)] decay products that are hazardous if inhaled. If the radon does not escape from the tailings, its decay products remain there, and the gamma radiation they produce may increase the hazard to people near tailings.

Since thorium has a much longer half-life than its two immediate decay products, radium and radon, the amounts of radioactivity from radium and radon remain the same as that from thorium. The amount of radon released from a tailings pile remains effectively constant on a year-to-year basis for many thousands of years, decreasing only as the thorium, with its 77,000-year half-life, decreases.

In Figure 3-2 we show how the yearly production rate of radon in a tailings pile will decrease with time. It falls to 10 percent of its initial value in about 265,000 years. This time scale is typical of and illustrates the long term nature of most of the significant radiological hazards associated with uranium mill tailings.

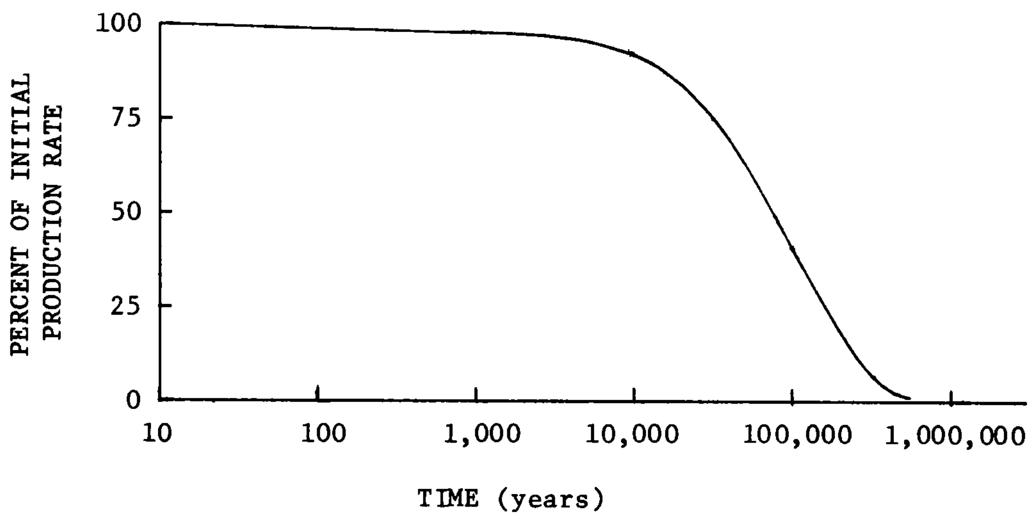

FIGURE 3-2. RADON PRODUCTION IN A TAILINGS PILE

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(1) A half-life is the time it takes for a given quantity of a radioactive isotope to decay to half of that quantity. Figure 3-1 shows the half-lives of the members of the uranium-238 decay series.

There are two types of chemical extraction used by uranium mills: the acid-leach process and the alkali-leach process. The process selected at a particular mill depends on the nature of the ore. The radioactive and chemical characteristics of the tailings and, to a degree, the way radionuclides are distributed within a tailings pile depend on which process is used.

When discharged from the mill, tailings have both solid and liquid components. The solid portion of tailings can be characterized as either coarse sands or fine slimes. In both the acid process and the alkali process, the residual uranium and radium content of slimes is about twice that of sands. Usually, the total amount of thorium and radium is the same for both processes when the pile is considered as a whole, but differences in details of mill chemical processes sometimes change this ratio at various places within a pile.

Radioactive materials are also discharged to tailings piles in liquid wastes. The amount of radioactive thorium is much higher in liquids discharged from acid-process mills than from alkaline-process mills, because thorium dissolves readily in acidic but not in alkaline solvents. About 5 percent or less of the radium in ore is dissolved by either method. The chemical processing recovers only dissolved uranium, so that essentially all of the dissolved thorium, radium, and other radionuclides are discharged to the tailings pond (Se75).

In general, no more than about 20 percent of the radon produced by the radium in a tailings particle leaves the particle. The remaining 80 percent (and therefore its subsequent decay products) stays locked within the particle (Cu73). In addition, much of the radon escaping from tailings particles decays before reaching the atmosphere and therefore also leaves its decay products within the pile. The depth of the tailings pile (and any cover), its porosity, and its moisture content determine how much of the radon released from tailings particles is ultimately released to the atmosphere. The variability of these factors makes it difficult to predict these releases accurately.

In Table 3-1 we show, for each of the designated sites, the quantity of tailings, area of the pile, average ore grade, estimated average radium concentration (based on average ore grade), estimated annual radon release and release rate from the pile, total quantity in curies(1) of radium, maximum measured radium concentration, and some limited information on the measured radon release rate.

"Upgrader" sites are locations from which the fine slimes have been removed for the purpose of reworking them elsewhere to recover residual uranium. At these sites the average radium concentration is

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(1)The curie (Ci), a basic unit of radioactivity, is equal to 37 billion nuclear transformations per second.

probably lower than the estimated values in Table 3-1, which are based on the average ore grade. Of the 24 sites, Green River, Monument Valley, Slick Rock (UC), and Converse County were upgrader sites. The Naturita mill also operated as an upgrader shortly before it was shut down.

3.2 Toxic Materials in Tailings

A number of nonradioactive toxic materials from ore or from chemicals used in processing have been found in both liquid and solid uranium mill wastes (Se75, FB76-78). The contaminants present depend on the ore source and the type of processing. In Table 3-2 we indicate the average concentration of 15 elements found in 19 inactive tailings piles as adapted from the work of Markos and Bush (Mac81a). These data show wide variations of element concentration among the different piles as well as wide variations of element concentration above and below those values for "typical soil." In Table 3-3 we give an example of more complete data that shows how elements are divided between sands and slimes of a tailings pile at an alkaline-leach uranium mill (Ambrosia Lake). We do not have similar data for an acid-leach mill. The ratio of the concentration in fine slimes, which are usually more contaminated, to that in a nearby soil sample is included for comparison. Uranium and thorium, while radioactive, are also potentially toxic elements and are included in this table.

3.3 Offsite Contamination Due to Natural Forces

In this section we discuss contamination of land, surface and groundwater, and air. The land contamination is from tailings transported by wind and water erosion; surface and groundwater contamination is from the leaching of radionuclides and potentially toxic elements in the tailings; and air contamination results from emissions of radon and fine tailings particles into the air.

Land Contamination

The action of wind and water can erode tailings from unstablized piles onto nearby land. To determine the extent of this contamination, EPA conducted gamma radiation surveys at most of the inactive tailings sites in the spring of 1974. Contour lines corresponding to gamma radiation levels (above normal background) of 40 microroentgens/hr,(1) 10 microroentgens/hr, and zero microroentgens/hr (i.e., background) were identified and plotted on site maps to characterize contaminated areas (Do75). In Table 3-4 we summarize estimates of the areas within these contour lines for the 20 inactive sites for which these surveys were carried out. In Chapter 7 we discuss how we have used these gamma radiation levels to estimate the extent of radium contamination in the surface soil.

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(1) The roentgen (R) is a unit measuring the electrical charge gamma radiation produces when absorbed in air (i.e., 2.58 x 10^{-4} C/kg). A microroentgen is one millionth of a roentgen.

TABLE 3-1. RADIOACTIVITY IN INACTIVE URANIUM MILL TAILINGS PILES

Location	Amount of Tailings (Millions of Tons)	Area of Tailings (Acres)	Average Ore Grade[a] (% U_3O_8)	Radium-226[b] Average Concentration (pCi/g)	Radium-226[c] Maximum Measured Concentration (pCi/g)	Radium-226 (Ci)	Radon-222[d] Assumed Release Rate (Ci/y)	Radon-222 Estimated Release Rate (pCi/m^{2}s)	Radon-222[e] Measured Release Rate (pCi/m^{2}s)
Monument Valley, Arizona	1.2	30	0.04	50	1,300	50	200	50	14-29
Tuba City, Arizona	0.8	22	0.33	920	1,880	670	2,600	920	11-400
Durango, Colorado	1.6	21	0.25	700	1,800	1,200	1,900	700	35-310
Grand Junction, Colorado	1.9	59	0.28	780	1,800	1,350	5,900	780	25-660
Gunnison, Colorado	0.5	39	0.15	420	1,100	200	2,100	420	480
Maybell, Colorado	2.6	80	0.098	270	600	640	2,800	270	75-100
Naturita, Colorado	0.0	(23)	Tailings pile has been moved, only residual contamination remains					1-124	
New Rifle, Colorado	2.7	32	0.31	870	1,900	2,130	3,600	870	70-1,400
Old Rifle, Colorado	0.4	13	0.36	1,000	5,400	320	1,700	1,000	210-1,300
Slick Rock (NC), Colorado	0.04	19	0.28	780	350	30	1,900	780	4-250
Slick Rock (UC), Colorado	0.35	6	0.25	690	120	70	500	690	6-24
Lowman, Idaho	0.09	5	0.19	530	240	10	300	530	50-150
Ambrosia Lake, New Mexico	2.6	105	0.23	640	900	1,520	8,600	640	40-300
Shiprock, New Mexico	1.5	72	0.25	700	4,000	950	6,400	700	53-160 (g)(440-1200-2200)
Belfield, North Dakota	(h)0	(i)7.5	-	-	-	-	-	-	1.3-63
Bowman, North Dakota	(h)0	(i)12	-	-	-	-	-	-	48-94

See footnotes at end of table.

TABLE 3-1. RADIOACTIVITY IN INACTIVE URANIUM MILL TAILINGS PILES (Continued)

Location	Amount of Tailings (Millions of Tons)	Area of Tailings (Acres)	Average Ore Grade[a] (% U_3O_8)	Radium-226[b] Average Concentration (pCi/g)	Radium-226[c] Maximum Measured Concentration (pCi/g)	Radium-226 (Ci)	Radon-222[d] Assumed Release Rate (Ci/y)	Radon-222 Estimated Release Rate (pCi/m^2s)	Radon-222[e] Measured Release Rate (pCi/m^2s)
Lakeview, Oregon	0.13	30	0.15	420	420	50	1,600	420	187-710 [j](3-31)
Canonsburg, Pennsylvania	0.4	18	-	-	4,200	-	-		185-296
Falls City, Texas	2.5	146	0.16	450	160	1,020	8,400	450	3-78
Green River, Utah	0.12	9	0.29	810	220	20	900	810	32-128
Mexican Hat, Utah	2.2	68	0.28	784	1,900	1,560	6,800	784	16-1,600
Salt Lake City, Utah	1.7	100	0.32	900	2,000	1,380	11,500	900	[k]1-20 [l](130-300-650)
Converse County, Wyoming	0.19	5	0.12	340	650	60	200	340	190-2,860
Riverton, Wyoming	0.9	72	0.20	560	1,100	[m]544	5,100	560	50-80
Total	24.42	970.5				13,774	73,000		

NC North Continent pile. UC Union Carbide pile.

(a) Phase II Reports (FB76-78).
(b) Calculated from average ore grade, assuming 700 pCi/g per 0.25%.
(c) Phase II Reports (FB76-78). Value shown is for highest reported soil, sediment, or tailings sample. Tailings were not sampled in all cases.
(d) Calculated from average radium-226, assuming 1 pCi/m^2s of radon-222 is released (annual average) for each pCi of radium-226 per gram of tailings.
(e) Phase II Reports (FB76-78), unless indicated otherwise.
(f) Pile has been removed from site; only residual amounts remain.
(g) Bernhardt, et al. (Be75), reported values ranging from 590 to 1,320 pCi/m^2s for uncovered and 440 to 2,200 pCi/m^2s for stabilized tailings.
(h) Residual contamination only.
(i) Area within site boundaries.
(j) Bernhardt, et al. (Be75), reported values for stabilized tailings ranging from 3 to 31 pCi/m^2s.
(k) Measurements by FBDU are based on a sample of tailings in a barrel, with varying moisture contents.
(l) Bernhardt, et al. (Be75), reported values for 11 sites ranging from 130 to 650 pCi/m^2s, with a median of about 300 pCi/m^2s. Measurements by Bernhardt indicated overlapping ranges of radon release rates for uncovered and covered (up to several feet) tailings.
(m) Sw76.

TABLE 3-2. AVERAGE CONCENTRATION OF ELEMENTS FOUND IN INACTIVE URANIUM MILL TAILINGS[a] (in ppm)

Tailings Pile	As Arsenic	Ba Barium	Cd Cadmium	Cr Chromium	Cu Copper	Fe Iron	Pb Lead	Hg Mercury	Se Selenium	Ag Silver	U Uranium	V Vanadium	Zn Zinc	Ra-226[b] Radium ($\times 10^{-6}$)
	ELEMENT													
Arizona														
Monument Valley	1.5	-	-	-	-	-	--	--	0.064	--	60	1850	--	50
Tuba City	82	86	4	6	1160	7230	812	0.001	10	6	370	620	249	920
Colorado														
Durango	0.80	82	0.20	8.8	95	62	62	0.87	1.2	1.2	480	3900	304	700
Grand Junction	14	121	1.6	29	14	1170	50	0.026	3.1	0.72	180	1760	45	780
Gunnison	254	66	0.26	5.2	30	20800	137	--	1	3.8	90	80	120	420
Maybell	1.5	18	0.09	9.3	3.1	2100	13	0.09	13	0.15	120	120	17	274
Naturita	59	172	0.07	3.5	54	16400	48	--	0.47	1.1	500	2890	75	--
New Rifle	4.2	100	1.1	55	8	807	187	0.001	1.9	1.4	240	3990	31	870
Old Rifle	3.7	155	8.7	20	18	8250	38	0.25	2.7	0.46	380	520	359	1000
Slick Rock NC	34	453	0.027	4.9	35	6540	1250	109	0.76	1.7	80	620	21	780
Slick Rock UC	6.6	134	0.074	3.4	17	4080	29	0.074	2.2	0.57	50	1480	21	690
New Mexico														
Ambrosia Lake	2.6	96	3.6	8	58	90	--	0.002	68	0.15	210	1590	47	640
Shiprock	0.004	-	-	-	-	-	--	--	0.18	--	120	330	--	700
Utah														
Green River	1.9	73	0.40	17	102	1210	121	0.001	231	0.070	60	1390	21	810
Mexican Hat	63	12	0.70	1.0	488	3650	40	--	6	1.0	140	1350	57	780
Vitro Uranium[c]	210	2130	-	1010	310	31100	3060	--	--	0.022	180	100	340	
Vitro Vanadium[c]	244	3860	-	2030	1080	213000	350	--	--	0.066	50	830	350	900
Wyoming														
Spook	87	46	0.37	26	14	15299	2.5	--	262	2.2	130	350	31	340
Riverton	161	64	0.32	23	21	21800	3.2	--	391	2.4	70	240	38	560
"Typical" Soil[d]	6	500	0.06	100	20	38000	10	0.03	0.2	0.1	1.0	100	50	1.5

(a) Adapted from G. Markos and K.J. Bush, "Physico-Chemical Processes in Uranium Mill Tailings and Their Relationship to Contamination" (Mac81a)
(b) Table 3-1 (1 pCi/g = 1 x 10^{-6} ppm, for Ra-226).
(c) Two different parts of the Vitro Site, Salt Lake City, Utah.
(d) Bo66.

TABLE 3-3. ELEMENTS PRESENT IN TAILINGS SANDS AND SLIMES FROM AN ALKALINE-LEACH MILL[(a)]

Element	Concentration in Sands (ppm)	Concentration in Slimes (ppm)	Ratio of Quantity in Slimes to that in Local Soil
Uranium	211	380	160
Molybdenum	-	300	160
Selenium	31.3	133	100
Vanadium	204	2050	70
Arsenic	27	79	18
Chlorine	ND	580	13
Antimony	0.69	2.2	5
Calcium	2830	2670	5
Cerium	90	163	5
Bromine	2.5	7.6	4
Sodium	1080	1970	4
Iron	1060	3550	3
Terbium	0.37	0.63	3
Cobalt	2.9	9.3	2.5
Aluminum	4280	6660	2
Barium	663	572	2
Europium	0.95	1.48	2
Gallium	5.5	17	2
Lanthanum	24	44	2
Manganese	335	388	2
Scandium	2.5	7.0	2
Zinc	15	68	2
Chromium	10	25	1
Potassium	2350	2110	1
Thorium	4.6	8.8	1
Titanium	1330	2140	1
Ytterbium	1.6	2.9	-
Cesium	2.4	2.4	1
Hafnium	3.6	4.8	1
Magnesium	4190	2180	1
Rubidium	82	63	1
Tantalum	0.42	0.62	1
Strontium	183	ND	-
Tungsten	0.49	ND	-
Neodymium	41	95	-

(a) Elements reported for Ambrosia Lake (Dr78).
(-) No data. (ND) Not detected. (ppm) parts per million

TABLE 3-4. ESTIMATED AREA OF CONTAMINATION AT INACTIVE MILLS[a]

Location	Contaminated Area (Acres): Greater than 40 uR/hr above background	Greater than 10 uR/hr above background	Above background
Monument Valley[b] Arizona	(c)	52	-
Tuba City Arizona	130	170	200
Durango[d] Colorado	-	-	-
Grand Junction[e] Colorado	-	-	310
Gunnison Colorado	12	26	68
Maybell Colorado	320	450	750
Naturita[f] Colorado	-	-	110[g]
Rifle (New) Colorado	110	170	310
Rifle (Old) Colorado	17	44	240
Slick Rock (NC) Colorado	-	12	33
Slick Rock (UC) Colorado	3	41	81
Lowman Idaho	-	11	16
Ambrosia Lake New Mexico	210	390	620
Shiprock New Mexico	-	130	230

See footnotes at end of table.

TABLE 3-4. ESTIMATED AREA OF CONTAMINATION AT INACTIVE MILLS[a] (Continued)

Location	Contaminated Area (Acres) Greater than 40 uR/hr above background	Greater than 10 uR/hr above background	Above background
Belfield North Dakota	-	-	29[g]
Bowman North Dakota	-	-	36.5[g]
Lakeview[h] Oregon	-	-	-
Canonsburg[i] Pennsylvania	-	-	-
Falls City Texas	140	260	410
Green River Utah	-	44	150
Mexican Hat Utah	-	130	460
Salt Lake City Utah	110	200	510
Converse County Wyoming	-	88	190
Riverton Wyoming	-	99	460

(NC) North Continent pile; (UC) Union Carbide pile.

[a]Reference (Do75) unless otherwise noted.
[b]Rock outcroppings and scattered ore made measurements difficult.
[c](-) Data not available.
[d]Ponds covered with topsoil; contaminated area not determined.
[e]Due to extensive development around site, contaminated area could not be determined.
[f]Contamination from plume extends several miles down valley.
[g]Land estimated to have radium in excess of 5 pCi/g (FB81).
[h]Gamma survey not done, at request of State.
[i]Gamma survey not done.

Little data is available about contamination of land with windblown toxic materials. However, it is likely that such contamination of land exists in generally the same proportion to radioactive contamination as it does in the tailings piles. Surface runoff may also deposit tailings particles, and therefore toxic materials, in the vicinity of the pile. In these cases also, the amount of radioactivity should usually be a reasonably good indicator of the concentrations of other elements because they, like radioactive elements, are assumed to be relatively well fixed in tailings particles. (If they were not, process liquids and rain water would have leached them downward into the soil beneath the pile.)

Water Contamination

Tailings can contaminate both surface and groundwater. However, most of this contamination appears to occur as the result of seepage of liquid waste discharges from the mill to the tailings pile when the mill was active. Kaufmann, et al. (Ka75), in a study conducted by EPA, estimated that 30 percent of the process water from two active tailings ponds in New Mexico had seeped into the ground. Purtyman, et al. (Pu77), in a study carried out for DOE, estimated a 44 percent seepage loss from another pile in New Mexico during its active life.

The NRC, in its Final Generic Environmental Impact Statement (FGEIS) on Uranium Milling (NRC80), assumes that a model site will experience a 40 percent water loss by seepage and uses mathematical models to estimate the movement of this seepage through unsaturated soil, formation of a seepage "bulb" in the saturated soil zone, and the movement of pollutants with groundwater. For its model mill in an arid region, NRC concluded that about 95 percent of the possible contamination of groundwater would be associated with the active phase of the pile and only 5 percent with long-term losses from the inactive pile (NRC80).

There is evidence that groundwater near some inactive sites is contaminated, probably due to seepage of liquids from tailings ponds during and soon after their active use (Dr78). Groundwater contaminant concentrations near the inactive mills were surveyed as part of the Phase II studies (FB76-78), and some cases of elevated concentrations were found. Additional case histories showing some water contamination problems near uranium mills and mines are given in a recent report (UI80). Contamination that extends up to 8,000 feet from active tailings piles has been found, but this is usually in shallow alluvial aquifers (UI80). In Table 3-5 we summarize the elements found in elevated concentrations in groundwater near tailings piles.

Contamination of deep aquifers has not been observed, but may be possible (UI80). Markos has shown that many of the soluble elements in piles tend to precipitate and form a barrier when liquids move downward in the pile to the soil at the tailings-soil interface (Mac79, Mac81a-81b). This would prevent contamination of groundwater from inactive tailings. However, how long this barrier will last is not known, and there could be channels through the barrier at locations other than

TABLE 3-5. ELEMENTS FOUND IN ELEVATED CONCENTRATIONS IN GROUNDWATER NEAR TAILINGS SITES

Tailings Site[a]	Elements[b]
Gunnison, Colorado	Arsenic, Barium, Chromium, Iron, Lead, Selenium, Vanadium
Ambrosia Lake, New Mexico	Barium, Lead, Vanadium
Falls City, Texas	Arsenic, Barium, Chromium, Iron, Lead, Selenium, Radium, Vanadium
Green River, Utah	Arsenic, Chromium, Lead, Selenium
Ray Point, Texas[c]	Arsenic
Grants Mineral Belt, N.M. (Active Mills)	Polonium, Selenium, Radium, Vanadium, Uranium, Ammonia, Chloride, Nitrate, Sulfate

(a) (FB76-78, Ka75).
(b) At most sites there are other potential sources of toxic material contamination; see orginal reports for details.
(c) Not designated under the Act because the uranium produced was not sold to the U.S. Government.

those sampled. DOE is currently sponsoring additional studies of the potential for groundwater contamination.

Markos also concludes that the deliquescent and hygroscopic properties of the salts in piles act to scavenge moisture from the atmosphere or shallow water tables and move water from areas of low salt concentration to high salt concentration (Mac79). Osmotic and capillary pressure in tailings can also cause a net movement of water to the surface of a pile. This can lead in turn to the deposition of radioactive and other salts on pile surfaces. In contrast, studies by Klute and Heermann (K178) indicate that even in dry climates precipitation can produce a downward flow of water through tailings.

Standing water with elevated concentrations of toxic materials has been reported on and adjacent to some tailings sites (Mac81b, FB76-78). Usually these concentrations are intermediate between those reported for waters within piles and normal levels in surface water. Surface water runoff from rains and floods can wash surface salt deposits and tailings from an unprotected pile, causing spread of toxic and radioactive elements to nearby land and streams. However, the limited studies that have been made do not show nearby streams being contaminated by inactive tailings piles (FB76-78).

Future contamination of surface or groundwater by a pile is likely if there is erosion of toxic elements from a pile by rain, by flooding, or, possibly, by the flushing action of seasonal changes in the water table when it can reach a pile. Severe floods have greater but unevaluated potential for producing significant contamination in streams and rivers. Future groundwater contamination from the seepage and flushing action of seasonal change in the water table is uncertain.

Air Contamination

The most significant radionuclide released to air is radon. In Table 3-1 we show both calculated and measured radon emission rates(1) from the 24 designated sites. Most of the calculated emission rates range from 300 pCi/m^2s to 1000 pCi/m^2s. Radon emission rates from uncontaminated soils are much lower, averaging close to 1 pCi/m^2s, with a range of perhaps as much as a factor of 2 or 3 higher and lower.

To estimate the annual radon release rates reported in Table 3-1 we assumed that the radon emission rate per unit area is 1.0 pCi/m^2s per pCi/g radium; this value was also used by NRC (NRC80, Appendix G). We have also assumed that the piles are dry, homogeneous, not covered, and at least 3 meters deep. By way of comparison, Haywood (Ha77) has calculated values of 0.35, 0.65, and 1.2 pCi/m^2s radon per pCi/g radium for wet, moist, and dry tailings, respectively.

The measured radon release rates listed in Table 3-1 are generally less than we have estimated using the average radium concentration in tailings and assuming dry piles. In reality, of course, many tailings piles still contain significant residual moisture. Several have also been subjected to temporary stabilization measures, which should also reduce the release of radon. However, we consider it reasonable to assume that, over the term of interest for the hazards associated with release of radon (hundreds of thousands of years), the piles would be dry most of the time and that any existing temporary stabilization would not persist for such time spans.

Tailings piles also release fine tailings particles to the air. Schwendiman et al., have studied particle release rates from an active pile (Scb80). Their data show that for wind speeds from 7 mph to 25 mph, the airborne mass loading downwind from the pile is roughly 5×10^{-4} g/m^3. This is an order of magnitude greater than the mass loading measured just upwind from the site. The airborne concentrations of several radioactive and toxic elements were also measured, showing that the windblown particles from a tailings pile contain a variety of radionuclides, as well as selenium, lead, arsenic, mercury, and molybdenum. However, the air concentrations observed were

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(1)The term emission rate is used rather than fluence rate or flux density, which although more precise are generally less familiar.

well below the 8-hour threshold limit values to which workers can be repeatedly exposed without adverse effect. (These values for occupationally exposed workers were established by the American Conference of Governmental Industrial Hygienists (AC81).)

Potential for Massive Tailings Dispersal by Floods

Most of the 24 designated sites are in locations that are not vulnerable to severe flooding or water erosion and the massive dispersal of tailings that would accompany such events. However, some sites are, in varying degrees, subject to these hazards because of their nearness to streams or because they are located in the flood plains of rivers. The following is a brief descriptive listing of conditions at piles that may be subject to such hazards (FB81):

Durango:	The tailings are piled in a steep, unstable slope above the Animas river. Large slides into the river are possible.
Grand Junction, Slick Rock (UC), Slick Rock (NC):	The piles are vulnerable to the 100-year flood of a major watercourse (the Colorado and Dolores rivers).
Canonsburg, Salt Lake City:	The piles are vulnerable to the 100-year flood of a minor watercourse (Chartiers and Mill creeks).
New Rifle, Old Rifle:	The piles are vulnerable to the 500-year flood of a major watercourse (the Colorado River).
Lowman:	The pile is on a mountainside terrace. Some areas of this small pile, if it remains in its present configuration, could experience severe erosion in heavy rainstorms. These are projected to occur at a frequency of one in ten years.

3.4 Offsite Contamination Caused by Man

In 1972, using a detector mounted on a van, EPA and AEC personnel surveyed towns near tailings piles and located a large number of gamma radiation amomalies--locations exhibiting higher-than-normal gamma radiation levels.

As a followup, teams from EPA and State health departments conducted further studies to determine the sources of these anomalies (EPA73). The results are summarized by State and town in Table 3-6. The sources were categorized in these studies as (1) uranium mill tailings, (2) uranium ore or manmade sources, (3) naturally occurring radioactivity not due to uranium tailings or ore, and (4) unknown. At over 6,500 locations (roughly 5,000 in Grand Junction, Colorado,

TABLE 3-6. LOCATION AND NUMBER OF GAMMA RADIATION ANOMALIES--1972 SURVEY[a]

Location	Number and Type of Anomaly				
	Uranium Tailings	Uranium Ore or Manmade Source	Other Natural Radioactivity	Unknown	Total Anomalies
Arizona					
Cane Valley[b]	15	4	-	-	19
Cameron	-	1	-	2	3
Cutter	-	5	-	-	5
Tuba City	7	-	3	7	17
Subtotal	22	10	3	9	44
Colorado					
Cameo	1	-	-	2	3
Canon City	36	24	99	28	187
Clifton	159	34	14	876	1083
Collbran	4	2	-	139	145
Craig	8	7	46	25	86
Debeque	2	-	1	106	109
Delta	1	3	29	10	43
Dove Creek	59	19	2	3	83
Durango	118	67	67	102	354
Fruita	58	48	26	1144	1276
Gateway	12	2	-	3	17
Glade Park	1	-	-		1
Grand Junction[c]	5178	[d]7229	[d]	2135	14542
Grand Valley	10	2	-	98	110
Gunnison	3	9	28	7	47
Leadville	18	2	65	6	91
Loma	10	4	4	181	199
Mack	6	2	-	82	90
Mesa	1	2	-	120	123
Mesa Lakes	-	-	-	3	3
Molina	-	-	-	43	43
Naturita	10	20	1	2	33
Nucla	3	6	2	2	13
Palisade	107	39	14	779	939
Plateau City	1	-	-	27	28
Rifle	168	27	1	614	810
Salida	6	2	52	4	64
Slick Rock	3	6	-	-	9
Uravan	208	-	-	1	209
Whitewater	-	4	2	49	55
Subtotal	6191	[d](7560)	[d]453	(6591)	20,795
Idaho					
Idaho City	-	-	2	1	3
Lowman	9	-	3	-	12
Salmon	1	2	65	9	77
Subtotal	10	2	70	10	92
New Mexico					
Bluewater	1	1	-	-	2
Gamerco	-	-	5	-	5
Grants	7	50	25	19	101
Milan	5	27	1	8	41
Shiprock	8	1	-	-	9
Subtotal	21	79	31	27	158

See footnotes at end of table.

TABLE 3-6. LOCATION AND NUMBER OF GAMMA RADIATION ANOMALIES--1972 SURVEY[(a)]
(Continued)

Location	Uranium Tailings	Uranium Ore or Manmade Source	Other Natural Radioactivity	Unknown	Total Anomalies
	Number and Type of Anomaly				
Oregon					
Lakeview	-	2	10	6	18
New Pine Creek	-	1	-	3	4
Subtotal	-	3	10	9	22
South Dakota					
Edgemont	43	3	1	8	55
Edgemont and Dudley[(e)]	17	16	51	-	84
Hot Springs	-	3	17	25	45
Provo	3	1	-	-	4
Subtotal	63	23	69	33	188
Texas					
Campbellton	-	1	6	-	7
Coughran	-	-	1	-	1
Falls City	2	-	3	-	5
Fashing	-	1	-	-	1
Floresville	-	-	14	2	16
George West	-	-	10	-	10
Karnes City	2	-	6	2	10
Kenedy	1	1	13	7	22
Panna Maria	-	-	3	-	3
Pawnee	-	1	-	-	1
Pleasanton	-	3	17	1	21
Poth	-	-	14	1	15
Three Rivers	1	-	2	2	5
Tilden	-	-	11	-	11
Whitsett	-	-	1	-	1
Subtotal	6	7	101	15	129
Utah					
Blanding	10	21	3	4	38
Bluff	-	1	-	1	2
Cisco	-	2	-	-	2
Crescent Junction	-	1	-	1	2
Green River	1	14	1	7	23
Magna	1	2	21	3	27
Mexican Hat	-	5	-	-	5
Mexican Hat (Old Mill)	10	3	1	-	14
Moab	15	83	6	21	125
Monticello	31	19	-	9	59
Salt Lake City[(f)]	70	15	76	64	225
Thompson	26	3	-	1	30
Subtotal	164	169	108	111	552
Washington					
Creston	-	-	3	-	3
Ford	-	-	1	-	1
Reardan	-	-	10	-	10
Springdale	-	-	2	-	2
Subtotal	-	-	16	-	16

See footnotes at end of table.

TABLE 3-6. LOCATION AND NUMBER OF GAMMA RADIATION ANOMALIES--1972 SURVEY[a] (Continued)

Location	Number and Type of Anomaly				Total Anomalies
	Uranium Tailings	Uranium Ore or Manmade Source	Other Natural Radioactivity	Unknown	
Wyoming					
Hudson	-	2	5	1	8
Jeffery City	13	10	3	2	28
Lander	4	9	53	20	86
Riverton	15	15	33	23	86
Shirley Basin	9	-	-	-	9
Subtotal	41	36	94	46	217
GRAND TOTAL	6518	[d]7889	[d]955	6851	22,213

[a](EPA73).
[b]From EPA report ORP/LV-75-2, August 1975. Cane Valley was not included in the initial gamma survey program.
[c]A remedial action program for buildings with tailings has been in progress since 1972 under Public Law 92-314.
[d]Survey data for Grand Junction, Colo. does not distinguish the category "Radioactive source or ore" from "Natural radioactivity."
[e]Survey of additional anomalies conducted in 1978.
[f]Salt Lake City was not completely surveyed.

alone), the presence of tailings was identified. The fourth category (unknown sources) may include some locations where tailings were the cause of the anomaly but could not be positively identified as such.

In later studies at Grand Junction, Colorado, tailings were found at about 6,000 locations (DOE79b). This number is comparable with the 1972 gamma survey of mill tailings communities and suggests that the 1972 survey provides a fairly reliable census of the offsite use of tailings from the designated sites.

Tailings at these anomalies were used in miscellaneous ways on offsite properties and in building construction. Common uses of tailings were in sidewalks, driveways, fence footings, and in gardens. Generally, most of the tailings were used with relatively little dilution, so one would expect that radium concentrations at these locations are usually in excess of a few tens of picocuries per gram. Tailings used in building construction were commonly used as fill around the foundations and under concrete slabs.

Contaminated properties

We expect the number of contaminated offsite properties, exclusive of uses in buildings construction, to be about equal to the total number of anomalies due to misuse of tailings. When tailings were used in building construction they were usually used eleswhere on the property. The 1972 survey would count both as a single anomaly.

Therefore, we estimate there are about 6,500 contaminated properties, of which about 5,200 are in Grand Junction alone. We do not have detailed information of the amounts of tailings on these properties. However, inspection of a sample of the survey records for Grand Junction reveals, for uses not associated with habitable buildings, the following distribution of tailings locations:

Location	Percent of Locations
City walks	22
Yards, lawns	16
Driveways, carports	14
Flower beds, gardens	14
Private walks	12
Patios	9
Detached buildings	6
Fences and posts	4
Other	3

Contaminated Buildings

Tailings have been used in the construction of a large number of buildings, principally in Grand Junction, Colorado. This practice has often resulted in significant levels of radioactive contamination, most commonly observed as elevated levels of radon decay products in indoor air. To correct this, a remedial program has been underway in Grand Junction for several years (under PL 92-314). Most of our assessments of the impact of tailings used in other communities and of the costs for their removal are based upon the experience to date in Grand Junction. In Grand Junction, tailings were used primarily as fill around structures, in footings, and under basement slabs. In a few cases tailings were incorporated into concrete or mortar. A preliminary analysis of the extensive surveys conducted by EPA in 1972 indicates that tailings were used in other communities in the same ways as in Grand Junction.

Although it is impossible to determine the exact number of buildings in other communities that have been contaminated by tailings, the 1972 EPA survey provides some basis for an estimate. In Grand Junction, the 1972 survey recorded 5178 anomalies attributed to the use of tailings. If anomalies of unknown origin are added, the total is 7313. From subsequent detailed monitoring in Grand Junction, it is estimated that 740 structures will require remedial action based on a criterion of 0.017 Working Levels.(1) This is roughly one-seventh of the number of tailings-related anomalies and one-tenth of the total anomalies.

The 1972 survey identified 1340 anomalies caused by tailings in all other communities combined. If the same one-seventh ratio applies, then about 200 buildings are contaminated. The total in other communities for tailings plus unknown anomalies is 6056; if the one-tenth ratio applies to this much higher value, then about 600 buildings are contaminated. On this basis, we guess that the number of contaminated buildings in communities other than Grand Junction lies between 200 and 600.

To estimate the distribution of radon decay product levels in buildings we also relied on the Grand Junction experience. Of the 740 buildings identified as requiring remedial work in Grand Junction, we have detailed measurements on 190 carefully monitored residential buildings on which remedial work has already been carried out. In these buildings the mean indoor radon decay product concentration before remedial work was 0.08 WL. The distribution of these measured levels is shown in Figure 3-3. We have assumed that the distribution of levels in contaminated buildings in other communities will be similar.

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(1)Working Level (WL) is a measure of exposure to radon decay products. It is defined as any combination of short half-life radon-222 decay products in 1 liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts. It was developed to measure exposure to workers in uranium mines. The Grand Junction survey is using as a screening criterion for starting remedial action the radon decay product level of 0.01 WL above background where the background is assumed to be 0.007 WL.

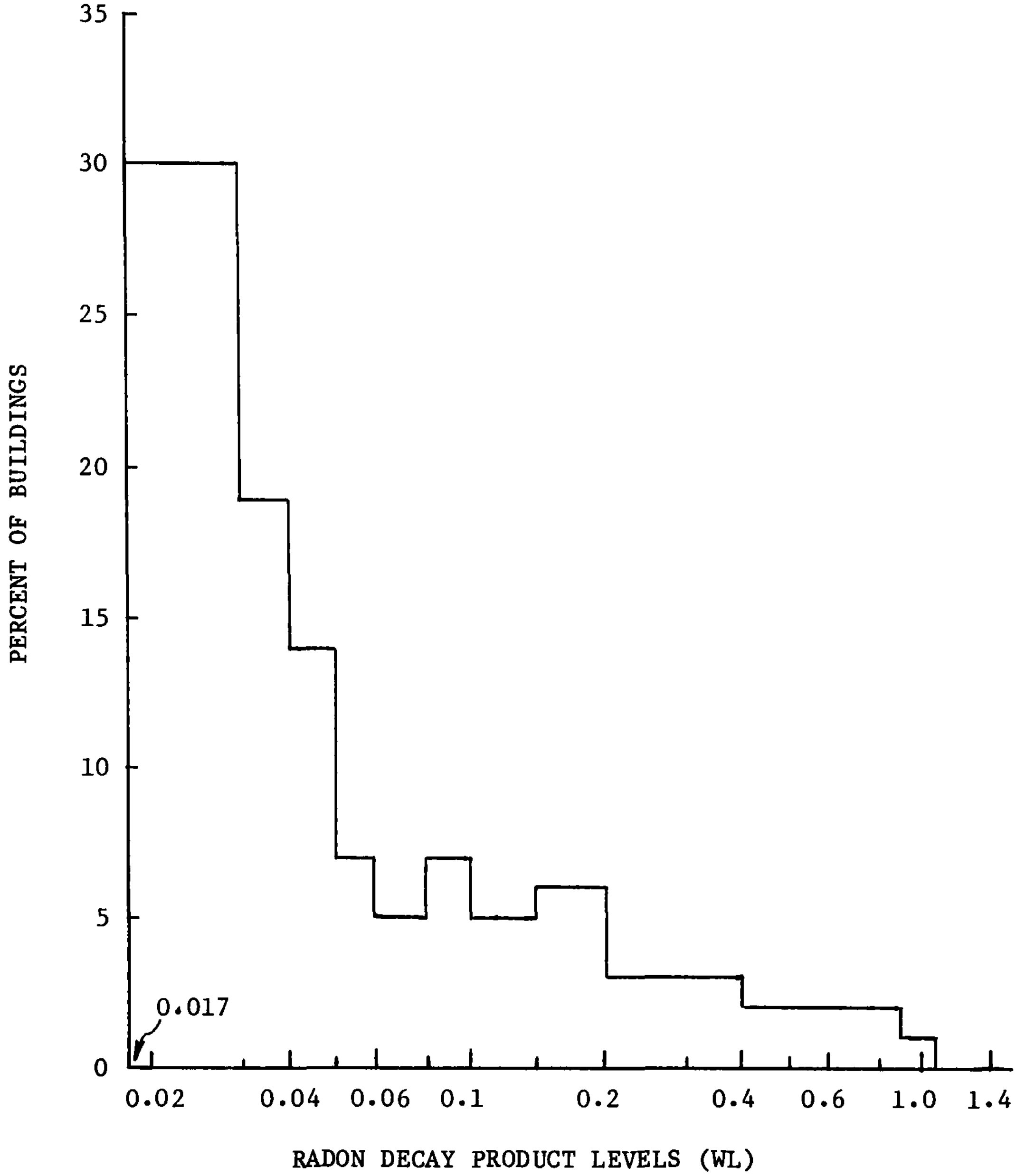

FIGURE 3-3. DISTRIBUTION OF RADON DECAY PRODUCT LEVELS IN 190 CONTAMINATED RESIDENTIAL BUILDINGS IN GRAND JUNCTION, COLORADO(Laa79)*

*Only homes with measured levels greater than 0.017 WL are included.

The indoor gamma radiation level in these contaminated buildings in Grand Junction was also measured. Roughly 65 percent had a gamma radiation level more than 10 microroentgens/hr above background, 35 percent more than 20 microroentgens/hr above background, and about 10 percent more than 40 microroentgens/hr above background. Of all the buildings in Grand Junction in excess of 20 microroentgens/hr above background, about 94 percent also had radon decay product levels exceeding 0.017 WL (or 0.01 WL above background)(DOE80).

3.5 Indoor Radon Decay Product Concentrations Due to Natural Causes

Virtually all indoor atmospheres contain some measurable radon decay products. The radon decay product concentration in a building affected by tailings is the sum of the contributions from tailings and the natural environment. The separate contribution from each cannot be distinguished by measurement of air concentration. In order to judge the degree of contamination of buildings, therefore, knowledge of radon decay product concentrations in buildings unaffected by tailings is needed.

The most complete studies of normal indoor radon decay product concentrations in the United States have been performed on residences in Grand Junction, Colorado (Peb77); New Jersey and New York (Ge78); and Florida (FD78). The New Jersey-New York buildings were mostly single-family one- or two-story buildings. The Grand Junction buildings were mainly houses identified as free of tailings, about half of which had basements, and the data are for the lowest "habitable portion" of the building (Laa79). The Florida buildings were mainly single-family houses, without basements, in areas free of phosphate minerals. A more recent study in a Montana mining community provides a good example of anomalously high indoor decay product levels comparable to those found due to tailings in Grand Junction (RPC80). This is not a useful example of normal indoor levels, however, because of the unique circumstances involved.

Selected results from these studies are summarized in Table 3-7. In all cases, the reported concentrations are the average of several measurements taken over a 1-year period. The data for most locations exhibit a range of about a factor of 10 in normal indoor radon decay product concentrations. The New Jersey-New York data show that concentrations in rooms at ground level are generally about half of those in basements. An unpublished analysis of the Grand Junction data shows a similar effect (Laa79).

In summary, the above studies indicate that:

1. Indoor radon decay product concentrations normally vary over about a factor of 10.

2. Indoor radon decay product concentrations greater than 0.01 WL in a usable part of a building are common.

3. Excluding basements, normal concentrations greater than 0.02 WL are rare, except in localities with unusually large sources of radon.

TABLE 3-7. INDOOR CONCENTRATIONS OF RADON DECAY PRODUCTS IN AREAS FREE OF TAILINGS[(a)]

Grand Junction, Colorado[(b)]

Sample:	29 buildings free of tailings, about half with basements.
Range:	0.002-0.017 WL
Median:	0.007 WL
Above 0.01 WL:	30%
Above 0.02 WL:	0% (approximately)

New Jersey-New York[(c)]

Sample: 21 houses, mostly single-family with full basements.

	Basement	First Floor
Range:	0.0017-0.027 WL	0.0019-0.013 WL
Median:	0.008 WL	0.004 WL
Above 0.01 WL:	40%	10%
Above 0.02 WL:	17%	0%

Florida[(d)]

Sample:	28 single-family houses, without basements.
Range:	0.001-0.012 WL
Median:	0.0035 WL
Above 0.01 WL:	3%
Above 0.02 WL:	0%

New Mexico (Grants/Ambrosia Lake region)[(e)]

Sample:	6 houses
Range:	0.004 - 0.015 WL
Median:	0.009 WL
Above 0.01 WL	50%
Above 0.02 WL	0%

Butte, Montana (a highly mineralized mining area)[(f)]

Sample:	56 houses
Range:	0.004-0.2 WL
Median:	0.017 WL
Above 0.01 WL:	75%
Above 0.02 WL:	38%

(a) Average annual concentrations.
(b) References (Pe77) and (La79), values from lowest habitable locations.
(c) Reference (Ge78).
(d) Reference (Fl78); this sample excludes houses on phosphate lands, which generally show elevated levels of indoor radon.
(e) Unpublished EPA data, completed May 1981.
(f) Reference (RPC80).

Chapter 4: RISKS TO HEALTH FROM URANIUM TAILINGS

In this Chapter, after an introductory general discussion and a characterization of radon exposure, we examine the major pathways by which radioactive and toxic materials from tailings can reach man. We then review the risks to man exposed to these materials. Finally, using this information, we estimate potential effects of tailings on the health of local, regional, and national populations.

4.1 Introduction

Among metallic ore wastes, uranium tailings piles are unusual because of the amount of radioactivity they contain. Radioactivity constitutes the principal source of hazard to health of these wastes, although nonradioactive toxic chemicals such as arsenic, lead, selenium, mercury, sulphates, and nitrates are usually present. Milling of uranium ore removes about 90 percent of the uranium in the ore. The remainder, along with most other radioactive materials and toxic chemicals, is discarded in the liquid and solid wastes discharged to tailings piles.

