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Chapter 5: URANIUM MINES

5.1 General Description

In uranium mining operations, ore is removed from the ground in concentrations of 0.1 to 0.2 percent U_3O_8 or 280 to 560 microcuries of uranium-238 per metric ton of ore. Since the uranium-238 in the ore is normally present in secular equilibrium with its daughter products, these ores also contain equal amounts of each member of the uranium-238 decay series.

After mining, the ores are shipped to a uranium mill to separate the uranium. Radioactive emissions to air from uranium mines and mills consist of radionuclide bearing dust and radon-222 gas.

Uranium is mined in both open pit and underground mines. In 1982 there were 139 underground and 24 open pit uranium mines in operation in the United States (Table 5-1). These mines accounted for about 75 percent of the uranium produced (DOE83).

Table 5-1. Distribution of 1982 U_3O_8 production by mining method (DOE83)

Source	Number	Tons U_3O_8 [a]	Percent of total
Underground mines	139	6,200	46
Open pit mines	24	3,900	29
Solution Mining (In-Situ)	18	1,500	11
Others: heap-leach, mine water, byproduct, and low-grade stockpiles	15	1,800	14
Total	196	13,400	100

[a] Short tons

In recent years in-situ solution mining has been more widely used; this method is expected to increase in future years. During 1982 this method accounted for 11 percent of the uranium mined in the United States. The radioactive emissions from this source are small compared to the other sources.

Table 5-2 indicates that at present all uranium is mined in the western United States, mostly in the states of New Mexico, Wyoming, and Texas. Exploration for uranium is being conducted, however, in the eastern and midwestern parts of the United States.

Table 5-2. Distribution of 1982 U_3O_8 production by State (DOE83)

State	U_3O_8 (Short tons)	Percent of total
New Mexico	3,800	28
Wyoming	2,700	20
Texas	2,200	17
Arizona, Colorado, Florida, Idaho, Utah, & Washington	4,700	35
Total	13,400	100

Major publicly-held corporations account for a large share of ownership in the uranium industry. The industry grew rapidly in the early and mid-1970's, stimulated by expectations of rapid increases in demand. However, the expectations were too optimistic with supply outstripping demand. The result was an economic slump for the industry. The industry is now faced with excess capacity, large inventories, lower-than-expected demand, and the potential for increased competition from imports (EPA83a).

5.2 Process Description

Underground Mining

Underground uranium mining is usually carried out using a modified room and pillar method. In this method, a large diameter main entry shaft is drilled to a level below the ore body. A haulage way is then established underneath the ore body. Vertical raises are driven up from the haulage way to the ore body. Development drifts are driven along the base of the ore body connecting with the vertical raises. Mined ore is hauled along the development drifts to the vertical raises and gravity fed to the haulage way for transport to the main shaft for hoisting to the surface.

Figure 5-1 is an example of an underground mining operation. Ventilation shafts are installed at appropriate distances along the ore body. Typical ventilation flow rates are on the order of 200,000 cfm. The principal radioactive effluent in the mine ventilation air is radon-222 which is released during mining operations. Additional radon-222 and particulate (uranium and its decay products) emissions result from surface operations at the underground mine.

Surface Mining

Open pit mining usually is carried out by excavating a series of pits in sequence. The topsoil and overburden are removed from above the ore zone and stockpiled in separate piles for use in future reclamation operations. The uranium ore is removed from the exposed ore zone and stockpiled for transport to a uranium mill. Ore stockpiles range in size up to several hundred thousand metric tons of ore. During the mining of the uranium ore, low grade waste rock is also removed from the pits and stored in a waste stockpile for possible future use.

Figure 5-2 is an example of an open pit mining operation. As the mining progresses, mining and reclamation operations take place simultaneously--pits are mined in sequence, and the mined-out pits are reclaimed by backfilling with overburden and topsoil. In some cases, the last of the open pits in a mining operation are not backfilled but are allowed to fill with water, forming a lake. Radioactive emissions from open pit mining operations are radon-222 gas and fugitive dust containing uranium and its decay products.

In-Situ Mining

In this method, a leaching solution is injected through wells into the uranium-bearing ore body to dissolve the uranium. Production wells bring the uranium-bearing solution to the surface where the uranium is extracted. The solution (lixiviant) can be recovered and reused.

Radon-222 gas is emitted from the processing operations and waste impoundments. With solution mining, less than 5 percent of the radium from an ore body is brought to the surface (NRC80). Consequently, the amount of radon released is considerably less than that from conventional mining. The major sources of radon are the surge ponds, enclosed surge tanks, inplant surge tanks, and absorption columns (Br81). It is estimated that the radon released is about 19 percent of the amount released from a conventional uranium mill (Bra81).

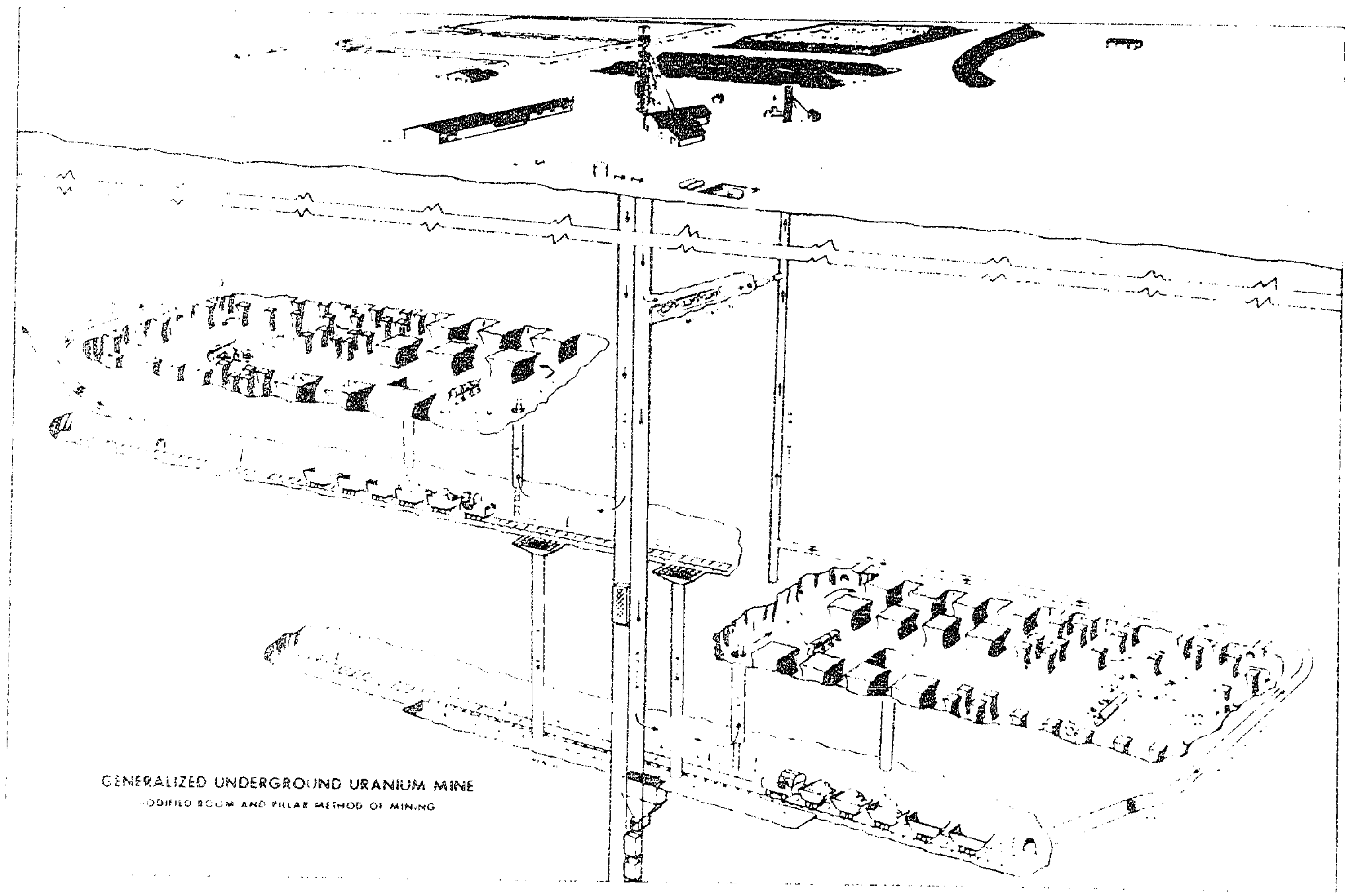


Figure 5-1. An underground uranium mining operation.