The principal isotope of uranium, uranium-238, decays over billions of years to become lead, a stable nonradioactive element. This lengthy decay process involves a series of intermediate radioactive decay products, such as thorium-230, radium-226, and radon-222. Figure 3-1 traces the steps in this decay process. The decay of uranium since the ore was formed millions of years ago has built up an inventory of these decay products, which are present in uranium mill tailings in various concentrations.

The dominant hazard from tailings is due to the radioactive decay products of uranium-238, particularly radium-226 and its short half-life decay products. Each gram of natural uranium ore contains about 500 pCi of uranium-238. In addition, natural uranium ore contains about 23 pCi of uranium-235 and 2 pCi of thorium-232. Because they occur in relatively small proportions and/or pose much less risk to health, uranium-235 and thorium-232 and their radioactive decay products may usually be ignored in evaluating the hazard of uranium tailings.[1]

Uranium tailings emit three kinds of radiation: alpha particles, beta particles, and gamma rays. All are forms of ionizing radiation, which breaks up molecules into electrically charged fragments called ions. In biological tissues, this ionization can produce harmful cellular changes. At the low radiation levels usually encountered in the environment we expect the effects of such changes to be difficult to detect. Studies show, however, that people exposed to radiation have a greater chance of developing cancer. If the ovaries or testes are exposed, the health or development of future children may also be damaged.

One cannot predict with precision the increased chance of cancer or genetic damage after exposure to radiation. We have based our risk estimates on studies of persons exposed at doses higher than those usually resulting from tailings and the assumption that at lower doses the effects will be proportionally less. This assumption may overestimate or underestimate the actual risk, but it is the best that can be done at present (EPA76a).

Alpha, beta, and gamma radiations from mill tailings can all cause cancer or genetic damage. However, the major threat comes from breathing air containing radon decay products with short half-lives--polonium-218, for example--and exposing the lungs and other internal organs to the alpha radiation these decay products emit. In addition, people may be directly exposed to gamma rays from radioactive material in the tailings pile, and radioactive tailings particles may be transported into the body by breathing or ingestion.

The body's internal organs would still be exposed to radiation from radionuclides even if uranium tailings piles suddenly disappeared, because radon, radium, uranium, thorium, and other radioactive elements occur naturally in the air, rock, and soil. One picocurie of radium per gram of soil is a typical concentration; outdoor air contains a few tenths of a picocurie of radon per liter (UN77). Normal eating and breathing introduces these and other radioactive materials into the body, increasing the potential for cancer and genetic changes. This discussion, therefore, also compares the health risks from tailings to those from normal exposure--not to justify the tailings risk, but to provide a realistic context for comparison.

Tailings also contain toxic elements that could eventually be inhaled or ingested by man and animals or absorbed by plants. Windblown

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[1] U-235 decay products are usually present in tailings at much lower levels than U-238 decay products. However, at one inactive site (Canonsburg, Pa.), U-235 decay products may be present in elevated concentrations (C179).

tailings inhaled by man or animals are unlikely to cause any toxicity problems because the mass of inhaled material is so small. However, the toxic elements in windblown tailings could be absorbed by plants growing near a pile and could be a potential pathway leading to chronic toxicity diseases in men or animals eating those plants. Moreover, toxic elements from tailings could leach or seep into water supplies used for irrigation or drinking. Finally, windblown tailings and radon decay products could be deposited directly onto some foods, such as lettuce and spinach.

It is important to distinguish between acute and chronic toxicity. Acute toxicity (or poisoning) occurs when enough of the toxic element is consumed to interfere with a vital body or organ function. The severity of the poisoning is usually proportional to the amount of the toxic element consumed, and in extreme cases death or permanent injury will occur. Chronic toxicity is more insidious. It occurs when small amounts of a toxic element are consumed over a prolonged period of time. A small fraction of each intake may be deposited in tissues or organs. Toxic symptoms appear when the cumulative deposit exceeds a critical level. Alternatively, each intake of a toxic element may cause a small increment of organ damage. Symptoms of toxicity become apparent when this damage accumulates to a critical extent. Symptoms of chronic toxicity may be reversible if consumption of the toxic element is stopped, or they may be irreversible, progressive, or both.

In the case of tailings, acute toxicity would be a problem only if standing water adjacent to or on a pile is consumed. Chronic toxicity is more likely and is therefore examined in later discussions.

4.2 Radon and Its Immediate Decay Products

Since the milling and extraction processes have removed most of the uranium from the ore, the longevity of the remaining radioactive members of the uranium series is determined by the presence of thorium-230, which has an 80,000-year half-life. The thorium-230 decay product, radium-226, has a 1600-year half-life. Both thorium and radium are relatively insoluble and immobile in their usual chemical forms. However, the decay product of radium-226 is radon-222, an inert radioactive gas, that readily diffuses through interstitial spaces to the surface of the tailings pile where it becomes airborne. The half-life of radon-222 is 3.8 days, so some radon atoms can travel thousands of miles through the atmosphere before they decay.

As shown in Figure 3-1, the radon decay process involves seven principal decay products before ending with nonradioactive lead. The four short half-life radioactive decay products immediately following radon are the most important source of cancer risk. These decay, for the most part, within less than an hour. Members of the decay chain with relatively long half-lives (beginning with lead-210, which has a

22-year half-life) are more likely to be ingested than breathed and represent much smaller risks.

The principal short half-life products of radon are polonium-218, lead-214, bismuth-214, and polonium-214. Polonium-218, the first decay product, has a half-life of just over 3 minutes. This is long enough for most of the electrically charged polonium atoms to attach themselves to microscopic airborne dust particles that are typically less than a millionth of a meter across. When breathed, these small particles have a good chance of sticking to the moist epithelial lining of the bronchial tubes in the lung.

Most of the inhaled particles are eventually cleared from the bronchi by mucus, but not quickly enough to keep the bronchial epithelium from being exposed to alpha radiation from polonium-218 and polonium-214. This highly ionizing radiation passes through and delivers radiation doses to several types of lung cells. The exact doses delivered to cells that eventually become cancerous cannot be characterized adequately. Also, we do not have detailed knowledge of the deposition pattern of the radioactive particles in the lung and the distances from them to cells that are susceptible. Further, there is some disagreement about the types of bronchial cells where cancer originates. Therefore, we have based our estimates of lung cancer risk on the amount of inhaled radon decay products to which people are exposed, rather than on the dose absorbed by the lung.

The exposure to radon decay products is expressed in terms of a specialized unit called the Working Level (WL). A Working Level is any combination of short half-life radon decay products that emits 130,000 million electron volts of alpha-particle energy in 1 liter of air. The unit of cumulative exposure to radon decay products is the Working Level Month (WLM), which is exposure to air containing 1 WL of radon decay products for a working month, which is defined as 170 hours. (These units were developed to measure radiation exposure of workers in uranium mines.) Continuous exposure of a member of the general population to 1 WL for 1 year is equivalent to about 27 WLM. For exposures occurring indoors, we assume a 75 percent occupancy factor. Thus, an indoor (residential) exposure to 1 WL for 1 year is equivalent to about 20 WLM (EPA79a-b).

4.3 Exposure Pathways

Tailings, depending on how they are managed or misused, may lead to radiation exposure of man in a number of ways. Tailings removed from piles and used for landfill, for improving drainage around foundations, or for other construction purposes typically pose the largest hazard by increasing indoor concentrations of radon decay products. Tailings at a disposal site emit radon gas into the atmosphere and are a source of radioactive windblown particulates and direct gamma radiation. They may also be a source of toxic chemicals through erosion and leaching.

4.3.1 Indoor Exposure Due to Misuse of Tailings

The greatest hazard from tailings removed from piles and used in construction is their potential to increase levels of radon decay products in buildings. The concentration of radon decay products in a building will depend mainly on the amount of radium in the tailings that are in, under, or adjacent to it. However, so many other factors affect the indoor concentration that establishing a useful correlation with the amount of radium is difficult.

Healy and Rogers (He78) have anaylzed exposure pathways due to radium in soils, whether it occurs naturally or as contamination. They argue that one might expect indoor radon decay product concentrations of 0.01 WL for soils with radium concentrations of 1 to 3 pCi/g to a depth of 1 meter or more. NRC estimates (NRC79) that it takes 3 to 5 pCi/g of radium to cause indoor concentrations of 0.01 WL. Radium concentrations near the lower end of these ranges, 1 pCi/g, correspond to common soils. The indoor concen- trations reported in Chapter 3 are, in general, consistent with the NRC estimates.

4.3.2 Exposure to Radon Decay Products from Tailings Piles

We have estimated radon decay product exposures to local, regional, and national populations. Because of radon's 3.8-day half-life, worldwide impact is not significantly greater than the sum of impacts on these three groups. Details of the local and regional dispersion calculations and population estimates have been published by EPA (Sw81).

In the immediate vicinity of a tailings pile, measurements can distinguish enhanced levels of radon due to the pile from the ambient concentration due to other radon sources. We have used these experimental measurements to estimate the risks to the individuals living near six urban piles. Radon from the inactive piles makes only a small increment in the total radon exposure of the U.S. population. Nevertheless, inactive tailings piles increase ambient levels of radon, and we have not disregarded this even though the increase is not directly measurable.

Windblown tailings on nearby land supplement the pile as a source of radon. It has been estimated that radon emissions from a pile site may be increased as much as 20 percent if the emanation from windblown tailings is taken into account (Scb80).

For purposes of estimating impacts, we have assumed a theoretical pile that has a uniform radium concentration of 500 pCi/g, is completely dry, and has not been stabilized (e.g., covered with clean earth). For these conditions, we assume an emission rate of 1.0 pCi/m^2s radon per pCi/g of radium. We further assume that the pile covers an area of 31 acres and is infinitely deep.(1) The resulting radon release rate for this pile is 2000 Ci/y.

We have estimated the impact of radon releases for specific piles by scaling results calculated for the theoretical pile (Sw 81) according to the annual radon release of the pile. Referring to Table 3-1, we see the estimated radon release rates range from 200 to 11,500 Ci/y. Corrections were not made for pile area sizes different from the theoretical pile. Such corrections for persons at distances greater than twice the pile radius from the pile center would be less than 10 percent. These corrections are small compared to those that could result if site specific meterology dispersion data were used instead of the Fort St. Vrain dispersion data averaged over all directions (see below).

Radon Dispersion

The atmospheric dispersion of radon from the above theoretical pile at distances up to 7.5 miles was calculated using a sector-averaged gaussian plume model (Gia68) and wind frequency data (directon, speed, and stability) for the Fort St. Vrain reactor site in Colorado (Sw81). Dispersion factors were averaged over all directions to estimate a single value for each distance; i.e., dispersion was assumed to be the same in all directions. The average windspeed for the site was 6.5 mph.

We used this generic approach because adequately detailed meteorological data for site-specific dispersion estimates are not available. Clearly, such site-specific estimates would show differences with both distance and direction. However, the generic approach should provide reasonable estimates of the average exposure of individuals living near a pile. We do not expect a high degree of accuracy for any specific individual's location, since wind direction patterns can be highly asymmetric.

Regional (7.5 miles to 50 miles) dispersion estimates for radon from the pile were based on a model developed by the National Oceanic and Atmospheric Administration (NOAA) (Maa73). Again, local meteorology was not considered for these estimates, and dispersion was averaged over all directions.

Recently, NOAA has developed a model for the Nuclear Regulatory Commission (NRC79) to calculate the concentration in air across the continent due to radon emitted from four sites in the West. National

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(1)By infinitely deep, we mean that we do not reduce our radon release estimates to correct for the finite depth of a pile. A pile 10 feet deep has a radon emission rate only about 4 percent less than an infinitely deep pile.

collective exposures from these four sites range from 0.42 to 0.76 person-WL per 1000 Ci released per year. We have used the average of these estimates, 0.56, to make estimates of the total exposure of the United States population.

In addition to these offsite calculations, we have also estimated radon concentrations over and close to the edge of a generic covered tailings pile, which, for calculational convenience, we take as circular in shape. For these calculations we assumed that the cover reduces the radon emission rate to a uniform 20 pCi/m^2s over the covered tailings. Concentrations for other emission rates would be proportionately higher or lower. The concentration calculations were made using generic wind data from the NRC GEIS (NRC80) and the AIRDOS-EPA dispersion model (EPA79c). The resulting average concentrations are shown in Figure 4-1 for a small (5 ha or 12 acres), a medium (20 ha or 49 acres), and a large (80 ha or 196 acres) tailings pile. Our calculations show that the average concentration near the center of the pile and at the edge of the pile are relatively insensitive to the size of the pile. For the 20-hectare pile, Figure 4-1 also shows the results in the directions for which the concentration is maximum or minimum. The wind data (and therefore the dispersion) and the shape of the pile at actual sites would differ

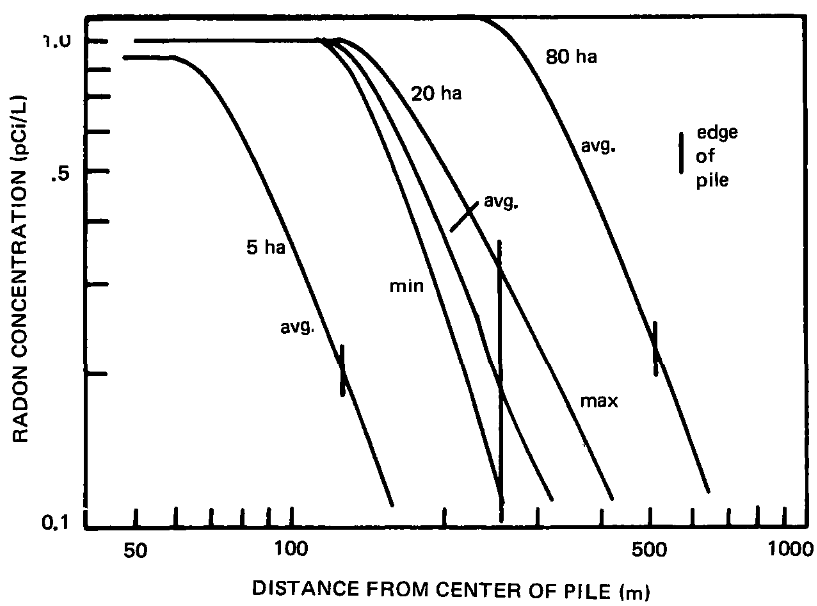

FIGURE 4-1. RADON CONCENTRATION VERSUS DISTANCE FROM TAILINGS PILE CENTER. RADON EMISSION RATE IS 20 pCi/m^2s

from the one used for these calculations. In particular, lower wind velocity and greater directional asymmetry would tend to increase the maximum concentration at the edge of the tailings somewhat above the value of 0.3 pCi/l shown in Figure 4-1 for a 20-ha pile. We have not performed site-specific calculations, however.

Ingrowth of Radon Decay Products

At the point radon diffuses out of the ground the concentration of associated decay products is zero because these decay products have been captured in earth. As soon as radon is airborne decay product ingrowth continues and an equilibrium between the amount of radon and the amount of each decay product is approached. At equilibrium there is equal activity of all the short half-life radon decay products in air, and alpha radiation is maximized. We use a concept called the equilibrium fraction, which is the fraction of the potential alpha energy from decay products at complete equilibrium to that actually present. Since the radon and its decay products are transported by the wind, the equilibrium fraction increases with distance from the pile as the decay products grow in.

Evans (Ev69) has calculated decay product ingrowth with time for a constant radon concentration. Since the half-life of radon is much greater than that of its short-lived decay products, these values can be used to calculate approximately the outdoor equilibrium fraction, as a function of distance, for an assumed wind speed. Our outdoor equilibrium fraction values are calculated on the assumption that the radon has been released at the center of the pile and travels at an average windspeed of 6.5 mph. The release location is actually distributed over the entire pile, and the windspeed is distributed over a range of values. Therefore, these assumptions tend to slightly underestimate the equilibrium fraction close to the source. Depletion processes, such as dry deposition or precipitation scavenging, will remove some decay products, so complete equilibrium with the radon will seldom, if ever, be reached.

When radon enters a structure, it remains for a mean time that is inversely proportional to the ventilation rate. Hence, the building entilation rate becomes an important factor affecting further changes in the equilibrium fraction. This value can also be affected by other considerations, such as the indoor surface-to-volume ratio and the dust loading in indoor air. We here assume a 70-percent equilibrium fraction for the indoor radon and decay products.

We have assumed that, on the average, Americans spend approximately 75 percent of their time indoors, mostly in their homes (Moa76, Oa72). We have weighted the indoor and outdoor equilibrium fractions for a given location by factors of 0.75 and 0.25, respectively, to estimate an average value for calculating exposure to radon decay products from a specific pile. Since indoor exposure is dominant, this average equilibrium fraction does not depend strongly on the distance from the tailings pile.

The Population at Risk

We used 1970 census data to estimate the population distribution near each of the piles. For local and regional estimates we used census enumeration district data. These districts vary greatly in physical size; they are generally small in urban areas and large where the population is sparse. Occasionally, census data are not adequate to estimate the local population. We have used supplementary data sources for our population estimates in those instances (Sw81). These population estimates are based on residential data only. We have not attempted to project local population changes between 1970 and 1980 because the data available are inadequate.

Population data for distances greater than 50 miles are based on 1970 census data for cities, counties, and states and assume a continental U.S. population of 200 million persons. A projected 1980 continental population of 220 million would increase the collective exposures and corresponding total impact by about 10 percent.

4.3.3 Exposure to Gamma Radiation from Tailings Piles, Windblown Tailings, and Misuse of Tailings

Many of the radioactive materials in tailings piles emit gamma radiation. Unlike alpha radiation, which must originate within the body to become hazardous, gamma radiation can penetrate both air and tissue up to considerable distances. Near the edge of a pile, gamma radiation can be much larger than the background level in uncontaminated areas. The gamma radiation from a pile, however, decreases rapidly with distance; at more than a few tenths of a mile from most of the inactive tailings piles, the increase cannot be differentiated from the normal background, which is 80 to 100 mrem/y.

Levels of gamma radiation from an uncovered pile depend on the amount of radium in the tailings sands and slimes and how these are distributed within the pile. The radium content of processed ore may also vary during the milling operation.

Field measurements indicate that on top of a pile, gamma radiation levels range up to 4000 to 8000 mrem per year (FB76-78, FB81). This is much higher than Federal guidance for nonrestricted areas, where the radiation protection guide is 500 mrem/y for an identifiable individual and 170 mrem/y for persons not being individually monitored (FRC60). Areas adjacent to piles and contaminated by windblown tailings sometimes show increased gamma radiation levels as high as 500 mrem/y or more, and levels of from 100 to 200 mrem/y are common (Do75).

Increased levels of gamma radiation may also occur on open lands, due to the misuse of tailings as fill or for other purposes. Natural or contaminated soils with radium concentrations of 5 pCi/g through a depth of several feet can produce gamma radiation exposure rates of about 80 mrem/y (NP76). Exposure rates are proportionately higher or lower for other radium concentrations and decrease as the layer of radium-containing material becomes thinner or is covered over by other materials.

4.3.4 Exposure to Radioactivity and Toxic Materials from a Tailings Pile through Water and Food Pathways

Airborne transport of tailings, with subsequent deposition on ground where food crops or feeds are grown, and the transport or leaching of tailings by water used for drinking or irrigation can lead to human exposure to radioactive and toxic substances. The degree of detail with which we can treat these potential pathways varies. The food pathway for radioactive materials blown from a pile has been modeled in considerable detail (NRC79). This generic model is conservative in that it assumes the sole source of the diet is locally grown food and feeds. Modeling of water pathways requires site-specific data on sources and uses of water. As yet, the existence of actual water pathways for radioactive and toxic materials from inactive tailings piles has not been verified, so we discuss these pathways in general terms only. The food pathway for toxic materials has not been investigated in the field but could exist close to a pile. We have analyzed this pathway by assuming that toxic chemicals and radioactive isotopes are transported simultaneously in tailings particles.

Water Pathway for Radioactive Materials

Significant contamination of ground water or flowing surface water has not been confirmed at any of the designated inactive tailings sites. However, for unstabilized (i.e., uncovered) tailing piles, tailings could contaminate nearby surface and ground water. Wind erosion, floods, tailings slides into adjacent streams, seepage through the pile, and runoff of rainwater are all potential routes for surface water contamination. However, quantities of radioisotopes washed or leached into flowing surface waters could be so dispersed and so rapidly diluted that it is unlikely that surface water flow would ever pose a significant health problem, except through major disruption of piles by a flood.

Ground water contamination could occur when water seeps from tailings into an underlying aquifer (a water-bearing layer of permeable rock). Since people may draw water from a single underground aquifer at many different places, the potential for exposure depends on the hydrology between the points of contamination and use. Except in very coarse or cracked media, through which contaminants flow relatively unimpeded, the concentrations of contaminants reaching ground water are likely to be reduced along the flow path by mixing, by absorption, by adsorption, and by ion exchange with the ground material. The level of user exposure to contaminated ground water depends on the amount drunk, as well as on the level of contamination. The total amount consumed depends, in turn, on the palatability and quality of the water, the purpose for which it is used, and the number of users.

There is little data on actual behavior of contaminants in ground water on which to base conclusions on the effects of the factors just cited. Available data indicate that some private wells in the Grants Mineral Belt in New Mexico (Ka76) are contaminated with radioactive materials to concentrations exceeding the National Interim Primary Drinking Water Regulations that apply to community water systems (EPA76b). However, it is not known if this contamination is due to seepage during the active phase of nearby tailings piles or to continuing contamination by inactive piles.

The NRC model for ground water contamination suggests that radionuclides from active tailings will travel slowly and that the concentration of contaminants in the ground water does not drop off rapidly (NRC79). Therefore, we believe that the small amounts of material that might be leached from inactive tailings are likely to constitute a hazard, close to the site of their disposal, unless the surfaces of the piles are effectively stabilized.

In summary, there is no firm evidence that radioactive contaminants leached from inactive tailings are a general problem. Instead, the possibility of such contamination should be considered on a site-specific basis.

Water Pathway for Toxic Materials

There is also no confirmed case of water contamination by toxic chemicals at the designated inactive mill sites. All of the preceding general statements on pathways for radioactive elements apply to toxic substances as well. To assess the potential for a problem at specific sites, chemical and hydrological characteristics can be used to identify substances most likely to enter and be carried through ground water. However, different specific substances will be present at each site, depending on the local geology and the nature of the tailings. For example, some organic compounds--amines, kerosene, and higher alcohols--are present in tailings from acid-leach mills. But the main long-term potential ground water hazard is from leached inorganic toxic substances.

Movement of contaminants through soil to ground water depends on complex chemical and physical properties of the underground environment and on local climatic conditions, such as precipitation and evaporation. Chemical and physical processes in the subsoil remove a portion of some contaminants from water passing through it. However, some contaminants (e.g., selenium, arsenic, and molybdenum) can occur in forms that may not be removed.

While not enough information is available to estimate the chance that toxic substances from inactive tailings will move through water to expose people, some migration of these substances in ground water near tailings piles has been observed (Ka76). Studies of leaching at tailings piles (Dr78) and leachates from municipal land fills (EPA78d) help determine which substances generally will be relatively mobile or immobile and which will have a mobility varying with local conditions (EPA78e). Limited studies of pollutant migration into ground water near tailings piles indicate which elements will be most mobile (see below and FB76-78, Ka76, DA77). However, there has been no systematic study to establish the magnitude of ground water contamination for tailings at either active or inactive sites.

Based on available information, chromium, mercury, nickel, arsenic, beryllium, cadmium, selenium, vanadium, zinc, and uranium have a high probability of being mobile in water pathways under certain conditions (EPA78d, Dr78). Lead, radium, and polonium are not predicted to be mobile in water pathways, but they appear to be mobile at some locations (see Table 3-4). Experimental data on the mobility of other toxic elements are not available. Therefore, conservative assumptions should be used for ions that are generally mobile, such as nitrate, chloride, and sulfate. Certain anions (e.g., arsenic, manganese, molybdenum, and selenium) and organic complexes of trace metals may also be relatively mobile, although confirming field data are extremely limited.

In summary, toxic elements contamination of standing surface water in the immediate vicinity of tailings could cause wild or domestic animals drinking such water to develop acute toxic effects. However, contamination of flowing surface water should not cause such a problem because of normal dispersion and dilution. Finally, there are no data showing significant ground water contamination from inactive tailings piles and no adequate models to predict how such contamination will travel, if it occurs. Ongoing studies supported by the Department of Energy may provide a basis for assessing the potential hazard of ground water contamination from inactive piles, but there is no existing basis for assuming a health risk for this pathway.

Food Pathway for Radioactive Materials

Windblown tailings can deposit directly on plants, on the ground, or on surface waters used for irrigation. Any of these events can lead to contamination of crops. Persons eating these crops will absorb part of the radioactive material. Animals eating these crops as feed will absorb part of the radioactive material some of which will be deposited in tissues or milk. Persons ingesting milk or meat from these animals will also, in turn, absorb part of the radioactive material.

The NRC has developed a model (NRC79) to estimate the amount of radioactive material in tailings that becomes airborne, is deposited directly on plants or on the ground, and enters the food pathway. This model considers meteorological factors, particle sizes, deposition rates, and transfers from soil to plants, animals, and milk and from food to humans. In the NRC model, the overall amount of radioactivity reaching humans in small. The transfer eoefficient from soil to the edible portion of most food crops (B_{vi}) is assumed to be about 0.02

for radium and 0.002 to 0.004 for uranium, thorium, and lead. Potatoes are an exception; the coefficient for radium is 0.003. The transfer coefficient from soil to pasture crops is about 0.07 for radium and lead and about 0.002 to 0.004 for uranium and thorium. Further discrimination occurs in animals. The concentration ratios for radionuclides transferred from feed to milk or meat is between 0.01 and 0.15 (except the milk-to-feed ratio for thorium which is 0.003). The overall concentration ratio for material transferred from soil-to-feed crops to milk-or meat is the product of the soil-to-plant transfer coefficient and the milk or meat-to-feed concentration ratio. These values range from 0.000001 for the thorium milk-to-soil concentration ratio to 0.01 for the radium meat-to-soil concentration ratio. In general, the concentration in meat or milk is much less than 1 percent of the soil concentration. Humans also discriminate against uptake of these radioactive materials; only 0.01 percent of thorium and 10 percent, 20 percent, and 8 percent of uranium, radium, and lead, respectively, are absorbed through the gastrointestinal tract.

Using this model, NRC calculated expected radionuclides intake and radiation doses from food pathways for individuals and populations between 1 and 80 kilometers from the NRC model mill.[1] Using this data on individuals we estimated the regional impact of the food pathway for windblown tailings and for deposition of lead-210 and polonium-210 from the decay of radon from the tailings. The results of this analysis are given in Section 4.5.2. No attempt has been made to model the food pathway for radioactive materials via irrigation water. This pathway should not increase the estimated doses significantly since the collecting area of surface waters in the vicinity of inactive tailings is small compared to any realistic total cultivated deposition area. Moreover the transfer from water to soil to food will be less than the direct transfer from soil to food.

Food Pathway for Toxic Materials

The processes discussed under the food pathway for radioactive materials should apply equally well for toxic materials. Since the airborne transport and deposition of tailings are governed more by the size and density of the tailings particle than by their composition, the toxic elements from tailings should be distributed in the environment in the same way as the radioactive particles. No measurements have been made of the movement of toxic elements from

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[1]The NRC analysis for the ingestion pathway is conservative for several reasons. It assumes that all food eaten is locally produced. The transfer coefficient of radium from feed to meat (0.003 day/kg) is also larger than usually assumed (EPA78a, McD79). For the final GEIS (NRC80), NRC has revised the transfer coefficients for radium and lead; they are generally less than those used in the draft GEIS (NRC79) and would reduce ingestion pathway radionuclide intakes accordingly.

tailings through food pathways. As a first approximation, therefore, we assume that the ratios of concentrations of elements are the same at any location where windblown tailings are deposited as they are in the tailings pile.

For example, at the Slick Rock, Colorado, pile the average concentration of radium is 784 pCi/g; of lead, 1250 ppm; and of mercury, 109 ppm (see Appendix C). Where the concentration of windblown tailings is 5 pCi/g of earth, the expected earth concentration of lead would be 8 ppm and of mercury, 0.7 ppm. A person eating crops grown on this contaminated land might be exposed to levels near to those that are potentially toxic to humans (see Appendix C). These relationships of toxic to radioactive elements in the food chain must be evaluated on a site-specific basis because of the great variability in concentrations of elements in the various inactive piles. However, if an effective cover is employed for stabilization, this pathway should not exist.

4.4 Estimates of Health Risks from Radioactive and Toxic Materials

In this section we develop the risk estimates we use for the principal radiological and toxicological impacts from tailings.

4.4.1 Risk of Lung Cancer from Inhaling Radon Decay Products

The high incidence of lung cancer mortality among underground miners is well documented (EPA79b, Ar79, Ar81). Uranium miners are particularly affected, but lead, iron, and zinc miners exposed to relatively low levels of radon decay products also show an increased lung cancer mortality that correlates with exposure to radon decay products. The type of lung cancer most frequently observed in the early studies, moreover, is relatively uncommon in the general population.

Risk estimates for the general public based on these studies of miners are far from precise. First, and most important, the relatively small number of miners at risk injects considerable statistical uncertainty into estimating the number of excess lung cancer cases (see Figure 4-2). Second, although the cumulative lifetime exposure in contaminated buildings can be comparable to that of some miners, most of the miners studied were exposed to much higher levels of radon decay products than usually occur in the general environment. Third, the exposure levels are uncertain. Fourth, significant demographic differences exist between miners and members of the general public--the miners were healthy males over 14 years old, many of whom smoked. However, information from the studies of miners can provide useful estimates, if not precise predictions, of the risks to the general population from radon decay products.(1)

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(1) See "Indoor Radiation Exposure due to Radium-226 in Florida Phosphate Lands" (EPA79b) for greater detail of such an analysis.

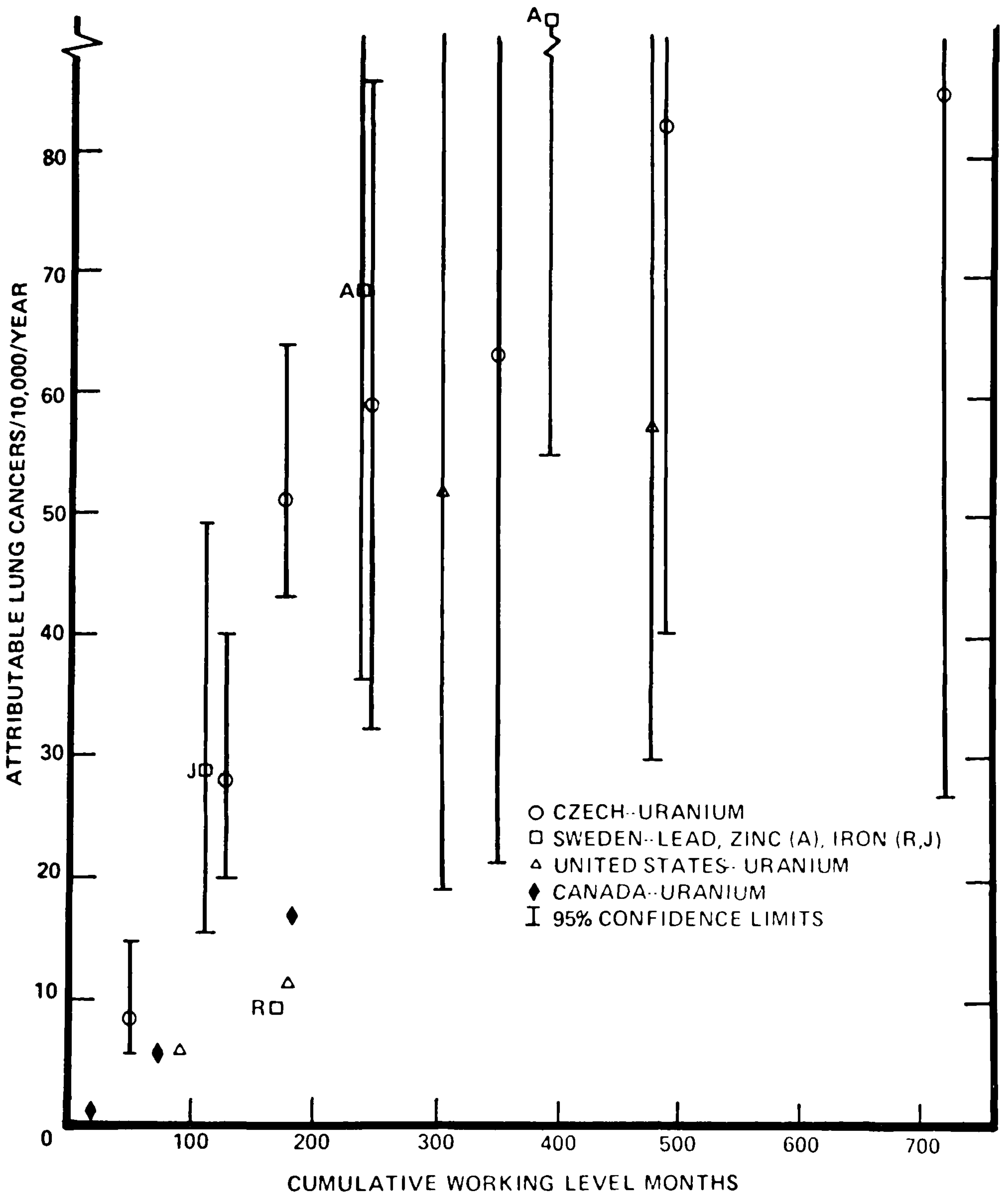

FIGURE 4-2. EXCESS FATAL LUNG CANCER IN VARIOUS MINER GROUPS BY CUMULATIVE EXPOSURE (Ar79).

Since the miners being studied have not all died, their eventual excess lung cancers must be projected from current data by using mathematical models. There are two ways to use the observed frequency of lung cancer deaths among the exposed miners to estimate the risk from inhaling radon decay products over a person's lifetime. One, commonly called the relative-risk model, yields the percent increase in the normal incidence of cancer per unit of exposure. The other, called the absolute-risk model, yields the absolute numerical increase in cancers per unit of exposure. In the relative-risk model it is assumed that the increased risk is proportional to the age-dependent natural incidence of the disease for each year an individual remains alive following exposure. In the absolute-risk model it is assumed that the added risk is independent of natural incidence, i.e., the risk is constant each year an individual remains alive following exposure.

As a basis for calculating estimates using the relative-risk model, we have concluded (EPA79b) that a 3-percent increase in the number of lung cancer deaths per WLM is consistent with data from the studies of underground miners. However, because of the differences between adult male miners and the general population, we have estimated (EPA79b) that the risk to the general population may be as low as 1 percent or as high as 5 percent. For our absolute-risk estimates, we use the estimate of 10 lung cancer deaths per WLM for 1 million person-years at risk reported by the National Academy of Sciences (NAS76). Both of these risk coefficients are used here to examine the potential consequences of lifetime exposure to radon decay products. Unless we state otherwise, we estimate excess cancer fatalities, i.e., those caused by elevated radiation levels that are in addition to those from other causes.

To estimate the total number of lung cancer deaths from increased levels of radon in the environment, we have used a life-table analysis of the additional risk due to radiation exposure (Bu81). This analysis uses the risk coefficients just discussed. It also takes into account the time a person is exposed and the number of years a person survives other potential causes of death, based on 1970 U.S. death-rate statistics. The result is expressed as the number of premature lung cancer deaths that would occur due to lifetime radiation exposure of 100,000 persons. We assume, further, that injury caused by alpha radiation is not repairable, so that exposed persons remain at risk for the balance of their lifetimes.

Using the relative-risk model, we estimate that a person exposed to 0.01 WL (.27 WLM/y) over a lifetime incurs a 1.7 percent (1 in 60) additional chance of contracting a fatal lung cancer. [This is equivalent to a lifetime risk of 1.2 percent (1 in 80) estimated for a residential situation where a person spends 75 percent of the time exposed to 0.01 WL. This results in 0.20 WLM/y of exposure and was the basis for our risk estimate discussions in Section 4.2 and 4.3 of the Draft Environmental Impact Statement and in EPA79a and EPA79b.] This estimate was made assuming children are no more sensitive than adults. If exposure to radon decay products during childhood carries a three times greater risk, this estimated lifetime relative risk would increase by about 50 percent (EPA79a-b). Using a similar life-table analysis and an absolute-risk model, we estimate that a person exposed to 0.01 WL over a lifetime incurs a 0.7 percent (1 in 140) additional chance of contracting a fatal lung cancer. (This corresponds to 0.6 percent for exposure 75 percent of the time.) Again, equal child and adult sensitivities are assumed (EPA79a-b). For comparison, a life-table analysis for the same population not exposed to excess radiation yields a 2.9-percent chance of lung cancer death. Therefore, our relative (absolute) risk estimate for lifetime exposure to an increment of 0.01 WL corresponds to a 60 percent (20 percent) increase in the expectation that a person will die of lung cancer.

Even though, under either of these models, the risk of radon-induced lung cancer varies with age, it is sometimes convenient to express these risks on an average annual basis. We have calculated a person's average annual risk from a lifetime of exposure by dividing the lifetime risk estimates given above by an average lifespan of 71 years.(1) Based on the risk models and assumptions just described for lifetime exposure we estimate an average of 1.0 to 2.4 lung cancer deaths per year for each 100 person-working-levels of such exposure. "Person-working-levels" is the population's collective exposure; that is, the number of people times the average concentration of radon decay products (in working levels) to which they are exposed.

For the entire U.S. population, the estimated number of cancers is larger using the relative-risk rather than the absolute-risk model, but this does not hold for all locations because the lung cancer rate varies considerably in different parts of the country. Therefore, we based our relative-risk estimate for each inactive site on the lung cancer death rate for the state in which the site is located. Lung cancer death rates are lower than the national average in several of the states where inactive tailings sites are located, so at some localities the absolute risk is greater than the relative risk.

Radiation risk can also be stated in terms of years of life lost due to cancer death. In the relative-risk model, the distribution of ages at which lung cancer caused by radiation occurs is the same as that for all lung cancer in the general population. Since lung cancer occurs most frequently in people over 70 years of age, the years of life lost per fatal lung cancer--14.5 years on the average--is less than for many other fatal cancers. The absolute-risk model assumes that lung cancer fatalities occur at a uniform rate throughout life and, therefore, each fatality reduces the lifespan by a larger amount--an average of 24.6 years. Thus, even though the estimated number of lung cancer fatalities

(1)Note that this is not the same as applying the risk coefficient for 71 years, since the life-table analysis accounts for other causes of death.

using the relative-risk model (nationwide) is nearly twice that using the absolute-risk model, estimates of the total years of life lost in the exposed population are nearly the same.

Because we used recent population data, our assessments are for current conditions around tailings piles. If the population lifestyle, medical knowledge, and other patterns of living affecting mortality remain unchanged, then these rates of lung cancer death could persist for the indefinite future. We have not attempted to assess the effects of future change, which may either increase or decrease our risk estimates. It is prudent, we believe, to assume that estimated risks based on current data could persist over the indefinite future.

4.4.2 Cancer and Genetic Risks from Gamma Radiation

Gamma radiation from tailings exposes the entire body so that all organs are at risk. The estimated frequency of fatal cancer and serious genetic effects due to a lifetime exposure of 100 mrem per year is listed in Tables 4-1 and 4-2. People who live or work near tailings piles will incur risks from long-term exposures in proportion to the excess of their average lifetime annual dose rate above normal background (approximately 100 mrem per year.)

4.4.3 Risks from Toxic Materials

Toxic materials have been considered in this EIS if they are in substantially greater concentration in tailings than in native rocks or soils or in a relatively mobile form (anionic or cationic). We have included materials that are harmful to livestock and plants as well as those potentially affecting humans directly. Evaluating the potential risks from nonradioactive toxic substances in tailings requires different methods from those used for radioactive substances.[(1)] With nonradioactive toxic materials, the type of effect varies with the material; the severity of the effect--but not its probability of occurring--increases with the dose. Moreover, because the body can detoxify some materials or repair the effects of some small doses, often no toxic effects occur below a threshold dose.

We cannot construct a numerical risk assessment for nonradioactive toxic substances because we do not have enough information. We can, however, qualitatively describe risks of toxic substances in terms of their likelihood of reaching people (or animals, or agricultural products), concentrations at which they may be harmful, and their toxic effects.

[(1)]Many nonradioactive substances can induce cancer in experimental animals (Go77, Ve78). However, for nonradioactive substances found in uranium mill tailings, we do not feel that dose-response relationships adequate for estimating such risks for oral intake have been developed.

TABLE 4-1. ESTIMATED RISK OF FATAL CANCER FROM LIFETIME EXPOSURE TO GAMMA RADIATION AT 100 mREM/Y

	Risk Model[a]	
	Relative	Absolute
Lifetime risk of fatal cancer	5 in 1000	0.8 in 1000
Life expectancy lost per fatality[b]	14 years	23 years
Average life expectancy lost per exposed person	24 days	7 days

[a]Chronic lifetime exposure; the exposure and the risk from this exposure is assumed to continue until death.
[b]The 1970 population statistics used for this analysis yields an average life span of 70.7 years.

TABLE 4-2. ESTIMATED RISK OF SERIOUS GENETIC ABNORMALITIES FROM LIFETIME EXPOSURE OF THE GONADS TO 100 mREM/Y[a]

	First Generation	All Succeeding Generations
Risk per 1000 live births	0.04 to 0.6	0.14 to 5

[a]Currently, 60 to 100 serious abnormalities per 1000 live births (not related to excess radiation) are observed in the United States. We calculate the risk from radiation using the observed distribution of ages of parents when these live-born are conceived.

No acute effects--death in minutes or hours--could occur except by drinking liquid directly from a tailings pond. Severe sickness, or death within days to weeks, from the use of highly contaminated water is possible, but unlikely.

Chronic toxicity from the continuous consumption of contaminants at low concentrations could be a problem. Toxic substances can accumulate slowly in tissues, causing symptoms only after some minimum amount has accumulated. Such symptoms of chronic toxicity develop slowly, over months or years.

In Tables 3-2 and 3-3 we listed many chemical elements and ions that have been found in tailings piles. Many of these occur in tailings in only slightly higher concentrations than in background soils, and they also have low toxicity when taken orally (Ve78). The following elements are in this category: lanthanides, including cerium, europium, lanthanum, and terbium; silicates; and zirconium, scandium, boron, gallium, and aluminum. Some other elements may be in elevated concentrations in tailings, but they, too, are not very toxic. These include copper, manganese, magnesium, cobalt, iron, vanadium, zinc, potassium, chloride, and sulfate. Some elements and ions at concentrations well below levels toxic to humans and animals will cause water to have an objectionable taste and color. Examples are iron, copper, manganese, chloride, and sulfate.

Other substances are both present in tailings and are regulated under the National Interim Primary Drinking Water Regulations (NIPDWR). Listing in the NIPDWR is an indication of a significant need to limit direct human consumption of these substances. The NIPDWR cover the following elements: arsenic, barium, cadmium, chromium, lead, mercury, nitrate, selenium, and silver. The toxicologies of these substances are discussed in Appendix C. Molybdenum is both toxic and present in tailings in elevated concentrations; its toxicity is also discussed in Appendix C. Appendix C also discusses both the chemical and radiological toxic effects of ingesting radium, thorium, and uranium. Tailings are not known to be significant sources of other toxic materials regulated under NIPDWR, such as organic substances, microbiological organisms, and man-made radioactivity.

4.5 Estimated Effects on Health due to Tailings

Health is affected when tailings are removed from a pile and misused and when there is radon emission and gamma radiation from a pile.

4.5.1 Effects from Misuse of Tailings

When tailings are used in building construction there can be serious risks to the health of those who live in such buildings. The Grand Junction experience is an example of what can happen when this kind of misuse occurs. There, about 700* buildings are contaminated with enough tailings to increase indoor radon decay product levels by 0.01 WL or more; a few houses have levels higher than 0.5 WL. If it is assumed that the useful lifetime of these buildings is 70 years, we estimate about additional 70-150 lung cancers would occur if remedial measures were not taken.

The estimated risks to individuals exposed to these high levels of radon decay products are very large. For persons living in a house with a concentration of 0.1 WL, the potential excess lifetime risk of lung cancer is 0.5 to 1 chance in 10.

Other misuses of tailings, e.g., tailings used in gardens or underneath detached buildings, can cause effects on health, but these cannot be estimated accurately. The risks depend on the particular way in which the tailings are used, because effects on health may be due to gamma radiation, ingestion of radionuclides through food chains, or inhalation.

4.5.2 Effects of Radon Emissions from Tailings Piles

We have separated the discussion of radon from tailings piles into two parts. The first concerns exposure of individuals living very close to the piles, and exposure of populations in the local environment (within 50 miles of the tailings piles). The second deals with exposure of the population of the rest of the North American continent, and world-wide populations.

Local and Regional Populations

Detailed information is needed to determine the exposure due to radon decay products to a local population. An accurate calculation of the collective exposure from a particular pile would require, besides the number of people exposed, the site and ventilation characteristics of each person's residence and work place, the length of time a person is at each place, and the average annual distribution of wind speed and direction. These data are unavailable for the inactive sites.

We have estimated local and regional exposure at 6 of the 24 inactive sites (SW81). Although this sample is limited, it includes all important urban sites except Canonsburg, Pa. The remaining piles are in remote areas and collectively have only about one tenth of the local and regional population exposures that these six piles collectively have. The methods used to estimate exposures were described in Section 4.3.2. Although we have ignored population changes since 1970, a future increase in population at several of the urban sites seems likely.

In Table 4-3 we summarize the results for the six sites in terms of estimated excess lung cancer deaths and average days of life loss per exposed person. The estimated number of lung cancer deaths associated with a tailings pile is highly variable, being highly dependent on the

TABLE 4-3. ESTIMATED RISK OF FATAL LUNG CANCER TO LOCAL AND REGIONAL POPULATIONS DUE TO THE LIFETIME EXPOSURE TO THE RADON FROM UNSTABILIZED URANIUM TAILINGS PILES

Local Population at Risk[a] (Size)	Absolute-Risk Model		Relative-Risk Model	
	Fatal Cancers[b] (Number/100y)	Average Life Loss Per Exposed Person (days)	Fatal Cancers[c] (Number/100y)	Average Life Loss Per Exposed Person (days)
Salt Lake City, Utah				
Local population (361,000)	79	1.4	72	0.8
Regional population (494,000)	5	0.06	4	0.03
Mexican Hat, Utah				
Local population (None permanent)	-	-	-	-
Regional population (14,100)	0.05	0.02	0.05	0.01
Grand Junction, Colorado				
Local population (39,800)	18	2.9	29	2.6
Regional population (30,600)	0.2	0.03	0.2	0.03
Gunnison, Colorado				
Local population (5,060)	2	2.5	3	2.3
Regional population (17,060)	0.01	0.004	0.02	0.003
Rifle, Colorado (Newer pile)				
Local population (2,700)	1	1.7	1	1.5
Regional population (35,900)	0.02	0.003	0.03	0.003
Shiprock, New Mexico				
Local population[d] (7,200)	3	2	4	1
Regional population (63,600)	0.1	0.01	0.1	0.007

(a)Local population, those people within 7.5 miles; regional population, those people between 7.5 and 50 miles.
(b)Life loss per fatal cancer--15 years.
(c)Life loss per fatal cancer--25 years.
(d)Within 10 miles.

population density in its immediate vicinity. The estimated number of fatal cancers for Utah residents based on the absolute-risk model is greater than that based on the relative-risk model. This is because the lung cancer death rates in Utah are comparatively low. The risks listed in Table 4-3 are based only on direct radon emissions from the tailings pile and include no additional risk from any offsite tailings material used in construction or elsewhere.

Effects on health were estimated separately at Canonsburg, Pa., because most of the radon exposure is received by persons working at the site. We estimate the excess risk to these workers and to the local population as 17 to 29 fatal lung cancers per 100 years, for the absolute-risk and relative-risk models, respectively.

The excess risk to people due to exposure to radon decay products depends on their distance from the pile. Table 4-4 gives calculated exposures and estimated excess risks to individuals for lifetime residency, as a function of distance from a theoretical pile with a radon emission rate of 2,000 curies per year. The decay product concentrations are based on a dispersion factor that depends on the area of the pile out to a distance of several pile diameters. Beyond that distance the theoretical pile can be considered as a point source for the purpose of estimating concentation levels. The estimates for this pile are based upon the absolute-risk model only since relative-risk estimates are site specific.

Ford, Bacon, and Davis have published plots of the outdoor radon concentration vs. distance from the edge of the pile for the sites they studied (FB76-78). We have used those data (identified by Ford, Bacon, and Davis as from measurements) together with estimates of distance from the pile to the nearest residents (Ga82) to estimate the exposure level to the nearest residents at several of the sites. Essentially, the decay product exposure level assumes an indoor radon concentration equal to the outdoor concentration and an average equilibrium fraction of 0.7. The estimated exposure levels and calculated lifetime risks for residents near several tailings piles are shown in Table 4-5. Since these are site-specific estimates based on measured values which include background radon, they are not directly comparable to those in Table 4-4. Estimates in Table 4-5 of the excess individual risk for lifetime exposure are as high as a 1-in-25 chance of death from lung cancer.

In Table 4-6, we provide estimates of the risks from naturally occurring radon decay products found in homes that are not near mill tailings or any other specifically identified radon source. National data on radon decay products in homes are scanty and vary widely among individual houses. These estimates are based on the assumption that the average radon decay product concentration is 0.004 WL in homes and that they are occupied 75 percent of the time. This assumed average level of radon decay products is based on recent data on 21 houses in New York and New Jersey (Ge78) and on 26 houses in Florida (EPA79b) and is consistent

TABLE 4-4. EXCESS RISK OF FATAL LUNG CANCER DUE TO LIFETIME RADON DECAY PRODUCT EXPOSURE AS A FUNCTION OF DISTANCE FROM A THEORETICAL TAILINGS PILE[a]

Distance from Center of Pile (miles)	Dispersion Factor (s/m^3)	Radon Decay Product Concentration (WL)	Lifetime Excess Risk[b] (Chances per Million)
0.2	1.1×10^{-5}	3.8×10^{-3}	2,700
0.5	2.4×10^{-6}	8.5×10^{-4}	600
1.0	5.7×10^{-7}	2.1×10^{-4}	150
2.0	2.1×10^{-7}	8.1×10^{-5}	58
5.0	4.4×10^{-8}	1.9×10^{-5}	14
10.0	1.1×10^{-8}	5.2×10^{-6}	4
20.0	2.0×10^{-9}	9.9×10^{-7}	0.7
50.0	5.7×10^{-10}	2.8×10^{-7}	0.2

(a)Tailings pile parameters:
Radon release rate: 2,000 Ci/y.
Area: 31 acres.
Uniform radium concentration: 500 pCi/g.
Radon emission rate: 1 pCi/m^2s radon per pCi/g of radium.

(b)Absolute-risk model of fatal lung cancer from lifetime exposure to radon decay products. The expected lung cancer mortality for a stationary population with 1970 U.S. mortality rates is 29,000 per million (EPA79a-b).

with data obtained in other countries (UN77). For comparison, these risks are about 10 percent of the expected lifetime risk of lung cancer death from all causes (0.029) in a stationary population having 1970 U.S. lung cancer mortality rates.

Effects on the U.S. Population

Radon emissions from tailings piles may affect the health of populations beyond 50 miles from tailings piles. Estimates of lung cancer deaths among persons living more than 50 miles from specific inactive tailings piles are listed in Table 4-7. The aggregate effect on persons living more than 50 miles from these piles is summarized in Table 4-8. These results are estimates of the total risk over 100 years for an exposed population of 200 million persons.

The Canonsburg, Pa., site was not included because our dispersion estimates were developed for western sites only. The effect on continental populations due to Canonsburg is not likely to be larger than that from a western pile. Thus, the aggregate effects listed in Table 4-8 are not significantly affected by this omission.

Effects from Long-Lived Radioactive Decay Products of Radon

The long-lived decay products of radon (beginning with lead-210) are also potential hazards (see Figure 3-1). The consequences of eating and breathing long-lived decay products cannot be established without site-specific information--on food sources, for example. The only detailed study is that provided for a model site in the NRC Draft GEIS on Uranium Milling (NRC79). However, the NRC results are likely to overestimate exposures at many of the inactive sites. We use the results of the NRC analysis here only to identify important exposure routes and to compare their importance to that of the short-lived decay products of radon. These results should not be taken as quantitative estimates of the actual risk at specific inactive sites.

The NRC model uranium mill and tailings pile is located in a sparsely populated agricultural area dominated by cattle ranching. The population in this region is assumed to produce all of its own food, which is unlikely. For tailings near urban areas, with a large number of people living close to the tailings pile, complete dependence on locally supplied food is even less likely.

The five sources of exposure in the NRC analysis are shown in Table 4-9. The largest risk is from breathing short-lived radon decay products; it is more than 10 times greater than the next highest risk from ingesting windblown tailings through vegetables and meat. Lead-210 and polonium-210, formed in air through radon decay, are also sources of risk through food and inhalation pathways. According to the NRC analysis, the risk from each of these pathways equals about one-hundredth of the risk from breathing short-lived radon decay products. Persons living more than 50 miles from an inactive pile would be less heavily exposed, and their risk would be considerably below that indicated in Table 4-9. We conclude that the risks from these pathways can be ignored compared to that from indoor short-lived radon decay products.

4.5.3 Effects of Gamma Radiation Emissions from Tailings Piles

Gamma radiation exposure of individuals depends on how close to the edge of a pile people live or work. The collective gamma radiation dose depends on both the number of people exposed and their average dose. In a few cases individual doses can be approximated from available data, but generally this cannot be done without a variety of detailed information, such as where people live and work and the amount of shielding provided by buildings. Outdoor gamma radiation doses in the vicinity of some tailings piles at inactive sites are summarized in Table 4-10. In several cases, even the nearest residents are far enough from the pile that they receive essentially no excess gamma

TABLE 4-5. ESTIMATED RISK OF FATAL LUNG CANCER DUE TO RADON FOR AN ASSUMED LIFETIME RESIDENCE NEAR SPECIFIC TAILINGS PILES[a]

Location (Distance from Pile and Exposure Level)	Risk of Lung Cancer (Chance per Lifetime)	
	Absolute-Risk Model[b]	Relative-Risk Model[c]
Salt Lake City, Utah (0.05 mile, 0.045 WL)	0.03[d]	0.03
Grand Junction, Colorado (0.1 mile, 0.045 WL)	0.03	0.04
Durango, Colorado (0.1 mile, 0.026 WL)	0.02	0.03
Rifle, Colorado (0.5 mile, 0.007 WL)	0.005	0.008
Gunnison, Colorado (0.5 mile, 0.008 WL)	0.006	0.009

(a) Radon decay product exposure levels are based on site-specific outdoor radon concentrations (FB76-78).
(b) Life loss per fatal cancer--25 years.
(c) Life loss per fatal cancer--15 years.
(d) A risk of 0.03 is the same as 30 chances in a thousand.

TABLE 4-6. LIFETIME RISK OF FATAL LUNG CANCER DUE TO NATURALLY-OCCURRING RADON IN RESIDENTIAL STRUCTURES[a]

	Estimated Risk to an Individual[b]	
	Absolute-Risk Model	Relative-Risk Model
Risk of lung cancer (Chance per lifetime)	0.002	0.004
Life loss per fatality (Years)	25	15
Average life loss per exposed person (Days)	18	23

(a) A risk of 0.004 is the same as 4 chances in 1 thousand.
(b) Calculated on the basis of 0.004 WL, home occupied 75% of the time, and 1970 U.S. mortality rates (EPA79a-b).

TABLE 4-7. RISK OF FATAL LUNG CANCER TO THE U.S. POPULATION DUE TO RADON FROM SPECIFIC TAILINGS PILES[a]

Site of Tailings Pile	Excess Risk of Lung Cancer (Deaths per 100 Years): Absolute-Risk Model	Excess Risk of Lung Cancer (Deaths per 100 Years): Relative-Risk Model
Arizona		
Monument Valley	0.3	0.6
Tuba City	0.2	0.4
Colorado		
Durango	1	2
Grand Junction	3	7
Gunnison	1	2
Maybell	2	4
Naturita	2	3
Rifle, Colorado[b]	3	6
Slick Rock, Colorado[b]	1	3
Idaho		
Lowman	0.2	0.5
New Mexico		
Ambrosia Lake	5	10
Shiprock	2	4
North Dakota		
Belfield	<0.1	<0.1
Bowman	<0.1	<0.1
Oregon		
Lakeview	1	2
Texas		
Falls City	5	10
Utah		
Green River	0.5	1
Mexican Hat	3	6.5
Salt Lake City	7	15
Wyoming		
Converse	0.1	0.3
Riverton	3	7

(a) Does not include effects within 50 miles of the site (see Table 4-3), and assumes piles are not stabilized. Canonsburg, Pa., site not included.

(b) Two inactive piles.

TABLE 4-8. RISK of FATAL LUNG CANCER TO THE U.S. POPULATION DUE TO RADON FROM ALL INACTIVE TAILINGS PILES[a]

	Estimated Risks to U.S. Population[b]	
	Absolute-Risk Model	Relative-Risk Model
Lung cancers (Number/100 years)	42	88
Life loss per fatality (Years)	25	15
Average life loss per exposed person (Days)	0.0013	0.0017

(a)Canonsburg, Pa., site not included.
(b)Does not include people living within 50 miles of the site, and assumes piles are not stabilized.

TABLE 4-9. RISK of FATAL CANCERS TO REGIONAL POPULATIONS DUE TO RADIONUCLIDES FROM INACTIVE TAILINGS PILES

(NRC Model Pile, Population at Risk - 57,000)

Exposure Pathway	Estimated Risk of Cancer (Deaths/y)
Inhalation of short half-life radon decay products	0.06[a]
Ingestion of radioactive windblown tailings	0.004[b,c]
Inhalation of lead-210/polonium-210	0.0006[b]
Ingestion of lead-210/polonium-210	0.0006[b]
Inhalation of resuspended tailings from open lands	0.00006[b]

(a)EPA relative risk estimate.
(b)EPA estimate based on individual nuclide concentrations calculated by NRC to prepare dose summary tables for the draft GEIS (NRC79).
(c)Particles containing U-238, U-234, Th-234, Th-230, Ra-226, Pb-210, Bi-210 (See Figure 3-1).

TABLE 4-10. RADIATION EXPOSURE TO NEAREST RESIDENTS DUE TO GAMMA RADIATION FROM INACTIVE TAILINGS PILES[a]

Location of Inactive Site	Location of Nearest Resident Distance from Pile Edge (miles)	Gamma Radiation Exposure[b] (mrem/y)
Colorado		
Durango	0.1	200-300
Grand Junction	0.1	580
Gunnison	0.5	(c)
Rifle	0.25	(c)
Idaho		
Lowman	1.0	(c)
New Mexico		
Ambrosia Lake	1.5	(c)
Pennsylvania		
Canonsburg	0.04	150
Utah		
Green River	0.15	(c)
Salt Lake City	0.05	465
Wyoming		
Spook	1.5	(c)

(a) Ambient gamma radiation background at each site has been subtracted.
(b) Measured in air (Roentgens). At these energies continual exposure to 1 mR/y gives an annual dose of 1 mrem.
(c) No detectable increase above background.

TABLE 4-11. EXCESS RISK OF FATAL LUNG CANCERS DUE TO RADON FROM ALL INACTIVE URANIUM MILL TAILINGS PILES

Population at Risk	Estimated Fatal Lung Cancer Risk (number/100 years) Absolute-Risk Model	Relative-Risk Model
People within 50 miles of any site[a]	130	150
People more than 50 miles from all sites[b]	40	90
TOTAL	170	240

(a) Summary of estimates given in Table 4-3, plus estimates for Canonsburg, Pa.
(b) Summary of estimates given in Table 4-8.

radiation. At others, a few residents are located close enough to perhaps double the dose from gamma radiation that would occur without the pile. In a few cases, the dose to the nearest resident may be several times normal background levels. In most of these localities, normal background due to penetrating gamma radiation is about 100 mrem per year (FB76-78).

In summary, lack of information precludes detailed calculation of the collective gamma radiation dose and risk to all persons living or working near the inactive piles. The total impact, however, is small, because the gamma-radiation intensity falls rapidly with distance from the pile.

4.6 Summary

The most significant individual health risk caused by the inactive tailings piles is that from inhaled short-lived radon decay products. This arises for two reasons: misuse of tailings in and around buildings and direct radon emission from the piles. Compared to the risk from short-lived radon decay products, the other radiological risks are much less significant. At most, they increase by 10 percent the risk estimated for the regional population, and the additional risk to the national population is much less. This incremental risk is small compared to the uncertainty--at least a factor of two--in the estimated risk for lung cancer deaths from indoor radon decay products.

The six sites in Table 4-3 represent all but one of the designated sites in areas with relatively large local and regional populations. The other inactive piles are either in remote areas or are small and do not contribute much to the total risk. Summing the estimated fatal cancers for these six sites gives our best estimates of the risk to regional and local populations due to all inactive uranium mill tailings piles. Our best estimate of the total risk to the continental U.S. populations due to all inactive uranium mill tailings piles is made by summarizing the values in Table 4-7. We summarize these risks in Table 4-11. Most risk is to people within 50 miles of the six sites, but the aggregate risk to more distant people is significant.

The nonradioactive toxic substances present in an inactive tailings pile and their potential impact on public health and the environment must be determined for each site. Substances with the highest potential for causing a health risk are those that can move through ground water and that have the greatest toxicity. These include forms of arsenic, barium, cadmium, chromium, lead, mercury, molybdenum, nitrate, selenium, and silver. In addition, among radioactive substances, uranium is most likely to be mobile in ground water, while radium and polonium are possibly mobile.

Chapter 5: METHODS FOR CONTROL OF TAILINGS PILES AND FOR CLEANUP OF CONTAMINATED LANDS AND BUILDINGS

Our goal is to reduce the health risk from tailings by isolating them from the biosphere. Remedial actions are usually needed in two general areas: 1) at the tailings pile and near the pile where tailings are scattered as a result of milling operations, and 2) at other locations where tailings are found, including tailings used in building construction and for fill, and wind-blown tailings on lands near the mill site.

Section 5.1 contains a brief discussion of the objectives of control measures for tailings piles, contaminated buildings, and lands contaminated with tailings. In Section 5.2 we give a more detailed discussion of the engineering and institutional controls that are available for tailings piles. In Sections 5.3 and 5.4, we do the same for contaminated buildings and lands, respectively.

5.1 Objectives of Remedial Methods

For tailings piles, the major objectives of control methods are to provide effective long-term stabilization and isolation, to control radon and gamma emissions from the tailings, and to protect water quality.

The long-term integrity of remedial methods undertaken to achieve these objectives is an overriding consideration. Because of the long half-life of some of the radioactive materials in tailings, and the permanent toxicity of some of the other contaminants, the risks due to tailings will exist for hundreds of thousands of years. In order to make judgements on the degree of health protection feasible for future generations, we have assessed long-term durability and need for periodic repair for each remedial method.

Long-term stabilization and isolation should do the following things: 1) reduce the chance of human intrusion so as to prevent the use of tailings as a construction material, as backfill around structures, and as landfill; 2) protect the piles from natural spreading by wind erosion and surface water runoff; 3) prevent spreading by flood damage to the piles; and 4) prevent tailings from contaminating surface and groundwaters. Radon and gamma emission controls prevent or inhibit such emissions from the piles. Water quality controls prevent contamination of water through leaching of radioactive or other hazardous materials from the tailings into surface water, or groundwater aquifers.

For contaminated buildings, the major objectives are to reduce radon decay product levels and (sometimes) to reduce gamma radiation. For contaminated lands, the major objectives are to reduce gamma ray exposure and to prevent high levels of radon decay products in any new buildings. Remedial measures for land may also be required to protect surface and groundwater, and to avoid exposure of man through food chains.

5.2 Remedial Methods for Tailings Piles

Both active and passive remedial control methods for tailings piles are available. Active controls require that some institution, usually a government agency, have the responsibility for continuing oversight of the piles and for making repairs when needed. Fencing, warning signs, periodic inspection and repairs, and restrictions on land use are examples of the measures that may be used. Passive controls are measures of sufficient permanence that little or no upkeep or active intervention by man is needed to maintain their integrity. Passive controls include measures such as thick earth or rock covers, barriers (dikes) to protect against floods, burial below grade, and moving piles out of flood-prone areas or away from population centers. Some measures may be either active or passive, e.g. thin earth covers require maintenance, thick ones do not. Similarly, vegetative cover that requires irrigation is a control requiring active (institutional) maintenance, but the establishment of indigenous vegetation is a passive means of control.

Active and passive controls for tailings can be classified into two groups: those that are currently available and have a reasonable likelihood of being successfully used, and advanced methods that require further development and testing. The first group includes earth and clay covers over tailings, plastic or clay liners between tailings and underlying earth, and dikes or embankments around the edges of tailings. The second group includes untested methods such as covering tailings with asphalt or other impermeable barriers, moving tailings to worked-out underground mines, solidifying tailings in cement or asphalt matrices, and chemically separating radium and thorium from tailings followed by solidifying and disposing of radium and thorium in deep geologic formations.

Only available methods are considered in detail in this analysis, since costs and performance can be reliably predicted for them. We have, however, included a potential method using soil cement as a control method in Chapter 6 and Appendix B. Advanced methods could be used when they are shown to be effective and economical.

In this section we describe specific methods to achieve stabilization, reduce radon and gamma emissions, and protect water quality. The longevity of these methods is discussed separately in Section 5.2.5 because it is a major consideration. Advanced methods are briefly reviewed in Section 5.2.6.

5.2.1 Stabilizing Tailings

Preventing Misuse of Tailings

Risks to health arise from uranium tailings (see Chapter 4) when they are removed from processing sites and used in construction or as fill around inhabited structures. There is real potential for this if, as has happened at many piles, people identify a disposal site as a resource area for sand. Tailings are a high grade sand that would be ideal for use in construction or as fill if the material were not a health hazard. This kind of misuse can be prevented by active methods of control such as fences, inspections, disposal site ownership, restrictions on land deeds, and by passive methods of control, such as placing physical barriers around the tailings. Ideally, passive barriers should be effective so that unusual effort would be required to overcome them before the tailings could be removed and used. Examples of barriers are thick earthen covers, heavy rock covers, dikes, and below-ground burial.

The thickness of barriers needed to prevent unintentional intrusion can be estimated. A variety of human activities involve excavation to depths of 6 to 8 feet. Sewer and water pipes are buried below the frost depth which may be 4 to 6 feet deep in cold climates. Footings for foundations of houses with basements often are placed at depths of 8 feet or greater, and this may imply needs for sewer pipes at slightly greater depths. Graves are dug to 6 feet. Thus, an earth cover used to provide passive protection for tailings piles should be of substantial thickness; we estimate that a cover 10 feet thick would prevent most casual intrusions into tailings.

Two controls that might encourage human degradation of control methods are the use of small-sized rock for erosion protection, and fences. Rock and fencing have intrinsic value and may be stolen, especially at remote sites. The likelihood of this is difficult to evaluate; however, it provides an argument in support of earthen covers, which have little resource value, and heavy rock covers. The theft of rock is assumed to be inhibited if the individual pieces are large and difficult to handle (400 pounds or larger).

Preventing Erosion

Any covering will prevent the erosion of tailings as long as its integrity is maintained. Both thin impermeable covers and thick earth covers will prevent tailings from becoming windborne or waterborne. When earth covers are used, the problem becomes that of protecting the earth cover from erosion. Rock or vegetation is usually used to provide this protection.

Gully erosion of covers is caused by surface water runoff from rain or snow. The cover is cut through, exposing tailings which are then eroded by wind and water. Thin impermeable covers can be designed to withstand gullying as can thick earthern covers having properly graded slopes and rock or vegetation for surface stabilization.

Rock cover is a means of protecting underlying soil from erosion by wind and water runoff. We distinguish between 3 types of rock cover: riprap, rock, and rocky soil. Riprap generally refers to an orderly placement of large rocks that have often been shaped to fit together. It provides good protection against erosion and is also effective in protecting against damage from floods. It is quite expensive. In the control methods discussed in Chapter 6 and Appendix B, we have specified the use of riprap for shielding embankments which protect piles threatened by floods. We use rock to refer to a less orderly placement of rocks that have not been shaped to fit together. We specify its use for protecting the slopes and tops of piles from erosion by wind and water runoff. Rocky soil refers to soil with significant rock content. It is used as the top layer of earth cover that is to be protected from erosion by vegetation, where it is feared that the vegetation may fail. If the vegetation fails, erosion would remove the fine grained soil particles, leaving a protective layer of rock on the surface, protecting the underlying earth. We have estimated that a 0.33 meter thickness of rocky soil would be sufficent for this purpose. For the long term, all forms of rock covers can provide good control of erosion and require little or no maintenance.

Vegetation can also be effective for stabilizing earthen covers. When they can be established, shallow-rooted vegetative cover provides the best protection to the earth cover. A number of shallow-rooted plants native to the West and Southwest are available which will grow in less than 3 feet of soil (BL82). This vegetation must be periodically grazed or pruned to assure adequate growth for continued stabilization. If not, the plants will mature and die. Most of these plants are palatable to livestock, with excellent-to-good forage value. However, shallow-rooted plants probably cannot survive the droughts that frequently occur in the western and southwestern regions of the United States without irrigation.

Frequent drought conditions favor the establishment of a predominance of deep-rooted plants. Over time, the natural succession of native local plants could be expected to replace introduced species if maintenance is not performed (EP78f). Deep-rooted indigenous vegetation may be able to survive on the tops and sides of the piles and provide sufficiently good ground cover to stabilize the surface of the pile. If the indigenous ground cover does not provide a cover sufficently dense to protect the entire surface, a layer of rocky soil will provide a rock cover in places where the vegetation fails.

Vegetation should be irrigated and fertilized to provide the best protection. One control method discussed in Chapter 6 and Appendix B uses this means of controlling erosion of earth covers and specifies continuing maintenance and irrigation to maintain the vegetation.

Flood Protection

Piles can be protected against floods by constructing barriers designed to withstand floods, or by moving the piles to new sites. Barriers are made by: (1) grading the piles so that the sides of the piles have gradual slopes and providing protective rock on the slopes (and on the top if needed), and (2) constructing embankments or dikes on the sides of the piles and protecting exposed sides of the embankments with riprap. Where the vulnerability to floods is great enough, the piles can be moved to less vulnerable sites.

5.2.2 Preventing Radon Emissions

Radon emissions to the atmosphere from tailings piles can be controlled by covering them with an impermeable barrier, like plastic, or by covering the with enough semipermeable material, like earth, to slow the passage of radon and increase the amount of radioactive decay that takes place within the cover. Generally, the more permeable the cover material and the lower the moisture content, the thicker it must be to reduce radon emissions.

Natural cover materials are earth, clay, gravel, or a combination of these. Clay, especially when moist, is generally more resistant to the passage of radon than an equal thickness of earth or sand. Figure 5-1 shows curves for the percentage of radon which would penetrate various thicknesses of different cover materials (FB76-78). The half-value layer (HVL) is defined as that thickness of material which reduces radon emissions to one-half its initial value. HVLs at actual sites depend on earth composition, compaction, moisture content, and other factors which vary from site to site with time. About 7 HVLs of cover reduce radon emission to less than 1 percent of the uncovered rate, and about 10 HVLs reduce the release to less than 0.1 percent. Reductions are multiplicative; for example, 1 HVL of earth plus 1 HVL of clay reduces radon emissions to 25 percent of the uncovered value (i.e., 50 percent x 50 percent = 25 percent).

Figure 5-1 is a simplified description of radon retention presented for illustrative purposes only. Appendix P of the NRC GEIS (NRC80) contains a more complete discussion. Momeni et al. (Mob79) have measured radon emissions from two tailings plots that had been experimentally covered with increasing thicknesses of earth. The results were in good agreement with calculations based on the predictive methodology described in (NRC80) and (Mob79), at least over the ten- to twenty-fold emission reduction range covered by the experiment.

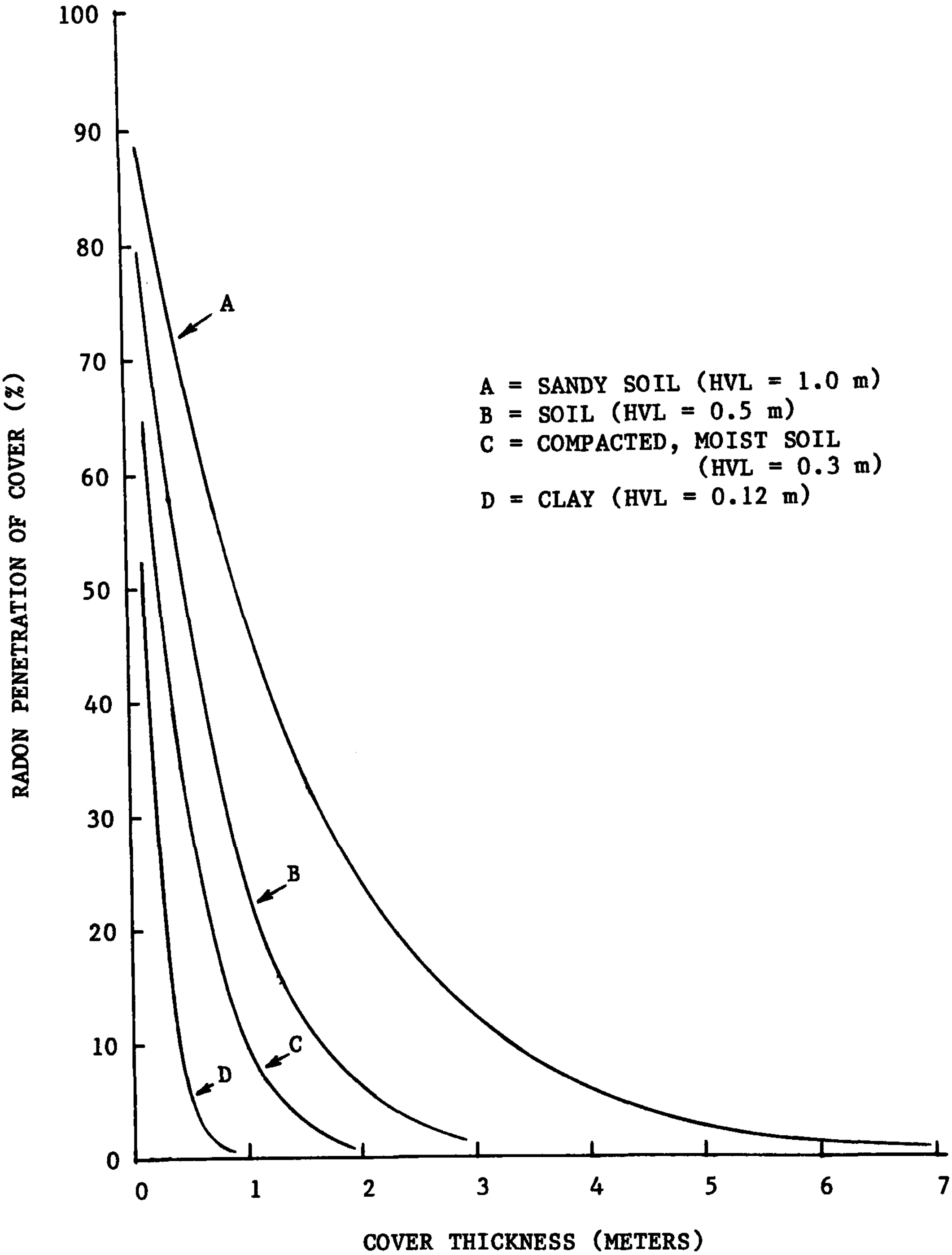

FIGURE 5-1. PERCENTAGE OF RADON PENETRATION OF VARIOUS COVERS BY THICKNESS.

5.2.3 Controlling Direct Gamma Radiation

Covering tailings piles to stabilize them will also reduce direct gamma radiation. Attenuation of gamma radiation depends on the thickness of the cover. In Figure 5-2 we show how packed earth reduces the primary gamma radiation for an extended source (Jab68) assuming an alternation coefficient of 0.693 m^{-1} (Sca74). This reduction of gamma radiation is roughly approximated by a half-value layer of 0.04 m.

The actual reduction of gamma radiation from a tailings pile is much more complicated. Gamma rays from the radon decay products are distributed over a wide energy range. Primary radiation would be supplemented by scattered radiation of lower energy. There are further complicating factors such as the extent to which radon diffuses through the cover before emitting gamma radiation thereby decreasing the shielding thickness; this depends on the degree of earth compaction, moisture content, type of earth, and other parameters.

If all of these corrections were applied, it would not drastically alter Figure 5-2. A detailed analysis would still support the following conclusions: a thin, impermeable cover, such as a plastic sheet, will not reduce gamma radiation; earth thick enough to sustain vegetation will significantly reduce gamma radiation; and earth or other materials thick enough to reduce radon emissions will reduce gamma radiation to insignificant levels.

5.2.4 Protecting Groundwater Quality

Groundwater contamination is caused by direct contact of groundwater with tailings resulting in leaching of radioactive and nonradioactive contaminants. There are several approaches that can be used to protect groundwater. First, the tailings can be placed far enough above the water table to avoid contact. Second, an impermeable barrier can be imposed between the tailings and the groundwater, provided that rain water does not percolate down and seep over the barrier. In some cases, to make these controls feasible and long lasting, the pile may have to be moved to a new site, or an infiltration gallery constructed.

Virtually all tailings piles are in areas where evapotranspiration exceeds rainfall. Therefore, rain water does not percolate through the piles and contribute to additional contamination of groundwater. However, water supplies could become contaminated in the near or distant future by toxic materials that are already in the ground due to operations that took place when the mill and tailings pile were active.

These substances may be migrating to an aquifer, but they are expected to move slowly. Groundwater itself often moves less than a few feet per year, and only in coarse or cracked materials does it exceed 1 mile per year. For these reasons, pollutants released from tailings into the earth around the pile may not affect the quality of nearby water supplies for decades or longer. Once polluted, the

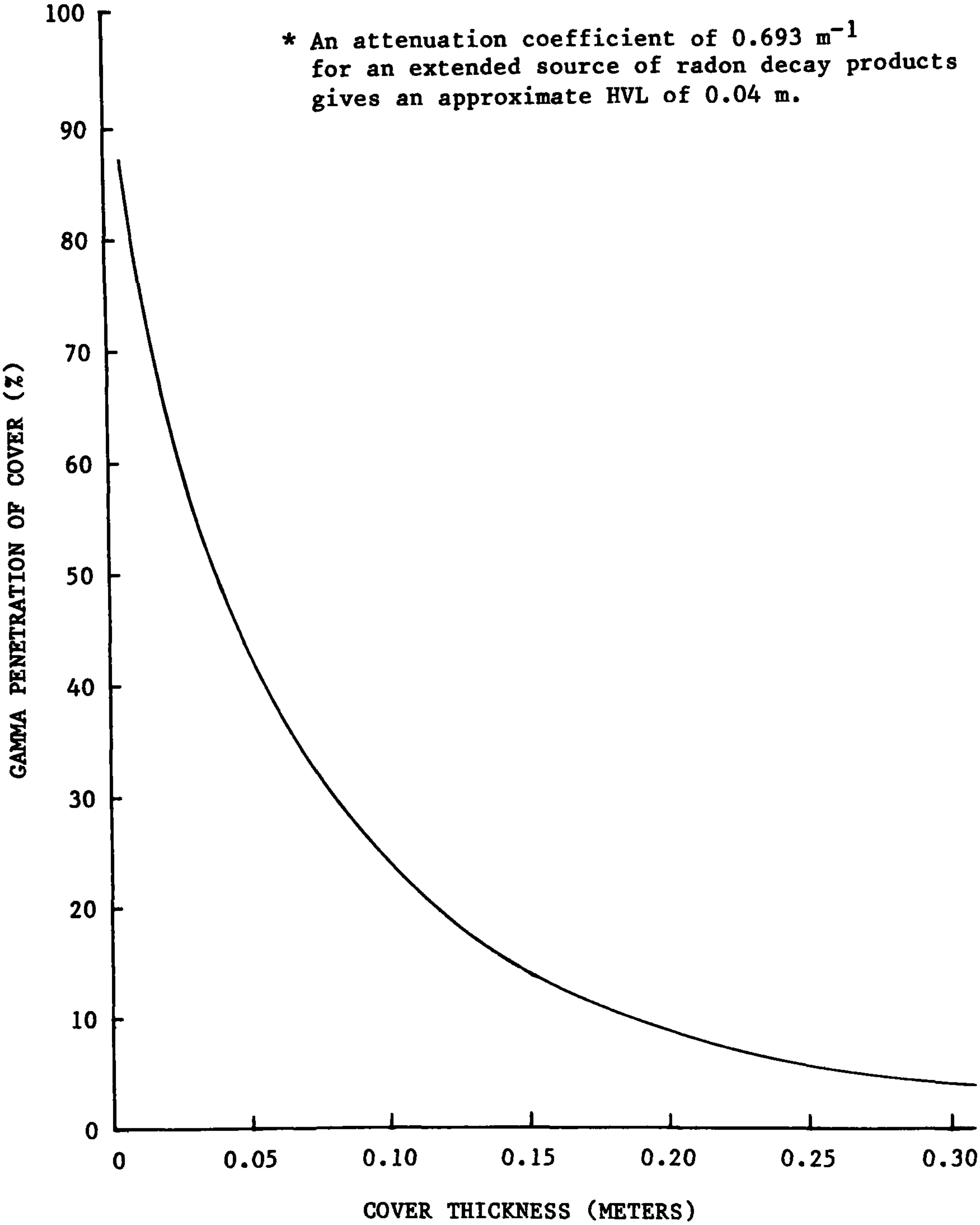

FIGURE 5-2. REDUCTION OF GAMMA RADIATION BY PACKED EARTH COVER (HVL* ~ 0.04 m).

quality of such water supplies cannot be quickly restored by eliminating the source of pollutants.

Recent reports prepared for EPA (JA80, AW78) review methods that can sometimes improve the quality of an already contaminated aquifer. Other reports for EPA (SE80, MC80, GM78) present case studies of toxic waste sites that have polluted groundwater and review remedial actions for them. A group at the University of Idaho has reviewed water pollution problems associated with six active uranium mills (UI80). From such studies, it is clear that feasible remedial actions are very site-specific. The economic and technical practicality of achieving any preset degree of cleanup is uncertain. The only generally-applicable control measure is to monitor the quality of the aquifer and limit the use of its water. The length of time this may be necessary would depend on the degree of contamination, the rate of groundwater movement, the amount of dilution and dispersion taking place, and the intended use of the water.

5.2.5 Assuring Long-Term Control

The ultimate objective of a tailings disposal program is not only to reduce the potential hazards to an acceptable level now, but also to provide this control for the anticipated life of the hazard. Unfortunately, because of the long lifetimes of the radioactive contaminants (thorium-230 has a half-life of about 80,000 years) and the presence of other toxic chemicals (which never decay), the potential that tailings have for harming people and the environment will persist indefinitely (see Figure 3-2).

In this section we examine the technical and social factors that influence the permanence of measures for controlling tailings. Maintaining the integrity of thin impermeable covers over periods even as short as tens to hundreds of years is highly uncertain under the chemical and physical stresses that are likely to occur. We do not consider them as a means of ensuring long-term control against erosion, radon emission, misuse, and other hazards due to tailings.

Effects of Long-Term Erosion

Earthen covers will withstand erosion caused by rain and surface water for long periods of time, but it is difficult to estimate how long this will be. Some values for overall earth erosion rates in the United States are given in Table 5-1. These erosion rates are average and do not mean that all surfaces are eroded uniformly by this amount. Widely varying rates of erosion, and also of deposition, can be found within any drainage basin. Water erosion in the Colorado River drainage basin is believed to range from 0.09 to 0.25 meters per 1000 years, based on several studies (Table 5-1). These rates can reasonably be applied to the inactive mill tailings sites. This range is probably applicable to controlling tailings below grade level. We assume that the upper end of the range is probably applicable to controlling tailings above grade level where vegetation and rock covers are used.

TABLE 5-1. SOIL EROSION RATES IN THE UNITED STATES

Erosion Rate (cm/1,000 years)	Measurement Technique	Comments	Reference
6	River load*	Average for U.S.	Ju64
4	River load	Columbia River	Ju64
17	River load	Colorado River	Ju64
5	River load	Mississippi River	Haa75
9	River load	Colorado River	Haa75
5	Radioactive dating	Amount of erosion of volcanic extrusion in southern Utah	Haa75
25	River load	Colorado River	Yo75
5	River load	Average for U.S.	Da76
3	River load	Average for North American continent	Pr74

*River load refers to erosion rate estimates based on the sediment load (dissolved and detrital particles) carried by rivers.

Rapid erosion rates are to be expected if vegetation and rock covers are not used, or if their integrity is not maintained. For example, erosion on some steep shale slopes (20^{o} to 40^{o}) in Arizona averages 600 cm per 1000 years; even for slopes if less than 10^{o}, the rate is 250 cm per 1000 years (Gib68). It is also noted that the maximum rate of erosion occurs in areas with about 10 inches (25 cm) of rainfall per year (Lac58) which is typical of the uranium mining and milling areas in the western United States.

Wind erosion will be insignificant when a pile is protected from water erosion by rock or vegetative cover. However, in dry areas with bare earth covers, wind erosion could be severe. We conclude that earthen covers several meters thick, stabilized with vegetation or rock, should provide adequate protection against erosion for several thousand years, unless a site is susceptible to catastrophic damage from severe flooding or severe gully erosion (with no provision for short-term corrective action).

Effects of Natural Forces

Natural forces such as floods, heavy rains, windstorms, tornados, earthquakes, and glaciers, may disrupt attempts to stabilize tailings (EPA78b, GS78, Lu78, Lab80). These forces are numerous and sometimes interrelated; some are so powerful we have little chance of providing protection against them. We believe that stability against natural forces can be provided for a few hundred to a few thousand years by designing protective measures on a case-by-case basis and taking site-specific factors into account. Predictions of stability become less certain as the time period increases. Beyond several thousand years, long-term geological processes and climatic change will determine the effectiveness of most "permanent" control methods. Glaciation, volcanism, uplifting and denuding of the earth's surface, or deposition of material have occurred in the western United States as recently as 10,000 years ago and are likely to occur in the future.

Nelson and Shepherd (Ne78), have considered the impact on covers by natural phenomena, including floods, windstorms, tornadoes, earthquakes, and glaciers. These events could disperse the tailings, making possible chronic exposure to their radioactive and nonradioactive toxic constituents. The following comments are summarized from their report.

Flooding, resulting from large rainstorms, rapidly melting snow, or local cloudbursts, can disperse tailings over large areas in a very short time. Also, increased earth moisture from flooding may make steep slopes unstable, leading to landslides and eventual loss of cover and disposal of tailings.

The size of floods to be designed for can be determined from historical stream flow data and techniques of geomorphology. There is, however, always a chance that an actual flood will exceed the designed maximum flood. Also, with changes in climate, the frequency and size of floods may change. Pluvial conditions in the Pleistocene era (1 million to 10,000 years ago) resulted in abundant rainfall and freshwater lakes in the western United States that were as large as the contemporary Great Lakes.

Flood protection design must be based on very infrequent but high-magnitude floods.[1] These floods typically depart significantly from the trend of more frequently observed floods and will influence the design of protective measures. Where historical records are of short duration compared to the required longevity of the protection measures, prediction of extreme floods must rely on techniques of geomorphology (Cob78). Once the size of flood event to be used has been determined, flood protection can be incorporated into the design of remedial measures.

Another measure of flood severity that is sometimes used as a design criterion is the Standard Project Flood (SPF), which results from the most severe combination of weather and hydrologic conditions that are reasonably characteristic of the region involved, excluding extremely rare combinations.

The "design flood" is the flood adopted as the basis for flood protection for a facility after considering both hydrologic and economic factors. In most areas, the characteristics of relatively frequent floods, such as the 50-year flood, have been well established, and engineers routinely design facilities protected from such events. Where the failure of flood protection systems could result in loss of lives and great property damage, however, a design based on the maximum probable flood (MPF) may be justified. The standard project flood (SPF) is often considered an appropriate design basis for facilities where some risk would be tolerable, and the added cost of providing greater protection would be significant.

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[1] It is customary to rank the severity of floods in terms of the average time over which floods of a given size or greater may be expected to recur. For example, there will be an average of 5 floods in 1,000 years that reach or exceed the "200-year flood". The "maximum probable flood" (MPF), on the other hand, is the largest flood that one would expect to occur in a given region for that climate era. Geomorphic data are best for determining the past rate of occurrence of very large floods. When such data are unavailable, the MPF can be estimated from historical records, but such estimates are frequently shown to be inadequate when new severe rainstorms occur.

Sometimes the differences between various classes of floods are not great. For example, the difference in height between the 100-year flood and the SPF at the Grand Junction and Durango tailings piles have been reported as 1 and 4 feet, respectively (FB76-78). The differences in water velocity can be significant, however, and adequate protective systems must be considered for the specific site.

Uncertainties in design specifications and performance may affect the practicality of long-term flood protection systems. The characteristics of long-term recurrence floods, such as the 1000-year flood, are usually much less certain than those frequently occurring during historical periods. Furthermore, because of potential damage from erosion and earthquakes, our confidence in the ability of conventional flood protection systems, such as dikes and stone reinforcements, to withstand a flood declines with time into the future. In view of these combined uncertainties, very conservatively designed systems would be required to satisfy long-term flood protection requirements. Whether for technical or economic reasons, if those requirements could not be satisfied at the present location of a tailings pile, it would have to be moved to a new site where long-term floods are a more manageable threat.

The frequency and intensity of windstorms and tornadoes are historically predictable. With a suitable cover or cap on the tailings and protection of the surface against wind erosion, winds and tornadoes should have little effect.