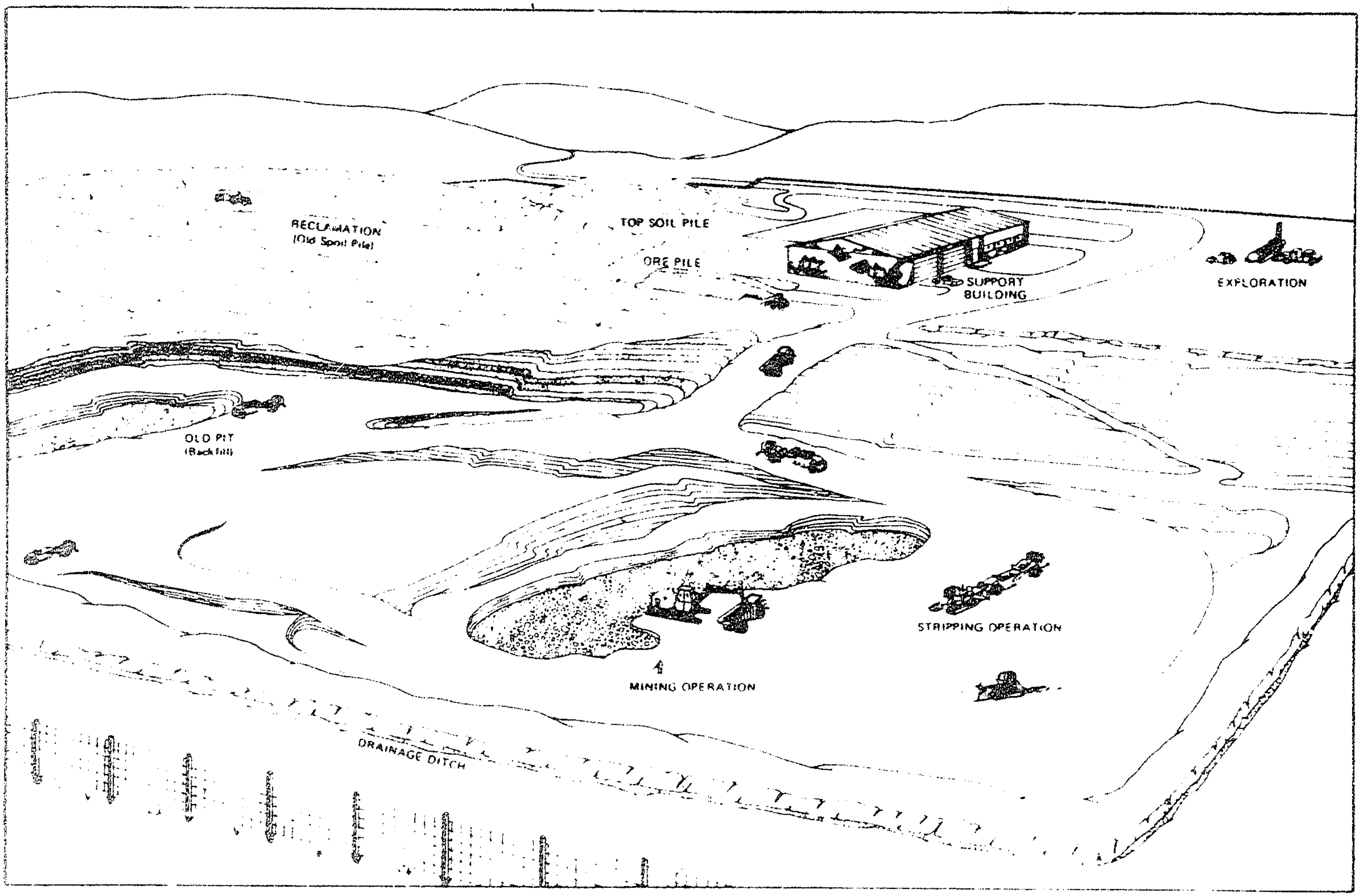


Figure 5-2. An open pit uranium mining operation.

A small amount of radon is released from the waste impoundments used to store contaminated liquids from the operation. Some examples of solid wastes (EPA83b) that might be generated by the alkaline leach in-situ process are:

(1) Materials filtered from the lixiviant line,
(2) Sediments from the surge tanks,
(3) Calcium carbonate from the calcium control unit,
(4) Barium sulfate from the cleanup of the elution/ precipitation circuit of the recovery process,
(5) Materials deposited in the evaporation ponds,
(6) Drill hole residues,
(7) Solids from aquifer restoration.

EPA has previously evaluated radionuclide emissions from uranium mining activities (EPA79, EPA83b). These evaluations indicate that underground uranium mining releases the largest quantities of radon-222 to air and results in the most significant health impacts when compared to other mining methods. Because of the lower amounts of radon released from surface mines, in-situ solution mining, and other mining methods, the potential health impact of underground uranium mining is of the most concern and therefore, Sections 5.3 through 5.8 of this chapter deal only with underground uranium mines.

5.3 Control Technology

Several methods to control radon emissions from underground uranium mines have been evaluated. These are: 1) use of sealant coating on exposed ore surfaces; 2) bulkheading of worked-out areas; 3) activated carbon adsorption of radon from contaminated mine air; 4) mine pressurization; and 5) miscellaneous technologies.

Sealant Coating

One method for controlling radon in an underground uranium mine is to prevent radon from entering the mine air by sealing exposed surfaces. A summary of field tests and a review of the literature on this subject performed for EPA (Ko80) is summarized as follows:

1) Under laboratory conditions sealants are very effective in attenuating radon emissions from ore surfaces, but in an actual mine application, the presence of "pinholes" and the difficulty of applying a perfect coating on a mine wall or ceiling surface reduces the effectiveness of these sealants considerably.

2) In field tests a three-coat system of HydroEpoxy 156 and HydroEpoxy 300, preceded by Shotcrete base coating, was found to be effective (50 to 75 percent radon stoppage). For the theoretical mine, the sealant probably would be 60 percent effective with an eight-month lifetime.

3) The amount of sealants used varied considerably for different mines. Kown and his associates (Ko80) chose the following amounts for their study which were greater than other studies on this subject.

Shotcrete	-	909 gal per 1000 ft^2
HydroEpoxy 156	-	18 gal per 1000 ft^2
HydroEpoxy 300	-	32 gal per 1000 ft^2

4) The sealant coating applied to drifts of an underground mine has a limited life of about eight months because the drift area is mined after pillars are extracted in a room-and-pillar stope mine.

5) An asphalt emulsion sealant has been tested in the laboratory and on tailing piles and is found to be an effective, inexpensive sealant. However, it has not yet been tested in an underground mine atmosphere.

The cost of coating 530,000 ft^2 of drift surfaces in the mine was $348,100 ($1.45 per ton of ore removed). The floors were not considered to be coated because ore loaders will destroy the coating on the semiconsolidated muck. The three sealants were applied every two months. Cost estimates of other sealants range from $0.30 to $1.10 per square foot (Fr81) which is comparable to the cost estimates ($0.66 per square foot) of the sealants used in this study. Because of its high cost, the Bureau of Mines feels that sealants may only be used economically in shops, lunchrooms, and possibly high-emanating areas in intake airways (Frc83).

A recent study by Battelle (B184) of [illegible] mines shows an average cost of $5.80 per ton of ore mined ($0.34 per square foot) if 80 percent of the surface is sealed. This EPA-sponsored study has shown that sealants could reduce the radon emanation from the active stopes of the mines by 23 percent. If the total mine is included (25 extracted stopes), only 11 percent of the radon was reduced. This second figure should be used when determining the amount of radon released from the mine.

Other studies by the Bureau of Mines (Fra81) have shown that 50 to 75 percent of the radon can be retained in the rock by sealants. The study by Battelle (B184) shows that a 56 percent reduction in radon emissions can be achieved by applying sealant to 80 percent of the mine surfaces.

Bulkheading

Bulkheading of mined-out areas, such as extracted stopes, is the most common radon control method currently practiced in underground mines (Ko80). In general, it is used to isolate worked-out areas of stopes from workers so that the radon concentrations in the working areas of the mine will be lower. If the bulkhead is air tight, the radon behind the barrier will decay to innocuous levels. However, all bulkheads leak to some extent, and usually a small 3- to 6-inch ventilation pipe is used as a bleeder pipe to provide negative pressure in the extracted stope (Fra81) and to allow the contaminated air to be diverted to the ventilation system. A small fan may be required to maintain the negative pressure. Ideally, only 10 percent of the air behind the bulkhead would be diverted to the outside atmosphere. This air stream can also be connected to an activated carbon filter or trap to reduce concentrations further.