Earthquakes can damage caps and covers, as well as disrupt barriers under disposal sites. The number and magnitude of past earthquakes in an area is suggestive of the probability of earthquakes in the future. As with any natural phenomenon, confidence in such predictions rises as the reliability of earthquake and faulting information increases. The likelihood that controls will fail because of an earthquake depends on the chance of an earthquake of greater intensity than controls were designed to withstand. Even if a plan is designed on the basis of the maximum credible earthquake, there is always the chance of an even larger earthquake. If an earthquake occurs at a site, the likelihood that controls may partially fail will generally be high. The quantity of tailings released, however, may be small.

Glaciers occur in mountain valleys and as extensive (continental) ice sheets, as in Greenland. Because of the magnitude of the forces associated with glaciation, no portion of a surface depository would be likely to survive even a small, relatively short-term glacier. The likelihood of continental glaciation in the Western United States, even far into the future, is remote. No evidence exists of continental glaciation south or west of the Missouri River. Increased valley glaciation in the west is a possibility, however. Several glaciers exist high in the Rocky Mountains, and heavy glacial activity existed in the mountains as recently as 10,000 years ago. An increase in valley glaciation is likely over the long term. Previously glaciated mountain valleys are less desirable as tailings control sites than nonglaciated sites, such as flat terrain or valleys created entirely by erosion. The possibility of valley glaciation should be considered in choosing between surface or below-ground disposal methods.

Effects of Human Activity

People may disrupt any measures undertaken to isolate tailings. The NRC has discussed this problem (in Chapter 9 of their FGEIS (NRC80)), as a justification for land use controls. Construction on top of a disposal site, excavating or drilling, or using the surface land for grazing and tilling, could disrupt controls or accelerate natural erosion processes. It has been suggested that a disposal site should not be made more attractive to human or animal habitation than the surrounding environs, and perhaps that it should be made even less attractive (Sh78).

The Act requires that uranium tailings control sites for residual radioactive material be owned by an agency of the Federal Government and licensed by the NRC (42 USC 7901). Such Federal responsibility should provide control of any human activity which might disrupt the isolation of the tailings for as long as that responsibility is exercised. From a historical perspective, however, we should not expect institutions to perform such functions for more than several centuries (Ro77, Sca77, EPA78a, Bi78, Lu78). In its proposed criteria for the management of radioactive wastes (EPA78d), EPA has suggested that one should not plan to rely on institutional controls for more than 100 years. During the period of effective institutional control, it should be possible to detect and remedy defects due to wind or water erosion. This should provide some assurance of continued stability against natural forces for a longer period of time.

Selecting remote or deep underground locations, to isolate tailings from expected habitation and land-use patterns, is one way to protect against degradation and intrusion by human activity after institutional controls have become ineffective. Another which does not require moving tailings is a thick earth cover with effective surface stabilization.

5.2.6 Advanced Methods of Controlling Tailings

Uranium mills have generally been located near the mines where ore is obtained, and often other mines are nearby. Placing tailings in these mines is one obvious control method. The thick cover and erosion protection implied by mine storage would prevent misuse and almost completely control radon emissions for a substantially longer period than could generally be expected from above-grade control methods. However, since mines are usually below the water table, elaborate and costly groundwater protection methods might be needed, and it is not clear that effective methods are available. Trans- portation hazards and other costs also may be high. A major difficulty is that using mines for tailings disposal makes future development of the mine's residual resources impossible.

Nitric acid leaching to remove radium-226 and thorium-230 from the tailings is a potential pretreatment technique. The technology has not been fully developed but appears to be technically feasible. It is attractive because about 90 percent of the radium and thorium can be concentrated in a much smaller volume and the hazard of the tailings greatly reduced. Major difficulties are the nonremoval of toxic chemicals and high costs. Therefore, further remedial actions on the tailings would still be required, and the volume of the tailings would not be significantly reduced. There seems to be no incentive for using this technique.

The use of caliche-type cover material for mill tailings piles has been suggested (Br81) since this material may be effective in preventing excessive mobilization of certain radionuclides and toxic elements. However, the effectiveness and long-term performance of such covers are not yet known.

Another recently investigated method is the sintering of tailings to reduce the amount of radon emanating from the individual tailings particles (Dr81a, Thb81). This is attractive since it would greatly reduce risks if the tailings are misused as fill material around buildings. More evaluation of this method is needed (especially costs) before we can decide if it is practical.

Advanced methods for controlling uranium mill tailings are discussed further in Section B.6 of Appendix B.

5.3 Remedial Measures for Buildings

The only remedial measure that permanently eliminates the hazards due to contaminated buildings is to remove all tailings from under and around buildings and to dispose of them. Because this does not require continued attention of the occupant to maintain its effectiveness, we call this a "passive" control. The cost and complexity of removing tailings from buildings depends on the amount and location of tailings. For example, tailings used as backfill around the outside of a foundation can be removed easily at relatively low cost. Removing tailings from under a floor or foundation involves breaking up concrete to reach the tailings, a costlier and more complex procedure. For some buildings the cost of removing the tailings can exceed the value of the structure.

Air cleaning, improving ventilation, or sealing the pathways through which radon migrates indoors from tailings are active controls that are effective but they are not permanent and require maintenance. Air cleaning systems using standard electronic air filters have achieved a factor of ten reduction in radon decay product levels in test houses (Wi78) and in experimental rooms (Ru81). Electronic air cleaners do not remove radon from the air but do remove decay products with about an 80 percent efficiency. To attain a factor of 10 reduction in radon decay product levels, about 5 house-volumes of indoor air per hour must be circulated through the electronic air filter, requiring a few hundred watts of electricity for fan power. Circulation through an efficient filter can provide reductions in radon decay product levels (Ru81) similar to electronic air cleaners, but increased fan power is required.

Doubling ventilation rates will typically reduce radon levels in half and decay product levels somewhat more. Even larger increase in ventilation will reduce radon and radon decay products levels proportionately. With windows and doors closed, the ventilation rate in the average house is between 0.5 and 1 air changes per hour. Opening several windows and doors will increase the house ventilation rate several-fold. Comparable increases in ventilation can also be achieved by forced ventilation supplied by exhaust fans and whole-house fans.

Increased ventilation is a practical control measure during temperate seasons when heating and cooling systems are not in use; at other times, the cost of energy to heat or cool a few house-volumes of air per hour is prohibitive. At such times of year selective ventilation of unheated basements and crawl spaces may still be practical. Some forced ventilation of the living space may also be practical if air-to-air heat exchangers are used to recapture heat from the exhausted air. Such devices can recycle up to 70 percent of the energy which would otherwise be wasted.

Identifying and sealing pathways of radon entry does not require the operation of equipment, but the long-term effectiveness of sealants is not known. Therefore, we assume periodic inspection and repair will be needed. Common routes of entry are cracks in the foundation slab and walls, gaps in utility penetrations of the foundation, and channels inside hollow concrete blocks which often are used for foundation walls. Cracks and gaps can be caulked to prevent radon entry. Pathways in hollow blocks can be eliminated somewhat less successfully by filling the block walls with grout. These and similar measures have been used with some success in both Elliot Lake, Ontario (DS80), and in the phosphate region of central Flordia (DS81).

In summation, removal of tailings is the only permanent remedial measure and generally is the most effective. However, where indoor gamma exposures are not high, active controls can be equally effective or, in some cases, more effective at much lower cost. This is especially true when radon decay product levels are within a few standard deviations above normal average indoor levels. Active measures do not reduce gamma radiation, however.

5.4 Remedial Measures for Contaminated Lands and Offsite Properties

The methods of land cleanup are somewhat different for land near piles compared to offsite properties, so we will cover them separately. The tailings near piles have usually been transported by wind and water erosion, while the distant tailings have been transported by people for use as fill, soil additives, and other purposes.

5.4.1 Land Near the Tailings Pile

There are two distinct control measures: disposal and limitation of access. The first requires removal of all contaminated soil and disposal of it along with the rest of the pile. For most sites this involves scraping off the first few inches (occasionally feet) (Ha80, Fo76-78) of earth from several dozen acres around the pile. Removal of deeper contamination, from water erosion and leaching will require additional heavy equipment such as backhoes, scrapers, and tractors. This will generally involve a much smaller area than for windblown contamination. The use of earthmoving equipment to clean up a tailings site is documented in a recent report (Hab80).

The second control measure is to limit access to and use of contaminated areas. This must include stabilization of the surface to prevent further spreading of contamination, the construction and maintenance of fences, a monitoring program to monitor and prevent the spread of contamination, and withdrawal of land from productive use for an indefinite period of time.

5.4.2 Land Distant from the Tailings Pile

For offsite properties distant from the pile, where tailings have been misused (over 6500 have been identified), the only feasible control measure is to remove the tailings (with hand tools or earthmoving machinery) from the properties and transport them back to the tailings piles or other approved control areas. Some of these properties clearly pose a present or potential hazard. One example would be a highly contaminated property where people spend a large amount of time, or which potentially could be a site for a new building or an addition to an existing building. In other places, offsite contamination causes no significant present or potential hazard. Examples are tailings under public sidewalks or used as fill around sewer lines.

The recovery of tailings (used in the construction of sidewalks, driveways and sewer lines, for example) is often costly and may require destruction and reconstruction actions. Topsoil may have to be used to replace tailings that have been used in gardens and yards. Vegetation may need to be replaced after tailings are removed.

Chapter 6: COSTS AND BENEFITS OF ALTERNATIVE STANDARDS FOR CONTROL OF TAILINGS PILES

6.1 Alternative Standards for Control of Tailings Piles

We have investigated six alternatives for standards to control tailings piles (one is EPA's proposed standard of January 9, 1981 (46 FR 2556)). Each is analyzed in terms of representative control methods that should reduce to the desired level the radiological and toxic chemical hazards from tailings piles and from tailings deposited on contiguous property. The methods, as well as their costs and effectiveness, vary over wide ranges.

Three basic philosophical approaches are taken in the development of alternative standards:

1. Provide minimum acceptable health protection and rely primarily on institutional controls, incurring the least cost.

2. Rely on optimizing benefits versus costs and provide longer term health protection without using institutional controls. The costs for this optimized cost-benefit approach would be somewhat higher.

3. Provide the best control reasonably achievable and prevent any degradation of the environment. Costs are substantially higher.

The Proposed Standard and Standard A are best characterized as nondegradation alternatives; B and C are optimized cost-benefit alternatives; D and E are least-cost alternatives.

All of the standards have three principal objectives:

1. To prevent erosion and misuse of tailings for long periods of time.

2. To limit radon emissions from the surface of the pile.

3. To control the amount of degradation of water quality.

TABLE 6-1. ALTERNATIVE STANDARDS FOR CONTROL OF URANIUM MILL TAILINGS

Alternative	Principal Requirements: Minimum Time That Controls Should Prevent Erosion and Misuse (years)	For Radon Emissions from Top of Pile (pCi/m^2s)	For Water Quality Protection
No standards	None (radioactivity decays to 10% in 265,000 years)	No limit (The average emission is 500 pCi/m^2s)	None (Toxic chemicals in tailings at concentrations 100 times background)
EPA Proposed Standard	1,000	2 above background	No increased concentration of toxic chemicals
Alternative A	1,000-10,000	2 above background	No degradation that would prevent present uses
Alternative B	200-1,000	20	Guidance, based on water quality criteria
Alternative C	Indefinite, long-term	100	Guidance, based on water quality criteria
Alternative D	Durable cover; 100-year institutional control; discourage moving of piles	No requirement	Prevent significant erosion of tailings to surface water or groundwater, or treat water before use.
Alternative E	Minimal cover to prevent windblown erosion only; 100- to 200-year institutional control; move only piles in immediate danger due to floods	No requirement	No protection required

In Table 6-1, we show, for each alternative, the requirements selected to meet these objectives. Most of the requirements are expressed quantitatively, and in combination they achieve the overall objective of reducing risks to people from tailings.

The entry entitled "No standards" in Table 6-1 represents the present situation, the conditions to be expected if nothing is done (see Chapter 3). The piles will remain hazardous for a long time, taking about 265,000 years for the radioactivity to decay to 10 percent of present levels. The radon emission rate from an average pile is approximately 500 pCi/m^2s, compared to the background rate for typical soil surfaces of 0.2 to about 1.8 pCi/m^2s. While we have little indication that degradation in water quality has already taken place, we do know the concentration of some toxic chemicals in the tailings to be hundreds of times the background levels in ordinary soils, so that the potential for contaminating water is present and continues indefinitely.

The Proposed Standard. The Proposed Standard specified that control measures should limit radon emissions and water pollution for at least 1,000 years. Thus, controls are designed so there is reasonable expectation that the measures undertaken to stabilize the piles and to prevent any degradation of water quality will remain effective for at least that long. The proposed radon emission limit is 2 pCi/m^2s (above background).

Alternative A. Control measures are designed to be effective for 1,000 to 10,000 years. The radon emission limit is 2 pCi/m^2s above background and the quality of water is to be maintained so that present usage can continue. For water quality, this is less stringent than the requirement in the proposed standard, since water quality can be degraded, but not to the point at which contamination levels would be inconsistent with the present uses of the water.

Alternative B. In this alternative, the longevity requirement is reduced to 200 to 1,000 years. The radon emission limit is increased to 20 pCi/m^2s. Measures are recommended to help assure that applicable water quality criteria are met.

Alternative C. The number of years over which the integrity of control measures shall be designed to be maintained is not specified, but controls should remain effective for an "indefinite time." The radon emission limit is increased to 100 pCi/m^2s. Measures are recommended to help assure that applicable water quality criteria are met.

Alternative D. This alternative consists of qualitative requirements. A durable cover is specified to be applied to the piles, so that only reasonable maintenance is needed to maintain the cover for 100 years. Moving the piles is specifically discouraged. No radon emission limit is specified. Erosion that leads to contamination of surface or ground water must be prevented, or contaminated water must be treated before it is used, whichever costs less.

Alternative E. This alternative requires sufficient cover to control windblown erosion only, with the integrity maintained for a period of 100 to 200 years. Radon control is not required, and there is no protection required for surface water or ground water.

6.2 Control Methods Selected for Each Alternative Standard

Our purpose is to estimate the cost and benefits of each standard. Though we make every effort to provide realistic estimates, we are most concerned about the accuracy of relative costs and benefits. Therefore, all assumptions were applied consistently to the various control methods chosen.

In this section a specific combination of control methods is chosen to meet the requirements for each of the alternative standards (Table 6-1). Numerous combinations of control methods (which we discussed in Chapter 5) could be devised for satisfying each alternative standard, so we have attempted to pick least-cost options relying on standard construction methods. A detailed explanation of how these costs were estimated is presented in Appendix B.

The length of time that control measures must maintain their integrity determines how they are engineered. As we increase the time we want the controls to last, control measures tend to become more massive and expensive. The following are examples: For longer protection against floods and erosion, piles can be designed with more gradually sloped sides; but this requires additional grading and more earth cover. Dikes can be added to give long-term stability against floods. For greater resistance to erosion and floods, earth covers can be made thicker and an additional rock cover can be added. Large rock can be used rather than small rock to provide better protection against weathering and the pressure of floods. (Large rock is also less likely to be stolen).

The control methods selected for each alternative standard are summarized in Table 6-2. The cover materials are clay, earth, and rock, which are widely available and have low unit costs compared to processed materials such as cement, asphalt, and plastic compounds. Flood protection is provided through embankments or dikes, with riprap on sides that are vulnerable to floods.

Under the most protective alternative (A), we estimate that as many as 12 piles may have to be moved; 9 because of the likelihood of flooding and an additional 3 because of their proximity to population centers (see Chapter 3). If a pile is moved, it is assumed that the new site will not be vulnerable to flooding and, thus, no embankments will be needed for flood protection, but vegetation and rock covers are provided to resist erosion. No ground water protection measures are provided, because we assume that the selected new sites avoid this hazard.

TABLE 6-2. CONTROL METHODS SELECTED FOR EACH ALTERNATIVE STANDARD

Alternative	Control Methods: Stabilization: Maximum Slope of cover (Horizontal:Vertical)	Stabilization: Thickness of Cover (Clay) (m)	Stabilization: Thickness of Cover (Earth) (m)	Add Rock Cover: Thickness of Cover Sides (m)	Add Rock Cover: Thickness of Cover Top (m)	Add Vegetative Cover	Maintain Access Control and Repair Cover	Provide Flood Control Measures (Number of Sites)	Move the Pile (Number of Piles)
EPA Proposed Standard	5:1	0.6	3	0.33	None	Top	No	0	9
Alternative A	8:1 (Most stable)	0.6	3	0.5	0.15	None	No	0	12
Alternative B	4:1	None	3	0.33	None	Top	No	6	3
Alternative C	5:1	None	1	0.33	0.15	None	Yes[a]	1-6	3-8
Alternative D	3:1	None	0.5	0.15	0.15	None	Yes	3	1
Alternative E	3:1 (Least stable)	None	0.5	None	None	Slopes & Top	Yes	0	1

[a]Limited to fencing.

EPA Proposed Standard. The sides of the piles would be contoured to a 5:1 slope. The tailings piles are to be covered with 0.6 meters of clay and 3 meters of earth, and the earth on the slopes would be stabilized with a cover of 0.33 meters of rock, with the top of the pile planted with indigenous vegetation. The upper 0.33 meters of earth on the tops of the piles should be a rocky soil that would provide protection in case the vegetation fails. To prevent erosion by floods, nine piles are to be moved; at the new sites, pits will be dug, the tailings placed in the pits, and the excavated earth used to cover the tailings.

Alternative A. The sides of the piles would be contoured to an 8:1 slope and the tailings piles are to be covered with 0.6 meters of clay and 3 meters of earth. The earth on the slopes and the tops would be stabilized with covers of 0.5 and 0.15 meters of rock, respectively. To prevent spreading by floods, nine piles are moved. Three additional piles are moved because of proximity to people. At the new sites, pits are to be dug, the tailings are to be placed in them, and the excavated earth would be used to cover them.

Alternative B. In this option the tailings would be graded to a 4:1 slope, and the entire tailings piles would be covered with 3 meters of earth. The earth on the slopes would be covered with 0.33 meters of rock and the tops planted with local vegetation. Approximately the upper 0.33 meters of earth on the tops of the piles would be a rocky soil to provide rock covers in case the vegetation fails. Flood protection embankments are to be provided at six of the vulnerable sites. Ground water and flood protection is to be achieved for the other three piles by moving them to new sites. For these piles, pits are to be excavated at the new sites, tailings put into the pits, and the excavated material used as covers.

Alternative C. The sides of the piles are to be contoured to a 5:1 slope and the entire tailings piles would be covered with 1 meter of earth. The slopes are to be stabilized with 0.33 meters of rock; the tops with 0.15 meters of rock. The number of piles requiring flood protection would vary from one to six, depending on further examination of the flooding risk and the number of piles to be moved. The number of piles to be moved varies from three to eight, depending on further evaluation of the risk of flooding. For piles that are to be moved, earth would be excavated to serve as a cover material for the disposed tailings. The disposal site would be fenced, and the fence maintained for an indefinite period.

Alternative D. The sides of the tailings piles would be contoured to a 3:1 slope and the entire piles covered with 0.5 meters of earth. A 0.15-meter rock cover is to be placed on the tops and the slopes. Special flood protection, using dikes or protective embankments, would be provided at three sites. The tailings would be moved from one site to provide flood protection. The disposal sites would be fenced and maintained for 100 years.

Alternative E. The sides of the tailings piles would be contoured to a 3:1 slope and the piles covered with 0.5 meters of earth. The tops and slopes of the pile are then to be covered with vegetation, and an irrigation system installed to provide wind and water erosion control. One pile would be moved to prevent spreading by floods. The disposal sites are to be fenced and maintained for 100 to 200 years.

6.3 Costs of the Control Methods

Cost estimates were made by considering the control costs for two model tailings piles, a "normal" pile representing the 17 larger designated piles and a "small" pile representing the remaining 7 small piles. These costs were then scaled to generate the cost for all piles combined. We developed cost estimates for two sizes of piles because of the disparity in the sizes of the piles covered by the remedial action program. Details of the unit costs and other assumptions are in Appendix B.

The costs of in-place control and for moving and control at a new site, for both the normal pile and the small pile, are shown in Table 6-3 (from Tables B-2 and B-3 in Appendix B.) These costs do not include overhead or contingencies.

The costs for each control method, estimated for all the designated sites, are shown in Table 6-4. These costs are derived from Table B-4 in Appendix B; they include a 50-percent allowance for the costs of engineering, overhead, profit, and contingencies. The final total also includes DOE's estimated cost for overhead to administer the entire program. DOE does not expect this overhead to vary significantly for any of the alternatives considered.

6.4 Risk of Accidents When Carrying Out Control Methods

One of the costs of control is the possibility of accidental deaths during the installation of control methods and when moving tailings. Table 6-5 shows our estimate of the number of accidental deaths that could be associated with each tailings alternative standard. In general, more than half of the deaths are occupationally related--accidental deaths of workers and premature, radiation-induced deaths of construction workers at the tailings sites. The balance are, for the most part, accidental deaths to members of the public occurring while tailings are being transported.

There are two important parameters in this simplified analysis of the number of occupational and accidental deaths associated with controlling tailings. The first is the number of person-hours of labor required to do the job. This was used to estimate the number of construction-related deaths, as well as the number of premature deaths from radiation exposure. The second is the number of truck-miles traveled over public roads to move tailings to new sites or to bring cover and other materials to the sites.

TABLE 6-3. ESTIMATED 1981 COSTS OF CONTROL METHODS FOR TWO MODEL URANIUM MILL TAILINGS PILES

Alternative	Control Onsite (millions of dollars)		Move and Control at New Site (millions of dollars)	
	Normal Pile	Small Pile	Normal Pile	Small Pile
EPA Proposed Standard	4.9	1.2	11.0	1.0
Alternative A	7.0	1.6	12.6	1.2
Alternative B	2.9	0.7	10.1	0.9
Alternative C	3.0	1.0	9.8	1.3
Alternative D	2.2	0.8	8.9	1.2
Alternative E	1.7	0.7	8.6	1.2

Table 6-4. ESTIMATED 1981 COSTS FOR CONTROLLING URANIUM MILL TAILINGS PILES[a]
(in Million of Dollars)

Alternative	Cost of Control Method					Overhead & Contigency Costs	DOE Overhead Costs	Total Costs
	Cleaning up Sites	Controlling Piles	Adding Embankments	Moving Piles[b]	Subtotal Costs			
EPA Proposed Standard	35	91	(0)	43. (9)	169	85	118	372
Alternative A	35	129	(0)	56 (12)	221	110	118	448
Alternative B	35	55	6 (6)	21 (3)	117	58	118	294
Alternative C1[c]	35	58	1 (1)	42 (8)	136	68	118	322
Alternative C2[c]	35	58	6 (6)	20 (3)	120	60	118	297
Alternative D	35	43	3 (3)	7 (1)	88	44	118	250
Alternative E	35	34	(0)	7 (1)	76	38	118	232

[a]Numbers in parentheses are the number of piles to which the control method applies.
[b]Portion of total cost that is attributable to moving piles to new disposal sites.
[c]The distinction between Alternatives C1 and C2 is in the number of piles moved rather than protected in place with embankments.

The labor required for piles that are to be controlled onsite is proportional to the amount of earthmoving to be done; a gradual slope requires more earthmoving than a steep slope, roughly in proportion to the ratio of the slopes, and a thick cover requires more earthmoving than a thinner one. Based on figures from a DOE contractor (DeW81), we estimated that Alternatives D or E would require about 30 person-years of labor for a large pile. If we adjust this for different slopes and different cover thicknesses (assuming a 25-percent increase for each additional meter of cover), the labor requirements for Alternatives C, B, A, and the Proposed Standard are 60, 75, 150, and 100 person-years, respectively. When a pile is to be moved, the labor requirements at the disposal site are about the same as for Alternatives C, B, and A, but there is an additional labor need of about 50 person-years at the original tailings site.

The labor requirements to control all the piles under the various alternatives are summarized in Table 6-5. The occupational deaths resulting from this are estimated from mortality statistics for the construction industry: 60 deaths per 100,000 worker-years (NS78). This corresponds to 6×10^{-4} accidental deaths per person-year.

Radiation-induced deaths are difficult to estimate since it is impossible to anticipate measures that might be used to protect workers. However, in the worst case, the gamma radiation exposure rate over a bare tailings pile (typically 1 mrem/h) for a working year would lead to exposures of about 2 rem/y. Inhalation of radon decay products would, at most, lead to a comparable risk. In Table 6-5, we have assumed that the maximum risk of premature, radiation-induced death is equivalent to the risk from an exposure of 4 rem (whole-body equivalent) of gamma radiation per person-year of labor.

The transportation deaths in Table 6-5 were calculated by assuming that, when a pile is moved, it is transported in 12-yd^3 trucks to a site 10 miles away. For a 1.1 million cubic-yard pile of tailings, roughly 1.8 million truck-miles are logged. Using a figure of 0.7×10^{-7} deaths per truck-mile among drivers and the public (DOE80a), we estimated 0.13 deaths for each pile moved. We have not estimated deaths from the transport of cover materials, since most of these materials will be obtained close to the disposal site and, therefore, do not entail a great deal of travel over public roads. Their bulk volume is also small compared to the volume of a tailings pile.

6.5 Advanced Control Methods

There are other control methods in addition to those considered here. One is the use of a soil cement cap over the tailings. The soil cement is made from the tailings. We have analyzed the costs and benefits of a 6-inch soil cement cap over the sides and top of the piles with a 1 meter earthen cover protected by rock. The costs and benefits of this method are about the same as those achieved by Alternative B. This method is more fully discussed in Appendix B.

TABLE 6-5. ESTIMATED ACCIDENTAL DEATHS ASSOCIATED WITH ALTERNATIVE STANDARDS

Alternative	Large Piles to be Moved		Accidental Deaths to Workers at Tailings Sites	Radiation-Induced Deaths to Workers	Transportation Deaths (Workers & Public)	Total Deaths
	Number	Labor (person-years)				
EPA Proposed Standard	7	2000	1.2	0.6	0.9	2.7
Alternative A	10	3000	1.8	0.9	1.3	4.0
Alternative B	3	1400	0.8	0.4	0.4	1.6
Alternative C	3	1200	0.7	0.3	0.4	1.4
Alternative D	1	600	0.4	0.2	0.13	0.7
Alternative E	1	600	0.4	0.2	0.13	0.7

Other control methods were not included in the cost-benefit analysis because of their high costs and our limited knowledge of their long-term environmental impact. These methods are: nitric acid leaching for the removal of hazardous material, burial in nearby strip mines, burial in underground mines, and thermal stabilization. If their costs were not prohibitive, nitric acid leaching and thermal stabilization could significantly reduce the hazards from contaminants in the tailings. In addition to the high costs of burying the tailings in strip mines and underground mines, the tailings may contaminate ground water. These control methods have been briefly described in Chapter 5. Their costs are more fully discussed in Appendix B.

6.6 Benefits Associated with the Alternative Standards

The benefit we are best able to estimate is the number of adverse health effects averted by radon control. We can estimate the reduction in radon emissions resulting from the placement of earthen cover, and we can translate radon emissions reduction into health effects averted by using models for estimating the health effects from inhaling radon (see Chapter 4). Therefore, the benefits of radon control are quantifiable in number of adverse health effects averted and in reduction in risk to persons residing closest to the piles.

Most of the other benefits from controlling the tailings piles are not quantifiable, although the goal is well defined: the reduction of health risks from exposure to the hazardous materials contained in the tailings. For example, we are unable to translate flood protection measures into the number of health effects averted. The missing linkages are: (1) the translation from flood protection measures to flood damage averted; (2) the translation from flood damage to quantities of tailings spread along the downstream river valley; and (3) the translation from the tailings spread along the river valley to the number and degree of exposures. There are similar problems with quantifying the chance and consequences of misuse and the permanence of control, i.e. the years of erosional spreading avoided, and the years of water quality protection, and the consequences avoided.

Our estimates of benefits for each alternative have been listed in Table 6-6. Benefits are quantified when we are able to do so. The benefits of each of the options are measured against the status quo; that is, no remedial action on the tailings piles themselves and no cleanup of the mill sites and mill buildings.

Benefits of Stabilization

We have characterized the benefits of stabilizing the tailings piles in terms of the reduced chance of misuse, the permanence of controls for inhibiting misuse, the years of erosional spreading avoided, and the reduction in vulnerability to floods. The number of health effects averted cannot be estimated.

TABLE 6-6. BENEFITS DERIVED FROM CONTROLLING URANIUM MILL TAILINGS PILES

Alternative	Benefits of Stabilization				Benefits of Radon Control			Benefits of Protecting Water
	Chance of Misuse	Permanence of Control Against		Number of Sites Vulnerable to Flooding	Residual Risk of Lung Cancer (% reduction)	Deaths Avoided		Surface Water Protected (years)
		Misuse (years)	Erosional Spreading (years)			In first 100 years	Total	
No standards	Most likely	0	0	9	3 in 10^2 (0)	0	0	0
EPA Proposed Standard	Very Unlikely (Thick cover)	>1000	Many thousands	0	1 in 10^4 (99.7)	200	Many thousands	Many thousands
Alternative A	Very Unlikely (Thick cover)	>1000	Many thousands	0	1 in 10^4 (99.7)	200	Many thousands	Many thousands
Alternative B	Very Unlikely (Thick cover)	>1000	Many thousands	0	1 in 10^3 (97)	190	Many thousands	Many thousands
Alternative C	Unlikely (Medium cover)	1000	Thousands	0	6 in 10^3 (80)	150	Thousands	Thousands
Alternative D	More likely (Thin cover)	100	Hundreds	5	1.5-3 in 10^2 (less than 50)	100	800	Hundreds
Alternative E	More likely (Thin cover)	100-200	Few hundred	8	1.5-3 in 10^2 (less than 50)	100	600	Few hundred

The major benefit of stabilizing a pile is the prevention of the hazards associated with human intrusion and misuse of the tailings piles; this can be expressed only in qualitative terms. We have estimated, as best we can, the number of years that control is anticipated to inhibit misuse. This ranges from greater than 1,000 years for the Proposed Standard and Alternatives A and B, to 1,000 years for Alternative C, 100 to 200 years for Alternative E, and 100 years for Alternative D. The likelihood of misuse during the period of effectiveness of these options ranges from "very unlikely" for the proposed standard and Alternatives A and B to "more likely" for Alternatives D and E.

The Grand Junction cleanup program is an example of the kind of expensive remedial actions that stabilization should prevent. The tailings in Grand Junction buildings are now being cleaned up at a cost of about $23 million to avoid an estimated 75-150 lung cancer deaths. The additional cost of cleaning up contaminated offsite land is estimated at $22 to $31 million.

A second benefit of stabilization is the prevention of erosion. Erosion of existing piles over the last 20 to 30 years has contaminated about 4,000 acres of land which now cannot be used for most purposes. Depending on the cleanup standards (see Chapter 7), this will cost about $10 million to clean up (or $0.3 to $0.5 million per year of erosion). If piles are not stablized, long-term erosion would necessitate repeated cleanups or indefinite restrictions on land use. Controls needed to prevent erosion are less strict than controls to prevent misuse; therefore, erosion is usually controlled longer than misuse for a given alternative.

The benefit of preventing tailings erosion can be expressed in a semiquantitative way by estimating the number of years that erosional spreading is prevented. Protection from erosion is estimated to range from a few hundred years for Alternative E to many thousands of years for the Proposed Standard and Alternatives A and B. Since erosion is now taking place, benefits can be derived from any remedial measure that reduces erosion.

A third benefit of stabilization is to prevent floods from washing tailings downstream to flood plains, where land use is residential and agricultural. Should this happen, very expensive remedial measures would probably be needed. A recent tailings "spill" (failure of a dam containing a tailings pile at an active mill) in the Southwest contaminated hundreds of acres of land (of limited value) over a distance of about 20 miles. We estimate the cost of cleanup of that spill to be $1 million to $5 million, depending on the cleanup criteria used. The total radioactivity spilled was less than 5 percent of that in an average inactive pile.

Although the benefits of having tailings piles resistant to flood damage cannot be directly measured, we can estimate the number of piles vulnerable to floods under each of the alternatives. Benefits of protection from flood damage are then quantified as the number of piles that would be moved from a flood-prone area and the number of cases in which dikes would be constructed around piles left in place. We estimate that nine of the inactive sites are now vulnerable to long-term floods. One tailings pile, on the side of a bluff overlooking a river, is considered so vulnerable that it is to be moved under all options. The number of sites moved to reduce their vulnerability to floods is one for Alternatives D and E, three for Alternative B, three to eight for Alternative C, and nine for the Proposed Standard and Alternative A. Under Alternative E, none of the eight remaining sites vulnerable to floods are diked; under Alternative D, three of those sites are diked.

Benefits of Radon Control

The estimated benefits of radon control can be quantified (under certain assumptions, as described in Chapter 4). A total of 200 lung cancer deaths from radon emissions from all tailings piles is estimated to occur in each 100 years, continuing for many tens of thousands of years, unless remedial actions are undertaken. Re- medial actions taken under the Proposed Standard and Alternative A will avert virtually all of these cancer deaths for many thousands of years, and Alternative B provides about 96-percent protection for nearly the same period of time. The number of deaths averted is less with the other options, decreasing to approximately 100 for Alternatives D and E. The total deaths averted in the future is estimated to be many thousands for the Proposed Standard and Alternatives A and B but will be lower for the other options, decreasing to approximately 600 for Alternative E.

A second benefit of radon control is the reduction of risk to nearby individuals. The maximum risk of death from radon emissions to the persons living near the piles is estimated to be 1.5 to 3 chances in 100 for Alternatives D and E, 6 in 1,000 for Alternative C, 1 in 1,000 for Alternative B, and 1 in 10,000 for the Proposed Standard and Alternative A.

Benefits of Protecting Water

Measures to safeguard water quality are of benefit because they prevent toxic and radioactive contamination. We cannot quantify the number of health effects averted, but we have attempted to estimate the benefit of each option in terms of the number of years water will be protected. EPA's Proposed Standard and Alternatives A and B should provide thousands of years of protection. The least amount of protection, a few hundred years, is provided by Alternative D.

6.7 Summary of Benefits and Costs

We have analyzed the benefits and costs of the control methods that satisfy the basic objectives of six alternative standards. In Tables 6-4, 6-5, and 6-6, we show that the least costly standards provide the fewest benefits and that benefits increase with higher costs. The following is a summary, beginning with the least restrictive.

Alternative E. The objective of this standard is to prevent wind erosion for a period of 100 to 200 years. This would provide some protection against erosion from water runoff, but there is no protection from floods for eight of the nine piles believed to be vulnerable. One tailings pile is to be moved because of its high vulnerability to floods. This option provides no control of radon emissions or protection of water quality.

This least protective control method uses thin covers of earth held in place by vegetation that must be irrigated. Sites are to be fenced. For an indefinite period this method relies on institutional controls such as regular inspection and repair of the cover and fence, operation and management of the irrigation system, and periodic replacement of irrigation equipment.

The risk of lung cancer from inhalation of radon decay products is 1.5 to 3 in 100 for persons residing near the piles. An estimated 100 lung cancer deaths will be avoided in the first 100 years, and approximately 600 future deaths would be avoided in total.

The estimated cost is $232 million. We estimate that this alternative will lead to one accidental death of a worker or of a member of the public.

Alternative D. A thin earth cover and a minimum cover of rock hold surfaces in place. One pile will be moved. Embankments or dikes will protect the three other piles most vulnerable to floods. The rock gives the cover some durability but is not thick enough to reduce the likelihood of misuse. Misuse is prevented by institutional controls. Periodic inspections and repairs of the fence and cover are required. About 100 lung cancer deaths are avoided in the first 100 years, and about 800 future deaths would be avoided. There is some control of water quality. Measures to prevent erosion that might cause surface water or ground water contamination or to treat contaminated water are included.

The estimated cost of this alternative is $250 million. In carrying out the operations required under this option, we estimate that there would be one accidental death of a worker or of a member of the public.

Alternative C. This alternative provides thick cover, gradual slopes, and thick layers of rock on the slopes. The controls are durable, and the resistance to misuse is great. Some form of flood protection for all nine vulnerable sites would be provided by moving three to eight sites (depending on site characteristics) and adding embankments to the rest.

This alternative specifically limits radon emissions to 100 pCi/m^2s. The maximum risk of lung cancer from radon to the nearest resident is 6 in 1,000; 150 lung cancer deaths are averted in the first

100 years, with thousands of deaths averted in the future. Recommendations are made for adequate water protection.

These benefits would cost about $300 million. Between one and two accidental deaths of workers or of members of the public are predicted to occur in carrying out operations to put this alternative into effect.

Alternative B. Control methods under this alternative provide thick earth covers but allow relatively steep slopes on the sides of the piles. Thin rock covers on the slopes and vegetation on the tops of the piles are to be used. No irrigation would be provided, so vegetation must be indigenous. No fence is required, and no institutional controls are necessary. This method provides good resistance to misuse, good cover durability, and long-term erosion control. Nine piles are protected from floods, three piles are to be moved, and embankments are to be placed around the rest. Radon emissions would be limited to 20 pCi/m^2s above background. The risk of lung cancer for the nearest residents is to 1 in 1,000. About 190 lung cancer deaths would be avoided in the first 100 years, and the total future deaths averted are many thousands. Water quality protection recommendations are made to provide adequate protection.

These benefits would cost about $290 million. Construction activities for this alternative are expected to result in between one and two accidental deaths of workers or of members the public.

Alternative A. The control method under this alternative uses clay caps on the tops of the tailings protected by thick earth covers, with relatively thick layers of rock over that. The maximum slopes are gradual, misuse is very unlikely, and the cover should last thousands of years. No fences are needed, therefore no institutional controls are required. Twelve piles are to be moved; nine are to be moved for protection from floods, three because they are close to population centers. The clay caps provide almost complete radon control. The radon emission limit is 2 pCi/m^2s. The risk of lung cancer to the nearest resident is reduced to 1 in 10,000; The number of lung cancer deaths averted in the first 100 years is 200. Many thousands of deaths are averted in the future. This alternative provides strict water pollution controls; no degradation in use is allowed.

This is a relatively high-cost alternative that allows virtually no degradation of the environment. The cost is estimated to be about $450 million. Under this alternative, we estimate that construction activities will cause four accidental deaths of workers or members of the public. It probably provides the best control achievable without burying the piles below grade.

Proposed Standard. Thick stable long lasting covers are provided. No fences or institutional controls are required. Nine piles vulnerable to floods would be moved but piles near population centers would not. There are 200 lung cancer deaths avoided in the first 100 years; many thousands are avoided in the future. No increased concentration of contaminants in surface and ground water is allowed.

The Proposed Standard Alternative is a high-cost alternative, with a cost of $370 million. There should be virtually no degradation of the environment. Construction activities are expected to cause three accidental deaths of workers or of members of the public.

Chapter 7: COSTS AND BENEFITS OF CLEANUP STANDARDS FOR BUILDINGS AND LAND CONTAMINATED WITH TAILINGS

In this chapter we discuss the costs and benefits of cleanup standards for buildings and land. Near-site contaminated lands and more distant offsite contaminated properties present different problems, and we consider them separately.

7.1 Cleanup Standards for Buildings

We have analyzed four cleanup standards for buildings with the objective of reducing indoor radon decay product concentrations and gamma radiation levels caused by tailings. All four standards reflect some balancing of costs and benefits.

High-cost standards that prevent any degradation of the environment were not considered. There are potentially a large number of buildings contaminated with small amounts of tailings where the contribution to indoor radon levels from the tailings is but a small fraction of the indoor radon levels from natural causes. It is not practical to locate these buildings (expensive and time consuming measurements are required). Furthermore, remedial measures applied to these buildings would realize very marginal benefits at high cost.

Least-cost standards were not considered because these leave large amounts of tailings in close proximity to people and unjustifiably high risks continue indefinitely, even after the buildings are torn down and replaced.

Each standard sets requirements for indoor radon decay products and gamma radiation levels and also specifies when active or passive control methods are advised. The indoor radon decay product concentration, measured in working levels, is used because it is a measure of the health hazard resulting from tailings misused in construction. We established a gamma radiation level criterion because gamma radiation is also a health hazard and occasionally gamma radiation levels are high even though the indoor radon decay product levels may be low.

Alternative Standards B1, B2, and B3 achieve a balance of costs and benefits primarily through the discretionary use of low cost active remedial measures when the criteria are only slightly exceeded. In B4, the balance is achieved by a flexible numerical standard which allows broad discretion as to whether to use remedial methods within a range of criteria. However, B4 does not permit the use of active measures.

Alternatives B1 and B2 are based on a single numerical decay product concentration above which remedial action is required. Alternatives B3 and B4 are based on two numerical decay product concentrations; for buildings exceeding the highest level, remedial action is required; for buildings exceeding only the lower level, action is optional but encouraged if cost effective.

The alternative standards for cleanup of buildings are as follows:

Alternative B1 (The EPA standard proposed in April 1980). Remedial action is required if a building contains tailings and the indoor radon decay product concentration exceeds 0.015 WL (including background). Tailings are removed (or active remedies applied when the level is only slightly exceeded) until the indoor level is below 0.015 WL (including background) or no tailings remain.

Alternative B2. Remedial action is required if a building contains tailings and the indoor radon decay product concentration exceeds 0.02 WL (including background). Tailings are removed (or active remedies applied when the level is only slightly exceeded) until the indoor level is below 0.02 WL (including background) or no tailings remain.

Alternative B3. Remedial action is required if a building contains tailings and the indoor radon decay product concentration exceeds 0.02 WL (including background). A building qualifies for possible remedial action at 0.005 WL (above background). Active controls are used when the required remedial action level is only slightly exceeded.

Alternative B4. Remedial action is required if a building contains tailings and the indoor radon decay product concentration is 0.05 WL (above background). A building qualifies for remedial action at 0.01 WL (above background). Active remedies are not used.

Alternatives B1 to B4. For each of the alternatives, exposure to indoor gamma radiation cannot exceed 20 microroentgens/h above background. (This should require the removal of tailings when large amounts are present but allow smaller amounts to remain when they do not contribute significantly to indoor radon.)

For each alternative, we show in Table 7-1 our estimates of the number of buildings in the United States requiring remedial action, cleanup costs, and health benefits. For B3 and B4, which include a range over which remedial action is optional, the cost estimates were derived by assuming a value within the range which would typically be achieved and costing controls to reach this level. For B3, we assumed that at least 0.015 WL (including background) would be achieved. For B4, we assumed that at least 0.03 WL would be achieved.

The extent of contamination of buildings as well as the cleanup costs will not be known in detail until the cleanup program is well underway. Therefore, we used the Grand Junction remedial action program as the basis for our estimates. Appendix B contains a summary of the Grand Junction experience and the cost calculations which support the estimates in Table 7-1.

The cost estimates for each alternative standard are determined by the number of buildings requiring remedial work and the cost per building. As the remedial action criterion is lowered, more buildings will need to be cleaned up, increasing costs. A lower criterion also increases the cleanup costs per building since this requires more complete tailings removal. In many cases, successive actions are needed when the first remedial action does not meet the cleanup criterion. Using active measures to meet a cleanup criterion when the level is only slightly exceeded is much cheaper than tailings removal, roughly one-tenth as costly.

The benefit of cleaning up contaminated buildings is expresed by the number of lung cancer deaths avoided. This is estimated by assuming the risk factors discussed in Chapter 4 are appropriate, an initial distribution of decay product levels in contaminated buildings identical to that for the buildings monitored in Grand Junction, a 50-year average useful life remaining for the stock of contaminated buildings, and a 3-person household size. Also, benefits of cleanup are expressed by the maximum residual risks to people living in the buildings. This risk to an individual is calculated assuming lifetime exposure to radon decay products at the highest level each alternative standard allows.

7.2 Alternative Cleanup Standards for Near-site Contaminated Land

We have analyzed four alternative cleanup standards for near-site (on the site or adjacent to the site) contaminated lands. All have requirements that limit the amount of radium contamination because the presence of radium is a reasonable index of the health hazard, including that due to toxic chemicals as well as other radionuclides.

Alternative L1 approaches a high-cost nondegradation alternative; below this proposed radium limit it is usually not possible, using conventional survey equipment, to accurately distinguish between contaminated land and land with high naturally-occuring levels of radium. Alternatives L2 and L3 approximate optimized cost-benefit standards, but L2 demands a more rigorous cleanup of the soil

TABLE 7-1. COSTS AND BENEFITS OF ALTERNATIVE CLEANUP STANDARDS FOR BUILDINGS (in 1981 dollars)

Alternative Standards	Radon Decay Product Limit (WL)[a]	Number of Buildings Requiring Cleanup[b]	Total Cost (millions of dollars)	Deaths Avoided (in first 50y)[c]	Estimated Residual Risk of Lung Cancer[d]
B1	0.015	370	11.5	65	0.8 in 100
B2	0.02	330	8.5	60	1.3 in 100
B3	0.005 (above background) to 0.02	420	9.0	65	1.3 in 100
B4	0.01 (above background) to 0.05 (above background)	350	9.5	55	5 in 100

(a) The specified value includes background unless otherwise noted. Background in Grand Junction is approximately 0.007 WL.