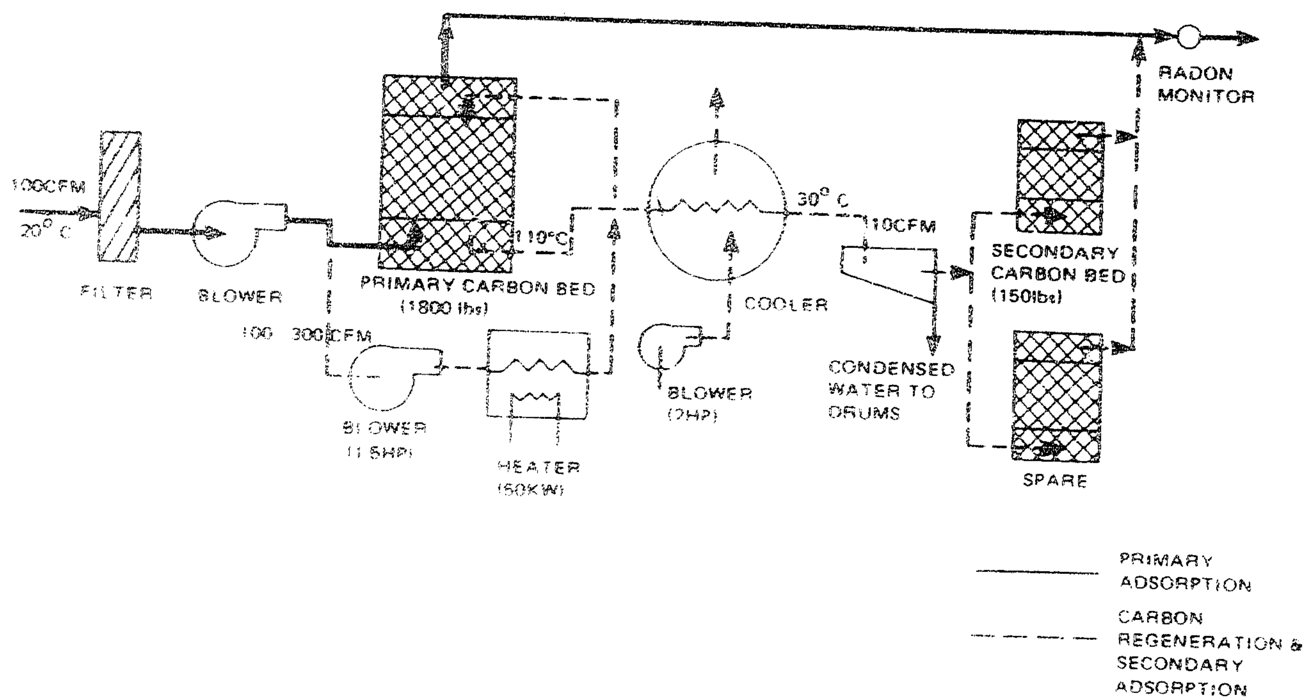
In an EPA study (Ko80) it was assumed that 12.5 stopes per year would be sealed using 100 bulkheads. The cost for material, labor, and maintenance was estimated to be $80,400 or $0.34 per ton of ore removed. It was also assumed that a six-inch pipe provided a 100 cfm bleeding rate from each bulkheaded area. In a Battelle study (B184) the average cost to bulkhead 80 percent of the mine at 13 sites was only $0.08 per ton of ore. Up to 10 bulkheads in each mine were used in making these estimates.

An estimate of the effectiveness of reducing radon by this system was made using many crude assumptions. For the total mine, bulkheading was estimated to achieve about a 14 percent reduction in radon emissions (Ko80). A preliminary study conducted by Battelle on an actual mine indicated that a radon reduction of 35 percent could be obtained by using bulkheads (Dra80). Using bulkheads extensively in a mine can reduce radon emissions up to 60 percent (B184).

Radon Adsorption on Activated Carbon

Leakage of high radon concentrations through bulkheads used to control radon concentrations in mines is another problem. One method to relieve this problem is to insert a small bleeder pipe in the bulkhead to provide negative pressure within the enclosed area behind the bulkhead. This bleeder pipe is usually connected to the exhaust ventilation system. Although this may prevent exposure to the workers, the radon emissions to the environment may still be high. An [illegible] carbon adsorption system may be attached to the radon effluent pipe before releasing this air to the exhaust ventilation system [illegible].

An effective radon control system for the bleeder [illegible] under study. The system chosen by investigators in an EPA [illegible] is shown in Figure 5-3. It consists of two carbon adsorption [illegible] in series. The flow from the bleeder pipe is filtered to remove [illegible] particles and radon daughter products. The radon is then adsorbed [illegible] the carbon column. The carbon column is regenerated [illegible] hot air. The contaminated air from the regeneration [illegible] second carbon column to again adsorb the radon gas [illegible] may be required in the second column due to buildup [illegible]



Radon removal from mine air by carbon adsorption.

In evaluating control technology in a model mine, EPA (Ko80) found that an average of 12.5 activated carbon systems must be installed each year to treat the contaminated air from the stopes sealed by the bulkheads. The capital and operating costs for each unit are as follows:

<u>Capital Cost of Each Unit</u>

Major equipment		$22,000
Auxiliaries & Installation		$11,000
	Total	$33,000

<u>Annualized Cost of Each Unit</u>

Material (carbon, filters, piping)		$ 1,000
Utilities (25,000 kwh @ 4¢/kwh)		$ 1,000
Labor (0.25 person-year)		$ 8,000
Amortizing (an avg. 5-year life at 10 percent interest)		$ 8,700
	Total	$18,700

Assuming the lifetime of each unit is 5 years and 12.5 units per year are needed, the cost over five years would be $1,037,500 or $0.86 per ton of ore mined. The carbon system was assumed to be 95 percent efficient in removing radon.

The effectiveness of the entire system, including bulkheading and carbon traps, was estimated to be 49 percent. A study by Battelle (Dra80) estimates a 45-68 percent effectiveness, using absolute sorption traps in combination with bulkheading. The total cost for bulkheading and carbon traps would be $1.20 per ton of ore mined for 100 bulkheads. In the study by Battelle (B184) the average cost to bulkhead with a carbon trap at 13 mines was $0.11 per ton of ore with an efficiency of 80 percent. Up to 10 bulkheads in each mine were used for their estimate.

There are some definite disadvantages to the carbon adsorption system. Skilled operators, usually not available in mining communities, are necessary to operate and maintain the system. Safety problems to the miners are possible due to interrupted electrical service or system malfunction. Excess radon concentrations would then be present. The carbon columns would have to be shielded to prevent gamma exposure to the miners. The system may not work in wet mines because of moisture absorption by the carbon.

The system does appear to be technically feasible utilizing commercial carbons and standard equipment. However, additional developmental work may be necessary before such a system can be used in a mine environment. A recent study by Hopke (Ho84) has concluded that activated carbon can be used for effective cleaning of small volumes of air such as effluents from a bleeder pipe for a bulkhead.

Mine Pressurization

Positive mine pressurization has been tried several times to force the radon in the mine atmosphere back into the walls of the mine (Ko80 and Fra81). In general, these efforts have been successful in reducing the radon concentrations in the mine itself. An "air" sink is necessary to accept the radon. If the radon is forced through the ore body or surrounding area to the surface, the radon can decay before coming to the surface. If the area is impermeable, however, radon levels will return to previous levels. In tests by the Bureau of Mines (Fra81), the radon levels in the mine were reduced by 20 percent (releases to the atmosphere were not determined). The surrounding soil needs to be permeable enough to hold radon and allow for its decay, but not so permeable so as to allow significant increases in surface emissions (Ko80). The costs of mine pressurization were not available because the process was in a development stage. In a recent report, Battelle (Bl84) concluded that positive pressure ventilation has been proven ineffective in reducing atmospheric emissions of radon.

Miscellaneous Radon Control Technology

Argonne National Laboratory is experimenting with strong oxidizing agents, such as bromine triflouride and dioxygenyl hexaflouro-antimonate, to convert the radon to another form that can be absorbed on a scrubber or absorption bed (Fra81). However, the corrosive and toxic nature of the reactants makes their use in mines impracticable and questionable. Battelle (Bl84) mentions other methods such as cryogenic methods, chemical removal, and gas centrifuge, but the costs are prohibitive. The study by Hopke (Ho84) reviewed methods for the removal of radon from uranium mine effluents. Methods, including cryogenic condensation, molecular sieves, gas centifugation, semipermeable membranes, and hybrid systems, do not offer much promise for a practical removal system. They do suggest the exploration of the class of perfluorinated hydrocarbon compounds as possible candidate scrubbing fluids for a radon scrubbing system.

Backfilling of worked-out areas with classified mill tailings is practiced by mine operators to provide ground support in the mine (Fr81). This procedure can also reduce ventilation requirements. A study, by the Bureau of Mines and Kerr-McGee Nuclear, to determine the effectiveness of reducing radon emissions by backfilling mill tailings into the mine stopes indicated a net radon reduction of 84 percent from the stope (Frb81). This was done for only one stope in a mine. PNL (Bl84) estimated an efficiency up to 80 percent if classified mill tailings and surface sands are used for backfilling with an average cost of $12.64 per ton of ore mined.

Increasing the height of vents is a possible method to reduce ground level radon concentrations in ambient air (Dra80). One of the conclusions based on a theoretical model was that "a 20-meter release height reduces the annual average concentration (when compared to a ground-level release) by about 60 percent at one mile from a source and by about 30 percent at ten miles from the source." An estimate of cost is $0.493 - $0.881/ton of ore for a 20-meter stack (Brb84). The average number of vents for a mine is about 5 (Ja80). Thus, the cost per mine would be about $3.44 per ton of ore produced.

Vent orientation is an important factor in radon concentrations near a mine (Drc84). Because of plume rise, concentrations are much lower when vents are in a vertical configuration (rather than horizontal), resulting in a reduction factor of 80 at sites near a mine with a vertical vent configuration.

Summary of Costs and Efficiencies

A summary of the costs and efficiencies of the various radon control technologies discussed previously is shown in Table 5-3.

Table 5-3. Cost and efficiencies of radon control technologies for underground uranium mines

Method	Radon reduction (Percent)	Cost ($/ton of ore)
Sealant coating	11 - 56	1.45 - 5.80
Bulkheading	14 - 60	0.08 - 0.34
Bulkheading with activated carbon	49 - 80	0.11 - 1.20
Mine pressurization	20	-
Stacks	60[(a)]	3.44
Backfilling	80 - 84	12.64

(a)Reduction in exposure to nearby individuals.