(b) See Section 3.4. For Alternative B4, which is identical to the Grand Junction criteria for action, we assumed the geometric mean of our two extreme estimates for the number of buildings requiring remedial action. Assuming the distribution of radon decay product levels will be the same as in Grand Junction, the number of buildings in the United States requiring action was adjusted for the other options.

(c) Based upon the relative risk model. Estimates based upon the absolute risk model are a factor of two lower. Health benefits attributable to reductions in gamma radiation levels are much smaller and have not been quantified.

(d) Lifetime risk to the individual living in a house at the radon decay product concentration limit. This risk is calculated after subtracting background from the level permitted by the standard.

surface. Standard L4 is a least-cost alternative that allows high radiation levels that are close to Federal Guidance recommendations for exposure of individuals to all sources of radiation excepting natural background and medical uses.

The four alternative standards are:

Standard L1. (The standard proposed in April 1980). Land should be cleaned up to levels not exceeding an average 5 pCi/g of radium-226 in any 5-cm layer within 1 foot of the surface and in any 15-cm layer below 1 foot of the surface.

Standard L2. Land should be cleaned up to levels not exceeding an average of 5 pCi/g in the 15-cm surface layer of soil, and an average of 15 pCi/g over any 15-cm depth for buried contaminated materials.

Standard L3. Land should be cleaned up to levels not exceeding an average of 15 pCi/g in any 15-cm depth of soil.

Standard L4. Land should be cleaned up to levels not exceeding an average of 30 pCi/g in any 15-cm depth of soil.

In Table 7-2 we list the estimates of the costs and benefits of each alternative standard for near-site contamination around inactive tailing piles. In each standard, the only remedial method for which we estimated cost was the removal and disposal of contaminated soil, since this is generally less costly than placing earth cover and vegetation over contaminated areas and excluding access by fencing. The benefits are expressed by (1) the number of acres of land that are cleaned up and returned to productive use, and (2) the typical maximum residual risk to individuals living in houses that might then be built on this land.

The number of acres requiring cleanup under each option was based upon the results of the EPA gamma radiation survey of twenty inactive mill sites (Table 3-4). By assuming a typical depth profile of the radium contamination, it is possible to relate the gamma radiation levels measured by the survey to the areas of land contaminated above a specific concentration level of radium. If the top 15-cm layer of earth is uniformly contaminated with 30 pCi/g of radium, the gamma field at the surface would be 63 percent of the gamma flux from an infinitely thick layer, or 34 microroentgens/hr (He78). However, if the 30-pCi/g average in the top 15 cm of earth is due to a thin surface layer of nearly pure tailings of a few hundred pCi/g, the resulting gamma radiation at the surface would be about 54 microroentgens/hr. Since we expect windblown contamination profiles to be somewhere in between these extremes, we estimate that, on the average, 44 microroentgens/hr above background (385 mrem/y) implies 30 pCi/g radium contamination in the top 15 cm of soil (Standard L4). Similar analyses for Alternative Standards L1, L2, and L3 result in 3. 7 and

TABLE 7-2. COSTS AND BENEFITS OF ALTERNATIVE CLEANUP STANDARDS FOR LAND (in 1981 dollars)

Alternative	Radium-226 Soil Concentration Limit (pCi/g)	Number of Acres Requiring Cleanup[(a)]	Total Cost (millions of) dollars)	Estimated Residual risk of Lung Cancer[(b)]
L1	5	2700	21	2 in 100
L2	5 to 15	1900	14	2 in 100
L3	15	900	7	6 in 100
L4	30	250	2	10 in 100

(a) Areas of land near inactive tailings piles that have radium contamination in excess of the soil concentration limit.

(b) The lifetime risk of lung cancer to the individual living in a house built on land contaminated to the limits allowed by the alternative standards. This is based on the relative-risk model; use of the absolute-risk model gives risks which are about a factor of two lower.

22 microroentgens/hr, respectively (or 26, 61, and 193 mrem/y, respectively). Additional deeper contamination would yield only slightly higher gamma values because of shielding by the surface layer.

Using these correlations between radium contamination levels and gamma radiation levels, the areas requiring cleanup under each standard were estimated based on the EPA survey data. The total costs of cleanup were then calculated assuming a cleanup cost of $7650 (1981 dollars) per acre. This cost was estimated from EPA field experience (a cleanup program at the Shiprock mill site) and is in agreement with cost estimates of DOE contractors. Areas of heaviest contamination, such as the ore storage area and mill buildings, are excluded from this analysis since we have included them in the analysis of disposal costs for the piles.

The highest risk to people living in houses built upon contaminated land is due to the inhalation of radon decay products from radon that seeps into the house. In the worst case, Standards L1 and L2 would allow thick-surface earth layers with 5 pCi/g contamination, while Standards L3 and L4 would allow thick layers of contaminated soil at 15 pCi/g and 30 pCi/g, respectively. On the average, houses built on such 5 pCi/g earth would be expected to have indoor radon decay product levels of about 0.02 WL. Houses with poorer-than-average ventilation would have higher levels, while well-ventilated houses would have lower levels. Houses built on land more heavily contaminated than 5 pCi/g would have higher average indoor decay product levels in proportion to the contamination. The estimated risks due to lifetime exposure from these levels are listed in Table 7-2. These are maximum estimates since most contaminated land away from the immediate mill sites (where houses might be built) has only thin layers (a few tens of centimeters) of contaminated material.

The gamma radiation levels to individuals permitted under the four alternative standards are 80 mrem/yr for L1 and L2, 240 mrem/yr for L3, and 470 mrem/yr for L4. This assumes a thick layer of contaminated material over a large area at the maximum permitted levels of radium concentrations. These doses would lead to increased risk of many kinds of cancer, but this increase would be small compared to the lung cancer risks due to radon decay products.

7.3 Alternative Cleanup Standards for Offsite Properties

Tailings on offsite properties which are not associated with building construction are usually there because someone transported them from a tailings pile. Examples of this kind of misuse are tailings used as fill around fence posts and sewer lines, as the basis for sidewalks and driveways, and as conditioners for soil in gardens. Most tailings misused in this way are still concentrated; they are not diluted by large quantities of earth or spread thinly over large areas.

The major hazard stems from the chance that indoor radon levels will be high in new buildings constructed on contaminated offsite properties. There could also be a significant gamma radiation hazard if people spend a lot of time close to the tailings.

We expect that offsite properties where tailings were misused will typically exceed all the radium concentration limits specified for land contamination in Alternative Standards L1 through L4. Therefore, virtually all of the 6500 contaminated sites identified in Chapter 3 would require cleanup under any standard. Based on engineering assessments and similar cleanup work near a mill site in Edgemont, South Dakota, we estimate it would cost $6,000 to clean up each of these properties. This implies a total cleanup cost of $39 million. However, many of these sites are unlikely to cause a significant present or future hazard, either because of their location or because the quantity of tailings involved is so small. Cleaning up such sites implies high cost without significant benefits.

It is consistent and simple to use the same numerical cleanup criteria for offsite contamination of properties as for near-site land contamination. Since some offsite contaminated properties present a minimal hazard and would cost a great deal to clean up to any reasonable radium concentration criterion, additional criteria are considered in one of the following alternative standards for contaminated offsite properties:

Standard P1: Offsite properties should be cleaned up to the same levels as near-site land,(1) with no exceptions.

Standard P2: Offsite properties should be cleaned up to the same levels as near-site land, with the following exceptions:

a. When contamination levels averaged over 100 m^2 are less than the action levels required for near-site lands.
b. When the hazard from the tailings is judged to be insignificant because of location.

Small amounts of tailings will be eliminated from consideration if levels are averaged over an appropriate area. For Standard P2 we have selected 100 m^2 as a reasonable area for this purpose since this is the typical area of the foundation of a house. Thus, risk levels allowed under Standard P2 should be no higher than the risks allowed under the corresponding near-site land cleanup standard. Additional sites will be eliminated under Standard P2 because of their location.

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(1) Alternative Standards L1, L2, L3, or L4; whichever is selected as a land cleanup standard.

Based on an analysis of misused tailings that are not associated with buildings (Section 3.4), we estimate that, because of location or small quantity, Standard P2 would not require the cleanup of minor locations such as under sidewalks or around fence posts. Also, we estimate that half of the garden beds, yards, and detached buildings in which tailings were used and one-fourth of all driveways with tailings under them would not require cleanup. This would eliminate approximately 4,000 sites and save about $24 million, for a total cost of about $15 million.

Chapter 8: SELECTING THE STANDARDS

In this chapter we compare alternative disposal standards for tailings piles, cleanup standards for buildings, and cleanup standards for land in light of the findings of Chapters 6 and 7. When reasonable to do so, these alternatives were chosen to span three approaches to environmental standards: nondegradation, cost-benefit, and least cost. We consider the relative benefits, costs, and other factors for these alternatives, and then select preferred standards.

In the preamble to the Act Congress stated the finding that tailings "...may pose a potential and significant radiation health hazard to the public [and] that every reasonable effort should be made to provide for stabilization, disposal, and control in a safe and environmentally sound manner...in order to prevent or minimize radon diffusion into the environment and to prevent or minimize other environmental hazards from such tailings." The Environmental Protection Agency was directed to set "...standards of general application for the protection of the public health, safety, and the environment" to assure that these objectives will be met.

The Committee report accompanying the Act expressed the view that remedial actions should be effective for more than a short period of time. It stated that "The committee believes that uranium mill tailings should be treated...in accordance with the substantial hazard they will present until long after existing institutions can be expected to last in their present forms," and that "The Committee does not want to visit this problem again with additional aid. The remedial action must be done right the first time." (H.R. Rep. No. 1480, 95th Cong., 2nd Sess., Pt. I, p. 17, and Pt. II, p. 40 (1978).) In addition to considering benefits, costs, and other factors, we reviewed the alternatives in the light of these views.

Our analysis of the hazards from tailings shows that they arise mainly from tailings that have been removed from piles by people and used in or near buildings and from radon emissions to the outdoor air from the piles. In addition, long-term weathering of unprotected piles will spread tailings, thereby increasing radon emissions and contaminating nearby land. Environmental contamination also can occur if radioactive or toxic chemicals from tailings enter surface or underground water, although the potential for this depends strongly on individual site characteristics. Floods could spread tailings over river valleys at some sites. All of these hazards will persist for an almost indefinite time. The total benefits from controlling tailings will depend, therefore, on the length of time disposal remains effective.

Some parts of the standards address control of more than one of these hazards. For example, a standard requiring control measures that substantially reduce radon emissions from tailings piles will also inhibit wind and water erosion. Furthermore, durable covers are generally thicker and more difficult to penetrate than covers designed to last for only a relatively short period of time, so that a standard for longevity of disposal is related to the likelihood that tailings will be removed for inappropriate uses. Such relationships should be borne in mind in the following discussions of alternative standards.

8.1 Standards to Control Tailings Piles

In Chapter 6 we selected three types of criteria with which to specify standards to control tailings piles. These are longevity of disposal, the radon emission limit, and measures to protect water quality. When these are chosen, all of the various hazards from tailings are controlled to some degree.

8.1.1 Longevity of Control

By longevity we mean the minimum period of time that tailings piles are required to be stabilized. In general, barriers would be placed between the tailings and the environment to accomplish this; the longer the specified time, the thicker, more massive, and more conservatively designed would be the barrier. Also, the longer the time specified the more likely it becomes that the implementing agencies would find it necessary to place primary reliance on passive rather than active control measures.

We have concluded that standards that specify periods longer than 10,000 years would be impractical. Providing a reasonable expectation of compliance over such long periods, if possible at all, could be done only by burying the tailings several hundred feet or more beneath the earth's surface, where long term changes are likely to be gradual and predictable, or in shallow pits in exceptionally favorable locations. For reasons described in Chapters 5 and 6, deep burial of uranium tailings is not usually practical. However, if standards were to apply for 10,000 years or more, no other disposal method appears to be adequate.

In Chapter 6 we considered six alternative standards for longevity:

a) 1,000-10,000 years (Alternative A),

b) at least 1,000 years (Proposed Standard); or, for an indefinitely long time (unspecified) of at least 1,000 years (Alternative C),

c) 200-1,000 years, relying primarily on passive control methods (Alternative B),

d) an unspecified long time, relying on active control methods for the first 100-200 years (Alternative D), or

e) 100-200 years only, relying primarily on active methods (Alternative E).

These alternatives can be viewed as either performance or design standards. Compliance with performance standards is verified by monitoring and assured through maintenance. We do not believe it is reasonable to rely on performance standards for more than one or two centuries. Therefore, alternatives that specify longer time periods must be viewed as design standards. That is, the designers of a control system would plan it to last for the required period with "reasonable assurance" by considering the physical properties of the disposal system and the environmental stresses to which it would be subjected.

In order to estimate the relative benefits of the different alternatives, we have assumed that any control system will be at least partially effective for longer than the minimum design period. As indicated in Table 6-6 we expect the total benefits to be much greater under the Proposed Standard and Alternatives A, B, and C than under Alternatives D and E, since systems relying heavily on institutional controls would probably degenerate more quickly when care is no longer required.

It appears technically feasible to isolate most tailings piles for at least 1,000 years on the earth's surface. The primary threat to stabilization during this period is flood damage. Engineering methods for protecting tailings against floods are available. These engineering methods, however, may not be applicable at every inactive site, and they do not remain effective indefinitely. The longer the time for which flood protection is required, the more likely it is that piles will have to be moved to safer sites. As the longevity requirement is increased, we postulate that more tailings piles would have to be moved to new sites to provide reasonable assurance that surface control will remain effective. Moving piles increases the total costs of control rapidly. This general trend is reflected in Table 6-2.

Prevention of Misuse of Tailings

We have seen (Chapters 3 and 4) that the most significant hazard is the potential for misuse of tailings in or near buildings. We presume tailings will continue to be attractive indefinitely to people for such purposes if they are unaware of or unconcerned about the hazard. However, we do not consider standards containing criteria that directly address misuse to be practical. Instead, we address the issue through the implied access-inhibiting properties of methods needed to satisfy the criteria for degree of longevity of disposal and radon control.

The Proposed Standard and Alternatives A and B require a high degree of longevity and radon control. This is most likely to be achieved through use of thick earthen covers. As we noted in Chapter 5, thick earthen covers should significantly discourage unauthorized access to the tailings. Furthermore, tailings under thick covers are unlikely to be exposed inadvertently by people who dig into the cover for other reasons.

Alternative C incorporates a requirement for long-term integrity of the tailings control system, with emphasis on protection against floods. The less stringent radon emission limit, however, can be satisfied with relatively thin covers that would provide little security against intruders. Depending on other site-specific requirements, there may not be sufficient stabilization of the cover provided (e.g., rock cover) to constitute a significant barrier to intrusion without resorting to active (institutional) controls.

In Alternatives D and E control is designed to last for only a few centuries, and depends upon use of cheaper active measures. The physical properties of the required cover would provide virtually no protection against intrusion.

Prevention of Erosional Spreading of Tailings

All the alternatives control wind and water erosion to some degree. The major difference among the alternatives is the length of time over which erosion is prevented. The costs, too, depend on longevity because the longevity criterion determines the degree of resistance of the cover to erosion, and, therefore, the quantity and quality of cover material that must be used.

The Proposed Standard and Alternatives A through C would control erosion effectively for periods much longer than the minimum longevity requirements. Alternative D is a non-numerical standard requiring a durable surface on the pile and any needed maintenance for 100 years. It would therefore include control of wind and water erosion of tailings for at least 100 years, but for an uncertain period of time beyond. Alternative E requires surface stabilization for a period of 100 to 200 years. Occasional small releases of tailings due to spontaneous or gradual localized containment failures should be expected; otherwise, this alternative would be tantamount to a much longer longevity requirement, because methods that prevent localized releases for 100-200 years would be generally effective for much longer. Under Alternative E, minor breaks in the cover are assumed to be repaired periodically over a period of 100-200 years.

8.1.2 Control of Radon Emissions

The six alternatives analyzed in Chapter 6 specify four radon emission control levels:

a) to emission rates near background (2 pCi/m^2s) (Proposed Standard and Alternative A),

b) to 20 pCi/m^2s (Alternative B),

c) to 100 pCi/m^2s (Alternative C), or

d) no requirement (Alternatives D and E).

Under Alternatives C, D, and E, radon concentrations in air above the tailings and for some distance around each site would not meet Federal standards for unrestricted access by the general public. NRC regulations, based on Federal Radiation Protection Guides, specify that members of the general public shall not be exposed to radon concentrations greater than 3 pCi/liter. Therefore, monitoring and land-use restrictions would be needed for adequate public health protection under these alternatives. The Proposed Standard and Alternative A would reduce radon emissions so that such restrictions would be unnecessary. Under Alternative B, radon emissions from the piles would be of concern only under the most unfavorable circumstances (residency on the tailings).

Under the Proposed Standard and Alternative A, emissions from the tailings piles would be reduced by more than 99 percent. This would eliminate most of the risk to nearby individuals as well as most of the cumulative effects on populations. Alternative B would reduce emissions by 96 percent, resulting in a maximum individual risk of about one in a thousand. Alternative C would reduce emissions by 80 percent, but the maximum risk to nearby individuals would be about 1 in 200. Alternatives D and E do not directly limit radon emissions, but the surface stabilization required should reduce emissions by about 50 percent, leaving a maximum individual risk of a few parts in 100.

Costs of Limiting Radon Emission

Since longevity, radon emission, and water protection requirements differ among the alternatives, it is not possible to isolate the costs of radon emission control alone. For example, if all other aspects of controlling tailings piles are held constant, we estimate the total cost of applying 1 meter of earth to all 24 piles to be $18.5 million.

From Figure 5-1 we can determine how much radon emission would be reduced by adding one meter of earth. If the only benefit of thicker covers were to reduce radon emissions, we would find the cost-effectiveness of each additional meter of earth to be considerably less than that of the first meter. But thick covers have additional benefits: they last longer than thinner covers and are barriers against intrusion. Therefore, the net benefits of reducing radon emissions cannot be isolated.

The disposal cost analysis in Chapter 6 applies only under the stated assumptions. If local earth near a pile is very sandy, or if suitable earthen materials are not available nearby, then satisfying the Proposed Standard and Alternative A, which have the strictest radon emission control level, could require several additional meters of cover. Conversely, if earthen materials are more easily available or of higher quality (i.e., clays) than is assumed, the costs will be lower. Because of the lack of full-scale disposal experience, however, there is a greater risk of the cover requirements for the Proposed Standard and Alternative A being significantly underestimated than for Alternatives B through E.

NRC (NRC80) has evaluated the potential environmental impacts of obtaining cover materials in regions where uranium is mined. As a rule, the environmental impacts will be greatest for the Proposed Standard and Alternative A, less for Alternative B, and least for Alternatives C through E. Even under relatively unfavorable conditions, however, the effects are largely temporary; the longest-lasting effects are changes of topography at borrow sites for the cover material. This issue is highly site-specific, however, and definitive information on the environmental effects of obtaining cover materials at the 24 inactive sites is not yet available. We expect such effects will be small overall, but the Proposed Standard and Alternative A are the most likely to cause significant temporary environmental disturbances.

Form of the Radon Standard

We have expressed the radon limit in terms of the release rate per unit area from the tailings. However, a number of alternative criteria could be used to control radon emissions from the piles:

a) dose rate limits for individuals or populations, (mrem/y, person-rem/y, person-WLM/y),
b) radon concentration limits in air (pCi/l),
c) total radon release rate limits (pCi/s), and
d) release rate limit per unit area (pCi/m^2s).

Because short-term fluctuations are unimportant, we will consider all of these as annual averages. Radon emissions from tailings to the air cannot be separated from those from a cover or normal land, however. Therefore, a standard using any of these criteria must apply to either the total radon release rate from the surface of a pile or to the radon release rate from tailings with allowance being made for the radon from the cover and other land. These alternative criteria are discussed briefly below:

a) Dose or exposure rate standards for individuals can be related directly to risk. They could be satisfied by restricting emissions or by restricting occupancy in areas where the standards might be exceeded. Such standards would permit flexible implementation and might be inexpensive in practice because they can be satisfied by land-use restrictions rather than physical control. Limits on population dose would be hard to implement, however, because of relatively high-cost continuing data-gathering and modeling requirements. Whether for individuals or populations, dose rate standards require calculating or measuring quantities that may be small compared to natural background values. Such standards would need oversight by the implementing agency for as long as the standard applies, unless the disposal permanently reduces radon emissions to levels at which no restrictions on occupancy would be ever needed. We rejected these approaches as impractical for this long-term hazard.

b) Radon concentrations in air are easily measured but highly variable and unpredictable, and it is difficult to distinguish the radon coming from piles from the natural radon background. A practical standard would have to be significantly higher than normal background levels, and, therefore, could apply only very close to the tailings, where it would still be a highly variable quantity, subject to a variety of meteorological parameters. We rejected this alternative as offering no advantage over criterion d, which is more closely related to the total emission of radon.

c) A standard that limits the total radon release rate from each pile would not take into account significant differences among the piles. Piles of different areas would need different thicknesses of cover material to meet the standard. This alternative would place unreasonable control requirements on large piles or permit inadequate cover on small piles to control individual dose and discourage intrusion. Furthermore, the total radon release rate must be estimated from the release rate per unit area (criterion d, below).

d) A limit on release rate per unit area can be applied uniformly to all sites. It is also the most meaningful criterion for comparing the emissions of a pile with that of normal land. It is, however, relatively difficult to measure and varies considerably with location on the pile, climate, time of day, and other factors. The release rate per unit area can be estimated, however, from the radium and moisture contents of a pile and its cover (NRC80, Mob79), averaged over suitable times and areas.

As indicated above, checking compliance with these standards by direct measurements could be very difficult. This reinforces our belief (see Section 8.1.1) that compliance should be demonstrated through the design rather than the performance of the tailings control system.

8.1.3 Protection of Groundwater Quality

Since most inactive uranium processing sites are in dry climates, much of the water that may ever infiltrate them has already done so during the operating period of the mill. However, some tailings piles are in contact with groundwater during periodic elevations of the water table, and one pile is located in a wet climate. Nonetheless, although studies of the inactive sites are inconclusive, they provide little evidence that radioactive and nonradioactive toxic substances are moving from any of the piles to groundwater. Elevated levels of toxic substances have been found in wells near some active mills, but seepage pathways from the tailings ponds are not always unequivocally implicated (UI80). Further, seepage is much less at inactive sites, and there is evidence that geochemical mechanisms help prevent many contaminants from entering groundwater (Mac81a).

Groundwater is used for drinking, irrigating crops and watering livestock, and industrial purposes. Existing national water quality standards for these uses apply to surface waters and public drinking water supplies. There are also no national standards for some uses of water containing certain potentially hazardous substances found in tailings, such as molybdenum and uranium.

Disposal standards for protecting groundwater near inactive uranium mill sites must be considered, therefore, in the context of uncertain hazard and incomplete regulatory precedents.

Alternative Approaches to Groundwater Protection

In Chapter 6, we analyzed four basic approaches to protecting groundwater:

a) nondegradation: establish standards to protect water of drinking quality and do not increase toxic levels of lower quality water (Proposed Standard);

b) highest use: establish standards to protect the highest use for which water is potentially suitable (Alternative A);

c) site-specific: do not establish general standards, but require site-specific determinations of potential hazards and uses, and

   1) preventive action, guided by State and Federal criteria and other requirements (Alternatives B and C), or

2) prevention of significant water movements from tailings to groundwater or treatment of any contamination at the point water is used, depending on which method is less costly (Alternative D); or

d) no standards: do not address groundwater protection (Alternative E).

These approaches refer to the long-term potential of tailings piles to contaminate groundwater after disposal. We discuss the possibility of remedial actions for previous releases from the piles in Section 8.1.5.

Nondegradation

The nondegradation approach (Proposed Standards) is the most protective we consider. After a tailings pile is disposed of, concentrations of specified toxic contaminants in groundwater could not (1) exceed the safe level for drinking water, or (2) increase, if these levels are already exceeded. The standards would apply to aquifers that now supply drinking water and others in which the concentration of total dissolved solids is less than 10,000 milligrams per liter. The requirements would apply 1 km from tailings disposed of at an existing site, or 0.1 km from a tailings pile moved to a new site.

Most of the specified contaminants are inorganic substances covered by the National Interim Primary Drinking Water Regulations (NIPDWR) (EPA76b). Uranium and molybdenum, which may have serious toxic effects on humans, animals, or plants, are abundant in tailings and expected to be environmentally mobile, but are not covered by the NIPDWR. This deficiency requires us to determine human health protection levels for these substances, which we believe could be widely misinterpreted and applied as equivalent to new Primary Drinking Water Regulations. Since PDWR are based on toxicity, prevalence in water systems, practicality of analytical methods, and treatment costs, such confusion would be unfortunate. Standards for public drinking water supplies have much larger health and economic significance than standards for controlling uranium tailings at the 24 inactive mill sites.

A nondegradation approach would be very restrictive. Water that is already highly contaminated would be protected from further degradation without regard to its usefulness, and without site-specific consideration of the benefit of water protection measures that may be very costly. However, tailings piles disposed of in accordance with the "nondegradation" standard should not cause groundwater "problems" for people in the future, whereas one cannot be as sure that more lenient standards will be adequately protective.

Any approach depending on generally applicable numerical standards may be difficult to implement at certain sites because our ability to perform hydrological assessments is limited. Studies of active mills suggest that uranium processing sites are often difficult to characterize hydrologically. For some sites in dry climates "reasonable assurance" that a numerical standard will be satisfied may be based on a simple water balance analysis--i.e., a showing that there is no net downward flow through the tailings. More complex analyses may be needed when groundwater is in contact with the tailings, or where the climate is wet. However, state-of-the-art analyses may not be sufficiently conclusive to avoid specification of very expensive disposal methods, such as moving piles to new sites and/or installing liners, because the complete absence of a significant threat to groundwater cannot be demonstrated.

Highest Use

Groundwater would be protected for the highest use for which it is potentially usable. Standards would be needed for various uses. As indicated above, there are national standards (the NIPDWR) for drinking water quality, but they do not cover molybdenum and uranium. EPA has also published water quality criteria (NAS72, EPA76c) that provide a basis for standards for different water uses; molybdenum and uranium are not covered. All States have adopted either narrative or numerical surface water quality standards under the Clean Water Act, but most do not cover uranium and molybdenum. These numerical standards also vary. Therefore, while there is a framework for establishing standards based on use, there is no single or complete set of standards that can be directly applied to groundwater near uranium mill tailings.

The "highest use" approach has the same effect as the nondegradation approach for groundwater that meets or exceeds the quality required by the NIPDWR, as both would permit degradation to the NIPDWR limits. However, for water of lesser quality, the "highest use" approach is more flexible. It permits degradation so long as the usefulness of the water is not impaired. If the existing water quality is marginal for some use, then it permits no increase in the concentration of the substances whose concentrations are already marginal for that use, but concentrations of other substances may increase. Under this approach, however, other pollution sources may combine with tailings effluents to degrade the usefulness of groundwater resources.

It may be easier to implement a highest use approach than a nondegradation approach. Similar techniques are needed, but the required analytic precision is less.

Site-Specific Approaches

Under this approach, EPA would provide guidance, but the primary responsibility for determining groundwater protection requirements would rest with the implementers. Providing such guidance recognizes that general numerical groundwater standards may not be needed for this program, that they are difficult to establish, and possibly difficult to implement.

Under the first alternative for this approach, the guidance would reference relevant precedents, but emphasize protecting groundwater rather than treating it after the fact. The implementers would have discretion to decide what constitutes adequate groundwater protection, subject to the requirements of NEPA (National Environmental Policy Act), existing State and Federal water quality criteria, and consonant with the objectives of the EPA regulations under the Solid Waste Disposal Act, as amended. Remedial actions at designated sites will be selected and performed by DOE with the concurrence of NRC and the full participation of any State that pays part of the cost (Section 108 of the Act). Therefore, basic site-specific decisions on groundwater protection under this alternative would be made jointly by several parties, all having access to EPA's general guidance, and subject to public review under NEPA.

The Act authorizes EPA to revise its remedial action standards for inactive sites "from time to time." If further investigation of the tailings sites revealed considerable real or potential groundwater pollution, then EPA could issue generally applicable standards to supplement the guidance. EPA is currently developing general groundwater protection policies, especially for its remedial action and disposal programs for hazardous materials under the Solid Waste Disposal Act, as amended, and the Comprehensive Environmental Response Compensation and Liability Act ("Superfund"). If the need should be demonstrated, these policies, when adopted, could provide the basis for groundwater protection standards under this Act.

A second site-specific approach is a narrative (non-numerical) prescription to provide the lowest cost remedies for any groundwater use that may be affected by contamination from tailings. The implementers would have discretion regarding the manner and degree of remedy, subject to the least cost criterion. They would decide the significance of any contaminant movements in groundwater and determine adequate treatment levels for various water uses. Under this alternative there would be no specified limit on the degree to which tailings could contaminate an aquifer, provided users of the water could be compensated at a cost lower than that for preventing the contamination. For example, if water treatment is not economic, substitute water sources could be provided.

Since the extent of future use may be difficult to estimate, the total cost of treating contaminated water may be impossible to determine. The current costs of avoiding contamination might be higher than the apparent treatment costs, yet, over a long time, cumulative prevention costs might be lower. In addition, as noted in Chapter 5, physical control methods (prevention) are assumed to be more reliable over a long term than institutional methods (treatment).

No Standards

Under this approach EPA would not issue standards or guidance for protecting groundwater. This would be justified by concluding that tailings piles at inactive sites are not significant sources of groundwater contamination or that remedial actions to satisfy other aspects of the standards would adequately protect groundwater. Such a conclusion would be controversial. (Controlling radon emissions with impervious covers, for example, would keep rain water from flowing into a tailings pile. However, any contamination resulting from direct contact of tailings with groundwater would not be affected by a cover.)

The approach might simplify or complicate the remedial action program, resulting in either cost and time savings or increases, depending on site-specific circumstances. The implementers might determine, for example, that groundwater protection assessments need not be performed and successfully defend any attempt by others to reverse that decision. On the other hand, they might determine that such assessments are necessary to comply with NEPA. If a potential for groundwater pollution were found, the implementers would not have available either EPA standards or guidance.

8.1.4 Protection of Surface Water

Wind, rain, or floods could carry tailings into rivers, lakes, and reservoirs. Pollutants may also seep out of piles or rise to the surface and form toxic salt deposits. However, streams and rivers near inactive uranium processing sites show very little contamination from the (unstabilized) tailings piles. We expect any effects of stabilized piles on surface water will be even less for as long as they remain stabilized, since stabilized tailings will not be able to release particulates to wind or water.

Seepage and salt deposits emerge from the piles gradually and are periodically swept away (diluted) by rainfall. Such releases will not necessarily have significant consequences, but they could adversely affect the quality of nearby bodies of standing water, such as ponds. However, there are only a few such ponds at the designated sites and remedial actions can eliminate them or provide protective land contours.

Severe floods could spread large quantities of tailings into standing and flowing water, with possibly serious, though unevaluated, consequences. A requirement to stabilize tailings for a long period of time would provide good assurance that they not be subject to severe damage by such floods.

As long as disposal standards require surface stabilization that includes protection against flooding of sufficient longevity, the need for specific surface water protection standards appears marginal.

In Chapter 6 we analyzed four basic approaches to protect surface water:

a) nondegradation: prevent increases in concentration of any toxic substance in surface water (Proposed Standard);

b) highest use: protect surface water for the highest use for which it is potentially suitable (Alternative A);

c) site-specific:

   1) provide guidance for avoidance of contamination based on existing water quality criteria and other regulations (Alternatives B and C), or,
   2) require avoidance of significant water movement from tailings to surface water (Alternative D); or

d) no standards: do not address surface water protection (Alternative E).

The nondegradation approach formed the basis for the Proposed Standards. The surface water requirements of that standard would require any potentially harmful contaminated water from the tailings to have a lower concentration of contaminants than the surface water it entered. This requirement would apply to all harmful contaminants, some of which are present only in very low concentrations in surface water. This would require very strict control of releases to surface water of at least these substances. Thus, this approach could require avoidance of even insignificant releases to any surface water, regardless of its usefulness.

The "highest use" and "site-specific" approaches would have essentially the same advantages and disadvantages as discussed for groundwater under Section 8.1.3. The "no standards" approach could be justified if no surface water contamination is possible when other aspects of the standards are satisfied. However, the possibility of toxic salt migration to the surface of tailings piles and subsequent contamination of unprotected nearby bodies of standing water would not be addressed.

8.1.5 Remedial Action for Existing Groundwater Contamination

There is evidence of limited existing groundwater contamination at a few of the inactive sites. In Chapter 5 we referred to case studies of remedial actions for hazardous waste disposal sites that have leaked contaminants to their surroundings. We conclude that the practicality of such remedial actions must be determined site by site. The Department of Energy will prepare environmental impact statements or environmental assessment reports for each site to support its decisions, with NRC's concurrence, on control methods. We expect DOE to consider the need for and practicality of controlling contaminants that have already seeped into the ground and to apply technical remedies that are found justified. Institutional controls should also be considered. If tailings are found to be contaminating groundwater that is being used, we would expect DOE to consider providing alternate water sources or other appropriate remedies. However, although it may sometimes be practical to improve the quality of an already-contaminated aquifer, we believe a generally applicable requirement to meet preset standards is not feasible.

The Act will terminate DOE's authority 7 years after we promulgate standards, unless Congress extends the period. However, Section 104(f)(2) of the Act provides for Federal custody of the disposal sites under NRC licenses after the remedial action program is completed. The custodial agency is authorized to carry out such monitoring, maintenance, and emergency measures as the NRC may deem necessary to protect public health. We expect NRC's requirements will be sufficient to ensure detection of any contamination of usable groundwater near the disposal sites, and to cause the custodial agency to take such measures as may become necessary to avoid any significant public health problem for the duration of the hazard.

8.1.6 The Preferred Standard for Control of Tailings Piles

The preferred standard is Alternative B (See Table 6-1, page 128). The longevity requirement is 200 to 1,000 years. Radon emissions are limited to 20 pCi/m^2s. Control measures would be selected by the implementing agencies on a site-specific basis so that relevant water quality criteria and other guidance are met to protect ground and surface water.

The longevity and radon emission requirements combine to assure that tailings control systems will have durable covers that should inhibit unauthorized access to the tailings[(1)] and prevent tailings erosion by wind and floods. The radon emissions limit would reduce the risk of lung cancer to low levels and permit unrestricted use of lands adjacent to the disposal sites. The implementing agencies would assure that any water protection issues that may arise at individual sites will be resolved in the public's interest.

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(1) We note that Sec. 104(h) of the Act anticipates authorized uses of subsurface minerals at a tailings disposal site. It provides, however, that any tailings disturbed by such use "will be restored to a safe and environmentally sound condition." We propose, therefore to apply the disposal standards to restoration of a site following the use of any subsurface mineral rights acquired under the provisions of Sec. 104(h).

We believe the Proposed Standard and Alternative A present greater technical difficulties and costs and a higher risk of substantial unplanned costs than are necessary or wise for this remedial action program. The "nondegradation" standards would provide only marginally greater benefits than Alternative B. Alternatives D and E, on the other hand, do not require remedial actions that would yield significant benefits, although such remedial actions can be carried out for relatively small incremental costs. Tailings would remain subject to dispersal by flood and misuse by people. That is, Alternatives D and E require only short-term partial control of this long-term problem, and far more permanent and effective controls are available for small incremental costs. Alternative D would also be difficult to codify and to implement because its requirements are vague.

We prefer a radon emission standard to other forms of standards because of its direct relation to the cover requirements for tailings. More so than for alternative forms of standards, the radon release rate measures the quality of stabilization, the degree misuse is inhibited, and the reduction of the risk for nearby individuals and the cumulative risk for populations.

We prefer Alternative B to Alternative C because it provides significantly greater protection against intrusion and radon emissions at no increased cost. This is achievable primarily through substituting costs of more substantial cover and inplace flood protection for costs of moving piles to new sites to avoid highly improbable floods.

8.2 Standards For Cleanup of Buildings

Tailings that have been used in or around buildings are particularly hazardous and may cause indoor radon decay product concentrations that may be many times normal indoor concentrations. Thus, we conclude that a standard should specify the maximum allowable radon decay product concentration in buildings affected by tailings. The standards should also specify gamma radiation levels because tailings can cause high indoor gamma radiation levels without necessarily causing high radon decay product concentrations.

8.2.1 Previous Indoor Radon Standards

Government agencies of the United States and Canada have published several remedial action criteria for radon decay product concentrations in buildings. The following brief review is provided to clarify their relationship to the alternative standards in Chapter 7.

The U.S. Surgeon General's 1970 remedial action guidance for Grand Junction, Colorado, applies to buildings on land contaminated with uranium mill tailings (Pea70). EPA's guidance for the State of Florida applies to buildings on radium-bearing phosphate lands (EPA79a). Each of these guides has two radon decay product levels that specify the following: 1) above an upper level, action is required; 2) below a lower level, action is not required; 3) between these levels, local considerations must be used to determine the appropriate action.

The Surgeon General's Guides are implemented by 10 CFR 712, the Department of Energy's regulations for remedial action at Grand Junction, Colorado. In effect, they adopt the lower level as an action level for remediation of schools and residences, and the midpoint between the lower and upper levels as an action level for other buildings. This difference recognizes that people occupy residences and commercial buildings for different periods and that children should have added protection. When radon decay product concentrations are expressed in working levels (WL), these action levels are 0.01 WL and 0.03 WL, respectively, above background. The average indoor background determined by DOE for Grand Junction's remedial program is 0.007 WL.

Canadian cleanup criteria (AEB77) and EPA's recommendations for residences on phosphate lands in Flordia call for remedial action when indoor radon decay product concentrations are greater than 0.02 WL (including background). The EPA guidance further recommends that concentrations below 0.02 WL be reduced as low as can be reasonably achieved, but that reductions below 0.005 WL above the average normal background (0.004 WL in Florida) are not generally justifiable. In summary, EPA has recommended remedial action in Florida above 0.02 WL, stated that action is generally unjustified at concentrations less than 0.009 WL, and left the degree of action at intermediate levels to the judgment of local officials.

8.2.2 Indoor Radon

In Chapter 7, we analyzed four alternative criteria for indoor radon in buildings:

a) an action level of 0.015 WL, including background (the Proposed Standard, also called Alternative B1);

b) an action level of 0.02 WL, including background (Alternative B2, similar to the Canadian criterion);

c) a mandatory action level of 0.02 WL, including background; cleanup would be discretionary for levels between 0.005 WL above background and 0.02 WL including background (Alternative B3, similar to EPA's guidance for Florida phosphate lands); and

d) a mandatory action level of 0.05 WL above background; cleanup would be discretionary for levels between 0.01 WL above background and 0.05 WL above background (Alternative B4, similar to the Surgeon General's guidance for Grand Junction, Colorado).

The costs of meeting these alternatives were analyzed under a variety of assumptions regarding remediation methods. The results (Table 7-1) indicate that the costs and benefits of all the standards are approximately equal. Even though these results are not definitive, because the analysis was based largely on experience in Grand Junction where conditions may be different from those to which these standards will apply, feasibility of implementation and health risk appear to be the most significant factors when choosing between the alternatives, not cost. We also believe that the maximum risk permitted under Alternative B4 is unacceptably high.

Effect of Variations in Background Radiation on the Choice of a Standard

Indoor radon decay product concentrations in normal buildings vary widely. Because of fluctuations in normal indoor radon levels, it is often impossible to tell when small amounts of tailings are present unless they can be detected by other means, such as through gamma radiation measurements. Further, contaminated buildings vary in location, design, materials, and patterns of use, all of which affect indoor radon decay product concentrations. It is usually impractical to determine the background level for a particular building, either from measurements of unaffected buildings or by any other means. For these reasons, an action level expressed in terms of an increment over the background radon decay product concentration cannot be implemented easily.(1)

The closer the standard is set to median background levels, which in the western and northeastern United States appear to range from 0.004 WL to 0.008 WL, the less effective will be remedial actions for marginally contaminated buildings. In addition, an action level of 0.005 WL above "background" would often require remedial actions where tailings are not the principal source of indoor radon. This is because indoor radon levels in buildings that are not affected by tailings vary from typical values by more than 0.005 WL (see Table 3-7). Thus, efforts to reduce radon decay product levels by removing tailings would not work well, and the money would be wasted. Even where tailings are

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(1)As Table 3-7 shows, the background level of 0.007 WL determined for use in the Grand Junction program is simply the median of measurements of many buildings in Grand Junction that varied from 0.002 to 0.017 WL. The median background of 0.004 for the Florida phosphate guidance was determined from measurements of similar houses in a particular locale; the measurements varied from 0.001-0.012 WL. For the inactive uranium processing sites program, where the affected buildings are located in 10 States, any single "background" number would be very unrepresentative, and determining the average background separately for each affected community would be impractical.

not the major cause of elevated radon levels, however, ventilation and filtration devices would be effective in reducing radon decay product concentrations.

A standard specifying the total concentration level of radon decay products (including background) would have the advantage of providing the same action level for all affected buildings, even though background concentrations in one affected area may be higher than in another. When the standard level is above the typical range of variations in background levels, the standard would be simple and definite.

Appropriate Remedial Measures for Buildings

Remedial methods vary in the degree they assure long-term reductions in radon decay product concentrations. When risks are high, it is reasonable to provide a greater degree of assurance by using remedial methods that will not lose effectiveness if not maintained by the building residents. Removing tailings from buildings permanently reduces indoor radioactivity levels and cleans up the sites. Filtration and ventilation devices, and other relatively low cost remedial methods, whose long-term effectiveness depends on maintenance, can provide reasonable assurance of compliance at a much lower cost when the standard is only slightly exceeded.

8.2.3 Indoor Gamma Radiation

Tailings also emit gamma radiation. In general, we expect that the indoor radon decay product standard will usually be met by removing tailings from buildings and that this will eliminate any indoor gamma radiation problem. However, in unusual cases (such as a building that contains tailings, but is very well ventilated) a standard limiting gamma radiation exposure may be needed. An action level for gamma radiation of 0.02 mR/h above background[(1)] would allow flexibility in the choice of methods for reducing indoor radon decay product concentrations. Reducing this much below 0.02 mR/h would virtually eliminate flexibility in remedial methods and provide only a small additional health benefit to those few individuals who might be affected. If the occupants of a building were present 75 percent of the time, a level of 0.02 mR/h would allow gamma radiation doses from tailings of about 130 mrad per year. This would allow about twice the average annual background dose from gamma radiation in the regions where most of the piles are located.

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(1) Indoor background levels of gamma radiation are easier to determine and less variable than radon decay product concentration backgrounds.

8.2.4 Preferred Cleanup Standard for Buildings

The most desirable cleanup standard for buildings would draw elements from several of the alternatives analyzed. We conclude that indoor radon standards should be expressed in terms of the total concentration of radon decay products, including background, because this quantity is unambiguous and does not require measuring each community's background levels. Indoor gamma radiation standards should be expressed in terms of the increment above background, however, because gamma radiation is an important tool in detecting the presence of tailings, and the background level in a building is relatively easy to determine.

Our preferred cleanup standard for buildings has the following characteristics:

Tailings would be removed from buildings having indoor radon decay product concentrations above 0.03 WL. All practicable efforts should be made to reduce concentrations further to within 0.02 WL by any available means, including the use of relatively low cost air cleaning and ventilation devices. Indoor gamma radiation exposure should not exceed 0.02 mR/h above background.

Such a standard would require removal of tailings when indoor radiation levels are well above normal background levels. Removal is generally the mostly costly remedial method, however, so the standard would permit the use of other remedial methods for reducing radon decay product concentrations below 0.03 WL. We believe remedial actions are generally not warranted where radon concentrations are less than 0.02 WL, because tailings removal at these levels would often be ineffective and very costly, and active remedial devices are more likely to be required just to reduce background levels than for radon byproducts from tailings.

Such a cleanup standard for buildings would require the implementing agencies to reduce the occupants' exposure to radiation from tailings to the lowest reasonably achievable level and to provide reasonable assurance that the building sites will not pose hazards for future replacement buildings.

8.3 Standards for Cleanup of Land

Uranium mill tailings from inactive sites have been spread by wind, water, and people, thereby contaminating both nearby and distant land. The hazard this poses to people is most conveniently related to the concentration level of radium-226. Tailings on nearby lands usually result from erosion and are now mixed with soil. They may also occur at various depths. Therefore, a standard should specify the concentration of radium-226 in soil (pCi/g), the depth of soil over which this concentration criteria should be averaged (cm), and the thickness of the contaminated layer covered by the standard. Tailings on distant lands were carried there by people for use, usually as fill. These tailings were typically used without dilution with other material, and there are now small deposits of tailings at many thousands of locations.

8.3.1 Alternatives for Cleanup of Land

The greatest hazard from tailings on open land is due to the possibility of increased levels of radon decay products in future buildings built upon the land. Exposure to direct gamma radiation and contamination of drinking water and food may also occur, but generally this is of less concern.