5.4 Radionuclide Emission Measurements

Radon-222 is the radionuclide emitted from underground uranium mines which causes the greatest risk to people. The major source of radon-222 emissions to air are the mine vents through which the ventilation air is exhausted. A large underground mine will usually have several vents; some mines have as many as 14 vents. Radon-222 emissions from these vents are highly variable and depend upon many interrelated factors including: ventilation rate, ore grade, production rate, age of mine, size of active working areas, mining practices, and several other variables.

Pacific Northwest Laboratories (PNL) has measured the radon-222 emissions from 27 underground uranium mines (Table 5-4) (Ja80). The average radon-222 emission rate for these 27 mines was 5,600

Table 5-4. Measurements of radon-222 emissions from underground uranium mine vents (Ja80)

Mine	Number of vents	Measurements (Ci/y) 1979	1978	Average
A	4	7,400	-	7,400
B	6	4,700	4,300	4,500
C	4	5,200	3,900	4,600
D	2	3,600	-	3,600
E	14	29,800	-	29,800
F	13	9,200	9,500	9,400
G	5	2,200	1,500	1,800
H	10	15,200	-	15,200
I	11	1,700	-	1,700
J	9	7,800	8,100	7,900
K	4	7,000	5,900	6,400
L	8	1,500	1,300	1,400
R	8	15,000	14,600	14,800
T	5	1,900	-	1,900
U	3	900	-	900
V	2	1,000	-	1,000
Y	7	17,500	-	17,500
Z	3	-	2,600	2,600
AA	2	2,100	1,500	1,800
BB	5	2,100	1,800	2,000
CC	3	-	2,100	2,100
DD	2	-	1,000	1,000
EE	5	6,500	-	6,500
FF	3	2,500	-	2,500
GG	3	200	100	200
HH	2	1,000	-	1,000
II	2	500	-	500
Average	5	6,100	4,200	5,600

curies/year. The emissions from individual vents ranged from 2 to 9,000 Ci/year with an average of 1,000 Ci/year.

In addition to the mine vents, radon-222 is emitted to air from several above-ground sources at an underground uranium mining operation. These sources are the ore, subore, and waste rock storage piles. PNL has estimated the radon-222 emissions from these sources to be about 2 to 3 percent of the emissions from the vents (Ja80). EPA has estimated the emissions from the above-ground sources to be about 10 percent of mine vent emissions (Table 5-5).

Table 5-5. Estimated annual radon-222 emissions from underground uranium mining sources (EPA83b)

Source	Average large mine[a] (Ci/y)
Underground	
Mine vent air	3,400
Aboveground	
Ore loading and dumping	15
Sub-ore loading and dumping	5
Waste rock loading and dumping	0
Reloading ore from stockpile	15
Ore stockpile exhalation	53
Sub-ore pile exhalation	338
Waste rock pile exhalation	3
Total	3,829

[a] Ore grade = 0.1 percent U_3O_8. Annual production of ore and sub-ore = 2×10^5 MT, and waste rock = 2.2×10^4 MT.

The above-ground sources also emit radionuclides to air as particulates. The particulate emissions result from ore dumping and loading operations and wind erosion of storage piles. EPA has estimated that about 2E-2 Ci/y of uranium-238 and 3E-4 Ci/y of thorium-232 and each of their decay products would be emitted into the air at a large underground mine (EPA83b). An assessment of the health risks from these emissions showed that the risks from the particulate emissions were much smaller (a factor of 100 less) than the risks from radon-222 emissions (EPA83b). Therefore, the health risk assessment presented in the subsequent sections of this chapter will be limited to radon-222 emissions.

5.5 Reference Underground Uranium Mine

Table 5-6 describes the parameters of the reference mine which are used to estimate the radon-222 emissions to the atmosphere and the resulting health impacts. These parameters were chosen primarily from information in Tables 5-7 and 5-8. The reference mine has 5 vents in the configuration as shown in Figure 5-4.

Table 5-6. Reference underground uranium mine

Parameter	Value
Ore grade	0.22 percent U_3O_8
Ore production	112,000 tons/y
Days of operation	250 days/y
Number of vents	5
Vent height[a]	3 meters
Radon emissions	11,000 Ci/y[b]

[a] In estimating radon-222 concentrations in Table 5-9 for releases with plume rise, the following vent parameters were used: vent diameter is 1.5 meters, exit velocity is 16.2 meters/sec, and the exit temperature is 287°K (Drc84).
[b] 2,200 Ci/y from each vent.

Table 5-7. Summary of radon-222 emissions by age of underground uranium mine (Ja80)

	New mines		Old mines	
Mine	Age (years)	Radon-222 emissions (Ci/y)	Age (years)	Radon-222 emissions (Ci/y)
A	3	7,400	-	-
B	9	4,500	-	-
C	9	4,600	-	-
D	7	3,600	-	-
E	-	-	21	29,800
F	-	-	20	9,400
G	4	1,800	-	-
H	-	-	21	15,200
J	-	-	20	7,900
K	-	-	19	6,400
L	-	-	29	1,400
R	-	-	20	14,800
U	4	900	-	-
V	2	1,000	-	-
Y	6	17,500	-	-
Z	-	-	17	2,600
Average	6	5,200	21	10,900

[a] Data from measurements made in 1978 and 1979.

Table 5-8. Estimated ore production of selected mines, 1982 (Brb84)

Mine	Estimated 1982 production (10^3 tons/y)
New Mines (Mines less than 10 years old)	
King Solomon	38.0
Velvet	51.6
Tony M	137.6
Hack Canyon	63.1
Pidgeon	(a)
Kanab North	(a)
La Sal	81.7
Hecla	14.8
Big Eagle	16.6
Golden Eagle	(a)
Mt. Taylor	328.5
Old Church Rock	28.6
Church Rock-East	72.3
Kerr-McGee	
Section 19	127.2
Nose Rock	(a)
Mariano Lake	36.8
Average	62
Old Mines (10 years or more)	
Sunday	41.7
Dermo-Snyder	58.5
Wilson-Silverbell	16.5
Lisbon	73.3
Sheep Mtn.	0
Church Rock-NE	171.9
Church Rock-1	176.8
Kerr-McGee	
Section 30-East	119.5
Section 30-West	132.4
Section 35	195.1
Section 36	111.2
Homestake	
Section 23	208.9
Section 25	67.9
Schwartzwalder	198.8
Average	112

[a]Not operational.

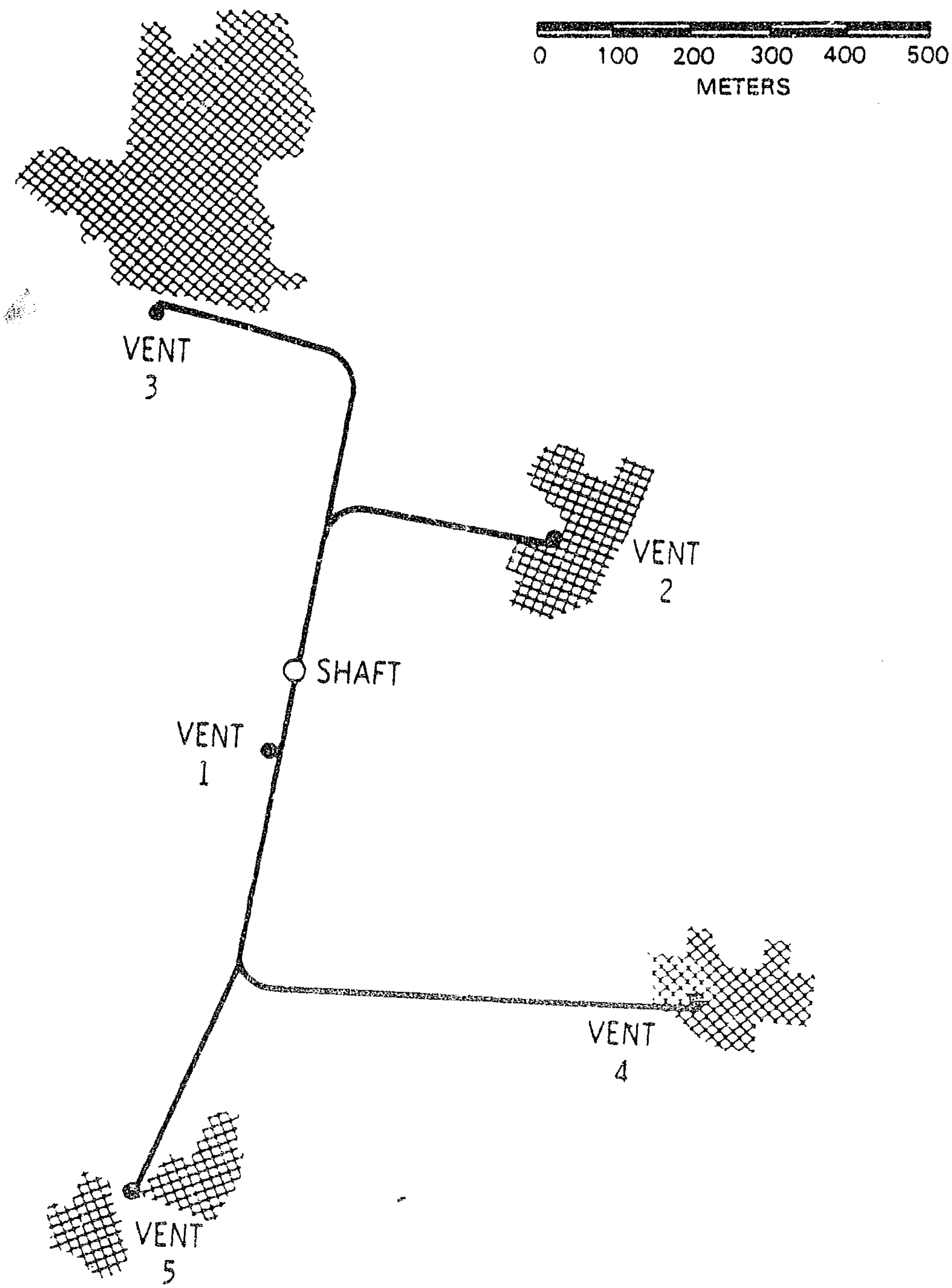


Figure 5-4. Reference underground mine.