In Chapter 7 we analyzed four alternative cleanup criteria for radium-226 concentration in contaminated land near a tailings pile:

a) 5 pCi/g in any 5 cm layer within one foot of the surface and in any 15 cm layer below one foot (the Proposed Standard, also called Alternative L1);

b) 5 pCi/g for surface deposits, 15 pCi/g for buried materials, both averaged over 15 cm layers (Alternative L2);

c) 15 pCi/g averaged over 15 cm layers, whether on or below the surface (Alternative L3);

d) Same as "c," but 30 pCi/g (Alternative L4).

For distant lands, where tailings were likely to have been misused in concentrated form, we considered two additional criteria:

e) use the same criteria as for nearby land (Alternative P1);

f) use the same criteria as for nearby nearby lands with the following exceptions (Alternative P2):

    1) when contamination levels averaged over 100 m^2 are less than the action levels required for offsite lands; and

    2) when the hazard is judged to be not significant because of the location of the tailings.

We found that the projected maximum residual risk under all the alternatives is undesirably high (see Table 7-4, for example), but is particularly high for Alternatives L3 and L4. However, this maximum risk is unlikely to occur, fot several reasons. First, we estimated the risk by assuming that the highest acceptable radium concentration persists deeply. In reality, tailings spread by erosion tend to remain on the surface of the ground. Second, people usually clear a construction site in some manner, which would further reduce the amount of residual tailings underneath a new building.

In view of these considerations, we believe that significantly elevated radon levels in buildings on open land are unlikely to occur under Alternatives L1 and L2. Elevated indoor radon levels are more likely under Alternatives L3 and L4, and the residual gamma radiation levels around the building would be high.

Cleanup costs for contaminated land adjacent to tailings piles vary considerably for Alternatives L1 through L4. However, for Alternatives L3 and L4, the lowest cost alternatives, people would incur high risks from living in houses built upon land contaminated to the maximum allowed by the standard. Furthermore, these alternatives would be in conflict with the existing Federal radiation exposure guidance of 500 mrem/y for an identifiable individual, and 170 mrem/y for a group of persons not individually monitored.

EPA sought the opinion of an ad hoc group of radiation measurement experts on the implementation of soil cleanup standards. Their report (EPA81) indicates that portable field survey instruments can be useful tools in implementing the surface contamination portions of Alternatives L1 through L4. This would be important to minimize remedial action costs. Subsurface contaminants can only be detected by measurements in bore holes or on samples of subsurface material. This is a relatively slow and expensive process, but it can be performed with currently available techniques for any of the alternatives. There is need for this only where there is reason to believe that tailings may be buried.

Form of the Land Cleanup Alternatives

We expressed the alternatives in terms of a radium concentration after considering the following options:

(1) radium concentration levels,
(2) gamma radiation levels,
(3) radon release rates,
(4) predicted radon decay product concentrations in buildings.

All these would restrict residual radiation hazards, but with the following advantages and disadvantages.

(1) Radium concentration is directly related to the hazard of most tailings. (Occasionally it is not sufficient where other specific radioactive or toxic elements in uranium ore processing residues have been concentrated.) Quantities (2), (3), and (4) result directly from the radium in tailings.

(2) Gamma radiation levels can be conveniently measured, but they are related to only part of the hazard. Tailings that are covered with a few feet of earth could satisfy a gamma radiation standard, yet be hazardous to build upon because of radon emissions.

(3) Radon emission is usually the principal hazard from uranium mill tailings. Radon release rates vary greatly with changes in weather and soil moisture, however. A standard based on the radon release rate would require repeated measurements over varied conditions to determine meaningful averages.

(4) The predicted radon decay product concentration is related to the hazard, but estimates of the indoor radon decay product concentrations are very uncertain. Furthermore, either the radium concentration or radon release rate from the land must first be determined to make such estimates, so (4) offers no advantage over (1) or (3).

8.3.2 Preferred Cleanup Standard for Land

We prefer Alternatives L2 and P2 as cleanup standards for near and distant land, respectively. Specifically, land should be cleaned up to levels not to exceed an average of 5 pCi/g of radium-226 in the first 15 cm surface layer of soil and an average of 15 pCi/g of radium-226 in any layer of 15 cm depth at deeper levels. Offsite properties should be cleaned up to these same action levels, with the following exceptions:

a) when contamination levels averaged over 100 m^2 are less than these action levels; or

b) when the hazard from the tailings is judged to be not significant because of their location.

A 5 pCi/g limit over the first 15 cm can be easily implemented with relatively low cost gamma radiation survey methods. For tailings below 15 cm, the concentration limit of 15 pCi/g is also easy to implement. Alternative L1 would require more skill and training of personnel, and greater use of expensive measuring techniques, but cleanup would only be marginally more complete. Very thick deposits of material with up to 15 pCi/g of radium-226 generally would be hazardous to build on, but are unlikely to occur. A concentration of 15 pCi/g is likely to occur only in thin layers at the edges of more concentrated deposits that would be cleaned up under a 15 pCi/g criterion. Under most foreseeable circumstances, we believe the residual hazard would be acceptably low under Alternative L2.

Alternatives L3 and L4 do not take full advantage of practicable cleanup. Several thousand acres next to disposal sites would require land-use controls. The costs saved are small in relation to total costs and do not warrant the higher risks that would remain.

We believe it is neither practical nor worthwhile to cleanup contaminated areas to surface concentrations below 5 pCi/g. Identifying contaminated surface soils with radium concentrations less than 5 pCi/g is difficult and expensive. Complex measurement techniques are required. Increasingly large land areas would need to be cleaned up. Doing this would provide very little gain in health protection, because such slightly contaminated soils are usually thin layers containing small amounts of tailings that pose insignificant risks.

For offsite properties, the cleanup costs vary little with the choice of numerical cleanup standards because tailings typically have been used with little mixing with other materials. If a standard based on Alternative L2 for nearby land is rigidly applied, up to $39 million may be spent in cleaning up these properties. However, many of these contaminated offsite properties present little existing or potential hazard because of the small amount of tailings involved, or because of their location. In Chapter 7 we considered applying the land cleanup standard for offsite locations only when appropriate threshold conditions are exceeded. This was projected to save $24 million without sacrificing protection of people. We therefore selected this alternative.

<u>Radiation Hazards not Associated with Radium-226</u>

Radium-226 concentrations in the residual tailings may not adequately measure the radiation hazard in all cases. The possibility that this could happen at one or more inactive processing sites cannot be ruled out, but we do not know of a site where this has happened. Should such circumstances occur, our supplemental standards (see below) will require the implementing agencies to reduce residual radioactivity to levels that are as low as may reasonably be achieved.

8.4 Supplemental Standards

In view of the varied conditions and our limited remedial action experience with tailings, these standards must be flexible. We believe our standards are the most protective that can justified for general application at all the inactive sites. However, the standards could be too strict in any specific application if the costs or undesirable side effects of the remedial actions were grossly disproportionate to the benefits of full compliance. We anticipate that such circumstances might occur. Therefore, we prefer to provide criteria under which the implementers may perform alternate remedial actions that they believe come as close to meeting the disposal and cleanup standards as is reasonably achievable under the pertinent circumstances.

When the agencies implementing the disposal, land, and building cleanup standards for uranium mill tailings determine that one or more of the following criteria apply at a specific location, then the agencies may apply supplemental standards. For this we list the following criteria:

(1) Public health or safety would be unavoidably endangered by otherwise required remedial actions.

(2) Remedial actions would cause significant environmental damage, in comparison to the environmental and health benefits that would result from satisfying the standard.

(3) The costs of land cleanup would be unreasonably high relative to the long-term benefits, and the residual radioactive materials do not pose a clear present or future hazard.

(4) The remedial action costs for buildings are clearly unreasonably high relative to the benefits.

(5) Radionuclides other than those upon which the standards are based (i.e., radium-226 and its decay products) cause significant hazards.

(6) There are no known remedial actions available.

Chapter 9: IMPLEMENTATION

9.1 Standards Implementation Process

Administrative Process

The Act (PL 95-604) requires that the Secretary of Energy implement these standards for cleanup and disposal of uranium mill tailings from inactive processing sites. The Secretary or a designated party will select and perform remedial actions for designated processing sites with the participation of any State that shares the cost. The Act also requires that NRC concur in selecting and performing remedial actions, and affected Indian tribes and the Secretary of the Interior be consulted as appropriate. Finally, the Act prescribes how the Federal Government and the States will share the costs of the remedial actions.

Implementing the Disposal Standards

The standards will be implemented through analyses that show the selected control method provides a reasonable assurance of satisfying the requirements of the standards for the required period of time. These analyses will include the physical properties of the site and the planned control system, and the long-term effects of natural processes. Computational models, theories, and expert judgment will be major tools in assessing whether a proposed control system will satisfy both short and long-term requirements. The results of such assessments will necessarily be uncertain. The standard, therefore, requires only "reasonable assurance" of compliance with its specifications. The implementers ultimately must make the judgment whether or not a control system will meet the requirements.

Post-remediation monitoring can determine whether the radon emission standards are satisfied and that the control system is performing as expected. Demonstrating compliance with long-term standards cannot reasonably be done by monitoring only, however. Compliance must instead depend on the adequacy of the design and implementation of the control system. In any case, exhaustive measurements are not appropriate because the consequences of small deviations from the standards are minor.

Implementing the Standards for Cleanup of Buildings and Open Land

The DOE will make radiation surveys of open lands and buildings in areas that are likely to have tailings and determine whether remedial actions are required. After remedial actions, compliance with the standards will have to be verified. DOE, working with NRC and the participating State, will develop radiological survey, sampling, and measurement procedures to determine necessary cleanup actions and the results of the cleanup. We have published elsewhere a discussion of the general requirements for an adequate land cleanup survey (EPA78c).

The choice of verification procedures is important to assure both effective and economic implementation of the standards. In view of this, we considered providing more details for the implementation as part of our rulemaking. But, so as to give more flexibility to the implementers, we chose not to do so. We believe this is warranted because conditions at the processing sites vary widely and are incompletely known. Our intent is also to avoid the unproductive use of resources that could result if implementation guidance were interpreted so strictly that complying in all situations would be unreasonably burdensome.

The purpose of cleanup standards is to protect public health and the environment. The standards should provide adequate protection if implemented using search and verification procedures of reasonable cost and technical specifications. Since, for example, we intend the building cleanup standards to protect people, measurements in locations such as crawl spaces and furnace rooms are inappropriate for determining compliance. Compliance decisions should be based on radiation levels in occupiable parts of the building. The standards for cleaning up land surfaces limit exposures of people to gamma radiation and to radon decay products in future building. In most circumstances, failure to detect a few square feet of land contaminated by tailings would be insignificant. Similarly, reasonableness must prevail in determing where and how deeply to search for tailings beneath the surface on open land. It would be unreasonable to require proof that all possible buried tailings had been found. In all applications of our proposed cleanup standards, search and verification procedures that provide reasonable assurance of compliance with the numerical requirements will be adequate. Necessary measurements should be performed within the accuracy of available field and laboratory instruments used in conjunction with reasonable survey and sampling procedures.

9.2 Effects of Implementing the Standards

Health

The Proposed Standards and Alternatives A, B, and C reduce average radon emissions from the tailings piles by about 99.6, 99.6, 96, and 80 percent, respectively. By extrapolating the current projected rate of lung cancer deaths due to radon from the piles over the first 1,000 years, we estimate that applying the standards will prevent 2,000, 2,000, 1,900, and 1,500 premature lung cancer deaths, respectively, and will prevent additional deaths thereafter in similar varying degree, but for different lengths of time. Alternatives D and E do not explicitly require reduction of radon releases, but we estimate radon reductions implicit to their implementation would prevent a total of 800 and 600 premature deaths, respectively. Under the Proposed Standards and Alternative A, people living very near tailings piles during the next several thousand years would bear a risk of premature death from lung cancer of about 1 chance in 10,000; under Alternative B about 1 in 1,000; under Alternative C about 6 in 1,000; under Alternatives D and E the risk would be reduced by at most 50 percent for a few hundred years, to several chances in 100.

The misuse of tailings in constructing buildings poses the greatest hazard to human health associated with tailings piles. Under the Proposed Standards and Alternatives A and B, we believe the possibility of unauthorized removal of the tailings will be unlikely for many thousands of years. Alternative C would provide such protection for at least a few thousand years. Under Alternatives D and E there would be no substantial physical barrier to human access to the tailings; misuse is much more likely after the few hundred years institutional controls are required to be maintained for these alternatives.

We estimate that performing remedial actions to meet the Proposed Standard could result in 3 accidental deaths among workers and the public, and 4, 2, 1, 1, and 1 accidental deaths under Alternatives A-E, respectively.

After remedial actions are completed on eligible buildings, building occupants will be subject to premature death from residual tailings at a maximum risk of about 1 percent under Alternatives B1, B2, and B3, and 5 percent under Alternative B4. The number of premature deaths avoided by the remedial actions will be approximately 65, 60, 65 and 55, under Alternatives B1-B4, respectively.

After completing remedial actions to eligible land, residual radioactive materials will give an individual a maximum risk of about 2 in 100 under Alternatives L1 and L2; 6 in 100 under Alternatives L3; and 10 in 100 under Alternative L4. The dose to persons exposed continuously to gamma radiation would be about 26, 60, 193, and 385 mrem/y, respectively, under Alternatives L1-L4.

About 6500 offsite locations where tailings have been used could be cleaned up under any of the Alternatives. This number will be reduced to about half, however, if remedial actions are performed only where there is a significant quantity of tailings in a location that poses a clear present or future hazard.

Environmental

Under the Proposed Standards and Alternatives A, B, and C, the integrity of all 24 tailings piles would be maintained for at least

1,000 years, and probably much longer; neither floods nor erosion should spread the tailings for many thousands of years in most cases. Under Alternative D a small number of piles could be damaged by floods during the first 1,000 years and some erosional spreading occur thereafter. Under Alternative E, severe flood damage during this period is likely at several sites, and erosional spreading may occur at most sites after a few hundred years.

Radon gas releases from tailings piles under the Proposed Standards and Alternative A would be essentially the same as from ordinary land for thousands of years. Releases well above normal levels, but well below current emission levels, should prevail for thousands of years at most piles under Alternatives B and C. Under Alternatives D and E, radon releases from the piles would be only slightly reduced from current levels. The environmental effects of such releases are negligible. (Effects on human health are discussed in the previous section).

It is not clear whether the current condition of tailings piles poses a significant threat to water quality. Under the Proposed Standards and Alternative A, however, all surface and ground water supplies will be assured protection for at least 1,000 years from significant degradation that results from post-remediation releases of harmful substances from tailings piles. Under Alternatives B and C, any significant potential water pollution should be avoided to the extent the implementing agencies determine reasonable. Under Alternative D, harm from any water polluted by tailings would be avoided for 100 years by either passive (preventive) or active (treatment or substitution) methods. Alternative E would not avoid any potential water pollution.

Contaminated land will be subjected to scraping and digging by the cleanup operations. Generally, these operations will occur immediately adjacent to the piles; offsite areas where tailings have been deliberately used also will be affected. We estimate that 2,700, 1,900, 900, and 250 acres near the piles would be cleaned up under Alternatives L1-L4, respectively. Approximately 6,500 offsite locations would be cleaned up under the Alternatives L1-L4; about half this number could be exempted under the Supplemental Standards (see Section 8.4).

Much of the contaminated land near the piles already has been disturbed during mill operations. Virtually all the offsite locations have been disturbed to some degree. It is likely, however, that some higher grade soils will be removed from undisturbed areas, perhaps with long-term (a few decades) detrimental local environmental effects. Control methods and the means of minimizing undesirable environmental effects will have to be considered for each site. The general ecological effects of land cleanup and restoration operations are examined in detail in a separate EPA report (EPA78c).

Disposal operations may require large quantities of earth, clay, and rock for covering the tailings, depending on the control method. Most of these materials need not be high quality or suitable for agricultural or other priority uses. Some waste materials may be available, such as existing mine wastes. We expect that the Proposed Standards, Alternative A, and Alternative B will make the greatest demand for such materials, Alternative C a moderate demand, and Alternatives D and E the least.

Economic

Estimating the total control and stabilization costs for all the tailings piles eligible under PL 95-604 is difficult, primarily because methods will be chosen specifically for each site. The assumptions we made (see Chapter 6) minimize the uncertainty in relative costs of the control standards we considered. We estimated the total tailings pile control costs for meeting the requirements of the Proposed Standards and Alternatives A-E as $372, $448, $294, $322 or $297, $250, and $232 million, respectively, in 1981 dollars.

We estimated the cleanup costs for open land near tailings piles as $21, $14, $7, and $2 million (1981 dollars) for satisfying Alternatives L1-L4, respectively. Cleanup costs for offsite properties would be about $39 million (1981 dollars) under any of the standards we considered. If only contaminated offsite locations that pose a clear present or future hazard are cleaned up, the cost would be $15 million (1981).

To satisfy Alternatives B1-B4, we estimated the cleanup costs for buildings to be $11.5, $8.5, $9, and $9.5 million, respectively. Here, however, we assumed somewhat different remedial methods for each alternative in order to explore the effects on the costs and benefits. Therefore, the relative cost estimates under each alternative may not be precise, but the range of estimates is a likely indicator of actual program costs under any of the alternatives.

The highest and lowest total program cost estimates obtainable under the standards are $540 million and $260 million, respectively. The costs of satisfying EPA's preferred standards (see Chapter 8) correspond approximately to those of control Alternative B and cleanup Alternatives L2 and B2 (assuming that Alternative L2 is applied only where there is a clear present or future hazard), or about $330 million. The Federal government will assume a 90 percent share, and the government of any State in which an inactive processing site is located will pay 10 percent. We expect the expenditures will be spread over the seven-year authorization of the program. Most of these expeditures will occur in the regions where the tailings are located. Their local significance will depend on the amount expended, the size of the local economy, and the availability of necessary equipment and labor.

Cleaned up land and buildings might be made available for use as a result of the cleanup program. On the other hand, moving tailings to a new location removes the new site from other potential uses.

We estimate that the remedial program could result in net economic benefits of decreased unemployment and increased business activity for the regions where the piles are located. We expect little or no perceptible national impact because the maximum average annual expenditures over the seven years of this program will be small compared to the annual Federal budget (less than 0.01 percent of the 1981 budget outlays), the annual Gross National Product (less than 0.003 percent of the 1981 GNP), and the construction industry (less than 0.03 percent of 1981 value of structures put in place).

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GLOSSARY OF TERMS AND ABBREVIATIONS

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AEC

Atomic Energy Commission (discontinued with formation of ERDA and NRC on January 19, 1975.)

alpha particle

A positively charged particle having the mass and charge of a helium nucleus; i.e., two protons and two neutrons.

aquifer

A water-bearing layer of permeable rock or soil. A subsurface formation containing sufficient saturated permeable material to yield significant quantities of water.

Curie (Ci)

A special unit of radioactivity equal to 37 billion nuclear transformations (e.g., decays of radium into radon) per second.

decay

The spontaneous nuclear (radioactive) transformation of one nuclide into another or into a different energy state of the same nuclide through a process which results in the emission of radiation.

decay chain

The sequence of radioactive transformations from one nuclide to other nuclides eventually ending in a nonradioactive nuclide.

decay products

The subsequent nuclides formed by the radioactive transformation of a given nuclide.

DOE

U.S. Department of Energy. Established by Executive Order in October 1977. Comprises the following former agencies: Energy Research and Development Administration, Federal Energy Administration, Federal Power Commission, and parts of the Department of Interior.

dose
The energy imparted to matter by ionizing radiation per unit mass of irradiated material at a specific location. A unit of absorbed dose is the rad. A general term indicating the amount of energy absorbed from incident radiation by a specified mass.

EPA
U.S. Environmental Protection Agency.

emission rate
The amount of a substance emitted from a source over a defined period of time.

erosion
The process of wearing away the land surface by the action of wind, water, glaciers, and other geological agents.

g
grams

gamma radiation
Electromagnetic energy (photon) emitted as a result of a nuclear transition.

GJO
Grand Junction Office, Department of Energy.

ground water
Water in the zone of saturation beneath the land surface.

half-life
A half-life is the time it takes for a given quantity of a radioactive isotope to decay to half of that quantity.

ICRP
International Commission on Radiological Protection

m
1. meter
2. as a prefix, milli. See "milli."

milli
Prefix indicating 1/1,000 or 10^{-3} (abbreviated "m").

NRC
U.S. Nuclear Regulatory Commission (former regulatory part of AEC).

nuclide
An atomic nucleus specified by its atomic mass number, atomic number, and energy state. A radionuclide is a radioactive nuclide.

p
Pico. Prefix indicating 1/1,000,000,000,000 or 10^{-12}.

person-rem

A unit of population dose equivalent. The population dose equivalent is equal to the sum of the individual dose equivalents (to the same target tissue) for all members of the population considered.

pH

A measure of the hydrogen ion concentration in aqueous solutions. Acidic solutions have a pH less than 7. Basic solutions have a pH greater than 7.

ppm

Parts per million.

rad

A special unit of absorbed dose. It is the amount of energy imparted per unit mass of irradiated material at the place of interest by ionizing radiations (one rad equals 0.01 Joules per kilogram).

rem

A special unit of dose equivalent to a specific organ or tissue or to the whole body. It is obtained by multiplying the absorbed dose in rads by weighting factors chosen to provide nominal biological effect equivalence for different ionizing radiation (e.g., neutrons, alpha particles, gamma radiation, etc.)

Roentgen (R)

A special unit of radiation exposure to air. It is the measure of electrical charge per unit mass produced in air by X or gamma radiation. One roentgen is equal to 2.58×10^{-4} coulomb per kilogram of air. [Note: For X or gamma radiation, the numerical value of absorbed dose (rad) in tissue is generally of the same magnitude as the numerical value of exposure (R)].

Working Level (WL)

A special unit of exposure rate to short-lived radon decay products in air. The unit was originally developed to measure radon decay product exposure to workers in uranium mines. The exposure rate is the total alpha particle energy which would be released by the combined radon decay products per unit volume of air. One Working Level is equal to 130,000 million electron volts of alpha-particle energy per liter of air.

Radon decay product exposure is the Working Level Month (WLM). It is obtained by multiplying the exposure rate by the time spent at that exposure rate. One WLM is the exposure that would result from a 170-hour period (a working month) at an exposure rate of 1 WL.

APPENDIX A

STANDARDS FOR REMEDIAL ACTIONS AT INACTIVE URANIUM PROCESSING SITES

Appendix A: STANDARDS FOR REMEDIAL ACTIONS AT INACTIVE URANIUM PROCESSING SITES

A new Part 192 is added to 40 CFR Chapter I, Subchapter F, as follows:

Part 192 - HEALTH AND ENVIRONMENTAL PROTECTION STANDARDS FOR URANIUM MILL TAILINGS

Subpart A -- Standards for the Control of Residual Radioactive Materials from Inactive Uranium Processing Sites

Sec.
192.00 Applicability
192.01 Definitions
192.02 Standards

Subpart B -- Standards for Cleanup of Land and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

192.10 Applicability
192.11 Definitions
192.12 Standards

Subpart C -- Implementation

192.20 Guidance for Implementation
192.21 Criteria for Applying Supplemental Standards
192.22 Supplemental Standards
192.23 Effective Date

AUTHORITY: Section 275 of the Atomic Energy Act of 1954, 42 U.S.C. 2022, as added by the Uranium Mill Tailings Radiation Control Act of 1978, PL 95-604.

Subpart A -- Standards for the Control of Residual Radioactive Materials from Inactive Uranium Processing Sites

192.00 Applicability

This subpart applies to the control of residual radioactive material at designated processing or depository sites under Section 108 of the Uranium Mill Tailings Radiation Control Act of 1978 (henceforth designated "the Act"), and to restoration of such sites following any use of subsurface minerals under Section 104(h) of the Act.

192.01 Definitions

(a) Unless otherwise indicated in this subpart, all terms shall have the same meaning as in Title I of the Act.

(b) Remedial action means any action performed under Section 108 of the Act.

(c) Control means any remedial action intended to stabilize, inhibit future misuse of, or reduce emissions or effluents from residual radioactive materials.

(d) Disposal site means the region within the smallest perimeter of residual radioactive material (excluding cover materials) following completion of control activities.

(e) Depository site means a disposal site (other than a processing site) selected under Section 104(b) or 105(b) of the Act.

(f) Curie (Ci) means the amount of radioactive material that produces 37 billion nuclear transformation per second. One picocurie (pCi) = 10^{-12} Ci.

192.02 Standards

Control shall be designed* to:

(a) be effective for up to one thousand years, to the extent reasonably achievable, and, in any case, for at least 200 years, and,

(b) provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not:

(1) exceed an average** release rate of 20 picocuries per square meter per second, or

(2) increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than one-half picocurie per liter.

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* Because the standard applies to design, monitoring after disposal is not required to demonstrate compliance.

** This average shall apply over the entire surface of the disposal site and over at least a one-year period. Radon will come from both residual radioactive materials and from materials covering them. Radon emissions from the covering materials should be estimated as part of developing a remedial action plan for each site. The standard, however, applies only to emissions from residual radioactive materials to the atmosphere.

Subpart B -- Standards for Cleanup of Land and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

192.10 Applicability

This subpart applies to land and buildings that are part of any processing site designated by the Secretary of Energy under Section 102 of the Act. Section 101 of the Act, states, in part, that "processing site" means --

(a) any site, including the mill, containing residual radioactive materials at which all or substantially all of the uranium was produced for sale to any Federal agency prior to January 1, 1971 under a contract with any Federal agency, except in the case of a site at or near Slick Rock, Colorado, unless --

(1) such site was owned or controlled as of January 1, 1978, or is thereafter owned or controlled, by any Federal agency, or

(2) a license (issued by the (Nuclear Regulatory) Commission or its predecessor agency under the Atomic Energy Act of 1954 or by a State as permitted under Section 274 of such Act) for the production at

site of any uranium or thorium product derived from ores is in effect on January 1, 1978, or is issued or renewed after such date; and

(b) any other real property or improvement thereon which --

(1) is in the vicinity of such site, and

(2) is determined by the Secretary, in consultation with the Commission, to be contaminated with residual radioactive materials derived from such site.

192.11 Definitions

(a) Unless otherwise indicated in this subpart, all terms shall have the same meaning as defined in Title I of the Act or in Subpart A.

(b) Land means any surface or subsurface land that is not part of a disposal site and is not covered by an occupiable building.

(c) Working Level (WL) means any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts.

(d) Soil means all unconsolidated materials normally found on or near the surface of the earth including, but not limited to, silts, clays, sands, gravel, and small rocks.

192.12 Standards

Remedial actions shall be conducted so as to provide reasonable assurance that, as a result of residual radioactive materials from any designated processing site:

(a) the concentration of radium-226 in land averaged over any area of 100 square meters shall not exceed the background level by more than --

(1) 5 pCi/g, averaged over the first 15 cm of soil below the surface, and

(2) 15 pCi/g, averaged over 15 cm thick layers of soil more than 15 cm below the surface.

(b) in any occupied or habitable building --

(1) the objective of remedial action shall be, and reasonable effort shall be made to achieve, an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 WL. In any case, the radon decay product concentration (including background) shall not exceed 0.03 WL, and

(2) the level of gamma radiation shall not exceed the background level by more than 20 microroentgens per hour.

Subpart C -- Implementation

192.20 Guidance for Implementation

Section 108 of the Act requires the Secretary of Energy to select and perform remedial actions with the concurrence of the Nuclear Regulatory Commission and the full participation of any State that pays part of the cost, and in consultation, as appropriate, with affected Indian Tribes and the Secretary of the Interior. These parties, in their respective roles under Section 108, are referred to hereafter as "the implementing agencies."

The implementing agencies shall establish methods and procedures to provide "reasonable assurance" that the provisions of Subparts A and B are satisfied. This should be done as appropriate through use of analytic models and site-specific analyses, in the case of Subpart A, and for Subpart B through measurements performed within the accuracy of currently available types of field and laboratory instruments in conjunction with reasonable survey and sampling procedures. These methods and procedures may be varied to suit conditions at specific sites. In particular:

(a) The purpose of Subpart A is to provide for long-term stabilization and isolation in order to inhibit misuse and spreading of residual radioactive materials, control releases of radon to air, and protect water. Subpart A may be implemented through analysis of the physical properties of the site and the control system and projection of the effects of natural processes over time. Events and processes that could significantly affect the average radon release rate from the entire disposal site should be considered. Phenomena that are localized or temporary, such as local cracking or burrowing of rodents, need to be taken into account only if their cumulative effect would be significant in determining compliance with the standard. Computational models, theories, and prevalent expert judgment may be used to decide that a control system design will satisfy the standard. The numerical range provided in the standard for the longevity of the effectiveness of the control of residual radioactive materials allows for consideration of the various factors affecting the longevity of control and stabilization methods and their costs. These factors have different levels of predictability and may vary for the different sites.

Protection of water should be considered in the analysis for reasonable assurance of compliance with the provisions of Section 192.02. Protection of water should be considered on a case-specific basis, drawing on hydrological and geochemical surveys and all other relevant data. The hydrologic and geologic assessment to be conducted at each site should include a monitoring program sufficient to establish background groundwater quality through one or more upgradient wells, and identify the presence and movement of plumes associated with the tailings piles.

If contaminants have been released from a tailings pile, an assessment of the location of the contaminants and the rate and direction of movement of contaminated ground water, as well as its relative contamination, should be made. In addition, the assessment should identify the attenuative capacity of the unsaturated and saturated zone to determine the extent of plume movement. Judgments on the possible need for remedial or protective actions for groundwater aquifers should be guided by relevant considerations described in EPA's hazardous waste management system (47 FR 32274, July 26, 1982) and by relevant State and Federal Water Quality Criteria for anticipated or existing uses of water over the term of the stabilization. The decision on whether to institute remedial action, what specific action to take, and to what levels an aquifer should be protected or restored should be made on a case-by-case basis taking into account such factors as technical feasibility of improving the aquifer in its hydrogeologic setting, the cost of applicable restorative or protective programs, the present and future value of the aquifer as a water resource, the availability of alternative water supplies, and the degree to which human exposure is likely to occur.

(b) Compliance with Subpart B, to the extent practical, should be demonstrated through radiation surveys. Such surveys may, if appropriate, be restricted to locations likely to contain residual radioactive materials. These surveys should be designed to provide for compliance averaged over limited areas rather than point-by-point compliance with the standards. In most cases, measurement of gamma radiation exposure rates above and below the land surface can be used to show compliance with Section 192.12(a). Protocols for making such measurements should be based on realistic radium distributions near the surface rather than extremes rarely encountered.

In Section 192.12(a), "background level" refers to the native radium concentration in soil. Since this may not be determinable in the presence of contamination by residual radioactive materials, a surrogate "background level" may be established by simple direct or indirect (e.g., gamma radiation) measurements performed nearby but outside of the contaminated location.

Compliance with Section 192.12(b) may be demonstrated by methods that the Department of Energy has approved for use under PL 92-314 (10 CFR 712), or by other methods that the implementing agencies determine are adequate. Residual radioactive materials should be removed from buildings exceeding 0.03 WL so that future replacement buildings will not pose a hazard [unless removal is not practical--see Section 192.21(c)]. However, sealants, filtration, and ventilation devices may provide reasonable assurance of reductions from 0.03 WL to below 0.02 WL. In unusual cases, indoor radiation may exceed the levels specified in Section 192.12(b) due to sources other than residual radioactive materials. Remedial actions are not required in order to comply with the standard when there is reasonable assurance that residual radioactive materials are not the cause of such an excess.

192.21. Criteria for Applying Supplemental Standards

The implementing agencies may (and in the case of Subsection (f) shall) apply standards under Section 192.22 in lieu of the standards of Subparts A or B if they determine that any of the following circumstances exists:

(a) Remedial actions required to satisfy Subparts A or B would pose a clear and present risk of injury to workers or to members of the public, notwithstanding reasonable measures to avoid or reduce risk.

(b) Remedial actions to satisfy the cleanup standards for land, Section 192.12(a), or the acquisition of minimum materials required for control to satisfy Section 192.02(b), would, notwithstanding reasonable measures to limit damage, directly produce environmental harm that is clearly excessive compared to the health benefits to persons living on or near the site, now or in the future. A clear excess of environmental harm is harm that is long-term, manifest, and grossly disproportionate to health benefits that may reasonably be anticipated.

(c) The estimated cost of remedial action to satisfy Sec. 192.12(a) at a "vicinity" site (described under Sec. 101(6)(B) of the Act) is unreasonably high relative to the long-term benefits, and the residual radioactive materials do not pose a clear present or future hazard. The likelihood that buildings will be erected or that people will spend long periods of time at such a vicinity site should be considered in evaluating this hazard. Remedial action will generally not be necessary where residual radioactive materials have been placed semi-permanently in a location where site-specific factors limit their hazard and from which they are costly or difficult to remove, or where only minor quantities of residual radioactive materials are involved. Examples are residual radioactive materials under hard surface public roads and sidewalks, around public sewer lines, or in fence post foundations. Supplemental standards should not be applied at such sites, however, if individuals are likely to be exposed for long periods of time to radiation from such materials at levels above those that would prevail under Section 192.12(a).

(d) The cost of a remedial action for cleanup of a building under Sec. 192.12(b) is clearly unreasonably high relative to the benefits. Factors that should be included in this judgment are the anticipated period of occupancy, the incremental radiation level that would be affected by the remedial action, the residual useful lifetime of the building, the potential for future construction at the site, and the applicability of less costly remedial methods than removal of residual radioactive materials.

(e) There is no known remedial action.

(f) Radionuclides other than radium-226 and its decay products are present in sufficient quantity and concentration to constitute a significant radiation hazard from residual radioactive materials.

192.22 Supplemental Standards

Federal agencies implementing Subparts A and B may in lieu thereof proceed pursuant to this section with respect to generic or individual situations meeting the eligibility requirements of Section 192.21.

(a) When one or more of the criteria of Section 192.21(a) through (e) applies, the implementing agencies shall select and perform remedial actions that come as close to meeting the otherwise applicable standard as is reasonable under the circumstances.

(b) When Section 192.21(f) applies, remedial actions shall, in addition to satisfying the standards of Subparts A and B, reduce other residual radioactivity to levels that are as low as is reasonably achievable.

(c) The implementing agencies may make general determinations concerning remedial actions under this Section that will apply to all locations with specified characteristics, or they may make a determination for a specific location. When remedial actions are proposed under this Section for a specific location, the Department of Energy shall inform any private owners and occupants of the affected location and solicit their comments. The Department of Energy shall provide any such comments to the other implementing agencies. The Department of Energy shall also periodically inform the Environmental Protection Agency of both general and individual determinations under the provisions of this section.

192.23 Effective Date

Subparts A, B, and C shall be effective (in 60 days after promulgation).

APPENDIX B

DEVELOPMENT OF COST ESTIMATES

APPENDIX B: DEVELOPMENT OF COST ESTIMATES

CONTENTS

CONTENTS--continued

TABLES

Appendix B: DEVELOPMENT OF COST ESTIMATES

B.1 Introduction

This appendix details the development of cost estimates for:

- The alternative standards for control of tailings piles discussed in Chapter 6,
- Additional methods of controlling tailings not considered in Chapter 6, and
- Cleanup of buildings as discussed in Chapter 7.

Costs for the six alternative standards considered in Chapter 6 are in Sections B.2 through B.5; for the additional methods, in Section B.6; and for building cleanup, in Section B.7.

B.2 The Model Uranium Mill Tailings Piles

All cost estimates are for model tailings piles at a hypothetical site. Two sizes of model piles are considered, a normal pile and a small pile. Individual site characteristics are used only for determining the number of piles to be moved. The characteristics of the two model piles are:

	Normal Pile	Small Pile
Volume (cubic yards)	1,100,000	90,000
Area (acres)	53.0	13.6
Height (feet)	13.5	4.3

The model piles are assumed to be square, with vertical sides before remedial action is undertaken. When remedial action is completed, the piles are assumed to have the shape of truncated pyramids with slopes as specified in the alternative standards (see Table 6-2). All piles are assumed to be located on flat ground.

B.3 Unit Costs for Controlling Tailings Piles

Unit costs, expressed in 1981 dollars, for estimating the costs of characteristic tasks of controlling tailings piles are presented in Table B-1. We have attempted to determine unit costs that are typical of the tasks to be undertaken. Since these costs are used in developing all costs for controlling tailings piles, we believe they accurately reflect the differences between the alternative standards. Differences in costs are a major consideration in the selection of a standard.

Earth Moving

The unit costs of earth moving are grouped in Table B-1 according to the type of work performed. Earth work costs can vary appreciably depending on local conditions. For example, soils like hard packed shale increase the costs of excavation. Local labor costs and equipment rental costs can also vary.

Earth work costs are taken directly from the Dodge Guide (DG81), with the exception of the unit costs for clay which are taken from the AMC comments (AMC81) and are adjusted for inflation.

Transportation for short hauls (up to 2 miles off the highway) are included under earth work because multipurpose equipment, such as scrapers, can be used for short-distance hauling as well as for excavation and spreading. For longer, off-highway hauls, large off-highway trucks are used. Table B-1 provides costs for hauls of 3,500 feet by scraper and hauls of 2 miles by off-highway trucks.

If the cover material is not available on the site, we assume it must be purchased. The cost of purchasing dirt cover, including excavation and loading at the supply site and reclamation of the borrow pit, is $2.25 per cubic yard. The cost of spreading and compacting the cover material at the tailings site is $0.60/cubic yard.

Transportation on Highways

The unit cost of transporting earthlike materials on highways is considerably higher than that for off-highway hauling. We estimate that the unit cost of hauling these materials is $0.40 per cubic yard-mile or about $0.30 per ton-mile (DG81). We used these unit costs in estimating the costs of moving piles because we consider it likely that 10-mile hauls will require use of public roads. On-highway costs would probably be applicable for hauling dirt, clay, and rock if these materials are not available nearby.

Rock Cover

Rock cover means a less orderly placement of rocks than is commonly associated with riprap. Rock cover also implies a less stringent size gradation for the rocks than riprap. Costs for rock cover are highly variable from site to site. The AMC estimate for 18-inch rock cover is $15.20/yd^2 (AMC81) and the NRC estimate is $6.70/yd^2 (NRC80). We used a value between these estimates but closer to the higher value.

Landscaping

Unit costs for landscaping are taken from the Dodge Guide (DG81). The difference between the two values given in Table B-1 is the availability of loam or top soil at the disposal site. If loam must be both purchased and hauled for distances greater than about 2 miles, landscaping costs greatly increase.

Landscaping used to protect 3m-dirt covers is assumed to support a vegetative cover (mostly grasses) requiring no continuing maintenance. This factor has been tested at the Monticello site (Ro81) where some vegetation remains after 20 years with little maintenance. It is assumed that maintenance, as well as irrigation, is required for those sites having only 0.5m earth and vegetative covers.

Fencing

Heavy-duty chain link fencing was selected for this analysis. The unit cost is $21.60 per foot for an installed 6-foot-high chain link fence made of 6-gauge aluminum wire (DG81).

Maintenance and Inspection

Maintenance and inspection costs are calculated for:

1. An irrigation system for maintaining vegetation on thin earth covers.

2. Fencing maintenance.

3. Annual inspections including ground water monitoring, repair, and revegetation of eroded areas.

The irrigation system design, developed for EPA by PEDCO Environmental Incorporated (PE81), is for a 40-acre site. It consists of a 150-hp motor and pump unit, polyethylene piping, and plastic spray heads. The capital cost of this system is $127,000; it is assumed that it must be replaced every 20 years. The present value of capital requirements for 100 years of operation is $149,000, using a 10 percent discount rate and replacement at 20, 40, 60, and 80 years. Annual costs of operation are $12,000 per year for maintenance and labor, $9,300 year for electrical power, and $6,000 per year for overhead, assuming the system is operated 8 hours per week, 8 months per year. The present value of these

TABLE B-1. UNIT COSTS FOR TASKS ASSOCIATED WITH CONTROLLING URANIUM MILL TAILINGS PILES
(1981 Dollars)

Task	Cost
Earth work:	
Grading:	
Move and spread by dozer.	$1.07/yd^3$
Placing clay liners and covers:	
Purchase clay, haul 2 miles, dump, spread, and compact.	$8.84/yd^3$
Placing earthen cover:	
Excavate, haul, spread, and compact-by scrapers for 3,500 feet.	$2.06/yd^3$
Excavate, load, haul by truck for 2 miles off-highway, dump, spread, and compact.	$2.00/yd^3$
Excavating pits:	
Excavate, haul, and spread by scrapers for 3,500 feet.	$1.83/yd^3$
Moving tailings:	
Excavate by drag line. Load, haul 2 miles off highway, spread, and compact.	$2.50/yd^3$
Transportation:	
Over highway hauling of earth, tailings, clay, loam, etc.	$0.40/yd^3 mile
Rock cover:	
6" thick.	$4.53/yd^2$
12" thick.	$9.07/yd^2$
18" thick.	$13.60/yd^2$

TABLE B-1. UNIT COSTS FOR TASKS ASSOCIATED WITH CONTROLLING URANIUM MILL TAILINGS PILES (Continued)
(1981 Dollars)

Task	Cost
Landscaping:	
Loam from site used. Preparation of area, spread loam 6" thick, and hydraulically spread lime, fertilizer, and seed.	$3,000/acre
Loam purchased with 2-mile haul. Prepare area, spread loam 6" thick, and hydraulically spread lime, fertilizer, and seed.	$7,900/acre
Fencing:	
Chain link, 6 feet high, 6 gauge aluminum.	$21.60/ft
Maintenance and inspection:	
Installation and operation of an irrigation system for 100 years - present worth at 10% discount rate.	$10,500/acre
Maintenance of fencing at 1% of capital cost per year. Present value at 10% discount rate for 100 years.	0.10 x capital cost of fencing
Annual inspections including ground water monitoring and repair and revegetation of eroded areas. Present value at 10% discount rate for 100 years.	$95,000/site

annual costs is $273,000 for 100 years, using a 10 percent discount rate. Therefore, the total present value of providing irrigation for 100 years is $422,000 for a 40-acre site, or $10,500 per acre. This translates into a present value of $617,000 for a normal pile and $153,000 for a small pile.

Maintaining the fence for 100 years is assumed to cost 1 percent of the installation cost annually. The present value of this maintenance cost for 100 years at 10 percent discount rate is 0.10 x fencing capital cost.

The cost for annual inspections at a site is taken directly from Appendix R of NRC's GEIS (NRC80). For this purpose, we used NRC's Scenario IV, which requires only limited maintenance. Their inspection costs are $10,500 annually. This includes $1,000 per year for maintenance of the fence. Since this cost is already considered, it is subtracted from the NRC value to give an annual cost of $9,500 per site. The present value is $95,000 per site using a 10 percent discount rate for 100 years.

B.4 Cost Estimates for Alternative Standards

We have made 24 cost estimates: for the two model piles for each of the alternative standards described in Chapter 6 and for controlling piles onsite and at new sites.

Costs for Onsite Control

Estimated costs for onsite control are summarized in Table B-2. This table also provides the parameters that affect costs: slopes of the sides of the piles, cover and rock thickness, and vegetation. Costs for fencing are included in Alternatives C, D and E. The fencing is assumed to be placed at a distance of 0.5 km from the edge of the covered tailings, providing an exclusion zone. The cost of fencing is about $430,000 per site for all normal piles and about $350,000 per site for all small piles.

The total area of a tailings pile includes the area over which the contouring operation will spread the tailings from the initial edge of the pile. This is determined by the vertical dimension of a pile and the slope of the sides. This total area is used to estimate costs for cover materials and vegetation.

Costs for Control at New Sites

Estimated costs for control at new sites are summarized in Table B-3. The parameters that affect costs are listed as they were for the onsite options (Table B-2). Costs for fencing are included in Options C, D, and E.

We have assumed that any new site is excavated so that the tailings are partially buried, and that the excavated material is

TABLE B-2. SUMMARY OF COSTS FOR ONSITE CONTROL OF TAILINGS

Alternative	Maximum Tailings Slope (H:V)[a]	Cover Material and Thickness	Rock Cover Thickness (location)	Vegetation	Estimated Cost (1981$ in Millions) Normal Pile	Small Pile
EPA Proposed Standards	5:1	0.6m clay 3m earth	0.33m (slopes)	top	4.9	1.2
Alternative A	8:1	0.6m clay 3m earth	0.5m (slopes) 0.15m (top)	none	7.0	1.6
Alternative B	4:1	3m earth	0.33m (slopes)	top	2.9	0.7
Alternative C	5:1	1m earth	0.33m (slopes) 0.15m (top)	none	3.0	1.0
Alternative D	3:1	0.5m earth	0.15m (top and slopes)	none	2.2	0.8
Alternative E	3:1	0.5m earth	none	top and slopes[b]	1.7	0.7

[a] Slope is the ratio of horizontal (H) to vertical (V) distance (i.e. H:V).
[b] For this alternative the vegetation is maintained for 100 years by weekly irrigation for eight months each year. Costs also include maintenance and repair of earth covers.

TABLE B-3. SUMMARY OF COSTS FOR MOVING AND CONTROLLING TAILINGS AT A NEW SITE

Alternative	Maximum Tailings Slope (H:V)[a]	Cover Material and Thickness	Rock Cover Thickness (location)	Vegetation	Estimated Cost (1981$ in Millions) Normal Pile	Small Pile
EPA Proposed Standard	5:1	0.6m clay 3m earth	0.33m (slopes)	top	11.0	1.0
Alternative A	8:1	0.6m clay 3m earth	0.5m (slopes) 0.15m (top)	none	12.6	1.2
Alternative B	4:1	3m earth	0.33m (slopes)	top	10.1	0.8
Alternative C	5:1	1m earth	0.33m (slopes) 0.15m (top)	none	9.8	1.3
Alternative D	3:1	0.5m earth	0.15m (top and slopes)	none	8.9	1.2
Alternative E	3:1	0.5m earth	none	top and slopes[b]	8.6	1.1

[a] Slope is the ratio of horizontal (H) to vertical (V) distance (i.e. H:V).
[b] For this alternative the vegetation is maintained for 100 years by weekly irrigation for eight months each year. Costs also include maintenance and repair of earth covers.

used as cover material. We also assume that one of the criteria for selecting the new control site is its inherent ability to protect against ground water contamination. Thus, no plastic or clay liner is required for ground water protection, and no costs are added for liners. The excavated area is about 110,000 square meters for the normal pile and about 11,000 square meters for the small pile.

The tailings are excavated, loaded on trucks, hauled to the new site, and dumped in the excavated pit. They are then spread and compacted. The tailings are covered with the earth excavated from the pit and rock, if required for the alternative. The pile is then landscaped, if required for the alternative. We assume the control site is 10 miles from the existing site. Considerable reductions in costs can be realized if a new site can be located close to or adjacent to the existing site.

The estimated costs for moving a small pile to a new site are less than the costs for onsite control for the EPA Proposed Standards and Alternative A (compare costs in Table B-2 with those in Table B-3). This is because the smaller area to be covered after the pile has been moved more than offsets the additional excavation and transportation costs. If the hauling distance is decreased and off-highway transportation becomes feasible for moving to a new site, the costs for new-site disposal can decrease appreciably.

Costs for Flood Protection Embankments

For some sites, flood protection is needed if the tailings are to be controlled onsite. Flood protection can be provided by building embankments around the tailings or on those sides of the tailings susceptible to flooding. The extent of the embankments around the piles depends on the topography of the tailings site and the vulnerability of the site to floods.

For this analysis we assumed that embankments are required around the tailings pile, that embankments will be built to the same height as the top of the cover material placed on the tailings, and that riprap will be placed on the outer face of the embankment. The embankments are 5 meters wide at the top, have a 2:1 slope on the outer face, are 546 meters (1,780 feet) long on each side, and have riprap placed on the lower 5 meters of the outer face. The estimated cost of this embankment is about $1,000,000 and is assumed to be the same for the normal and small piles.

B.5 Total Cost Estimates for Controlling Tailings

Total costs of controlling tailings for each of the six alternatives, shown in Table B-4, are derived from the cost estimates for the generic piles in Tables B-2 and B-3. There are 17 normal-sized piles and 7 small piles. The number of piles controlled onsite or moved and controlled at a new site is shown in parentheses in

TABLE B-4. ESTIMATED COSTS OF CONTROLLING URANIUM MILL TAILINGS[(a)]
(in millions of 1981 dollars)

Alternative	Cleaning Up Sites	Onsite Control		Adding Embankments	Move and Control		Subtotal	Overhead and Contingencies	Total
		Normal Pile	Small Pile		Normal Pile	Small Pile			
EPA Proposed Standard	35 (24)	49 (10)	6 (5)	0	77 (7)	2 (2)	169	85	254
Alternative A	35 (24)	49 (7)	8 (5)	0	126 (10)	2 (2)	221	110	331
Alternative B	35 (24)	41 (14)	5 (7)	6 (6)	30 (3)	0	117	58	175
Alternative C1[(b)]	35 (24)	33 (11)	5 (5)	1 (1)	59 (6)	3 (2)	136	68	204
Alternative C2[(b)]	35 (24)	42 (14)	7 (7)	6 (6)	29 (3)	0	120	60	180
Alternative D	35 (24)	35 (16)	6 (7)	3 (3)	9 (1)	0	88	44	132
Alternative E	35 (24)	27 (16)	5 (7)	0	9 (1)	0	76	38	114

(a) Numbers in parentheses are the number of piles receiving the respective action.
(b) The distinction between Alternatives C1 and C2 is in the number of piles assumed moved rather than protected in place with embankments.

Table B-4. The number of piles requiring embankments is also indicated. Factors determining the number of piles to be moved and to be protected by embankments are more fully discussed later. Embankments are estimated to cost $1 million in all cases.

Total costs include the costs of remedial actions for contaminated structures, settling ponds, raffinate pits, mill yards, and other remnants of mill operations on each site. We assumed this cleanup to be the same for all alternatives. The estimated cost of $35 million is based on EPA field experience (HaIP) in the 1978 cleanup program performed at the Shiprock site and has been adjusted for inflation.

All costs are adjusted upward by 50 percent to account for contractor overhead, contingencies, profit, and engineering. This adjustment appears reasonable for most operations (DG81). Other costs, not shown in Table B-4, include the Department of Energy's costs for management, research and development, inactive tailings site acquisition, and NEPA (National Environmental Policy Act) actions, all of which are independent of the selection of a standard. These costs, estimated to be $118,000,000, have been included in Table 6-4, Chapter 6.

Flood Control Measures

The number of piles moved and the number of piles requiring embankments for flood protection are important factors in estimating total costs. Variations in these factors influence total costs for each alternative.

Two factors determine whether tailings piles need to be moved: the likelihood of flooding that could cause severe erosion and proximity to population centers (for Alternative A only). These factors affect 12 sites; 9 are subject to potential flood damage from nearby streams or rivers, and 9 are near population centers.

EPA Proposed Standard - We estimate that nine piles must be moved to meet the stability objective for an indefinite period (over 1,000 years) because the piles are threatened by the flooding of nearby rivers or streams. No piles would be moved under this alternative because of their proximity to population centers since we assumed that the 3-meter dirt cover provides sufficent protection from misuse and radon emissions.

Alternative A - Any piles that are close to population centers must be moved. Otherwise, the alternative is the same as the EPA Proposed Standard. This criterion adds three normal-size piles to the total number moved.

Alternative B - The stability objective of 200 to 1,000 years for this alternative allows the use of engineering controls for flood protection, rather than moving the piles to new locations. These controls are embankments, or dikes, that are built around the tailings pile. For this alternative it is estimated that the stability criterion can be achieved at six sites with embankments, leaving only three piles to be moved. No piles would be moved because of nearness to population centers under this alternative. The three piles to be moved are normal piles.

Alternative C - The objective of stability for an indefinite period (over 1,000 years) for this alternative is assumed to require flood protection for nine piles. However, it is assumed that embankments can adequately protect as many as six of these piles. Thus, this alternative requires less stringent flood protection measures than either the EPA Proposed Standard or Alternative A. Three piles are assumed to be moved for meeting the least stringent interpretation of Alternative C, and eight piles are assumed to be moved to meet the most stringent interpretation. Embankments are assumed to be constructed for the remaining nine piles believed to be threatened by floods. The high and low ends of this range are labled C1 and C2, respectively, in Table B-4. No piles need to be moved because of proximity to population centers under this alternative.

Alternative D - The 100-year stability objective for this alternative requires that only one pile be moved. This pile is on a steeply graded site restricted by a cliff and a river. It probably cannot be stabilized onsite. It is assumed that embankments would be required to meet the 100-year criterion at three other sites. This leaves five piles with no flood protection. No piles would be moved because of closeness to population centers.

Alternative E - The 100- to 200-year stability objective for this alternative is based on annual maintenance and inspection requirements. However, it is assumed these requirements would be inefffective for the pile on a steeply graded site described under Alternative D. Thus, it is assumed that one pile would be moved for this alternative. The other eight sites considered vulnerable to floods would remain vulnerable. The annual maintenance requirement would probably prevent significant spreading of the tailings from chronic events. No piles would be moved because of closeness to population centers or of need to protect water quality.

B.6 Advanced Control Methods

There are a number of possible alternatives to the control methods previously considered. One method we have considered in some detail is placing a soil cement cap over the tailings. Other methods have also been considered. Most rely on unproven technology and are potentially very costly. Several methods are discussed in the NRC FGEIS (NRC80). Two of these methods are summarized here: nitric acid leaching for the removal of hazardous materials, and burial in a stripmine or underground mine. These alternatives potentially offer considerable radon attenuation (to levels below 0.5 pCi/m^2s), but the long-term environmental impact of these methods has not been tested. Thermal stabilization is another control method that has recently been analyzed.

Soil Cement

We have evaluated the use of soil cement as a control measure for tailings disposal. The specifications of the design are:

a. Sides of piles graded to 3:1 (H:V) slopes;

b. Soil cement caps, 0.15 meter thick, placed on the tops and sides of the piles;

c. Earth covers, 1 meter thick, placed over the soil cement caps, on the tops and sides of the piles;

d. Rock, 0.33 meter thick, placed on the slopes of the piles;

e. Rocky soil, 0.33 meter thick, placed on the tops of the piles;

f. The tops of the piles planted with indigenous vegetation.

Available information indicates that uranium tailings can be used to produce a good quality soil cement. It should be relatively tough and withstand freezing and thawing. Soil cement, together with the 1-meter earth cover and the 0.33-meter rock cover on the slopes of the piles should create an effective barrier to human intrusion.

The tops and slopes of the piles must be shaped, fine graded, and compacted in preparation for placing the soil cement. We assume that the soil cement can be placed using procedures similar to those used for highway construction. After the soil cement has been laid down, graded, and compacted, we assume a thin layer of tar is used as a curing agent. The tar would, we believe, increase the longevity of the soil cement, and reduce radon emissions through the soil cement.

There is some doubt that vegetation can be maintained on the top of the pile without continuing maintenance, because shallow-rooted vegetation probably cannot survive the droughts typical of the region of most of the piles, and deep-rooted vegetation cannot be established in the 1 meter of soil above the soil cement. Therefore, 0.33 meters of rocky soil is to be placed on top of the 1-meter earth cover before planting vegetation. If the vegetation fails, much of the fine grained materials in the top 0.33-meter layer of rocky soil will be eroded away, leaving a layer of rocks to form a protection cover over the underlying earth.

The effectiveness of soil cement as a barrier to radon emissions has not been tested. Nevertheless, our analysis leads us to conclude that the soil cement, together with the compacted tailings immediately below the soil cement, and the layer of tar, will control emissions to approximately the same level as a 2-meter earth cover. Therefore, this design, which includes a 1-meter earth cover over the soil cement, would provide radon control approximately equal that provided by the EPA Proposed Standard and Alternatives A and B.

The costs of control are estimated to total $163,000,000, including moving three piles, providing embankments for six piles, $35,000,000 for cleanup of mill facilities, and a 50 percent increase for overhead, contingencies, profit and engineering. Therefore, this control method appears to be equivalent to Alternative B in control levels achieved and in cost.

Extraction and Control of Hazardous Materials

The technology of nitric acid leaching has not been developed for extracting radium or nonradiological toxic elements from the tailings because there has been no need for it.

A nitric acid leaching plant could be developed to remove the radium and thorium in the tailings. The cost of such chemical treatment of tailings is, as yet, undetermined, but could be expected to be as expensive as the original milling process, excluding ore grinding.

It would require the construction and operation of a nitric acid leaching mill, a means of disposing of the concentrated nitric acid leachate, and control of the residual tailings. Since this technique is expected to be only about 90 percent effective, some action would still be required to isolate the tailings from the biosphere. The leachate would probably have to be controlled in a licensed radioactive waste burial site. Tailings from this process would still require some treatment, though the radioactivity level would be considerably lower. Some hazardous nonradiological elements would remain. A potential problem is that seepage from the new pile would contain nitrates instead of the sulfates found in a conventional mill tailings. Nitrates become quite mobile if they reach ground water.

The construction and operation of a nitric acid leaching mill is quite expensive. The NRC FGEIS (NRC80) estimates that a model nitric acid leaching mill costs $47 million to construct and an additional $50 million to equip (1981 dollars), while operating costs are expected to run $17 per ton of processed uranium mill tailings.

The normal size generic pile contains 1.48 million short tons of tailings. Assuming that a model nitric acid leaching mill can process 1,984 short tons of mill tailings and produce 55 short tons of nitric acid leachate per day, then 750 days of operation would be required to process the mill tailings. In addition, approximately 41,000 short tons of nitric acid leachate will be generated. Consequently, the total operating cost for a model nitric acid leaching mill at the model inactive mill tailings pile is expected to run $25 million.

Some of the construction materials used in a model nitric acid leaching mill might be employed at more than one inactive mill tailings site, or might have some scrap value. These possibilities are not analyzed here, due to the uncertainties of apportioning construction costs and determining future scrap values. We therefore assume that each inactive mill tailings site requires building a new nitric acid leaching mill at a cost of $47 million.

On the other hand, we assume that the nitric acid leaching equipment can be used at more than one inactive mill tailings site. As a result, cost of the nitric acid leaching equipment is equal to its depreciated value. Assuming two years of use at the model inactive mill tailings site, a 15-year life expectancy for the nitric acid leaching equipment, and straight-line depreciation, the expected cost of the nitric acid leaching equipment is $7 million at each model inactive mill tailings site. An additional $7 million is added to cover the costs of transportation between different mill tailings sites, set-up and take-down costs, and extra wear and tear on the equipment, as well as other contingencies.

We therefore expect the total nitric acid leaching equipment costs to be about $14 million. In total, we expect nitric acid leaching to cost about $82 million (1981 dollars) to construct, equip, operate and close down a plant for a normal tailings pile.

When combined in an asphalt or cement matrix, the nitric acid leachate matrix has a volume of 19,000m^3 and requires a 10-meter cover for proper disposal. The disposal of the nitric acid leachate would require a 15-meter pit covering an area of 0.5 hectares (100m by 50m). The possible costs of nitric acid leachate disposal are presented in Table B-5.

The NRC-FGEIS (NRC80) estimates that the concentration of radium remaining in the residual tailings after nitric acid leaching is at least an order of magnitude greater than background levels. If soil with average radon attenuation properties is available in the area, a 3.8-meter cover will provide attenuation to 0.1pCi/m^{2}s. Assuming that the nitric acid leaching process insignificantly alters the quantity of residual tailings, the control costs for the residual tailings can be computed. The costs of controlling the residual tailings are presented in Table B-6.

In summary, nitric acid leaching of the tailings for the model inactive mill site will cost $82 million. Under the best conditions, disposal of the nitric acid leachate can be expected to cost an additional $800,000 (normal soil excavation, stabilization with vegetation--no irrigation required--and isolation with a chain-link fence). Under the worst conditions, disposing of the nitric acid leachate will cost $1,300,000 (shale excavation, riprap stabilization and security fence for isolation). Control costs for the residual tailings will be $9 million at best; that is, if no liner is required,

TABLE B-5. COSTS OF NITRIC ACID LEACHATE DISPOSAL (1981$ in thousands)

Task	Cost
Earth work	
Normal digging	$300
Shale	$450
Fixation	
Asphalt	$840
Cement	$570
Stabilization	
Vegetation	
No need to purchase soil	$6
With soil purchase	$45
Irrigation	$3
Rock	$90
Gravel	$15
Chemical	$5
Fencing[a]	
Chain link	$15
Security (prison grade) fence	$53
Future costs	
Irrigation	$15
Chemical stabilization	$45
Chain link fence	$3
Value of land	$2

[a]Includes a 20m isolation around the disposal pit.

TABLE B-6. COSTS OF CONTROLLING RESIDUAL TAILINGS
(1981$ in thousands)

Task	Cost
Earth Work	
Clay liner not required	
Normal digging	$4,200
Shale	$6,290
Liner	
Clay	
With clay available	$320
With clay purchase	$780
Asphalt	$280
Synthetic	$700
None	-
Tailings excavation, loading, spreading and compacting	$1,500
Tailings transportation	
Truck	$1,300
Truck and rail	$1,100
Pipeline	$1,270
Stabilization	
Vegetation	
No need to purchase soil	$130
With soil purchase	$440
Irrigation equipment	$30
Riprap	$2,280
Gravel	$450
Chemical	$130
Fencing	
Chain link	$50
Future Costs	
Irrigation equipment	$100
Chemical stabilization	$500
Chain-link fence	$10
Value of land	$20

excavation is in normal soil, tailings are transported by truck and rail, vegetation requiring no irrigation is used to stabilize the control site, and the control site is isolated with a chain-link fence. On the other hand, the costs of controlling the residual tailings could be as high as $17 million if a clay liner is used and the clay must be purchased; if the pit excavation is in shale and trucks are the only transportation available for the tailings; if the control site is stabilized by riprap and isolated by a security fence. As a result, the cost of controlling uranium mill tailings at the normal size generic pile, using a nitric acid leaching process, could be expected to range between $92 and $100 million.

Long-Term Radon and Hydrology Control

It is unreasonable to expect that the uranium mill tailings can be completely isolated at many of the existing sites for periods much longer than 1,000 years. The concept of such long-term isolation (of both radon and ground water) essentially requires special site selection and emplacement techniques. The NRC FGEIS (NRC80) describes two methods that conceivably will meet these criteria: control in an open-pit mine and control in a deep underground mine.

In the case of an open-pit mine, the mill tailings may be loosely deposited in the pit but enclosed in a watertight liner and cap, or they can be combined with asphalt or cement to prevent leaching into the surface and ground water environment. Table B-7 presents cost estimates which assume an available open-pit coal mine or copper quarry within 10 miles. Long-term radon and hydrology control could cost as little as $10 million. This includes expenses only for excavating tailings by dragline, transporting tailings by truck and rail, and enclosing loose tailings in a watertight liner and cap. These cost estimates are relatively low because it is assumed that there is an operating open-pit mine close to the mill tailings pile, and that the mine owners are willing to cover the mill tailings at no cost as part of their post-operation reclamation of the mine site.

On the other hand, costs could increase to $86 million, if the mill tailings are deposited in an abandoned open pit mine, transported by truck, dried by a thermal evaporator, and incorporated into an asphalt matrix. It is also assumed that the control site is stabilized with vegetation, requiring the purchase of suitable top soil. Unlike the previous control levels, however, there is no long-term commitment to institutional maintenance and the site will be available for alternative future uses.

In another approach, it is assumed that a nearby abandoned underground mine is available. In this case, it is assumed that the tailings will need to be fixed in an asphalt or cement matrix to prevent

TABLE B-7. COST ESTIMATES FOR CONTROLLING URANIUM TAILINGS WHEN A NEARBY OPEN-PIT MINE IS AVAILABLE
(1981$ in thousands)

Task	Cost
Evacuate & load tailings	$1,800
Tailings transportation	
Truck	$2,000
Truck & rail	$1,700
Pipeline	$2,000
Tailings control	
Loose with liner & cap	$6,900
Cement fixation	
Thermal evaporator	$26,900
Filter bed	$16,200
Asphalt fixation	
Thermal evaporator	$37,400
Filter bed	$26,800
Disposal of mine contents	$42,200
Vegetation cover	
No need to purchase soil	$1,040
Soil purchase required	$6,900

leaching; holes will be bored into the mine cavities for depositing the asphalt or cement matrix. Cost estimates for control of the mill tailings in a deep underground mine are presented in Table B-8. Implementing this method of tailings control would cost from $20 million to $41 million.

Thermal Stabilization

Thermal stabilization involves firing the tailing to 1,200°C (22,200°F) in a rotary kiln. The high temperature changes the character of the tailings from predominantly crystalline to significantly amorphous. The amorphous material traps or "locks in" the radon and allows it to decay in place. In tests (Dr81) the emanating power of radon (from the tailings) is reduced from about 20 percent to less than 1 percent. This greatly reduces the risk from radon decay products if the tailings are misused as fill, soil conditioner, or even construction material around structures.

Thode (Th81) reports that the costs of thermal stabilization and subsequent disposal are $16 to 41 per ton of tailings. These costs can be compared to onsite costs of $2 to $7 per ton and costs of $9 to $13 per ton for moving and controlling the tailings as developed for the six alternatives. The cost of coal delivered to the tailings site is the greatest variable in Thode's analysis. He concludes that thermal stabilization could be economical under some or all of the following conditions:

1. Coal for kiln operations is inexpensive.
2. Topsoil for cover is not readily available.
3. Transportation costs to remote control areas are high.
4. Environmental (radiological) monitoring costs are high for transport to remote control areas.

B.7 Remedial Costs for Cleanup of Buildings

Summary of Relevant Data from the Grand Junction Remedial Action Program

To estimate cleanup costs for buildings, we have relied on experience accumulated in the Grand Junction remedial action program. This section summarizes the relevant experience for 217 buildings covered by that program for which data is available (Co81). Of the 217 buildings, 88 percent were residential buildings; the rest were commercial buildings (offices, motels, retail stores, etc.) and schools.

Cleanup costs are largely determined by the number of buildings requiring cleanup with passive measures (i.e. tailings removal). This number can be estimated from the distribution of radon decay product levels measured in the residential buildings (See Table 3-7) before remedial work was undertaken. (Nonresidential buildings are assumed

TABLE B-8. COST ESTIMATES FOR CONTROLLING URANIUM TAILINGS WHEN A NEARBY UNDERGROUND MINE IS AVAILABLE
(1981$ in thousands)

Task	Cost
Evacuate & load tailings	$1,800
Tailings transportaton	
Truck	$2,000
Truck & rail	$1,600
Pipeline	$1,900
Bore holes	$30
Tailings control	
Cement fixation	
Thermal evaporator	$27,800
Filter bed	$16,200
Asphalt fixation	
Thermal evaporator	$37,400
Filter bed	$26,800

to have the same distribution). We then determine the number or percentage of buildings which would have qualified for remedial action under alternative action levels for passive and active remedial work.

Different remedial action levels also influence costs because lower remedial action levels are harder to achieve; at lower levels a remedial effort will sometimes fail to reduce sufficiently the radon decay product of a buildings. This results in extra costs because these buildings will require more than one remedial action. Table B-9 shows the percent of buildings in the Grand Junction sample which exceed selected levels of radon decay products after the first remedial action effort or contract. The average number of contracts required to meet each level is determined by the formula $1/(1-x)$ where x is the fraction equivalent of the percent value in Table B-9.

The average cost of each passive remedial action (i.e. contract for residences) since the Grand Junction remedial action program began in 1972 has been about $10,000 (Co81). The cost for nonresidential buildings has averaged close to $50,000. Given the proportion of residential buildings, the average remedial cost for all buildings is about $15,000. If we multiply this by an inflation factor of 1.7 we arrive at a present average passive remedial cost per building of roughly $25,000 (1981 dollars).

Available active measures (discussed earlier) are much cheaper. These would cover a range of initial and maintainance costs, but for this exercise, we have used $2,500 as the average present cost of an active remedial measure.

Estimation of Costs

In order to estimate the cleanup cost under each alternative, it is necessary to make some specific assumptions about flexibility in using the numbers in some of the alternatives and under what circumstances active remedial measures will be used instead of (or in addition to) passive measures. These assumptions are outlined below:

Option B1: All buildings exceeding 0.015 WL would receive one initial passive remedial action. However, after the first attempt at tailings removal, buildings exceeding this level by less than 0.01 WL are assumed to receive active remedial action.

Option B2: All buildings initially exceeding 0.02 WL by more than 0.005 WL would receive passive remedial action. The rest (between 0.02 and 0.025 WL) would receive active measures. For subsequent actions, those still exceeding 0.02 WL by more than 0.01 WL would receive additional passive actions while those between 0.02 and 0.03 WL would receive additional active measures.

TABLE B-9. PERCENT OF RESIDENCES REMAINING ABOVE A SELECTED RADON DECAY PRODUCT LEVEL AFTER FIRST PASSIVE REMEDIAL ACTION[a]

Selected Radon Decay Product Concentration (WL)	Buildings Exceeding Selected Concentration After One Passive Remedial Action (Percent)	Estimated Average Number of Actions Required to Meet the Selected Concentration[b]
0.015	39	1.6
0.017	29	1.4
0.020	22	1.3
0.025	17	1.2
0.030	12	1.13
0.037	8	1.08
0.057	3	1.03

(a)Grand Junction Data.
(b)Assuming that only passive remedial actions are used.

Option B3: All buildings initially exceeding 0.02 WL by more than 0.005 WL would receive passive remedial action. The rest (between 0.012 and 0.025 WL) would receive active measures. For subsequent actions, those exceeding 0.02 WL by more than 0.01 WL would receive passive actions while those between 0.01 and 0.03 WL would receive active measures.

Option B4: All buildings initially exceeding 0.017 WL (0.007 WL above background) would receive passive remedial measures. For subsequent remedial actions only those exceeding 0.037 WL (0.03 WL above background) would receive additional passive remedial actions. No active measures are used in this alternative.

Using Grand Junction data, we have estimated in Table B-10 the number of contaminated buildings (covered by the cleanup mandated by the Act) with radon decay product levels initially above selected levels. Using this table in conjunction with Table B-9, cost data previously cited, and the implementation assumptions just detailed, we are able to estimate the cleanup costs under the various alternatives:

Option B1: Table B-10 shows that 370 buildings would require initial passive remedial actions. Table B-9 shows that these buildings would require 1.2 remedial actions on the average. Thus the total cost of passive remedial actions would be 370 x 1.2 x $25,000 = $11.1 million. We have assumed another 100 active remedial actions would be needed at a cost of $0.25 million. Thus the total remedial cost would be about $11.5 million.

Option B2: Table B-10 shows that 290 buildings would require an initial passive action and Table B-9 shows that subsequent remedial actions will increase the number of needed actions by a factor of 1.13. Thus the total costs of passive remedial action would be $8.2 million. An additional 100 active remedial actions would add $0.25 million to this for a total of roughly $8.5 million.

Option B3: Like B2, B3 will cost $8.2 million for passive remedial action. We have further assumed 300 active remedial actions for a total cost of $0.75 million, bringing the total cost to about $9 million.

Option B4: In this option, 350 buildings will require a passive remedial action. Subsequent actions will increase the number of actions by a factor of 1.08, because remedial actions stop when 0.03 WL is achieved. The total cleanup costs will, therefore, be about $9.5 million.

TABLE B-10. ESTIMATED NUMBER OF CONTAMINATED BUILDINGS EXCEEDING SELECTED CONCENTRATIONS OF RADON DECAY PRODUCTS

Selected Radon Decay Product Concentration (WL)	Number of Buildings Exceeding the Selected Concentration[a]
0.012	420
0.015	370
0.017	350
0.02	330
0.025	290
0.03	245
0.04	175
0.05	125

[a] Based on Grand Junction data, this is the number of buildings we estimate to be now contaminated above each level with tailings from all inactive tailings piles.

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Dr81 Dreesen D.R., Williams J.M. and Cokal E.J., "Thermal Stabilization of Uranium Mill Tailings," in: *Proc. 4th Symposium Uranium Mill Tailings Management*, Fort Collins, Colorado, October 1981.

EPA80 Environmental Protection Agency, *Draft Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192)*, EPA 520/4-80-011, Office of Radiation Programs, USEPA, Washington, D.C., December 1980.

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NRC80 Nuclear Regulatory Commission, *Final Generic Environmental Impact Statement on Uranium Milling*, NUREG-0706, Washington, D.C., September 1980.

PE81 PEDCO Environmental Inc., *Evaluation of Costs to Control Fugitive Dust from Tailings at Active Uranium Mills*, EPA Contract No. 68-02-3173, Task No. 053, USEPA, Washington, D.C., August 1981.

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APPENDIX C

TOXIC SUBSTANCES IN TAILINGS

APPENDIX C: TOXIC SUBSTANCES IN TAILINGS

CONTENTS

TABLES

CONTENTS (Continued)

Appendix C: TOXIC SUBSTANCES IN TAILINGS

In this appendix, we examine the toxic hazards posed by non-radioactive elements that may be present in tailings piles. We describe the types of toxicity and also (in Annex 1) describe the toxicologies of many elements likely to be found in tailings piles. We describe the various levels of concentration of substances that are known to be toxic to humans, animals, and plants and estimate the hazards from tailings. Because not all tailings piles have the same characteristics, evaluation of toxic hazards from tailings must be made on a site-specific basis.

The discussion of toxicity of these elements is not meant to be exhaustive; only acute and chronic toxicity data are usually mentioned. No attempt was made to quantitatively assess toxic element carcinogenesis, teratogenesis, or mutagenesis (God77, Ve78) because of both the scarcity of dose-response data and the controversy surrounding attempts to extrapolate data from animal carcinogenesis studies to human dose-response estimates for oral exposure (when data is available). Likewise, no attempt was made to quantitatively evaluate effects of chemical elements on specific organ systems, e.g., the cardiovascular system (Caa80) or factors influencing the toxicity of elements (Le80, EH78) as these also are unquantified or controversial toxic effects.

C.1 Concentration of Potentially Toxic Elements in Tailings

Compared to surrounding soils, mill tailings contain high concentrations of many chemical elements, some of which may be toxic. Some of these elements were laid down in the ore-bearing rock over the same time period during which the uranium was concentrated and by the same processes that concentrated the uranium, while other elements were introduced during ore processing. Since there is a detailed analysis of background soil around the tailings at only one tailings site (Dr78), some authors have compared tailings to "typical" soil (Dr81a, Table 3-3 of this EIS) or to sedimentary rock (Ma81). Such analyses may give misleading estimates of the extent and potential added impact of elemental concentration in tailings.

Dreesen and co-workers have made relatively detailed analyses at four pile sites (Dr78, Dr81a) in Table C-1 and Table 3-3. Markos and Bush (Ma81) have summarized published data for 19 piles, and an adaptation of their work is shown in Table 3-2.

TABLE C-1. ELEMENTS PRESENT IN TAILINGS FROM ACID-LEACH MILLS AND IN TYPICAL SOIL[(a)]

Element	Concentration of Element (ppm)					
	"Typical"[(b)] Soil	Salt Lake City, Utah	Shiprock New Mexico	Durango Colorado	Lakeview Oregon	Other Piles
Uranium	1.0	58-271	25-56	170-477	22	
Molybdenum	2.0	330-550	-	-	260	
Selenium	0.2	5.9-69	23-233	<0.7-28.6	40	
Vanadium	100	158-3040	709-4440	1540-4110	-	1850-2350
Arsenic	6	73-419	21-200	44-632	2030	
Chlorine	100	55-6820	27-122	521-2700	-	
Antimony	2-10	8.6-160	1.2-67	<0.5-10.1	-	
Calcium	14000	25000-82000	9000-87000	7000-57000	-	
Cerium	50	44-159	18-76	77-279	-	
Bromine	5	<1.4-6.3	<1.7	<5.0	-	
Sodium	6000	4000-10000	1000-2000	7000-47000	-	
Iron	38000	8000-316000	1200-11000	10000-41000	-	
Terbium	0.6	<0.2-1.3	<0.1-5.4	<0.2-2.3	-	
Cobalt	8	5.5-42	0.8-4.9	9.2-138	-	
Aluminum	71000	20000-67000	11000-43000	14000-72000	-	
Barium	500	194-3860	726-1240	869-4080	-	
Europium	0.5	0.35-1.33	0.33-1.27	0.36-2.13	-	
Gallium	30	<19-76	<19	<27-123	-	
Lanthanum	30	10.9-35.7	4.6-27.6	8.1-43.8	-	
Manganese	850	79-2080	21-114	91-1280	100-10000	
Scandium	7	3.0-9.5	1.1-6.9	1.8-8.4	-	
Zinc	50	<24-350	<17-175	155-2270	32	
Chromium	100	22-7250	18-54	12-3250	16	
Potassium	14000	<5000-25000	6000-19000	<1000-8000	-	
Thorium	5	4.5-33.1	1.2-7.0	1.9-9.6	-	
Titanium	5000	1420-5660	471-3130	<533-3160	-	
Ytterbium	2	<1.1-6.3	<0.5-4.2	<0.8-5.8	-	
Cesium	6	4.5-15.1	0.9-4.1	1.3-4.4	-	
Hafnium	6	2.9-7.0	3.5-8.0	4.1-8.7	-	
Magnesium	5000	<2000-14000	<1000-17000	<2000-10000	-	
Rubidium	100	46-560	18-79	39	-	
Tantalum	0.8	<0.6-1.9	<1.0	<0.5-2.6	-	
Strontium	300	<198-4130	<71-4.8	127-575	-	
Tungsten	1	4.6-570	<.05-7.6	<.05-8.7	-	
Mercury	.03	<0.01-0.13	<0.03	<0.01-0.30	34	
Lead	10	350-3100	-	-	104	812
Copper	20	310-1080	-	-	-	1160
Tin	-	60-6200	-	-	-	-
Nickel	40	550-1070	-	-	-	550-1070

(a) (Dr78, Dr81a, and FB76-78). (b) (Bo66). (-) No data.

TABLE C-2. SELECTED ELEMENTS MEASURED IN SOILS AND ROCK

		Concentration in Soil (parts per million)		Concentration in Rock (Parts per million)			
Element	Symbol	Background[a]	"Typical"[b]	Sedimentary[c]	Sandstone[d]	Limestone[d]	Shale[d]
Aluminum	Al	3730	71000	--	25000	4200	80000
Antimony	Sb	0.48	2-10	0.0n	0.05	0.2	1.5
Arsenic	As	4.4	6	1	1	1	13
Barium	Ba	351	500	n0.0	50	120	580
Boron	B	--	--	--	35	20	100
Cadmium	Cd	--	0.06	--	0.05	0.035	0.3
Chromium	Cr	22	100	35	35	11	90
Cobalt	Co	3.7	8	0.3	0.3	0.1	19
Copper	Cu	--	20	1	5	4	45
Iron	Fe	1210	38000	28000	9800	3800	47200
Lead	Pb	--	10	7	7	9	20
Manganese	Mn	167	850	400	50	1100	850
Mercury	Hg	--	0.03	--	0.03	0.04	0.4
Molybdenum	Mo	1.9	2.0	0.2	0.2	0.4	2.6
Nickel	Ni	--	40	2	2	20	68
Radium-226	Ra	--	1.5×10^{-6}	--	7×10^{-7}	4×10^{-7}	1.1×10^{-6}
Selenium	Se	1.3	0.2	--	0.05	0.08	0.6
Silver	Ag	--	0.1	0.0n	0.05	0.05	0.07
Thorium	Th	6.2	5	--	1.7	1.7	12
Tin	Sn	--	--	0.n	0.5	0.5	6
Uranium	U	2.4	1.0	--	0.45	2.2	3.7
Vanadium	V	20	100	20	20	20	130
Zinc	Zn	29	50	16	16	20	95

(a) Concentrations measured in soil around a tailings pile by Dreesen, et al., (Dr78).
(b) Concentrations in a hypothetical "typical" soil (Bo66).
(c) (Ma81).
(d) (Cap77).
"n" represents any digit from 1 to 9.

Most of the uranium ores mined in the United States are obtained from sandstones, but some also come from limestones and lignites (La80). Table C-2 lists concentrations of elements in selected soil and rock. The extent to which toxic elements are concentrated during processing of uranium ore can be determined by comparing the concentration in tailings with that in rock from which the ore was mined. However, this is not a proper measure of the hazards associated with tailings. Rather, the ratio of an element's concentration in the tailings to that in the soil surrounding the tailings is one acceptable measure of the potential hazard associated with the tailings. This concentration ratio is also a measure of the potential for contaminating ground water. If the ratio is low (e.g., <5), there is little potential for contaminating soil or ground water; if it is high (e.g., ≥ 5), then the situation should be carefully evaluated so that contamination of soil or of ground water can be avoided.

Regardless of the basis for comparison, e.g., background soil or sandstone, when Table 3-2 is compared to Table C-2, all elements are noted in elevated concentrations at one or more tailings sites. Since all sites have one or more element present in elevated concentrations, at each site these elements will have to be further evaluated on the basis of the levels at which toxicity is expected to occur in man and animals.

C.2 Acute and Chronic Toxicity

Many of the elements present in tailings are essential to life; others, as far as is known, are only toxic. However, as Mertz (Me81) and others before him have pointed out, essential elements follow Bertrand's rule, which says that for essential elements there is a level of intake:

1. So low that deficiency symptoms develop;
2. Low enough that the function of the organism is marginal;
3. Adequate, so that function is optimal;
4. High enough that function becomes marginal;
5. So high that toxicity symptoms develop.

With tailings, our concern is for the toxic effects associated with high levels of intake. In the following sections, only acute and chronic toxicity are discussed. Mutagenesis, carcinogenesis, and teratogenesis are not considered due to lack of quantitative data on intake levels associated with these toxic responses.

Acute Toxicity

In sufficient quantity, all elements can cause an acute toxic response or death. Acute toxicity is a threshold type of response; i.e., unless the concentration of toxic elements in the food or water consumed is great enough, acute toxicity symptoms will not develop. The amount of an element that must be consumed to produce these symptoms is usually specific for both the element and the chemical form in which the element is consumed (Ve78). Symptoms such as nausea, vomiting, extreme discomfort or pain, convulsions, and coma may occur, depending on the element involved (Un77, Ve78, God77). These symptoms develop very rapidly after consumption of the toxic element and in some cases eventually lead to death.

Acute toxicity, however, does not appear to be a major consideration in tailings disposal decisions. Unless the fresh-tailings pond liquid or ground or surface water with a pulse of high-level contamination from the tailings is consumed, it is unlikely that elements from tailings would be present at a concentration high enough to cause an extremely rapid toxic response.

Chronic Toxicity

Most elements can produce chronic toxicity. This condition usually occurs after continuous consumption of the element at levels well below those that cause acute toxicity. Many elements are quite insidious, since they slowly accumulate in tissues and cause the symptoms of toxicity only after a specific minimum amount has accumulated in the body (Ve78, God77). Symptoms such as lethargy, impaired function of specific organs, growth disturbances, and changes in levels of specific enzymes develop gradually and may not be noticed until they are well developed.

Much of the human data on chronic toxicity are anecdotal and do not provide an adequate base for dose-response analysis or for establishing a good "no observed effect" level. While some data on chronic toxicity are available for laboratory and domestic animals, they often refer to less-than-lifetime exposure and are for poorly defined doses. Also, there is great species variation in sensitivity to specific elements and in the physiological response to the element. So, although there are some "no observed effect" levels established for a few species, the overall picture of chronic toxicity is incomplete.

To provide a better understanding of some of the considerations involved, the toxicologies of the following selected substances found in tailings are summarized in Annex 1 following this appendix.

arsenic	mercury
barium	molybdenum
boron	nickel
cadmium	nitrates
chromium	radium
copper	selenium
cyanide	silver
iron	thorium
lead	uranium
manganese	vanadium

C.3 Estimates of the Concentration Expected to Produce Chronic Toxicity

Estimates of Chronic Toxicity in Humans

There is relatively little data on chronic toxicity of trace elements in humans. However, the National Academy of Sciences has presented material in the report, "Drinking Water and Health, Volume 3," (NAS80), which permits an estimate of a daily intake that might cause chronic toxicity. Recommendations are presented in Table C-3 as ratios of the toxic intake level to the intake level recommended by the National Academy of Sciences to satisfy nutritional requirements (Recommended Daily Allowances--RDA) in adult humans.

TABLE C-3. RATIO OF TOXIC INTAKE TO THE RECOMMENDED DAILY ALLOWANCE (NAS80)

Element	Ratio of Toxic Intake to Adult Required Daily Intake
Arsenic	10
Chromium	1000
Copper	40-135
Iron	340-1700
Manganese	120
Molybdenum	10-40
Nickel	112
Selenium	100
Vanadium	50-450
Zinc	40-280

The National Academy of Sciences characterized human daily intakes as Recommended Dietary Allowances (RDA's) when requirements were well defined or Adequate and Safe Intakes when human requirements are not well established. They also recommended intake levels for arsenic, nickel, and vanadium, although nutritional requirements for these elements are not even well established for any animals.

The estimated daily intakes, in milligrams, of elements that may cause chronic toxicity are listed in Table C-4. We have calculated these intakes using the ratios shown in Table C-3; because the estimated toxic daily intake is uncertain, actual intakes of these elements probably should not be allowed to exceed one tenth of the calculated values. Estimates of total daily intake can be calculated on the basis of the concentration of an element in the food and water (in parts per million (ppm) or micrograms per gram (ug/g)) and the amount of each consumed by persons living near the tailings. These can then be compared to the estimates of potentially toxic intake in Table C-4 to determine the

TABLE C-4. COMPARISON OF DAILY INTAKE LEVELS OF SELECTED ELEMENTS (in mg)

Element	Recommended Dietary Allowances[a]	Adequate and Safe Intake[a]	Typical Food Intake[a]	Potentially Toxic Intake[b]
Arsenic	-	(0.025-0.05)[c]	0.0114[d]	0.2-0.5
Chromium	-	0.05-0.20	0.062	5-200
Copper	-	2-3	1.5	80-400
Iron (men)	10			3000-20000
(women)	18		19	6000-30000
Manganese	-	2.5-5	1-6.4	300-600
Molybdenum	-	0.15-0.50	0.10	2-20
Nickel	-	(0.05)[c]	0.165-0.500	6
Selenium	-	0.05-0.20	0.15[e]	5-20
Vanadium	-	(0.025)[c]	0.02	1-3
Zinc	15	-	12	600-4000

[a] (NAS80).
[b] Estimated from Table C-3 and (NAS80).
[c] Estimated from animal studies--not a true recommended adequate and safe intake.
[d] Total dietary intake (food and water).
[e] Total dietary intake (food and water)--variable by region.

hazard to man. While Table C-4 was developed on the basis of the requirements of a healthy adult (e.g., 20-50 y), age-specific estimates can also be developed if required for site-specific analyses.

Estimates of Toxicity in Livestock

While there is little data on the chronic toxicity of micronutrient and elements in livestock via the water pathway, some estimates may be derived from published oral-toxicity data. The National Academy of Sciences (NAS72c) estimated water consumption for several species of livestock; both ruminants (beef cattle, dairy cattle, and sheep) and nonruminants (swine and poultry). The estimate was based on the quantity of dry matter in the ration, ambient temperature, and milk production (in the case of dairy cattle). Estimated water consumption, in liters per kilogram of dry matter in ration, for a temperate climate (70° F) are:

Beef Cattle (450 kg) - 5.3
Dairy Cattle (450 kg, 12.8 kg/day milk) - 39
Sheep - 1.5
Swine - 2.5
Poultry - 2.5

Water consumption estimates may have to be increased by a factor of two to three in hot weather, and those for dairy cattle increased further by a factor of two to three for higher milk production.

TABLE C-5. CONCENTRATION OF ELEMENTS IN ANIMAL RATION LEADING TO CHRONIC TOXICITY[(a)]

(in ppm)

Element	Beef Cattle	Dairy Cattle	Sheep	Swine	Poultry
Copper[(b-e)]	200-500	200-500	100-150	250-750	800-1600
Lead[(f)]	300	300	-	-	80
Manganese[(c)]	-	-	390-700	500	1000+
Molybdenum[(c,d)]	20-100	20-100	5-20	1000	200-4000
Selenium[(b,c,g)]	4-8	4-8	4-10	7-15	8-15
Vanadium[(c,d)]	(*** young	ruminants 20	***)	-	35+
Zinc[(c)]	900-1700	900-1700	700-1500	4000+	1200-1400

(a) Animal ration is the total feed intake, including water.
(b) (Hi77).
(c) (Un77).
(d) (Ve78).
(e) (Ro74).
(f) (NAS72a).
(g) (Fib77).

From the preceding estimates of water consumption and toxicity, when the intake in feed leading to toxic symptoms is reported, an estimate can be calculated of the concentration in water leading to a similar intake of the element. For example, concentrations in ration leading to chronic toxicity (Table C-5) have been translated, on the basis of water consumption only, to the potentially toxic water concentrations in Table C-6.

Almost all micronutrients and elements seem to interact with one another in some way, but specific recommendations are difficult to make because of incomplete data on all elements in food and water (Sa80). Therefore, it would seem prudent to limit the levels of toxic elements in water given to livestock. •Reasonable levels to recommend for continuous consumption of water might be one tenth of the lowest level expected to lead to chronic toxicity, as calculated in Table C-6. These levels are shown in Table C-7.