5.6 Health Impact Assessment of the Reference Underground Uranium Mine

The lifetime risk to nearby individuals and the number of fatal cancers per year of operation due to radon-222 emissions from the reference underground uranium mine are presented in this section.

The risks to nearby individuals are treated in more detail than the population risks because risks to nearby individuals can be relatively high. These exposures generally occur in structures built around the mines. Radon-222 enters the building and decays into other radionuclides which become attached to dust particles in the air. The concentration of these radionuclides builds up in the air within the structures.

EPA estimated the health risks from radon-222 emissions from uranium mines using the general assumptions discussed in Volume I of this report. The actual risk to nearby individuals may differ from these estimates because the circumstances involving the exposure may differ significantly from the assumptions used to make the estimates. For example, because mines have a limited lifetime (10 to 20 years), the period of exposure is probably less in real cases than assumed in the models. Furthermore, since the risk is due primarily to the radioactive decay products of radon which build up indoors, these estimates may need to be corrected for occupancy times.

Risks to Nearby Individuals

In assessing the health risks to individuals living near underground uranium mines, an evaluation was made of a series of vents from a single mine, (i.e., the reference mine), and multiple vents from mines which are close together. The radon-222 concentrations in air near an underground mine are highly dependent upon a number of other factors. In addition to emission rates and meteorological parameters, these would include the spatial distribution of the vents, the orientation of the vents (vertical or horizontal), and the momentum flux of the exhaust air (velocity times flow rate). Plume rise from the momentum flux can significantly affect the ground level radon-222 concentrations near the mine vents. Discharges through horizontal vents will have little or no plume rise while discharges through vertical vents will usually have a significant amount of plume rise. The extent to which plume rise actually affects the ground level radon-222 concentrations near underground uranium mines is somewhat uncertain because of limited information on vent configurations and momentum fluxes. In addition, the relatively low height of the vent releases makes it uncertain that the computed plume rise will be realized in all cases. Near-release influences, such as buildings, walls, hills, and vegetation, can easily change local flow characteristics so that downwash of the plume occurs. Even when downwash does not occur, such objects increase local dispersion and will tend to decrease the plume rise effect. To show the range of potential radon-222 concentrations which would exist near an underground uranium mine, the ground level concentrations resulting from emissions from the reference mine were calculated for both ground level (all horizontal vents, i.e., no plume rise) and an elevated release (all vertical vents with plume rise). A ground level release with no plume rise represents a worst case assumption in terms of the computed ground level radon-222 concentrations. A release with plume rise represents a lower bound case for computed radon-222 concentrations. The radon concentrations computed with these two assumptions will cover the range of concentrations which can result from various local influences on plume rise.

Table 5-9 shows the estimated radon-222 concentrations and resulting working levels and lifetime fatal cancer risks at various distances from the shaft of the reference mine for releases with and without plume rise. The most likely radon-222 concentrations at these locations will fall somewhere within the range of values shown. These concentrations were computed using EPA's Industrial Source Complex Long Term Model (Drc84).

The estimated concentrations from ground level releases shown in Table 5-9 for distances at 500 and 1000 meters from the mine shaft are worst case situations with locations sited between a series of mine vents or relatively close (within a few hundred meters) to one of the vents where all of the vents involved are horizontal (i.e., no plume rise). It is unlikely at the present time that such extremely high concentrations actually exist near an underground uranium mine or that any individual is actually exposed to these high levels. However, as shown in Table 5-13, several hundred people are living within 1000 meters of underground uranium mine shafts, and these people are estimated to be exposed to increased radon-222 concentrations somewhere within the range of values shown for these locations in Table 5-9.

Table 5-10 shows estimated equilibrium ratios for radon at various distances assuming a wind speed of 1 m/sec from the uranium mine. Estimates of the radon-222 concentration at various distances from an underground uranium mine with five vents emitting 11,000 Ci/y of radon-222 are shown in Table 5-9 (Drc84). Also shown in this table are the estimated lifetime risks of fatal cancer to nearby individuals from the inhalation of radon-222 decay products produced (inside a house) by radon-222 concentrations. Table 5-11 shows the relationship between working levels and risk. The basic assumptions used in developing this table are discussed in Chapter 8, Volume I. This relationship is not linear because of competing risks of death from other causes. Using the relationship between equilibrium ratio and radon concentrations, the working level inside a structure at the specified distance is calculated as shown in Table 5-9. Table 5-11 is then used to estimate the lifetime risk for a person living in a structure 75 percent of the time near these sites.

To evaluate the extent to which emissions from multiple mines located close together will influence the radon-222 concentrations in

Table 5-9. Estimates of working levels and risk of fatal cancer in buildings at selected distances from the reference underground uranium mine[a]

Distance[b] (meters)	Ground level release: Radon-222[c] (pCi/L)	Working levels	Lifetime risk to nearby individuals[d]		Release with plume rise: Radon-222[c] (pCi/L)	Working levels	Lifetime risk to nearby individuals[d]	
500	27.6	.113	1E-1	(5E-2)	0.4	.0016	2E-3	(8E-4)
1,000	10.2	.045	5E-2	(2E-2)	0.4	.0019	2E-3	(9E-4)
2,000	2.2	.011	1E-2	(5E-3)	0.2	.001	1E-3	(5E-4)
3,000	1.1	.006	7E-3	(3E-3)	0.2	.001	1E-3	(5E-4)
5,000	0.5	.003	3E-3	(2E-3)	0.1	.0006	7E-4	(3E-4)
7,000	0.3	.002	2E-3	(1E-3)	0.1	.0006	7E-4	(3E-4)
10,000	0.2	.001	1E-3	(5E-4)	0.1	.0006	7E-4	(3E-4)

(a)The lifetime risks were estimated depending on the equilibrium ratios calculated in the structures at various distances (See Table 5-10).

(b)The distance is measured from the shaft of the model mine. This is different from the distances shown in Tables 5-8 and 5-9 of the Draft Background Information Document (EPA83d) where the distances listed were distances from vent 5.

(c)Drc84.

(d)The values in the first column are based on BEIR-3, NRPB, and EPA models (see Chapter 8, Volume I). The values in parentheses are based on UNSCEAR and ICRP risk estimates (see Chapter 8, Volume I).

Table 5-10. Outdoor and indoor equilibrium ratios for radon emitted from an underground uranium mine at selected distances from the mine[a]

Distance (meters)[b]	Time for plume to reach distance (min)	Equilibrium ratio (Outdoors)	Equilibrium ratio (Indoors)[c]
500	8.3	0.15	.41
1,000	16.7	0.26	.44
2,000	33.3	0.45	.50
3,000	50.0	0.60	.55
5,000	83.3	0.80	.62
7,000	116.7	0.90	.65
10,000	166.7	0.96	.67

(a)A wind speed of 1 m/sec is assumed.

(b)The distance is measured from the shaft of the model mine.

(c)This calculation assumes a ventilation rate of 1 h^{-1} and an effective plate out rate of 1 h^{-1} (EPA83c).

Table 5-11. Relationship between working level and risk of fatal cancer

Working level	Lifetime risk[a]	
.0001	1E-4	(5E-5)
.001	1E-3	(5E-4)
.01	1E-2	(5E-3)
.1	1E-1	(5E-2)

[a]The values in the first column are based on BEIR-3, NRPB, and EPA models (see Chapter 8, Volume I). The values in parentheses are based on UNSCEAR and ICRP risk estimates (see Chapter 8, Volume I).

air, PNL carried out a modeling study using the Ambrosia Lake District of New Mexico as a "case study" (Drb81). Using a Gaussian diffusion model, estimates were made of the radon-222 concentrations in air resulting from emissions from 117 mine vents. Figure 5-5 shows the distribution of mine vents used in the study and Figure 5-6 the computed radon-222 concentrations (above background) in air for this region. Although these computed concentrations are only approximate values, because of the complexities of this modeling study, the results indicate that the radon-222 concentrations in an intensive underground uranium mining area will be significantly elevated above background. The vents are also the greatest sources of the radon concentrations in the immediate area of mining and milling activities. Another study of multiple mines done by PNL (Drc84) confirms these conclusions. The PNL also looked at the effect of plume rise on concentrations from multiple mines due to vertical vents. If it is assumed that all the vents in a multiple mine area are vertical (plume rise), the concentrations are much lower than if the vents are assured to be horizontal (ground level release).

Two measurement studies were also conducted in the Ambrosia Lake, New Mexico, area to determine the concentrations of radon around uranium mines and mills. The EPA conducted the first study in November 1975 (EPA75) at the request of the New Mexico Environmental Improvement Agency and found that ambient outdoor radon concentrations were in excess of typical background levels. It was suggested that a better definition of background levels in the area be determined and a thorough evaluation of specific source terms be conducted.