TABLE C-6. CONCENTRATIONS OF ELEMENTS IN WATER POTENTIALLY TOXIC TO LIVESTOCK
(in ppm)

Element	Beef Cattle	Dairy Cattle	Sheep	Swine	Poultry
Copper	37.8-94.3	5-13	67-100	100-300	533-1067
Lead	56.6	7.7	-	-	53
Manganese	-	-	260-467	200	667+
Molybdenum	3.8-18.9	0.51-2.6	3.3-13.3	400	133-2667
Selenium	0.75-1.5	0.10-0.20	2.7-6.7	2.8-6	5.3-10
Vanadium	3.8	0.51	13.3	-	23+
Zinc	170-321	23-44	467-1000	1600+	800-933

TABLE C-7. RECOMMENDED MAXIMUM CONCENTRATIONS OF ELEMENTS IN WATER FOR LIVESTOCK
(in ppm)

Element	Estimates based on Table C-6		NAS Recommendations for Livestock (NAS72c)
Aluminum	-	-	5
Arsenic	-	-	0.2
Boron	-	-	5
Cadmium	-	-	.05
Chromium	-	-	1
Cobalt	-	-	1
Copper	40	(0.5 for dairy cattle)	0.5
Fluoride	-	-	2
Lead	5	(0.5 for dairy cattle)	0.1
Manganese	20	-	-
Mercury	-	-	.01
Molybdenum	0.3	(0.05 for dairy cattle)	-
Nitrate-N	-	-	100
Selenium	0.1	(0.01 for dairy cattle)	0.05
Vanadium	0.4	(0.05 for dairy cattle)	0.1
Zinc	20	(2 for dairy cattle)	25

For most of the elements addressed in Table C-7, the NAS in 1972 had recommended concentrations in water for livestock. However, in the case of many elements, the NAS proposed upper limits in water were based on the usually low natural level of the element in sources of water rather than the toxicity of the element. Thus, in Table C-7, the estimates based on Table C-6 and the NAS recommendations are, not surprisingly, different because their bases are different.

The levels of elements in Table C-6 have about a tenfold uncertainty. Also, the estimated toxic level would vary by site. Estimated levels in water causing toxicity may be increased by a factor of two to three for interactions of various elements (e.g., high copper partially offset by high zinc and iron) or be increased a factor of two or three because of differences in biological availability of various elements. On the other hand, the estimated level in water causing toxicity may have to be reduced a factor of two or three in the case of larger animals or higher average temperatures. The level may also have to be decreased to allow for high levels of the same elements in forage.

Estimates of Toxicity in Crops

In their publication, "Water Quality Criteria, 1972," the National Academy of Sciences (NAS72c) estimated levels of elements in irrigation water that might be toxic to agricultural crops grown using such water (Table C-8). The authors considered these elements to be retained in the soil and to reach a level toxic to crops in 20 years or 100 years, depending on soil type. Since a negligible concentration of the elements was removed from the soil by crops during the 20- or 100-year period of irrigation, the soil concentrations would build up and would be in the range of concentrations that had been reported in published literature to be toxic to crop plants. No specific consideration was given to bioaccumulation, bioconcentration, or biological availability of the elements in crops. Note that for some of the elements addressed, water meeting the Maximum Contaminant Levels in the National Interim and Secondary Drinking Water Regulations would not be suitable for irrigation.

The estimate of irrigation water concentrations developed by the National Academy of Sciences also provides a way to estimate soil concentrations of equivalent impact. In the NAS estimate (NAS72c), irrigation water is used at a rate of 3-acre ft/acre per year, so that an element present at 1 ppm will be deposited at the rate of 8.13 lbs/acre per year, mixed in the top 6 inches of soil. For example, if the soil weighs 1.5 grams per cubic centimeter, 1 ppm in irrigation water would yield a soil concentration of 4 ppm in soil per year of irrigation.

This conversion factor is used to estimate the concentration in soil toxic to crops (Table C-9). The soil concentrations calculated are for ions or soluble salts of the element and not for the total concentration of the element in soil. Soils containing elements at

TABLE C-8. MAXIMUM CONCENTRATION OF ELEMENTS IN IRRIGATION WATER NOT IMMEDIATELY TOXIC TO CROPS (NAS72c)
(in ppm)

Element	Water used continuously on all soils (calculated on the basis of 100 years)	Water used up to 20 years on fine textured soils of pH 6.0 to 8.5
Aluminum[a]	5.0	20.0
Arsenic	0.10	2.0
Beryllium	0.10	0.5
Boron	0.75	2.0
Cadmium	0.01	0.05
Chromium	0.10	1.0
Cobalt	0.05	5.0
Copper	0.20	5.0
Fluoride	1.0	15.0
Iron	5.0	20.0
Lead	5.0	10.0
Lithium	2.5[b]	2.5[b]
Manganese	0.20	10.0
Molybdenum	0.010[c]	0.05[c,d]
Nickel	0.20	2.0
Selenium	0.02[c]	0.02[c]
Vanadium	0.10	1.0
Zinc	2.0	10.0

(a) Soil conditioned with $CaCO_3$ when necessary.
(b) 75 ug/l for citrus crops.
(c) Rased on potential toxicity in animals.
(d) Relatively high iron oxide content in soil.

TABLE C-9. CONCENTRATIONS OF ELEMENTS IN IRRIGATION WATER AND SOIL THAT COULD BE IMMEDIATELY TOXIC TO CROPS (in ppm)

Element	All Soils		Finely Textured Soils (pH 6.0 to 8.5)	
	Irrigation Water[a]	Soil	Irrigation Water[b]	Soil
Aluminum	500	2	400	1.6
Arsenic	10	0.04	40	0.16
Beryllium	10	0.04	10	0.04
Boron	75	0.3	40	0.16
Cadmium	1	0.004	1	0.004
Chromium	10	0.04	20	0.08
Cobalt	5	0.02	100	0.4
Copper	20	0.08	100	0.4
Fluoride	100	0.4	300	1.2
Iron	500	2	400	1.6
Lead	500	2	200	0.8
Lithium	250[c]	1	50[c]	0.2
Manganese	20	0.08	200	0.8
Molybdenum	1[d]	0.004	1[d,e]	0.004
Nickel	20	0.08	40	0.16
Selenium	2[d]	0.008	0.4[d]	0.0016
Vanadium	10	0.04	20	0.08
Zinc	200	0.8	200	0.8

(a) 100 years times the appropriate concentration from the first column of Table C-8.

(b) 20 years times the appropriate concentration from the second column of Table C-8.

(c) 7.5 ppm for citrus crops.

(d) Based on potentially high toxicity in animals.

(e) Relatively high iron content in soil.

NOTE: Soil concentrations listed here are concentrations of the element in ionic or soluble form and do not represent the total soil concentration of the element.

concentrations shown in Table C-9 would probably not be good for agricultural needs regardless of whether windblown or water-borne tailings were the source of the contamination. Because of differences among tailings sites in elements and concentrations of elements, soils, and plant life, the possibility of toxicity to plants from tailings should be considered on a site-specific basis. Shacklette, et al., have reviewed much of the literature on trace elements in plants and have listed reported concentrations of elements in various plants and estimates of their potential toxicity (Sha78). Some plants and foodstuffs probably should not be grown or may be impossible to grow around tailings.

The question of toxicity to humans or animals from plants grown in the presence of tailings or irrigated with water containing elements from tailings must also be addressed on a site-specific basis. The question is too complex for generic analysis. Studies have shown bioconcentration of elements by many plants. Clover concentrates selenium and molybdenum (Fu78), and selenium and arsenic bioconcentration has been reported in native plants growing on inactive piles (Dr78). Such findings suggest that livestock access to vegetation growing near (even stabilized) tailings may have to be restricted.

The level of protection afforded human health may not be adequate for animals and plants. In specific cases, animal rations may have to be supplemented or special soil conditioners used. Land and streams near mill tailings may never be suitable for dairy or citrus farming, or trout fishing, but, at worst, only transient economic losses would occur.

C.4 Estimate of Hazards from Tailings

Water

Although there is no proof of ground water contamination from inactive tailings (Chapter 4 in this EIS), the potential exists. The daily intake of selected elements in water expected to cause toxicity in man is given in Table C-4, and the concentrations of selected elements in water expected to cause toxicity in animals or plants are given in Tables C-6 to C-9. Either measured or calculated levels of contamination in ground water can be compared with the values in these tables to estimate the margin of safety or potential hazard associated with use of the water.

The National Academy of Sciences (NAS72c) pointed out some of the many differences between ground and surface waters. Movement of ground water can be extremely slow, so that contamination of an aquifer may not become evident at the site of use for tens, hundreds, or even thousands of years; bodies of ground water cannot be adequately monitored by sampling at the point of use. Mixing is different in ground and surface waters. Dispersion in ground water is often incomplete for many years. The long underground retention of ground water facilitates microbial and chemical reactions that may remove pollutants.

However, because of their common use as private water supplies in rural areas, all geologically unconfined (water-table) aquifers could be classified as raw surface waters used for public water supplies (NAS72c). In fact, the NAS recommended that raw ground water criteria should be more restrictive than those for raw surface water because of the assumption that no treatment, or very little treatment, is given to ground water (NAS72c). This would be particularly true in rural areas, where ground water is used extensively since its sources are generally regarded as a more dependable supply and are less variable in composition than surface water sources (NAS72c).

While protecting groundwater to at least the same level as finished drinking water would provide protection to persons drinking the untreated groundwater, the degree of protection provided by finished drinking water will not protect livestock from all toxic elements. Restricting water use to specific purposes may be required in some cases to minimize not only human health effects but also economic loss from agricultural impact.

Food and Feeds

While contamination of ground water is only a potential hazard, contamination of soil with windborne tailings has been observed. Douglas and Hans (Dob75) estimated the extent of windblown tailings based on gamma count rate contours at 21 inactive sites. They reported measurable increases due to windblown tailings at some hundreds of meters from the piles; the maximum distance was about 1.5 km at one pile. Schwendiman, et al. (Scb80), sampled soil and air around a tailings pile and assayed the samples for radioisotopes and stable elements. At the site studied, radium-226 was found in concentrations of 4.5 pCi/g at 4.8 kilometers and 2.25 pCi/g at 8 kilometers in the prevailing downwind direction. Since elevated concentrations of both radioisotopes and stable elements were measured in air samplers, stable elements from the pile are probably distributed to the same extent as the radium-226.

The real hazard of these windblown tailings has been demonstrated by two analogous situations in which molybdenosis has been observed in cattle grazing on contaminated land. In the first case, windblown flyash from rotary kilns ashing lignite coal to upgrade the uranium content apparently contaminated pastureland in southwestern North Dakota (Chc68-69). In the second case, copper deficiency/molybdenosis was associated with spoils or other sequelae of open-pit uranium mining in Karnes County, Texas (Doa72). Whether the local contamination was due to wind or to water erosion is not clear, but the source of contamination is certain.

The possibility of ingesting elements from windblown tailings via the food pathway can be estimated, but only in a very general way. The concentration of elements in tailings is site-specific, as are the meteorological conditions that would disperse them. Land composition and agricultural practices are also site-specific. All these factors would influence a site-specific evaluation of hazards from the tailings.

The approach suggested here uses the ratio of the average concentration of an element in tailings to the average concentration of radium-226 in tailings as a conversion factor. This conversion factor allows us to calculate, as a first approximation, the concentration of the element at any point at which we know the radium-226 concentration. Since the physical processes moving tailings around the environment are relatively independent of composition, we consider this ratio a constant. Thus, if there is 100 ppm of an element and 100 pCi/g of radium-226 in a tailings pile, the ratio is one, and if the measured radium-226 concentration in windblown tailings is 10 pCi/g, the expected element concentration is 10 ppm, etc.

Radium-226 was chosen as the reference isotope since so many studies of tailings piles have been directed to establishing the extent of windborne contamination with radium-226 (Dob75). However, ratios could be developed for any two elements. The distribution of radioisotopes with distance around the pile studied by Schwendiman, et al. (Scb80), suggests the ratio is good within a factor of plus or minus three.

To estimate the hazard level of a pile, the calculation must consider not only soil concentrations, but also the uptake of elements from soil by crops. Investigators at Oak Ridge National Laboratory have been developing transfer factors for soil/plant uptake (i.e., the ratio of ppm of an element in plant tissue to ppm of the element in soil) as a function of element. Two transfer factors have been described:

1. b_v, for uptake in vegetative (e.g., stems and leaves) portions of plants,

2. b_r, for uptake in the reproductive and storage portions (e.g., fruits and tubers) of plants (Baa81).

In addition, the total quantity of vegetative and reproductive portions of plants will vary with diet and age of persons eating them. This also must be considered. Rupp has developed estimates of age-specific average daily intakes of foods (Ru80). Her estimates can be used to group foods by age for the two factors b_v and b_r (Table C-10).

TABLE C-10. ESTIMATED AVERAGE DAILY INTAKE OF FOODS BY SELECTED AGE GROUPS[a] (in grams)

Food	Uptake Class[b]	Age Group: 1 yr	1-11 yrs	12-18 yrs	>18 yrs	Avg[c]
Potatoes	(b_r)	6	49	67	69	65
Vegetables:						
Deep Yellow	(b_r)	12	7	7	8	8
Legumes	(b_r)	12	22	28	25	25
Leafy	(b_v)	2	20	30	50	43
Other	(b_v)	50	58	82	99	90
Fruit:						
Citrus, Tomato	(b_r)	23	74	93	99	93
Other	(b_r)	112	112	116	87	94
Dry	(b_r)	3	2	1	1	1
Grain	(b_r)	21	87	113	97	96
Nuts, Nut Butter	(b_r)	2	9	10	5	6
		243	440	547	540	521
Total						
b_v		52	78	112	149	133
b_r		191	362	435	391	388

(a) Data from Rupp (Ru80).
(b) Classes from Baes, et al. (Baa81):
b_v, for uptake in vegetative portions of plants.
b_r, for uptake in reproductive and storage portion of plants.
(c) Age-weighted average using weights of 1/71, 11/71, 7/71, and 52/71 for each age group.

Using the uptake factors b_v and b_r, we can estimate the concentration of elements in soil that will produce an elemental concentration of 1 ppm (100 ug/100g air-dried weight of food) in the components of a locally grown diet (Table C-11). The estimated soil concentrations for 1 ppm of elemental uptake calculated on an air-dried weight basis can be converted to soil concentrations yielding 1 ppm of an element in fresh food crops (S_h = soil concentration in ppm yielding 1 ppm in air-dried crops consumed by humans) and forage crops (S_a = soil concentration in ppm yielding 1 ppm in air-dried crops consumed by animals). This assumes the air-dried weight is 25 percent of the fresh weight (Baa81). These soil concentrations, yielding 1 ppm of an element in food crops, are compared (Table C-12) with:

1. The concentrations that, in a 500-gram diet (25 percent b_v vegetative, 75 percent b_r reproductive crops), would yield a daily intake equal to the limit of Safe and Adequate Intakes recommended by the National Academy of Sciences and concentrations that would yield a potentially toxic intake as estimated from data published by the National Academy of Sciences.

2. Those potentially toxic (in the case of forage crops) concentrations in the livestock rations. The uncertainty in the intake leading to chronic toxicity is reflected in the range of estimates for some elements.

Using values in Table C-12 and Table 3-2, we can estimate the potential land contamination around each pile that would produce crops that are hazardous to man and animal. For example, the Slick Rock (NC), Colorado, site may be contaminated with hazardous levels of lead out to the 28-pCi/g radium 226 contour if the hazardous soil concentration of lead is considered to be 45 ppm. Mercury levels may be hazardous out to the 45-pCi/g radium-226 contour.

Similar analyses could be developed when contaminated water is used to irrigate crops. In any case, the potential hazard associated with uncovered inactive tailings should be evaluated on a site-specific basis. The analysis should consider not only radioactive, but also stable elements in tailings and food or feed and water pathways.

C.5. Plants and Animals on Tailings Piles

Plants

Plants growing on tailings piles may take up elements from the tailings. Uptake of radioactive and other elements from tailings has been reported by several investigators (Dr78, Dr79, Mo77). Although uptake can produce appreciable concentrations of radionuclides in plants growing on tailings, there does not seem to be any radioisotope bioconcentration, i.e., the concentration in vegetation does not exceed the concentration in the tailings (Dr78, Dr79, Mo77). For example, radium-226 concentration in vegetation is usually 0.03 of that in tailings or less (Dr79, Mo77). However, in some species of vegetation, the radium-226 concentration has been as high as 0.25 or 0.30 of that in the tailings (Dr79).

In the case of most elements, the concentration is from 0.0006 to 0.40 of that of the tailings (Dr78, Dr79). However, some elements are bioconcentrated; i.e., nickel, selenium, molybdenum, arsenic, which attain concentrations 1 to 10 times that in the tailings (Dr78, Dr79). Animals consuming such vegetation may be protected to some extent,

TABLE C-11. ESTIMATED CONCENTRATION OF ELEMENTS IN SOIL THAT WILL PRODUCE A CONCENTRATION OF 1 ppm IN CROPS

Element	Transfer Factor (x 10^{-3})			Soil Concentration (ppm) Yielding 1 ppm in Air Dried Crop	
	b_v	b_r	b_e [(a)]	Food[(b)] S_h	Forage[(c)] S_a
Arsenic	40	6.0	15	67	25
Barium	150	15	49	20	6.7
Boron	4000	2000	2500	0.40	0.25
Cadmium	550	150	250	4.0	1.8
Chromium	7.5	4.5	5.3	190	130
Copper	400	250	290	3.4	2.5
Iron	4.0	1.0	1.8	560	250
Lead	45	9.0	18	56	22
Manganese	250	50	100	10	4.0
Mercury	900	200	380	2.6	1.1
Molybdenum	250	60	110	9.1	4.0
Nickel	60	60	60	17	17
Selenium	25	25	25	40	40
Silver	400	100	180	5.6	2.5
Tin	30	6.0	12	83	33
Vanadium	5.5	3.0	3.6	280	180
Zinc	1500	900	1100	0.91	0.67

(a) $b_e = 0.255\ b_v + 0.745\ b_r$.
b_v = vegetative portions of plants
b_r = reproductive and storage portions of plants

(b) Crops used in human diet:
S_h = soil concentration (ppm) that yields 1 ppm in crops consumed by humans.

(c) Crops used to feed livestock:
S_a = soil concentration (ppm) that yields 1 ppm in crops consumed by animals.

TABLE C-12. SOIL CONCENTRATIONS OF ELEMENTS THAT MIGHT BE ASSOCIATED WITH TOXIC CONCENTRATIONS IN THE FOOD PATHWAY

Element		Soil Concentration Yielding 1 ppm (1 ug/g) Wet Wt.[a]	Concentrations[b] (ppm) in Ration Toxic to Livestock		Human[c] Adequate & Safe Intake	Soil[d] Concentration for Potentially	
			Ruminants	Nonruminants	(ug/d)	Safe Human Intake (ppm)	Toxic Human Intake (ppm)
Arsenic	S_h	268	-	-	50	26.8	322 to 1610
	S_a	100	-	-	-	-	-
Boron	S_h	2.5	-	-	-	-	5000+
	S_a	1.0	-	-	-	-	-
Barium	S_h	80	-	-	-	-	16000+
	S_a	26.8	-	-	-	-	-
Cadmium	S_h	16	-	-	-	-	19.2
	S_a	7.2	-	-	-	-	-
Chromium	S_h	3960	-	-	200	1580	79200
	S_a	520	-	-	-	-	-
Copper	S_h	13.6	-	-	3000	82	41 to 6800
	S_a	10	100-500	250-1600	-	-	-
Iron	S_h	2240	-	-	18000	80640	N/A
	S_a	1000	-	-	-	-	-
Lead	S_h	224	-	-	-	-	44.8 to 1434
	S_a	88	300	80	-	-	-
Manganese	S_h	40	-	-	5000	400	1600
	S_a	16	400-700	500+	-	-	-
Mercury	S_h	10.4	-	-	-	-	6.24
	S_a	4.4	-	-	-	-	-
Molybdenum	S_h	36.4	-	-	500	36.4	728 to 1092
	S_a	16	5-100	200-4000	-	-	-
Nickel	S_h	68	-	-	50	6.8	760
	S_a	68	-	-	-	-	-
Selenium	S_h	160	-	-	200	64	224 to 22400
	S_a	160	4-10	7-15	-	-	-
Silver	S_h	22.4	-	-	-	-	9.0
	S_a	10	-	-	-	-	-
Tin	S_h	332	-	-	-	-	9960 to 43160
	S_a	132	-	-	-	-	-
Vanadium	S_h	1120	-	-	25	56	22400
	S_a	720	20 (Young)	35+	-	-	-

(a) Calculated from Table C-11 on the basis of: Air Dry Weight = 0.25 Wet Weight.
(b) From Table C-5.
(c) From Table C-4.
(d) Calculated on the basis of data in NAS80.
\- (No data).

since the major concentration may occur in the roots of the plants (Chb79). However, the biological availability of the elements may be changed by incorporation into the plants (Ti77). The extent to which this occurs and the consequences are unknown.

For a few plants, whether the tailings are covered or uncovered may be moot. Whicker (Wh78) cites reports that many of the species of grasses and forbs of the Great Plains have root systems that penetrate to 2 to 5 meters; 50 percent of the plains and prairies species penetrate 5 to 7 meters and some desert basin plants 2 to 3 meters. Depending on cover depth and erosion rates, even covered tailings may be accessible to the roots of plants growing over them.

Such root penetration should not cause a major problem, since potentially affected areas are small (See Table 3-6) and, even if access is not restricted, these plants will not be the only source of food for the animals. In addition, as the roots enter zones of higher element concentrations, the root uptake should decrease. Barber and Claassen (Bab77) have reported that the root uptake-soil concentration relationship was curvilinear, asymtoticly reaching a maximum total uptake as soil concentration increases; i.e., the uptake fraction decreases as soil concentration increases.

Animals

Small burrowing and other animals may penetrate covered and uncovered tailings. Whicker (Wh78) cites reports showing that most burrowing animals confine their activity to the top meter of soil, although the Great Basin pocket mouse (Perognathus parvus) may burrow to a depth of 2 meters and harvester ants (Pogonomyrmex occidentalis) may go to a depth of over 3 meters. There are no data on elemental poisoning in these animals.

ANNEX 1

TOXICOLOGY OF SELECTED ELEMENTS FOLLOWING ORAL ADMINISTRATION

ARSENIC

Arsenic is a metal which is perhaps, but not yet proven, essential to human nutrition (NAS80). It is widely distributed in nature and used extensively in medicine and agriculture. The pentavalent form (As^{+5}) is less toxic than the trivalent form (As^{+3}), but usually more teratogenic[(1)] (Ve78). Twenty-three milligrams of arsenic taken as arsenic trioxide have been fatal (Jo63).

Chronic arsenic poisoning produces skin abnormalities, proteinuria, anemia, and swelling of the liver. Some cardiac and nervous disorders have been observed in Japan among persons drinking well water containing 1 to 3 ppm of arsenic (Te60). Epidemiologic studies of chronic arsenic poisoning in Antofagasta, Chile, found a high incidence of skin and cardiovascular abnormalities, chronic coryza and abdominal pain, and some chronic diarrhea in children who drank water containing 0.6 to 0.8 ppm of arsenic (NAS77). The incidence of skin lesions decreased by a factor of about 16 when the arsenic content of the water was decreased to 0.08 ppm (NAS77), but the effects did not disappear completely.

Chronic consumption of arsenic has also been associated with increased incidence of lung cancer (Ve78) and skin cancer (Ve78, NAS77, God77). Another epidemiologic study of chronic arsenic poisoning in Taipei found skin cancer, hyperpigmentation, keratosis and blackfoot disease (peripheral arteriolar disorder leading to gangrene of extremities, especially the feet) with prevalence of 1.6, 18.3, 7.1 and 0.89 percent, respectively, in persons drinking well water containing arsenic (Ye73). The prevalence of skin cancer, hyperpigmentation and keratosis increased with age. Hyperpigmentation developed after at least a 5-year exposure to the arsenic in water, keratosis after at least 14 years and skin cancer after at least 20 years (Ts77). The concentration of arsenic in well water used by these people ranged from about 20 to 1100 micrograms per liter (Ts77).

BARIUM

Barium is another metal apparently not essential to human nutrition. It is widely distributed in nature and used in industry, medicine, and agriculture. Consumption of 550 to 600 milligrams of barium as barium chloride has been reported to be fatal (So57).

Acute toxic doses of ingested barium cause abnormal muscle stimulation due to induced release of catacholamines from the adrenal medulla. This may be accompanied by salivation, vomiting, violent diarrhea, high blood pressure, hemorrhage into organs, and muscular

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[(1)] Teratogenicity is the capability to cause abnormal fetal development.

paralysis. There is, however, no evidence of chronic toxicity from long-term consumption of barium in humans or in animals (NAS77, Un77).

BORON

Boron is a minor element in the environment, extracted primarily from evaporated deposits in a few borax lakes. It may be released in volcanic gases or dissolved from deposits by water and transported as boric acid or as a borate. Boron is an essential element for plants, but it does not seem to be essential for animals (Un77). Although boron is essential for plants, it is also toxic. Some crops are sensitive to concentrations greater than or equal to 1.0 ppm of boron in irrigation water (NAS72a).

Acute poisoning has occurred from boric acid and borax, usually accidentally. The fatal dose of boric acid is around 3 to 6 grams in infants and 15 to 20 grams in adults (Goa54, Gob65), and for borax around 25 to 30 grams (Goa54). The first symptoms are nausea, vomiting, and diarrhea followed by a drop in body temperature, skin rash, headache, depression of respiratory centers, cyanosis, and circulatory collapse. Death may occur in hours or a few days.

No chronic toxicity from boron compounds has been reported. Gastrointestinal and pulmonary disorders have been reported in lambs grazing on pastures with high boron concentrations and drinking water containing 0.2 to 2.2 ppm boron. However, mice, given 5 ppm boron in drinking water during lifetime studies, showed no effects (Un77).

Human diets normally supply 2 to 4 mg boron per day, but since boron occurs in higher concentrations in foods of plant origin, people consuming large quantities of fruits and vegetables may have daily boron intakes of 10 to 20 milligrams (Un77).

CADMIUM

Cadmium is a metal distributed in the environment in trace quantities, except in some zinc, copper, and other ores. It is not essential to human nutrition and is used mainly in industry. Acute fatal poisoning with cadmium is rare because cadmium salts cause vomiting when consumed. Acute poisoning from consuming food or drink contaminated with cadmium occurs 15 to 30 minutes after swallowing 15 to 30 milligrams of cadmium (EPA79). Symptoms include continuous vomiting, salivation, choking sensations, abdominal pain, and diarrhea. Acute toxicity symptoms have been reported in school children eating popsicles containing 13 to 15 ppm (EPA79).

Absorbed cadmium is toxic to all body organs, damaging cells and enzyme systems. It is bound tightly in the body, and little is excreted, so it accumulates over the lifetime. In Japan, among people who consumed about 0.6 milligrams of cadmium per day, chronic toxicity was reported (EPA76). The illness was called "Itai-itai" disease and resulted in bone and kidney damage. Symptoms were seen mostly in older women whose diets were lacking in protein and calcium (Un77, NAS77). Since cadmium toxicity is moderated by calcium, zinc, copper, manganese (Un77), selenium, iron, vitamin C, and protein (God77), diet is an important factor in cadmium poisoning.

The earliest symptom of chronic cadmium toxicity is kidney damage, evidenced by increased protein in the urine. This occurs when the cadmium level in the renal cortex reaches 200 to 300 ppm of wet weight (EPA76, EPA79). This 200-ppm level can be reached after consuming about 350 micrograms of cadmium a day for 50 years (EPA76). Consumption of only 60 micrograms a day has been estimated to cause kidney damage in 1 percent of the exposed group (EPA79). The body retains as much cadmium from smoking one pack of cigarettes per day as from ingesting 25 micrograms of cadmium a day (EPA79).

High levels of cadmium have caused reproductive disturbances and teratogenesis in experimental animals (Ve78, Un77, EPA79, NAS77). It has also been implicated in human hypertension, cardiac problems, and prostatic carcinogenesis (Un77, EPA79, God77, NAS77), but the connection is not well defined. However, a well-defined pathology in heart, liver and kidneys of animals fed 5 ppm of cadmium in their diet has been established (Ko78).

CHROMIUM

Chromium (Cr^{+3}) is a metal that is essential to human nutrition; it is involved in glucose and lipid metabolism and protein synthesis (Un77). It is widely distributed in nature and has many industrial applications. Oral toxicity is low; humans can tolerate 500 milligrams daily of chromic sesquioxide (Ve78). Hexavalent chromium (Cr^{+6}) is much more toxic than trivalent (Cr^{+3}) (Un77, NAS80, Ve78). The principal damage in acute chromium poisoning is tubular necrosis in the kidney. Large enough doses of hexavalent chromium can cause gastrointestinal tract hemorrhaging, but lifetime exposure of laboratory animals to less than 5 ppm of chromium in drinking water caused no reported effects (NAS77, Un77).

No information exists on the effects of chronic chromium consumption by humans. Skin hypersensitivity to chromium has been reported to be second only to nickel hypersensitivity as the most common form of skin sensitization in some studies (Ka78).

COPPER

Copper is widely distributed in nature. Its principal uses are industrial, especially electrical. It is an essential element in human nutrition.

The prompt emetic action of copper salts tends to limit their acute toxicity. However, copper is occasionally leached into acidic beverages. Symptoms of toxicity following ingestion (cramps, vomiting, and diarrhea) usually occur in 10 to 90 minutes and last less than 24 hours (Ve78). Copper is usually more toxic in drink than in food. In infants, 7 ppm of copper is fatal (Ve78). In adults, 175 to 250 milligrams of copper taken as copper sulfate may be fatal (Ve78).

Persons with Wilson's disease, a disorder of copper metabolism, and persons with glucose-6-phosphate dehydrogenase defficiency may be abnormally sensitive to chronic copper poisoning (Ve78). Persons with Wilson's disease may be adversely affected by consumption of about 1.5 milligrams of copper a day (NAS80).

CYANIDE

Cyanide is composed of carbon and nitrogen (CN). The most toxic forms of cyanide are hydrogen cyanide (HCN) and free cyanide ions (CN^-). It is not essential to human nutrition and is used or formed in many industrial processes and used in agriculture.

Consumption of 50 to 200 milligrams of cyanide or its salts causes death in 50 percent of those exposed (Goc76). Death usually occurs within 1 hour. Cyanide interferes with the essential enzyme cytochrome C oxidase. This enzyme is required by all cells using oxygen, particularly those in the brain and heart. However, there is no chronic or cumulative toxicity, since the adult body can convert doses of 10 milligrams or less to the much less toxic thiocyanate ion and excrete it (EPA76).

IRON

Iron, a metal essential for human nutrition, is involved in oxygen transport and enzyme systems. The element is very widely distributed in nature and has medical, agricultural, and industrial applications. Ingestion of 40 to 590 milligrams of iron per kilogram of body weight as $FeSO_4$ has been fatal (Ve78); however, intakes of 25 to 75 milligrams per day have been cited as safe (Un77). Toxic doses of iron, e.g., 100+ milligrams per kilogram, can cause liver and gastrointestinal tract damage, hypotension, prostration, and peripheral cardiac failure (Ve78).

There are no reports of chronic toxicity due to iron ingested by animals or humans in the United States. Consumption of 200 mg of soluble iron per day has caused siderosis in malnourished Bantus in South Africa (Un77).

LEAD

Lead is a metal widely distributed in nature and used extensively in industry and agriculture; it is not essential to human nutrition. The amount of lead absorbed before symptoms of toxicity appear is rarely known; however, one man ingested 3.2 milligrams per day for 2 years before symptoms occurred (NAS72a).

Toxicity is usually related to levels of lead in the blood. A level of 3.3 ppm in blood has been associated with acute brain pathology and death in children (NAS72a). Levels of 0.8 ppm and greater have been associated with brain, peripheral nervous system, and kidney pathology and severe colic, seizures, paralysis, blindness, and ataxia in children (NAS72a, God77, NAS77, Un77). Subclinical (hard to detect because clinical symptoms are lacking) effects on the central nervous system, red blood cells, kidneys, and enzymes may occur at levels of 0.4 to 0.8 ppm in blood (God77). In women and children some changes in red cells can be detected at 0.25 to 0.3 ppm in blood (NAS77).

Continued drinking of water containing 0.1 ppm could produce lead levels of 0.25 to 0.4 ppm in blood (Un77, NAS77). Such exposure could contribute to clinical lead poisoning, particularly in children (NAS77).

MANGANESE

Manganese is a metal widely distributed in nature. It is used extensively in industry, but infrequently in medicine. It is essential to human health. Toxicity is related to its valence state, probably through solubility. Mn^{2+} is more toxic than Mn^{3+}, and higher oxides are more toxic than lower oxides (Ve78).

Most chronic manganese toxicity is related to industrial exposure. Metal fume fever, a pulmonary pneumonitis, may result from a few months inhalation of manganese oxide fumes at concentrations of 1000 ppm or greater depending on the oxidation state of the manganese and the chemical compound involved (Ve78). Chronic manganese toxicity can occur following inhalation or ingestion for 6 months to 2 years. "Manganism", the condition that results, is characterized by a severe psychiatric disorder resembling schizophrenia and is followed by a permanently crippling neurological disorder clinically similar to Parkinson's disease (Un77). There are degenerative changes in the brain, liver, and kidneys (Ve78). The condition appears to be irreversible (Un77, Ve78).

Normal dietary intakes of 3 to 7 milligrams per day (NAS77) or 8 to 9 milligrams per day (NAS80) have been considered safe. However, there is a report of manganism with neurological symptoms and death in two patients (one suicide case) in a Japanese incident where 16 persons were exposed to manganese and zinc in drinking water. While the duration of exposure and amount of water consumed are not known, the water contained 14 ppm of manganese and the estimated daily intake was 20 milligrams (NAS80).

MERCURY

Mercury is a metal not essential to human nutrition. It is distributed in nature as a trace element, except in some metal ores, and has many industrial applications. Consumption of 158 milligrams of mercury as mercuric iodide has been reported to be fatal (Ve78). Acute effects of nonfatal doses of mercury salts include local irritation, coagulation and necrosis of tissue, kidney damage, colitis, hallucinations, and a metallic taste in the mouth.

As is the case with lead, chronic mercury poisoning develops slowly. Many of the symptoms relate to the nervous system: impaired walking, speech, hearing, vision, or chewing and insomnia, anxiety, mental disturbances, and ataxia. There also may be damage to kidneys, blood cells, and the gastrointestinal tract, and enzyme systems (NAS77, Ve78). Studies of Minamata disease (methyl mercury poisoning) suggest that consumption of 1 milligram of mercury per day as methyl mercury over a period of several weeks will be fatal (Ve78); consumption of 0.3 milligrams per day will cause clinical symptoms of mercury poisoning (Un77, NAS77). About 10 times as much methyl mercury would be absorbed as inorganic mercury (God77).

Mercury passes through the placenta. It has caused cases of Minamata disease through fetal exposure (NAS77) and may cause birth defects (Ve78, Un77).

MOLYBDENUM

Molybdenum is a metal essential in trace quantities for human nutrition. It is present in nature in trace quantities, except in some ores. It has been widely used in industry. There are no data for acute toxicity of molybdenum following ingestion by humans, but the animal data (Ve78) show that toxicity results from intakes of around hundreds of milligrams per kilogram of body weight.

Chronic toxicity symptoms have been reported in 18 percent to 31 percent of a group of Armenian adults who consumed 10 to 15 milligrams of molybdenum per day and in 1 percent to 4 percent of a group consuming 1 to 2 milligrams of molybdenum per day (Cha79, NAS80). Clinical signs of the toxicity were a high incidence of a gout-like disease with arthralgia and joint deformities, and increased urinary excretion of copper and uric acid. Increased urinary copper excretion has been observed in persons who consumed 0.5 to 1.5 milligrams of molybdenum per day and in persons drinking water containing 0.15 to 0.20 ppm of molybdenum but not in persons drinking water containing up to 0.05 ppm of molybdenum (Cha79). The significance of the increased copper excretion is not known.

Recent reports have associated molybdenum deficiency and esophageal cancer (Lub80a,b). Until these reports are confirmed and evaluated, the minimum molybdenum requirements are uncertain.

NICKEL

Nickel is an element widely distributed in the environment and is used mostly for industrial purposes. It is essential in animal nutrition and perhaps for humans (NAS80). Oral toxicity is low, with most of the effect due to gastrointestinal irritation (NAS80). Extrapolation from animal studies suggests a daily oral dose of 250 milligrams of soluble nickel would produce toxic symptoms in man (NAS 80).

Inhalation of nickel carbonyl has caused severe toxicity in man and inhalation of nickel fumes with concentrations of the order of 0.08 to 1.2 ppm has led to lung cancer, errosion of nasal mucosa, and other problems (HEW77). Contact dermatitis related to nickel exposure has been reported, often with about 12 percent of people sensitive to cutaneously applied nickel (God77). An oral dose of 5.6 milligrams of nickel (as $NiSO_4$) can produce a positive reaction in nickel-sensitive persons within 1 to 20 hours (NAS80).

NITRATE

Nitrate, an anion of nitrogen and oxygen (NO_3^-), is the most stable form of combined nitrogen in oxygenated water. All nitrogenous materials in natural waters tend to be converted to nitrates (NAS77). The fatal dose has been estimated as 120 to 600 milligrams of nitrate (27 to 136 milligrams of nitrate-nitrogen) per kilogram of body weight (Bua61). Burden estimated the maximum permissible dose of nitrate-nitrogen as 12 milligrams in a 3-kilogram infant and 240 milligrams in a 60-kilogram adult (Bua61). Nitrate is converted to nitrite in the gastrointestinal tract, and the absorbed nitrite causes the toxicity, in this case methenoglobinemia (NAS72b, NAS77).

Chronic toxicity is usually observed in children. Symptoms of toxicity have been reported in children drinking water with 11 ppm of nitrate-nitrogen but not in those consuming 9 ppm or less (NAS72b, NAS77). Nitrates can be reduced to nitrites and combined with secondary amines or amides to form N-nitroso compounds, which are considered carcinogens (NAS72b, NAS77).

RADIUM

Radium is a metal widely distributed in the environment in trace quantitities, except in some ores. It is not essential to human nutrition. It was widely used in industry and medicine. No reliable data exist on acute radium toxicity in humans (Si45), and chemical toxicity, if any, is expected to be masked by radiation damage (Ve78,Shc74). Sharpe (Shc74) reported increases in assessory sinus and bronchial cancer and possible increases in other malignant cancers; blood dyscrasias and bone damage in former radium dial painters.

Chronic intake of radium is expected to be carcinogenic, especially in bone. Radium isotopes are expected to have roughly the same chronic toxicity per unit of activity (picocurie) consumed, but not per unit of weight (microgram) consumed (IP79). Radium-227, which is 1,000 to 10,000 times less radio-toxic than other radium isotopes (IP79), may be an exception.

Consuming one picocurie of radium per day continuously entails a lifetime risk of developing a radiation-induced cancer of about two chances in a million per year of radium consumption (Su81).

SELENIUM

Selenium, a metal, is widely but unevenly distributed in nature. It is essential in human nutrition in trace amounts (NAS77) and is used in industry and medicine.

Drinking water containing 9 ppm of selenium for a 3-month period caused symptoms of selenium toxicity: lethargy, loss of hair, and loss of mental alertness (EPA76). Other symptoms of selenium toxicity include garlicky breath, depression, dermatitis, nervousness, gastrointestinal disturbance, and skin discoloration (EPA76, NAS77). Consumption of 1 milligram per kilogram of body weight per day may cause chronic selenium poisoning (God77). Bad teeth, gastrointestinal disturbances, and skin discoloration have been associated with consumption of 0.01 to 0.1 milligram of selenium per kilogram of body weight per day (EPA76).

Selenium has also been suspected of causing increased teratogenesis and dental caries, but there are little data on these aspects of selenium toxicity (Ve78). Selenium has been reported to increase tumors in some animal models and have antitumor activity in other animal models (NAS77). It has also been reported that there is an inverse relationship between the level of selenium intake in humans and the age-specific death rates of specific heart diseases (Shb80). Additional studies are needed to illuminate the role of selenium in these reports.

SILVER

Silver is a metal distributed in trace levels in the environment, except in some ores. It is not essential to human nutrition and is widely used in industry, medicine, photography, and art. Data on acute toxicity in people are sparse, but consumption of 140 milligrams of silver nitrate causes severe gastroenteritis, diarrhea, spasms, and paralysis leading to death (Ve78).

Chronic toxicity from soluble silver salts is usually associated with argyria, a permanent blue-grey discoloration of the skin caused by deposited silver (EPA76, NAS77). Silver deposited in tissue, especially in the skin, apparently is retained there indefinitely (EPA76), perhaps as a harmless silver-protein complex or as silver sulfide or selenide (Ve78). If 1 gram of accumulated silver causes borderline argyria as postulated by the National Academy of Sciences, this level would be reached after 50 years of drinking water containing 0.05 ppm of silver or after 91 years at 0.03 ppm (NAS77). Prolonged consumption of silver salts may also cause liver and kidney damage and changes in blood cells (Ve78).

THORIUM

Thorium is a metal distributed in the environment in trace quantities, except in some ores. It is not essential to human nutrition and is used in industry. It was formerly used in medicine.

There are no data on oral toxicity in humans. In animal studies, thorium given orally at levels of about a gram per kilogram of body weight caused death in some of the animals (Ve78, So07).

Chronic toxicity appears limited to carcinogenesis associated with the radioactivity of the thorium. The various isotopes of thorium are expected to vary greatly in toxicity, considered on a per-unit-activity basis (IP79); all are expected to produce radiation-related cancers.

URANIUM

Uranium is a metal widely distributed in the environment in trace quantities. It is not essential to human nutrition and is used primarily in the nuclear power industry.

Acute toxicity from a single uranium exposure in humans has been estimated to occur, based on kidney damage, following absorption of 0.1 milligram per kilogram of body weight; some deaths would be expected following absorption of 1 milligram per kilogram of body weight (Lua58). If 20 percent of the uranium in water is absorbed by a 70-kilogram man, kidney damage could be expected following consumption of 2 liters of water containing 17.5 milligrams per liter, and death could result from consumption of water containing 175 milligrams per liter of uranium. This is consistent with observations that oral doses of 10.8 milligrams of uranium (as uranyl nitrate hexahydrate) apparently caused no kidney damage (Hu69). However, consumption of 470 milligrams of uranium (1 gram of uranyl nitrate) caused vomiting, diarrhea, and some albuminuria (Bub55).

Building up a tolerance to uranium is apparently possible. Uranium nitrate was used to treat diabetes and various urinary problems by homeopathic physicians, usually reporting no untoward side effects (Sp68, Ho73). Spoor (Sp68) cites reports, from the medical literature of the 1890's, of cases in which uranyl nitrate was used to treat diabetes, starting with a conditioning dose of about 60 milligrams of uranyl nitrate three times a day after meals and gradually raising the daily dose over a period of a few weeks to 3 grams, or 6 grams in one case. If such doses were given without conditioning, they would be expected to be fatal.

Chronic toxicity may also be related to enzyme poisoning in the kidneys (Lua58), with some liver damage as a result of the kidney damage (Ve78). Experiments with animals that inhaled uranium compounds for a year showed mild kidney changes associated with deposition of about 1 microgram of uranium per gram of kidney. Extending these results, for a human kidney weight of 300 grams, absorption of 20 percent of uranium in water and deposition of 11 percent of absorbed uranium in the kidney and retained with a 15-day half-life (Sp73), chronic chemical toxicity could develop in humans who drink water containing about 0.315 ppm of uranium.

Uranium can also cause chronic toxicity in the form of radiation-related carcinogenesis (Du75, Fia78). The various uranium isotopes vary greatly in their carcinogenic potentials, as considered on a unit activity basis (IP79). There is some question as to whether radiation-related cancer or chemical toxicity would be the major response to some uranium isotopes (Ad74).

VANADIUM

Vanadium is a metal widely distributed at low concentrations in nature. It is not known to be essential to human nutrition, although it is in some animals (NAS80). Vanadium salts are not very toxic when given orally (Wa77). The lethal dose has been estimated as 30 mg of V_2O_5 (16.8 mg V) introduced into the blood in soluble form (Wa77). Gastrointestinal absorption has been estimated as 0.1 percent to 1.0 percent of soluble vanadium compounds (Wa77). So, the lethal dose of soluble vanadium given orally, might range from 1,700 to 17,000 milligrams.

Chronic toxicity resulting from oral exposure to vanadium has not been reported. In human studies, 4.5 milligrams of vanadium per day given as oxytartarovandate caused no symptoms over a 16-month period (Un77). However, if animal studies can be extrapolated to man, daily oral administration of 10 milligrams of vanadium or more may cause chronic toxicity (NAS80).

APPENDIX C

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The Environmental Protection Agency is issuing final standards for the long-term control of tailings piles at inactive uranium processing sites and for cleanup of contaminated open land and buildings. These standards apply to tailings at locations that qualify for remedial actions under Title I of Public Law 95-604, the Uranium Mill Tailings Radiation Control Act of 1978. This Act requires EPA to promulgate standards to protect the environment and public health and safety from radioactive and nonradioactive hazards posed by residual radioactive materials at the twenty-two uranium mill tailings sites designated in the Act and at additional sites where these materials are deposited that may be designated by the Secretary of the Department of Energy. The Final Environmental Impact Statement (Volume I) examines health, technical considerations, costs, and other factors relevant to determining standards. Volume II contains EPA's responses to comments on the proposed standards and the Draft Environmental Impact Statement (EPA 520/4-80-011).

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