In 1978 the New Mexico Environmental Improvement Division conducted a two-year program (Bu83) to determine (1) sources of high concentrations of airborne radioactivity in uranium producing areas, (2) radioactivity levels due to background as well as levels associated with uranium milling and mining activities, and (3) if New Mexico

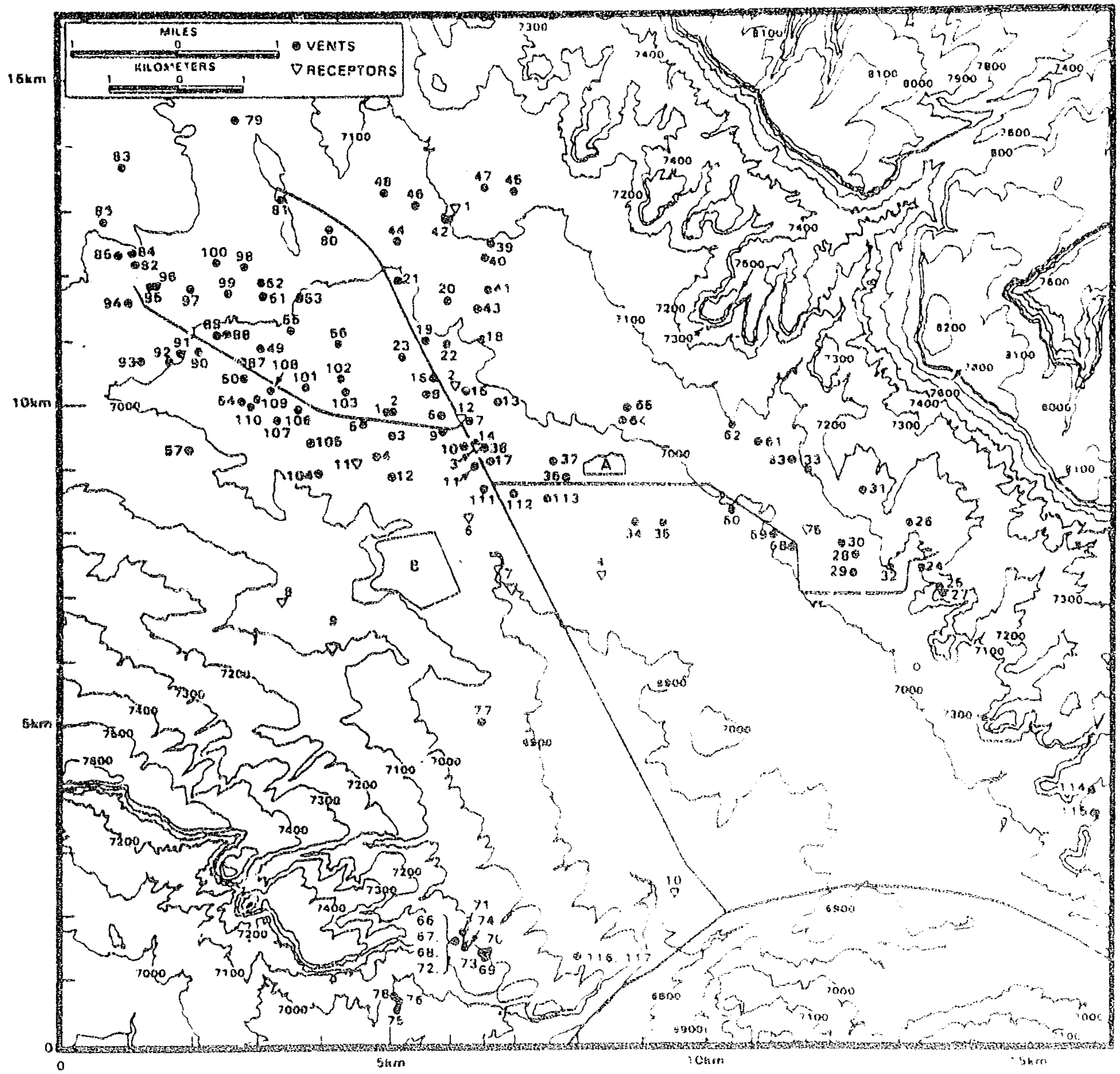


Figure 5-5. Detailed map of mining area showing mine vent source

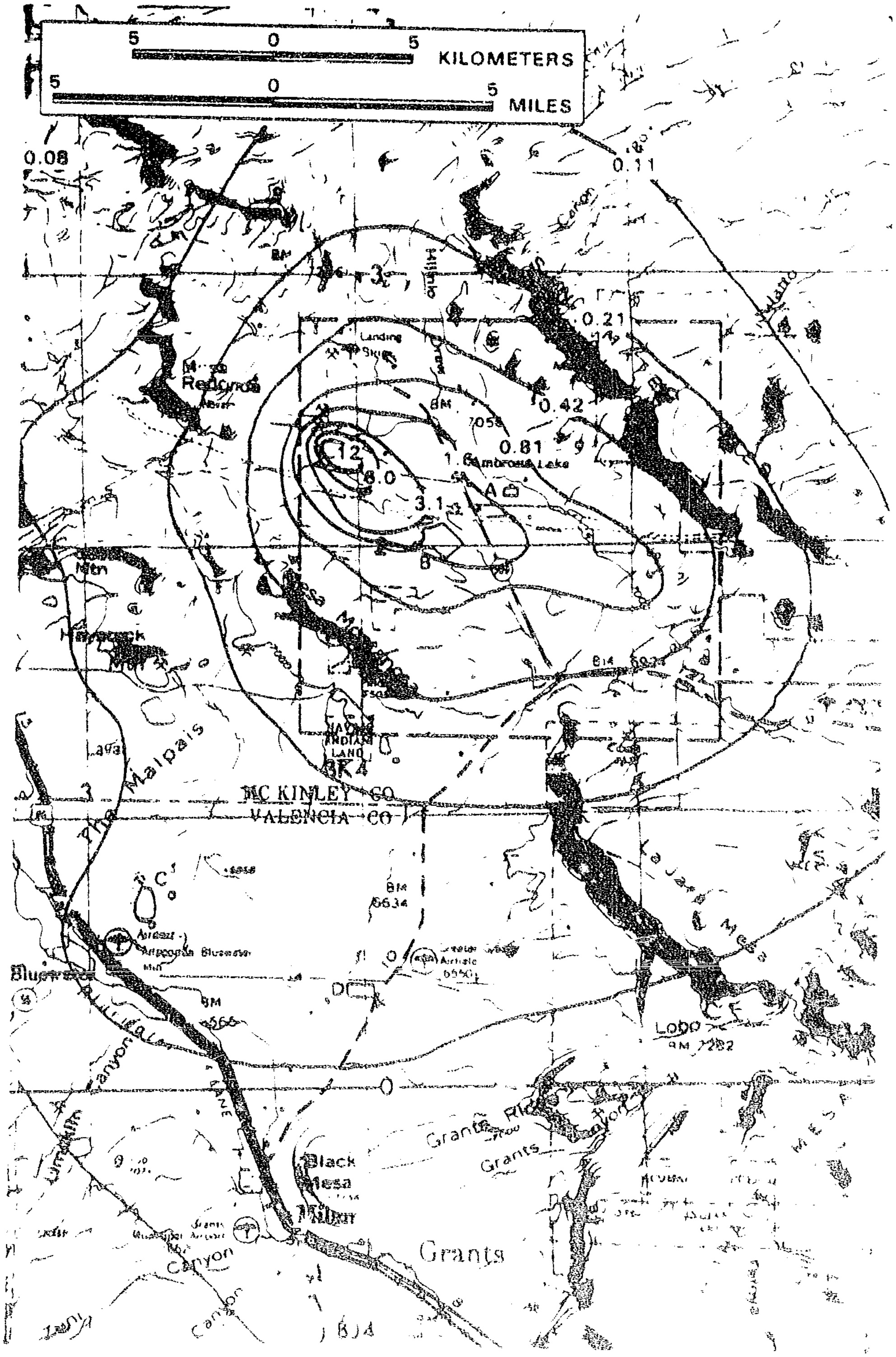


Figure 5-6. Computed radon concentration map [illegible]

standards are being exceeded. Background radon concentrations were determined at six representative undisturbed locations within the Grants Mineral Belt. Uranium mines were found to be the primary cause of elevated radon concentrations in Ambrosia Lake. Ambient radon concentrations near uranium mines exceeded the New Mexico radiation standard for an individual member (3pCi/l) of the public at three of the nine locations in the study.

Population Risks

The radon decay product exposures and the number of fatal cancers per year of operation for the reference underground uranium mine are shown in Table 5-12. These estimates are for a site near Grants, New Mexico, with a regional population of 36,000 using AIRDOS-EPA to calculate the radon exposures (Appendix A). The number of fatal cancers per year of operation of the reference mine is estimated to be about 0.04 to the regional population and 0.08 to the national population.

The inert radon gas emitted from mines can be transported beyond the 50-mile regional cutoff. A trajectory dispersion model developed by NOAA (Tr79) has been used to estimate the national impact of radon emissions from the mine. This model calculates the potential radiation exposure to the U.S. population for radon released from four typical uranium processing locations. (Descriptions of these typical mill sites--Casper, Wyoming; Falls City, Texas; Grants, New Mexico; and Wellpinit, Washington--are given in (Tr79).) Only exposures taking place beyond the 50-mile regional limit are considered. Details of the model are given in He75. The model yields radon concentrations (pCi/L) in air which were converted to decay product concentrations by assuming that 100 pCi/L of radon corresponds to a decay product concentration of 0.7 WL.

Table 5-12. Annual radon-222 decay product exposures and number of fatal cancers to the population from radon-222 emissions from the reference underground uranium mine

Source	Regional population		National population	
	(Person-WL-y)	(Fatal cancers/y of operation)[a]	(Person-WL-y)	(Fatal cancers/y of operation)[a]
Underground uranium mine	2.2	6E-2 (2E-2)	6.2	1E-1 (6E-2)

[a] The values in the first column are based on BEIR-3, NRPB, and EPA models (see Chapter 8, Volume I). The values in parentheses are based on UNSCEAR and ICRP risk estimates (see Chapter 8, Volume I).

5.7 Health Impact from Underground Uranium Mining

An estimate of the total health impact from radon-222 emissions from all underground uranium mining (using production values for 1982) may be made by multiplying the number of fatal cancers caused by emissions from the reference mine by the ratio of the amount of uranium produced by all underground mines to the amount produced by the reference mine. This ratio is about 25. The estimate for the regional population is about two fatal cancers/year and for the national population is about three fatal cancers/year.

5.8 Reduction of Exposures through Land Control

Rather than control radon emissions at the source, it may be more practical to limit the exposure to individuals near underground mines by controlling land near the vents to prevent people from living in houses in these areas. At the request of EPA, the Pacific Northwest Laboratory conducted a field study in January and February 1983 to determine the population, type of ownership, and cost of land around 30 large uranium mines (Brb83). These mines represented about 84 percent of the uranium production from underground mines at that time.

Table 5-13 shows the population data gathered from the PNL study. An estimate was made of all residents within 5 km of the mine shaft by locating all the residences on a map. The average 1980 census figure of residents per home in each county was used to estimate the population. If mines were close together, populations were evenly distributed among the mines according to the distances from the mines. Maps showing the distribution of population around these mines are located at the end of this chapter.

Table 5-14 represents the percent distribution of land ownership around the 30 surveyed mines. County tax assessors' records were reviewed for all properties within a 5-km radius of each mine. The ownership of the land was determined and percentages, according to three types of ownership (private, mine, or government), are shown for each mine. Land values for the private land were estimated from: (1) assessed valuations and applying applicable selling price to assessed valuation ratios, (2) estimates from local real estate agents, (3) information supplied by state and county assessors, and (4) local newspapers. The valuations were based on surface usage and rights only, since the mineral values would remain intact.

Table 5-15 summarizes the cost of the land around each mine. Since the land owned by the mine operator or a government agency can already be controlled, only costs to purchase private land were determined.

The Schwartzwalder mine near Denver, Colorado, is not included in the total cost of all surveyed mines shown in Table 5-15 because it is not a typical mine site. It is located near a large metropolitan area and the cost of the land is quite high since the land can be purchased or subdivided for mountain resort homes. The mine is also located in a mountainous region so that radon emissions may be confined in the immediate area of the mine and any land control which may be necessary would be relatively small.

The information in Tables 5-13 through 5-15 can be used to obtain a rough estimate of the cost to control land around underground uranium mines. The cost to control land within a 2-km radius of the mines surveyed is as follows:

Type of cost	Total cost (millions)	Yearly cost (millions)
Land cost (100 percent contingency with 10 percent yearly cost)	$15.0	$1.5
Structures (100 percent contingency with amortization over 5 years at 10 percent)	3.8	1.1
Relocation of 420 non-Indian residents ($5,000/person with amortization over 5 years at 10 percent)	2.1	0.6
Relocation of Indian residences ($18,000/person--198 Indians, with amortization over 5 years at 10 percent)	3.6	1.1
Total yearly cost		4.3

The 10 percent yearly cost assumes that the land value does not change and thus is a nondepreciated asset. The present worth factor for amortization over a 5 year period using a 10 percent interest rate is 0.264. This is rounded to 0.3 to account for taxes.

Assuming that the 29 mines produced 84 percent of the underground mine yearly production of 6,200 tons of U_3O_8 for the industry (Brb83), the cost of land control per pound of U_3O_8 can be estimated as follows:

$$\text{cost/lb } U_3O_8 = \frac{\$4,300,000}{(.84)(6,200)(2,000)} = \$0.41/\text{lb } U_3O_8$$

If production costs for U_3O_8 are $30/lb, the increased cost to the industry would be 1 percent of the cost of production. In a similar manner, it can be calculated that the cost per ton of ore would be $1.82/ton of ore. This can then be compared to the cost of radon control technologies in Table 5-3.

Table 5-13. Population around selected underground uranium mines (Brb84)

Mine	State	Distance from mine (km)					
		0-1/2	0-1	0-2	0-3	0-4	0-5
Sunday	Colo.	0	0	0	0	0	0
King Solomon	Colo.	0	0	0	0	0	0
Velvet	Utah	0	0	0	0	0	0
Tony M	Utah	0	0	0	0	0	0
Hack Canyon	Arizona	1	1	1	1	1	1
Pidgeon	Arizona	0	0	0	0	0	0
Kanab North	Arizona	0	0	0	0	0	0
Dermo-Snyder	Colo./Utah	0	5	21	49	67	83
Wilson-Silverbell	Utah/Colo.	0	0	0	12	20	23
Lisbon	Utah	0	0	0	4	44	44
LaSal	Utah	0	0	53	101	194	194
Hecla	Utah	16	16	20	40	73	73
Big Eagle	Wyoming	0	0	0	0	0	0
Golden Eagle	Wyoming	0	0	0	6	6	6
Sheep Mtn.	Wyoming	0	0	0	0	0	12
Mt. Taylor	New Mexico	0	100	317	336	336	336
Old Church Rock	New Mexico	9	9	70	139	187	364
Church Rock-NE	New Mexico	0	11	22	26	31	31
Church Rock-1	New Mexico	0	11	22	27	31	31
Church Rock-East	New Mexico	0	0	9	57	70	131
Kerr-McGee Sec 30 East	New Mexico	3	3	3	3	3	3
Kerr-McGee Sec 30 West	New Mexico	0	5	5	5	5	6
Kerr-McGee Sec 19	New Mexico	0	0	0	4	4	4
Kerr-McGee Sec 35	New Mexico	0	0	0	0	0	0
Kerr-McGee Sec 36	New Mexico	0	0	0	0	0	0

Table 5-13. Population around selected underground uranium mines (Brb84) (Continued)

Mine	State	Distance from mine (km)					
		0-1/2	0-1	0-2	0-3	0-4	0-5
Homestake Sec 23	New Mexico	0	0	0	3	3	4
Homestake Sec 25	New Mexico	0	0	0	0	0	0
Nose Rock[a]	New Mexico	0	0	0	0	26	35
Mariano Lake	New Mexico	13	44	75	196	274	352
Schwartz-walder[a]	Colorado	3	3	63	102	136	147
Totals		42	205	618	1,009	1,375	1,733

[a]The population around this mine is not included in the total because the location is not typical of the industry.

Table 5-14. Percent distribution of land ownership around selected underground uranium mines (Brb84)

Mine	Distance from mine (km)[(a)]					
	0-1/2	0-1	0-2	0-3	0-4	0-5
Sunday	0/0/100	0/0/100	0/0/100	3/1/97	8/1/91	10/1/89
King Solomon	0/0/100	0/2/98	0/5/95	0/3/97	0/3/97	0/3/97
Velvet	14/0/86	10/0/90	6/0/94	12/0/88	24/0/76	27/0/73
Tony M	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100
Hack Canyon	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100
Pidgeon	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100
Kanab North	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	1/0/99
Dermo-Snyder	84/0/16	87/0/13	84/0/16	89/0/11	85/0/15	81/0/19
Wilson-Silverbell	80/0/20	95/0/5	95/0/5	94/0/6	91/0/9	81/0/19
Lisbon	0/0/100	0/0/100	6/0/94	17/2/81	21/1/78	16/1/83
LaSal	8/0/92	25/0/75	34/0/66	41/0/59	34/0/66	26/0/74
Hecla	25/0/75	25/0/75	48/0/52	37/0/63	28/0/72	21/0/79
Big Eagle	0/100/0	0/88/12	0/80/20	0/8/92	0/5/95	1/3/96
Golden Eagle	60/20/20	89/7/4	85/3/2	94/1/5	91/1/8	90/1/9
Sheep Mtn.	30/45/25	18/42/40	5/28/69	2/18/80	4/11/85	12/8/80
Mt. Taylor	75/19/6	58/26/16	58/16/29	45/13/42	39/10/51	39/7/54
Old Church Rock	0/0/100	0/0/100	0/0/100	0/0/100	2/0/98	3/0/97
Church Rock NE	0/0/100	0/7/93	0/23/77	0/13/87	0/8/92	0/5/95
Church Rock #1	0/0/100	0/7/93	0/23/77	0/13/87	0/8/92	0/5/95
Church Rock East	0/0/100	0/7/93	0/6/94	3/4/93	5/2/93	3/1/96
Kerr-McGee Sec 30 East	11/89/0	4/91/5	2/70/28	4/78/18	10/79/11	13/77/10
Kerr-McGee Sec 30 West	11/89/0	24/76/0	17/72/11	16/69/15	22/66/12	27/57/16
Kerr-McGee Sec 19	0/100/0	23/77/0	46/39/15	45/39/16	32/37/31	29/38/33
Kerr-McGee Sec 35	0/100/0	0/85/15	8/59/33	14/55/31	10/57/33	14/52/34
Kerr-McGee Sec 36	5/42/53	14/22/64	27/14/59	36/8/56	36/5/59	39/3/58

See footnotes at end of table.

Table 5-14. Percent distribution of land ownership around selected underground uranium mines (Brb84) (Continued)

Mine	Distance from mine (km)[a]					
	0-1/2	0-1	0-2	0-3	0-4	0-5
Homestake Sec 23	74/0/26	68/0/32	61/6/33	50/18/32	47/17/36	53/12/35
Homestake Sec 25	100/0/0	85/0/15	59/0/41	58/1/41	50/2/48	43/10/47
Nose Rock	0/50/50	0/50/50	0/45/55	0/41/59	0/38/62	0/35/65
Mariano Lake	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100
Schwartz-walder[b]	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0
Average	20/22/58	22/20/58	22/17/61	23/13/64	22/12/66	22/11/67

[a] The first figure in the column represents the percent of private land, the second is land owned by the mine owner, and the third shows the percentage of land owned by a government agency. For example, in the case of the Sunday mine (at 0-1/2 km), 100 percent is owned by the government.

[b] The land ownership percentage for the Schwartzwalder mine was not included in the average for all the mines since the location is not typical of the industry.

Table 5-15. Estimated value of private land around selected underground uranium mines[a] (Brb84) (In thousands)

Mine	Distance from mine (km)					
	0-1/2	0-1	0-2	0-3	0-4	0-5
Sunday	NA	NA	NA	48.0	208.0	384.0
King Solomon	NA	NA	NA	NA	NA	NA
Velvet	5.5	16.0	36.0	172.8	603.2	1,048.0
Tony M	NA	NA	NA	NA	NA	NA
Hack Canyon	NA	NA	NA	NA	NA	NA
Pidgeon	NA	NA	NA	NA	NA	NA
Kanab North	NA	NA	NA	NA	NA	(b)
Dermo-Snyder	79.7	260.4	922.6	1,852.1	3,028.9	4,432.8
Wilson-Silverbell	39.1	186.4	535.8	1,667.2	2,861.6	3,968.7
Lisbon	NA	NA	50.0	306.0	810.5	810.5
LaSal	4.0	228.4	920.9	1,427.8	2,484.5	2,534.5
Hecla	36.8	147.3	380.0	691.0	965.9	1,000.5
Big Eagle	NA	NA	NA	NA	NA	NA
Golden Eagle	35.4	209.0	796.2	2,121.0	3,584.0	5,231.0
Sheep Mtn.	18.0	42.3	42.3	42.3	150.0	898.0
Mt. Taylor	39.6	391.5	2,523.7	2,834.2	3,227.4	3,918.8
Old Church Rock	NA	NA	NA	NA	543.3	1,443.1
Church Rock NE	NA	NA	NA	NA	NA	NA
Church Rock-1	NA	NA	NA	NA	NA	NA
Church Rock-East	NA	NA	NA	122.2	355.6	355.6
Kerr-McGee Sec 30 East	35.0	35.0	35.0	53.5	147.6	240.0
Kerr-McGee Sec 30 West	31.1	132.2	147.8	157.9	194.8	235.1
Kerr-McGee Sec 19	NA	194.4	844.8	1,229.4	1,405.1	1,532.8
Kerr-McGee Sec 35	NA	NA	37.0	137.8	168.0	336.0
Kerr-McGee Sec 36	3.4	23.5	124.3	336.0	588.0	977.8

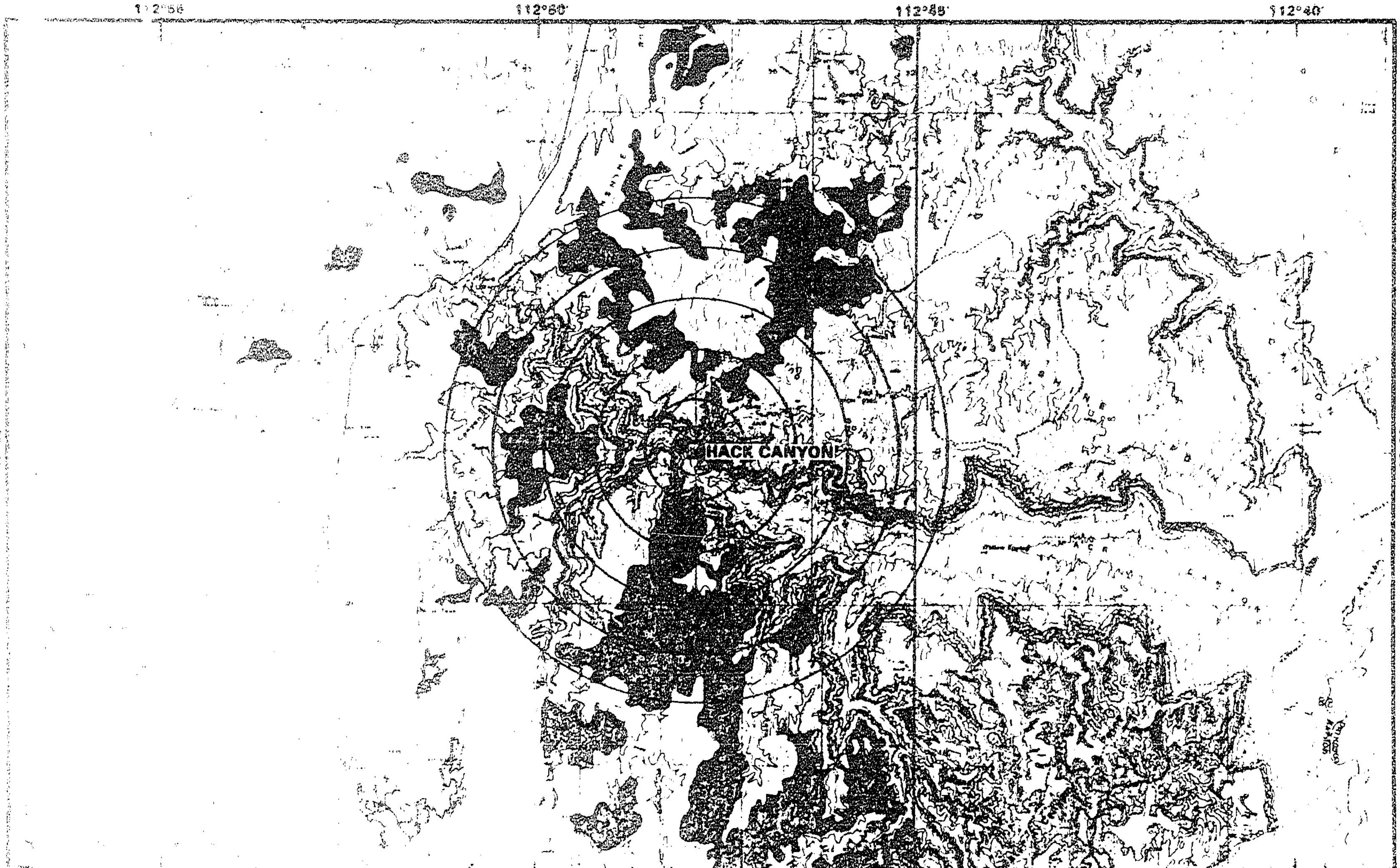
See footnotes at end of table.

Table 5-15. Estimated value of private land around selected underground uranium mines[a] (Brb84) (Continued)
(In thousands)

Mine	Distance from mine (km)					
	0-1/2	0-1	0-2	0-3	0-4	0-5
Homestake Sec 23	217.8	528.0	994.1	1,158.7	1,485.2	2,361.8
Homestake Sec 25	295.6	622.2	987.8	1,478.0	1,632.2	1,645.6
Nose Rock	NA	NA	NA	NA	NA	NA
Mariano Lake	NA	NA	NA	NA	NA	NA
Schwartz-walder[c]	880.0	3,400.0	15,200.0	33,600.0	58,400.0	89,200.0
Totals	841.0	3,016.6	9,378.2	15,835.8	24,443.8	33,354.6

[a]Includes cost of land (80 percent) and structures (20 percent).
[b]About 100 acres of patented mining claims.
[c]The costs for this mine were not included in the total costs because the location and cost of land is not typical of the industry.

NA Not assessed; all land owned by either the mine owner or the government.



HACK CANYON MINE
MOHAVE COUNTY, ARIZONA

ALL OCCUPIED DWELLINGS; MINE SHAFT LOCATION; POPULATION DISTRIBUTION

POPULATION DISTRIBUTION

MINE	0-1/2 km	0-1 km	0-2 km	0-3 km	0-4 km	0-5 km
HACK CANYON	1	1	1	1	1	1

0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS

LEGEND:

- SINGLE OCCUPIED DWELLING
- OCCUPIED DWELLING CLUSTER (NO IS STRUCTURES)
- MINE SHAFT

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